



CHAPTER 16 OF 29 · PROCESSES THAT SHAPE EARTH

Chapter 16: Earth's Tectonic Plates

Lesson 16: What evidence convinced scientists that the continents move?

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

PHENOMENON

A forest where nothing grows today

High in Antarctica's Transantarctic Mountains, rocks about 250 million years old hold fossil tree trunks with growth rings, broad leaves of the seed plant *Glossopteris*, and bones of *Lystrosaurus*, a pig-sized land animal that could not swim across an ocean. The same plant and the same animal turn up in rocks of the same age in India and southern Africa. Today the site is ice, with months of total darkness.

- Notice: what does a forest need that this place does not offer today?
- Wonder: how does a land animal that cannot swim reach three continents?
- Three possible stories: the animals moved, the climate moved, or the land moved.





LEARNING TARGETS

What you will be able to do

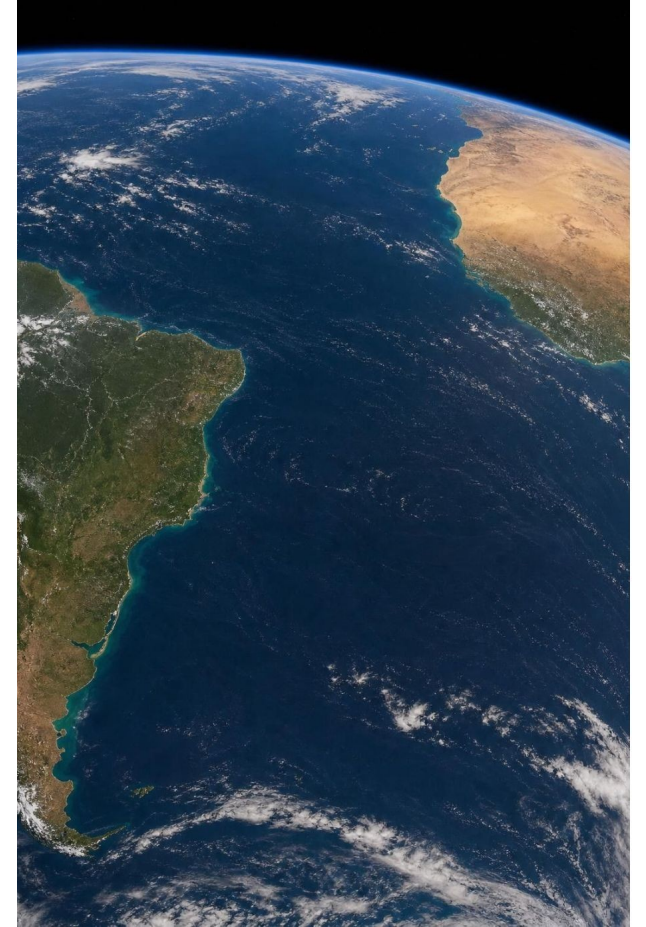
- Explain Wegener's continental drift hypothesis and the fossil, rock and shape evidence behind it.
- Explain why scientists set the idea aside and what kind of evidence was missing.
- Describe what earthquake waves, earthquake maps and sonar revealed about Earth and the seafloor.
- Analyze seafloor age and distance data to show that new seafloor forms at a ridge and spreads outward.
- Tell criteria from constraints in the design of a research drill ship.
- Classify plate boundaries by motion and use rate times time to estimate how far plates move.

A puzzle on the map: 1596 and 1912

1596: mapmaker Abraham Ortelius noticed the Atlantic coasts of the Americas and Africa look torn apart.

A hunch is not a hypothesis. A hypothesis makes predictions you can go out and test.

January **1912**: Alfred Wegener presented continental drift; his book followed in **1915**.

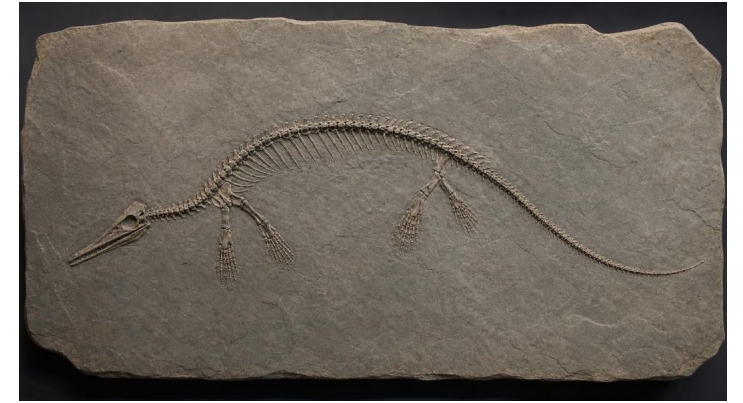


His claim: all the continents were once one landmass, Pangaea ('all lands'), that broke apart.

His prediction: if the lands were joined, their rocks, fossils and ice scars should match across the join.

Wegener's four lines of evidence

Model: What Wegener found, and what each find requires



Matching shapes: South America's east coast fits Africa's west coast. Requires: the two were once one piece.



Matching fossils: Mesosaurus (small shallow-water reptile) in Brazil and southern Africa; Lystrosaurus and Glossopteris on several southern lands. Requires: a land connection.



Matching rock belts: Old rock belts of the Appalachians continue in northwest Africa with the same rock types and ages. Requires: one belt later torn in two.



Ancient ice scratches: Scratches from glaciers about 300 million years ago point from today's oceans onto India, Africa, South America and Australia. Requires: one ice sheet over joined lands.

Each clue alone could have another explanation. Together they point to one answer.



VOCABULARY IN CONTEXT

Three words for an idea on trial

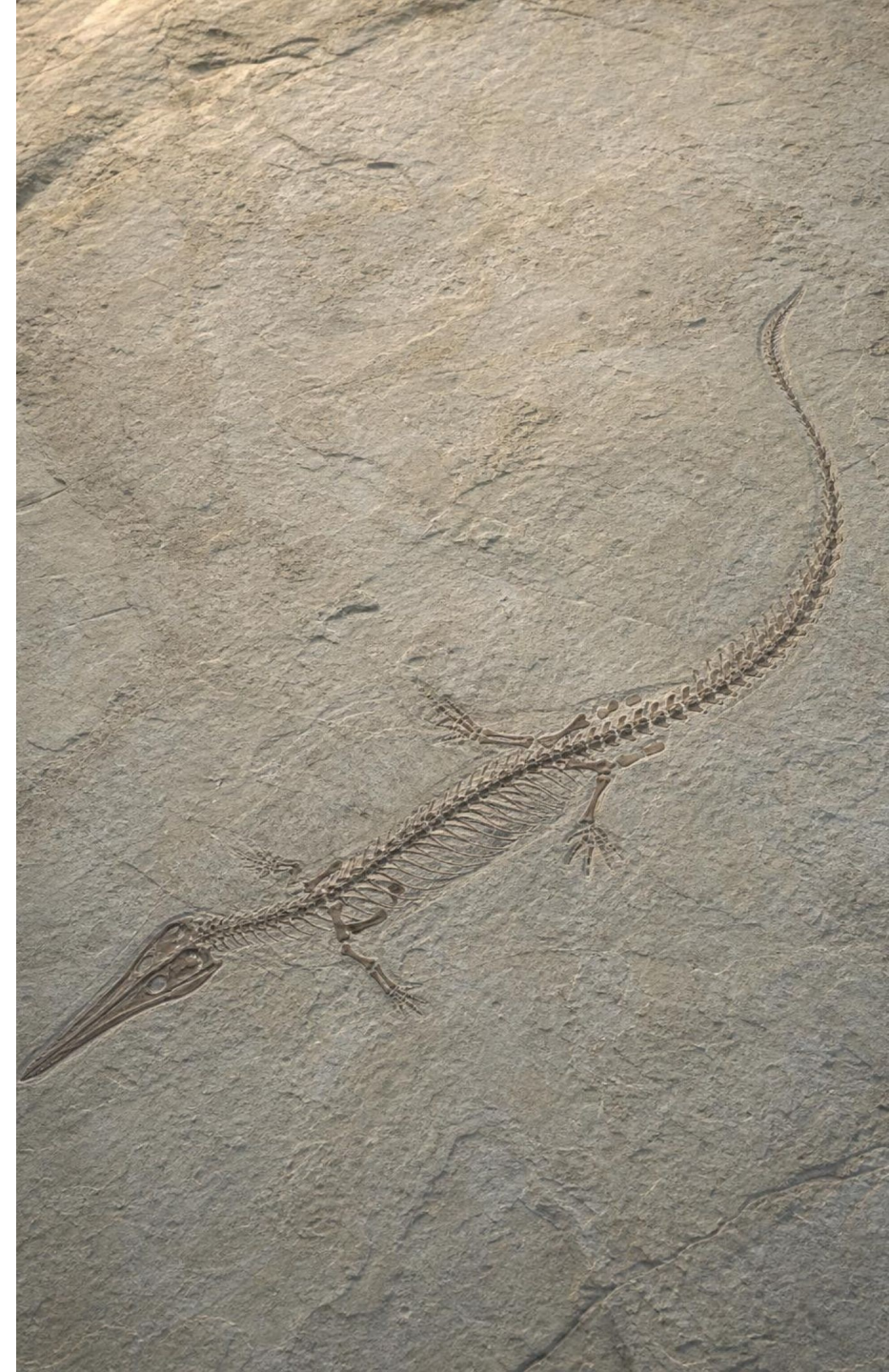
- **hypothesis:** A possible explanation, built on limited evidence, that makes predictions you can test. *Wegener's hypothesis predicted matching rock belts on facing coasts, so geologists went to check.*
- **continental drift:** Wegener's hypothesis that the continents were once joined in Pangaea and have slowly moved apart. *Continental drift explained the fossil matches but could not say what pushed the continents.*
- **Pangaea:** The supercontinent that held nearly all land, assembled about 300 million years ago and breaking up from about 200 million years ago. *Glossopteris fossils mark the southern part of Pangaea, which scientists call Gondwana.*

CHECK FOR UNDERSTANDING

Quick check: which clue is hardest to explain away?

Which find is hardest to explain without the two continents having been joined?

- A. Seeds of the same plant family on two continents
- B. Fossils of a small shallow-water reptile on two continents
- C. Similar-looking sand on beaches of two continents
- D. The same species of ocean bird nesting on two continents





Why was continental drift set aside?

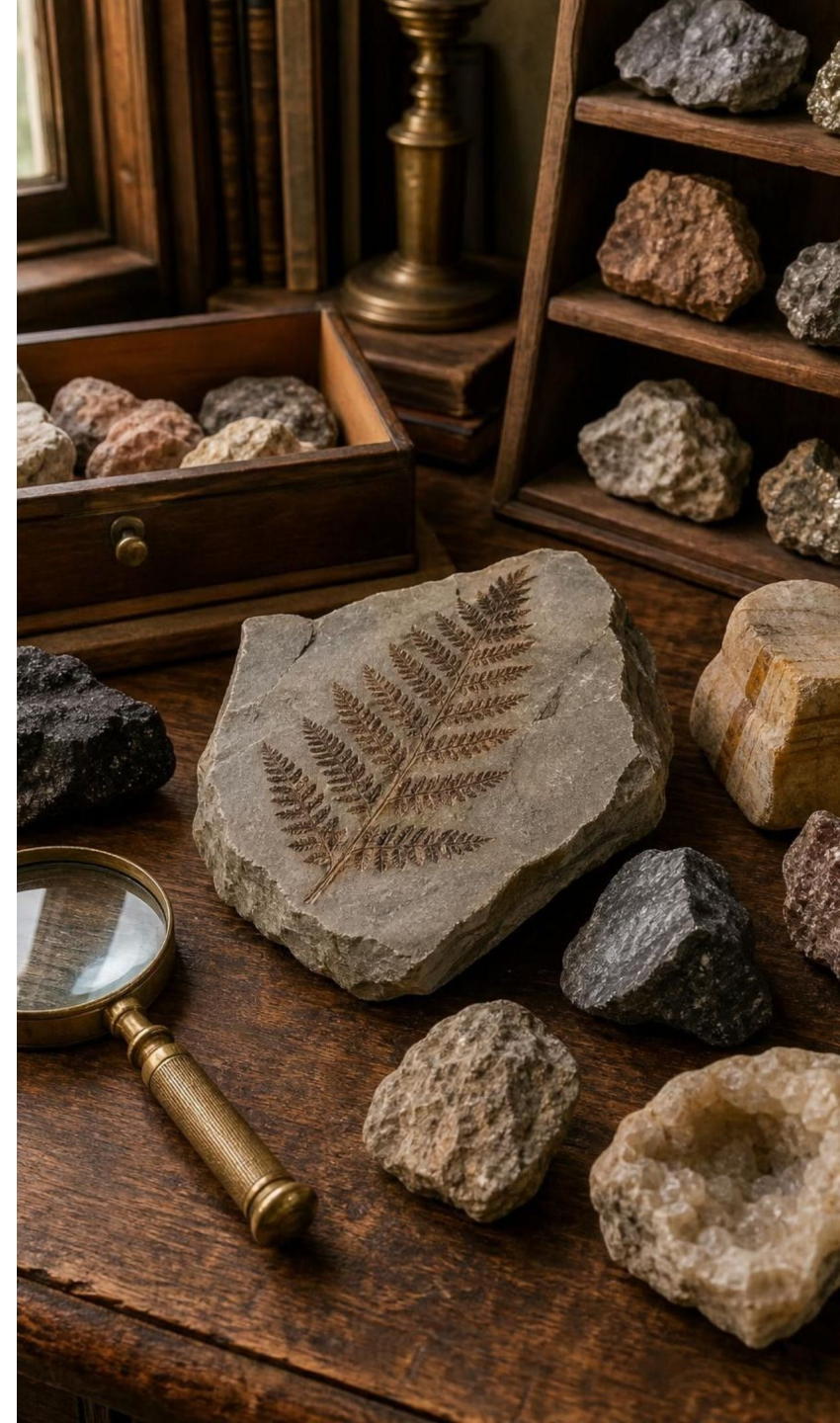
- Wegener could not name a force strong enough to move continents.
- The forces he suggested, tides and Earth's spin, were checked by physicists and found far too weak.
- Continents plowing through solid ocean floor seemed impossible, and it is.
- Many geologists preferred sunken land bridges to explain the fossils.
- Supporters remained: Alexander du Toit in South Africa, and Arthur Holmes, who proposed mantle flow in 1931.

THINK, PAIR, SHARE

Discuss: you are at the 1926 meeting

- For: fossils, rock belts, ice scratches and shapes all line up.
- Against: no known force can move a continent, and the proposed forces fail.
- Against: 'the fit is coincidence' or 'land bridges sank' could explain some clues.
- Decide: accept, reject, or 'promising but unproven'? What finding would settle it?

In 1926 geologists met in New York to debate continental drift, and many of the speakers rejected it. With only the evidence available then, what would you have decided, and what one finding would have changed your mind?



What earthquake waves revealed inside Earth

MODEL

Model: Earth's layers, top to bottom, as read from seismic waves

Top to bottom: Crust: oceanic about 5-10 km thick, continental about 30-70 km /

Rigid upper mantle: with the crust it forms the lithosphere, roughly 100 km thick /

Hot mantle below: solid rock that creeps slowly, carrying the lithosphere /

Lower mantle: solid, under enormous pressure /

Outer core: liquid iron and nickel /

Inner core: solid iron and nickel

No drill has cut through the crust into the mantle. Seismic waves change speed and bend at each boundary, and that is how the layers were found.

Belts of earthquakes and volcanoes

- From 1899, seismic stations around the world began logging where earthquakes happen.
- Earthquakes and volcanoes are not scattered; they crowd into narrow belts.
- The biggest belt, the Pacific Ring of Fire, has most active volcanoes and most large earthquakes.
- A second belt of earthquakes runs down the middle of the oceans, far from any coast.
- The belts outline huge, mostly quiet blocks. Could those blocks be the moving pieces?





CHECK FOR UNDERSTANDING

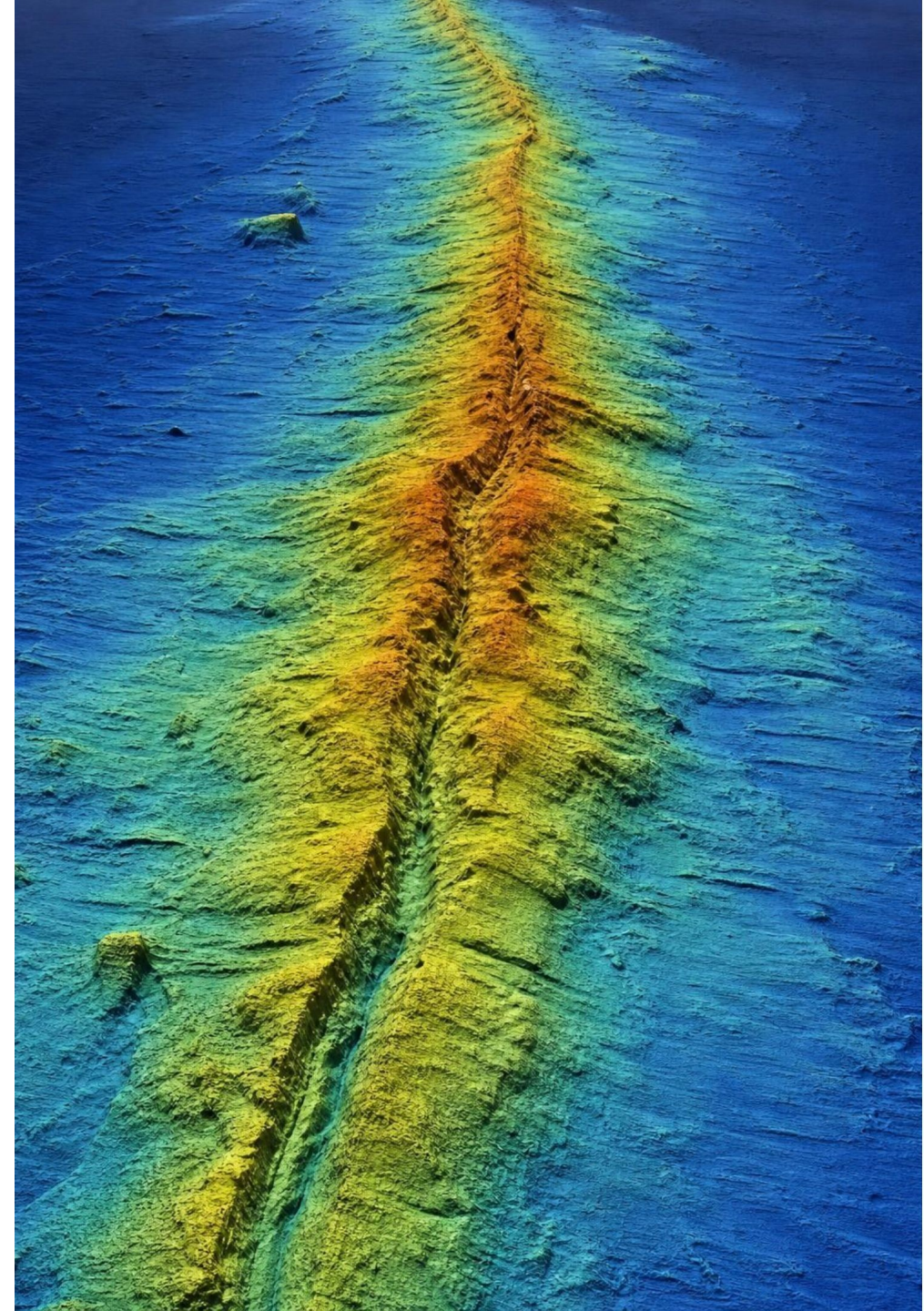
Quick check: reading the belt pattern

A town sits in the middle of a large quiet block, 2,000 km from the nearest earthquake belt. Which statement best fits the evidence?

- A. The town is on a piece that does not move
- B. The town is on a moving piece but far from its edges, so it rarely shakes
- C. The town must be on the ocean floor
- D. The town is on a belt that has not become active yet

Mapping the seafloor with sound

- For centuries, depth meant dropping a weighted rope and counting the length.
- From the 1920s, echo sounding timed a sound pulse to the bottom and back.
- A German ship (1925-27) used echo sounding to trace the ridge down the middle of the South Atlantic.
- In the 1950s Marie Tharp and Bruce Heezen turned thousands of soundings into the first detailed maps.
- Tharp found a deep valley running down the ridge crest, and earthquakes lined up inside it.





MODEL

Four structures sonar revealed

Model: Seafloor structures and what each one tells us



Mid-ocean ridge: A world-circling chain of underwater volcanic mountains, about 65,000 km long, with a rift valley along its crest.



Fracture zones: Long cracks that cross the ridge at right angles and offset it into segments. Between segments the two sides slide past each other.



Trenches: Narrow valleys up to 11 km deep, mostly around the Pacific, where earthquakes are deepest.



Continental shelves: The shallow, submerged edges of continents. Their outlines fit together even better than coastlines do.

A ridge, a crack, a trench and a shelf: each is a clue, and the next slide puts them in order.

VOCABULARY IN CONTEXT

Three words for the pieces and their edges

- **lithosphere:** Earth's rigid outer shell: the crust plus the cool, stiff top of the mantle, roughly 100 km thick, broken into plates. *A plate is a slab of lithosphere, so it carries ocean floor and continent together.*
- **mid-ocean ridge:** The chain of underwater volcanic mountains where plates move apart and new seafloor forms. *Iceland is one of the few places where the mid-ocean ridge rises above the sea.*
- **trench:** A long, narrow valley in the seafloor, several kilometers deep, where one plate bends down beneath another. *The deepest earthquakes on Earth happen in plates sinking at trenches around the Pacific.*



MODEL

Seafloor spreading: the prediction that could be tested

Model: The life of a piece of ocean floor, as proposed by Harry Hess in 1962



1 Plates pull apart at the ridge and the rift valley opens (**open**)

2 Molten rock rises into the gap and hardens into new seafloor (**fill**)

3 New seafloor moves outward on both sides, a few cm per year (**spread**)

4 Moving away, the seafloor cools, thickens and becomes denser (**age**)

5 At a trench the old, dense seafloor bends down into the mantle (**subduction**)

If this is right, seafloor must get older with distance from the ridge, and no seafloor should be very old.



MODEL

Criteria versus constraints: building a drill ship

Model: The Glomar Challenger, launched 1968, had to meet these

A criterion describes success; a constraint is a wall the design works inside.

Criteria (what success requires)	Constraints (limits the design had to live within)
Lower drill pipe through more than 6,000 m of water	No anchor can hold in 6 km of water, so position had to be held by thrusters
Drill hundreds of meters into the rock beneath the seafloor	A drill bit wears out, so the ship had to return to the same hole or stop
Bring up cores with the layers unbroken and in order	Ocean weather and waves limited when drilling could happen
Work on both sides of a ridge within one voyage	A fixed budget and schedule set by the project's funders

APPLY IT

Task: does the drill-core data fit spreading?

Simulated data for practice.

A drilling voyage sampled seafloor at seven sites across a ridge. For each side, find the half-spreading rate in km per million years. Does the age pattern fit the prediction?

Site	Distance from ridge (km)	Side	Age of oldest sediment on the lava (millions of years)
W3	900	west	45
W2	600	west	31
W1	250	west	12
R0	0	ridge	0.5
E1	300	east	14
E2	550	east	28
E3	1000	east	51





CHECK FOR UNDERSTANDING

Rate check: centimeters become oceans

Seafloor 1,000 km from a ridge is 50 million years old. What is the spreading rate on that side in centimeters per year?

- A. 0.2 cm per year
- B. 2 cm per year
- C. 20 cm per year
- D. 200 cm per year

From hypothesis to theory

- A hypothesis is an explanation on trial; a theory is one that has passed many independent tests.
- By the late 1960s: fossils, rock belts, earthquake belts, seafloor maps and seafloor ages all agreed.
- Plate tectonics: the lithosphere is broken into rigid plates that move slowly relative to each other.
- New seafloor forms at ridges; old seafloor sinks at trenches; continents ride along on plates.
- A theory stays open to revision. Scientists still study what moves plates and how plates began.



Timeline: 370 years from hunch to theory

Model: Key steps toward plate tectonics

1596: Ortelius: A mapmaker notices the Atlantic coasts fit like torn pieces.

1912-1915: Wegener: Continental drift presented, then published, with fossil, rock and ice evidence. No mechanism.

1962: Hess: Seafloor spreading proposed: new floor at ridges, old floor lost at trenches.

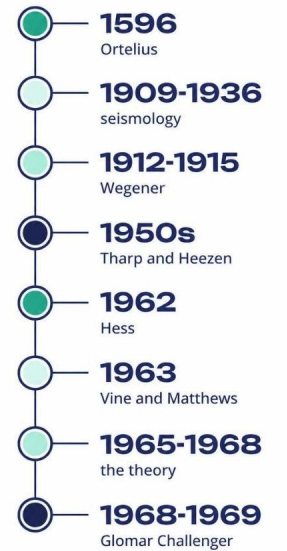
1965-1968: the theory: Wilson, Morgan, McKenzie, Parker and Le Pichon describe rigid plates moving on a sphere.

1909-1936: seismology: Earthquake waves reveal the crust-mantle boundary, the core and a rigid lithosphere.

1950s: Tharp and Heezen: Sonar soundings mapped into the first detailed seafloor maps; a rift valley runs along the ridge.

1963: Vine and Matthews: Magnetic stripes beside ridges explained as a record of spreading; surveys confirm their mirror-image pattern by 1966.

1968-1969: Glomar Challenger: Drill cores across the South Atlantic ridge show age rising with distance, as predicted.



Each step added evidence of a new kind. The theory arrived when they all agreed.

Three kinds of plate boundary

- Convergent: plates move toward each other. Denser plate sinks (subduction); trench and volcanoes form.
- Divergent: plates move apart. Molten rock fills the gap; a ridge or a widening sea forms.
- Transform: plates slide past each other. Rock sticks, stress builds, then slips: earthquakes.
- Rates are a few centimeters a year, about as fast as fingernails grow.

Boundary	Example	Motion	Approximate rate
Convergent	Nazca Plate under South America (the Andes)	toward each other	about 65-80 mm per year
Divergent	Arabian and African plates (Red Sea)	apart	about 15 mm per year in the south
Transform	Pacific and North American plates (San Andreas system)	sliding past	about 50 mm per year across the whole boundary





REAL-WORLD CONNECTION

California connection: a volcano cut in half

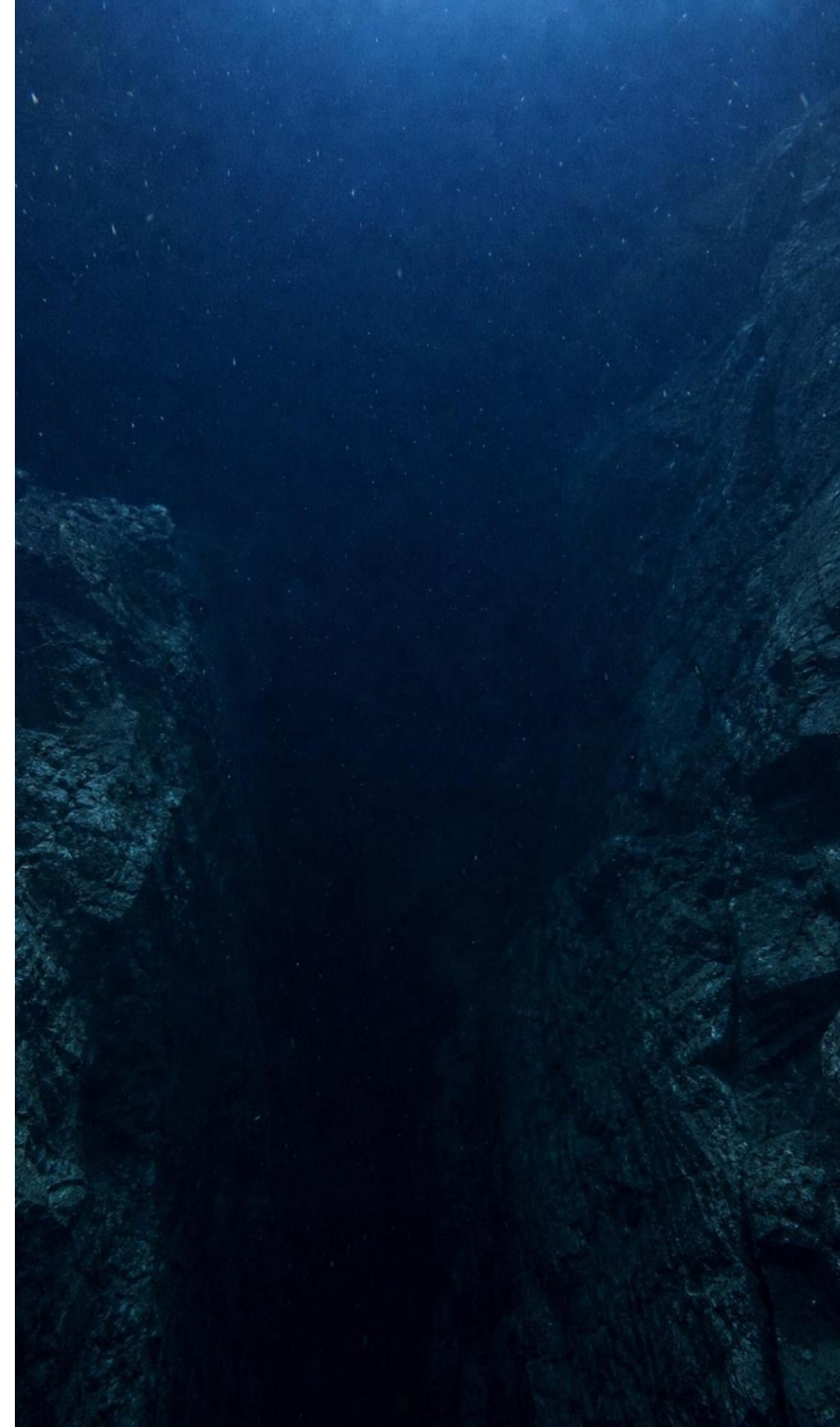
Pinnacles National Park, east of Salinas, is made of volcanic rock about 23 million years old. The other half of the same volcano, called the Neenach volcanic rocks, lies near Lancaster in southern California, about 315 km to the southeast. The San Andreas Fault runs between them. Over millions of years the Pacific side carried the Pinnacles half northwest, a few centimeters a year.

THINK, PAIR, SHARE

Discuss: if new seafloor keeps forming, why isn't Earth growing?

- Where is the oldest seafloor found, and what is next to it?
- Why are the deepest earthquakes found near trenches, not under ridges?
- No ocean floor is older than about 200 million years; the continents hold rocks over 4 billion years old.
- What would the age map look like if seafloor were never destroyed?

The ridge adds new seafloor every year on both sides. If Earth has stayed the same size, what must be happening somewhere else, and what evidence from the lesson supports it?





MISCONCEPTION CHECK

True or false? Continents float on liquid magma

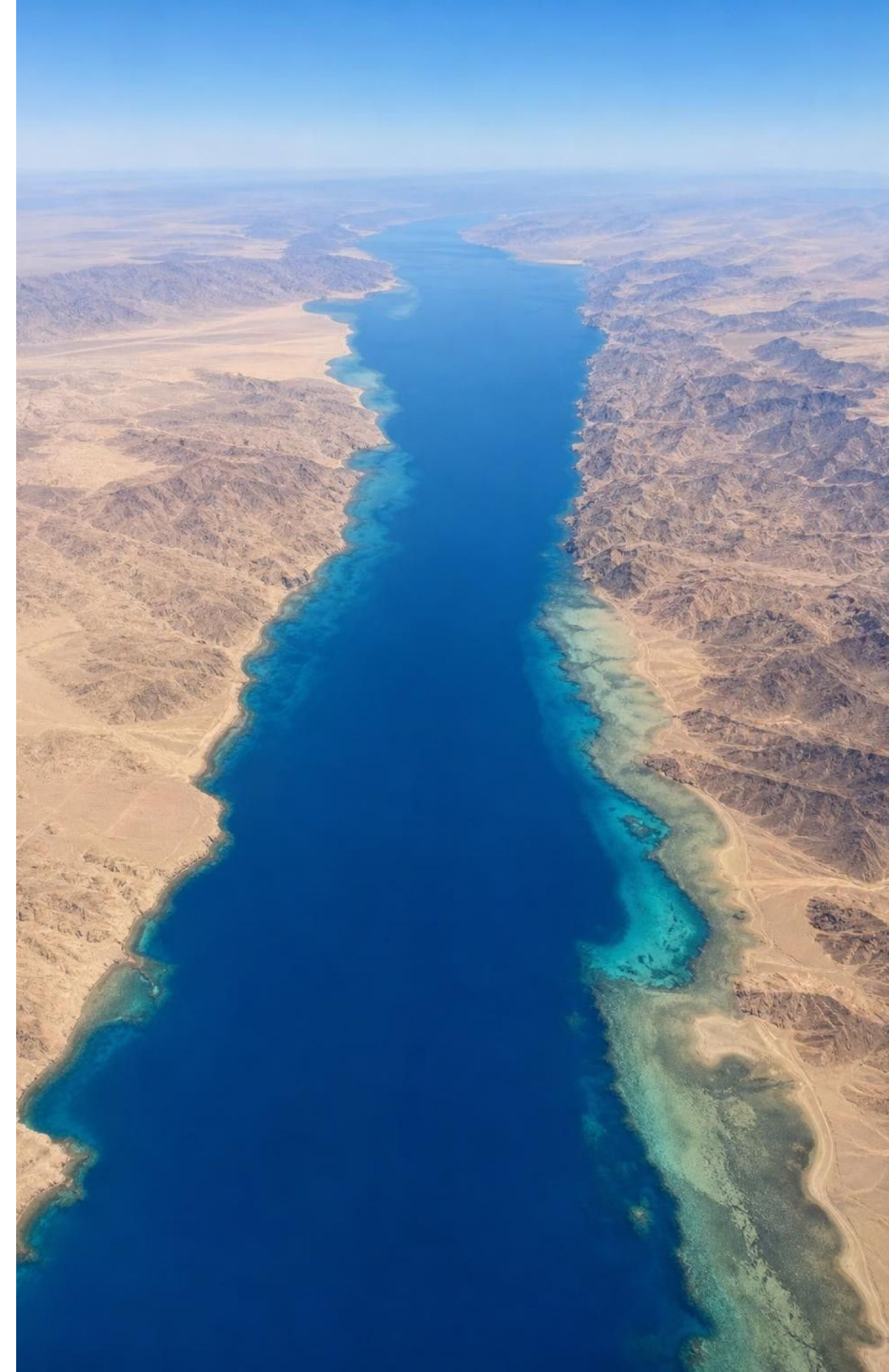
"Continents float on an ocean of liquid magma and plow through the ocean floor like ships, which is why they can drift."

True or false? Explain your reasoning.

PUTTING IT TOGETHER

Putting it together

- Wegener's land evidence (fossils, rock belts, ice scars, shapes) showed the continents were once joined.
- Without a mechanism, drift was set aside; the objection was fair.
- Seismic waves, earthquake belts and sonar revealed a rigid lithosphere, plate outlines and a global ridge.
- Drill cores showed seafloor age rising with distance from the ridge: spreading confirmed.
- Plate tectonics ties every line of evidence together, and rate times time turns centimeters into oceans.





EXIT TICKET

Exit ticket

- Name two different kinds of evidence Wegener used, and say what each one shows.
- Why was continental drift set aside, and what evidence later filled the gap?
- Seafloor 600 km from a ridge is 30 million years old. Find the spreading rate in km per million years.
- A plate boundary has a deep trench and volcanoes. Which kind of boundary is it?
- Write one sentence using 'lithosphere' correctly.