<u>Earth Science Literacy Initiative</u>
Draft Document (December 15, 2008)

Big Idea #1: Earth science explores our planet.

Supporting Concepts

1.1 Earth science is critically relevant to human existence.
The 21st century will be defined by grand challenges such as climate change and the availability of water and energy resources. Understanding the ideas and concepts of Earth science is critical for the ability of human society to respond successfully to these challenges and thrive in the decades to come.

1.2 Earth science research employs techniques from many sciences to understand how our planet works. Earth science combines aspects of geology, biology, chemistry, physics and mathematics in order to understand the complexities of the Earth system.

1.3 The process of Earth science takes many different forms. Earth scientists use multiple lines of evidence taken from field, analytical, theoretical, experimental, and modeling studies to interpret observations about Earth and forecast Earth's future.

1.4 Earth science research studies an enormous range of complex processes. Earth science examines natural processes that occur over spatial scales ranging from subatomic to planetary and over timescales ranging from nearly instantaneous to gradual over billions of years.

1.5 Most of Earth's interior is inaccessible to direct observation. Earth scientists must use complex remote methods to examine the structure, composition and dynamics of Earth's interior. These investigations include data from seismic waves, gravitational and magnetic fields, radar, sonar, and laboratory experiments on the behavior of materials at high pressure.

1.6 Earth scientists use multiple methods to reconstruct Earth's incomplete historical record. Earth scientists determine the history of rocks by examining their structures, fabrics, textures, compositions, and mineral grain sizes.

1.7 Technological advances, theoretical breakthroughs, and new observations continuously refine our understanding of Earth. Any Earth science literacy framework, including this one, must be a living document that grows along with our changing ideas and concepts.

Big Idea #2: Earth is 4.6 billion years old.

Supporting Concepts

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 absolute ages of the minerals within rocks. Understanding geologic processes active in the modern world is also crucial to interpreting Earth's past.

2.2 Our Earth and Solar System formed from a vast cloud of gas and dust 4.6 billion years ago. Some of this gas and dust is the remains of the supernova explosion of a previous star. This age has been well established using the decay rates of a variety of radioactive elements found in meteorites and rocks from the Moon.

2.3 Earth formed by the accumulation of dust and gas and multiple collisions of smaller planetary bodies. Earth's metallic core formed as iron sank to the center of a mostly-molten planet. The atoms of different elements combined to make minerals, which combined to form rocks. The rocks surrounding the core cooled slowly to form Earth's mantle and crust.

2.4 Earth's ocean, atmosphere and crust began to form more than 4 billion years ago from the rise of lighter materials out of the mantle. Continental crust persists at Earth's surface and can be billions of years old. Oceanic crust continuously forms and recycles back into the mantle and is nowhere older than 200 million years.

2.5 Studying other planetary 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.

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 form 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 slowly acting and catastrophic processes have produced enormous changes. Supercontinents formed and broke apart, the compositions of the atmosphere and oceans changed, sea level rose and fell, living species evolved and went extinct, ice sheets advanced and melted away, meteorites slammed into the Earth, and mountains formed and eroded away.

Big Idea #3: Earth is a complex system of interactions between rock, water, air and life.

Supporting Concepts
3.1 Systems of rock, water, air and life are contained within the geosphere, hydrosphere, atmosphere and biosphere. The geosphere includes a metallic core, solid and liquid rock, soil, and sediments. The atmosphere is the envelope of gas surrounding Earth. The hydrosphere includes ice, water vapor and liquid water in the atmosphere, oceans, lakes, streams, soils, and underground in rocks. The biosphere is 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 Energy from the Sun and Earth's interior flows through and between the systems, cycling matter within and among them. This flow causes chemical and physical changes to Earth's materials and living organisms. For example, large amounts of carbon continually move among systems of rock, water, air, organisms and fossil fuels like coal and oil.

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 meteorites and comets and loses mass by the escape of gases into space.

3.4 Earth's systems interact over a wide range of scales of space and time. These scales range from microscopic to global in size and operate over fractions of a second to billions of years.

3.5 Regions where organisms actively interact with each other and their environment are called ecosystems. Ecosystems are an important example of how Earth systems interact. Ecosystems provide the goods (food, fuel, fiber, nutrients) and services (climate regulation, water cycling and purification, soil development and maintenance) necessary to sustain the biosphere. As such, ecosystems are considered the essential life-support units of the planet.

3.6 Earth's systems continually adjust to changing influences. Components of Earth's systems such as magnetic fields, global climate, landscapes, ecosystems, and the extent of glaciers may appear stable, change slowly over long periods of time, or change greatly and abruptly with significant consequences for living organisms.

3.7 Changes in part of one system can cause new changes to that or 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.

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 a continuously changing planet.

Supporting Concepts

4.1 Earth's geosphere changes through geological, physical, chemical, hydrological, and biological processes that operate according to universal laws. These changes can be small or large, continuous or sporadic, and gradual or catastrophic. Examples of geologic processes that occur with a wide variation in the intensity and impact of events include the following: millions of earthquakes are recorded during any specific decade, but the most damage is done by the single largest earthquake; a stream may flow continuously through a valley for a decade, but the most alteration may occur from a single large flood.

4.2 Earth continues to cool over time, though additional heat is continuously generated by radioactive decay. 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. Convection in the iron-rich liquid outer core, along with Earth's rotation around its axis, generates Earth's magnetic field, which prevents solar wind from stripping away Earth's atmosphere. Convection in the solid mantle drives the many processes of plate tectonics, which forms and moves 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 sinks back into the mantle at ocean trenches. Tectonic plates move steadily and slowly at 0-10 centimeters per year, which is about the rate that human fingernails grow.

4.5 Many active and energetic geologic processes occur at plate boundaries. Plate interactions resulting from the processes of plate tectonics 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. Igneous rocks, sedimentary rocks, and metamorphic rocks are all derived from these three processes.

4.7 Landscapes result from the dynamic interplay between processes that form and uplift new crust and processes that depress and break it down. This interplay is affected by gravity, density differences, plate tectonics, climate, water, the actions of living organisms, and the relative resistance of rocks, sediments, and soils to weathering and erosion.

4.8 Weathered and unstable rock erode from some parts of Earth's surface and deposit in others. Under the influence of gravity, rocks fall downhill; eroded sediments are carried by water, ice, and air to lower, elevations, and ultimately to the ocean. Earth's ever-changing surface may be seen as a consistent function of the ebb and flow of depositional and erosional environments in the space-time continuum.

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, causing shorelines to advance and recede by hundreds of kilometers. Many rock layers on continents were originally deposited as shoreline and marine sediments when glacially and tectonically driven sea level changes repeatedly flooded and drained the interiors of continents.

Big Idea #5: Earth is the water planet.

Supporting Concepts

5.1 Water is found everywhere on Earth, from the heights of the atmosphere to the depths of the mantle. Earth's surface water is largely derived from its interior, outgassing and condensing 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 physical and chemical properties are essential to the dynamics of all Earth systems. These properties include water's ability to absorb and release heat, reflect sunlight, expand upon freezing, and dissolve 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 between the reservoirs of the ocean, atmosphere, streams, lakes, glaciers, and porous rocks and sediments beneath the ground. The total amount of water near the surface does not change significantly over human timescales.

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 Freshwater is less than 1% of Earth's total water. The largest source of freshwater, over 90%, is groundwater existing in pores and factures found within soil, sediment, and rock

5.9 The availability and distribution of clean, accessible water affects the security and quality of human life. Once contaminated, water quality is difficult to restore. In many places, both surface water and groundwater are withdrawn faster than they are replenished.

Big Idea #6: Life evolves on a dynamic Earth and continuously modifies Earth.

Supporting Concepts

6.1 Fossils are evidence of ancient life preserved in rocks. 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 life 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.

6.5 Mass extinctions occur when global conditions change faster than large numbers of species adapt. Mass extinctions are often followed by high rates of origination of new species as life evolves and fills vacated niches.

6.6 Microorganisms dominated Earth's early biosphere and continue today to be the most widespread, abundant, and diverse group of organisms on the planet. Some microbes even live in rocks kilometers beneath the surface and at seafloor vents, where hot fluids escape from ocean crust.

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

6.8 Life changes the physical and chemical properties of Earth's land, oceans, and atmosphere. Living organisms created most of the oxygen in the atmosphere through photosynthesis and are the foundation 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 environments, including extreme environments. Some of these environments may be similar to the conditions under which life originated and to those that exist on other planets.

Big Idea #7: Humans depend on Earth for resources.

Supporting Concepts

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 for spiritual inspiration.

7.2 Geology affects the distribution and development of human population. 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 finite. Earth's natural resources provide the foundation for all of the physical needs of human society, and most are non-renewable on human timescales and may run out without proper management.

7.4 Resources are distributed unevenly around the planet. This 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 itself. Earth scientists and engineers find and manage our freshwater resources, which are limited in supply.

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

7.7 Fossil fuels and uranium currently provide most of our energy resources. Fossil fuels like coal, oil and natural gas take tens to hundreds of millions of years to form. Earth scientists and engineers are developing ways to use renewable sources like solar, wind, geothermal, and hydroelectric energy to replace fossil fuels as they become more scarce and expensive to retrieve from Earth.

7.8 Oil and natural gas are unique resources that are central to modern life in many different ways. They are the precursor to chemicals used to make numerous products like plastics, textiles, medications and fertilizers. Most manufactured products are made out of or require the use of oil and gas.

7.9 Earth scientists develop new technologies to extract resources while reducing the pollution, waste, and ecosystem degradation caused by extraction.

7.10 Humans can move toward greater sustainability. We can develop more sophisticated renewable energy technologies and water purification techniques. Global cooperation and science informed stewardship can help to ensure the availability of resources for future generations.

Big Idea #8: Humans are threatened by Earth's natural hazards.

Supporting Concepts

8.1 Natural hazards pose risks to humans. These hazards result from Earth processes and include earthquakes, tsunamis, hurricanes, floods, droughts, landslides, volcanic eruptions, extreme weather, sinkholes, and coastal erosion.

8.2 Natural hazards affect 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 more become concentrated in existing areas.

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

8.4 Hazardous events vary greatly in duration. They range from sudden events like earthquakes and explosive volcanic eruptions to more gradual phenomena like droughts, which may last decades or longer. Changes caused by ongoing processes such as erosion and land subsidence can also result in hazards to human populations.

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 systems.

8.6 Earth scientists are continually improving estimates of when and where natural hazards occur. This is done through continuously monitoring the Earth, understanding the physical processes that underlie its changes, and developing models that can explain 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. These mitigation strategies are carried out over time and distance scales ranging from long-term planning for large regions, in the case of hazards such as hurricanes or floods, to the choice of location for a single house to move it away from unstable soils.

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

Big Idea #9: Humans have become a significant agent of change on Earth.

Supporting Concepts

9.1 Human activities significantly change the rates of many Earth processes. As human populations and per capita consumption of natural resources increase, so does our impact on Earth's systems. For example, deforestation increases erosion, soil loss, and atmospheric CO_2. Industrialized nations such as the United States have much higher per capita consumption of resources than other nations.

9.2 The geologic record distinguishes natural and human influences on Earth's systems, providing the basis for understanding rates of global change over time. Evidence for human influences on global changes is found in fossil distributions, ice cores, lake and ocean sediments, and soils.

9.3 Humans are the most significant agents of change in surficial Earth 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.

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

9.5 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. For example, these structures can have downstream consequences such as coastal land loss from to the trapping of sediment in reservoirs. Pollution from sewage runoff, agricultural practices, and industrial processes, reduce water quality, and overuse reduces water availability.

9.6 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. In the United States, the amount of land developed for urban use is larger than the size of the state of California, and the total area of roads and parking lots is larger than the state of Georgia. Such land surface changes impact Earth processes such as groundwater recharge and weather patterns.

9.7 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 urbanization, land destabilization, changed water flow patterns, and increased rain acidity. Earth scientists are developing ways to reduce these effects.

9.8 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.

9.9 Earth scientists document and seek to understand the impacts of humans on global

change involving the land, water, and air 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 others can be lessened and even reversed. An Earth-science-literate public is critical to the promotion of stewardship, policy, and international cooperation informed by current accurate scientific understanding.