Unit 9 Physics of the Geosphere

Content Area: **Science**
Course(s):
Time Period: **May**
Length: **5 Blocks**
Status: **Published**

Topic Outline

Understanding the Evidence that lead to the Theory of Continental Drift
Understanding the Evidence for the Theory of Plate Tectonics

- Analyze seismographs

Geological Timescales

- Cosmic Calendar

Earth's Changing Surface

- Volcanism, mountain building, erosion, feedback loops

Unit Summary

How much force and energy is needed to move a continent?

In this unit of study, students construct explanations for the scales of time over which Earth processes operate. An important aspect of Earth and space sciences involves making inferences about events in Earth's history based on a data record that is increasingly incomplete the farther one goes back in time. A mathematical analysis of radiometric dating is used to comprehend how absolute ages are obtained for the geologic record. Students develop *models and explanations* for the ways that feedback among different Earth systems controls the appearance of the Earth's surface. Central to this is the tension between internal systems, which are largely responsible for creating land at Earth's surface (e.g., volcanism and mountain building), and the sun-driven surface systems that tear down land through weathering and erosion. Students demonstrate proficiency in *developing and using models, constructing explanations, and engaging in argument from evidence.* The crosscutting concepts of *stability and change, energy and matter, and patterns* are called out as organizing elements of this unit.

updated from 11.19.15

Enduring Understandings

- The surface of the Earth has changed and continues to change due to volcanism, mountain building, erosion, and weathering.
- The history of the Earth is discussed in terms of a geological time scale.
- Some information about Earth is theory, which is supported by evidence in the fossil record, ice cores, radiometric dating, etc.
- Models are used to understand complex processes.

Essential Questions

- How has Earth's surface changed over time?
- How long does it take to make a mountain?
- How much force is needed to move a continent?
- What can possibly provide the energy to move a continent?
- How do we know if all rocks are the same age?
- How do changes in the geosphere affect the atmosphere and other processes?

Student Learning Objectives (PE, SEP, DCI, CCC) & Aligned Standards

- Less mathematical analysis of earthquake data will be conducted.

Performance Expectations

Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features. *[Clarification Statement: Emphasis ison how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth's surface.]* **(HS-ESS2-1)**

Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection. *[Clarification Statement: Emphasis is on both a one-dimensional model of Earth, with radial layers determined by density, and a three-dimensional model, which is controlled by mantle convection and the resulting plate tectonics. Examples of evidence include maps of Earth's three dimensional structure obtained from seismic waves, records of the rate of change of Earth's magnetic field (as constraints on convection in the outer core), and identification of the composition of Earth's layers from high-pressure* *laboratory experiments.]* **(HS-ESS2-3)**

Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks. *[Clarification Statement: Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks. Examples include evidence of the ages oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of North American continental crust increasing with distance away from a central ancient core (a result of past plate interactions).]* **(HS-ESS1-5)**

Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems. *[Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.]* **(HS-ESS2-2)**

Science and Engineering Practices

Developing and Using Models

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-ESS2-1),(HS-ESS2-3)

Analyzing and Interpreting Data

- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-ESS2-2)

Engaging in Argument from Evidence

- Evaluate evidence behind currently accepted explanations or solutions to determine the merits of arguments. (HS-ESS1-5)

Disciplinary Core Ideas

ESS2.A: Earth Materials and Systems

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. (HS-ESS2-1),(HS-ESS2-2)
- Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface

and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior. (HS-ESS2-3)

ESS2.B: Plate Tectonics and Large-Scale System Interactions

- The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection. (HS-ESS2-3)
- Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust. (HS-ESS2-1)

ESS2.D: Weather and Climate

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. (HS-ESS2-2)

ESS1.C: The History of Planet Earth

- Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old. (HS-ESS1-5)

Crosscutting Concepts

Energy and Matter

- Energy drives the cycling of matter within and between systems. (HS-ESS2-3)
- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS2-1)
- Feedback (negative or positive) can stabilize or destabilize a system. (HS-ESS2-2)

Patterns

- Empirical evidence is needed to identify patterns. (HS-ESS1-5)

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Connections to Engineering, Technology,

and Applications of Science

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development

(R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. (HS-ESS2-3)

Influence of Engineering, Technology, and Science on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ESS2-2)

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based on empirical evidence. (HS-ESS2-3)
- Science disciplines share common rules of evidence used to evaluate explanations about natural systems. (HS-ESS2-3)
- Science includes the process of coordinating patterns of evidence with current theory. (HS-ESS2-3)

SCI.9-12.1.5	Empirical evidence is needed to identify patterns.
SCI.9-12.2.2	Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.
SCI.9-12.2.4	Changes in systems may have various causes that may not have equal effects.
SCI.9-12.3.2	Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly.
SCI.9-12.3.3	Patterns observable at one scale may not be observable or exist at other scales.
SCI.9-12.4.3	Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.
SCI.9-12.4.4	Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.
SCI.9-12.5.1.12.A.c	Revisions of predictions and explanations are based on systematic observations, accurate measurements, and structured data/evidence.
SCI.9-12.5.1.12.B.2	Build, refine, and represent evidence-based models using mathematical, physical, and computational tools.
SCI.9-12.5.1.12.B.3	Revise predictions and explanations using evidence, and connect explanations/arguments to established scientific knowledge, models, and theories.
SCI.9-12.5.1.12.B.c	Empirical evidence is used to construct and defend arguments.
SCI.9-12.5.1.12.B.d	Scientific reasoning is used to evaluate and interpret data patterns and scientific conclusions.
SCI.9-12.5.1.12.C.1	Reflect on and revise understandings as new evidence emerges.
SCI.9-12.5.1.12.C.2	Use data representations and new models to revise predictions and explanations.
SCI.9-12.5.1.12.C.3	Consider alternative theories to interpret and evaluate evidence-based arguments.
SCI.9-12.5.1.12.C.a	Refinement of understandings, explanations, and models occurs as new evidence is incorporated.
SCI.9-12.5.1.12.C.b	Data and refined models are used to revise predictions and explanations.

SCI.9-12.5.1.12.C.c	Science is a practice in which an established body of knowledge is continually revised, refined, and extended as new evidence emerges.
SCI.9-12.5.1.12.D.1	Engage in multiple forms of discussion in order to process, make sense of, and learn from others' ideas, observations, and experiences.
SCI.9-12.5.1.12.D.2	Represent ideas using literal representations, such as graphs, tables, journals, concept maps, and diagrams.
SCI.9-12.5.1.12.D.a	Science involves practicing productive social interactions with peers, such as partner talk, whole-group discussions, and small-group work.
SCI.9-12.5.1.12.D.b	Science involves using language, both oral and written, as a tool for making thinking public.
SCI.9-12.5.2	Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.
SCI.9-12.5.4	Energy drives the cycling of matter within and between systems.
SCI.9-12.6.2	The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.
SCI.9-12.7.2	Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.
SCI.9-12.7.3	Feedback (negative or positive) can stabilize or destabilize a system.
SCI.9-12.CCC.3.1	students understand the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. They recognize patterns observable at one scale may not be observable or exist at other scales, and some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. Students use orders of magnitude to understand how a model at one scale relates to a model at another scale. They use algebraic thinking to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).
SCI.9-12.CCC.6.1	students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem. They infer the functions and properties of natural and designed objects and systems from their overall structure, the way their components are shaped and used, and the molecular substructures of their various materials.
SCI.9-12.CCC.7.1	students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability.
SCI.9-12.SEP.1.a	Ask questions
SCI.9-12.SEP.1.a.1	that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.
SCI.9-12.SEP.1.a.2	that arise from examining models or a theory, to clarify and/or seek additional information and relationships.
SCI.9-12.SEP.1.a.3	to determine relationships, including quantitative relationships, between independent and dependent variables.
SCI.9-12.SEP.1.d	Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design.
SCI.9-12.SEP.2.a	Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria.

SCI.9-12.SEP.4.c	Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.
SCI.9-12.SEP.4.d	Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.
SCI.9-12.SEP.4.e	Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.
SCI.9-12.SEP.5.b	Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.
SCI.9-12.SEP.5.d	Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model “makes sense” by comparing the outcomes with what is known about the real world.
SCI.9-12.SEP.8.a	Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
SCI.9-12.SEP.8.b	Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem.
SCI.9-12.SEP.8.c	Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.
SCI.9-12.SEP.8.d	Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible.
SCI.9-12.SEP.8.e	Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically).
SCI.9-12.HS-ESS2-1	Develop a model to illustrate how Earth’s internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.
SCI.9-12.HS-ESS2-7	Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.
SCI.9-12.HS-ESS2-5	Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.
SCI.9-12.HS-ESS2-6	Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
SCI.9-12.HS-ESS1-6	Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth’s formation and early history.
SCI.9-12.HS-ESS1-5	Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.
SCI.9-12.HS-ESS2-3	Develop a model based on evidence of Earth’s interior to describe the cycling of matter by thermal convection.
SCI.9-12.HS-ESS2-2	Analyze geoscience data to make the claim that one change to Earth’s surface can create feedbacks that cause changes to other Earth systems.
SCI.9-12.HS-ESS2-4	Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
	Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks. Examples include evidence of the ages oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of North American continental crust decreasing with distance away from a central ancient core of the continental plate (a result of past plate interactions).

Concepts & Formative Assessment

Part A: *How long does it take to make a mountain?*

Concepts

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
- Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history.
- Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust.
- Change and rates of change can be quantified and modeled over very short or very long periods of time.
- Some system changes are irreversible.

Formative Assessment

Students who understand the concepts are able to:

- Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.
- Develop a model to illustrate how the appearance of land features and sea-floor features are a result of both constructive forces and destructive mechanisms.
- Quantify and model rates of change of Earth's internal and surface processes over very short and very long periods of time.

Part B: How much force is needed to move a continent? What can possibly provide the energy for that much force?

Concepts

- Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of
- Earth with a hot but solid inner core, a liquid outer core, and a solid mantle and crust.
- Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior.
- The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection.
- Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet.
- Energy drives the cycling of matter within and between Earth's systems.

- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.
- Science knowledge is based on empirical evidence.
- Science disciplines share common rules of evidence used to evaluate explanations about natural systems.
- Science includes the process of coordinating patterns of evidence with current theory.

Formative Assessment

Students who understand the concepts are able to:

- Develop an evidence-based model of Earth's interior to describe the cycling of matter by thermal convection.
- Develop a one-dimensional model, based on evidence, of Earth with radial layers determined by density to describe the cycling of matter by thermal convection.
- Develop a three-dimensional model of Earth's interior, based on evidence, to show mantle convection and the resulting plate tectonics.
- Develop a model of Earth's interior, based on evidence, to show that energy drives the cycling of matter by thermal convection.

Part C: *Are all rocks the same age?*

Concepts

- Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old.
- Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history.
- Spontaneous radioactive decay follows a characteristic exponential decay law.
- Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials.
- Empirical evidence is needed to identify patterns in crustal rocks.

Formative Assessment

Students who understand the concepts are able to:

- Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.
- Evaluate evidence of plate interactions to explain the ages of crustal rocks.

Part D: *How do changes in the geosphere effect the atmosphere?*

Concepts

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.
- Feedback (negative or positive) can stabilize or destabilize a system.
- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

Formative Assessment

Students who understand the concepts are able to:

- Analyze geoscience data using tools, technologies, and/or models (e.g., computational, mathematical) to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

Resources

EarthViewer (IPAd or Android) or for Chrome browsers: Students explore the co-evolution of the geology and biology found on Earth to develop arguments from evidence for the co-evolution of geology and biology found on Earth. If IPads, Androids or Chrome browsers are not available, similar interactives may be found at this link, and this link.

Earth Systems Activity: Students model the carbon cycle and its connection with Earth's climate.

Greenhouse Effect: Students explore the atmosphere during the ice age and today. What happens when you add clouds? Change the greenhouse gas concentration and see how the temperature changes. Then compare to the effect of glass panes. Zoom in and see how light interacts with molecules. Do all atmospheric gases contribute to the greenhouse effect?

Assessments

- Model convection
- Reading seismographs
- Earth Problems Project

The Science Classroom

In this unit of study, students apply their knowledge of forces and energy as they examine Earth's dynamic and interacting systems, including the effects of feedback, and develop an understanding of plate tectonics as the unifying theory that explains the past and current movements of the rocks at Earth's surface. Plate tectonics also provides a framework for understanding Earth's geologic history. Students will begin by developing models, supported by evidence, to illustrate how the Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean floor features. Students should quantify and model long-term and short-term changes in the earth's crust, using examples such as continental drift, mountain building, earthquakes, and volcanic eruptions. Students might construct models using drawings, clay, graham crackers, or they might use mathematical models or video animations to demonstrate an understanding of these concepts. Models should illustrate both constructive (deposition) and destructive (erosion) forces. Students might also make strategic use of digital media in presentations to enhance understanding of Earth's internal and surface processes and the different spatial and temporal scales at which they operate. Students should quantify rates of change of Earth's internal and surface processes over very short and very long periods of time. In any quantitative representations of data, students should use units appropriately and consider the accuracy and limitations of any measurements. Students should also appreciate that some Earth system changes are irreversible.

Evidence used to create models should detail how plate movements are responsible for both continental and ocean floor features and for the distribution of rocks on the Earth's surface. Students might examine maps showing the distribution of minerals or fossils to draw inferences regarding how plates have moved over time. Students might also interpret geological layers to describe the history of Earth events by studying geological maps, core sample data, and fossil records in order to describe and model change and rates of change of Earth events.

Further evidence of plate movement could be determined by mapping earthquakes and volcanoes to show where these types of events are more likely to occur on the Earth's surface. This activity could be complemented by referencing catastrophic Earth events that have occurred in the last century and throughout the history of the Earth. This will show students how certain systems are predictable over long periods of time.

To determine how matter cycles in the Earth's interior, students should develop an understanding of how convection cells in the mantle move thermal energy throughout the Earth and how that energy affects superficial movement of the crustal plates. Students could perform experiments by creating and observing convection cells. For example, investigations could include materials such as a beaker of water containing pepper, raisins, glitter, or rice, placed on a hot plate. Students should observe the circular motion of the particles in the water as they move upward in the convection cell over the heat source. They should also observe the downward motion of the particles in other areas of the beaker. Connections should be made between this type of modeling activity and convection cells in the mantle. Emphasis should be placed on the importance of changing temperatures and density in these investigations so that students understand the cycling of matter due to the outward flow of energy from Earth's interior and the gravitational movement of denser materials toward the interior. Further discussion of this topic should emphasize how areas of tension over thermal uprisings create divergent boundaries (rifts) and areas of compression over cooling magma create convergent boundaries (subduction zones). Students should also examine how transform boundaries are created between convection cells flowing in opposite directions. An understanding of the sources of thermal energy within the Earth (radioactive decay, kinetic energy transfer from asteroid collisions, and pressure due to gravity) is also important to understanding convection in the mantle. Students should identify important quantities and use appropriate units when describing Earth's interior and the cycling of matter by thermal convection.

In order to develop an understanding of how current representations of the interior of the Earth were developed over time, students might research the historical contributions of individuals such as Wegener (continental drift), Vine (bathemetry), and Hess (sonar and bathemetry). Students should be able to explain how changes in technology (including mapping of continental shelves, sonar, bathemetry data, high pressure laboratory experiments, and seismic monitoring stations) have improved these representations. Students should explain the importance of seismic waves (P-waves and S-waves) and shadow zones in understanding the interior of the Earth. Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet. Students should also investigate and research the relative thickness, temperature, and composition of the main layers of the Earth (inner core, outer core, mantle, asthenosphere, lithosphere, and crust) and cite evidence from text to support their findings. Students should create models of the interior of the Earth that describe the cycling of matter by thermal convection; these models could include paper and pencil drawings, three-dimensional clay models, or computer animations. Models should demonstrate an understanding that Earth has a hot, solid inner core, a liquid outer core, and a solid mantle and crust.

Using knowledge of plate movements, students will next develop explanations for the ages of crustal rocks. Students should begin by identifying major plates and types of boundaries using maps of the Earth's surface showing the location of major plate boundaries, such as the United States Geological Survey (USGS) plate boundary map. Students should examine and evaluate evidence illustrating the following:

- Continental crust can be older than 4 billion years as compared to oceanic crust, which is less than 200 million years old, due to the subduction of oceanic crust beneath continental crust.
- The continents do not move over the ocean floor; rather, the entire plate moves over the mantle.
- Radioactive decay follows a characteristic exponential decay law and can be used to determine the ages of rocks and other materials. (Depending on where this course falls in relation to the chemistry course, students may or may not have a quantitative understanding of radioactive decay and half-lives. If this course is sequenced before chemistry, students should use only a qualitative understanding of how nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials.)

- Plates moving over hot spots create island chains (e.g., Hawai’ian islands) that can be used to track plate movement.
- Magnetic field lines are formed over time due to geomagnetic reversals. These lines can be used to plot the movement of plates over time. (Data showing how magnetic field lines on the ocean floor change over time will help students appreciate the amount of time and the frequency with which reversals take place.)
- Wilson cycles (taking 500 million years each) show that the continents have separated and come together several times over Earth’s history, so that the Earth’s surface has reformed about eight times in our 4.5-billion-year history.

Using evidence from their research, students should be able to write informative text about the ages of crustal rocks based on past and current movements of continental and oceanic crust. Their explanations should include evaluation of hypotheses, data, analysis, and conclusions, and attend to any gaps or inconsistencies. In their accounts, students should include narration of historical events and important scientific procedures or experiments.

After students have an understanding of the structure and formation of Earth’s surface, they will examine how changes to Earth’s surface create feedback. Students will also consider what changes to other Earth systems are a result of that feedback. Students should analyze data, using tools, technologies, and models to make claims about relationships between changes to Earth’s surface and feedback. Students might examine data from the Earth’s weather patterns to model how some weather patterns and Earth events are related to the use of natural resources. Examples of feedback include how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, thus reducing the amount of sunlight reflected from Earth’s surface, which in turn increases surface temperatures and further reduces the amount of ice. Other system interactions include how the loss of ground vegetation causes an increase in water runoff and soil erosion, how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion, or how the loss of wetlands causes a decrease in local humidity that further reduces the wetlands’ extent. Students should then provide and explain examples (such as CO_2 emissions, ozone depletion, changing weather patterns, etc.) of the negative and positive feedback that can stabilize and destabilize the environment. Students should be able to cite examples of new technologies (such as gasoline cars, hydrogen-fuel-cell cars, biofuel cars, solar power, alternative energy, etc.) and consider their impacts on society and the environment. Students might also consider the inorganic carbon cycle and geologic processes. For example, climate feedback could be modeled by understanding relationships between sediments containing carbon (calcium carbonate made by marine organisms) on the seafloor in subduction zones and carbon dioxide released through volcanoes.

Connecting with English Language Arts Literacy and Mathematics

English Language Arts/Literacy

- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of Earth's internal and surface processes and the different

spatial and temporal scales at which they operate and to add interest.
- Cite specific textual evidence to support analysis of the Earth's interior, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to model the Earth's interior and the cycling of matter by thermal convection to enhance understanding of findings, reasoning, and evidence and to add interest.
- Cite specific textual evidence to support analysis of the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Determine the central ideas or conclusions of a text about changes to Earth's surface changes and their effects on Earth systems; summarize complex concepts, processes, or information presented in a text describing Earth's surface changes and their effects on Earth systems by paraphrasing them in simpler but still accurate terms.
- Cite specific textual evidence of past and current movements of continental and oceanic crust to support analysis of the ages of crustal rocks, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
- Evaluate the hypotheses, data, analysis, and conclusions regarding the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
- Write informative texts about the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust, including the narration of historical events, scientific procedures/experiments, or technical processes.

Mathematics

- Represent symbolically an explanation for Earth's internal and surface processes and the different spatial and temporal scales at which they operate, and manipulate the representing symbols. Make sense of quantities and relationships about Earth's internal and surface processes and the different spatial and temporal scales at which they operate symbolically, and manipulate the representing symbols.
- Use a mathematical model to explain Earth's internal and surface processes and the different spatial and temporal scales at which they operate. Identify important quantities in Earth's internal and surface processes and the different spatial and temporal scales at which they operate and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.
- Use units as a way to understand problems and to guide the solution to multistep problems representing Earth's internal and surface processes and the different spatial and temporal scales at which they operate. Choose and interpret units consistently in formulas representing Earth's internal and surface processes and the different spatial and temporal scales at which they operate; choose and interpret the scale and the origin in graphs and data displays representing Earth's internal and surface processes and the different spatial and temporal scales at which they operate.
- Define appropriate quantities for the purpose of descriptive modeling of Earth's internal and surface processes and the different spatial and temporal scales at which they operate.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing Earth's internal and surface processes and the different spatial and temporal scales at which they operate.
- Represent an explanation for the Earth's interior and the cycling of matter by thermal convection symbolically and manipulate the representing symbols. Make sense of quantities and relationships about the Earth's interior and the cycling of matter by thermal convection symbolically and manipulate the representing symbols.
- Use a mathematical model to explain the Earth's interior and the cycling of matter by thermal

convection. Identify important quantities in the Earth's interior and the cycling of matter by thermal convection and map their relationships using tools. Analyze those relationships mathematically to draw conclusions, reflecting on the results and improving the model if it has not served its purpose.

- Use units as a way to understand problems and to guide the solution of multistep problems about the Earth's interior and the cycling of matter by thermal convection; choose and interpret units consistently in formulas representing the Earth's interior and the cycling of matter by thermal convection; choose and interpret the scale and the origin in graphs and data displays of the Earth's interior and the cycling of matter by thermal convection.
- Use units as a way to understand problems and to guide the solution of multistep problems about the ages of crustal rocks and past and current movements of continental oceanic crust; choose and interpret units consistently in formulas representing the ages of crustal rocks and past and current movements of continental and oceanic crust; choose and interpret the scale and the origin in graphs and data displays of the ages of crustal rocks and past and current movements of continental and oceanic crust.
- Define appropriate quantities for the purpose of descriptive modeling of the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities related to the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust.
- Represent an explanation for Earth's surface changes and their effects on Earth systems symbolically, and manipulate the representing symbols. Make sense of quantities and relationships about Earth's surface changes and their effects on Earth systems symbolically and manipulate the representing symbols.
- Use units as a way to understand problems and to guide the solution of multistep problems about Earth's surface changes and their effects on Earth systems; choose and interpret units consistently in formulas representing Earth's surface changes and their effects on Earth systems; choose and interpret the scale and the origin in graphs and data displays representing Earth's surface changes and their effects on Earth systems.
- Choose a level of accuracy appropriate to limitations on measurement when reporting quantities representing Earth's surface changes and their effects on Earth systems.
- Represent symbolically an explanation for the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust, and manipulate the representing symbols. Make sense of quantities and relationships about the ages of crustal rocks based on evidence of past and current movements of continental and oceanic crust symbolically and manipulate the representing symbols.

Modifications

Teacher Note: Teachers identify the modifications that they will use in the unit. The unneeded modifications can then be deleted from the list.

- Restructure lesson using UDL principals (http://www.cast.org/our-work/about-udl.html#.VXmoXcfD_UA)
- Structure lessons around questions that are authentic, relate to students' interests, social/family background and knowledge of their community.

- Provide students with multiple choices for how they can represent their understandings (e.g. multisensory techniques-auditory/visual aids; pictures, illustrations, graphs, charts, data tables, multimedia, modeling).
- Provide opportunities for students to connect with people of similar backgrounds (e.g. conversations via digital tool such as SKYPE, experts from the community helping with a project, journal articles, and biographies).
- Provide multiple grouping opportunities for students to share their ideas and to encourage work among various backgrounds and cultures (e.g. multiple representation and multimodal experiences).
- Engage students with a variety of Science and Engineering practices to provide students with multiple entry points and multiple ways to demonstrate their understandings.
- Use project-based science learning to connect science with observable phenomena.
- Structure the learning around explaining or solving a social or community-based issue.
- Provide ELL students with multiple literacy strategies.
- Collaborate with after-school programs or clubs to extend learning opportunities.

Prior Learning

Physical science

- Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
- Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.
- Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.
- Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.
- The total number of each type of atom is conserved, and thus the mass does not change.
- Some chemical reactions release energy, others store energy.
- Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.
- Gravitational forces are always attractive. There is a gravitational force between any two masses, but it

is very small except when one or both of the objects have large mass—e.g., Earth and the sun.

- Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object or a ball, respectively).
- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- A system of objects may also contain stored (potential) energy, depending on the objects' relative positions.
- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light.
- The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends.
- A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.
- However, because light can travel through space, it cannot be a matter wave, like sound or water waves.

Life science

- Food webs are models that demonstrate how matter and energy are transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.
- Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations.
- Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health.
- Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes.

Earth and space science

- The geologic time scale interpreted from rock strata provides a way to organize Earth's history. Analyses of rock strata and the fossil record provide only relative dates, not an absolute scale.
- All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from the sun and Earth's hot interior. The energy that flows and matter that cycles produce chemical and physical changes in Earth's materials and living organisms.
- The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history

and will determine its future.

- Maps of ancient land and water patterns, based on investigations of rocks and fossils, make clear how Earth's plates have moved great distances, collided, and spread apart.
- Water continually cycles among land, ocean, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as via downhill flows on land.
- The complex patterns of the changes and the movement of water in the atmosphere, determined by winds, landforms, and ocean temperatures and currents, are major determinants of local weather patterns.

Connections to Other Courses

Physical science

- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space; these fields can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.
- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.
- The availability of energy limits what can occur in any system.
- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.
- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features.
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.
- Photoelectric materials emit electrons when they absorb light of a high enough frequency.

Life science

- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small

fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and are conserved.

- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.
- A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, the ecosystem may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or in the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.
- Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change.
- Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.

Earth and space science

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.
- Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, and a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior.
- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.
- The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.
- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.
- Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.
- Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.

References

Adapted from the New Jesery NGSS Science Model Curriclum

Connections to NJSLS

English Language Arts/Literacy

Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-ESS1-5),(HS-ESS2-2),(HS-ESS2-3) **RST.11-12.1**

Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. (HS-ESS2-2) **RST.11-12.2**

Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ESS1-5) **RST.11-12.8**

Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-ESS1-5) **WHST.9-12.2**

Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-ESS2-5) **WHST.9-12.7**

Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. (HS-ESS2-1),(HS-ESS2-3) **SL.11-12.5**

Mathematics

Reason abstractly and quantitatively. (HS-ESS1-5), (HS-ESS2-1),(HS-ESS2-2),(HS-ESS2-3) **MP.2**

Model with mathematics. (HS-ESS2-1),(HS-ESS2-3) **MP.4**

Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-ESS1-5), (HS-ESS2-1),(HS-ESS2-2),(HS-ESS2-3) **HSN-Q.A.1**

Define appropriate quantities for the purpose of descriptive modeling. (HS-ESS1-5), (HS-ESS2-1),(HS-ESS2-3)**HSN-Q.A.2**

Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-ESS1-5) ,(HS-ESS2-1),(HS-ESS2-2),(HS-ESS2-3) **HSN-Q.A.3**