IS5

Earth and Space Sciences Instructional Segment 5: Causes and Effects of Earthquakes

California is famous for its earthquakes, but not because it has the most earthquakes or even the largest ones (Alaska holds both those titles among US states). It is probably most famous because its earthquakes impact more people than any other state. In this instructional segment, students learn about the effects of earthquakes, how earthquakes have shaped California's history and geography, and how forces deep within the Earth cause earthquakes.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 5: CAUSES AND EFFECTS OF EARTHQUAKES

Guiding Questions

- What causes earthquakes?

Performance Expectations

Students who demonstrate understanding can do the following:

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-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.]

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 5: CAUSES AND EFFECTS OF EARTHQUAKES

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.]

*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-6] Constructing Explanations (for science) and Designing Solutions (for engineering) [SEP-7] Engaging in Argument from Evidence	PS1.C: Nuclear Processes PS4.A: Wave Properties ESS1.C: The History of Planet Earth ESS2.A: Earth Materials and Systems ESS2.B: Plate Tectonics and Large-Scale System Interactions ESS3.A: Natural Resources ESS3.B: Natural Hazards	[CCC-1] Patterns [CCC-2] Cause and Effect: Mechanism and Explanation [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change

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

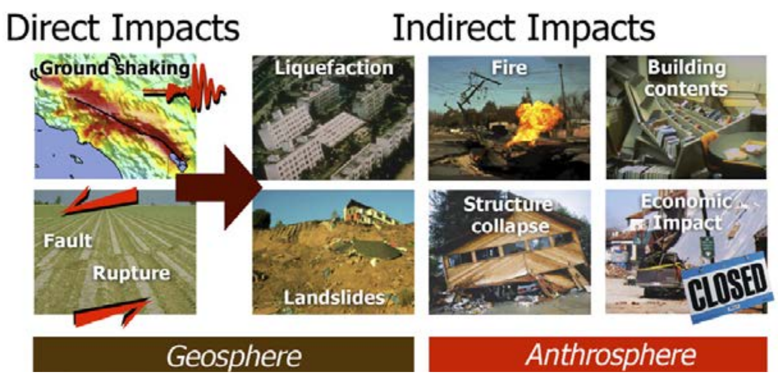
CA CCSS for ELA/Literacy Connections: SL.11–12.5; RST.11–12.1; WHST.9–12.2.a–e

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

The deadliest earthquake in US history was the 1906 earthquake in San Francisco (an estimated 3,000 people died), but many earthquake scientists argue that the 1906 earthquake was also the most scientifically valuable earthquake ever (USGS 2012). The CA NGSS push students to appreciate and be able to articulate the role of natural hazards in human history (ESS3.B), an example of geosphere-anthrosphere interactions. A historical overview of earthquakes in California helps illustrate those interactions and also motivates a deeper investigation of processes within the geosphere that cause earthquakes.

This instructional segment begins with students exploring the **evidence [SEP-7]** of how earthquakes affect people through a case study of a historical earthquake in California (HS-ESS3-1). Major earthquakes in Northern California (1989 Loma Prieta) and Southern California (1994 Northridge) make excellent case studies, as do smaller more local recent earthquakes. Internet image databases allow students to find images of a locally relevant earthquake (see The Earthquake Engineering Online Archive at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link62). Students can conduct independent research about this earthquake and compile a comprehensive list of hazards that earthquakes pose. Figure 8.59 shows an example of how these hazards can be classified. From the perspective of **cause and effect [CCC-2]**, earthquakes have only two effects that are caused directly by the earth movement: ground shaking and offset of land along fault ruptures. The rest of the disasters that occur during earthquakes are effects of those events, so events like tsunamis, fires, and building collapses are often referred to as indirect effects. Like many natural hazards, the events in the geosphere trigger a range of problems for the lives and property of humans (anthrosphere). In California, engineering designs have substantially reduced these indirect impacts. For example, the 1994 Northridge earthquake in Southern California was about the same magnitude as a 2003 earthquake in Bam, Iran. The impacts within the geosphere were similar, but the impact to the anthrosphere differed dramatically. Even though they both occurred in the center of cities in the early morning hours, fewer than 70 people died in California while more than 25,000 are estimated to have died in Iran because of widespread collapse of homes. The difference is primarily because laws adopted by California communities, called building codes, require builders to use innovative building designs that are strong enough to stand up to earthquakes. Building codes are updated regularly and enforced rigorously in California communities. Many countries around the world have adopted similar building codes, but in poorer nations they are not enforced because many of the measures require additional cost or expertise. Natural hazards usually impact poorer communities the most, and this remains true in California as much as the rest of the world.

Figure 8.59. Direct and Indirect Earthquake Impacts



Most earthquake impacts are indirectly caused by shaking and fault rupture. Figure by M. d'Alessio with images from USGS 2008, 15; National Oceanic and Atmospheric Administration/National Geophysical Data Center (NOAA/NGDC) 1964; San Francisco Fire Department 1989; NOAA/NGDC, U.S. Geological Survey 1980; NOAA/NGDC, University of Colorado at Boulder 1979; USGS 1995; USGS 2005; adapted from Hey Paul 2003
Long description of Figure 8.59.

Any discussion of earthquakes inevitably leads to the question of whether or not we can predict them; that requires knowing their root cause. The understanding of how Earth's internal processes cause earthquakes made some of its most important advances right here in California. A case study of the 1906 earthquake illustrates earthquake effects and ties to California history. As part of an effort to create accurate navigational charts, surveyors had mapped many parts of California in the mid-1800s. When the 1906 earthquake occurred, it was clear that the land had moved and there was great interest in the scientific community to see if there was a systematic pattern. Measurements taken shortly after the earthquake in 1906-07 showed that the Earth had moved up to 10 meters in some spots, and that locations west of the San Andreas fault all moved northwest while locations east of the fault moved the opposite direction. What was more dramatic was that surveys repeated several years later revealed that the Earth continued moving following this systematic pattern for years after the earthquake.

Opportunities for ELA/ELD Connections

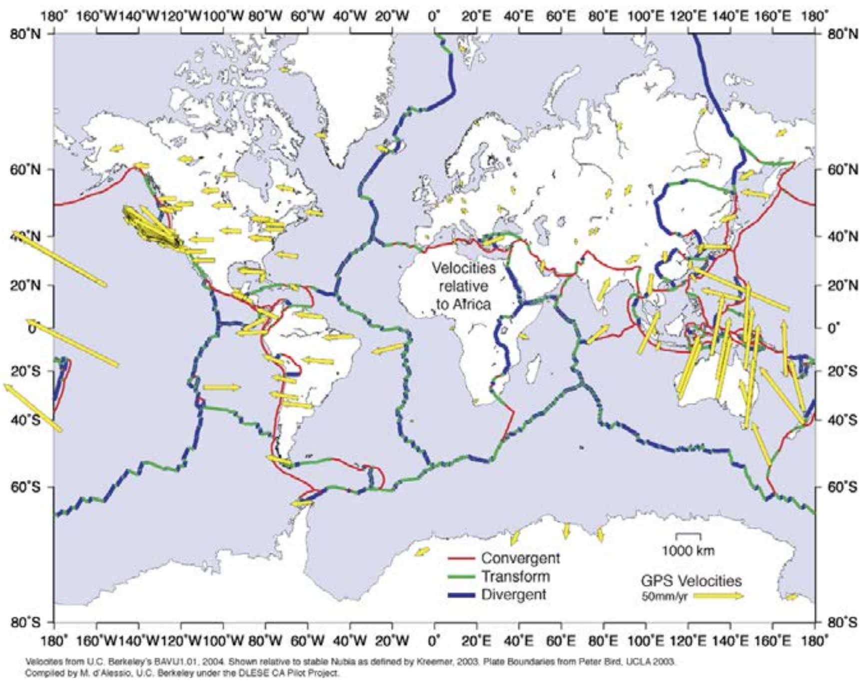
Students research and compare the cause(s) and effects of the 1906 San Francisco earthquake and a more recent earthquake, such as the 1989 Loma Prieta or the 1994 Northridge earthquakes. The informational report should include the potential impacts and hazards that earthquakes pose and any indirect effects of the earthquakes. Have students discuss which earthquake was more destructive than the other and support their views with evidence from the texts.

CA CCSS for ELA/Literacy Standards: WHST.9–12.2, 9; RST.9–12.1, 2, 9
CA ELD Standards: ELD.PI. 9–12.6, 10

Earth's systematic movements before, during, and after earthquakes are key pieces of evidence that establish the relationship between earthquake and broader plate motions. In middle grades, students already used continent shapes, fossils, and seafloor structures to provide evidence of past plate motions (MS-ESS2-3). In high school, students add a very modern piece of evidence from global positioning system (GPS) measurements throughout the world. These measurements work using the same system as navigation systems in cars and cell phones but are significantly more precise. Students examine real-time maps of motion around California and the globe recorded by these devices (see UNAVCO, Real-time velocity viewer, at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link63 or UNAVCO, Jules Verne Voyager Jr., at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link64).

These velocity maps (figure 8.60) reveal that large sections of the Earth all move together in the same direction at the same time (we call these section *plates*). Areas where the velocities of two adjacent sections are radically different are plate *boundaries* where dramatic things can happen. Students can identify plate boundaries on velocity maps and then relate them to the locations of earthquakes, volcanoes, mountains, and the shape of the ocean floor using either Google Earth or traditional paper maps (see Rice University Discovering Plate Boundaries at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link65). Students can use the relative motions shown by the velocity arrows along with these other surface features to discover that some plates move away from one another while others crash together or slide horizontally past one another (discovering the *types* of plate boundaries). Plate motions are one of the key constructive processes that build landscapes (figure 8.52) and extend the destructive processes explored in IS3. Using hands-on activities involving sandboxes (Feldman, Cooke, and Ellsworth 2010) or paper **models [SEP-2]** (Alpha and Lahr 1990), students visualize the deformation that occurs near the surface at these boundaries (HS-ESS2-1). Students use Google Earth to find real-world examples of topographic features such as linear mountain ranges or fault scarps. Students should be able to use the GPS velocity maps to identify those areas and use this information to explain the seafloor age patterns (HS-ESS1-5), which reveal locations where new magma rises up as plates spread apart forming new seafloor and where old seafloor dives under another plate when the plates crash together.

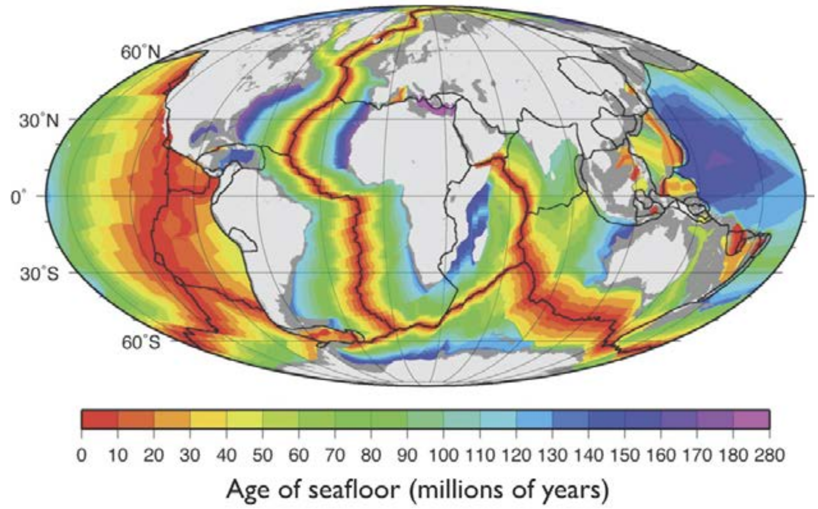
Figure 8.60. Present-Day Plate Motions



GPS velocities recorded at stations around the world reveal present-day plate motions. Arrow size relates to the speed of each point. Image credit: d'Alessio n.d.
Long description of Figure 8.60.

But why do plates move? One major clue comes from a key pattern in rock ages: the continents are much older than the oceans; the oldest continental rocks are more than 4 billion years old, but no seafloor is older than 280 million years (figure 8.61). We know that the Earth has had oceans for longer than that because pieces of ancient ocean floor can be found on land (Mehta 2007). So what is the difference between the continents and the ocean? One key observation is that continental rocks tend to have a lower density than oceanic rocks. This difference is important because we know of an important density-driven process that happens within the Earth: convection. Earth's interior is expected to be hot (from heat-generating radioactive elements in the interior) while its surface is adjacent to the cold emptiness of space. From physical science (HS-PS3-4), we know that heat will be transferred from the hot interior outward. Convection is an efficient heat transport mechanism that occurs when hot material rises upward, because it is less dense, while colder material sinks because it is more dense. The oceanic crust is cold and dense and sinks downwards at convergent plate boundaries. At the same time, hot magma, which is less dense, rises up at divergent plate boundaries. Plate motions are the surface expression of convection happening deep within the Earth. Students can create a model of convective heat transport (HS-ESS2-3) with a simple lava lamp or any of the various published demonstrations involving ice, warm water, and drops of food coloring. These **models [SEP-2]** do not capture the full complexity of convection in the Earth and its relationship to plate tectonics, but they are excellent visualizations of convection.

Figure 8.61. Seafloor Age



Sources: National Oceanic and Atmospheric Administration, National Centers for Environmental Information 2008
Long description of Figure 8.61.

Students should be able to use seafloor ages and surface motion rates as evidence that convection occurs in Earth's interior. They can **communicate [SEP-8]** their **argument [SEP-7]** with a pictorial **model [SEP-2]** of Earth's interior that has annotations to indicate how heat transfer drives movement within the Earth (HS-ESS2-3).

For communities in Northern California near Mt. Lassen and Mt. Shasta, it may be more appropriate to replace this instructional segment with an instructional segment on volcano hazards. While those areas also face significant earthquake hazard, their regional identity with these dramatic peaks makes volcanoes a more relevant topic. Teachers could develop an instructional segment helping students achieve the same performance expectations based on volcanoes instead of earthquakes.