Engineering Connection: Evaluating Renewable Energy Options

Ultimately, any discussion of climate change should begin to explore technological solutions that could reduce emissions of greenhouse gases. In a classroom, students can calculate their own carbon footprints to further understand how they contribute to the human impacts on the global carbon cycle. They can explore renewable energy options and debate the pros and cons of each possible energy source for meeting society's needs (National Energy Education Development Project 2012b) (HS-ESS3-2, HS-ETS1-1). They can complete the project by creating another summary product for their school that **communicates [SEP-8]** some steps that individuals could take to reduce their impact on the climate system, or recommend broader actions that their school and community could take that will have an even larger effect.

IS3 Earth and Space Sciences Instructional Segment 3: Mountains, Valleys, and Coasts

Earth scientists look at landscape and **ask questions [SEP-1]** about the processes that shaped it and the specific sequence of events in the past when those processes occurred. Scientists **plan and carry out investigations [SEP-3]** to answer those questions, but investigations in Earth and space science cannot always take the same experimental form with the testing of hypotheses as they might in analytical chemistry or experimental physics. Many Earth processes take millions of years and cover thousands of miles of area occuring too slowly and at too big a scale to reproduce in a lab. Geologists often refer to the Earth as their natural laboratory, but they are only permitted to look at the final result of its ancient experiments (Earth's present-day landscape). These investigations often begin when Earth scientists make careful observations of what the Earth looks like today and then try to reproduce similar features in small-scale laboratory experiments or computer simulations.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 3: MOUNTAINS, VALLEYS, AND COASTS

Guiding Questions

- How did California's landscape get to look the way it does today?
- What forces shape the Earth's surface?
- How do those processes affect humans?

Performance Expectations

Students who demonstrate understanding can do the following:

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.*] (Revisited from IS1 and again in IS4)

HS-ESS2-5. Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. [Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 3: MOUNTAINS, VALLEYS, AND COASTS

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems. [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] [*Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.*]

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or disciplinary core idea.

The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-2] Developing and Using Models [SEP-3] Planning and Carrying Out Investigations [SEP-4] Analyzing and Interpreting Data [SEP-6] Constructing Explanations (for science) and Designing Solutions (for engineering)	ESS2.A: Earth Materials and Systems ESS2.B: Plate Tectonics and Large-Scale System Interactions ESS2.C: The Role of Water in Earth's Surface Processes ESS3.A: Natural Resources ESS3.B: Natural Hazards ESS3.C: Human Impacts on Earth Systems ESS3.D: Global Climate Change ETS1.B: Developing Possible Solutions	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-7] Stability and Change Connections to Engineering, Technology, and Applications of Science Influence of Science, Engineering, and Technology on Society and the Natural World

Highlighted California Environmental Principles and Concepts:

Principle I The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services.

Principle II The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.

Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 3: MOUNTAINS, VALLEYS, AND COASTS

Principle IV The exchange of matter between natural systems and human societies affects the long-term functioning of both.

Principle V Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

CA CCSS for ELA/Literacy Connections: SL.11–12.5; RST.11–12.1, 2, 7, 8, 9; WHST.9–12.2a–e, 7

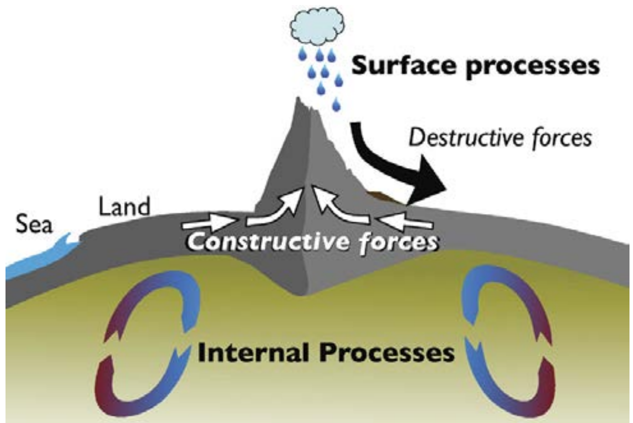
CA ELD Connections: ELD.PI.11–12.1, 5, 6a–b, 9, 10, 11a

Students can develop an Earth science mindset when they walk around their own schoolyard and make observations about the familiar processes that led to its present-day state (United States Geological Survey [USGS] 2015). Because they already have some familiarity with construction equipment and the everyday wear and tear that occurs on their school site, they will be able to recognize evidence of those past events. Most importantly, this process prompts them to realize that they can **ask questions [SEP-1]** about the world around them. Teachers can then introduce some of the natural geologic landscapes and processes that act on Earth.

Particular emphasis in this instructional segment is placed on the erosive power of water in shaping California's mountains, valleys, and coasts—the intersection between the hydrosphere and the geosphere (primarily addressed by ESS2.C). The effects of erosion include both the wearing down of surface features (destructive forces) and the building up surface features in other places (constructive forces). For example, as material is carved away from one place, it can pile up and collect in other places such as floodplains, deltas, and at the bases of landslides. Students should **develop models [SEP-2]** of how these surface processes shape features on land as part HS-ESS2-1.

HS-ESS2-1 is broadly written and encompasses a huge fraction of the processes in Earth science (constructive and destructive forces; surface processes and internal processes; features on land and the seafloor—all spanning a broad range of spatial and temporal scales). For this reason, it is revisited several times throughout this course. To reduce this vast performance expectation down to a scale that can be assessable in a classroom, teachers can select specific local features, and students can **draw models [SEP-2]** similar to figure 8.53 and figure 8.54 that **explain [SEP-6]** how the selected local landform was shaped over time. Or, teachers could take a broader view of this performance expectation and use it to explain global features like mountain chains, mid ocean ridges, and deep-sea trenches a part of a unit on plate tectonics.

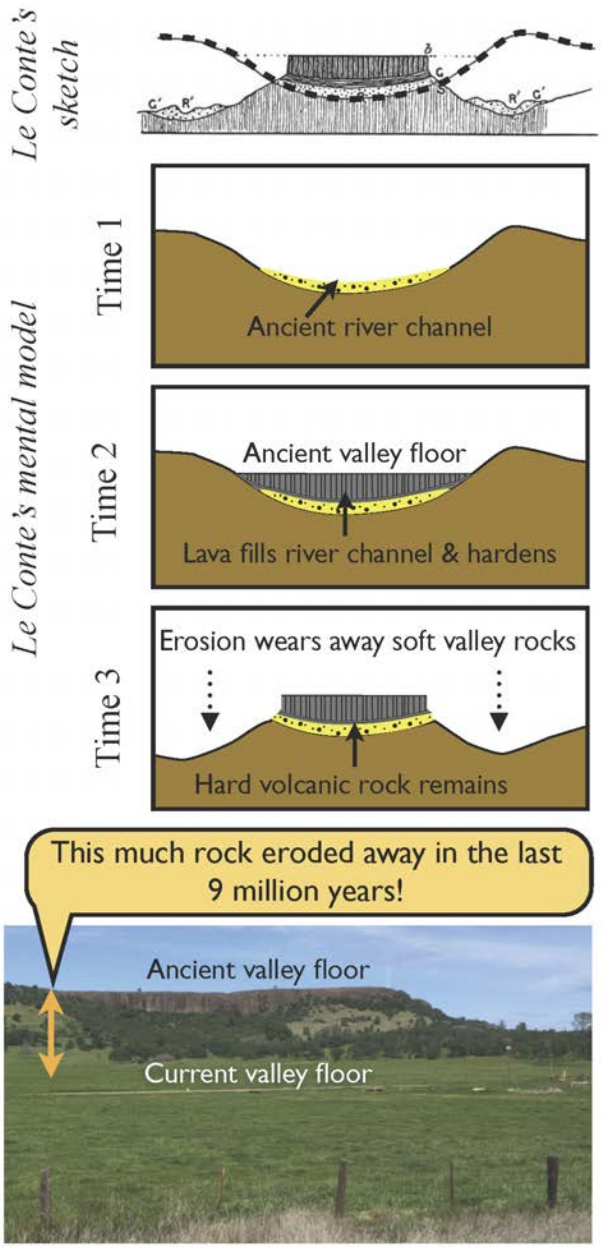
Figure 8.53. Forces that Shape Earth's Surface: Internal Versus External and Constructive Versus Destructive



Landscapes are shaped by the balance between constructive and destructive forces driven by processes inside the Earth and on the surface. In the CA NGSS, students are expected to develop a model of how these processes combine to shape the land surface and the seafloor (HS-ESS2-1). Diagram by M. d'Alessio.
Long description of Figure 8.53.

Today the tallest mountain in the contiguous United States is Mt. Whitney, but at one time the Sierra Nevada were much taller. Over time, layers of rock several miles thick have eroded away from these mountains. Early geologists conducted **investigations [SEP-3]** by making observations in the foothills of the Sierra Nevada and collected the first convincing evidence of this erosion. They observed ancient lava flows high above valley floors and named them "table mountains" because the flat tops of the lava flows resembled tables (figure 8.54). Since lava always flows to the lowest points in a landscape, such as river channels, geologists questioned what lava flows were doing on the top of the mountain. The best explanation is that lava flowed down river channels at the bottom of valleys. Then, water running off the slopes of the Sierra Nevada slowly eroded material away from these foothill locations. The lava was more resistant to erosion than the surrounding rocks, so erosion carried away the surrounding material and left the lava-filled meandering river channels sticking up. Two examples, each named Table Mountain, can be seen while driving along Highway 108 in Tuolumne County and Highway 70 in Butte County. These features allow visitors to visualize how much material has been carried away since the lava flows formed just a few million years ago. Where did that sediment go? Much of it was carried down to the Central Valley below, which has accumulated miles of deep sediment, including the top layer of fertile soil that gives the area its agricultural productivity (to be discussed in IS4 on Water and Farming).

Figure 8.54. Tuolumne Table Mountain Near Jamestown



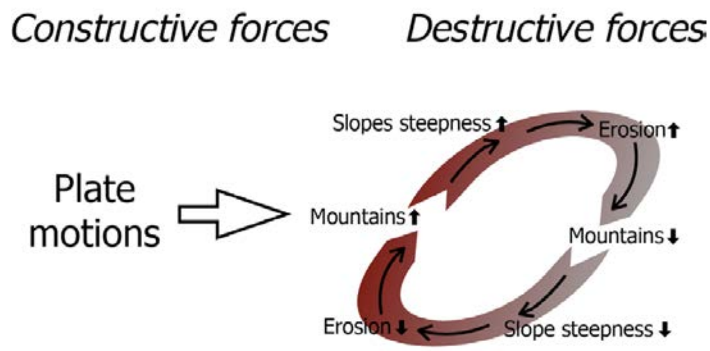
Tuolumne Table Mountain near Jamestown, CA reveals how much soil and rock has eroded. Joseph LeConte sketched the drawing on the top for a textbook he wrote in 1882. *Source*: LeConte 1892; photo by Kirk Brown; illustration by M. d'Alessio
Long description of Figure 8.54.

In the 1850s, geologists in California like Joseph LeConte[9] began to look at landscapes and construct mental models of how landscapes developed and changed by erosion. These mental models required testing, so Earth scientists conducted small experiments of erosion in laboratories. A stream table (a sloped table or plastic bin covered with sand and other earth materials and flooded with water) is a platform for exploring erosional processes; it can be used for hands-on **investigation [SEP-3]** and as a physical **model [SEP-2]** that can predict possible outcomes. Teachers can use stream tables to help meet some of the performance expectations of the CA NGSS, including having students **ask questions [SEP-1]** and plan their own **investigations [SEP-3]** (HS-ESS2-5). Students can recreate California landforms such as the Sierra Nevada and Central Valley in a stream table and watch as sediment slowly accumulates in deep layers in the valley, or even be given a range of materials to see if they can produce the mesa-like features of Table Mountain.

While erosion appears to happen slowly and steadily over time, most erosion events are actually quite rapid changes taking place as catastrophic events like landslides. This example of **stability and change [CCC-7]** builds on ideas about the rates of Earth processes first introduced in second grade (2-ESS1-1) and erosional processes explored in fourth grade (4-ESS2-1). In high school, students put those two ideas together, noticing how balancing feedbacks prevent erosion from staying fast for very long. When the movement of water drives erosion, the steepness of the slope has a huge impact on the rate of erosion because water builds up more kinetic energy when accelerating down a steep hill (PS2.A). As the water molecules collide with the soil and rock, they can dislodge individual pieces and carry them away. Steeper slopes erode more quickly, causing the slopes to flatten and slowing erosion (figure 8.55). Erosion occurs when the driving forces suddenly exceed the resisting forces. A cliff can fall if either the resisting force is reduced (by undercutting the supporting material at the base of the cliff) or if the driving forces are increased (by higher waves, faster river flows, or additional weight from new construction or a slope saturated with heavy water from irrigation or a rainstorm). When designing new buildings or landscape projects, geotechnical engineers make careful calculations of how their projects affect both the driving forces and resisting forces.

9. LeConte was one of the first faculty at the University of California and a charter member of the Sierra Club. There are several schools in California named after him including ones in Los Angeles and Berkeley.

Figure 8.55. Balancing Feedback in Erosion



A counter-balancing feedback loop causes erosion to occur at a slow and steady rate. Diagram by M. d'Alessio.
Long description of Figure 8.55.

In a classroom, students can observe slow and steady erosion punctuated by rapid landslides as well as the balancing feedback in a stream table. The slow movement of sediment from the base of a cliff eventually hits a critical point and a massive piece of the cliff suddenly falls. The erosion rate then slows because the cliff erodes into a flatter slope. California's coastal bluffs repeatedly face this problem, often eroding many feet in a single storm and then remaining stable for decades. Students can **investigate [SEP-3]** actual coastal erosion rates using online collections of historical photos as found in Google Earth and the California Coastal Record to measure the impact of waves on the coastline (HS-ESS2-5). Figure 8.56 shows oblique aerial photos of Pacifica, California from Google Earth that are precise enough that students can measure the amount of coastline erosion as a classroom experiment.

Figure 8.56. Coastal Erosion in Pacifica

Changes over time in coastal bluffs in Pacifica, California. The yellow triangle shows the migration of the cliff top from year to year at a single position. By 2010, the cliff is located directly beside the apartment building. *Source*: Images from California Coastal Records Project 2017. Copyright © 2002-2015 Kenneth & Gabrielle Adelman, California Coastal Records Project, www.californiacoastline.org
Long description of Figure 8.56.

Engineering Connection: Mitigating Erosion Hazards

When the natural process of erosion affects humans, it becomes a natural hazard. Students can explain some of the common impacts of erosion in California (HS-ESS3-1). They can also engage in an engineering design problem to reduce these impacts (HS-ESS3-4). Students can design and build erosion control measures using stream tables as well as read about actual measures that are taken in places like Pacifica and locations all along the California coastline. The engineering solutions either involve (1) increasing the strength of the hillside (by adding plants with root systems to stabilize the hillside, building support walls, or covering the cliff with concrete); or (2) reducing the driving forces (by placing rocks or sea walls to reduce the speed of waves when they hit the natural hillslope and through better drainage). Students should compare and evaluate solutions based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics. (HS-ETS1-3; EP&C V). Sometimes, technologies that reduce the impact of erosion on people can have adverse impacts on ecosystems (EP&C III). Students should consider and evaluate the environmental impacts of their design and refine it to reduce those impacts (HS-ESS3-4).

Using the **models [SEP-2]** they have developed, the CA NGSS asks students to make predictions about the future of erosion if California's climate shifts (HS-ESS3-5). California may face rising sea levels and periods of intense drought followed by intense storms. Rising sea levels combined with high storm surges means there will be greater driving forces for coastal erosion. Even if California receives less rainfall overall, intense bursts of rainfall could lead to increased erosion overall. The high runoff from intense storms causes faster flow rates in rivers and over the land surface, which also increase the driving forces of erosion.

EEI Curriculum unit *Liquid Gold: California's Water* explores human impacts resulting from the methods used to move large amounts of water. This unit is available from https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link54 and can be used in conjunction with this instructional segment to provide materials that examine California's EP&C V.