Using the Seafloor Magnetic Anomaly Globe in the Classroom

Kevin P Furlong
Professor of Geosciences
Penn State University

PennState

SEAFLOOR MAGNETIC ANOMALY GLOBE AND MAP

LEARNING ACTIVITIES - WHAT CAN I DO WITH THE GLOBE?

The ***Seafloor Magnetic Anomaly Globe*** provides an effective way for students across a range of levels, from Middle School to University, to explore key aspects of plate tectonics. We have previously worked many of the activities described here using a Mercator Map of magnetic anomalies (similar to the updated version provided here as a companion to the Globe). We have found that accomplishing the learning goals of these activities using a map brings with it a substantial amount of overhead in the form of additional calculations to go from measurements on the map to the actual plate boundary lengths, plate areas, or relative plate velocities desired. In contrast, by using the globe students can make these measurements directly.

Plate Tectonics is foundational to much of the Earth Sciences. Developing an understanding of basic Plate Tectonic concepts and processes is a learning goal for many curricula in Earth Science. Specific questions such as:

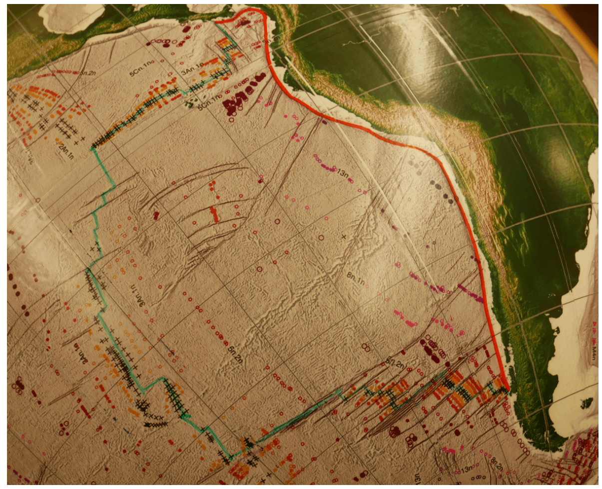
1. How big are plates?
2. How fast do plates move?
3. Do plate velocities change over time
4. Do plates spread apart symmetrically?
5. How do we describe plate motions on a spherical Earth?
6. Are plates rigid?
7. What makes plates move?

serve as the underlying basis of much of our coursework involving plate tectonics.

Here we provide examples of a range of specific activities that can be done with the globes to help students discover answers to these questions. In designing a particular lab session one of these activities could applied to several plate boundaries or different activities could be combined into a single laboratory exercise; we leave it to the individual instructor to decide how best to incorporate these learning activities into their specific course. The Laboratory Exercises that use the globes that I have used in teaching Plate Tectonics and Geodynamics courses will be available in the near future on the RWG web site. In this description, the activities are organized from the simpler (more basic concepts) to the more complicated.

Foundational Plate Tectonics

1. **Plate Boundaries** - (a) Students can use the magnetic anomaly patterns and the underlying seafloor bathymetry to sketch onto the globe the location of the system of Mid-Ocean Ridges (MOR). (b) Using a companion map of earthquakes, bathymetry and other information, they can identify other plate boundaries such as Trenches and major Transform Faults. (c) With this information they can compare the length of ridges (plate accretion zones) to the length of trenches (plate consuming zones), and assess similarities and differences. *[Use scaled ruler and/or spherical ruler provided in the educational kit]*



Above: Outline of Nazca Plate (west of South America) The East Pacific Rise and Galapagos Ridge (the MORs bounding the Nazca plate) are indicated by the green line; the trench along South America is marked in Red.

Left: Measuring the length of a segment of the East Pacific Rise using the scaled ruler provided in the educational kit

2. **Plate Motions/Velocities** - (a) to determine relative plate velocities across a section of a MOR, students can measure the distance from a specific anomaly to its pair across the MOR. With that distance and the age for that magnetic anomaly, the spreading velocity (mm/yr) over that time interval can be determined. Additionally the direction of relative plate motion at that location can be determined by measuring the angle (azimuth) of spreading with respect to North.

[Use scaled ruler provided in the educational kit, and a simple protractor]

Left: Measuring distance across the spreading ridge between Australia and Antarctica to determine spreading rate. The distance between Anomaly 5Cn.1n on either side of the ridge is approximately 1070 km and since that anomaly has an age of 16.01 Ma (young edge of anomaly) we find a full-spreading rate of ~ 67 km/Ma or 67 mm/yr

3. **Plate Velocity Through Time** - To investigate if plate velocities change over time. the student can measure the distance from the MOR to different anomalies (on the same side of the ridge). The distance from the ridge (y axis) is plotted against the age of the anomaly measured (x axis). The slope of the line between each measurement (age-distance pair) provides the half-spreading rate during that interval.

[Use scaled ruler provided in the   educational kit]

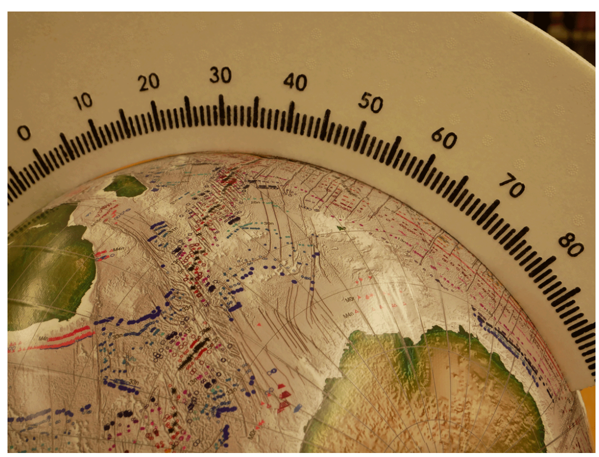
Right: Distance from the MOR (in this case the South Atlantic Ridge between Africa and South America) to a set of anomalies is measured. When plotted this provides interval plate velocity information

4. **Symmetric/Non-symmetric Seafloor Spreading—** To determine if the MOR is spreading symmetrically (i.e. adding similar amounts of new oceanic crust to each plate). The student can simply redo Activity 3 (*Plate Velocity Through Time*) on both sides of the MOR. If both data sets are plotted on the same graph it is easy to see if that MOR system exhibits symmetric spreading.
[Use scaled ruler provided in the educational kit]

Rigid Plates and Euler Poles

1. **Rigid Rotations** - Based on Plate Tectonic Theory (Euler's Theorem) motions of a rigid body on the surface of a sphere can be described by a rotation about a pole of rotation - the so-called *Euler Pole*. A corollary of this theory is that the spreading rate across the MOR will increase with distance from the Euler Pole with a Sine curve behavior (zero spreading rate at the pole increasing to a maximum spreading rate at a distance of 90° from the pole). We provide students with the location of the Euler Pole for a particular plate pair, and they measure the distance from the pole (using the spherical ruler) and the spreading rate at each position. When plotted on a graph of spreading rate (y-axis) versus distance from pole (x-axis, measured as an angular distance) the students will find their data matches a sinusoidal functional shape. *[Use scaled ruler and/or spherical ruler provided in the educational kit]*

Upper Right: Pairs of anomalies on either side of the Australia-Antarctic Ridge. The spreading rate between each set of paired anomalies is measured.



Lower Right: The distance form the Euler Pole to each measured anomaly pair is measured using the spherical ruler. This spreading velocity is plotted against angular distance to assess the rigid rotation hypothesis.

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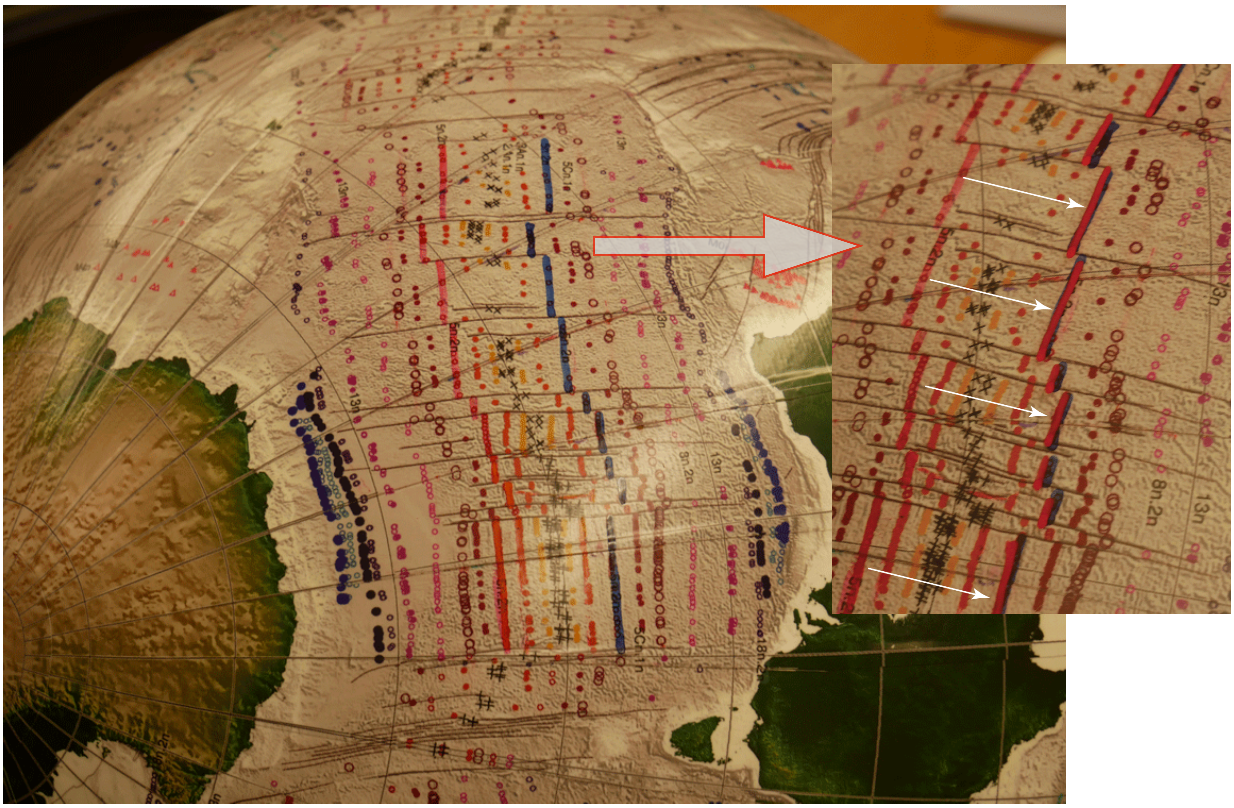
2. **Determining Euler Poles** - Following on from the Activity 1 (*Rigid Rotations*) described above, students can determine the distance to the pole of rotation by measuring spreading velocities (as a function of angular distance for an arbitrary reference point). If their measurements straddle a plate velocity maximum that indicates a distance of 90° from the Euler Pole. Otherwise the distance to the Euler pole can be estimated by fitting a sine wave to their data. They can find that their data is best explained if it is considered to occupy a particular range in angular distance. The spherical cap (with the Lat/Long grid) can be placed at the estimated position of the Euler Pole and if it is appropriate the "longitude" lines on the spherical cap will parallel the anomalies sets. *[Use scaled ruler and the spherical cap with the Lat/Long grid]*

Right: The spherical cap with the apex of the Lat/Long grind placed at the approximate Euler Pole for Australia/ Antarctica motions. The anomaly sets appropriately parallel the "longitudes".

3. **Reconstructing Plate Boundaries Through Time** - Under the assumptions of rigid plates, we can reconstruct the past positions of the plate boundary between two plates and other features on those plates. Using the spherical cap students can sketch the outlines of the particular feature to be reconstructed through time along with the appropriate anomalies. By closing the ocean (i.e. removing ocean lithosphere younger than the age of interest) the features will move into the reconstructed position. *[Use scaled ruler and spherical cap in the educational kit,]*



Above: Closing the ocean between Australia and Antarctica for a reconstruction at the time of Anomaly 5n.2n (old) which has an age of 10.95 Ma. With rigid body rotations the anomalies perfectly overlie their pairs on the other side of the ridge. The Spherical cap was used to rotate the Antarctica plate to its position relative to Australia at 10.95 Ma.

Age Distribution of Sea Floor

Some of the parameters that affect the rate of plate motion include the relative proportion of plate boundary length associated with subduction (slab pull), ridges (ridge push), and the actual age of lithosphere that subducts as compared to the overall plate area. The distribution of ocean crustal ages also affects the depth of the oceans. All of these parameters can be easily measured using the globe.

1. **Plate Age at Subduction** - Once the location of subduction zones are defined, the nearby anomalies allow the student to determine the age of lithosphere at subduction along a plate boundary. This can be compared to other subduction zones, and to the kinematics of the plates.
   [Use scaled ruler and/or spherical ruler provided in the educational kit]

2. **Global (Plate) Ocean Area - Age Distribution**- Determining the size of various plates and the areal distribution ages within a specific plate can be easily accomplished using the grid provided in the educational kit. Students can approximate the area by counting the number of boxes (of known area) filling the region of interest.
   [Use the grid overlays provided in the kit]

Right: Grid overlay on the northern part of the Nazca plate. Each box in the grid is 200 km x 200 km (4×10^4 km^2)

MS.History of Earth

MS.History of Earth

Students who demonstrate understanding can:

MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history. [Clarification Statement: Emphasis is on how analyses of rock formations and the fossils they contain are used to establish relative ages of major events in Earth's history. Examples of Earth's major events could range from being very recent (such as the last Ice Age or the earliest fossils of homo sapiens) to very old (such as the formation of Earth or the earliest evidence of life). Examples can include the formation of mountain chains and ocean basins, the evolution or extinction of particular living organisms, or significant volcanic eruptions.] [Assessment Boundary: Assessment does not include recalling the names of specific periods or epochs and events within them.]

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]

MS-ESS2-3. Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions. [Clarification Statement: Examples of data include similarities of rock and fossil types on different continents, the shapes of the continents (including continental shelves), and the locations of ocean structures (such as ridges, fracture zones, and trenches).] [Assessment Boundary: Paleomagnetic anomalies in oceanic and continental crust are not assessed.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to provide evidence for phenomena. (MS-ESS2-3)

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.

- Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (MS-ESS1-4),(MS-ESS2-2)

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Connections to Nature of Science

Scientific Knowledge is Open to Revision in Light of New Evidence

- Science findings are frequently revised and/or reinterpreted based on new evidence. (MS-ESS2-3)

Disciplinary Core Ideas

ESS1.C: The History of Planet Earth

- 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. (MS-ESS1-4)
- Tectonic processes continually generate new ocean sea floor at ridges and destroy old sea floor at trenches. *(HS.ESS1.C GBE) (secondary to MS-ESS2-3)*

ESS2.A: Earth's Materials and Systems

- 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. (MS-ESS2-2)

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

- 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. (MS-ESS2-3)

ESS2.C: The Roles of Water in Earth's Surface Processes

- Water's movements—both on the land and underground—cause weathering and erosion, which change the land's surface features and create underground formations. (MS-ESS2-2)

Crosscutting Concepts

Patterns

- Patterns in rates of change and other numerical relationships can provide information about natural and human designed systems. (MS-ESS2-3)

Scale Proportion and Quantity

- Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. (MS-ESS1-4),(MS-ESS2-2)

Connections to other DCIs in this grade-band: **MS.PS1.B** (MS-ESS2-2); **MS.LS2.B** (MS-ESS2-2); **MS.LS4.A** (MS-ESS1-4),(MS-ESS2-3); **MS.LS4.C** (MS-ESS1-4)

Articulation of DCIs across grade-bands: **3.LS4.A** (MS-ESS1-4),(MS-ESS2-3); **3.LS4.C** (MS-ESS1-4); **3.ESS3.B** (MS-ESS2-3); **4.ESS1.C** (MS-ESS1-4),(MS-ESS2-2),(MS-ESS2-3); **4.ESS2.A** (MS-ESS2-2); **4.ESS2.B** (MS-ESS2-3); **4.ESS2.E** (MS-ESS2-2); **4.ESS3.B** (MS-ESS2-3); **5.ESS2.A** (MS-ESS2-2); **HS.PS1.C** (MS-ESS1-4); **HS.PS3.D** (MS-ESS2-2); **HS.LS2.B** (MS-ESS2-2); **HS.LS4.A** (MS-ESS1-4),(MS-ESS2-3); **HS.LS4.C** (MS-ESS1-4),(MS-ESS2-3); **HS.ESS1.C** (MS-ESS1-4),(MS-ESS2-2),(MS-ESS2-3); **HS.ESS2.A** (MS-ESS1-4),(MS-ESS2-2),(MS-ESS2-3); **HS.ESS2.B** (MS-ESS2-2),(MS-ESS2-3); **HS.ESS2.C** (MS-ESS2-2); **HS.ESS2.D** (MS-ESS2-2); **HS.ESS2.E** (MS-ESS2-2); **HS.ESS3.D** (MS-ESS2-2)

Common Core State Standards Connections:

ELA/Literacy –

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts. (MS-ESS1-4),(MS-ESS2-2),*(MS-ESS2-3)*

RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-ESS2-3)

RST.6-8.9 Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. (MS-ESS2-3)

WHST.6-8.2 Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-ESS1-4),(MS-ESS2-2)

SL.8.5 Include multimedia components and visual displays in presentations to clarify claims and findings and emphasize salient points. *(MS-ESS2-2)*

Mathematics –

MP.2 Reason abstractly and quantitatively. (MS-ESS2-2),(MS-ESS2-3)

6.EE.B.6 Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set. *(MS-ESS1-4),(MS-ESS2-2),(MS-ESS2-3)*

7.EE.B.4 Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities. *(MS-ESS1-4),(MS-ESS2-2),(MS-ESS2-3)*

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

HS.History of Earth

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Students who demonstrate understanding can:

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. [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-ESS1-6. 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. [Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.]

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. [Clarification Statement: Emphasis is on 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.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).
- Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-ESS2-1)

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.
- Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. (MS-ESS1-6)

Engaging in Argument from Evidence
Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.
- Evaluate evidence behind currently accepted explanations or solutions to determine the merits of arguments. (HS-ESS1-5)

Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. (HS-ESS1-6)
- Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. (HS-ESS1-6)

Disciplinary Core Ideas

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)
- Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history. (HS-ESS1-6)

ESS2.A: Earth Materials and Systems
- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts. (HS-ESS2-1) *(Note: This Disciplinary Core Idea is also addressed by HS-ESS2-2.)*

ESS2.B: Plate Tectonics and Large-Scale System Interactions
- 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. *(ESS2.B Grade 8 GBE) (secondary to HS-ESS1-5)*,(HS-ESS2-1)
- Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust. (*ESS2.B Grade 8 GBE*) (HS-ESS2-1)

PS1.C: Nuclear Processes
- Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. *(secondary to HS-ESS1-5),(secondary to HS-ESS1-6)*

Crosscutting Concepts

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

Stability and Change
- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS1-6)
- 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)

Connections to other DCIs in this grade-band: **HS.PS2.A** (HS-ESS1-6); **HS.PS2.B** (HS-ESS1-6),(HS-ESS2-1); **HS.PS3.B** (HS-ESS1-5); **HS.ESS2.A** (HS-ESS1-5),(HS-ESS1-6)

Articulation of DCIs across grade-bands: **MS.PS2.B** (HS-ESS1-6),(HS-ESS2-1); **MS.LS2.B** (HS-ESS2-1); **MS.ESS1.B** (HS-ESS1-6); **MS.ESS1.C** (HS-ESS1-5),(HS-ESS1-6),(HS-ESS2-1); **MS.ESS2.A** (HS-ESS1-5),(HS-ESS1-6),(HS-ESS2-1); **MS.ESS2.B** (HS-ESS1-5),(HS-ESS1-6),(HS-ESS2-1); **MS.ESS2.C** (HS-ESS2-1); **MS.ESS2.D** (HS-ESS2-1); **MS.ESS2.E** (HS-ESS2-1); **MS.ESS3.C** (HS-ESS2-1); **MS.ESS3.D** (HS-ESS2-1)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	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-ESS1-6)*
RST.11-12.8	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),(HS-ESS1-6)
WHST.9-12.1	Write arguments focused on *discipline-specific content.* (HS-ESS1-6)
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. *(HS-ESS1-5)*
SL.11-12.5	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)*

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-ESS1-5),(HS-ESS1-6),(HS-ESS2-1)
MP.4	Model with mathematics. (HS-ESS2-1)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

HSN-Q.A.1	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-ESS1-6),(HS-ESS2-1)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling *(HS-ESS1-5),(HS-ESS1-6),*(HS-ESS2-1)
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities (HS-ESS1-5),(HS-ESS1-6),(HS-ESS2-1)
HSF-IF.B.5	Relate the domain of a function to its graph and, where applicable, to the quantitative relationship it describes. *(HS-ESS1-6)*
HSS-ID.B.6	Represent data on two quantitative variables on a scatter plot, and describe how those variables are related. *(HS-ESS1-6)*

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.