Science 7–8

Chapter 12 — Earth and space sciences A: the dynamic Earth

Aboriginal and Torres Strait Islander content has been excluded as accuracy cannot be guaranteed, and it is better to be respectful than cover the entire curriculum inaccurately.

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Plate boundaries and what they build: divergent, convergent and transform margins, and the volcanoes, earthquakes and mountains that form there

What we teach here — `VC2S8U10` (Victorian Curriculum F–10 Version 2.0, Science, Levels 7 and 8): *"Earth is a dynamic planet as demonstrated by tectonic activity, including the formation of geological features at divergent, convergent and transform plate boundaries; the theory of plate tectonics is supported by scientific evidence."* **This subtopic owns the first clause only**: tectonic activity, and the features formed at divergent, convergent and transform plate boundaries. The second clause — the scientific evidence supporting the theory — belongs to the partner subtopic **12B** († split delivery, D6). **In our words:** Earth's outer shell is broken into giant moving plates. Where two plates pull apart, push together, or slide past, they build ocean ridges, deep trenches, volcanoes, mountain ranges — and cause the earthquakes that come with all that moving. **Achievement-standard extract served here (D13):** *"They apply the theory of plate tectonics to explain geological phenomena including volcanoes, earthquakes, mountain formation and the distribution of earthquakes and volcanic zones around the globe."* **Elaborations drawn on:** `VC2S8U10.E02` (the impact of tectonic events on human populations, and engineering solutions that reduce it) and `VC2S8U10.E03` (modelling what happens at plate boundaries; the forces that move plates — shared with 12B). **Authored from the CD text (D12):** none of U10's six elaborations names the three boundary types. They appear only in the content description itself, so this subtopic is built from the CD text and from named Australian and global geology. The evidence-side elaborations are held for 12B.

Word watch — *theory*. In everyday talk, *theory* often means a guess. In science it means much more: an explanation that is backed by a great body of evidence and that ties together many observations. The Victorian Curriculum uses the word *theory* but does not define it; in this book it always carries the scientific sense given here, and every question can be answered on that meaning alone. How scientific theories grow and change is the subject of subtopic 1A.

Theory

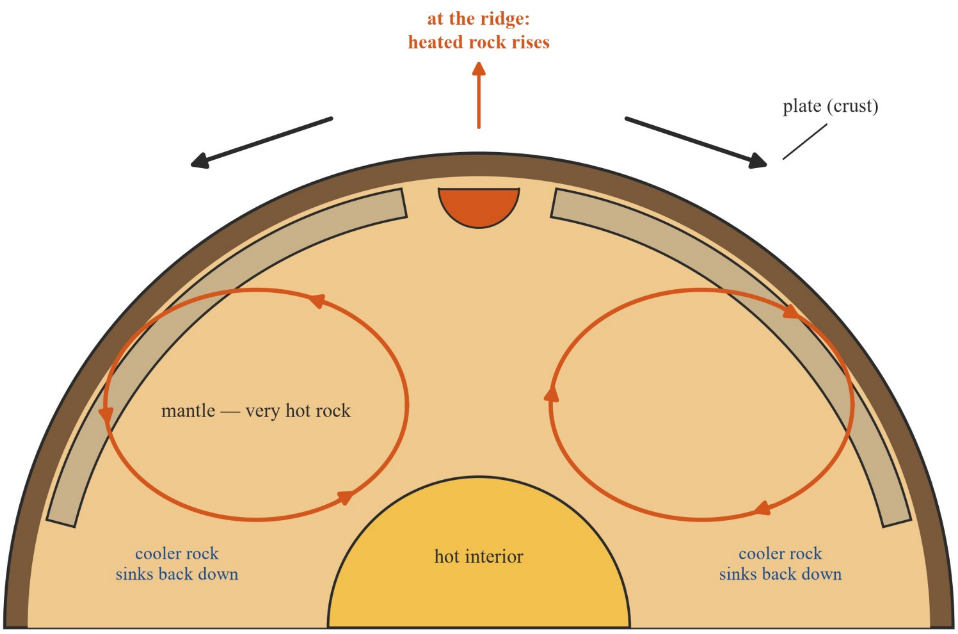
A moving shell

The ground feels solid and still, but on the scale of the whole planet it is on the move. Earth's outer shell — the **crust** — is broken into giant pieces of rock called **tectonic plates** (the word *tectonic* is about the building and shaping of Earth's crust). The largest plates number about seven, with several smaller ones fitted between them. Together the plates cover the whole planet, like the pieces of a jigsaw. Some plates carry mostly ocean floor; others carry continents and the shallow seas around them.

Below the plates lies a thick layer of very hot rock called the **mantle**. The deeper parts of Earth are hot — far hotter than any oven — and that heat keeps the rock of the mantle moving in huge, extremely slow loops: heated rock rises, and cooler rock sinks back down. This looped motion is called **convection**. You will meet convection again in subtopic 16B, where it is studied as a way energy moves; here we only need the idea that slowly moving rock can carry the plates above it (`VC2S8U10.E03`).

Convection is not the only force acting on the plates. Two more matter:

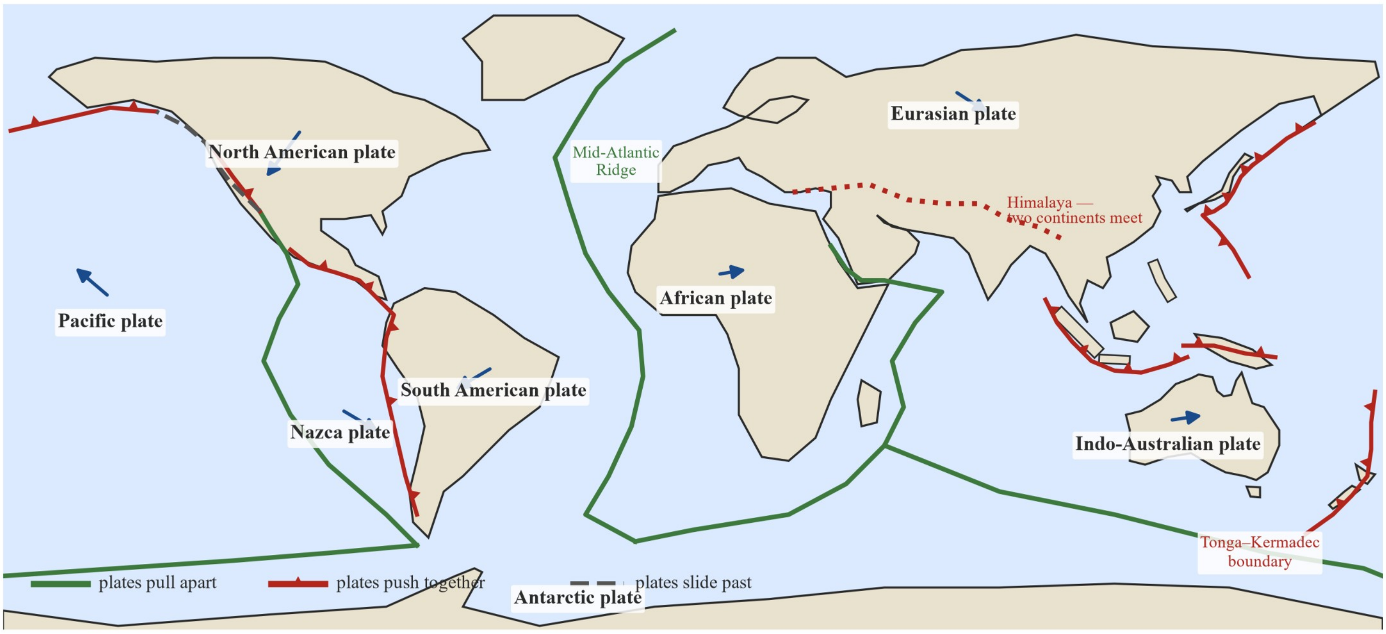
- **Ridge push** — at an underwater mountain chain (you will meet these in a moment), newly formed rock is hot and sits higher than the older rock beside it. Gravity makes the plate slide away downhill, pushing it outward from the ridge.
- **Slab pull** — where a plate sinks down into the mantle, the sinking end drags the rest of the plate along behind it, like a tablecloth being pulled off a table by one hanging corner.



Convection: heated rock rises, cooler rock sinks — huge, extremely slow loops in the mantle carry the plates above. Ridge push and slab pull act on the plates as well.

Diagram of Earth showing convection in the mantle: heated rock rises, cooler rock sinks back down, and the slow loops of moving rock carry the plates above

Scientists are still working out how much of the driving comes from each of these forces (`VC2S8U10.E03`); 12B looks at that balance and at the evidence for the whole theory. The key idea for this subtopic is simpler: **the plates move**, and almost all of Earth's volcanoes and earthquakes happen where plates meet.



Stylised map — the plates cover the whole planet like the pieces of a jigsaw; arrows show each plate's slow drift.

World map showing Earth's tectonic plates fitted together like a jigsaw, arrows showing the way each plate moves, and the divergent, convergent and transform boundaries between the plates

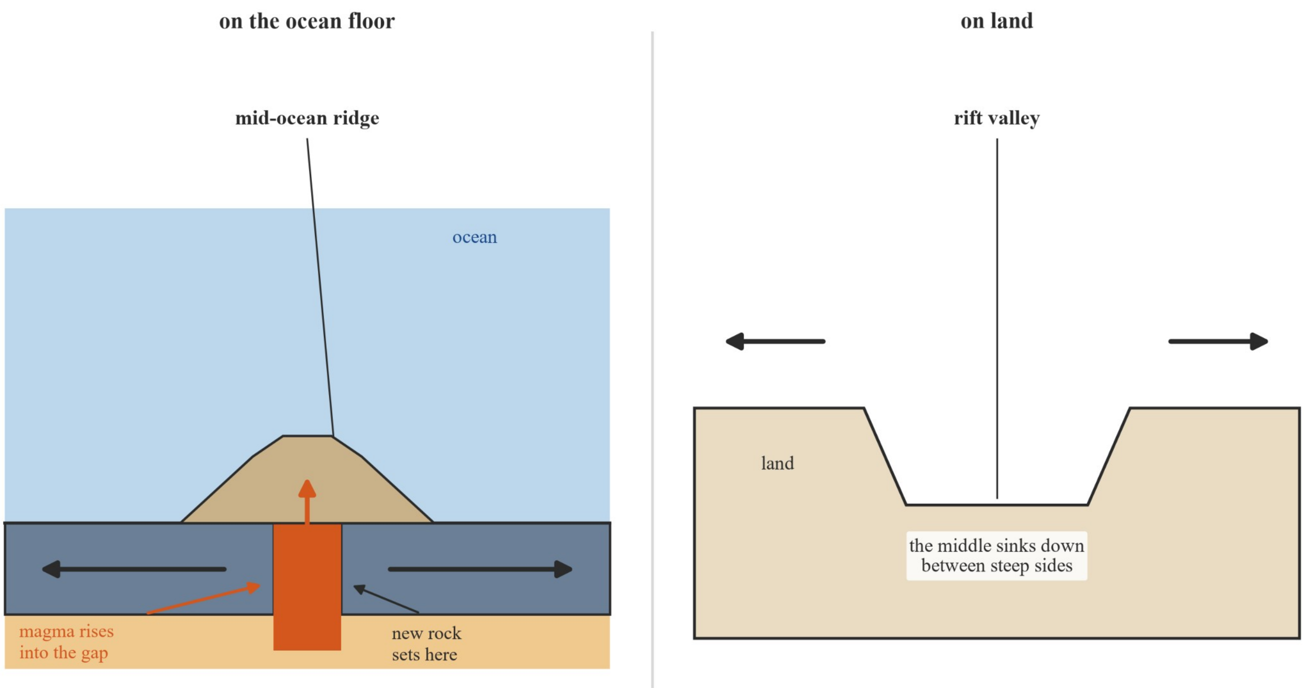
A **plate boundary** (or **margin**) is the edge where two plates meet. What happens there depends on which way the plates are moving relative to each other. There are three kinds of boundary, and each builds its own set of features.

Divergent boundary — plates pull apart

At a **divergent boundary** two plates move away from each other. Most divergent boundaries sit on the ocean floor. As the plates separate, a gap opens. Hot, melted rock from below rises up to fill it. Scientists call melted rock **magma** while it is underground, and **lava** once it reaches the surface. The rising lava cools and sets into new rock, so fresh ocean floor is made at the gap. Eruption after eruption builds up a long underwater mountain chain called a **mid-ocean ridge**.

On land, the same pulling-apart stretches the crust. The ground sinks along the middle, forming a **rift valley** — a long, low valley with steep sides. Parts of East Africa sit on one today: the land is slowly splitting, and in a very long time a new ocean will open there. Iceland is a rare place where a mid-ocean ridge rises above sea level, so you can walk on it.

Volcanoes at divergent boundaries are common but usually gentle: the lava runs easily and the gas in it escapes without violent blasts. Earthquakes there are common too, but most are small — the plates are separating, not jamming into each other.



A divergent boundary — plates pull apart. Rising lava sets into new rock: at sea it builds a mid-ocean ridge; on land it stretches the crust into a rift valley.

Two views of a divergent boundary: on the ocean floor, rising lava sets into new rock and builds a mid-ocean ridge; on land, the stretched crust sinks into a rift valley

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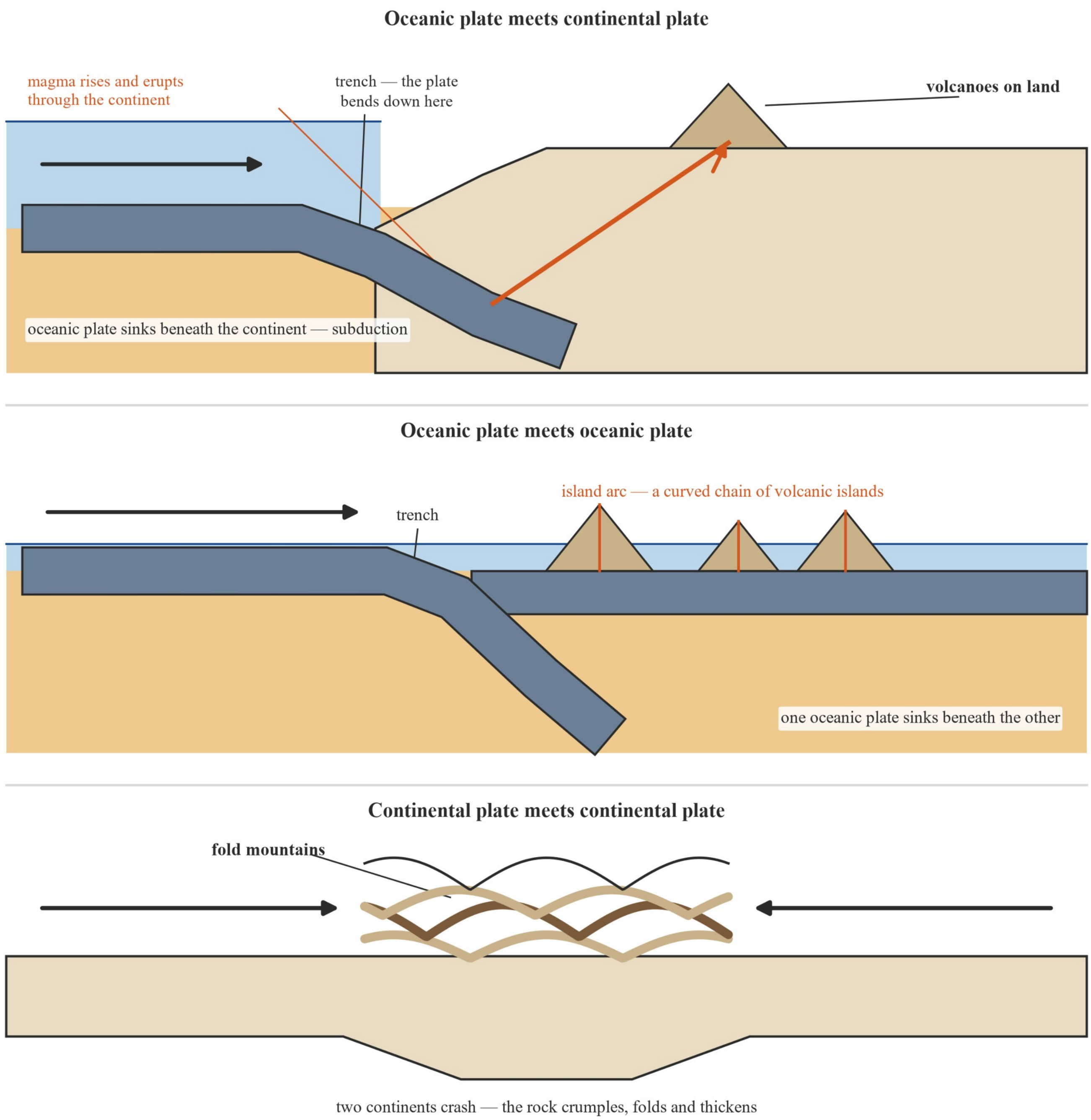
Convergent boundary — plates push together

At a **convergent boundary** two plates move towards each other. What gets built depends on what the plates are made of, because ocean-floor rock and continental rock are different: rock of the ocean floor is denser (it packs more mass into the same volume — density is from subtopic 10B) and thinner, while continental rock is less dense and thick.

- **Oceanic plate meets continental plate.** The denser ocean plate bends downwards and sinks beneath the continent. One plate sinking beneath another is called **subduction**, and the line where it bends down is marked by a **trench** — a long, narrow valley on the sea floor, and the deepest places in the ocean. As the sinking plate slides down into the hot mantle, it helps melt rock above it. That magma rises through the continent and erupts, building a line of volcanoes on land, roughly parallel to the coast. Strong earthquakes happen here too, where the two plates grind and stick. The Andes mountains of South America were built this way, and are still being pushed up, with volcanoes along their length.

- **Oceanic plate meets oceanic plate.** One plate subducts beneath the other, so there is a trench here too. The melting rock rises through the upper plate and erupts on the sea floor, building a curved chain of volcanic islands called an **island arc**. Many islands of the western Pacific, including Japan and the Mariana Islands, are built this way.
- **Continental plate meets continental plate.** Neither plate is dense enough to sink far, so instead of subducting, the two continents crash together. The rock along their edges crumples, folds and thickens — pushed upwards into **fold mountains**. The Himalaya, the highest mountain range on Earth, formed as the plate carrying India pushed into the plate carrying Asia, and the pushing is still going on today. Collisions like this cause large earthquakes, but they produce few volcanoes, because little rock melts in the crash.



A convergent boundary — plates push together. What gets built depends on what the plates are made of.

The three kinds of convergent boundary: an ocean plate subducts beneath a continent, building a trench and a line of volcanoes; two ocean plates build an island arc; two continents crash together into fold mountains

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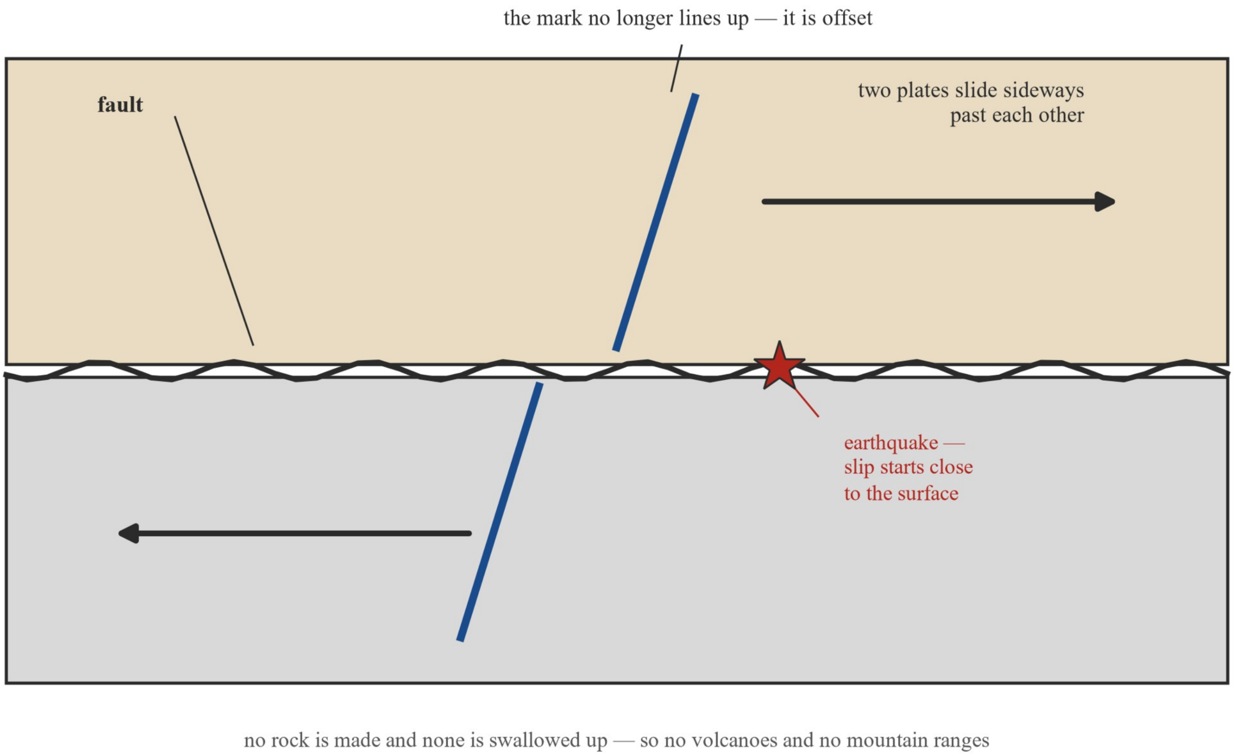
Transform boundary — plates slide past

At a **transform boundary** two plates slide sideways past each other. No rock is made and no rock is swallowed up, so transform boundaries build no volcanoes and no mountain ranges. Their mark is the earthquake. The rough edges of the plates catch and stick as they slide. Rock bends a little, stores the strain, and then slips suddenly — and the released energy shakes the ground. The crack in the crust where the slip happens is called a **fault**. Transform earthquakes start close to the surface, so even moderate ones can do serious damage. The San Andreas Fault in California and the Alpine Fault along New Zealand's South Island are transform boundaries.



A transform boundary. The rough edges catch and stick; rock stores the strain, then slips suddenly — the ground shakes.

Two plates sliding sideways past each other at a transform boundary, with a fault where the slip happens and arrows showing the opposite ways they move

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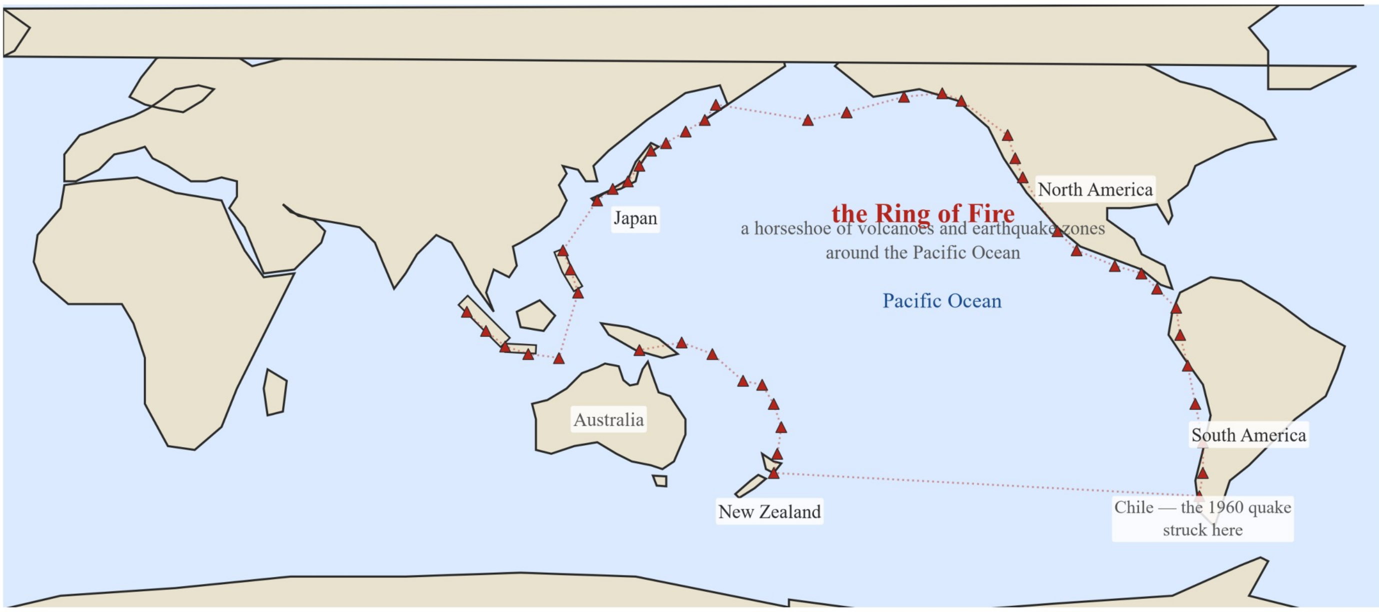
The pattern on the map

Plot the world's volcanoes and earthquakes on a map and they do not scatter at random. Most line up in long, narrow belts that trace the plate boundaries. The most famous belt circles the Pacific Ocean: the **Ring of Fire**, a horseshoe of volcanoes and earthquake zones that runs from New Zealand, up past Japan and across to the west coasts of North and South America. Why this pattern is one of the strongest clues that the plate theory is right is a question for 12B. The point here is that the pattern exists at all: **boundaries are where Earth does its building**.



Plot the world's volcanoes and earthquake zones and they crowd into narrow belts tracing the plate boundaries.

World map with the world's volcanoes and earthquake zones lined up in narrow belts around the Pacific Ocean — the Ring of Fire

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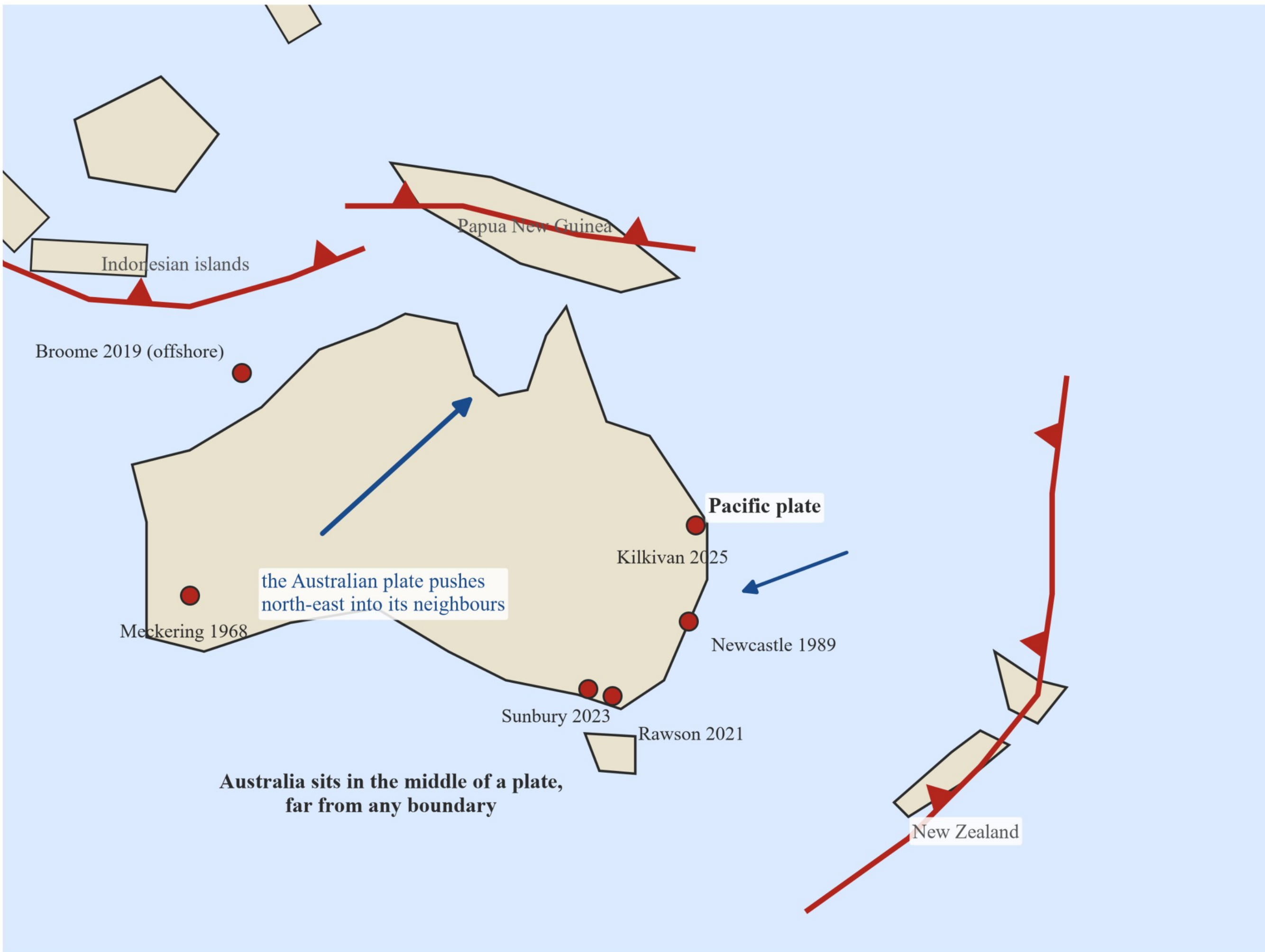
Australia: in the middle of a plate

Australia sits on the Australian plate, well away from any boundary — the nearest boundary runs through New Zealand and up through Indonesia and Papua New Guinea to our north (`VC2S8U10.E02` contexts below). You might expect that to make Australia perfectly still. It does not. As the Australian plate — which Geoscience Australia describes as the fastest-moving continental land mass on Earth — pushes into the Pacific plate to the north and east and into the Eurasian plate to the north-west, forces build up *inside* the plate. Old cracks in the crust can slip, and the ground shakes. An earthquake that happens inside a plate, away from its edges, is called an **intraplate earthquake**.



Yet forces build up inside the moving plate; old cracks in the crust slip, and the ground shakes — intraplate earthquakes. Dots: some recorded quakes.

Map of Australia sitting in the middle of the Australian plate, far from any boundary, with dots marking recorded intraplate earthquakes such as Meckering, Newcastle and Kilkivan

Geoscience Australia has mapped more than 370 intraplate faults across the continent. Some facts from their records:

- On average, around 100 earthquakes of **magnitude** 3 or larger are recorded in Australia each year. **Magnitude** is the number that measures the size of an earthquake — each whole step up (say, from 4 to 5) means a much stronger shake. Most of these quakes are never felt, because they are small or happen far from towns.
- About every 10 years, Australia has an earthquake of magnitude 6.0 or larger that could do real damage — such as the Meckering earthquake in Western Australia in October 1968, the offshore Broome earthquake of 2019, and the destructive 1989 Newcastle earthquake, magnitude 5.4.
- On 16 August 2025, a magnitude 5.6 earthquake struck near the town of Kilkivan in south-eastern Queensland, about 40 km west of Gympie. It was felt from Wollongong to Cairns, and more than 24 000 people sent in felt reports.
- Melbourne residents were woken late on 30 May 2023 by an earthquake near Sunbury, first measured at magnitude 3.8 and later upgraded to 4.0. More than 20 000 felt reports came in, from as far north as Bendigo and as far south as Hobart. In the five years before it, Victoria had four other earthquakes of magnitude 3 or larger, including a magnitude 5.9 north of Rawson in 2021.

Source: Geoscience Australia, “Recent seismic activity in Australia”, 2023. (*Seismic* means to do with earthquakes.) ga.gov.au — retrieved 2026-08-19.

Source: Geoscience Australia, "Magnitude 5.6 earthquake near Kilkivan, QLD", 2025. ga.gov.au — retrieved 2026-08-19.

Source: Geoscience Australia, "Melbourne residents woken by 3.8 magnitude earthquake", 2023. ga.gov.au — retrieved 2026-08-19.

Source: Geoscience Australia, "Earthquake", n.d. ga.gov.au — retrieved 2026-08-19.

Notice two things about this record. First, Australian earthquakes are real but rare and usually small compared with the great boundary quakes. Second, no one can say when the next one will be: Geoscience Australia is clear that earthquakes cannot be predicted or prevented. So the way communities protect themselves is by how they build, plan and prepare (`VC2S8U10.E02`).

Source: Geoscience Australia, "Australia and Papua New Guinea", n.d. ga.gov.au — retrieved 2026-08-19.

Mainland Australia has no active volcanoes today; the volcanoes that matter to us sit along the convergent boundary to our north, in Indonesia and Papua New Guinea. Geoscience Australia works with countries across the Indo-Pacific to monitor the volcano threat there.

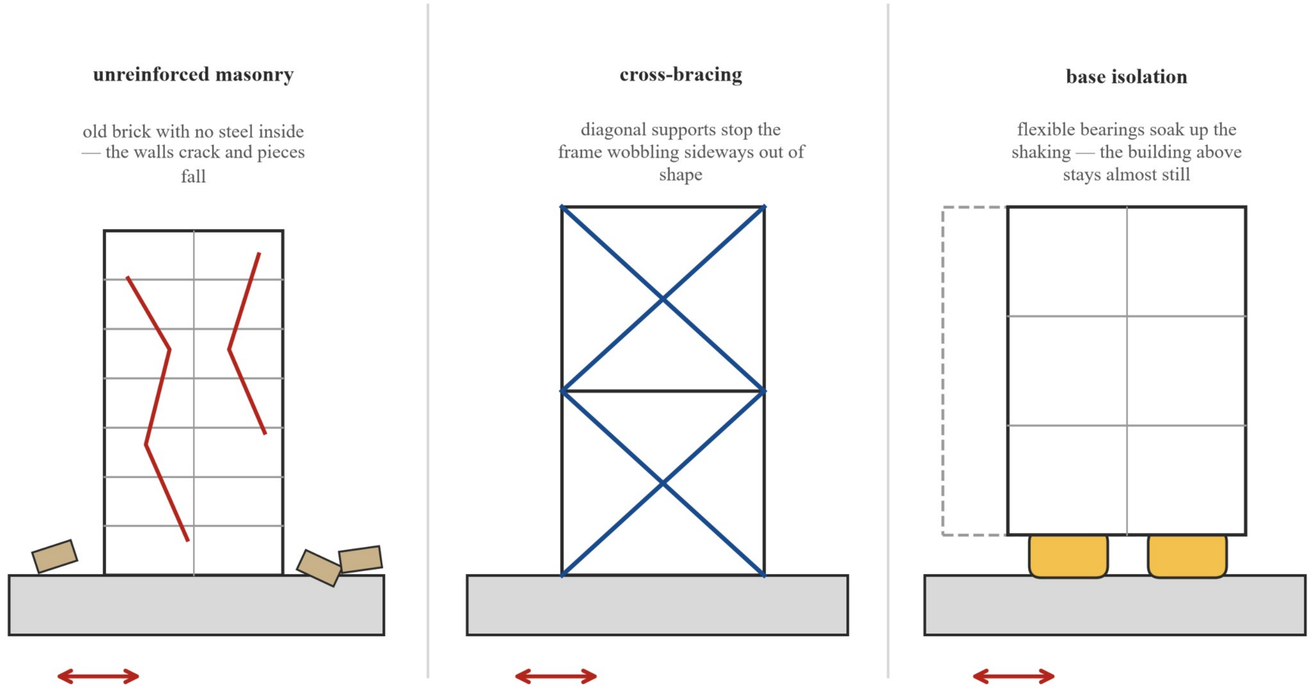
Source: Geoscience Australia, "Volcano", 2024. ga.gov.au — retrieved 2026-08-19.

Living near a boundary: impacts and engineering (`VC2S8U10.E02`)

Many people live near active volcanoes, and some of the world's biggest cities sit beside plate boundaries. The hazards are real: shaking that brings buildings down, fires started by broken gas lines, lava flows and hot ash from eruptions, and — for coastal towns near subduction zones — **tsunamis**. A tsunami is a series of enormous ocean waves, most often set off when an undersea earthquake suddenly lifts or drops a stretch of the sea floor.

What people cannot stop, they can prepare for. Engineers design buildings to survive the shake rather than to stand perfectly rigid:

- **Flexible frames.** Steel and timber frames can bend and sway without snapping. Old brick and stone buildings without steel inside them — called **unreinforced masonry** — are among the most dangerous in a quake, because the walls crack and collapse.
- **Cross-bracing.** Diagonal supports fitted across a frame stop it from wobbling sideways out of shape.
- **Base isolation.** The building rests on flexible pads or bearings that absorb the shaking, so the ground can move underneath while the building above stays almost still.
- **Retrofitting.** To retrofit a building is to strengthen the one already standing, rather than knocking it down and starting again.



What people cannot stop, they can prepare for: buildings designed to survive the shake rather than stand rigid.

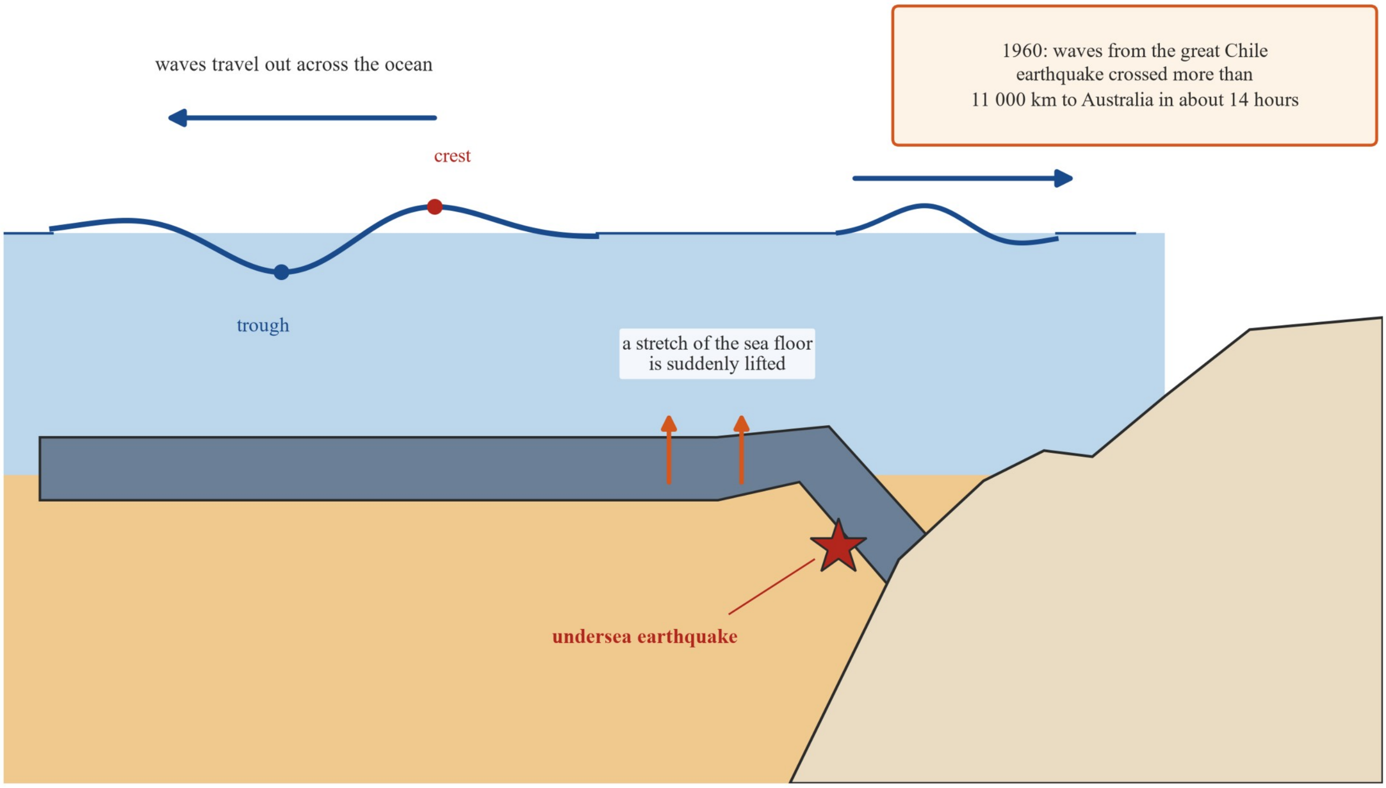
Three buildings in an earthquake: unreinforced masonry cracks and drops pieces, cross-bracing holds a frame in shape, and base isolation keeps a building almost still on flexible bearings

Victoria's own capital is a case in point. Melbourne's older brick buildings were raised long before anyone thought much about earthquakes there. Geoscience Australia researchers modelled what would happen if the city's older buildings were strengthened — a "virtual retrofit" of the city centre — and found that a 30-year retrofit program would cut overall money losses by about 15%, cut the money risk to unreinforced masonry buildings by 38%, and bring predicted deaths down from 537 to 439.

Source: Geoscience Australia, "Retrofitting Melbourne's buildings to withstand earthquakes", 2025. ga.gov.au — retrieved 2026-08-19.

Volcanoes bring their own preparations: geologists watch for the warning signs — small tremors, swelling of the ground, gas escaping — so that people can be moved out of harm's way before an eruption.

A tsunami that crossed an ocean. The reach of a boundary earthquake can be hard to believe until you see a real case. On 22 May 1960 the most powerful earthquake ever recorded struck the southern coast of Chile, at the boundary where the ocean floor slides beneath South America. Estimates at the time put it between magnitude 9.4 and 9.6, and the shaking ran for about ten minutes. It set off a tsunami that travelled more than 11 000 km to Australia's east coast in just 14 hours. Tide gauges — instruments that record sea level — picked up unusual tides along the south-east coast, with waves up to 1.7 m from crest (top) to trough (bottom), and observers in some river mouths reported waves of 3–4.3 m. Gauges as far apart as Cairns, Hobart and Fremantle all recorded the event. Subduction earthquakes like this one, in the Indian and Pacific Oceans, are the most common cause of tsunamis in the Australian region.



A tsunami is a series of enormous ocean waves, most often set off when an undersea earthquake suddenly lifts or drops the sea floor.

Diagram of the ocean showing a tsunami: an undersea earthquake lifts the sea floor, sending waves out across the ocean, each with a crest and a trough

Source: Geoscience Australia, "How the world's largest earthquake made waves in Australia", 2020. ga.gov.au — retrieved 2026-08-19.

Try it — model the three boundaries (`VC2S8U10.E03`)

You will need: two stiff pieces of cardboard, a thin layer of damp sand spread over each, and a flat table. The sand stands in for the rock layers at the top of the plates; the cardboard stands in for the plates themselves.

1. **Push together** — slide the two sheets towards each other. Watch what the sand does where the sheets meet.
2. **Pull apart** — slide the sheets away from each other. Watch the gap that opens in the sand.
3. **Slide past** — lay a stick or your finger in the sand to make a straight mark across both sheets, then slide the sheets sideways past each other. Watch what happens to the mark.

What you did	What it models	What it stands for in nature
Pushed the sheets together	Two plates moving towards each other	A convergent boundary — the sand crumples and rises like fold mountains
Pulled the sheets apart	Two plates moving away from each other	A divergent boundary — the gap stands for a rift
Slid the sheets sideways	Two plates sliding past	A transform boundary — the offset mark stands for a fault slipping in an earthquake

(The strengths and limits of models like this one are the business of subtopic 4B.) Every model has limits, and seeing them clearly is part of the skill. Ask yourself:

- The sand is not rock, and the cardboard is nothing like kilometres of solid plate. What does the model get right anyway?
- The whole demonstration takes seconds. Real plates move at speeds far too slow to see. What does that change about what you can learn from the model?
- Your hands supply the push. What supplies the forces on real plates? (Think: convection, slab pull, ridge push.)
- There is no heat in the model. Which features of real boundaries — magma, lava, volcanoes — can this model not show at all?

Worked examples

Example 1 — scaffolded

The three sketches below show pairs of plates. For each, name the boundary type, one feature it builds, and one hazard people face there.

Sketch	What the plates do
P	Two plates with arrows pointing away from each other, on the ocean floor
Q	An ocean plate bending down beneath a continental plate
R	Two plates with arrows pointing in opposite directions along a straight line

Working	Comment
P: the arrows point away from each other — the plates are separating, so P is a **divergent boundary**. Rising lava builds a **mid-ocean ridge**; the hazards are small earthquakes and gentle eruptions.	Match the motion to the boundary name first: apart = divergent. Then recall what the rising lava builds at the gap.
Q: one plate bends down beneath the other — that motion is **subduction**, so Q is a **convergent boundary**. It builds a **trench** where the plate bends down and a line of **volcanoes** on the landward plate; the hazards are strong earthquakes, eruptions, and tsunamis if the sea floor moves.	The sinking of one plate beneath another is the giveaway. Name both the underwater feature (trench) and the landward one (volcanoes).
R: the plates slide past each other sideways, so R is a **transform boundary**. It builds no volcano and no mountain range; its feature is a **fault**, and the hazard is **earthquakes**, often starting close to the surface.	No rock is made or destroyed at a transform boundary, so the hazard list contains earthquakes only — no volcanoes.

Example 2 — scaffolded

Geoscience Australia modelled a 30-year program to strengthen Melbourne's older, unreinforced masonry buildings against earthquakes. The model predicted that deaths in a large Melbourne earthquake would fall from **537** to **439** if the program went ahead, and that overall money losses would fall by about **15%**.

(a) How many fewer deaths does the model predict?
(b) That drop is what percentage of the original 537, to the nearest whole number?
(c) *(Simulated practice data.)* Suppose a city's predicted money losses without any retrofit were $80 million. At the same 15% saving, how much money would the program save, and what losses would remain?

Working	Comment
(a) 537 − 439 = **98 fewer deaths**.	Subtract the new prediction from the original.
(b) 98 ÷ 537 = 0.182…, so about **18%**.	Divide the drop by the original amount, then write it as a

Working	Comment
	percentage. Round to the nearest whole number, as asked.
(c) Saving = 15% of \$80 million = 0.15 × 80 000 000 = **\$12 million**. Losses remaining = 80 − 12 = **\$68 million**.	Find the percentage of the given amount, then subtract it. (The \$80 million figure is made up for practice; the 15% is the real figure from the Geoscience Australia model.)

Example 3 — unscaffolded

A coastal city stands on a continent. Off its shore, the sea floor bends downwards and slides beneath the continent. Explain why this city must plan for both earthquakes *and* volcanoes, and suggest one engineering measure that would reduce the earthquake risk to its buildings.

At the city's coast an oceanic plate is **subducting** beneath the continental plate the city sits on, so the city is beside a **convergent boundary**. The two plates grind and stick as one slides under the other; when the stuck rock slips suddenly, the city feels an **earthquake**. At the same time, the sinking plate helps melt rock in the mantle above it; the melted rock rises through the continental crust and erupts as **volcanoes** on land behind the coast — which is why the city must plan for both hazards. One engineering measure that would reduce the earthquake risk is **base isolation**: fitting the buildings on flexible bearings so that the ground can shake underneath while the buildings themselves move very little. ∴ the same boundary process — subduction — explains both hazards, and building design is the city's main way of cutting the earthquake risk, since earthquakes cannot be predicted or prevented.

Example 4 — unscaffolded

Using only two pieces of cardboard and some damp sand, describe how you would model what happens at a transform boundary. Say what each part of your model represents, and give one limit of the model.

Spread damp sand over both pieces of cardboard, and press a straight line into the sand running across both sheets. The two cardboard sheets represent the two **plates**, and the sand represents the rock layers on top of them. Slide the sheets sideways past each other: the line no longer matches up — it is **offset** where the sheets meet. The offset line represents a **fault** that has slipped in an earthquake, and the sudden slide represents the release of stored strain that makes the ground shake. One limit of the model is that the sand and cardboard are nothing like kilometres of solid rock, and the slide takes a second while real plates creep along far too slowly to watch — so the model shows *what slips and where*, but it cannot show the size or the slowness of real plate motion. It also has no heat, so it cannot show any feature that needs magma. ∴ the model captures the key idea — sideways slip, offset rock, sudden release — while leaving out the scale, the speed and the heat of the real thing.

Practice questions

Scaffolded

Q1. Answer the following about Earth's plates. (a) What is a tectonic plate? (b) Name the three kinds of plate boundary. (c) Where do most of Earth's volcanoes and earthquakes happen?

Q2. The Mid-Atlantic Ridge is a mountain chain on the floor of the Atlantic Ocean, built by eruptions where plates pull apart. (a) What name is given to a boundary where two plates move apart? (b) What is the difference between magma and lava? (c) State one feature that forms when plates pull apart on land, rather than on the sea floor.

Q3. Off the west coast of South America, the rock of the ocean floor bends down and slides beneath the continent, and the Andes mountains stand on the continent's edge with volcanoes along their length. (a) What is the name for one plate sinking beneath another? (b) Name the deep feature on the sea floor where the plate bends down. (c) Explain why volcanoes form on the continent above the sinking plate.

Q4. The Alpine Fault runs along New Zealand's South Island, where two plates slide past each other. (a) What name is given to a boundary where plates slide sideways past each other? (b) What is the crack in the crust called where the slip happens? (c) Explain why no volcanoes form at this kind of boundary.

Q5. Use the Australian earthquake record described in this subtopic. (a) About 100 earthquakes of magnitude 3 or larger are recorded in Australia each year. About how many is that per week? (b) Give one reason most of these earthquakes are never felt. (c) What name is given to an earthquake that happens inside a plate, away from the plate's edges?

Q6. Engineers design buildings to survive earthquakes. (a) State one way an earthquake can harm people in a city. (b) State two design features that help a building survive shaking. (c) In Geoscience Australia's Melbourne model, predicted deaths fell from 537 to 439 if older buildings were strengthened. How many fewer deaths is that?

Unscaffolded

Q7. Explain why a line of volcanoes forms on a continent beside a trench where an oceanic plate is sinking beneath it. *(3 marks)*

Q8. A student claims: *"Mountains only form where two continents crash together."* Using what happens at divergent boundaries, decide whether this claim is right, and give one example to support your answer. *(2 marks)*

Q9. Late in May 2023, an earthquake near Sunbury woke people across Melbourne, even though Melbourne is nowhere near a plate boundary. Explain why a city in the middle of a plate can still be shaken by earthquakes. *(2 marks)*

Q10. The table shows observations recorded in Australia after the great Chile earthquake of 22 May 1960.

Observation	Value
Magnitude of the earthquake (estimates at the time)	9.4–9.6
Time for the tsunami to reach Australia's east coast	about 14 hours
Distance travelled	more than 11 000 km
Wave height recorded by tide gauges, crest to trough	up to 1.7 m
Wave heights reported in some river mouths	3–4.3 m

(a) State two observations from the table. *(2 marks)*
(b) Explain how an earthquake off Chile could change the sea level on Australia's coast. *(2 marks)*

Q11. In the cardboard-and-sand model of the boundaries, the sand crumples when the sheets are pushed together. State one thing this model shows well about real fold mountains, and one way the model falls short. *(2 marks)*

Q12. A town beside a transform fault is planning a new school. Propose two features the building should have, and for each one explain how it protects the people inside when the fault slips. *(4 marks)*

Q13. Where two continents collide, the crust crumples into the highest mountain ranges on Earth, yet few volcanoes form there. Explain both facts: why the mountains rise, and why the volcanoes mostly do not. *(3 marks)*

Q14. *(Practice scenario — the island is imaginary.)* Explorers map an island in the ocean. They find a deep trench in the sea a little way offshore, a chain of volcanoes running along the island's middle, and records of frequent strong earthquakes. Identify the kind of plate boundary beside the island, and explain how that one boundary accounts for all three observations. *(4 marks)*

Answers

Q1. (a) One of the giant pieces of rock that make up Earth's outer shell. (b) Divergent, convergent and transform. (c) At plate boundaries. **Q2.** (a) A divergent boundary. (b) Magma is melted rock underground; lava is melted rock that has reached the surface. (c) A rift valley. **Q3.** (a) Subduction. (b) A trench. (c) The sinking plate helps melt rock above it; the melted rock rises through the continent and erupts. **Q4.** (a) A transform boundary. (b) A fault. (c) No rock is made or swallowed up there, so no magma rises. **Q5.** (a) About 2 (100 ÷ 52 ≈ 1.9). (b) They are small, or they happen far from towns. (c) An intraplate earthquake. **Q6.** (a) Falling buildings (or fires, or flying broken glass). (b) Any two of: flexible frames, cross-bracing, base isolation, retrofitting. (c) 98. **Q7.** The oceanic plate subducts into the hot mantle; the sinking plate helps melt rock above it; the magma rises and erupts on the continent. **Q8.** The claim is wrong: at divergent boundaries, eruption after eruption builds mountain chains too — mid-ocean ridges (or: mountains on land, as in Iceland). **Q9.** Forces from the moving plate build up inside the plate; when an old crack (fault) in the crust slips, the stored energy shakes the ground — an intraplate earthquake. **Q10.** (a) Any two values read from the table. (b) The earthquake suddenly moved the sea floor, setting off a tsunami that travelled across the Pacific; the waves reached Australia's coast about 14 hours later and changed the sea level there. **Q11.** Shows well: pushing rock together makes it crumple and rise. Falls short: sand is not rock / the model takes seconds while real mountain building takes times far longer than a human life / there is no heat, so no melting. **Q12.** Any two features with a matching explanation, e.g. base isolation (the ground shakes under the building while the building itself moves very little) and cross-bracing (the frame does not wobble out of shape). **Q13.** The two continents are too light (not dense enough) to sink, so the rock crumples, folds and is pushed up into mountains; few volcanoes form because little rock melts in the crash. **Q14.** A convergent boundary, with an oceanic plate subducting beneath the plate the island sits on. The trench marks where the plate bends down; the volcanoes are built by magma from the melting rock above the sinking plate; the earthquakes come from the two plates grinding and sticking as one slides beneath the other.

Fully-worked solutions

Q1. (a) A **tectonic plate** is one of the giant pieces of rock that make up Earth's outer shell, the crust; the largest number about seven, with several smaller ones between them. (b) The three kinds of boundary are **divergent**, **convergent** and **transform**. (c) Most of Earth's volcanoes and earthquakes happen **at plate boundaries**, where the plates meet.

Q2. (a) A boundary where two plates move apart is a **divergent boundary**. (b) **Magma** is melted rock while it is still underground; once it reaches the surface it is called **lava**. (c) When plates pull apart on land, the crust stretches and sinks along the middle, forming a **rift valley**.

Q3. (a) One plate sinking beneath another is called **subduction**. (b) The deep feature where the plate bends down is a **trench**. (c) As the oceanic plate sinks into the hot mantle it helps **melt rock above it**; the melted rock (magma) is lighter than the rock around it, so it **rises through the continental crust and erupts** as volcanoes on the land above the sinking plate.

Q4. (a) A boundary where plates slide sideways past each other is a **transform boundary**. (b) The crack in the crust where the slip happens is a **fault**. (c) At a transform boundary no rock is made and no rock is swallowed up, so there is **no gap for magma to rise through and no sinking plate to cause melting** — with no magma, there are no volcanoes.

Q5. (a) There are 52 weeks in a year, so 100 ÷ 52 ≈ 1.9 — about **2 earthquakes per week**. (b) Most are never felt because they are **small** (low magnitude) or because they happen **far from towns**. (c) An earthquake inside a plate, away from the edges, is an **intraplate earthquake**.

Q6. (a) Shaking can **bring buildings down** onto people; it can also start fires (broken gas lines) or send glass and rubble flying. (b) Any two of: **flexible frames** of steel or timber that bend without snapping; **cross-bracing** (diagonal supports that stop the frame wobbling out of shape); **base isolation** (flexible bearings under the building that absorb the shaking); **retrofitting** (strengthening older buildings already standing). (c) 537 − 439 = **98 fewer deaths**.

Q7. The oceanic plate is **subducting** — sinking beneath the continent — at a convergent boundary *(1 mark)*. As it slides down into the hot mantle, it **helps melt rock above it** *(1 mark)*. The melted rock (magma) **rises through the continental crust and erupts**, building a line of volcanoes on the continent beside the trench *(1 mark)*.

Q8. The claim is **wrong** *(1 mark)*: at **divergent boundaries** eruption after eruption also builds mountains — the **mid-ocean ridges**, long underwater mountain chains made of cooled lava; Iceland is a piece of one standing above sea level *(1 mark)*. (The continent crash the student describes is real, but it is not the only way mountains form.)

Q9. Melbourne sits in the middle of the Australian plate, and as the plate pushes into its neighbours, **forces build up inside the plate** *(1 mark)*. When an old crack in the crust — a fault — suddenly **slips**, the stored energy shakes the ground: an **intraplate earthquake** *(1 mark)*.

Q10. (a) Any two correct readings, for example: the earthquake's magnitude was estimated at **9.4–9.6** *(1 mark)*; tide gauges recorded waves **up to 1.7 m** from crest to trough *(1 mark)*. (Also accept: about 14 hours travel time; more than 11 000 km travelled; 3–4.3 m waves in some river mouths.) (b) The earthquake **suddenly moved the sea floor** at the boundary off Chile, lifting or dropping a stretch of water above it and setting off a **tsunami** *(1 mark)*. The wave train **travelled across the Pacific** — more than 11 000 km in about 14 hours — and changed the sea level on Australia's coast when it arrived *(1 mark)*.

Q11. Shows well: the model shows that **pushing two plates together crumples the rock between them upwards**, which is how fold mountains rise *(1 mark)*. Falls short (any one): the **sand is not solid rock** and the cardboard is nothing like kilometres of solid plate; the model takes seconds while real mountain building takes **times far longer than a human life**; or the model is cold, so it cannot show the **melting and magma** of real boundaries *(1 mark)*.

Q12. Example features (any two, each with a matching explanation): **Base isolation** — the school rests on flexible bearings that absorb the shaking, so the ground can jump along the fault while the classrooms above move very little, keeping walls and ceilings intact *(2 marks: feature + how it protects)*. **Cross-bracing** — diagonal supports keep the frame from wobbling out of shape, so the building stands up after the slip instead of leaning or collapsing *(2 marks: feature + how it protects)*. (Also accept: a light roof that does less harm if it does fall; flexible pipes and wiring that do not snap and start fires.)

Q13. The continental rock on both sides is **less dense than ocean-floor rock, so neither plate can sink** into the mantle; instead the two plates **crash, and the rock along their edges crumples, folds and thickens, pushed up into mountains** *(2 marks: why the mountains rise)*. Few volcanoes form because **there is no sinking plate to cause melting** — with little rock melted, little magma rises *(1 mark)*.

Q14. The island sits beside a **convergent boundary where an oceanic plate subducts** beneath the plate carrying the island *(1 mark)*. The **trench** marks the line where the oceanic plate bends down *(1 mark)*. The sinking plate helps melt rock above it, and the magma rises through the island's plate to build the **chain of volcanoes** *(1 mark)*. The **frequent strong earthquakes** come from the two plates grinding, sticking and suddenly slipping as one slides beneath the other *(1 mark)*. One boundary, three observations — trench, volcanoes and earthquakes all fit the subduction picture.

Sources

All factual data in this subtopic is drawn from Geoscience Australia, per the series' sourcing rules; every line below was retrieved 2026-08-19.

- Geoscience Australia, "Recent seismic activity in Australia", 2023. ga.gov.au
- Geoscience Australia, "Magnitude 5.6 earthquake near Kilkivan, QLD", 2025. ga.gov.au
- Geoscience Australia, "Melbourne residents woken by 3.8 magnitude earthquake", 2023. ga.gov.au
- Geoscience Australia, "Retrofitting Melbourne's buildings to withstand earthquakes", 2025. ga.gov.au
- Geoscience Australia, "How the world's largest earthquake made waves in Australia", 2020. ga.gov.au
- Geoscience Australia, "Earthquake", n.d. ga.gov.au
- Geoscience Australia, "Volcano", 2024. ga.gov.au
- Geoscience Australia, "Australia and Papua New Guinea", n.d. ga.gov.au

The $80 million figure in Worked Example 2(c) is **simulated data for practice**; the 15% saving it applies is the real figure from the Geoscience Australia retrofit model. Elaboration contexts used: `VC2S8U10.E02` (impacts and engineering) and `VC2S8U10.E03` (modelling boundaries and the forces that move plates).

The evidence for plate tectonics: sea-floor mapping, earthquake and volcano distribution, slab pull, ridge push and convection — and why the theory was accepted

What we teach here — `VC2S8U10` (Victorian Curriculum F–10 Version 2.0, Science, Levels 7 and 8): *"Earth is a dynamic planet as demonstrated by tectonic activity, including the formation of geological features at divergent, convergent and transform plate boundaries; the theory of plate tectonics is supported by scientific evidence."* **This subtopic owns the second clause only**: the scientific evidence supporting the theory of plate tectonics — sea-floor mapping, the distribution of earthquakes and volcanoes, the forces that move plates (slab pull, ridge push and convection) and why scientists came to accept the theory. The first clause — tectonic activity and the features built at boundaries — belongs to the partner subtopic **12A** († split delivery, D6). **In our words:** moving plates leave clues behind — new rock laid down at ridges, earthquakes and volcanoes tracing the plate edges, and a drift recorded in Australia's own landscape. Reading those clues is how a daring idea became the accepted theory of plate tectonics. **Achievement-standard extract served here (D13):** cited by reference to the header of the owner subtopic 12A, where the extract appears in full. **Elaborations drawn on:** `VC2S8U10.E01` (patterns of earthquake and volcanic activity, and explanations for them), `VC2S8U10.E03` (the forces involved in tectonic plate movement — slab pull, ridge push and convection — shared with 12A, which owns the boundary-modelling side), `VC2S8U10.E04` (the extreme age and stability of a large part of the Australian continent, related to its plate tectonic history), `VC2S8U10.E05` (Marie Tharp's topographic maps of the Atlantic Ocean floor and the acceptance of the theory) and `VC2S8U10.E06` (Aboriginal cultural accounts that give evidence of earthquakes and volcanoes — the records of Budj Bim in south-western Victoria). **Authored from the CD text and the elaboration contexts (D12):** the CD's second clause names "scientific evidence" without saying which; the five elaborations above supply the evidence contexts drawn on here. E06's wording is resolved against the primary sources — see the note in Sources.

Word watch — *proof* and *accepted*. In everyday talk, people say a fact *proves* a theory. In science, evidence never proves a theory once and for all — it *supports* it. A theory is **accepted** when it is the best explanation on offer: it ties together many observations, it supplies a working mechanism, and it keeps passing new tests. Acceptance is a status, not a finish line — stronger evidence could still change the story (subtopic 1A). In this subtopic, *accepted* always carries this meaning, and where everyday talk might reach for *proof*, this book uses *evidence* and *support*. (Subtopic 12A watched the word *theory*; this one watches what happens to theories.)

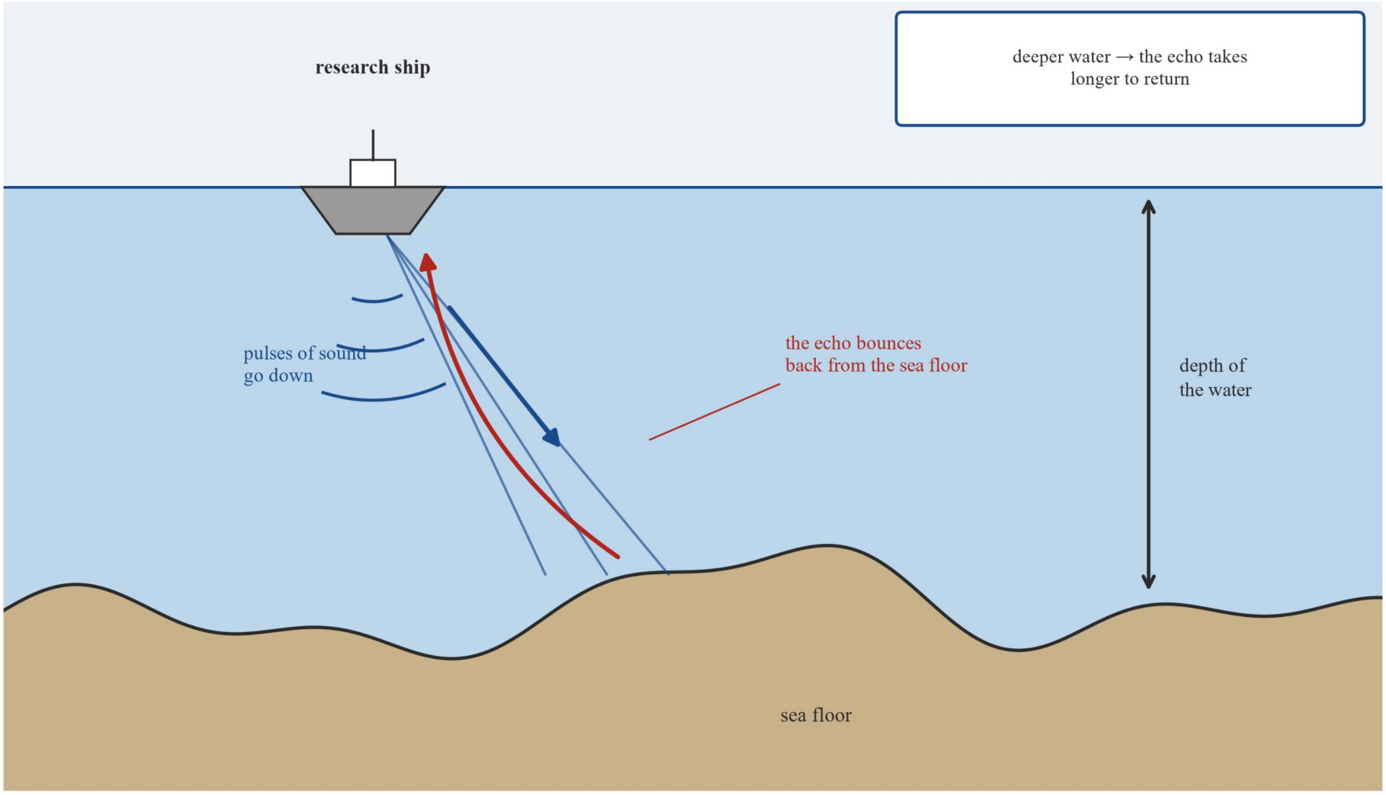
Theory

Clues for a slow-motion puzzle

Plates move far too slowly for anyone to watch them directly — nobody has ever seen the sea floor spread. So how can we know it happens? You look for the clues the movement leaves behind: the shape of the sea floor, the rocks it is made of, and the earthquakes and volcanoes it causes. This subtopic reads those clues one by one, then ends with the story of how they turned a daring idea into the accepted theory of plate tectonics. Subtopic 12A built the machinery — the plates and their boundaries. Here we ask the question that decides everything: *how do we know?*

Seeing the sea floor: echo sounding

For most of history, the sea floor was hidden beneath kilometres of dark water. Ships measured the depth beneath them by lowering weighted lines over the side — slow work, which produced only sparse sketches of the bottom. In the twentieth century, **echo sounding** changed all that: a ship sends out pulses of sound and listens for the echo bouncing back from the sea floor, and from the time the echo takes to return, the depth of the water can be worked out. Research ships crossed and re-crossed the oceans, taking depth measurements all the way. Thousands of measurements can be turned into a map of the sea floor — and those maps held the first big clues.



Echo sounding: a ship times how long the echo takes to return. Thousands of soundings, crossed and re-crossed, built the first true maps of the sea floor.

Cross-section of echo sounding: a research ship sends pulses of sound down to the sea floor and listens for the echo bouncing back; the time the echo takes tells the depth of the water

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Marie Tharp draws the Atlantic (`VC2S8U10.E05`)

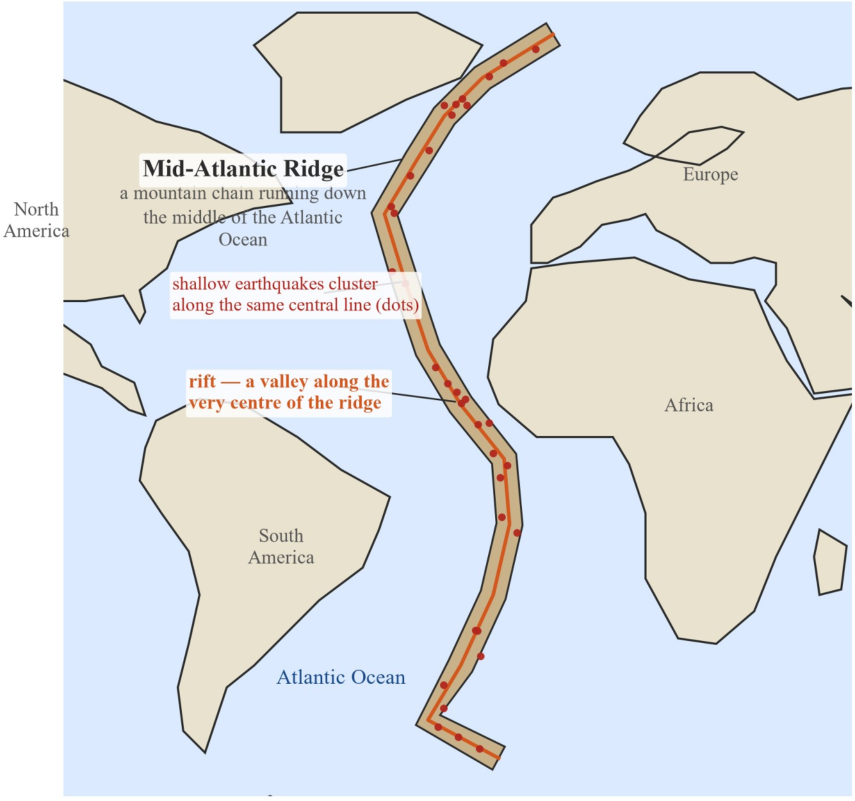
Marie Tharp was a geologist and oceanographic cartographer — a map-maker of the sea floor. In the 1950s, working with Bruce Heezen and Maurice Ewing, she used the depth measurements collected by research ships to draw detailed maps of the floor of the Atlantic Ocean. The team published the first of these maps in 1959.

The maps showed something remarkable. A giant mountain chain runs down the middle of the Atlantic Ocean — the **Mid-Atlantic Ridge**. And running along the very centre of that mountain chain was a valley, a **rift**, as if the sea floor were being pulled apart there. Shallow earthquakes were found to cluster along the same central line. Later work showed that the same ridge-and-rift system winds through all of the world's oceans, connected like the seams on a ball.

That pattern was exactly what the plate idea predicts at a **divergent boundary** (12A): where two plates pull apart, a gap opens, lava rises to fill it, and eruption after eruption builds an underwater mountain chain with a valley of newly opened rock along its middle. Tharp's maps gave scientists a picture of precisely that.

Source: Heezen, B.C., M. Tharp and M. Ewing, *The Floors of the Oceans*, Geological Society of America Special Papers, no. 65, 1959. DOI 10.1130/spe65-p1.

Source: Heezen, B.C. and M. Tharp, "Tectonic fabric of the Atlantic and Indian oceans and continental drift", *Philosophical Transactions of the Royal Society of London A*, vol. 258, 1965. DOI 10.1098/rsta.1965.0024.



Drawn from ship soundings by Marie Tharp and her colleagues. The same ridge-and-rift system winds through all the world's oceans, connected like the seams on a ball.

Map of the Atlantic Ocean showing the Mid-Atlantic Ridge, a mountain chain running down the middle of the ocean, with a rift along its centre and dots marking the shallow earthquakes found there

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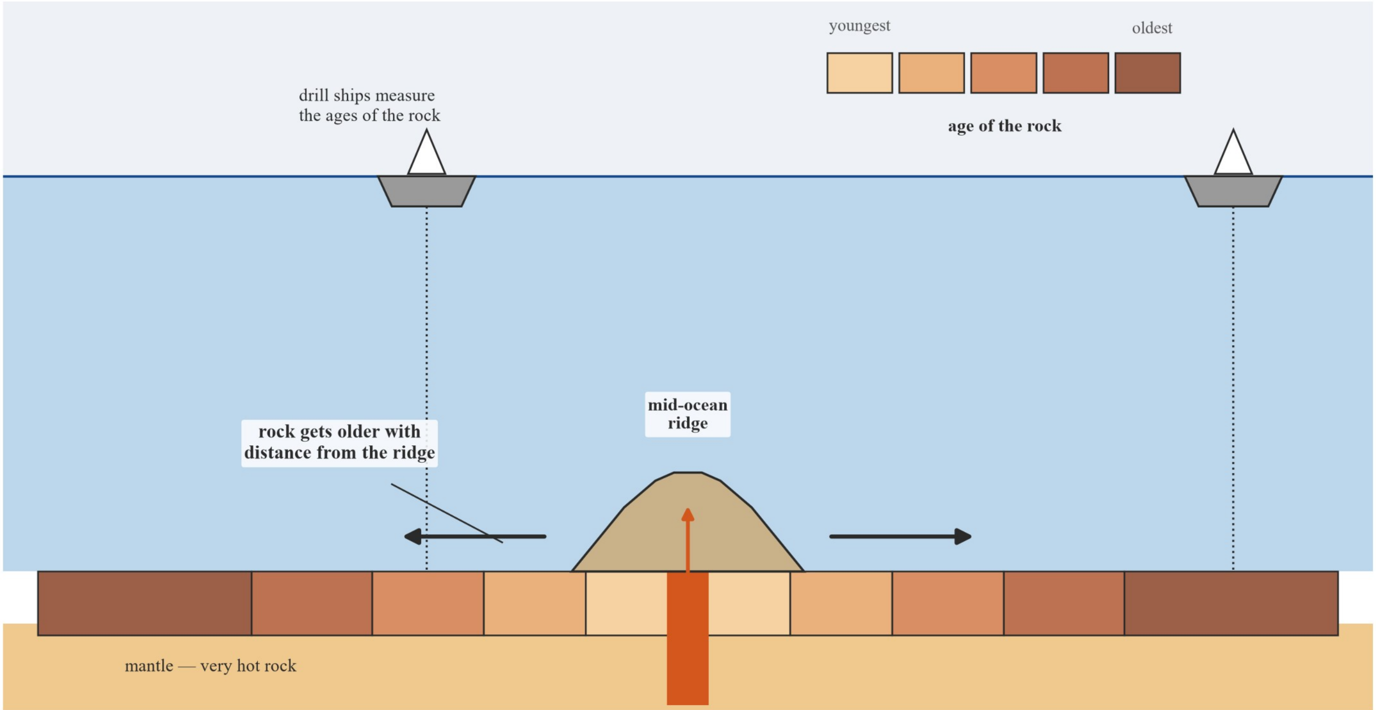
Stripes and ages in the sea-floor rock

The maps were only the first clue. Two more came from the rocks themselves.

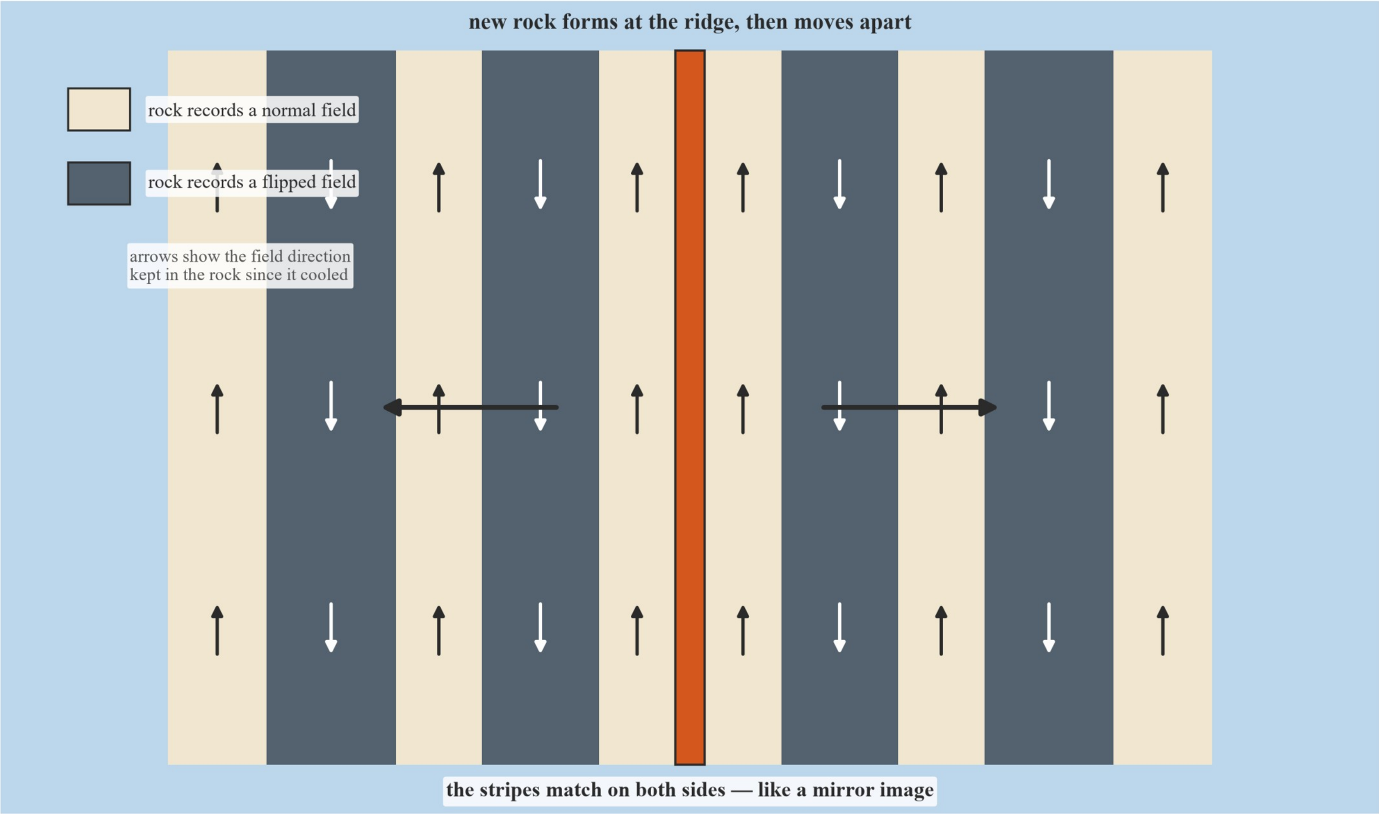
First, the ages. When scientists drilled into the sea floor and measured the ages of the rock, a clear pattern appeared: the rock is youngest at the ridges and gets older with distance away from them. The sea floor is also young compared with the continents — no sea-floor rock is nearly as old as the oldest continental rock. That fits the plate picture: sea floor is constantly being made at ridges and destroyed again where it sinks beneath other plates at trenches, so it never gets very old.



Drilled anywhere across the ocean, the sea floor is youngest at the ridge and grows older with distance away. (Band colours are schematic — the pattern is the point.)

Cross-section of the sea floor showing rock that is youngest at the mid-ocean ridge and grows older with distance away from the ridge on both sides

Second, the magnetism. Earth behaves like a giant magnet, surrounded by a **magnetic field**. When lava at a ridge cools and sets into rock, tiny grains inside it line up with Earth's magnetic field and stay that way — the rock keeps a record of which way the field pointed at the time. Earth's field is not fixed: every so often, after long stretches of time, it **flips**, so that its two magnetic ends swap places. In the 1960s, scientists mapping the magnetism of the sea floor found **stripes** running parallel to the ridges — stripes of rock that recorded a normal field, and stripes of rock that recorded a flipped field. And the pattern of stripes on one side of a ridge matched the pattern on the other side, like a mirror image. The simplest explanation is that new rock forms at the ridge, then moves apart, carrying half of each stripe away with it.



Magnetic stripes: rock that set in a normal field and rock that set in a flipped field lie in bands parallel to the ridge, matching on either side.

Map view of the sea floor on both sides of a mid-ocean ridge, with matching stripes of rock recording a normal field and a flipped field like a mirror image

Source: Vine, F.J. and D.H. Matthews, "Magnetic Anomalies Over Oceanic Ridges", *Nature*, vol. 199, pp. 947–949, 1963. DOI 10.1038/199947a0.

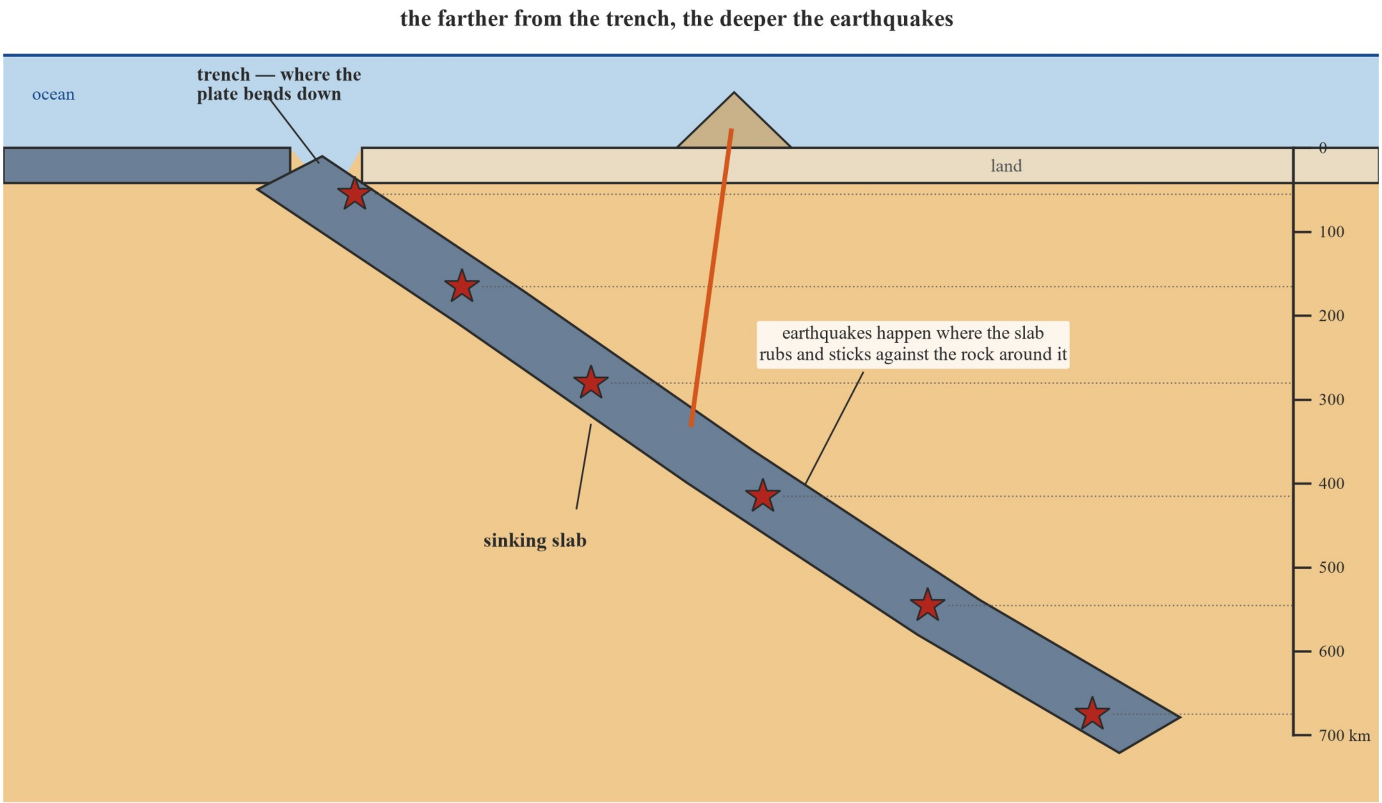
Earthquakes and volcanoes draw the plates (`VC2S8U10.E01`)

The third clue is the pattern of the hazards themselves. Plot the world's earthquakes on a map and they do not scatter at random: most fall in long, narrow **belts**. The same is true of volcanoes — active volcanoes generally occur close to the major tectonic plate boundaries. And those belts are not just near the boundaries; they *trace* them. The plate edges were first mapped by joining up the earthquakes and volcanoes.

Each kind of boundary leaves its own mark (12A):

- At **divergent boundaries**, where plates pull apart, earthquakes are shallow and mostly small — the plates are separating, not jamming.
- At **transform boundaries**, where plates slide past, earthquakes are shallow too, but can be strong, because the plates catch and stick before they slip.
- At **convergent boundaries**, the pattern is special: earthquakes grow deeper with distance from the trench, following the sinking slab down into the mantle. Geoscience Australia records that in these collision zones earthquake depths can range from the surface down to 700 km.

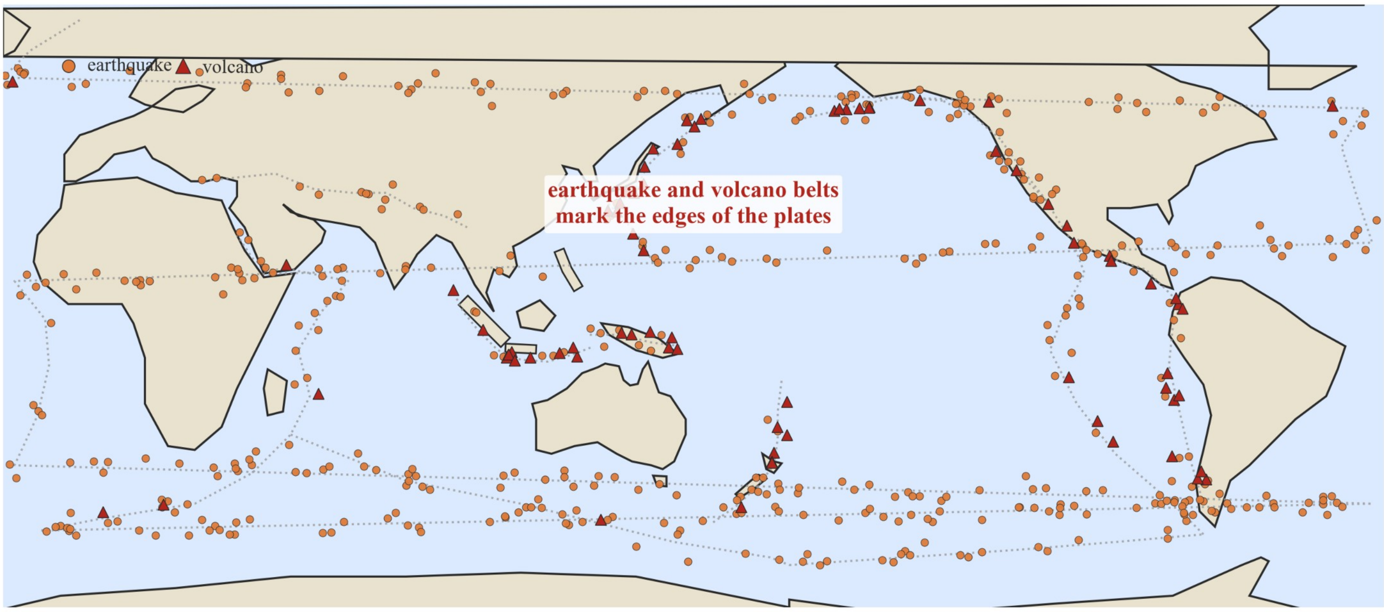
That deepening trail of earthquakes is one of the cleanest pieces of evidence in the whole theory: it is the sinking plate itself, recorded quake by quake as it slides down.



At a convergent boundary, earthquakes follow the sinking slab down into the mantle — in collision zones their depths can reach 700 km. (Vertical scale schematic.)

Cross-section of a sinking plate sliding down into the mantle at a trench, with earthquakes marked deeper and deeper the farther they are from the trench

Source: Geoscience Australia, “Earthquake”, n.d. ga.gov.au — retrieved 2026-08-19.



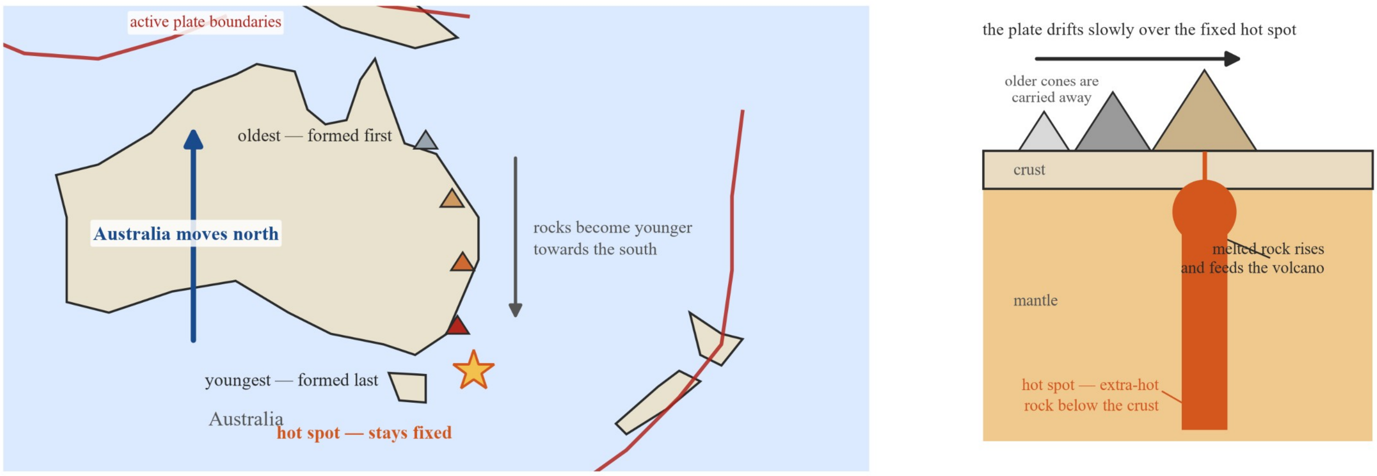
Plot the world's earthquakes and volcanoes: they fall in long, narrow belts that trace the plate boundaries. The plate edges were first mapped by joining them up.

World map showing earthquakes as dots and volcanoes as triangles, falling in long narrow belts that trace the edges of the tectonic plates

Australia: an old, quiet continent (`VC2S8U10.E04`)

Australia's own landscape is a clue too — a clue about what the *middle* of a plate is like. Geoscience Australia describes Australia as a stable continental region: the continent sits well inside the Australian plate, far from its busy edges. The results are striking.

- **No plate boundaries run through the continent**, so volcanoes are rare here. There are no actively erupting volcanoes on mainland Australia. The nearest active volcanoes lie to our north and east — in New Zealand, Papua New Guinea, the Solomon Islands, Vanuatu and Indonesia — and Australia's own active volcanoes are Heard Island and McDonald Islands, about 4 000 km south-west of Perth.
- **The land is extremely old and stable.** With no boundary to crumple it, much of the continent has sat quietly for vast stretches of time, and its ancient rocks and landscapes have survived. Australia's largest recorded earthquake, at Tennant Creek in 1988, was magnitude 6.6 — large, but small beside the giant boundary earthquakes of the Pacific rim.
- **The record of the drift is still there.** Along eastern Australia, volcanoes were active over the past 60 million years. The explanation is a **hot spot** — a fixed, extra-hot region below the crust that melts rock and feeds volcanoes above it. As the continent moved northward, the stationary hot spot formed volcanoes further and further south on the continent, so the volcanic rocks down the east coast become younger as you move southward. The chain is a record of Australia's own journey.



A fixed hot spot melts rock and feeds volcanoes above it. As Australia drifted north, each newer volcano formed farther south — the chain is a record of the journey.

Map of Australia moving north over a fixed hot spot, with volcanoes along the east coast that become younger towards the south; beside it, a cross-section of the hot spot feeding a volcano

In the south-east, the **Newer Volcanics Province** has been dormant — quiet, not erupting — for the past 5 000 years, and the beautiful Blue Lake at Mount Gambier sits in the crater of an extinct volcano. Dormant for 5 000 years sounds like a long time; on the time scale of plates, it is recent history.

Source: Geoscience Australia, "Volcano", n.d. ga.gov.au — retrieved 2026-08-19.

Budj Bim: Country remembers the volcanoes (`VC2S8U10.E06`)

There is one more kind of evidence — a human one. Aboriginal and Torres Strait Islander Peoples' cultural accounts give evidence of earthquakes and volcanoes, kept alive through storytelling over thousands of years.

Budj Bim National Park, in south-western Victoria, is an ancient volcanic landscape of crater lakes, lava channels and caves. It is Gunditjmara Country: the Gunditjmara are the Traditional Owners, with a deep and continuing connection to the land, and the park is jointly managed with the Gunditj Mirring Traditional Owners Aboriginal Corporation. The Budj Bim Cultural Landscape is on the World Heritage List, recognised for its Aboriginal cultural values. Those values include the channels, weirs and ponds the Gunditjmara built to farm short-finned eels — part of an aquaculture system thousands of years old (*aquaculture* means farming animals or plants that live in water).

The Gunditjmara oral records have preserved, for at least 4 000 years, knowledge of the volcanic events that formed the crater lakes at Budj Bim (`VC2S8U10.E06`). Written science has kept records of volcanoes for only a few hundred years at most — so these oral records are a rare, long-running account of what the land has done. They match what geologists read from the rocks of the Newer Volcanics Province: this landscape was shaped by eruptions within the memory of human culture.

Source: Parks Victoria, "Budj Bim National Park", n.d. parks.vic.gov.au — retrieved 2026-08-19.

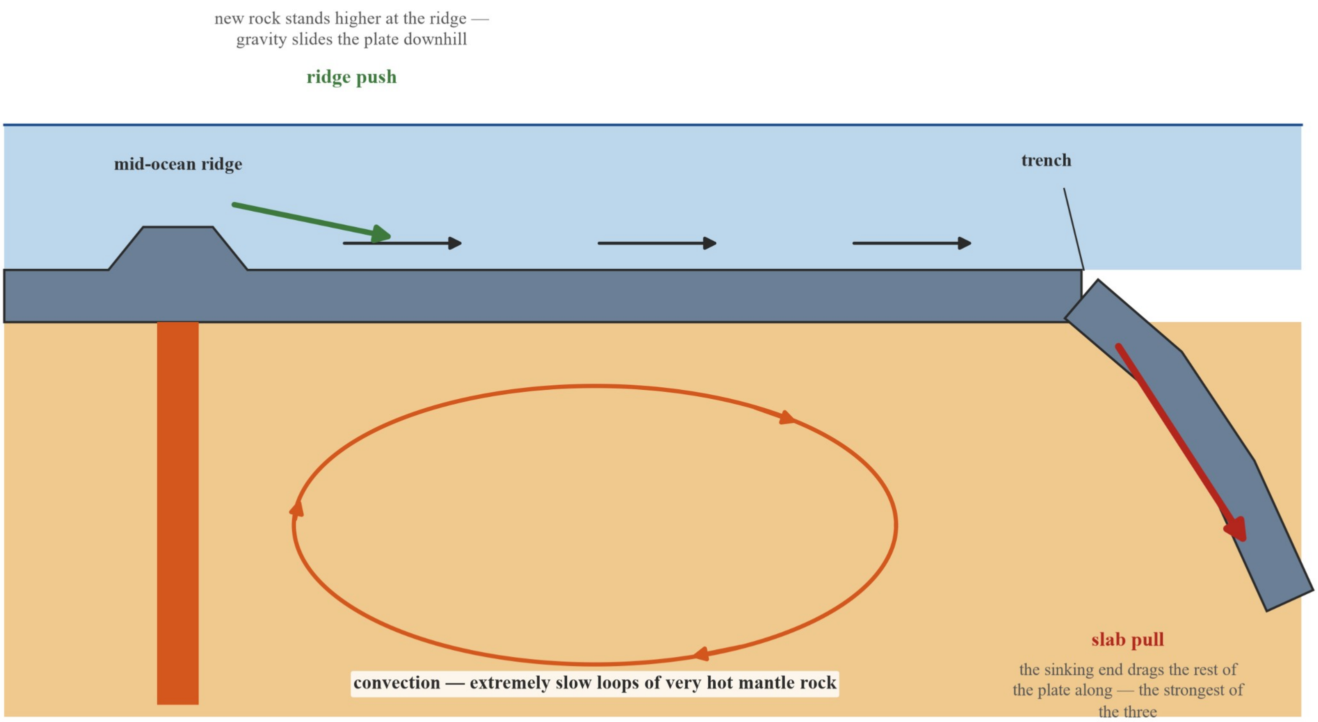
Source: Smith, A., I.J. McNiven, D. Rose, S. Brown, C. Johnston and S. Crocker, "Indigenous Knowledge and Resource Management as World Heritage Values: Budj Bim Cultural Landscape, Australia", *Archaeologies*, vol. 15, pp. 285–313, 2019. DOI 10.1007/s11759-019-09368-5.

What moves the plates — and which force leads? (`VC2S8U10.E03`)

Subtopic 12A introduced the three forces behind plate movement:

- **Convection** — the very hot rock of the mantle moves in huge, extremely slow loops: heated rock rises, and cooler rock sinks back down. (You will study convection itself as a way energy moves in subtopic 16B.)
- **Ridge push** — at a mid-ocean ridge, newly formed rock is hot and sits higher than the older rock beside it, so gravity makes the plate slide away downhill, pushing outward from the ridge.
- **Slab pull** — where a plate sinks into the mantle at a subduction zone (one plate sliding beneath another), the sinking end drags the rest of the plate along behind it.

Which of these does most of the driving? Measurements of plate movement give a clue: plates with long sinking edges generally move faster than plates with little or no sinking edge. That points to **slab pull as the strongest of the three forces** for most plates — the sinking slab hauls the rest of the plate along. Ridge push adds to the motion but is smaller. Convection is the hardest to weigh up: a slow loop in the mantle can grip the base of the plate above it and carry it along, or resist it, depending on which way the loop is moving. Scientists are still measuring and modelling to work out the exact share of each force — the *relative significance* of slab pull, ridge push and convection is a live question in geology (`VC2S8U10.E03`).



What moves the plates: convection in the mantle, ridge push at the ridge, slab pull at the sinking edge. Measurements point to slab pull as the strongest for most plates.

Diagram of the three forces that move plates: loops of convection in the mantle, ridge push sliding the plate downhill from the ridge, and slab pull where the sinking end drags the plate along

Try it — which force wins? (`VC2S8U10.E03`)

You will need: a long strip of stiff card (an old poster is perfect), a small weight such as a bag of counters, and one thin book. The card strip stands in for a plate; the edge of the table stands in for the line where a plate bends down to sink.

1. **Ridge push** — lay the strip flat on the table, with one end just past the edge. Raise the other end on the thin book, so the strip slopes gently down towards the edge. Watch: does the strip slide?
2. **Slab pull** — lay the strip flat again. Hang the small weight over the end that sticks past the table edge. Watch: does the strip move now?
3. Compare the two. Which setup made the strip move more easily?

What you did	What it models	What it stands for in nature
Raised end of the strip on the book	A plate standing higher at a ridge, with gravity pulling it downhill	Ridge push at a mid-ocean ridge
Weight hanging over the table edge	The sinking end of a plate dragging the rest along	Slab pull at a subduction zone
The strip sliding across the edge	A plate moving	Plate movement across Earth's surface

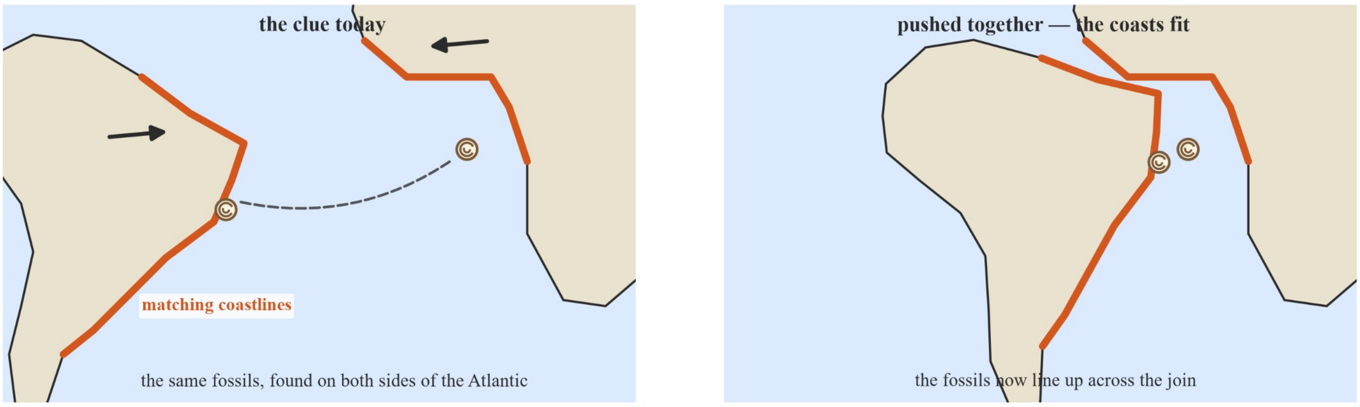
(The strengths and limits of models like this one are the business of subtopic 4B.) Every model has limits, and seeing them clearly is part of the skill. Ask yourself:

- The strip rubs on the table as it slides. Real plates do not rub on a table top — what do the plates actually ride on, and what does the rubbing in your model stand in for?
- The weight pulls straight down. A real sinking slab slides down at an angle into the mantle. What difference does that make to the pull?

- Nothing in this model moves in a loop. Which force is missing entirely — and where does its real loop happen?
- The strip moves in seconds. Real plates move far too slowly to see. What does that tell you about what models can and cannot show?

Why the theory was accepted

Early in the twentieth century, Alfred Wegener proposed that the continents had once been joined together and had slowly drifted apart. He pointed to real clues — the way some coastlines fit together like puzzle pieces, and matching fossils now found on continents separated by whole oceans. But he could not name any force strong enough to move a continent, and without a working mechanism, most scientists did not accept the idea. (The full story of how scientific knowledge grows and changes is the case study of subtopic 1A.)

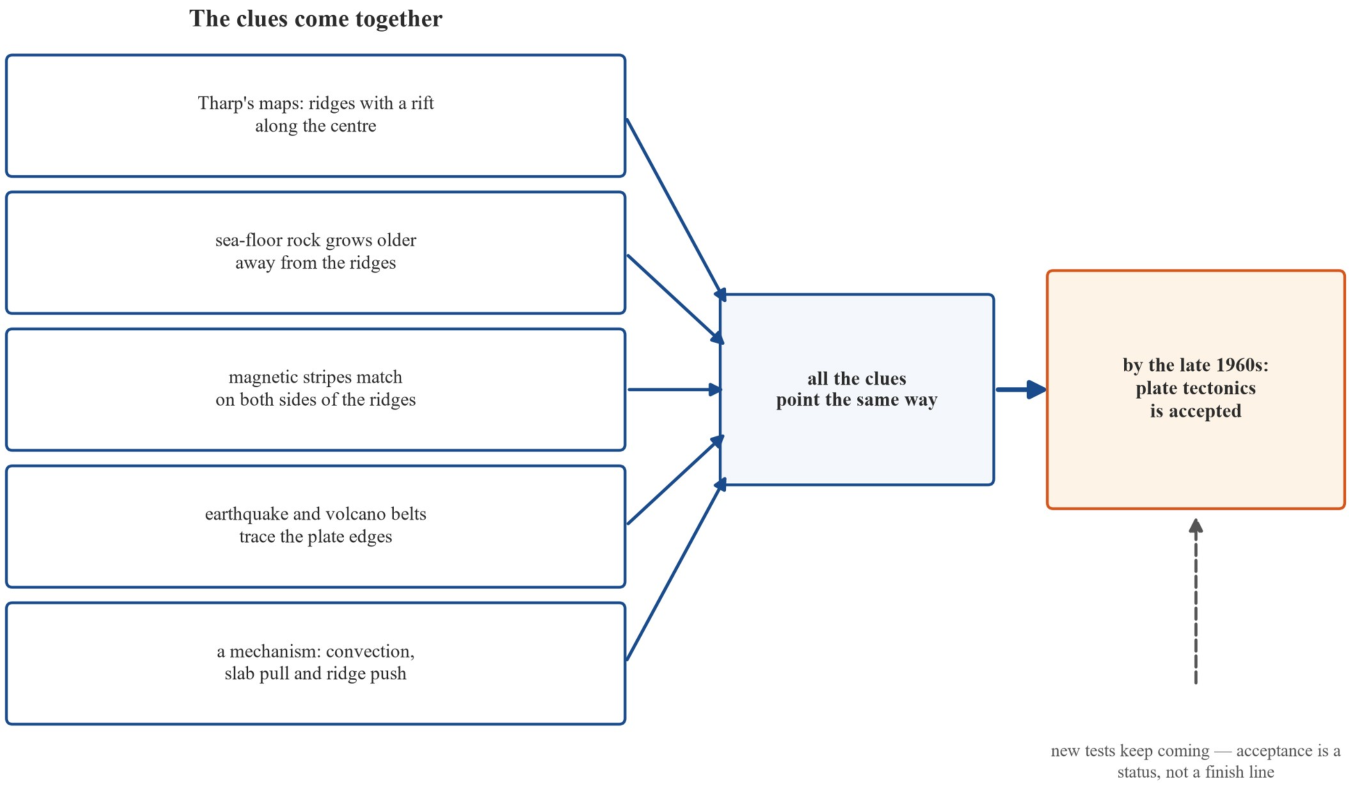


Wegener's clues: coastlines that fit like puzzle pieces, and matching fossils on continents now separated by a whole ocean. What he could not name was a force strong enough.

Two maps of South America and Africa: today's positions, and pushed together so the coastlines fit like puzzle pieces, with the same fossils found on both sides

By the 1960s, the situation had changed. Ships with echo sounders had mapped the sea floor; scientists had measured the ages and magnetism of sea-floor rock; earthquake records had been plotted on maps. What made the difference was not one clue — it was that all the clues pointed the same way:

- Tharp's maps showed ridges with central rifts — exactly what a divergent boundary should look like.
- The ages of the sea-floor rocks grew older with distance from the ridges, and the magnetic stripes matched on either side — exactly what moving sea floor should look like.
- Earthquake and volcano belts traced the plate edges, and deepening earthquakes traced sinking slabs — exactly what moving plates with boundaries should look like.
- And there was a mechanism at last: convection in the mantle, with slab pull and ridge push.



Independent lines of evidence, a working mechanism, and predictions that kept passing tests — that is how a theory becomes accepted.

Diagram joining the five clues for plate tectonics — sea-floor maps, rock ages, magnetic stripes, earthquake and volcano belts, and the forces that move plates — all pointing the same way to the accepted theory

The theory also passed tests. It made predictions about what scientists should find next — ages increasing away from ridges, earthquakes lining up along boundaries — and the measurements came back as predicted. When independent lines of evidence all agree, when a working mechanism exists, and when predictions keep passing tests, a theory becomes **accepted**. That is the story of plate tectonics: by the late 1960s, it was the accepted explanation of how Earth's surface moves. And because acceptance is a status, not a finish line, new evidence can still change parts of the story — as it has, many times, since.

Source: Wegener, A., *The Origin of Continents and Oceans*, 1915; English translation, Methuen, 1924.

Worked examples

Example 1 — scaffolded

A research ship drills into the sea floor at four sites along a line running away from a mid-ocean ridge. The table shows the results. *(Simulated practice data — real sea-floor ages follow this pattern, but the numbers here are made up for practice.)*

Site	Distance from the ridge	Age of the rock
A	0 km	less than 1 million years
B	300 km	10 million years
C	600 km	20 million years
D	900 km	30 million years

(a) Describe the pattern shown in the table.

(b) Where is new sea floor being made, and how can you tell?

(c) What name is given to the process that makes new sea floor at a ridge and carries it outward?

Working	Comment
(a) The farther a site is from the ridge, the older its rock. Site A, at the ridge, is the youngest; site D, 900 km away, is the oldest.	Read across both columns: distance increases, and age increases with it.
(b) At the ridge — site A holds the youngest rock (less than 1 million years old), so that is where fresh rock is forming now.	Youngest rock marks the place where new sea floor is being made.
(c) **Sea-floor spreading.**	New rock forms at the ridge and moves outward on both sides, carrying the older rock away.

Example 2 — scaffolded

At a convergent boundary, sea floor bends down and sinks beneath another plate. The table shows the depths of earthquakes recorded at different distances from the trench. *(Simulated practice data.)*

Distance from the trench	Earthquake depth
0 km	15 km
100 km	110 km
200 km	210 km
300 km	310 km

(a) Describe the relationship between distance from the trench and earthquake depth.

(b) What feature of plate tectonics do the deepening earthquakes trace?

(c) Geoscience Australia records that in collision zones like this one, earthquake depths can reach 700 km. Explain why the earthquakes grow deeper farther from the trench.

Working	Comment
(a) The farther from the trench, the deeper the earthquakes. Depth grows steadily with distance.	Compare the columns: each step of 100 km brings deeper quakes.
(b) The sinking plate — the slab sliding down beneath the other plate at the subduction zone.	Earthquakes happen where the sinking plate grinds against the rock around it.
(c) Earthquakes occur where the sinking plate rubs and sticks against the plate above it. The slab slides down at an angle, so the deeper parts of the slab lie farther from the trench — and that is where the deeper earthquakes happen.	Picture the slab tilting down into the mantle: deep quakes sit under land that is far from the trench.

Example 3 — unscaffolded

In the 1950s, Marie Tharp used depth measurements collected by ships to draw detailed maps of the floor of the Atlantic Ocean. Her maps showed a mountain chain running down the middle of the ocean, with a valley along its very centre. Explain how this discovery supported the idea that plates are moving apart. In your answer, link the mountain chain, the central valley and what happens at a divergent boundary.

At a **divergent boundary**, two plates pull apart and a gap opens between them; lava rises into the gap, cools, and sets into new rock. Eruption after eruption builds the new rock up into an underwater mountain chain — a **mid-ocean ridge** — so the mountain chain in Tharp's maps is exactly the feature a divergent boundary should build. The **valley along its centre** is the rift where the plates are still separating — the gap itself, with the youngest rock of the whole ocean floor inside it. The match between the maps and the predicted features — ridge where rock rises, rift where the plates part — is strong evidence that the plates of the Atlantic really are moving apart, with new sea floor spreading out from the middle. ∴ the shape of the sea floor itself records the motion of the plates.

Example 4 — unscaffolded

Early in the twentieth century, Alfred Wegener argued that the continents had drifted apart, but his idea was not accepted. By the late 1960s, the theory of plate tectonics was accepted by most scientists. Explain why the later theory was accepted when the earlier idea was not. In your answer, refer to the evidence and to the forces that move plates.

Wegener's idea had clues behind it — coastlines that fit together, and matching fossils on continents now far apart — but he could not name any force strong enough to move a continent. A claim without a working mechanism was not enough, so most scientists did not accept continental drift. The theory of plate tectonics succeeded where drift failed for two reasons. First, it had a **mechanism**: convection in the mantle moves hot rock in slow loops, and **slab pull** and **ridge push** act on the plates themselves. Second, it had many **independent lines of evidence that all agreed**: Tharp's maps of ridges with central rifts; sea-floor rocks growing older away from the ridges, with magnetic stripes matching on either side; and belts of earthquakes and volcanoes tracing the plate edges, with deepening quakes marking sinking slabs. The theory also made predictions — where new rock should be youngest, where earthquakes should line up — and the measurements came back as predicted. ∴ with a working mechanism, many agreeing lines of evidence and passed tests, the theory became accepted in a way continental drift never was.

Practice questions

Scaffolded

Q1. Answer the following about the evidence for plate tectonics. (a) State two kinds of evidence that support the theory of plate tectonics. (b) Where do most earthquakes and volcanoes occur? (c) What does that pattern tell you about Earth's outer shell?

Q2. Marie Tharp was a geologist and oceanographic cartographer. (a) What did she use to draw her maps of the Atlantic sea floor? (b) Her maps showed a mountain chain down the middle of the Atlantic. What ran along the very centre of that chain? (c) Why was a valley along the middle of an underwater mountain chain a clue that plates were moving apart?

Q3. Answer the following about the magnetism of sea-floor rock. (a) When lava cools and sets at a ridge, what does the rock record? (b) What pattern of magnetic stripes is found on either side of a mid-ocean ridge? (c) What does that pattern suggest about the sea floor?

Q4. Geoscience Australia records that in collision zones, earthquake depths can range from the surface down to 700 km. (a) At which kind of plate boundary do earthquakes reach such depths? (b) What is sinking at that boundary? (c) Why do the earthquakes grow deeper farther from the trench?

Q5. Answer the following about Australia and plate tectonics. (a) Why does mainland Australia have no actively erupting volcanoes? (b) Name the volcanic province in south-eastern Australia that has been dormant for the past 5 000 years. (c) The volcanic rocks down Australia's east coast become younger as you move southward. What does that pattern tell us about Australia's past movement?

Q6. Answer the following about the forces that move plates. (a) Describe slab pull. (b) Describe ridge push. (c) Which force do scientists judge to be the strongest for most plates, and what observation points that way?

Unscaffolded

Q7. Plotting the world's earthquakes and volcanoes on a map puts them in long, narrow belts. Explain why this pattern is strong evidence that Earth's outer shell is divided into moving plates. *(2 marks)*

Q8. The Gunditjmara of south-western Victoria keep oral records describing the volcanic events that formed the crater lakes at Budj Bim. Explain why these records are valuable to a geologist studying the region's volcanoes. *(2 marks)*

Q9. A student says: *"Plate tectonics is accepted now, so it can never change."* Evaluate this claim, using what you know about how scientific knowledge grows and changes (subtopic 1A). *(2 marks)*

Q10. Explain how convection — the slow loops of hot rock in the mantle — could help carry a tectonic plate along. Then state why scientists still weigh up the relative significance of slab pull, ridge push and convection, instead of treating the question as settled. *(3 marks)*

Q11. Four imaginary extinct volcanoes stand in a line along the east coast of a continent. *(Practice scenario — the volcanoes and ages are imaginary, but the pattern matches eastern Australia.)*

Volcano	Position along the coast	Age of the rock
W	far north	50 million years
X	middle-north	35 million years
Y	middle-south	20 million years
Z	far south	5 million years

(a) Describe the trend in the ages of the volcanoes. *(1 mark)*

(b) The volcanoes were formed by one stationary hot spot beneath the moving continent. Which way did the continent move — and how does the table show it? *(1 mark)*

Q12. Wegener's idea of continental drift was not accepted early in the twentieth century, but the theory of plate tectonics was accepted by the late 1960s. Explain the difference, referring to both the mechanism and the evidence. *(3 marks)*

Q13. In the Try it activity, a hanging weight pulling on the card strip models slab pull. State one thing this model shows well about slab pull, and one way the model falls short of the real thing. *(2 marks)*

Q14. Choose two of these three clues: Tharp's maps of the Atlantic; the magnetic stripes in sea-floor rock; the ages of sea-floor rocks. For each clue you choose, explain how it supports the idea that new sea floor forms at mid-ocean ridges and then moves apart. *(4 marks)*

Answers

Q1. (a) Any two of: sea-floor mapping (ridges with central rifts); sea-floor rock ages growing older away from ridges; magnetic stripes matching on either side of ridges; earthquake and volcano belts tracing plate edges. (b) At plate boundaries. (c) It is divided into plates that move — the belts mark where the plates meet. **Q2.** (a) Depth measurements collected by ships (echo soundings). (b) A valley — a rift. (c) It is what a divergent boundary should look like: plates pulling apart leave a gap, with lava rising to build the ridge on either side. **Q3.** (a) The direction of Earth's magnetic field at the time it cooled. (b) Matching stripes on either side — a mirror-image pattern of rock that recorded normal and flipped fields. (c) The sea floor is moving apart, carrying the stripes away from the ridge on both sides. **Q4.** (a) A convergent boundary. (b) One plate — the sea floor bending down beneath the other plate. (c) The slab slides down at an angle, so its deeper parts lie farther from the trench. **Q5.** (a) There are no plate boundaries on the continent. (b) The Newer Volcanics Province. (c) Australia moved northward over a stationary hot spot, so younger volcanoes formed further south. **Q6.** (a) The sinking end of a plate drags the rest of the plate along behind it. (b) New hot rock at a ridge sits higher than older rock, so gravity makes the plate slide away downhill from the ridge. (c) Slab pull — plates with long sinking edges generally move faster than plates with little or no sinking edge. **Q7.** The belts are not random — they trace the edges of the plates, marking where plates meet, grind and separate; a solid, still shell would not produce such neat belts. **Q8.** They are a long-running record of eruptions — kept for at least 4 000 years, far longer than written records — and they match what geologists read from the rocks. **Q9.** The claim is wrong: acceptance means the theory is the best explanation on offer now, not a final, unchangeable truth — new evidence can still change parts of it. **Q10.** A loop of slowly moving mantle rock can grip the base of a plate and carry it along. It is not settled because the loop can help or resist depending on its direction, and direct measurement of forces hundreds of kilometres down is hard — so scientists keep measuring and modelling. **Q11.** (a) The volcanoes become younger towards the south. (b) Northward — the continent moved so that each younger volcano formed further south over the same fixed hot spot. **Q12.** Wegener had clues but no working mechanism — no force strong enough to move continents — so drift was not accepted. Plate tectonics had a mechanism (convection, slab pull, ridge push) and many independent lines of evidence that all agreed, plus predictions that passed tests. **Q13.** Shows well: a sinking end (or hanging weight) can pull the rest of the plate along. Falls short (any one): the strip rubs on a table while real plates ride on mantle rock; the weight pulls straight down while a real slab sinks at an angle; the model moves in seconds, plates far too slowly to see. **Q14.** Any two correct explanations, e.g. Tharp's maps show a ridge with a central rift — the shape a divergent boundary should have — and the ages show rock youngest at the ridge and older farther away, so the floor must be made at the ridge and moving outward.

Fully-worked solutions

Q1. (a) Any two of the four clues taught here: **sea-floor mapping** showing mid-ocean ridges with central rifts; **sea-floor rock ages** growing older with distance from the ridges; **magnetic stripes** matching on either side of the ridges; **earthquake and volcano belts** tracing the plate edges. (b) Most earthquakes and volcanoes occur **at plate boundaries**, where the plates meet. (c) The pattern tells us Earth's outer shell is not one solid piece but is **divided into plates that move** — the belts mark the busy edges where the plates pull apart, push together or slide past.

Q2. (a) Tharp drew her maps from **depth measurements collected by research ships** — echo soundings sent down and timed as they bounced back from the sea floor. (b) A **valley** — a rift — ran along the very centre of the Mid-Atlantic Ridge. (c) A valley along the top of a mountain chain is exactly what a **divergent boundary** should look like: as two plates **pull apart**, a gap opens in the middle, and lava rising into the gap builds the ridge on either side — so the maps matched the plate idea's prediction.

Q3. (a) As the lava cools and sets, tiny grains in the rock line up with **Earth's magnetic field**, so the rock records the direction the field pointed at the time. (b) The sea floor carries **stripes of normal and flipped magnetism running parallel to the ridge, matching on both sides like a mirror image**. (c) The matching pattern means the sea floor **moves apart**: new rock forms at the ridge and then each side carries half of every stripe away with it — sea-floor spreading.

Q4. (a) Earthquakes reach such depths at a **convergent boundary**, where one plate sinks beneath another. (b) What is sinking is **one of the plates** — sea floor bending down into the mantle at a subduction zone. (c) The sinking slab slides down **at an angle**, so the deeper parts of the slab lie farther from the trench; earthquakes happen where the slab rubs and sticks against the rock around it, so the quakes grow deeper the farther they are from the trench.

Q5. (a) Mainland Australia has no actively erupting volcanoes because **there are no plate boundaries on the continent** — active volcanoes generally occur close to the major boundaries. (b) The **Newer Volcanics Province** in south-eastern Australia has been dormant for the past 5 000 years. (c) The pattern shows **Australia moved northward over a stationary hot spot**: as the continent moved, the fixed hot spot formed volcanoes further and further south, so the rocks become younger southward — a record of the continent's own drift.

Q6. (a) **Slab pull**: where a plate sinks into the mantle at a subduction zone, the sinking end drags the rest of the plate along behind it. (b) **Ridge push**: at a mid-ocean ridge, newly formed rock is hot and sits higher than the older rock beside it, so gravity makes the plate slide away downhill, pushing outward from the ridge. (c) Scientists judge **slab pull** to be the strongest for most plates: measurements show that **plates with long sinking edges generally move faster than plates with little or no sinking edge**, which points to the sinking slab doing most of the pulling.

Q7. The belts are **not random** — they line up in long, narrow traces *(1 mark)*. Those traces are exactly where plates meet, separate and grind, so the belts **mark the edges of moving plates**; a solid, still outer shell would give no reason for earthquakes and volcanoes to line up in such neat bands *(1 mark)*.

Q8. The oral records are a **long-running account of eruptions**, preserved for at least 4 000 years — much longer than any written record *(1 mark)*. They are valuable because they **match what geologists read from the volcanic rocks** of the region: both tell of eruptions that shaped the landscape within human memory *(1 mark)*.

Q9. The claim is **wrong** *(1 mark)*. In science, an accepted theory is **the best explanation on offer** — backed by many agreeing lines of evidence and passed tests — but acceptance is a status, not a finish line: **new evidence can still change parts of the story**, which is how scientific knowledge grows and changes (subtopic 1A) *(1 mark)*.

Q10. The mantle's hot rock moves in huge, extremely slow loops — **convection** — and a loop moving sideways beneath a plate can **grip the base of the plate and carry it along** *(1 mark)*, with slab pull and ridge push acting on the plate's edges at the same time *(1 mark)*. Scientists still weigh up the balance because **a convection loop can help or resist a plate depending on which way the loop moves**, and the forces act hundreds of kilometres down, where direct measurement is hard — so the exact share of each force is still being worked out by measuring and modelling *(1 mark)*.

Q11. (a) The volcanoes **become younger towards the south**: volcano W in the far north is the oldest (50 million years) and volcano Z in the far south is the youngest (5 million years) *(1 mark)*. (b) The continent moved **northward** *(1 mark)*: because the hot spot stays fixed, the continent sliding north over it leaves each new volcano forming further south — so the youngest volcano stands farthest south.

Q12. Wegener's drift had clues — fitting coastlines, matching fossils — but **no working mechanism**: he could not name any force strong enough to move a continent, so most scientists did not accept it *(1 mark)*. Plate tectonics brought a **mechanism** — convection in the mantle, with slab pull and ridge push acting on the plates *(1 mark)* — and **many independent lines of evidence that all agreed** (ridge-and-rift maps, sea-floor ages and magnetic stripes, earthquake and volcano belts, deepening quakes at subduction zones), plus predictions that measurements confirmed — and that is why it was accepted *(1 mark)*.

Q13. Shows well (any one): the model shows that **a sinking end can pull the rest of the plate along** — the hanging weight drags the strip, as a sinking slab drags its plate *(1 mark)*. Falls short (any one): the strip **rubs on the table** while real plates ride on mantle rock; the weight **pulls straight down** while a real slab sinks at an angle into the mantle; the model moves in **seconds**, while real plates move far too slowly to see; or there is **no loop of moving material** in the model, so convection is not represented *(1 mark)*.

Q14. Any two of the three, each explained (2 marks each — 1 for the clue, 1 for the link to moving sea floor): **Tharp's maps** show a mountain chain with a valley along its centre *(clue)* — exactly the shape a divergent boundary should make, with lava rising in the gap to build the ridge and the plates parting at the rift *(link)*. **The magnetic stripes** run parallel to the ridges and match on either side like a mirror image *(clue)* — which only makes sense if new rock forms at the ridge and then moves apart, carrying half of each stripe with it *(link)*. **The ages of sea-floor rocks** grow older with distance from the ridge *(clue)* — so the floor must be made at the ridge and carried outward, spreading as it goes *(link)*.

Sources

Web sources below were retrieved 2026-08-19.

- Geoscience Australia, "Earthquake", n.d. ga.gov.au
- Geoscience Australia, "Volcano", n.d. ga.gov.au
- Parks Victoria, "Budj Bim National Park", n.d. parks.vic.gov.au
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- Heezen, B.C., M. Tharp and M. Ewing, *The Floors of the Oceans*, Geological Society of America Special Papers, no. 65, 1959. DOI 10.1130/spe65-p1.
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- Vine, F.J. and D.H. Matthews, "Magnetic Anomalies Over Oceanic Ridges", *Nature*, vol. 199, pp. 947–949, 1963. DOI 10.1038/199947a0.
- Wegener, A., *The Origin of Continents and Oceans*, 1915; English translation, Methuen, 1924.

The tables in Worked Examples 1 and 2 and in Practice Question 11 are **simulated data for practice**; the real-world patterns they reflect (sea-floor rocks growing older away from ridges, earthquake depths increasing with distance from a trench, and eastern Australian volcanoes becoming younger southward) are as described in the Theory section under the sources above.

Elaboration contexts used: `VC2S8U10.E01` (patterns of earthquake and volcanic activity), `VC2S8U10.E03` (the forces involved in tectonic plate movement — shared with 12A, which owns the boundary-modelling side), `VC2S8U10.E04` (the age and stability of the Australian continent), `VC2S8U10.E05` (Marie Tharp's maps of the Atlantic sea floor) and `VC2S8U10.E06` (Aboriginal cultural accounts of earthquakes and volcanoes).

Teacher-facing note — attribution in E06 (not student text). The text of `VC2S8U10.E06` reads "the oral records of the Bungandidj People … Budj Bim National Park in south-western Victoria". The primary sources place Budj Bim on Gunditjmara Country: Parks Victoria names the Gunditjmara as the Traditional Owners jointly managing the park, and Smith et al. (2019) describe the Budj Bim Cultural Landscape's World Heritage values as Gunditjmara values. Per the TOC's §6 resolution of this contradiction, this subtopic attributes the Budj Bim records to the Gunditjmara, following the primary sources rather than the elaboration's wording, and records the discrepancy here instead of papering over it. The "at least 4 000 years" figure is the elaboration's own wording.