The Pine Mountain Thrust Fault
Standards and information from Appendix F & G:

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.*]

HS-ESS2-3. **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.]

Practice: Developing and using models (from NGSS Appendix F)

- 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.
- Design a test of a model to ascertain its reliability.
- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
- Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.
- Develop a complex model that allows for manipulation and testing of a proposed process or system.
- Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

CCC Stability and change (from NGSS Appendix G)

- Much of science deals with constructing explanations of how things change and how they remain stable.
- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.
- Feedback (negative or positive) can stabilize or destabilize a system.
- Systems can be designed for greater or lesser stability.

CCC Energy and matter (from Appendix G)

- The total amount of energy and matter in closed systems is conserved.

- 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.
- Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.
- Energy drives the cycling of matter within and between systems.
- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Disciplinary Core Ideas associated with the bundled Performance Expectations

ESS2.A: Earth Materials and Systems

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.

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. 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)

ESS2.A: Earth Materials and Systems

- 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.

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.

PS4.A: Wave Properties

- Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet. (secondary to HS-ESS2-3)

NOTES about this sample cluster:

- **Correct answers are intentionally omitted. This cluster was created as an example of the cluster/phenomenon based approach to assessment design, not as a "practice test."**
- **Several of the graphics contain information that in some cases provides some or all of the answer. On an actual assessment the graphics are customized to the question. The graphics in this example cluster are taken from sources on the web and are reproduced without modification. They are present in this cluster to help illustrate the design of the question, not to serve as exact examples.**
- **Images are in the public domain, used with permission, or with requested attribution.**
- **This cluster has not undergone review by content experts, nor bias review.**

The Pine Mountain Thrust Fault

Pound Gap is an opening in Pine Mountain, a long mountain that runs roughly north and south for over 100 miles along the Kentucky and Virginia border. For much of its length it is unbroken by streams or other gaps, making it a barrier to transportation.

A fault cuts through the mountain at Pound Gap, and weathering and erosion have created an opening. This opening made it easier to cross the mountain there. While building a new section of US Highway 23 through this area, the Pine Mountain Pound Gap Thrust Fault was exposed. A Thrust Fault is a break in the crust where one block of rock is pushed up and over another. In the case of Pine Mountain the exposed rock of the mountain would normally appear about 2000 feet below the surface.

The construction of US 23 in Letcher County exposed this fault and has provided a glimpse into the changes that have occurred in the area over millions of years. The Pound Gap road cut has been designated as a "Distinguished Geologic Site" because of its importance.

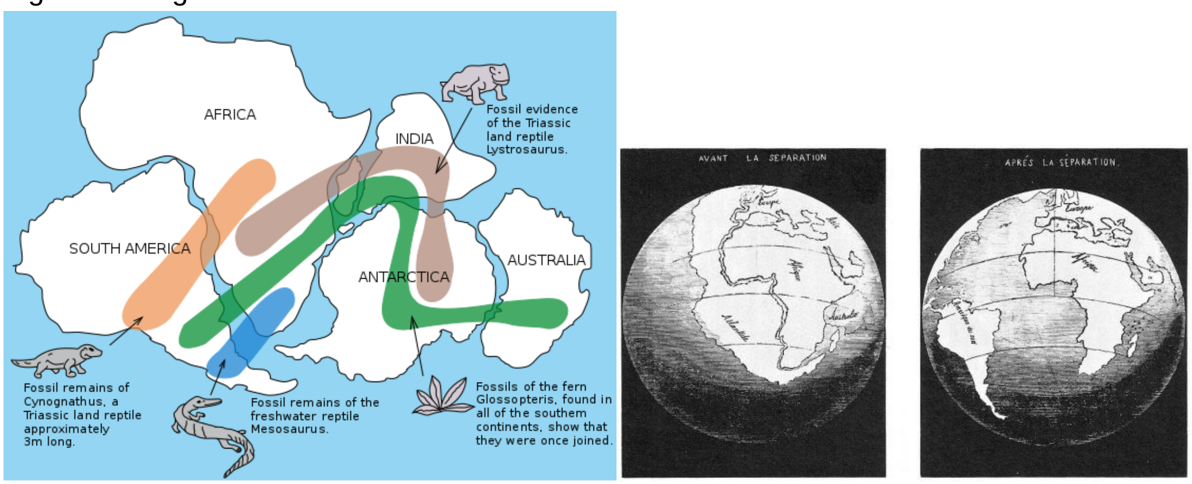
Figure 1. The Pound Gap Road Cut

https://en.wikipedia.org/wiki/Pound_Gap#/media/File:US23_cut_at_Pound_Gap.jpg

In order to understand the existence of Pine Mountain we must understand the forces and mechanisms that created it.

In 1912 German climatologist Alfred Wegener noticed that the different large landmasses of the Earth almost fit together like a jigsaw puzzle. This is especially apparent when based on the shape of the continents at the continental margins (the area of shallow water next to the continent.) Wegner proposed that the continents were once together as a single giant landmass that had split and drifted apart. He referred to this hypothesis as continental drift, and supported it with evidence from both fossil distribution and landforms

Figure 2. Wegner's Evidence for Continental Drift.



https://en.wikipedia.org/wiki/Continental_drift#/media/File:Snider-Pellegrini_Wegener_fossil_map.svg
https://en.wikipedia.org/wiki/Continental_drift#/media/File:Antonio_Snider-Pellegrini_Opening_of_the_Atlantic.jpg

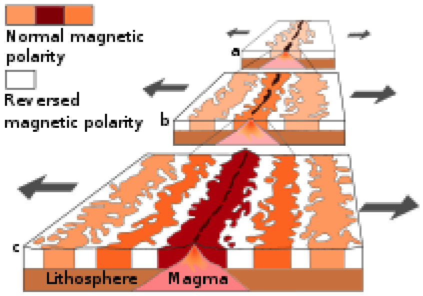
In spite of this evidence, scientists rejected this idea because they felt it was incomplete.

Q1. Wegner's original concept of continental drift was based primarily on the shapes of continents. What is the one most likely reason his idea was not widely accepted by the scientific community? DCI: ESS2.B, CCC: Energy and Matter

A. Did not account for the shape of the ocean
B. Did not include an explanation of a causal mechanism
C. Did not consider the effect of coastal erosion on the continental shorelines
D. Did not compensate for the lack of accuracy of the maps available at the time

After WWII magnetism detectors that were originally developed to detect submarines were used to study patterns of magnetism in the rocks on the ocean floor. It was noticed that that iron-rich basalt demonstrated a pattern of magnetism. Scientists knew that the earth's north and south magnetic poles have repeatedly reversed over time but they did not know this pattern had been captured in the magnetic orientation of seafloor rocks. When these magnetic patterns were mapped the ocean floor showed a zebra-like pattern of stripes with normal polarity next to ones with reversed polarity. The pattern of alternating bands of normally and reversely polarized rocks are referred to as magnetic striping. It was proposed that magnetic striping is evidence that the seafloor is spreading as the relatively thin seafloor rocks are torn apart and spread away from central points called mid-ocean ridges. As the seafloor spreads, the magma cools and freezes the pattern of magnetism.

Figure 3. Magnetic Sea Floor Striping



https://en.wikipedia.org/wiki/Plate_tectonics#/media/File:Oceanic.Stripe.Magnetic.Anomalies.Scheme.svg

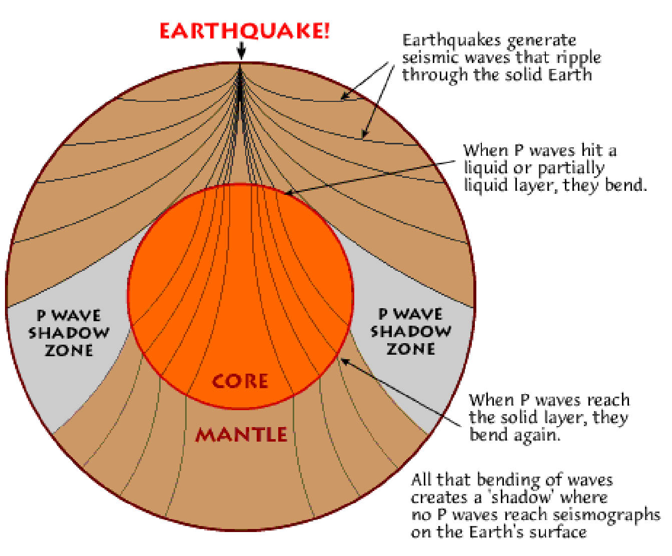
Q2. If the seafloor is actually spreading apart in two directions at the mid-ocean ridge, which of these observations would be true? DCI: ESS2.A, CCC: Stability and Change

Select the TWO best answers

A. The magnetic stripes are symmetrical around the crests of the mid-ocean ridges.
B. The normal and reversed polarity rocks are on opposite sides of the central mid-ocean ridge.
C. The rocks are very young at the ridge and they become progressively older away from the ridge crest.
D. The youngest rocks at the ridge crest always have reversed magnetic polarity.
E. Stripes of rock perpendicular to the ridge crest alternate in magnetic polarity.

Magnetic seafloor striping would only be possible if the solid crust were floating on a molten or partially molten layer below it. Much of what we know about the composition of the interior of the earth was not directly observed, but has been inferred based on observations. The movement and behavior of seismic waves (the vibrations caused by earthquakes) has allowed us to model the earth's interior through indirect observation. Earthquakes create two different kinds of waves, P and S waves, and they are observed to have different properties.

Figure 4. Seismic Wave Patterns



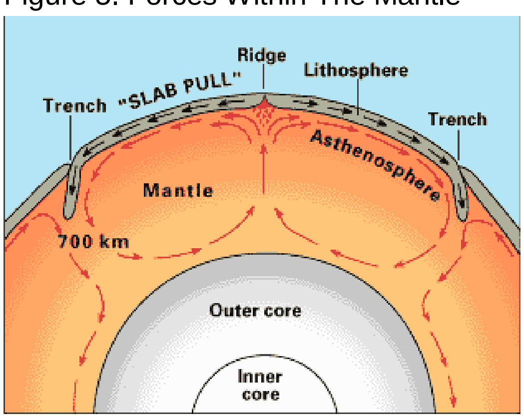
https://geomaps.wr.usgs.gov/parks/pltec/PSwaveEarthInterior.gif

Q3. For the model in Figure 4 to be helpful in explaining how seismic waves can be used to make inferences about the composition of the earth's interior, which one of these is most likely true?
DCI: PS4.A, SEP: Developing and Using Models, CCC: Energy and Matter

A. S waves travel poorly through liquids
B. The inner core absorbs P waves
C. Shadow zones are fixed in relation to geographic locations
D. The inner core is the hottest of the layers

Scientists have proposed that the forces needed to separate the ocean floor at mid-ocean ridges are the result of slow but powerful movements of magma within the earth's mantle. The currents, called convection currents are proposed as the driving force for the movement of the crust that floats above the mantle.

Figure 5. Forces Within The Mantle



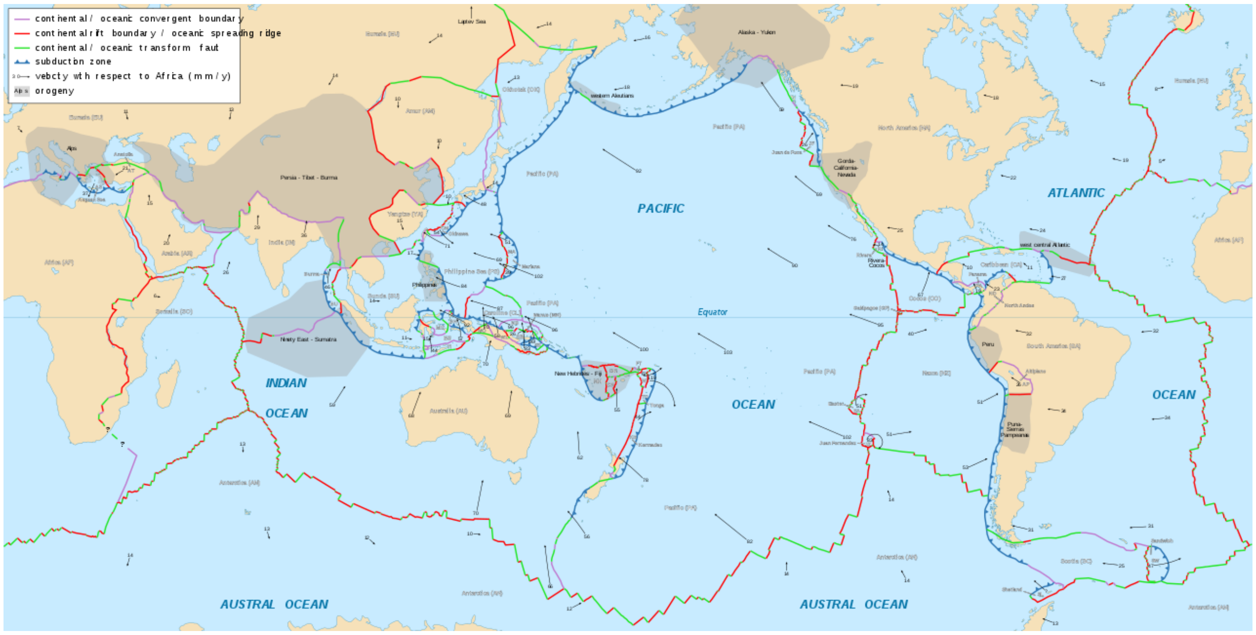
https://pubs.usgs.gov/gip/dynamic/unanswered.html

Q4. What features would need to be added to this Figure 5I to demonstrate the internal forces that are responsible for plate movement? DCI: ESS2.A, SEP: Developing and Using Models, CCC: Energy and Matter

Select the TWO best answers.

A. Magma sinking near the mid-ocean ridges
B. Magma rising near the mid-ocean ridges
C. Magma rising near subduction zones
D. Heat flowing from the core outward to the mantle
E. Heat flowing from the mantle into the core

Figure 6. Present Day Tectonic Plate Boundaries and Movements



By Eric Gaba (Sting - fr:Sting) - Background map: NGDC World Coast Line dataData: Prof. Peter Bird's map, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=130787

Scientists now understand the earth's crust is broken up into a number of distinct plates. At the boundaries of each plate a number of different interactions can occur, resulting in constructive and destructive forces. These include:

- Transform boundaries, where two plates grind past each other
- Convergent Subduction boundaries, where a thinner plate is forced under a thicker plate and melted back into magma
- Convergent collision boundaries, where two plates collide and thrust material upward
- Divergent boundaries, where new ocean floor crust is created at mid-ocean ridges

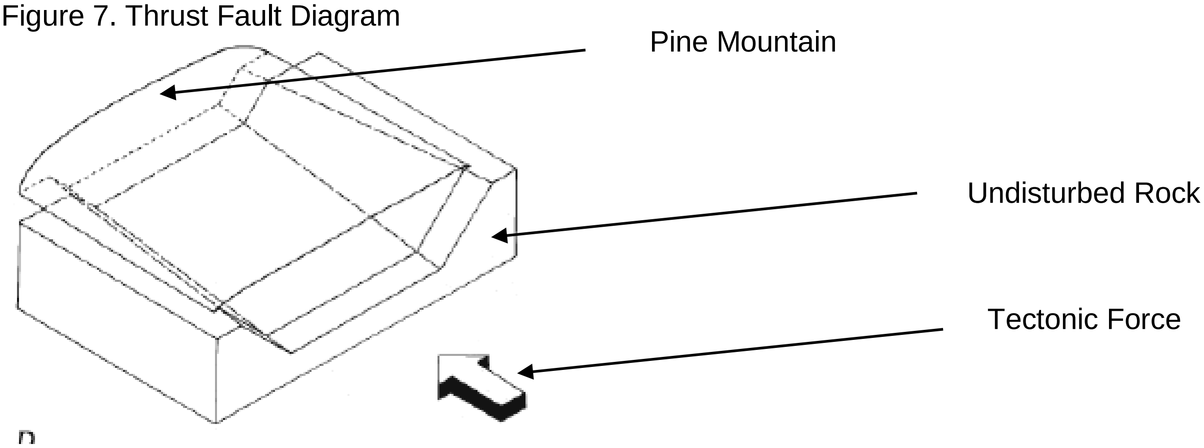
Figure 6 above represents the current shapes and relationships of plate boundaries, but these boundaries were quite different millions of years ago. It is widely theorized that at one time all of the continental landmass was together as a single continent surrounded by a single ocean. The plates have interacted in a number of different ways over the earth's long history.

Observations of the rocks atop Pine Mountain indicate they are older than the rocks in the valley below. This is contrary to the normal pattern of sedimentary rocks and is one reason Pine Mountain is such an unusual feature. Geologists believe the mountain was once a portion of TN that was shoved 11 miles to the NW and over the top of existing Kentucky rocks as shown in the figures below. Geologists believe tectonic interactions were responsible for creating Pine Mountain. Specifically, they believe that what was once the African continental plate smashed against the North American plate to provide the force that relocated the rocks of Pine Mountain.

Q5. Based on Figure 5, which of these statements must be true? DCI: ESS2.B, SEP: Developing and Using Models, CCC: Energy and Matter

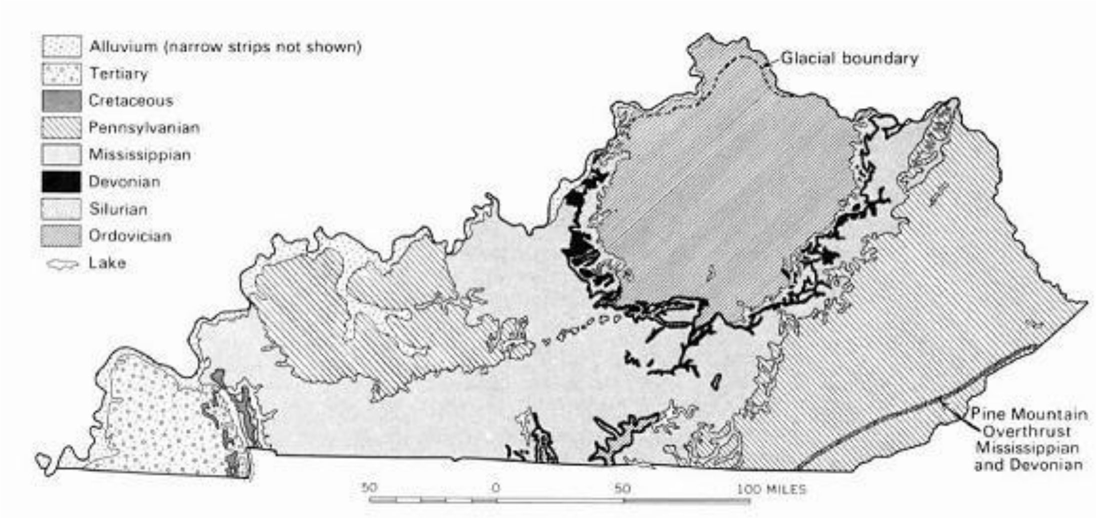
A. Average rates of collision at convergent boundaries must equal the rates of movement at transform boundaries
B. Average rates of collision at subduction boundaries must exceed the rates of movement at transform boundaries
C. Average rates of collision at convergent boundaries must equal the rates of spreading at divergent boundaries
D. Average rates of collision at convergent boundaries must exceed the rates of spreading at divergent boundaries

Figure 7. Thrust Fault Diagram



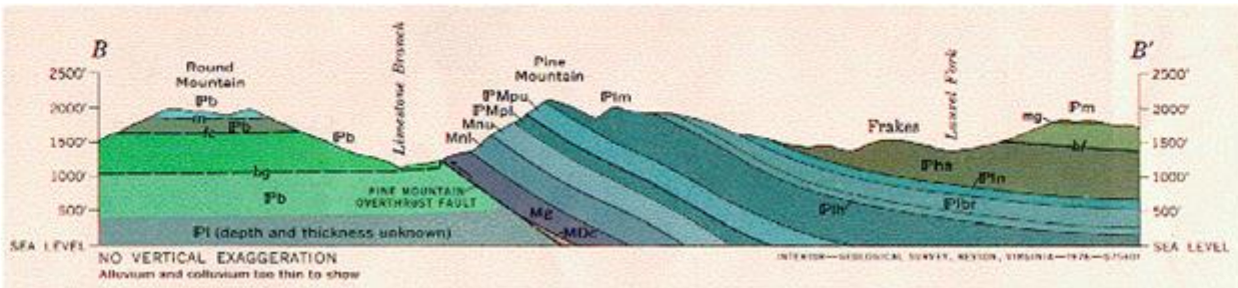
Adapted from https://pubs.usgs.gov/bul/b2163/pdf/b2163.pdf

Figure 8. Location and Orientation of the Pine Mountain Overthrust



McGrain, P,, 1983, The Geologic Story of Kentucky: Kentucky Geological Survey, Special Publication 8, Series XI, 74p.

Figure 9. Geologic Cross Section of Pine Mountain



http://www.uky.edu/KGS/education/pinemountain.htm

Q6. Consider the model of present day plate boundary interactions in Figure 6. Which one present day plate boundary interaction is most likely similar to the interaction that formed Pine Mountain some 275 million years ago? DCI: ESS2.B, SEP: Developing and Using Models, Cause and Effect (NOTE that Cause and Effect is not incorporated within either of the bundled Performance Expectations for this cluster. Since the major focus of the question cluster is explaining the cause of Pine Mountain's existence, using the "outside" CCC makes sense in the larger context of the cluster.)

A. The interaction of the African and North American Plates
B. The interaction between the African and South American Plates
C. The Interaction Between the Indian and Eurasian Plates
D. The Interaction between the Australian and Pacific Plates

The rock layers that make up the Pine Mountain overthrust are primarily sedimentary rocks. Fossil evidence from within these rocks indicates that the overthrust event occurred about 275 million years ago.

Q7. Two fossils of the same species and same age were found in different locations and elevations, one high atop of Pine Mountain and the other in a creek bed several miles to the northwest near Hazard. Which combination of forces is responsible for exposing similar fossils in such different environments? DCI: ESS2.B CCC: Cause and Effect (NOTE that Cause and Effect is not incorporated within either of the bundled Performance Expectations for this cluster. Since the major focus of the question cluster is explaining the cause of Pine Mountain's existence, using the "outside" CCC makes sense in the larger context of the cluster.)

A. Destructive force of uplift in Pine Mountain and destructive force of weathering in Hazard.
B. Constructive force of weathering in Pine Mountain and destructive force of weathering in Hazard.
C. Constructive force of uplift in Pine Mountain and destructive force of weathering in Hazard.
D. Destructive force of weathering in Pine Mountain and constructive force of uplift in Hazard.

Q8. Construct an explanation for how the formation and evolution of Pine Mountain into its present day form is a result of both constructive and destructive forces. Include in your explanation a discussion of the forces involved in driving the changes that have likely occurred over time. Use data from the models and text above to provide support for your explanation. DCI: ESS2.A and ESS2.B, SEP Developing and Using Models, CCC: Matter and Energy & Stability and Change