



CHAPTER 25 OF 29 · EARTH'S NATURAL HAZARDS

Volcanic Eruptions and Earthquakes

Lesson 25: Where will the ground shake or erupt next, and how do people get ready?

Angela's Wand · Bring Science Alive! 7th Grade Integrated

PHENOMENON

Fifteen seconds, and a bridge built for 1,500 years

October 17, 1989, 5:04 p.m.: rock beneath the Santa Cruz Mountains slipped, and the ground shook hard for about 15 seconds. Roughly 100 km north, part of the Bay Bridge's upper deck dropped onto the deck below. No one knew it was coming. Yet the new eastern span, opened in 2013, was designed to reopen quickly after the strongest shaking expected in about 1,500 years.

- Notice: what numbers are on the slide, and what does each one measure?
- Wonder: how could a bridge about 100 km away be damaged?
- Wonder: how can anyone plan for 1,500 years with only about 250 years of written records?





LEARNING TARGETS

What you will be able to do

1

Use earthquake and volcano maps to find plate boundaries, identify their type and spot the exceptions.

2

Explain how mostly solid rock melts into magma and why some eruptions explode.

3

Explain how stress builds on a locked fault and what the waves from an earthquake do.

4

Compare earthquakes with the logarithmic magnitude scale and use frequency data to forecast.

5

Explain why eruptions can often be forecast but earthquakes cannot be predicted.

6

Define precise criteria for a bridge, test designs fairly and choose a site using hazard data.

The pattern: hazards come in belts, not polka dots

- Plot a year of strong earthquakes and active volcanoes on a world map and you get narrow belts.
- The biggest belt circles the Pacific Ocean: the Ring of Fire, from Chile to Alaska, Japan and New Zealand.
- Most belts follow plate boundaries, where plates pull apart, push together or slide past each other.
- Exceptions: hot spots such as Hawaii and faults inside plates such as New Madrid, Missouri.
- Some regions, such as Minnesota and Florida, have few earthquakes and no active volcanoes.





Five settings, five different hazard mixes

MODEL

Model: Where earthquakes and volcanoes come from

Convergent (subduction):	One plate sinks beneath another. Volcano chains; earthquakes from shallow to 700 km deep, including the largest.
Divergent:	Plates pull apart. Volcanoes and small, shallow earthquakes, mostly along undersea ridges.
Transform:	Plates slide past each other sideways. Many shallow earthquakes, almost no volcanoes.
Hot spot:	A hot plume rises under a plate. Volcanoes and earthquakes far from any boundary.
Fault inside a plate:	Blocks of rock shift along an old crack. Occasional, sometimes strong, earthquakes; no volcanoes.

Volcanoes need rock that melts; earthquakes need rock that sticks and then slips. Some settings have both.

How mostly solid rock becomes magma

- The mantle is mostly solid rock. It is hot, but high pressure keeps most of it from melting.
- Add water: a sinking plate releases water, so the hot rock above it melts at a lower temperature.
- Lower the pressure: where plates pull apart, hot rock rises and partly melts as the pressure drops.
- Add a hot plume: unusually hot rock rises from deep in the mantle and partly melts near the top.
- Magma is less dense than the rock around it, so it rises through cracks; at the surface it is lava.



VOCABULARY IN CONTEXT

Words for where hazards come from

- **natural hazard:** A natural event, such as an earthquake or an eruption, that can hurt people or damage what they build. *An eruption on an empty island is a natural event; one beside a town is a natural hazard.*
- **magma:** Molten or partly molten rock, with dissolved gases and crystals, below Earth's surface; at the surface it is lava. *Magma collecting 6 km below the volcano lifted the ground above it.*
- **hot spot:** A place where a hot plume from deep in the mantle feeds volcanoes, sometimes far from any plate boundary. *The island of Hawaii sits over a hot spot in the middle of the Pacific Plate.*





CHECK FOR UNDERSTANDING

Quick check: name the setting

Seismologists map a 600 km line of shallow earthquakes, some as large as magnitude 7.5, with no volcanoes anywhere along it. What is the most likely setting?

A. A divergent boundary on the seafloor

B. A transform boundary

C. A subduction zone

D. A hot spot



MODEL

Runny magma pours; thick magma explodes

Model: Two kinds of eruption · *How thick the magma is, and how much gas it holds, decide how an eruption behaves.*

Runny (low-viscosity) magma

Thick (high-viscosity) magma

Flows easily, like warm syrup

Flows slowly, like cold peanut butter

Gas bubbles escape gently

Gas stays trapped and pressure builds

Lava flows and lava fountains

Blasts of ash, rock and gas; pyroclastic flows

Builds broad, gently sloping volcanoes

Builds steep cone-shaped volcanoes

Rarely kills people, but destroys what is in its path

The deadliest eruptions; ash can fall hundreds of km away

MODEL

Stick, build, slip: why faults jerk instead of glide

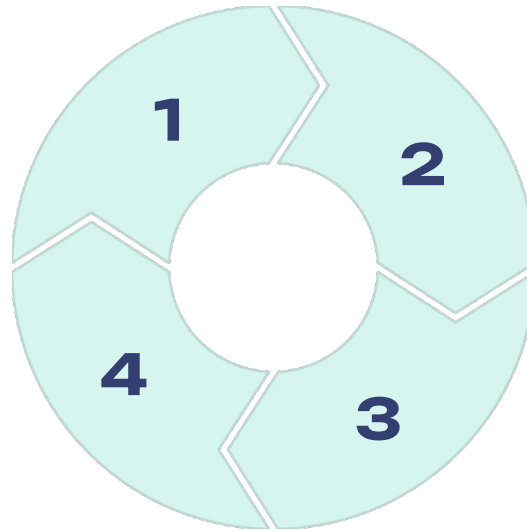
Model: The earthquake cycle on a locked fault

Rough fault surfaces
lock together

→ (for years to
centuries)

Seismic waves spread
out; the fault locks again

→ (and the cycle
repeats) (back to the
start)



Plates keep moving;
rock bends and stress
builds

→ (until)

Stress overcomes
friction; rock slips at the
focus

→ (in seconds)

The plates move a few centimeters a year. The fault moves meters in seconds, then waits.





Focus, epicenter and the waves that travel out

- The focus is where rock first slips, underground. The epicenter is the spot on the surface right above it.
- P waves (body waves) are fastest. They push and pull the rock and arrive first, often as a sharp jolt.
- S waves (body waves) arrive next. They shake rock side to side and can be violent near the source.
- Surface waves arrive last and travel along the ground, rolling it up and down and swaying it sideways.
- S waves and surface waves do most of the damage. Soft ground can make the shaking much stronger.

VOCABULARY IN CONTEXT

Words for an earthquake's anatomy

- **focus:** The place underground where rock first slips and an earthquake begins. *The Loma Prieta earthquake's focus was about 18 km below the Santa Cruz Mountains.*
- **epicenter:** The point on Earth's surface directly above an earthquake's focus. *News maps mark the epicenter with a star, even though shaking spreads far beyond it.*
- **seismic wave:** A vibration that carries energy away from an earthquake through rock: body waves inside Earth, surface waves along it. *The P wave reached the station 20 seconds before the S wave, so the earthquake was far away.*





CHECK FOR UNDERSTANDING

Quick check: reading a seismogram

A seismometer 400 km from an earthquake records the shaking. Which waves arrive first, and what does the time gap between the first two arrivals help scientists find?

A. Surface waves arrive first; the gap shows the magnitude

B. P waves arrive first; the gap grows with distance, so it helps locate the earthquake

C. S waves arrive first; the gap shows how deep the ocean is

D. All the waves arrive together, so there is no gap



Magnitude is logarithmic: each step is ten times more

- Magnitude is one number for an earthquake's size at its source, worked out from seismograms.
- Each step of 1 means **10 times** more ground motion on a seismogram and about **32 times** more energy.
- Intensity is different: it describes shaking at one place (Roman numerals I to XII) and varies by place.

Magnitude	Ground motion compared with M5	Energy compared with M5 (about)
5	1 time	1 time
6	10 times	32 times
7	100 times	1,000 times
8	1,000 times	32,000 times
9	10,000 times	1,000,000 times

VOCABULARY IN CONTEXT

Words for forecasting

- **precursor event:** A smaller, measurable change that often comes before a larger event. *A swarm of small earthquakes and swelling ground were precursor events before the eruption.*
- **frequency:** How often an event happens during a set amount of time. *Near the fault, magnitude 5 earthquakes have a frequency of about two per decade.*
- **forecast:** An estimate of how likely an event is in an area over a time span, such as a 30-year chance. *A forecast gives a 72 percent chance of a magnitude 6.7 or larger in the Bay Area by 2043.*





CHECK FOR UNDERSTANDING

Quick check: how much bigger?

About how many times more energy does a magnitude 7 earthquake release than a magnitude 5 earthquake?

A. 2 times

B. 20 times

C. About 100 times

D. About 1,000 times

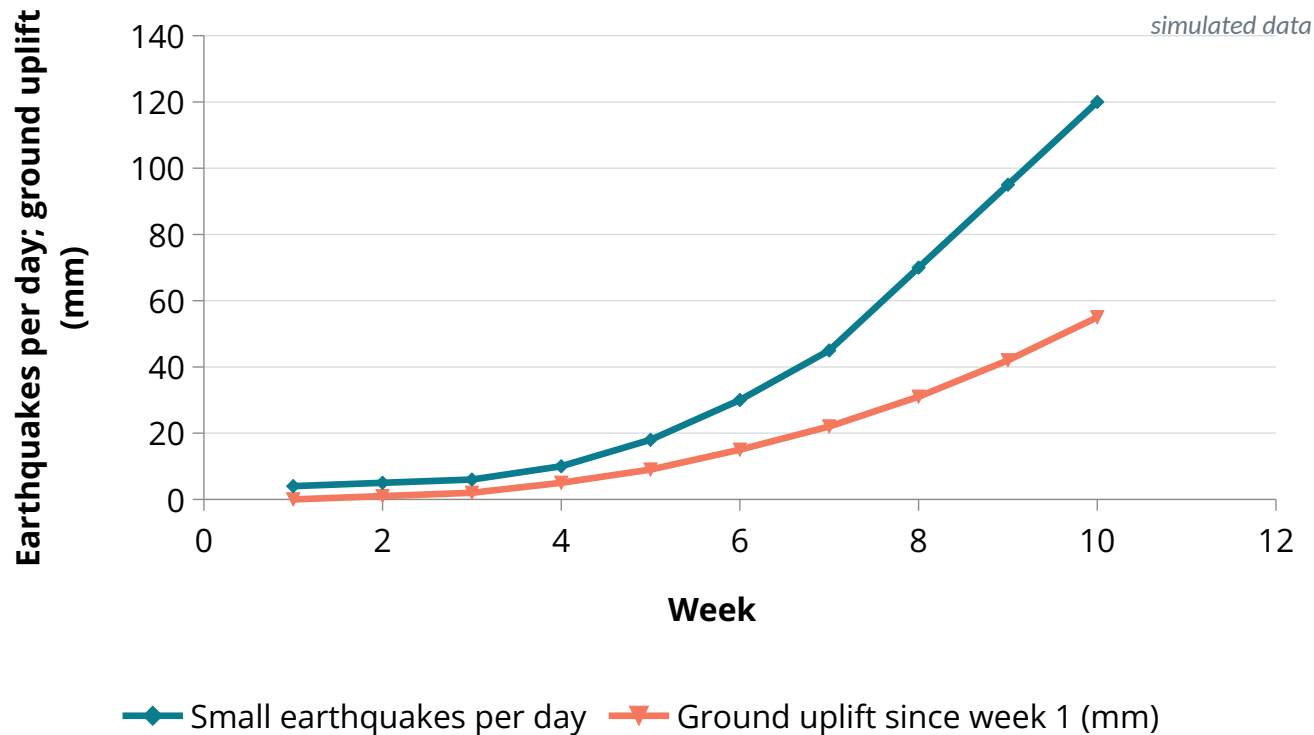
Volcanoes often give themselves away

- Rising magma cracks rock: swarms of small earthquakes appear beneath the volcano.
- Gas escapes: instruments measure more sulfur dioxide and carbon dioxide.
- The ground swells: GPS stations and satellite radar detect bulging, millimeters to meters.
- Scientists compare the signals with the volcano's past eruptions: how often and how big.
- Iceland, 2010: weeks of quakes and swelling at Eyjafjallajökull came before it erupted on March 20.
- A forecast is not a promise: unrest can last for years, or fade with no eruption at all.

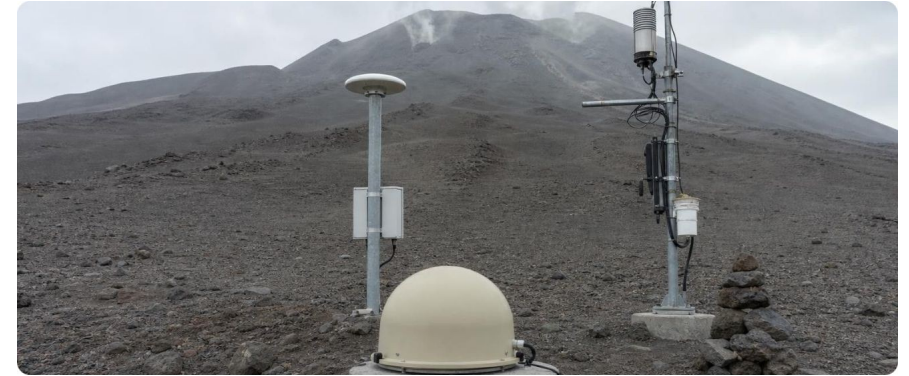


Task: read the monitoring data. When would you raise the alert?

Model: Ten weeks at Mount Calder (teaching dataset)



x: Week · y: Earthquakes per day; ground uplift (mm)



Simulated monitoring data for a fictional volcano. Sulfur dioxide output also doubled between weeks 6 and 9.

In which week would you raise the alert level, and what would you tell the nearby town? Can these data tell you the day the eruption will start? Explain.



Earthquakes: forecast the chances, not the date

- No reliable warning sign before earthquakes has been found, so no one can predict the date of the next one.
- Scientists study where faults are, how fast plates move and how often past earthquakes struck.
- Old earthquakes leave clues in soil and rock: offset layers, buried marshes, sand from tsunamis.
- From these data they forecast probabilities: the odds of a strong earthquake in a region over 30 years.
- Hazard maps turn those chances into colors that guide building codes, land use and insurance.

REAL-WORLD CONNECTION

California connection: the Bay Area's real forecast

USGS scientists combined fault maps, plate motion and the record of past earthquakes to forecast the San Francisco Bay region for 2014 to 2043. ShakeAlert, the West Coast early-warning system, does not predict earthquakes either: it detects one that has already begun and can send seconds of warning before strong shaking arrives.

Earthquake size	Chance of at least one in the Bay Area, 2014-2043
M6.0 or larger	98 percent
M6.7 or larger	72 percent
M7.0 or larger	51 percent
M7.5 or larger	20 percent



THINK, PAIR, SHARE

Discuss: does 72 percent mean 'it will happen'?

- Think about: what the other 28 percent means.
- Think about: whether a fault keeps a schedule.
- Think about: what a city should do with a 72 percent chance, and what a family should do.

A neighbor says, 'Scientists say 72 percent, so the big one will definitely hit before 2043, and if it doesn't, they were wrong.' What does the forecast really mean? Is the neighbor right?





REAL-WORLD CONNECTION

California's three headline hazards

Model: Faults, a subduction zone and a caldera

San Andreas Fault: Transform boundary between the Pacific and North American plates. Shallow quakes; great ones in 1857 and 1906. No volcanoes.

Cascadia subduction zone: About 1,000 km from Cape Mendocino to Vancouver Island. Last great quake January 26, 1700, about M9. Feeds Mount Shasta and Lassen Peak.

Long Valley Caldera: A 16 x 32 km caldera near Mammoth Lakes left by a huge eruption 760,000 years ago. Quake swarms, uplift and gas since 1980.

Three different settings, three different hazard mixes, one state.



CHECK FOR UNDERSTANDING

Quick check: which California hazard?

Which California hazard is capable of a magnitude 9 earthquake and a tsunami that crosses the Pacific Ocean?

A. The San Andreas Fault

B. The Cascadia subduction zone

C. Long Valley Caldera

D. The Hayward Fault



Mitigation and the bridge engineer's question

- Mitigation lowers harm: hazard maps keep building off the worst ground; codes make structures stronger.
- Engineers ask how strong and how frequent local shaking is, and how important the structure is.
- Criteria say what success means, in numbers. Constraints are the limits: money, time, materials, site.

Bridge type	Frequent, moderate shaking	Rare, strong shaking	Very rare, strongest shaking
Ordinary (farm road)	Minor damage, stays open	Closed, still standing	Closed, still standing
Important (main road)	No damage	Damaged, emergency use only	Closed, still standing
Lifeline (only hospital route)	No damage	Minor damage, stays open	Damaged, emergency use only

THINK, PAIR, SHARE

Discuss: why not build every bridge to the lifeline target?

- Think about: cost, and how many bridges a county has.
- Think about: how often each level of shaking happens.
- Think about: which roads people depend on right after an earthquake.

Building every bridge to survive the strongest possible earthquake with no damage would make every road safer. Why don't counties do that? What would they give up, and who should decide?



MISCONCEPTION CHECK

True or false? A magnitude 6 is just a bit stronger than a 5

"A magnitude 6 earthquake is only a little stronger than a magnitude 5, the same way 6 is only a little more than 5. So a magnitude 8 is about twice as strong as a magnitude 4."

True or false? Explain your reasoning.





PUTTING IT TOGETHER

Putting it together

- Earthquakes and volcanoes cluster along plate boundaries; hot spots and faults inside plates are exceptions.
- Magma forms only where something lets mostly solid rock melt: added water, lower pressure or a hot plume.
- Faults lock, store stress for years and slip in seconds, sending P, S and surface waves outward.
- Magnitude is logarithmic; intensity describes shaking at a place and depends on distance and ground.
- Eruptions often give precursors and can be forecast; earthquakes get probability forecasts, not dates.
- Engineers turn hazard data into precise criteria matched to how important a structure is.

EXIT TICKET

Exit ticket

A line of earthquakes gets deeper toward the east and has volcanoes above it. What is happening there?

How many times more energy does a magnitude 8 release than a magnitude 6? Show your work.

Give one reason an eruption can often be forecast and one reason an earthquake's date cannot.

Why might a lifeline bridge need a different design target than a farm-road bridge?

