

EARTH SCIENCE LITERACY PRINCIPLES



The Big Ideas and Supporting Concepts of Earth Science

EARTH SCIENCE LITERACY: The Big Ideas and Supporting Concepts of Earth Science

Each big idea is backed by supporting concepts comparable to those underlying the National Science Education Standards and the American Association for the Advancement of Science Benchmarks for Science Literacy.

What is Earth Science Literacy?

Earth Science Literacy is an understanding of Earth's influence on you and of your influence on Earth.

Earth Science Literacy Principles are defined by the scientists who carry out active research in many areas of Earth science and explain the complexities of how our planet works.

Earth Science Literacy is shaped by science educators, who can best translate the big ideas of Earth science into language and learning opportunities that can be understood by all.

Earth Science Literacy is an ongoing process, continually reshaped and rewritten by new discoveries in the areas of Earth science and learning theory.

An Earth-science-literate person:

- understands the fundamental concepts of Earth's many systems
- knows how to find and assess scientifically credible information about Earth
- communicates about Earth science in a meaningful way
- is able to make informed and responsible decisions regarding Earth and its resources

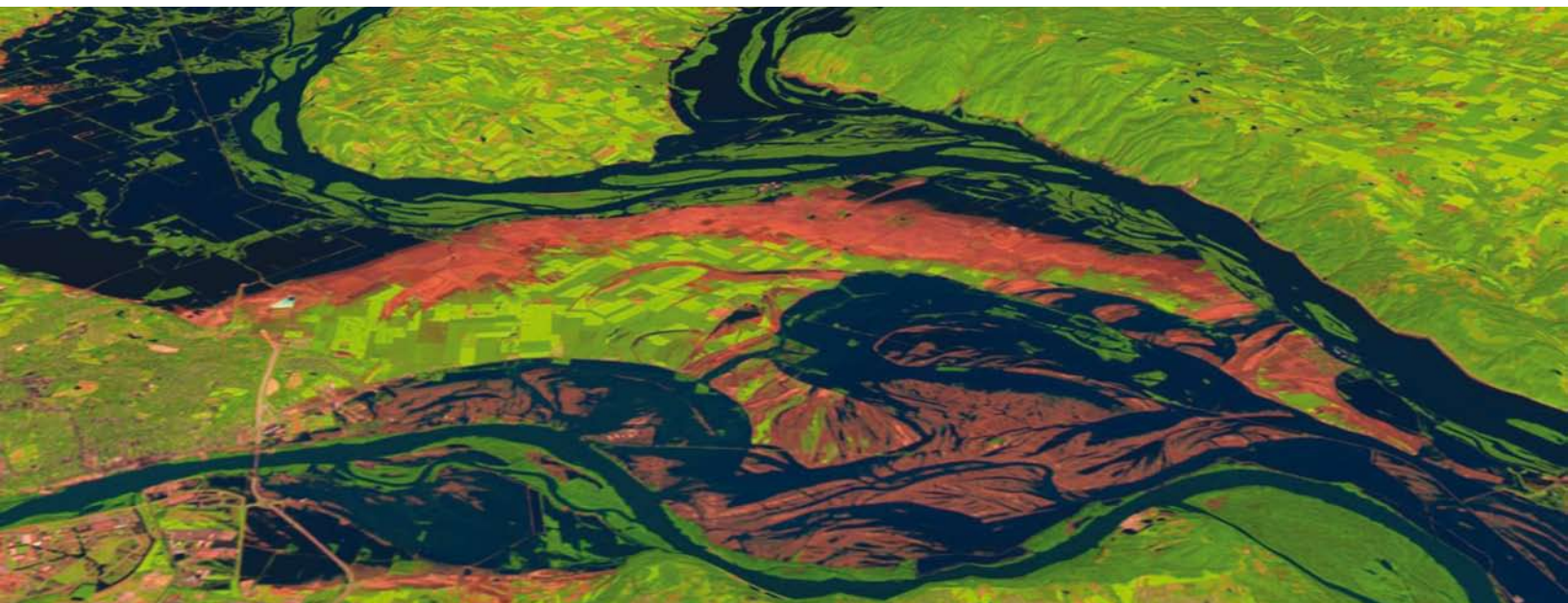
Junction of the Mississippi, Illinois, and Missouri rivers in August 1993 (near the peak of flooding) from Landsat-5/TM. (Courtesy NASA/Goddard Space Flight Center Scientific Visualization Studio)

Why is Earth Science Literacy Important?

Earth is our home. We rely upon it for our existence in many different ways. Its resources feed us and provide the materials of our way of life. Even modest changes to Earth's systems have had profound influences on human societies and the course of civilization. Understanding these systems and how they interact with us is vital for our survival.

Earth Science Literacy is especially important at this time in history. There are many challenges facing humanity—dwindling energy and mineral resources, changing climates, water shortages—directly relating to the Earth sciences. There are many difficult decisions that governments, local and national, will have to make concerning these issues, and how well humans survive the twenty-first century will depend upon the success of these decisions. We need governments that are Earth science literate.

Human history is a record of the creativity and ingenuity of people solving difficult problems. The solutions to the current Earth-science-related challenges will also come from human creativity, as individuals or corporate businesses. However, as our modern society and its needs have become increasingly complex, so have the solutions. It will take a deep and subtle understanding of Earth's systems for future generations to be able to feed, clothe, house, and provide a meaningful existence for all humans. We need citizens and businesses that are Earth science literate.





Louisiana coast with suspended sediments and organic matter flowing out of the Mississippi and other regional river systems into the Gulf of Mexico (MODIS Aqua satellite image, November 19, 2003, courtesy of Liam Gumley, Space Science and Engineering Center, University of Wisconsin-Madison)

How Does the Scientific Process Work?

Science is an ongoing process of discovery of the natural world. Earth science is part of this process. Science draws upon the innate sense of curiosity that all humans share. We see it in a child's excitement in the discovery of her world. Millions of scientists formally pursue the process of discovery by making observations, testing hypotheses, and refining scientific models. Scientific understanding advances through many stages of preparation and review. Like medical doctors, scientists go through many years of professional training and practice. Scientific research projects are funded through a highly selective review process conducted by experts in the field. Results from scientific research are only published in journals if they satisfy a rigorous process that includes presentations at professional meetings, debates at scientific workshops, and written "peer" reviews by established experts in the field. The power of the scientific process is seen in its relentless march toward better explanations of how the laws of the universe operate. The complex technology of the modern industrial world, including cell phones, space exploration, and cures to many diseases, is a tribute to the success of the process of scientific discovery.

For more information about
Earth Science Literacy, please visit
www.earthscienceliteracy.org.

About This Guide

This guide presents the big ideas of Earth science that all citizens should know, determined by the Earth science research and education communities. Several workshops involving hundreds of scientists and educators from academia, government, and industry were dedicated to creating this document, and it has undergone an extensive period of public review. This document, representing the current scientific knowledge in Earth science, is helping to shape decisions by government and industry and helping to guide the direction of educational curricula. It is a work in progress because the scientific process continues to improve our understanding of Earth. For the latest version of this document, as well as information about its construction, please visit www.earthscienceliteracy.org.

Using This Guide for Education

U.S. science education is structured around the National Science Education Standards. To serve the broader education community, the Earth Science Literacy Principles have been aligned with these standards. The matrix of this alignment can be found at <http://www.earthscienceliteracy.org/education.html>. This literacy document is being used to direct Earth science education funding within the National Science Foundation. Textbook companies are using it in the creation of new educational materials. Museums and science centers are using this document as a foundation for educational displays and exhibits. Teachers and school boards are using it to shape class instruction ranging from individual lessons to whole curricula.

BIG IDEA 1. Earth scientists use repeatable observations and testable ideas to understand and explain our planet.

1.1 Earth scientists find solutions to society's needs. Earth scientists work on challenging problems that face humanity on topics such as climate change and human impacts on Earth. Earth scientists successfully predict hazards to humans and locate and recover natural resources, making possible the flourishing of humans on Earth.

1.2 Earth scientists use a large variety of scientific principles to understand how our planet works. Earth scientists combine study of Earth's geology with aspects of biology, chemistry, physics, and mathematics in order to understand the complexities of the Earth system.

1.3 Earth science investigations take many different forms.

Earth scientists do reproducible experiments and collect multiple lines of evidence. This evidence is taken from field, analytical, theoretical, experimental, and modeling studies.

1.4 Earth scientists must use indirect methods to examine and understand the structure, composition, and dynamics of Earth's interior.

With the exception of wells and mine shafts drilled into Earth, direct observations of Earth's interior are not possible. Instead, Earth scientists observe the interior of the planet using seismic waves, gravity, magnetic fields, radar, sonar, and laboratory experiments on the behavior of materials at high pressures and temperatures.

1.5 Earth scientists use their understanding of the past to forecast Earth's future. Earth science research tells us how Earth functioned in the past under conditions not seen today and how conditions are likely to change in the future.

1.6 Earth scientists construct models of Earth and its processes that best explain the available geological evidence. These scientific models, which can be conceptual or analytical, undergo rigorous scrutiny and testing by collaborating and competing groups of scientists around the world. Earth science research documents are subjected to rigorous peer review before they are published in science journals.

1.7 Technological advances, breakthroughs in interpretation, and new observations continuously refine our understanding of Earth. This Earth Science Literacy framework must be a living document that grows along with our changing ideas and concepts of Earth.



Research Experiences in Solid Earth Science for Students (RESESS) participant Miriam Garcia joined researchers from the United States, Iceland, and Switzerland in August of 2008 to install high-rate GPS stations in Iceland. Data from this network will increase our understanding of volcanic and tectonic interactions. (Courtesy of P.I. Richard Bennett and RESESS)

BIG IDEA 2. Earth is 4.6 billion years old.

2.1 Earth's rocks and other materials provide a record of its history. Earth scientists use the structure, sequence, and properties of rocks, sediments, and fossils to reconstruct events in Earth's history. Decay rates of radioactive elements are the primary means of obtaining numerical ages of rocks and organic remains. Understanding geologic processes active in the modern world is crucial to interpreting Earth's past.

2.2 Our Solar System formed from a vast cloud of gas and dust 4.6 billion years ago. Some of this gas and dust was the remains of the supernova explosion of a previous star; our bodies are therefore made of "stardust." This age of 4.6 billion years is well established from the decay rates of radioactive elements found in meteorites and rocks from the Moon.

2.3 Earth formed from the accumulation of dust and gas, and multiple collisions of smaller planetary bodies. Driven by gravity, Earth's metallic core formed as iron sank to the center. Rock surrounding the core was mostly molten early in Earth's history, and slowly cooled to form Earth's mantle and crust. The atoms of different elements combined to make minerals, which combined to make rocks. Earth's ocean and atmosphere began to form more than 4 billion years ago from the rise of lighter materials out of the mantle.

2.4 Earth's crust has two distinct types: continental and oceanic. Continental crust persists at Earth's surface and can be billions of years old. Oceanic crust continuously forms and recycles back into the mantle; in the ocean, it is nowhere older than about 200 million years.

2.5 Studying other objects in the solar system helps us learn Earth's history. Active geologic processes such as plate tectonics and erosion have destroyed or altered most of Earth's early rock record. Many aspects of Earth's early history are revealed by objects in the solar system that have not changed as much as Earth has.



The Grand Canyon represents one of the most awe-inspiring landscapes in the United States. At the deepest parts of the canyon, nearly two-billion-year-old metamorphic rock is exposed. The Colorado River has cut through layers of colorful sedimentary rock as the Colorado Plateau has uplifted.

2.6 Life on Earth began more than 3.5 billion years ago. Fossils indicate that life began with single-celled organisms, which were the only life forms for billions of years. Humans (*Homo sapiens*) have existed for only a very small fraction (about 0.004%) of Earth's history.

2.7 Over Earth's vast history, both gradual and catastrophic processes have produced enormous changes. Supercontinents formed and broke apart, the compositions of the atmosphere and ocean changed, sea level rose and fell, living species evolved and went extinct, ice sheets advanced and melted away, meteorites slammed into Earth, and mountains formed and eroded away.

BIG IDEA 3. Earth is a complex system of interacting rock, water, air, and life.

3.1 The four major systems of Earth are the geosphere, hydrosphere, atmosphere, and biosphere. The geosphere includes a metallic core, solid and molten rock, soil, and sediments. The atmosphere is the envelope of gas surrounding Earth. The hydrosphere includes the ice, water vapor, and liquid water in the atmosphere, the ocean, lakes, streams, soils, and groundwater. The biosphere includes Earth's life, which can be found in many parts of the geosphere, hydrosphere, and atmosphere. Humans are part of the biosphere, and human activities have important impacts on all four spheres.

3.2 All Earth processes are the result of energy flowing and mass cycling within and between Earth's systems. This energy is derived from the sun and Earth's interior. The flowing energy and cycling matter cause chemical and physical changes in Earth's materials and living organisms. For example, large amounts of carbon continually cycle among systems of rock, water, air, organisms, and fossil fuels such as coal and oil.

Steam vigorously rises from the hot waters of Grand Prismatic Spring, known for its rainbow colors produced by thermophilic ("heat loving") organisms. This hot spring is fueled by heat from a large reservoir of partially molten rock (magma), just a few miles beneath Yellowstone, that drives one of the world's largest volcanic systems.



3.3 Earth exchanges mass and energy with the rest of the Solar System. Earth gains and loses energy through incoming solar radiation, heat loss to space, and gravitational forces from the sun, moon, and planets. Earth gains mass from the impacts of meteoroids and comets and loses mass by the escape of gases into space.

3.4 Earth's systems interact over a wide range of temporal and spatial scales. These scales range from microscopic to global in size and operate over fractions of a second to billions of years. These interactions among Earth's systems have shaped Earth's history and will determine Earth's future.

3.5 Regions where organisms actively interact with each other and their environment are called ecosystems. Ecosystems provide the goods (food, fuel, oxygen, and nutrients) and services (climate regulation, water cycling and purification, and soil development and maintenance) necessary to sustain the biosphere. Ecosystems are considered the planet's essential life-support units.

3.6 Earth's systems are dynamic; they continually react to changing influences. Components of Earth's systems may appear stable, change slowly over long periods of time, or change abruptly with significant consequences for living organisms.

3.7 Changes in part of one system can cause new changes to that system or to other systems, often in surprising and complex ways. These new changes may take the form of "feedbacks" that can increase or decrease the original changes and can be unpredictable and/or irreversible. A deep knowledge of how most feedbacks work within and between Earth's systems is still lacking.

3.8 Earth's climate is an example of how complex interactions among systems can result in relatively sudden and significant changes. The geologic record shows that interactions among tectonic events, solar inputs, planetary orbits, ocean circulation, volcanic activity, glaciers, vegetation, and human activities can cause appreciable, and in some cases rapid, changes to global and regional patterns of temperature and precipitation.

BIG IDEA 4. Earth is continuously changing.

4.1 Earth's geosphere changes through geological, hydrological, physical, chemical, and biological processes that are explained by universal laws. These changes can be small or large, continuous or sporadic, and gradual or catastrophic.

4.2 Earth, like other planets, is still cooling, though radioactive decay continuously generates internal heat. This heat flows through and out of Earth's interior largely through convection, but also through conduction and radiation. The flow of Earth's heat is like its lifeblood, driving its internal motions.

4.3 Earth's interior is in constant motion through the process of convection, with important consequences for the surface. Convection in the iron-rich liquid outer core, along with Earth's rotation around its axis, generates Earth's magnetic field. By deflecting solar wind around the planet, the magnetic field prevents the solar wind from stripping away Earth's atmosphere. Convection in the solid mantle drives the many processes of plate tectonics, including the formation and movements of the continents and oceanic crust.

4.4 Earth's tectonic plates consist of the rocky crust and uppermost mantle, and move slowly with respect to one another. New oceanic plate continuously forms at mid-ocean ridges and other spreading centers, sinking back into the mantle at ocean trenches. Tectonic plates move steadily at rates of up to 10 centimeters per year.

4.5 Many active geologic processes occur at plate boundaries. Plate interactions change the shapes, sizes, and positions of continents and ocean basins, the locations of mountain ranges and basins, the patterns of ocean circulation and climate, the locations of earthquakes and volcanoes, and the distribution of resources and living organisms.

4.6 Earth materials take many different forms as they cycle through the geosphere. Rocks form from the cooling of magma, the accumulation and consolidation of sediments, and the alteration of older rocks by heat, pressure, and fluids. These three processes form igneous, sedimentary, and metamorphic rocks.



Suspended clay particles, eroded from the Cascade Mountains of Washington State, give Lake Diablo its brilliant color. The active volcanoes of the Cascades result from the subduction of the Juan de Fuca plate beneath North America. (Courtesy of Nicole LaDue)

4.7 Landscapes result from the dynamic interplay between processes that form and uplift new crust and processes that destroy and depress the crust. This interplay is affected by gravity, density differences, plate tectonics, climate, water, the actions of living organisms, and the resistance of Earth materials to weathering and erosion.

4.8 Weathered and unstable rock materials erode from some parts of Earth's surface and are deposited in others. Under the influence of gravity, rocks fall downhill. Water, ice, and air carry eroded sediments to lower elevations, and ultimately to the ocean.

4.9 Shorelines move back and forth across continents, depositing sediments that become the surface rocks of the land. Through dynamic processes of plate tectonics and glaciation, Earth's sea level rises and falls by up to hundreds of meters. This fluctuation causes shorelines to advance and recede by hundreds of kilometers. The upper rock layers of most continents formed when rising sea levels repeatedly flooded the interiors of continents.

BIG IDEA 5. Earth is the water planet.

5.1 Water is found everywhere on Earth, from the heights of the atmosphere to the depths of the mantle. Early in Earth's history, surface water accumulated through both outgassing from its interior and the capture of some extra-terrestrial ice. Water vapor in the atmosphere condensed and rained out as the planet cooled.

5.2 Water is essential for life on Earth. Earth is unique in our Solar System in that water has coexisted at Earth's surface in three phases (solid, liquid, and gas) for billions of years, allowing the development and continuous evolution of life.

5.3 Water's unique combination of physical and chemical properties are essential to the dynamics of all of Earth's systems. These properties include the manner in which water absorbs and releases heat, reflects sunlight, expands upon freezing, and dissolves other materials.

5.4 Water plays an important role in many of Earth's deep internal processes. Water allows rock to melt more easily, generating much of the magma that erupts as lava at volcanoes. Water facilitates the metamorphic alteration of rock and is integral to plate tectonic processes.

5.5 Earth's water cycles among the reservoirs of the atmosphere, streams, lakes, ocean, glaciers, groundwater, and deep interior of the planet. The total amount of water at Earth's surface has remained fairly constant over geologic time, although its distribution among reservoirs has varied.

5.6 Water shapes landscapes. Flowing water in streams strongly shapes the land surface through weathering, erosion, transport, and deposition. Water participates in both the dissolution and formation of Earth's materials.

5.7 Ice is an especially powerful agent of weathering and erosion. Water expands as it freezes, widening cracks and breaking apart rocks. Movement of massive glaciers can scour away land surfaces. The flowing ice of glaciers covers and alters vast areas of continents during Ice Ages.

5.8 Fresh water is less than 3% of the water at Earth's surface. Most of this fresh water is stored as glaciers in Antarctica and Greenland. Less than 1% of Earth's near-surface water is drinkable liquid fresh water, and about 99% of this water is in the form of groundwater in the pores and fractures within soil, sediment, and rock.

Earth's water is in constant motion. Water moves at different speeds in different places, and in different forms. Water is continuously being exchanged among Earth's surface, atmosphere, and interior. Water is essential for life and for sculpting the world around us.



BIG IDEA 6. Life evolves on a dynamic Earth and continuously modifies Earth.

6.1 Fossils are the preserved evidence of ancient life. Fossils document the presence of life early in Earth's history and the subsequent evolution of life over billions of years.

6.2 Evolution, including the origination and extinction of species, is a natural and ongoing process. Changes to Earth and its ecosystems determine which individuals, populations, and species survive. As an outcome of dynamic Earth processes, life has adapted through evolution to new, diverse, and ever-changing niches.

6.3 Biological diversity, both past and present, is vast and largely undiscovered. New species of living and fossil organisms are continually found and identified. All of this diversity is interrelated through evolution.

6.4 More complex life forms and ecosystems have arisen over the course of Earth's history. This complexity has emerged in association with adaptations to new and constantly changing habitats. But not all evolution causes greater complexity; organisms adapting to changing local environments may also become simpler.

6.5 Microorganisms dominated Earth's early biosphere and continue today to be the most widespread, abundant, and diverse group of organisms on the planet. Microbes change the chemistry of Earth's surface and play a critical role in nutrient cycling within most ecosystems.

6.6 Mass extinctions occur when global conditions change faster than species in large numbers can adapt. Mass extinctions are often followed by the origination of many new species over millions of years as surviving species evolve and fill vacated niches.

6.7 The particular life forms that exist today, including humans, are a unique result of the history of Earth's systems. Had this history been even slightly different, modern life forms might be entirely different and humans might never have evolved.



A fossil of an ammonite, an extinct ocean-living mollusk related to the modern nautilus. Ammonites evolved about 400 million years ago and were plentiful in the ocean until the occurrence of a global mass extinction > 65 million years ago that correlates with an asteroid impact.

6.8 Life changes the physical and chemical properties of Earth's geosphere, hydrosphere, and atmosphere. Living organisms produced most of the oxygen in the atmosphere through photosynthesis and provided the substance of fossil fuels and many sedimentary rocks. The fossil record provides a means for understanding the history of these changes.

6.9 Life occupies a wide range of Earth's environments, including extreme environments. Some microbes live in rocks kilometers beneath the surface, within glacial ice, and at seafloor vents where hot fluids escape from the oceanic crust. Some of these environments may be similar to the conditions under which life originated, and to environments that exist on other planets and moons.

BIG IDEA 7. Humans depend on Earth for resources.

7.1 Earth is our home; its resources mold civilizations, drive human exploration, and inspire human endeavors that include art, literature, and science. We depend upon Earth for sustenance, comfort, places to live and play, and spiritual inspiration.

7.2 Geology affects the distribution and development of human populations. Human populations have historically concentrated at sites that are geologically advantageous to commerce, food production, and other aspects of civilization.

7.3 Natural resources are limited. Earth's natural resources provide the foundation for all of human society's physical needs. Most are nonrenewable on human time scales, and many will run critically low in the near future.

7.4 Resources are distributed unevenly around the planet. Resource distribution is a result of how and where geologic processes have occurred in the past, and has extremely important social, economic, and political implications.

7.5 Water resources are essential for agriculture, manufacturing, energy production, and life. Earth scientists and engineers find and manage our fresh water resources, which are limited in supply. In many places, humans withdraw both surface water and groundwater faster than they are replenished. Once fresh water is contaminated, its quality is difficult to restore.

7.6 Soil, rocks, and minerals provide essential metals and other materials for agriculture, manufacturing, and building. Soil develops slowly from weathered rock, and the erosion of soil threatens agriculture. Minerals and metals are often concentrated in very specific ore deposits. Locating and mining these ore deposits provide the raw materials for much of our industry. Many electronic and mechanical devices have specific requirements for particular rare metals and minerals that are in short supply.

7.7 Earth scientists and engineers develop new technologies to extract resources while reducing the pollution, waste, and ecosystem degradation caused by extraction. For example, land reclamation can partially restore surface environments following surface mining.



Humans rely on petroleum for the manufacturing of plastics, fertilizers, and other goods in addition to being a major source of energy. The thoughtful use of this resource is necessary to ensure its availability.

7.8 Oil and natural gas are unique resources that are central to modern life in many different ways. They are the precursors to chemicals used to make numerous products, such as plastics, textiles, medications, and fertilizers. Petroleum sources are needed to manufacture most industrial products.

7.9 Fossil fuels and uranium currently provide most of our energy resources. Fossil fuels, such as coal, oil, and natural gas, take tens to hundreds of millions of years to form. Their abundance will make them the dominant source of energy for the near future. New sources, such as methane hydrates, are being explored.

7.10 Earth scientists help society move toward greater sustainability. Renewable energy sources, such as solar, wind, hydroelectric, and geothermal, are being developed. They will replace fossil fuels as those become scarcer, more expensive to retrieve from Earth, and undesirable due to environmental damage. Earth scientists foster global cooperation and science-informed stewardship that can help to ensure the availability of resources for future generations.

BIG IDEA 8. Natural hazards pose risks to humans.

8.1 Natural hazards result from natural Earth processes.

These hazards include earthquakes, tsunamis, hurricanes, floods, droughts, landslides, volcanic eruptions, extreme weather, lightning-induced fires, sinkholes, coastal erosion, and comet and asteroid impacts.

8.2 Natural hazards shape the history of human societies. Hazardous events can significantly alter the size of human populations and drive human migrations. Risks from natural hazards increase as populations expand into vulnerable areas or concentrate in already-inhabited areas.

8.3 Human activities can contribute to the frequency and intensity of some natural hazards. These hazards include floods, landslides, droughts, forest fires, and erosion.

8.4 Hazardous events can be sudden or gradual. They range from sudden events such as earthquakes and explosive volcanic eruptions, to more gradual phenomena such as droughts, which may last decades or longer. Changes caused by continual processes such as erosion and land subsidence can also result in risks to human populations, as with the increased risk of flooding in New Orleans.

8.5 Natural hazards can be local or global in origin. Local events can have distant impacts because of the interconnectedness of both human societies and Earth's systems. For example, a volcanic eruption in the Pacific Ocean can impact climate around the globe.

8.6 Earth scientists are continually improving estimates of when and where natural hazards occur. This analysis is done through continuously monitoring Earth, increasing our understanding of the physical processes that underlie its changes, and developing scientific models that can explain hazard-related scientific observations.

8.7 Humans cannot eliminate natural hazards, but can engage in activities that reduce their impacts. Loss of life, property damage, and economic costs can be reduced by identifying high-risk locations and minimizing human habitation and societal activities in them, improving construction methods, developing warning systems, and recognizing how human behavior influences preparedness and response.

8.8 An Earth-science-literate public is essential for reducing risks from natural hazards. This literacy leads to the promotion of community awareness about natural hazards and to the development of scientifically informed policies that reduce risk.

A lava flow devours a road in Hawaii. This natural hazard creates an inconvenience; however, many natural hazards can be life threatening. The impact of natural hazards can be greatly reduced through the education of citizens about the risks in their region.



BIG IDEA 9. Humans significantly alter the Earth.

9.1 Human activities significantly change the rates of many of Earth's surface processes. Humankind has become a geological agent that must be taken into account equally with natural processes in any attempt to understand the workings of Earth's systems. As human populations and per capita consumption of natural resources increase, so do our impacts on Earth's systems.

9.2 Earth scientists use the geologic record to distinguish between natural and human influences on Earth's systems. Evidence for natural and human influences on Earth processes is found in ice cores and soils, and in lake, estuary, and ocean sediments.

9.3 Humans cause global climate change through fossil fuel combustion, land-use changes, agricultural practices, and industrial processes. Consequences of global climate change include melting glaciers and permafrost, rising sea levels, shifting precipitation patterns, increased forest fires, more extreme weather, and the disruption of global ecosystems.

Humans have significantly altered Earth's surface. The Bingham Copper Mine in Utah demonstrates that humans have moved entire mountains in a quest for resources. (Courtesy of Michael Collier)



9.4 Humans affect the quality, availability, and distribution of Earth's water through the modification of streams, lakes, and groundwater. Engineered structures such as canals, dams, and levees significantly alter water and sediment distribution. Pollution from sewage runoff, agricultural practices, and industrial processes reduce water quality. Overuse of water for electric power generation and agriculture reduces water availability for drinking.

9.5 Human activities alter the natural land surface. Humans use more than one-third of the land's surface not covered with ice to raise or grow their food. Large areas of land, including delicate ecosystems such as wetlands, are transformed by human land development. These land surface changes impact many Earth processes such as groundwater replenishment and weather patterns.

9.6 Human activities accelerate land erosion. At present, the rate of global land erosion caused by human activities exceeds all natural processes by a factor of ten. These activities include urban paving, removal of vegetation, surface mining, stream diversions, and increased rain acidity.

9.7 Human activities significantly alter the biosphere. Earth is experiencing a worldwide decline in biodiversity—a modern mass extinction—due to loss of habitat area and high rates of environmental change caused by human activities. The rates of extinctions are now comparable to the rates of mass extinctions in the geologic past.

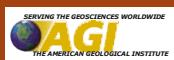
9.8 Earth scientists document and seek to understand the impacts of humans on global change over short and long time spans. Many of these human impacts on Earth's systems are not reversible over human lifetimes, but through human cooperation their impacts on future generations can be lessened and even reversed.

9.9 An Earth-science-literate public, informed by current and accurate scientific understanding of Earth, is critical to the promotion of good stewardship, sound policy, and international cooperation. Earth science education is important for individuals of all ages, backgrounds, and nationalities.

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