

California's Restless Edge: Modeling Where Magma and Earthquakes Come From

Learning target: I can use diagrams of plate settings to explain why some places have volcanoes and earthquakes while others have only earthquakes, and draw a labeled model of a subduction zone.

Diagrams and models

About 45 min

Individual

MS-ESS3-2 · practice

MS-ESS2-3 · supports

visual modeling

independent practice

writing

Standards connections

MS-ESS3-2 (practice, understanding the geologic forces behind hazard locations): The disciplinary core idea for this PE says that mapping past hazards together with an understanding of the related geologic forces helps forecast where future events are likely. Students model those forces for California's plate settings, which builds toward forecasting locations; the sheet does not ask them to analyze hazard data.

MS-ESS2-3 (supports): Students draw a trench and a sinking plate and explain why earthquake depths trace the plate, using the seafloor structures and plate boundaries from Lesson 16. Plate motion is background here; the sheet does not ask students to reconstruct past plate motions.

Purpose: build · **Time:** about 45 minutes · **Format:** individual

Answers with reasoning

Part A: Read the models

Cascadia subduction zone (north of Cape Mendocino)

The small Gorda and Juan de Fuca plates sink eastward beneath the North American Plate. Water released by the sinking plate helps mantle rock melt, feeding volcanoes such as Mount Shasta and Lassen Peak. Earthquakes happen on the shallow locked boundary and deeper inside the sinking plate. The locked

Salton Trough (southern end)

The boundary changes into short segments where the crust is pulled apart, linked by transform faults, like the spreading centers farther south in the Gulf of California. The crust is thin and hot: there are small young volcanic domes, geothermal power plants and swarms of small earthquakes

Mendocino Triple Junction (Cape Mendocino)

Three plates meet: the Pacific, the North American and the Gorda. Earthquakes are frequent, making this one of the most earthquake-active areas in California.

Long Valley Caldera (eastern Sierra, inland)

East of the Sierra Nevada, Earth's crust is being stretched. Long Valley Caldera near Mammoth Lakes formed in a giant eruption about 760,000 years ago and still has earthquake swarms and episodes of ground uplift.

San Andreas Fault system (Cape Mendocino to the Salton Sea)

The Pacific Plate slides northwest past the North American Plate. No plate sinks, so little magma forms and there are no volcanoes along most of the fault. Earthquakes are shallow, mostly within the top 15 to 20 km of the crust.

Figure 1. Five plate settings in and near California. Descriptions are simplified; real plate boundaries are zones of many faults.

From sinking plate to volcano

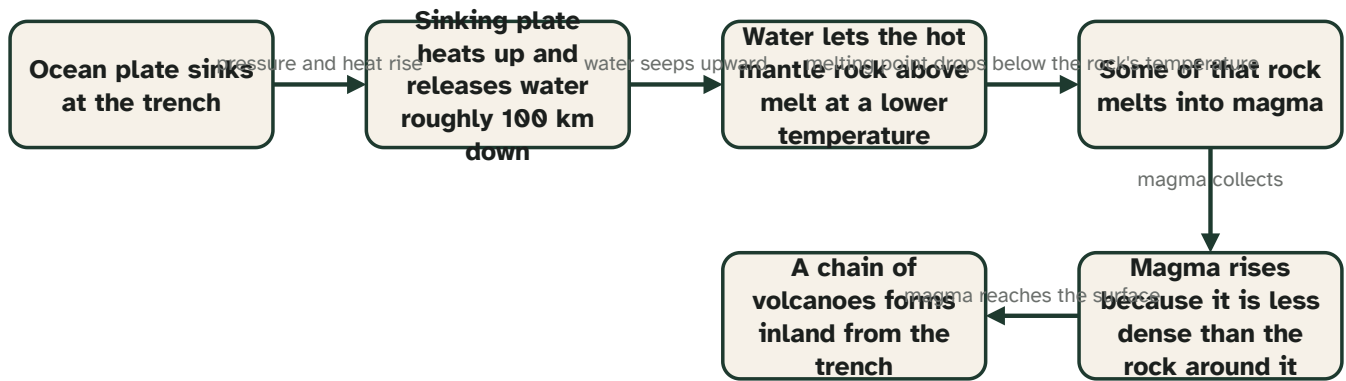


Figure 2. How magma forms above a sinking plate. The mantle is mostly solid rock; it melts only where something changes its melting conditions.

Stick, build, slip

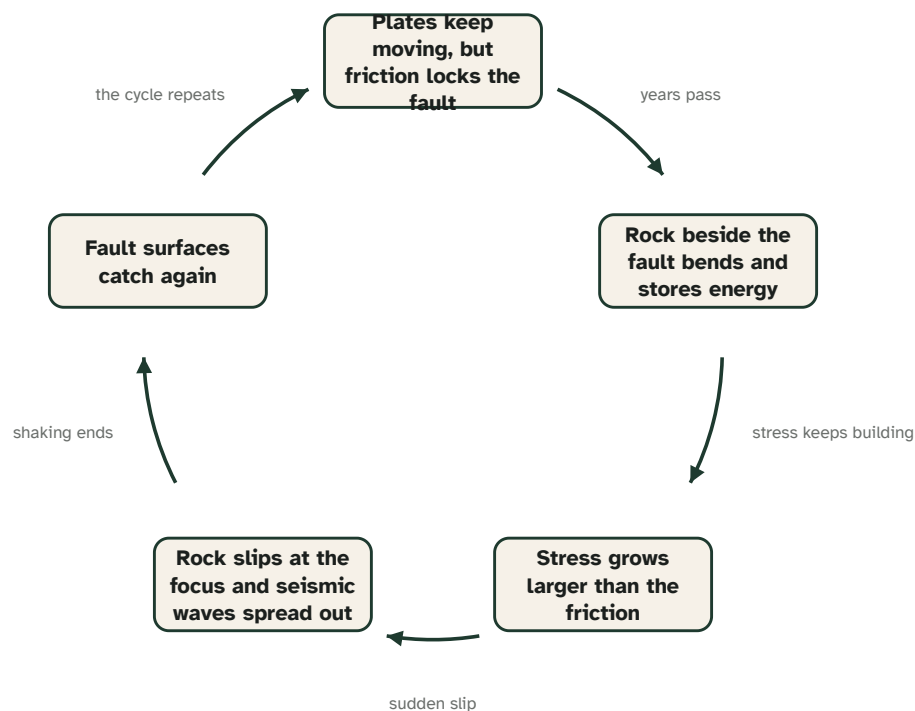


Figure 3. The stick-slip cycle on a fault. One trip around the loop can take decades to centuries; the slip itself lasts seconds to minutes.

1. According to Figure 1, which setting produces many earthquakes but almost no magma?

2 pts

Answer: B. The San Andreas Fault system.

Why: Figure 1 says plates slide past each other there, no plate sinks, little magma forms and there are no volcanoes along most of the fault, while earthquakes are common. The other three settings all have magma.

2. Use Figures 1 and 2 to explain why northern California has volcanoes like Mount Shasta, but the land along the San Andreas Fault does not. 3 pts

Answer: In northern California the Gorda and Juan de Fuca plates sink beneath North America (Figure 1). As a sinking plate goes deep it releases water, which lets the hot mantle rock above it melt at a lower temperature, so magma forms and rises to build volcanoes like Shasta (Figure 2). Along the San Andreas, the plates slide sideways past each other; no plate sinks, so no water is carried down and no magma forms. That boundary makes earthquakes but not volcanoes.

Why: The answer must contrast subduction (with its melting mechanism) and transform motion (with no melting mechanism).

Also acceptable: Accept 'convergent' and 'transform' as boundary names if the motion is described correctly.

- Says a plate sinks in the north and plates slide sideways along the San Andreas
- Explains that water from the sinking plate leads to melting
- States that no sinking plate means no magma along the transform boundary

3. In Figure 2, the mantle rock above the sinking plate melts even though it does not get hotter. Explain how that can happen. 2 pts

Answer: Water released from the sinking plate seeps into the hot mantle rock above and lowers the temperature at which that rock melts. The rock's temperature stays about the same, but its melting point drops below it, so part of the rock melts.

Why: This is flux melting. The textbook says material from the sinking plate mixes with the mantle; the more accurate statement is that water is the main trigger.

Also acceptable: Accept 'the melting point drops' or 'water makes rock melt at a lower temperature'.

- Names water from the sinking plate
- Explains that the melting temperature is lowered rather than the rock being heated

4. In Figure 3, which step is the earthquake that people feel? What is stored during the long quiet part of the cycle, and why does the cycle start over? 2 pts

Answer: The step 'Rock slips at the focus and seismic waves spread out' is the earthquake people feel. During the long quiet part, energy is stored in the bent rock beside the locked fault (stress builds). The cycle starts over because the plates keep moving after the slip, the fault surfaces catch again, and stress starts building again.

Why: Students must identify the brief slip as the quake and the long locked interval as the time of stress build-up.

Also acceptable: Accept 'elastic energy' or 'strain'.

- Identifies the slip step as the earthquake
- Says energy or stress is stored in bent rock
- Explains that continuing plate motion reloads the locked fault

Part B: Draw your own model

-  Draw a side view (cross-section) of the Cascadia subduction zone, with the Pacific Ocean on the left and inland northern California on the right. Label: the ocean plate, the North American Plate, the trench, an arrow showing which way the ocean plate moves, the mantle, the place where water is released and magma forms, magma rising, and a volcano. Mark at least six earthquake foci with an X: some on the shallow locked boundary near the coast and some deeper inside the sinking plate farther inland.

Answer: A thin ocean plate on the left bends down beneath a thicker North American Plate at a trench near the coast, with an arrow pointing toward and under the continent. The mantle lies below both plates. Above the sinking plate, well inland, a label shows water released and magma forming; a path of magma rises to a volcano on the surface (labeled, for example, Mount Shasta). At least six X marks: several on the shallow contact between the plates near the coast, and several deeper inside or along the top of the sinking plate farther inland.

Why: The model must show the geometry that explains both hazards: a locked shallow boundary for the largest quakes, a deepening plate for deeper quakes, and melting above the deep plate for volcanoes.

Also acceptable: Accept a simplified block diagram if the labels and positions are correct. Do not accept magma drawn as a layer under the whole crust.

- Ocean plate sinking beneath the North American Plate at a labeled trench
- Arrow showing ocean plate motion toward and under the continent
- Mantle labeled
- Magma forms above the sinking plate, not at the trench
- Volcano inland from the trench, above where the plate is deep
- Six or more X marks, shallow near the coast and deeper inland

Part C: Use your model

5. Complete the table using your drawing.

4 pts

Answer: Shallowest earthquakes: near the coast, on the contact between the two plates, because that is where the plates are locked together and stress builds. Deepest earthquakes: farther inland, inside the sinking plate, because the plate continues to bend and crack as it goes down. Magma forming: inland and deep, just above the sinking plate, where water released from the plate lets the mantle rock melt at a lower temperature. Volcano: inland, on the surface above where magma forms, because the less dense magma rises straight up through the crust.

Why: Each position follows from the subduction geometry students drew.

Also acceptable: Accept 'where the plates rub together' for the shallow quakes.

- Shallow quakes near the coast on the locked boundary
- Deep quakes inland within the sinking plate
- Magma above the deep part of the sinking plate
- Volcano inland above the magma source
- A reason for each

6. Seismologists plot quake foci along a line from the Cascadia coast inland. The foci get deeper the farther inland they are. What does this pattern trace?

2 pts

Answer: A. The top of the sinking ocean plate.

Why: Earthquakes at subduction zones happen on and within the sinking plate, so their foci outline it as it dives under the continent. Magma does rise inland, but it does not make a sloping band of quakes.

7. Which California setting in Figure 1 can produce the largest earthquakes? Use your model and Figure 1 to explain why. 3 pts

Answer: The Cascadia subduction zone. Its locked boundary between the sinking plate and North America is very long (it runs from northern California to Canada) and wide, so a huge area of fault can slip at once, storing and releasing far more energy than the narrower, near-vertical San Andreas. Figure 1 shows it produced a magnitude 9 earthquake in 1700, and a magnitude 9 releases about 32 times the energy of a magnitude 8 and about 1,000 times that of a magnitude 7.

Why: Earthquake size depends on the area of fault that slips. Gently sloping subduction boundaries offer the largest locked areas on Earth.

Also acceptable: Accept a reason based on the 1700 earthquake alone for partial credit; full credit needs the fault-area idea or a correct energy comparison.

- Names Cascadia
- Explains that a larger area of locked fault can slip
- Uses the 1700 magnitude 9 as evidence

8. The Hawaiian volcanoes sit more than 3,000 km from the nearest plate boundary. Which part of your model cannot explain them, and what does explain them? 2 pts

Answer: The subduction part of the model cannot explain Hawaii, because no plate is sinking there. Hawaii sits above a hot spot: a plume of unusually hot rock rising from deep in the mantle partly melts as the pressure on it drops near the top, and the magma builds volcanoes as the Pacific Plate moves over it.

Why: Hot spots are the main exception to the boundary pattern. The answer should not say the plume heats the rock above it or that the mantle is liquid.

Also acceptable: Accept 'a hot spot under the Pacific Plate' without the pressure detail.

- Says the model needs a sinking plate, which Hawaii lacks
- Names a hot spot or mantle plume as the explanation

9. Name two things your drawing leaves out or shows inaccurately, and say why a scientist would still find the model useful. 2 pts

Answer: Examples: it shows one flat slice of a three-dimensional system; the sizes and depths are not to scale; the plate motion is too slow to see; magma does not travel in a single pipe; real quakes are scattered, not neatly placed. It is still useful because it shows the arrangement that explains where shallow quakes, deep quakes, magma and volcanoes occur, which lets scientists forecast where hazards are likely.

Why: Students should name concrete limitations and connect the model's value to explaining and forecasting locations.

Also acceptable: Accept 'it doesn't show time' or 'it leaves out other faults' as limitations.

- Two specific limitations
- One reason the model is useful anyway

Teacher notes

Figure 1 is simplified from USGS descriptions of California tectonics. Points that are accurate but easy to overstate: the San Andreas is the main fault of a broad plate-boundary zone, not a single crack; there are volcanoes near parts of the plate boundary (Clear Lake, the Salton Buttes), so Figure 1 says 'most of the fault'; Cascadia's subducting plate is young and warm, so its earthquakes reach tens of kilometers deep, not the 600 to 700 km seen at some other subduction zones. The textbook says crustal material from the sinking

plate lowers the mantle's melting temperature; Figure 2 names water, the main trigger. The textbook also calls convergent-boundary earthquakes 'deep'; the largest subduction earthquakes, including Cascadia 1700, start on the shallow locked boundary, so q5 and q7 keep both. The Hawaiian hot spot is more than 3,000 km from the nearest plate boundary (USGS). The extension's triple-junction history is a simplified version of a well-supported explanation for the end of volcanism along the central California coast; treat it as enrichment.

Scaffold offered to students: A drawing checklist

Start with two long slabs: a thin ocean plate on the left that bends down under a thicker North American Plate on the right. The trench is the low point where the bend begins. Put the volcano well inland, above where the sinking plate is deep. Draw magma as a thin path rising from just above the sinking plate. Place X marks along the top of the sinking plate and inside it: shallow near the trench, deeper toward the right.

Extension: A boundary that is moving north

The Mendocino Triple Junction is slowly moving north along the coast as the Pacific Plate slides past. Scientists think that as it passed, no sinking plate was left beneath parts of central California, one reason subduction volcanoes stopped forming there while the San Andreas grew longer. Draw two quick sketches of the California coast, one long ago and one today, showing where subduction and the transform boundary were. Explain how this helps account for the old volcanic rock found in parts of central California.