The Earth and Plate Tectonics

Earth Science for 11 – 16 year olds

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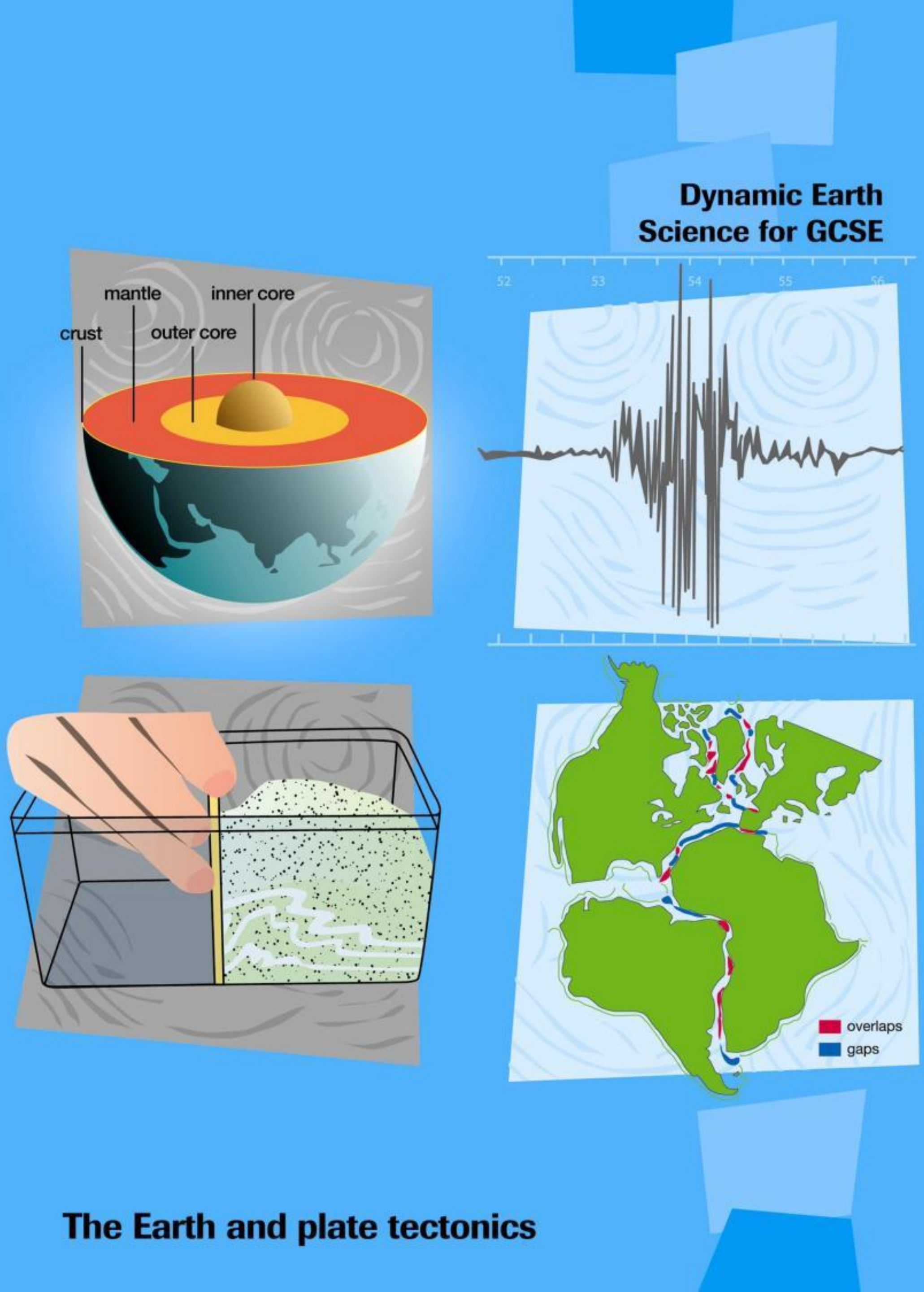

The Earth and plate tectonics

The Earth and Plate Tectonics

Summary

‘The Earth and Plate Tectonics’ workshop gets to grips with the wide-ranging evidence for the theory that underpins our detailed modern understanding of our dynamic planet – the theory of **Plate Tectonics**.

The workshop begins with an introduction and progresses through a series of activities that are designed to help students develop their understanding. It uses several independent sources of evidence supporting the theory, including using rock and fossil evidence, seismic records, geothermal patterns, geomagnetism, and large-scale topographical features, both above and below sea-level.

The workshop provides a reconstruction of plate movements over the past 450 million years which explains the record contained in the rocks of the UK - of an amazing journey across the face of our planet. It concludes by investigating some of the Earth hazards linked to plate tectonics, and how we can reduce loss of life.

The Earth and Plate Tectonics

Workshop outcomes

The workshop and its activities provide the following outcomes:

- an introduction to plate tectonics;
- distinction between the ‘facts’ of plate tectonics and the evidence used to support plate tectonic theory;
- a survey of some of the evidence supporting plate tectonic theory;
- an introduction to the evidence for the structure of the Earth and the links between the structure of the outer Earth and plate tectonics;
- explanation of some of the hazards caused by plate tectonic processes - earthquakes and eruptions
- methods of teaching the abstract concepts of plate tectonics, using a wide range of teaching approaches, including practical and electronic simulations;
- approaches to activities designed to develop the thinking and investigational skills of students;
- an integrated overview of the plate tectonic concepts commonly taught to secondary pupils through the KS4 National Curriculum for Science, as laid out in the GCSE Science specifications.

The Earth and Plate Tectonics

Think through the processes using this wide range of activities:

Note: those practical activities needing apparatus/materials are shown with a *

- The big picture and the 'facts' of plate tectonics
- The Story for Teachers: Plate Tectonics
- What Wegener knew – and what he didn't know
- Continental Jigsaws*
- Model Earth – Plasticine™ spheres*
- From Magnetic Globe to Magnetic Rock Evidence*
- The earthquake distribution evidence
- Earthquakes - the slinky seismic waves demo*
- Wave Motion – student molecules
- The seismic evidence for the structure of the Earth
- Why are the Earth's tectonic plates called plates?*
- Properties of the Mantle – potty putty™*
- What drives the plates?
- The heat flow evidence
- Evidence from the age of the sea floor
- Constructive plate margins - adding new plate material
- Faults in a Mars™ Bar*
- The magnetic stripes evidence*
- Model an ocean floor offset by transform faults*
- Destructive plate margins - recycling material
- Partial Melting*
- Volcano in the Lab*
- Plates in Motion – cardboard replica*
- Fold Mountains in a Chocolate Box*
- Plate Riding – how is the plate you live on moving now?
- Plate margins and movement by hand
- Prediction of Earthquakes – 'Brickquake'*
- Tsunami – making waves*

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Carry out risk assessments before the following activities:

Model Earth - Plasticine™ spheres
Magnetic stripes
Partial melting
Volcano in the lab
Prediction of earthquakes – ‘Brickquake’
Party popper simulation

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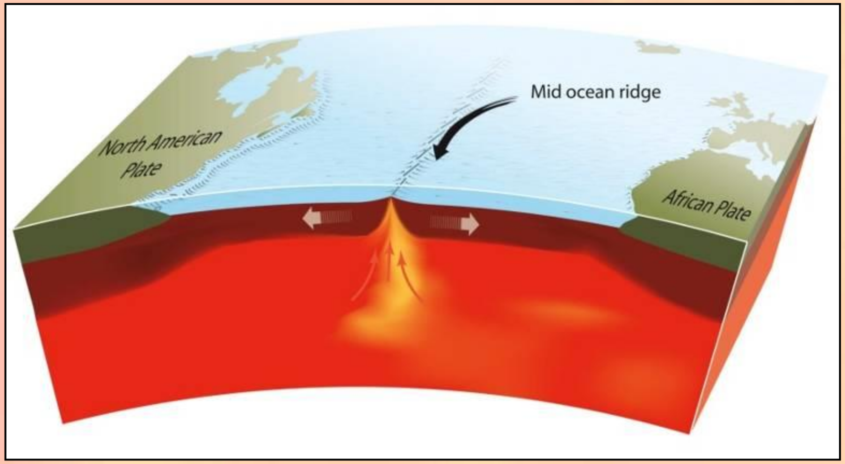
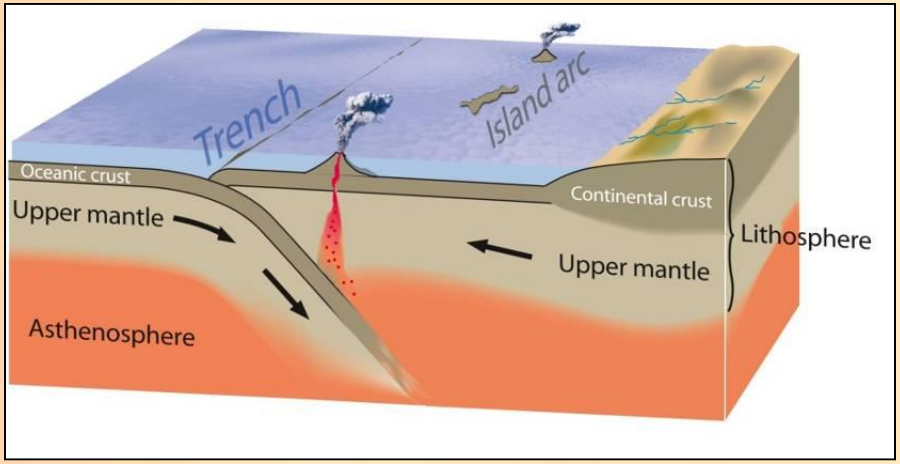
The big picture

and the ‘facts’ of plate tectonics



An oceanic ridge © Press & Siever, redrawn by ESEU



Continental plate collision zone. Reproduced with kind permission of USGS, redrawn by ESEU

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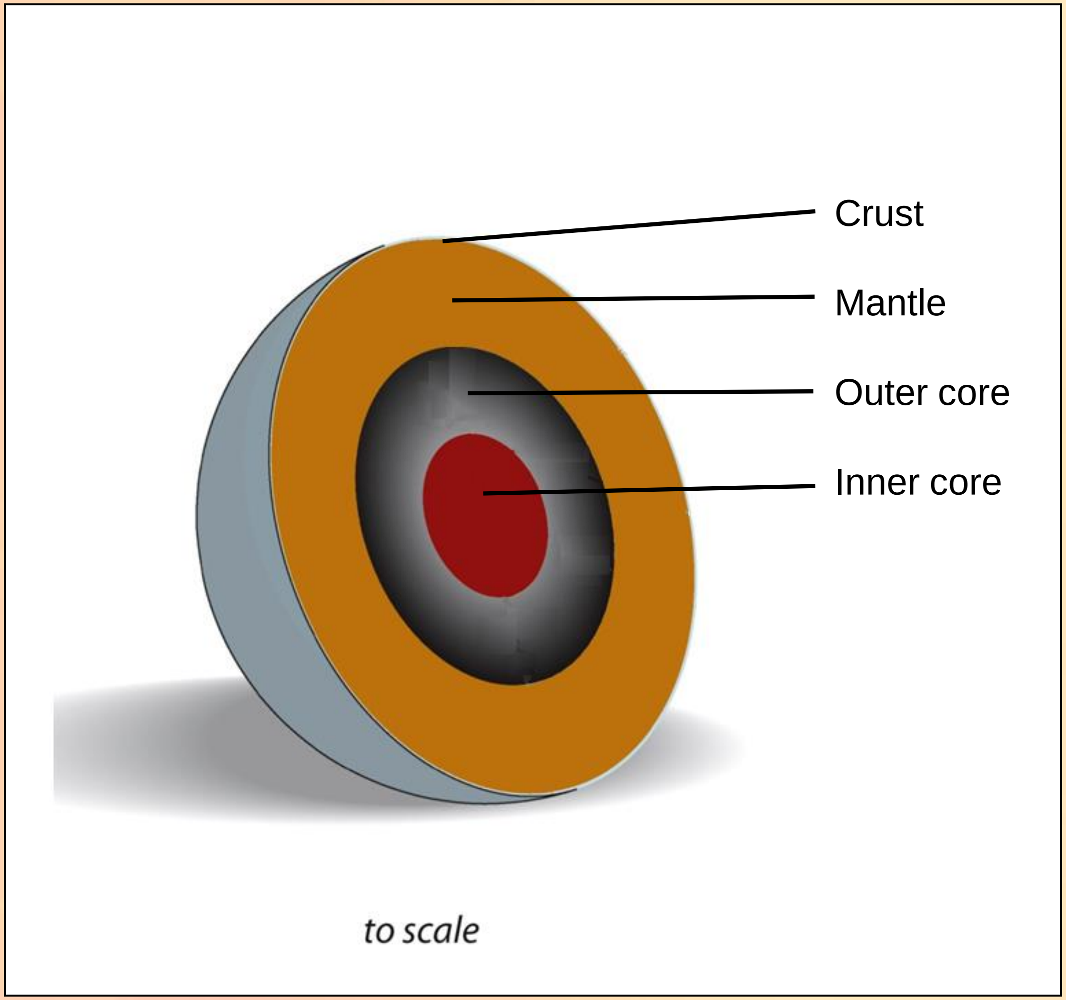
The Earth has a crust, mantle, outer and inner core



The Internal structure of the Earth - reproduced with kind permission of USGS, redrawn by ESEU

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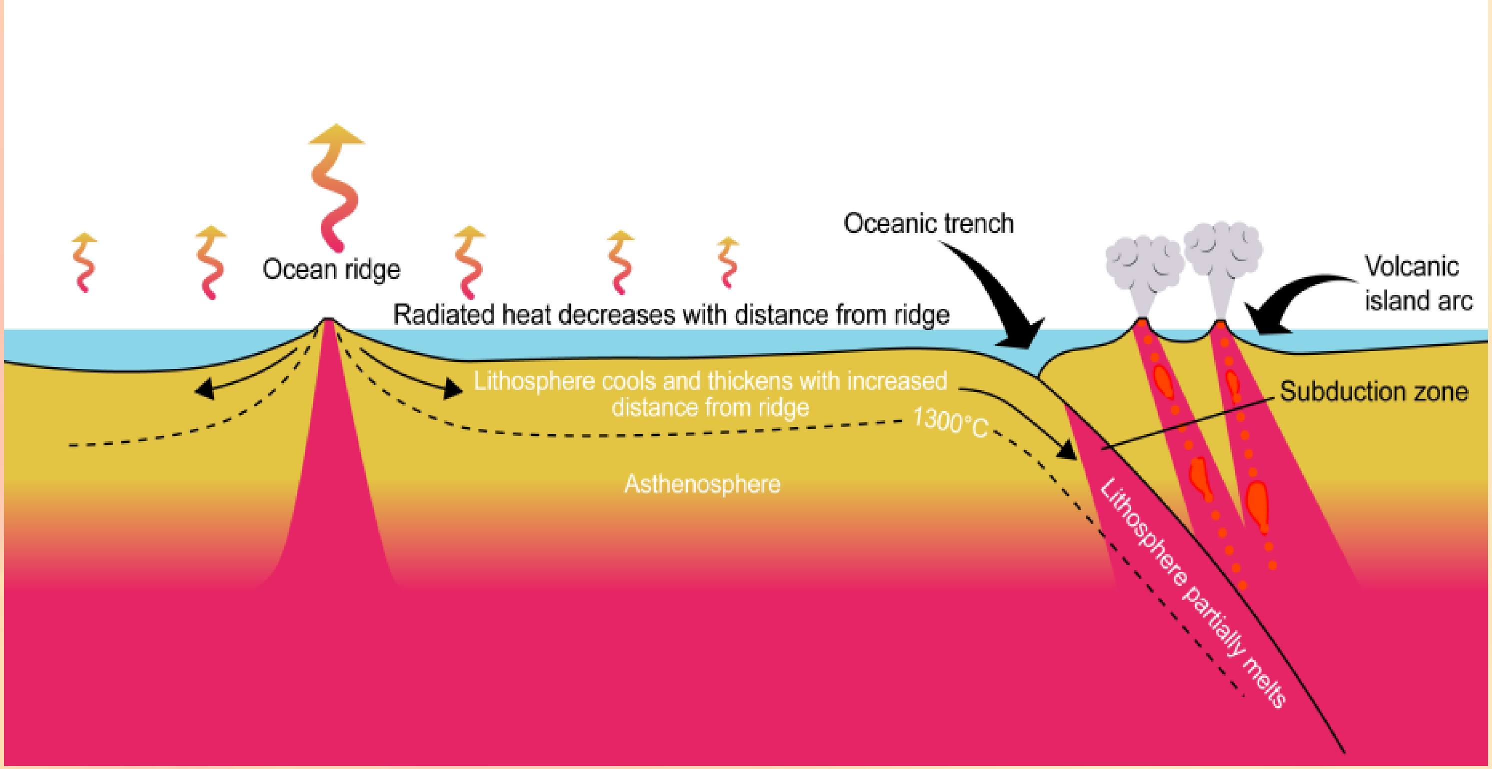
The upper part of the mantle and the crust

Over geological time the mantle can flow



The upper part of the mantle and the crust © Chris King and Dee Edwards, redrawn by ESEU

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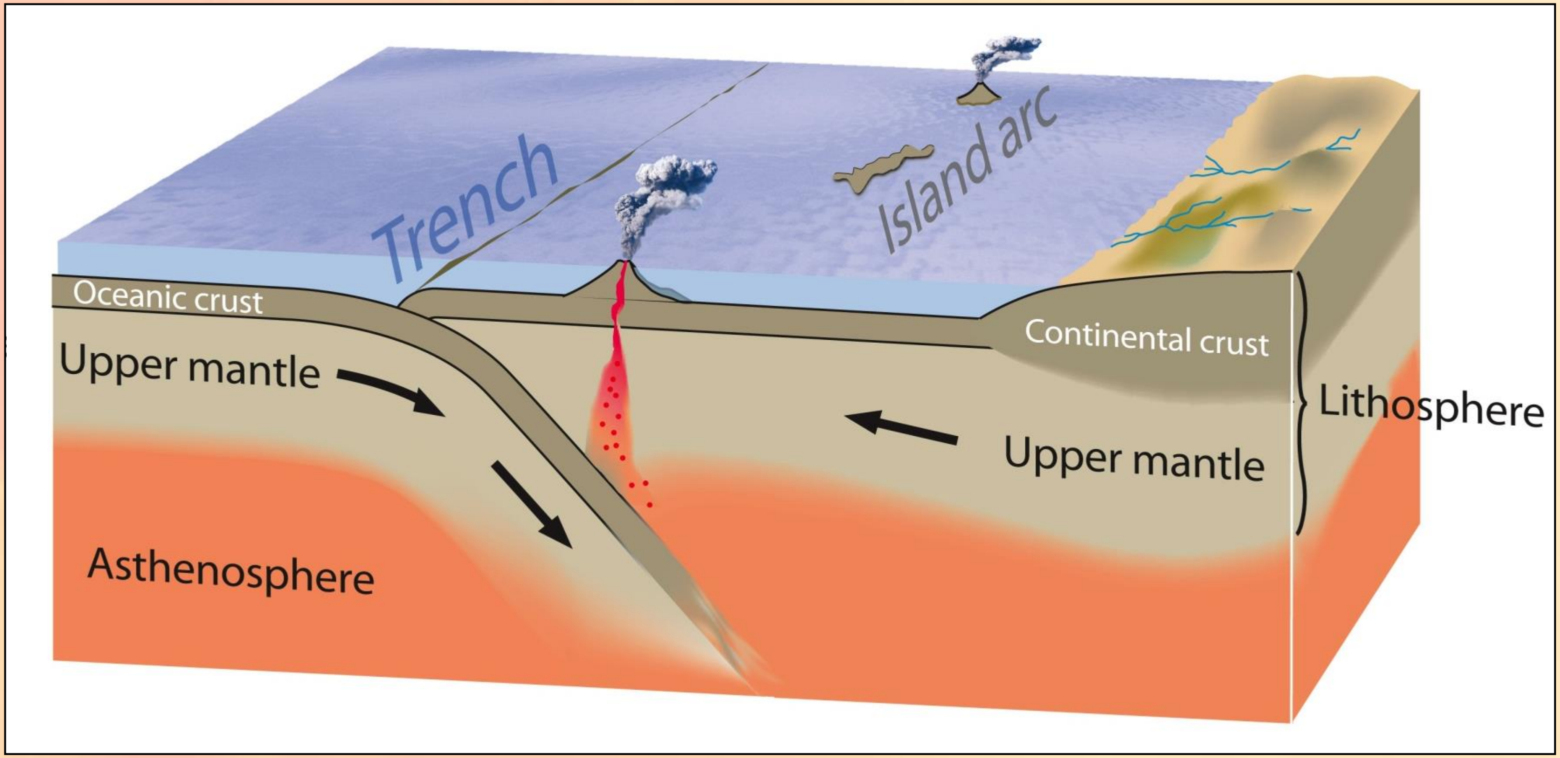
A subduction zone

When the currents in the mantle carry one plate down -
It partially melts and volcanoes are produced



Subduction zone ('partially melts and volcanoes are produced' 'molten rock cools down below the surface') - reproduced with kind permission of USGS, redrawn by ESEU

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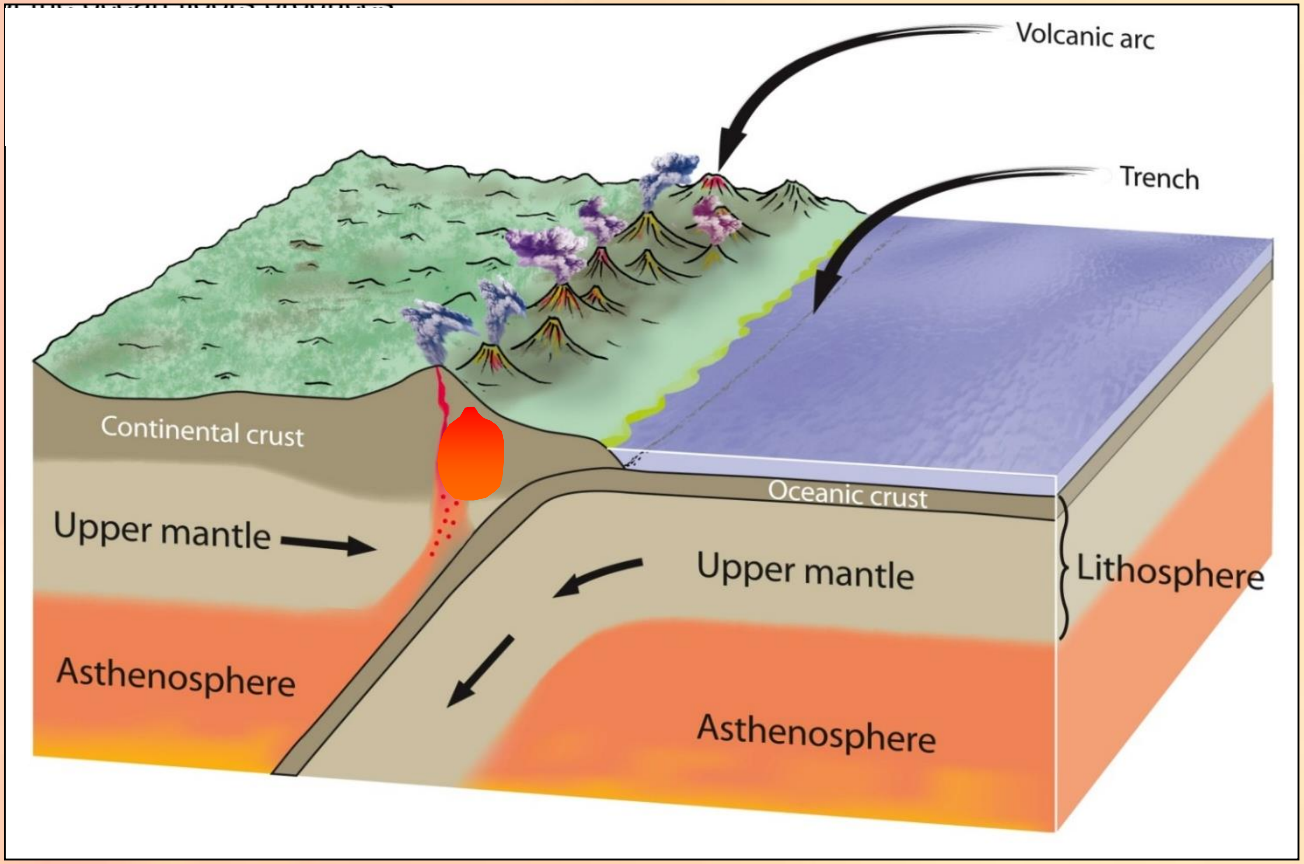
A subduction zone

Sometimes the molten rock cools down below the surface



Subduction zone ('partially melts and volcanoes are produced' 'molten rock cools down below the surface') - reproduced with kind permission of USGS, redrawn by ESEU

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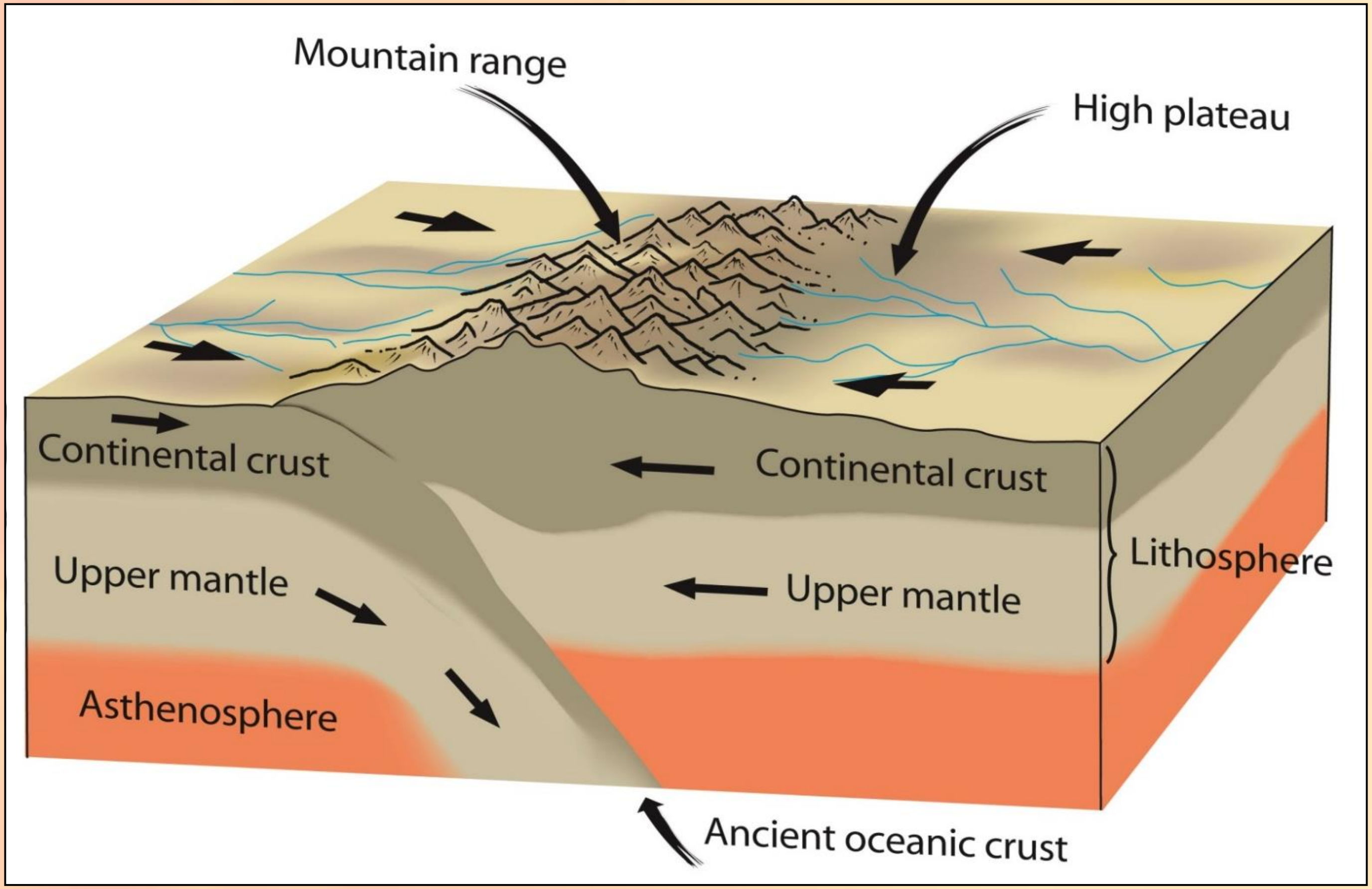
A subduction zone

When two plates carrying continents collide – mountain chains are built



Continental plate collision zone. Reproduced with kind permission of USGS, redrawn by ESEU

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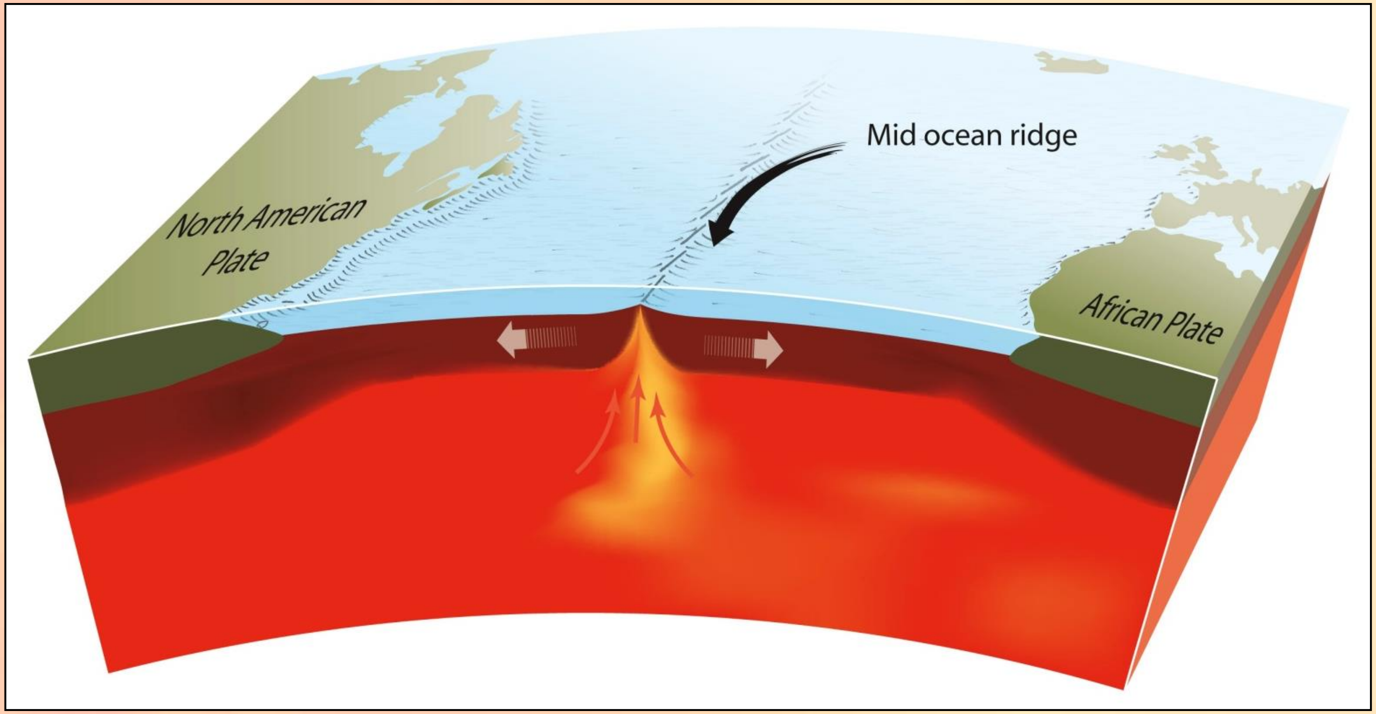
An oceanic ridge

If plates are being destroyed, new plate material must be being made somewhere else -

… at new plate margins



An oceanic ridge © Press & Siever, redrawn by ESEU

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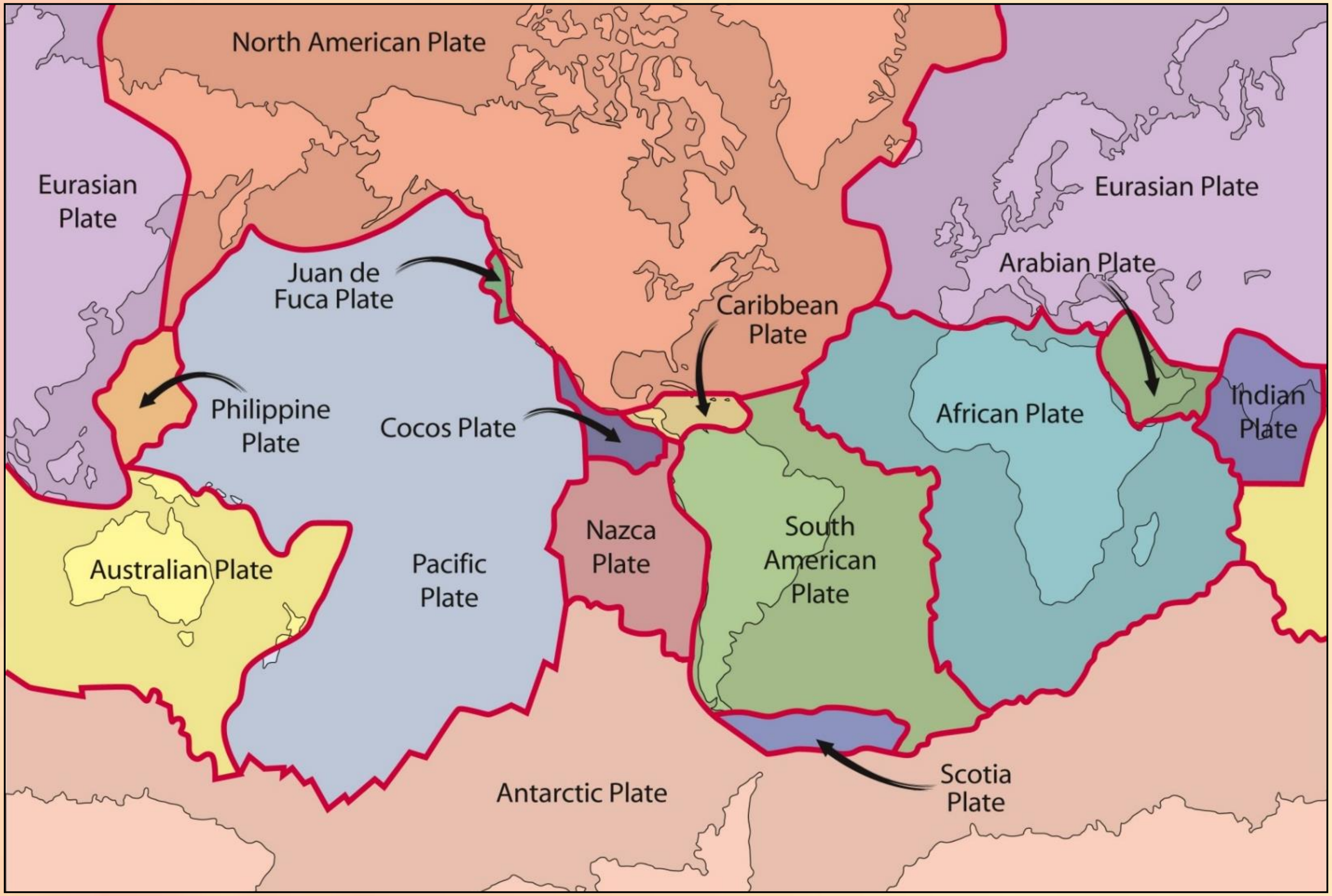
Map of plates

This is a map of plate margins today



Map of plates - reproduced with kind permission of USGS, redrawn by ESEU

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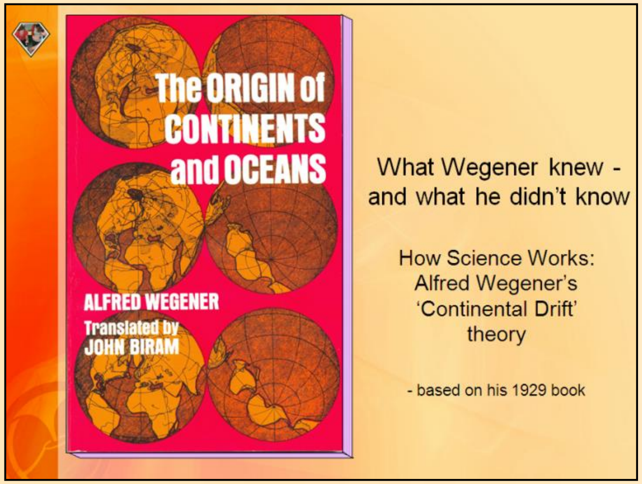
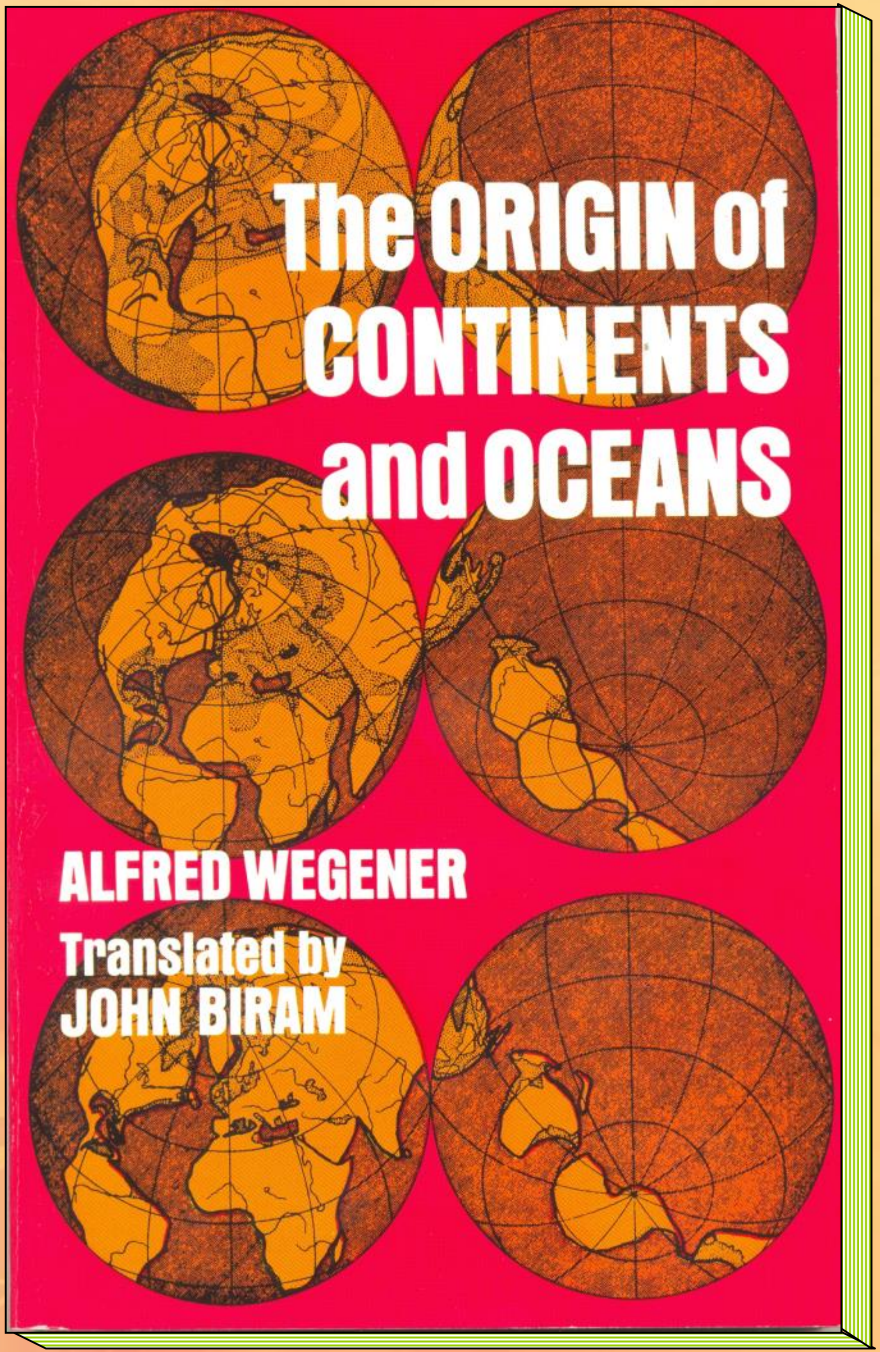
- So – that is the ‘big picture’ of plate tectonics
- But plate tectonics is not a series of facts, as suggested in the story above, but is a theory supported by evidence
- But what is this evidence and how does it support the theory?

The Earth and Plate Tectonics

- Where did the theory of plate tectonics come from?
- Back in the early 1900s, long before plate tectonics, Alfred Wegener put forward his theory of ‘continental drift’
- His story is an excellent example of ‘How science works’
- Test the thinking behind his theory using the ESEU ‘What Wegener knew’ PowerPoint

The following slides give ‘highlights’ of the ‘What Wegener knew’ PowerPoint





What Wegener knew -
and what he didn't know

How Science Works:
Alfred Wegener's
'Continental Drift'
theory

- based on his 1929 book

What Wegener knew - and what he didn't know

Find out -

what Wegener knew:

- continental coastline shape
- continental geology
- fossil evidence
- biological evidence
- geophysical evidence
- palaeoclimate evidence
- longitude evidence

what Wegener didn't know:

- sloping zones of earthquakes beneath trenches
- earthquakes and volcanic activity at ocean ridges
- ocean floor magnetic stripes
- age of the ocean floor
- lithosphere and asthenosphere
- modern movement of continents

about Wegener:

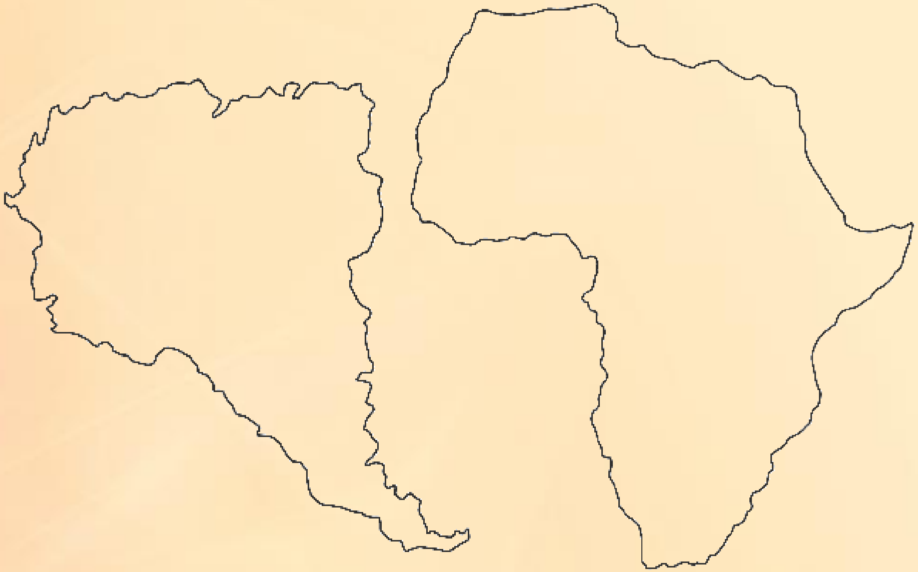
- contrasts between Wegener's 'continental drift and today's 'plate tectonics'
- why Wegener wasn't believed
- Wegener's adventurous life

All this - and more - through this interactive PowerPoint

Note: Wegener is pronounced as 'vain' (without the 'n') followed by 'gun' and 'er'

Similar shapes of coastlines - the ‘jigsaw fit’

- In 1910, Wegener noted, as others had before him, that the coastlines on either side of the Atlantic had similar shapes
- Hypothesis? - what explanations might account for this?



the continents were once together and have drifted apart

or

there was once a continent in between, that has sunk

or

it is coincidence

or

the continents and coastlines were made that way

The geology - the ‘picture on the jigsaw’

- Wegener found a scientific paper published in 1927 by du Toit (pronounced ‘dew toy’) showing that the geology of the South American and African coast areas matched closely
- Hypothesis? - what might account for this match?

the continents were once together and have drifted apart

or

there was once a continent with similar geology in between, that has sunk

or

it is coincidence or they were made that way

72 THE ORIGIN OF CONTINENTS AND OCEANS

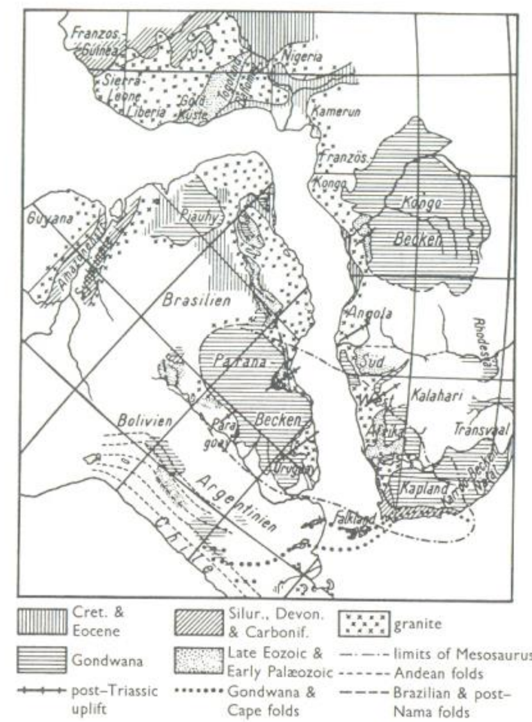
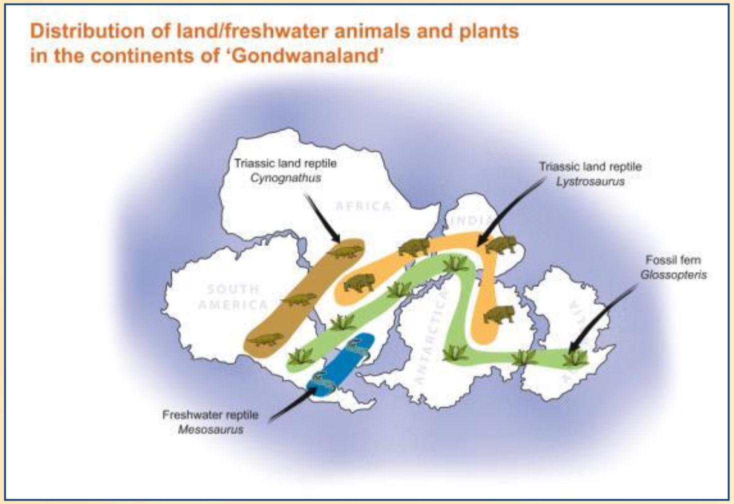


Fig. 18. Former relative position of South America and Africa, according to du Toit.

The fossils - more ‘picture on the jigsaw’

- Wegener knew about the published evidence that *Glossopteris* and related plants were found on different southern hemisphere continents - as shown in green on this ‘reconstruction’ of these continents (evidence from other fossils is also shown)
- Hypothesis? - what could have caused this distribution?



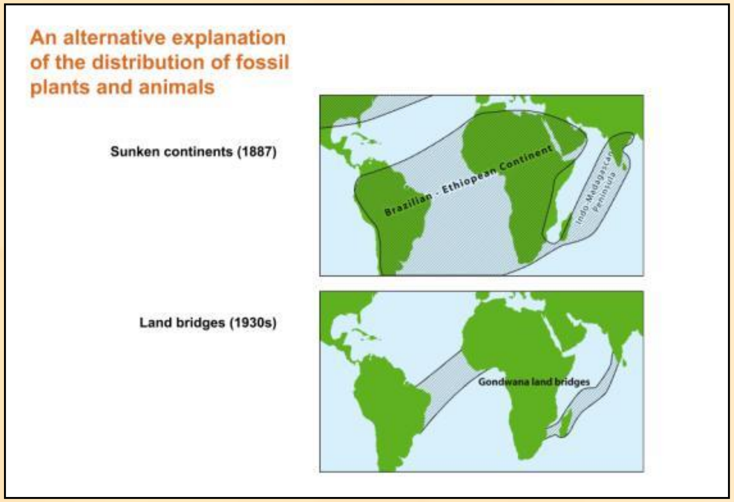
the continents were once together and have drifted apart

or

there were once ‘sunken continents’ or ‘land bridges’ between the continents

or

vegetation rafts, with their ‘cargo’ of animals floated on ocean currents between the continents



The palaeoclimate - more ‘picture on the jigsaw’

- Wegener and his father-in-law, Köppen, studied modern and ancient (palaeo-) climates. They noted that large ice sheets are only found in polar regions today. But published papers showed that 300 million year old rocks on the southern continents and India have evidence showing they were covered by ice sheets then (scratched rocks and ancient moraine and till deposits)

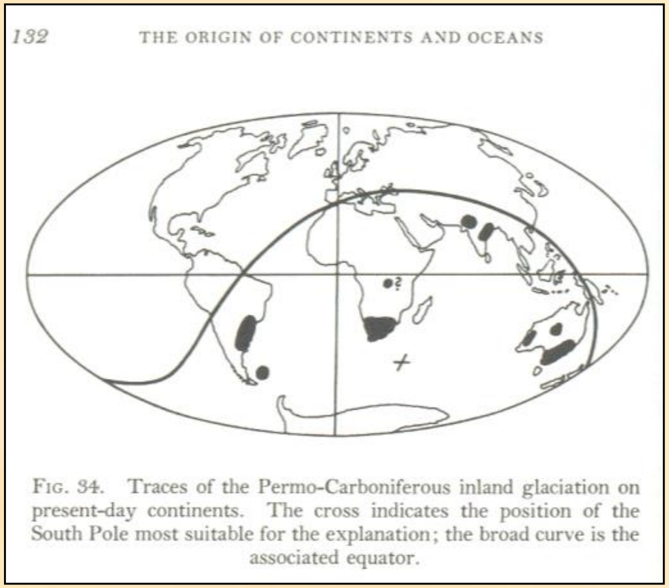

132 THE ORIGIN OF CONTINENTS AND OCEANS

FIG. 34. Traces of the Permo-Carboniferous inland glaciation on present-day continents. The cross indicates the position of the South Pole most suitable for the explanation; the broad curve is the associated equator.

Hypothesis? - what could have caused this pattern?

the continents were once near one of the poles, but have drifted away

or

most of the Earth was covered by an ice sheet at the time

or

Earth rotated differently, so the poles were in different places

Longitude evidence
- a test of movement over years

- Wegener knew that the longitude of Greenland had first been measured in 1820, then in 1870. He was an assistant on the Greenland expedition of 1906/8 when longitude was measured again. These measurements showed that Greenland was moving west at about 20 metres per year
- Hypothesis? - what could account for this measured movement?

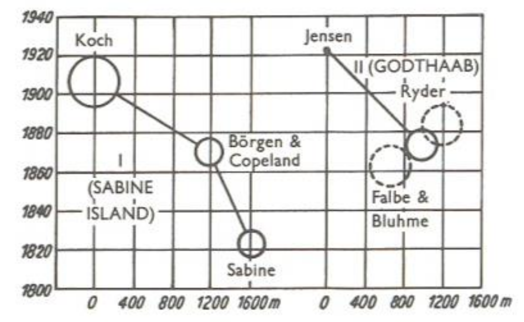


FIG. 6. Displacement of Greenland according to earlier determinations of longitude.

Greenland is moving at around 20 m per year (and so are the other continents)

or

the measurements were inaccurate

or

the calculations based on the measurements were incorrect

Why wasn't Wegener believed?

- It wasn't until 40 - 50 years later, in the 1960s, that scientists started to believe that the continents had moved, and developed the theory of 'plate tectonics'
- Hypothesis? - why do you think Wegener wasn't believed at the time?

Why wasn't Wegener believed?

It is difficult to get into the minds of scientists at the time to answer this question - but the following have been said:

- the scientific consensus view at the time was that everything was 'fixed' - continents might move up and down or be crumpled by a shrinking Earth, but they couldn't be moved laterally
- he was a meteorologist - how could he come up with ground-breaking ideas in geology?
- he was German - at a time when many nations had been at war with Germany
- he published in German - a language that was not widely read by scientists - none of his ideas, first formulated in 1912, were translated into English until 1924
- he was wrong about the rate of drift of Greenland
- the influential British physicist, Sir Harold Jeffreys, said that the continents didn't have enough strength for 'drift'
- the forces that Wegener proposed as the cause of 'drift (the 'flight from the poles') were nothing like strong enough

Born in Berlin, Germany on 1st November 1880

Studied at Universitie Heidelberg, Innsbruck and Berlin

Made a record balloon flight of 52.5 hours with his brother in 1

First d ‘contin theory Jan 1912

Joined the German army in 1914, shot in the arm nec

Published his id with four edition 1920, 1922, 1929 - the last two editions translated into English

Began his third polar expedition to Greenland in 1930

1880 | 1890 | 1900 | 1910 | 1920 | 19

Went to Köllsches secondary school

First beca astronomer, then a meteorologist

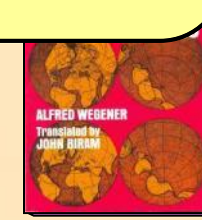
Became a polar explorer in 1906, second exp 1912

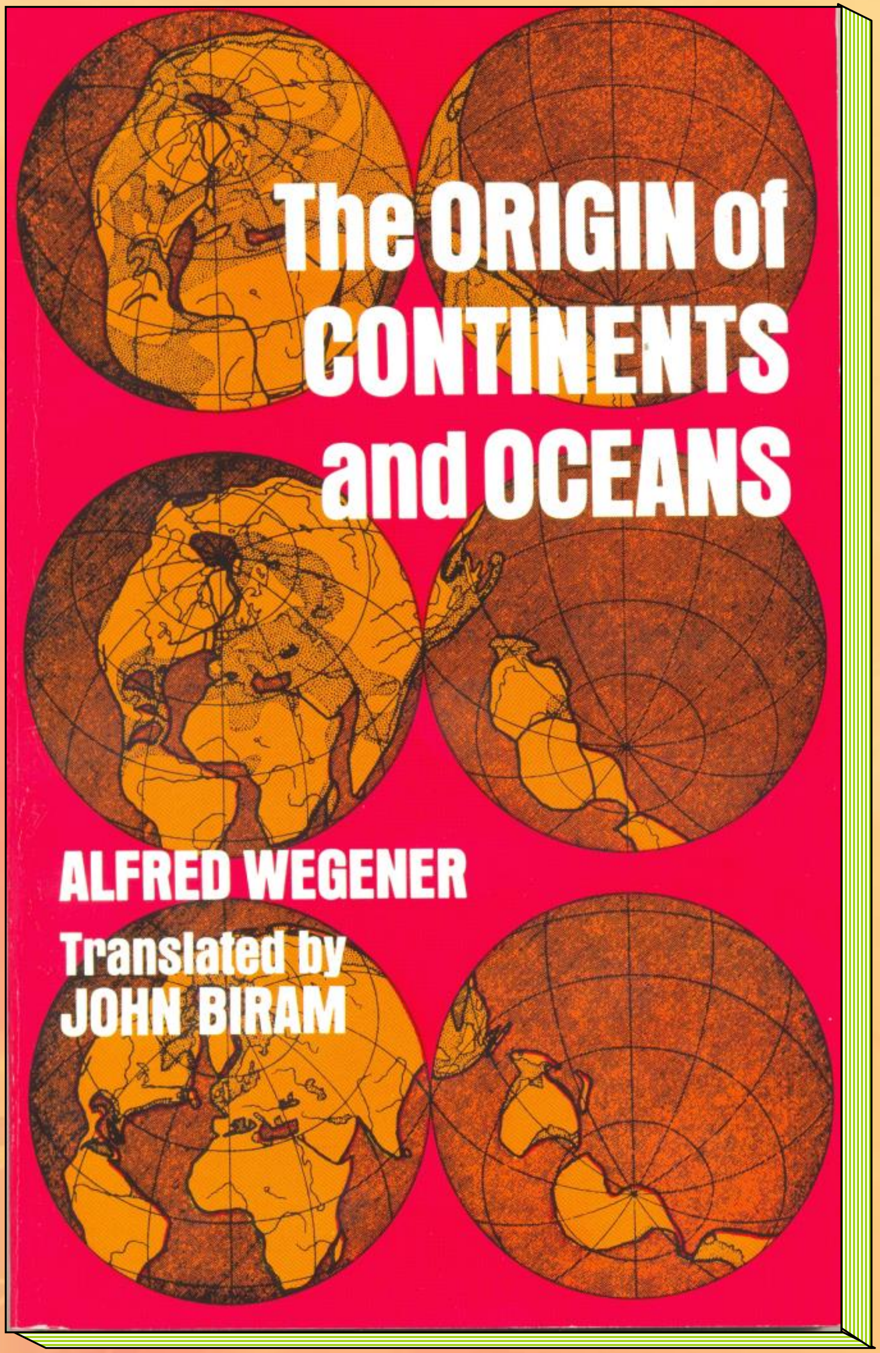
Marri Köpp a met professor, in 1912

Given leave from the army in 1915, ‘unfit for active service’

Became professor o meteorology in 1924

Died on the Greenland icecap in November 1930, aged 50





What Wegener knew - and what he didn't know

How Science Works:
Alfred Wegener's 'Continental Drift' theory

- based on his 1929 book

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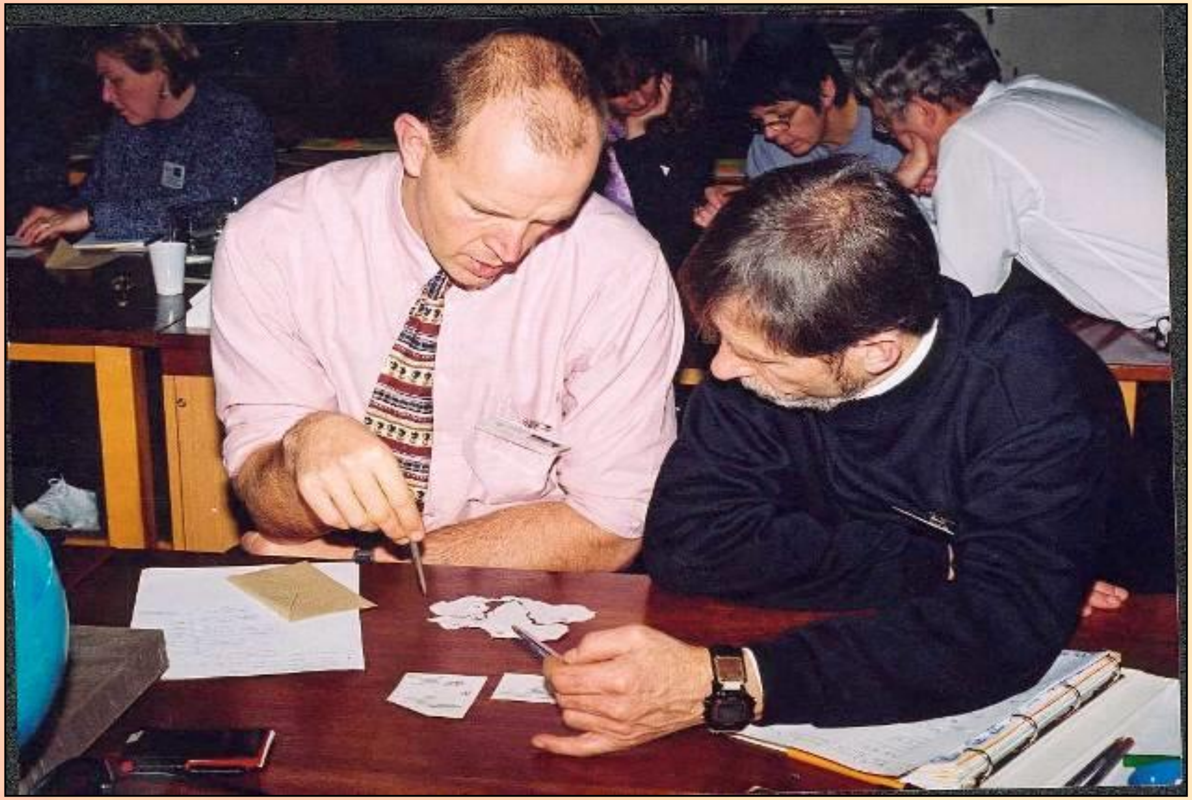
Continental jigsaws - the 'matching' evidence



Debating the reconstruction of the super-continent of 'Gondwanaland' © Peter Kennett

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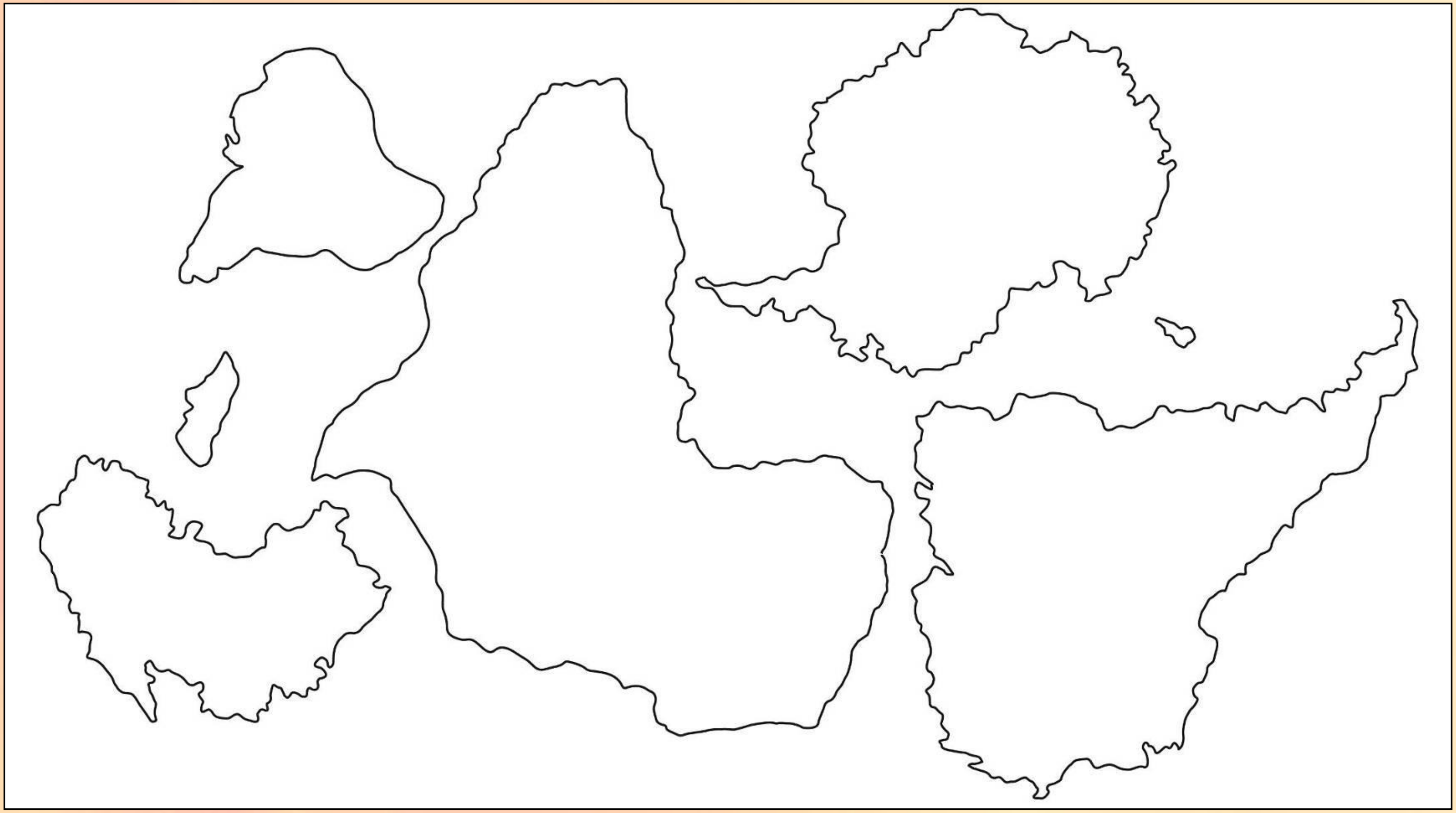
The Continental Jigsaw (the outlines of the Gondwana continents)



The Continental jigsaws (the outlines of the Gondwana continents) © Author/origin unknown – redraw by Peter Kennett

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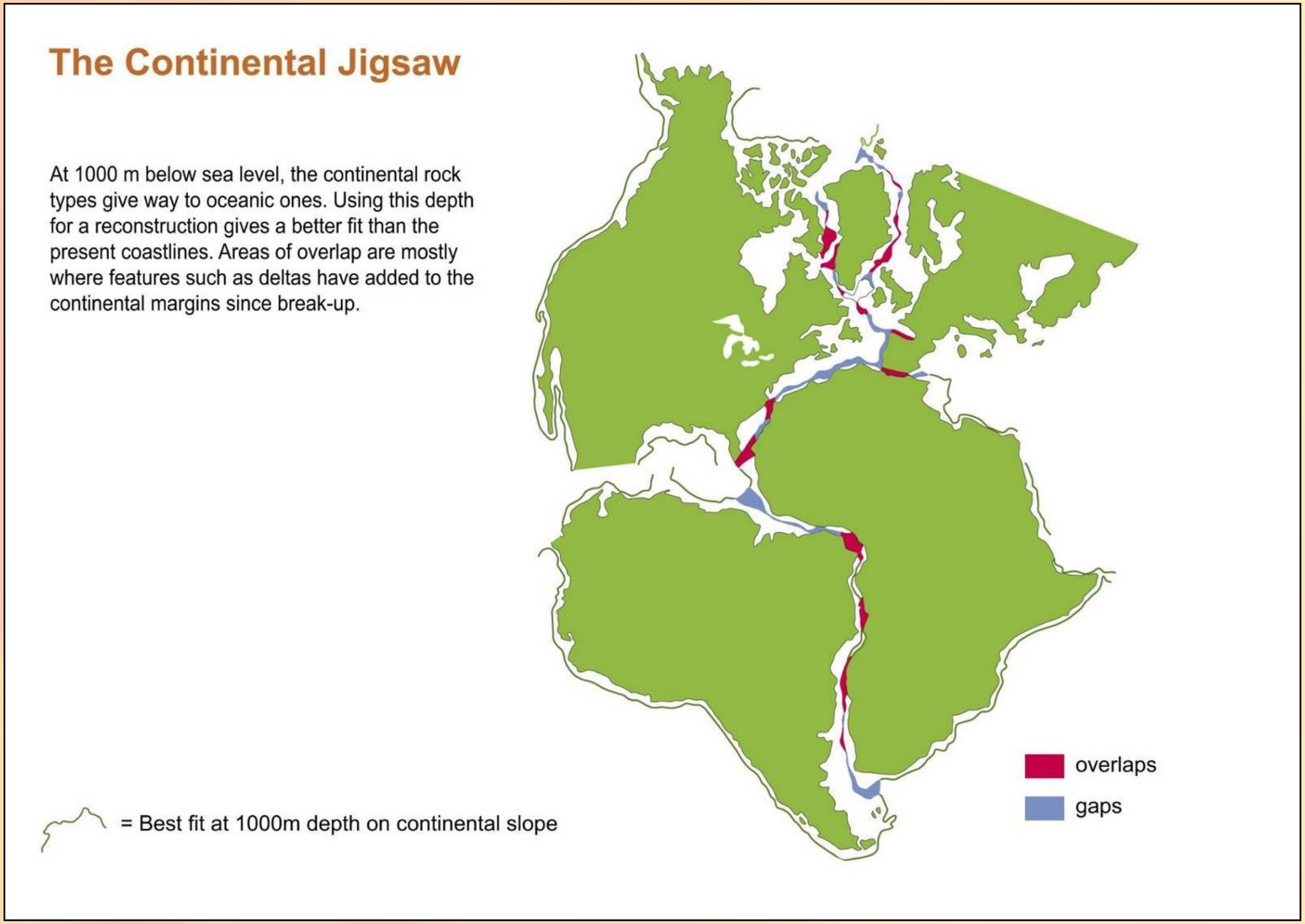
The Continental Jigsaw (continental shelf match at 1000m depth below sea level)



The Continental jigsaw, continental shelf (best fit at 1000m) © Andrew McLeish in 'Geological Science'

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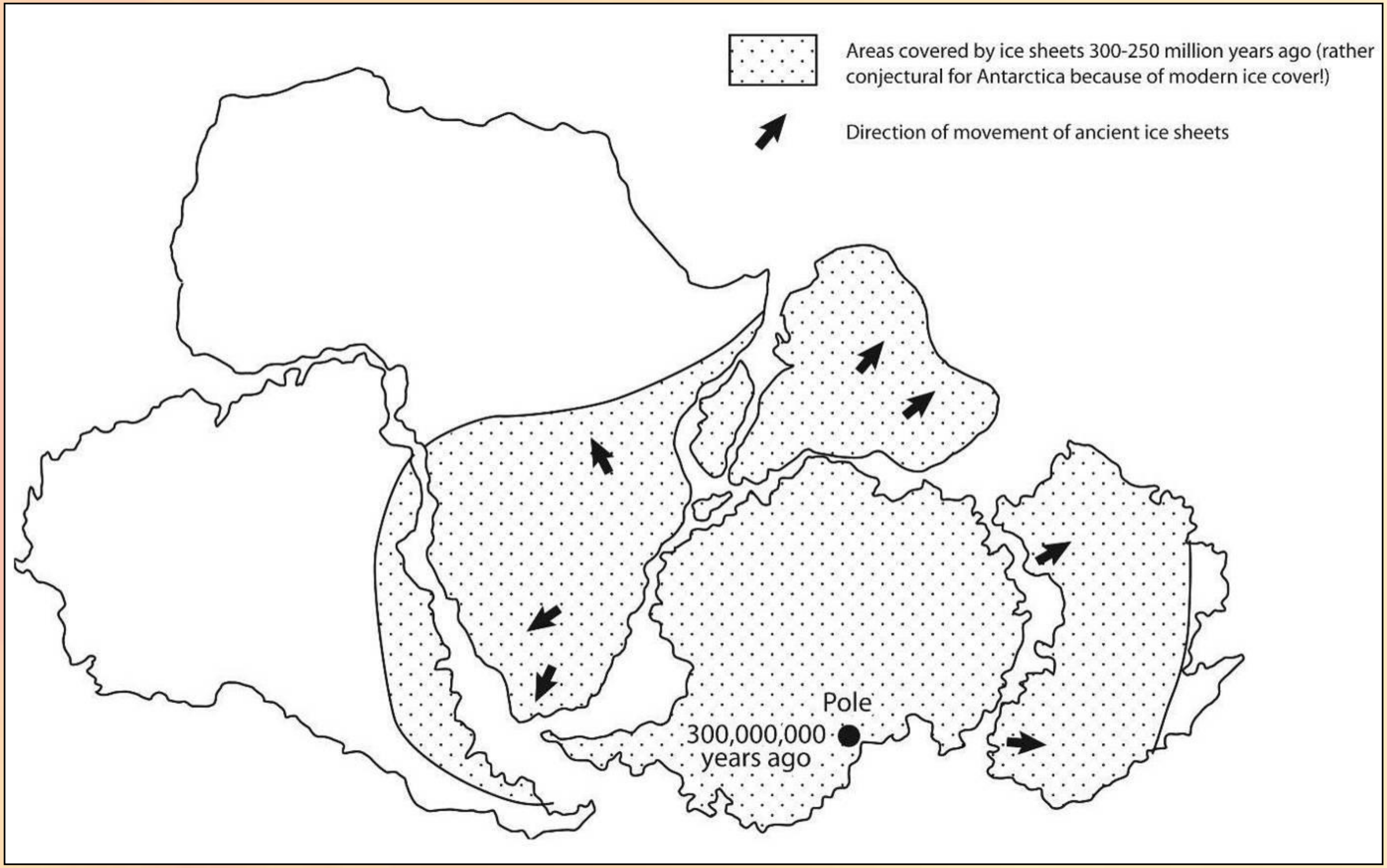
The Continental Jigsaw (former distribution of ice across the Gondwana continents)



The Continental jigsaws (former distribution of ice across the Gondwana continents) © Andrew McLeish in 'Geological Science'

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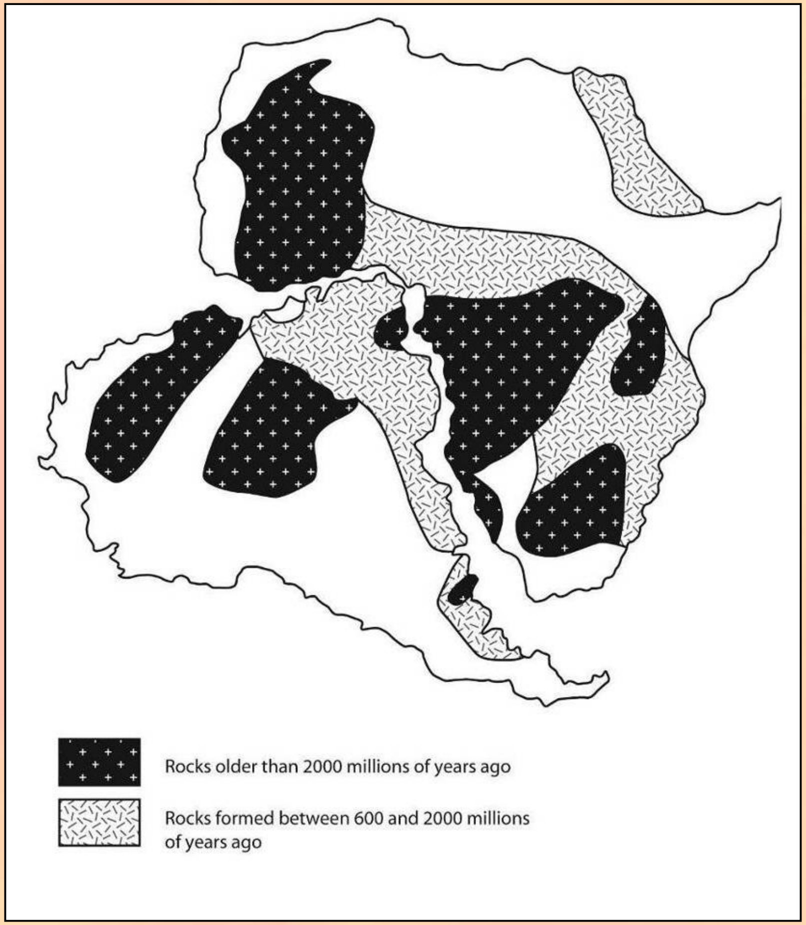
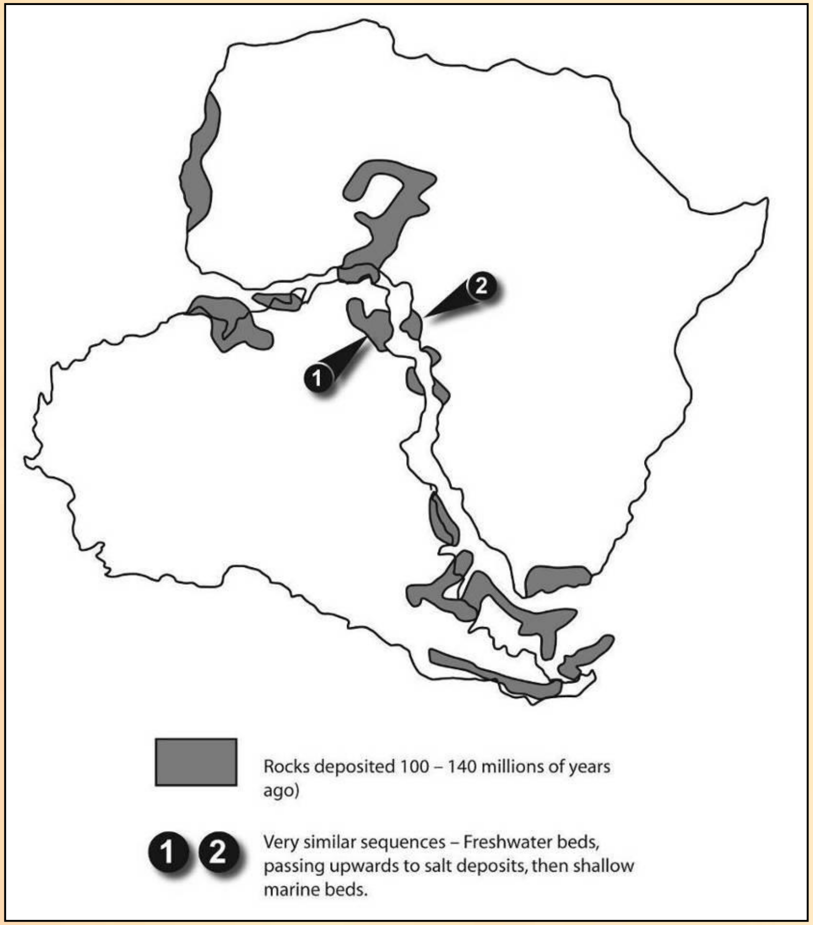
The Continental Jigsaw



The distribution of **ancient rocks** across South America and Africa



The distribution of **younger rocks** across South America and Africa up to the beginning of the continental split

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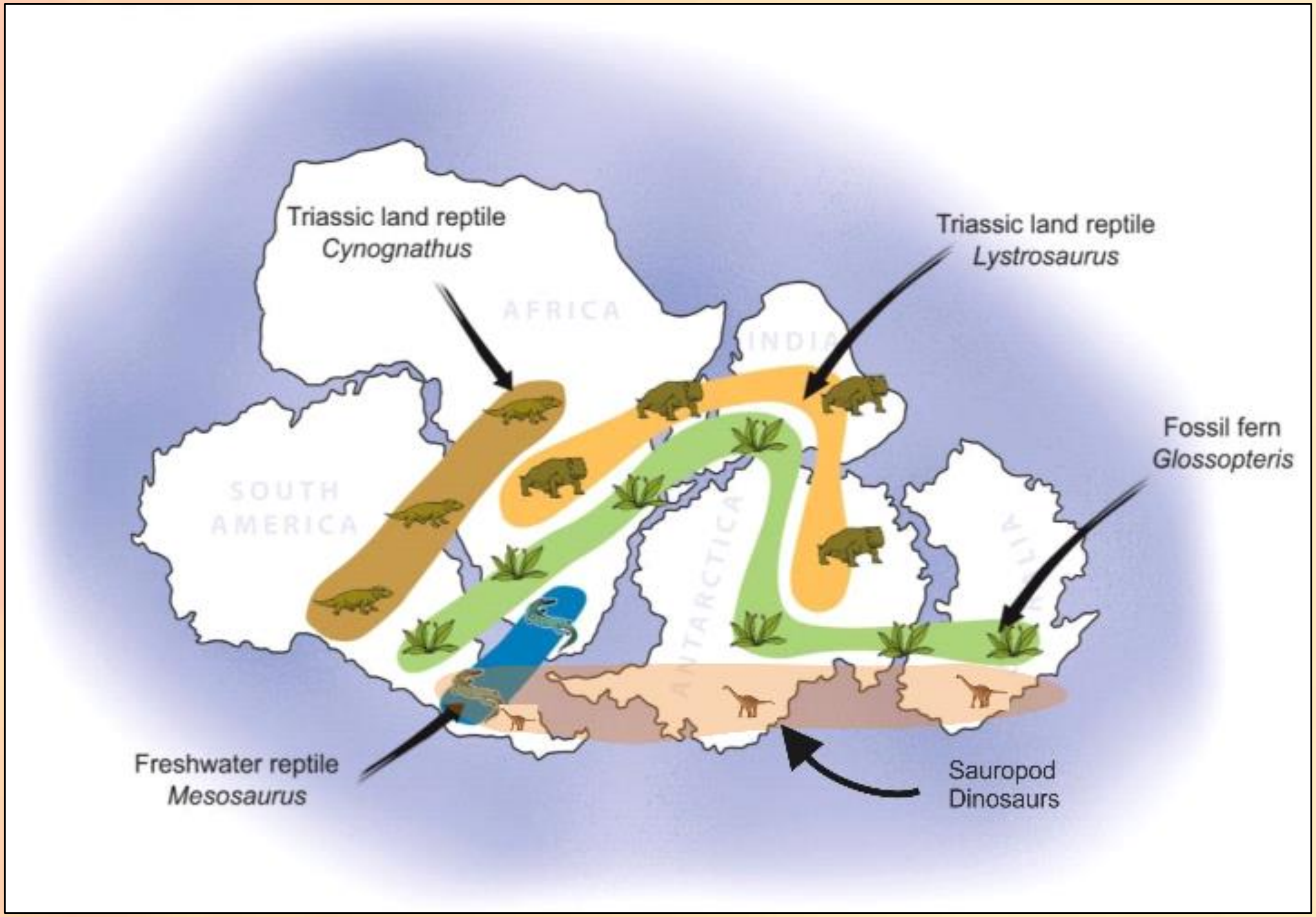
The Continental Jigsaw (distribution of land/freshwater animals and plants in the continents of 'Gondwanaland')



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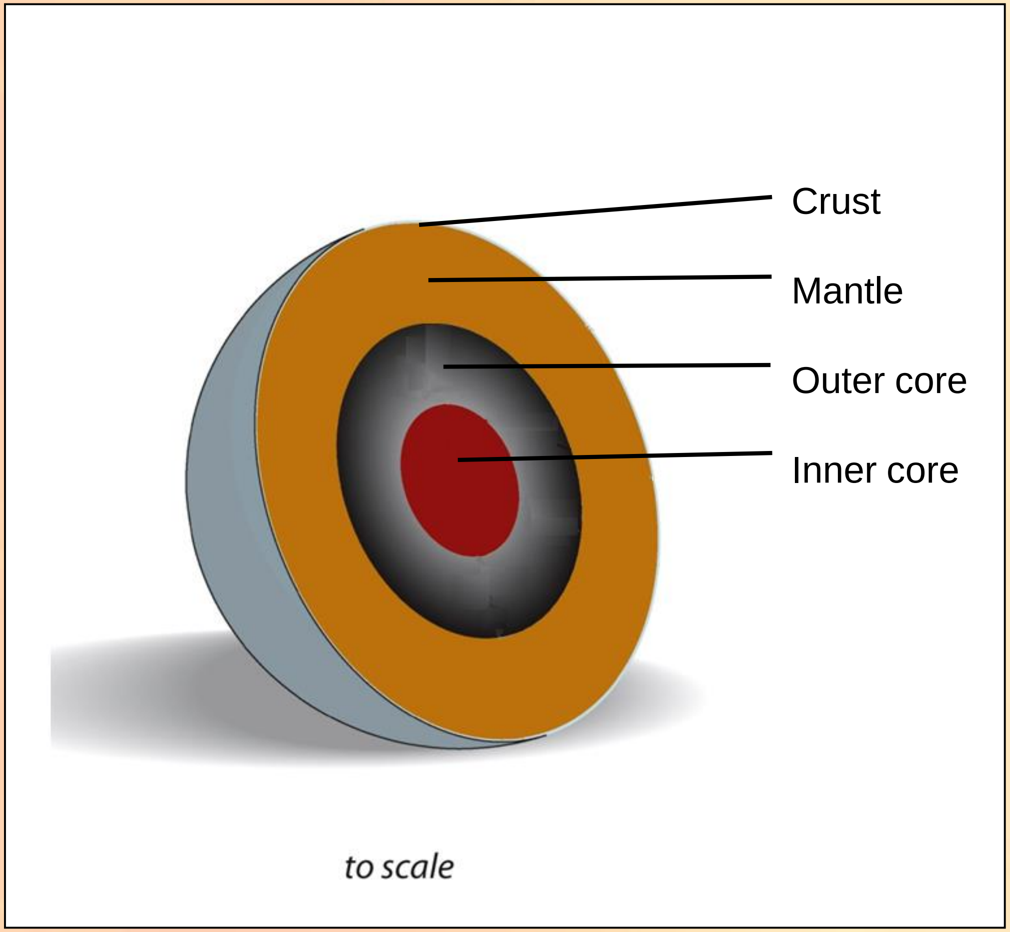
What is the best way to teach that the Earth has a core?

You could ask your students to draw a picture like this one



The Internal structure of the Earth - reproduced with kind permission of USGS, redrawn by ESEU

… or use: Model Earth – Plasticine™ spheres

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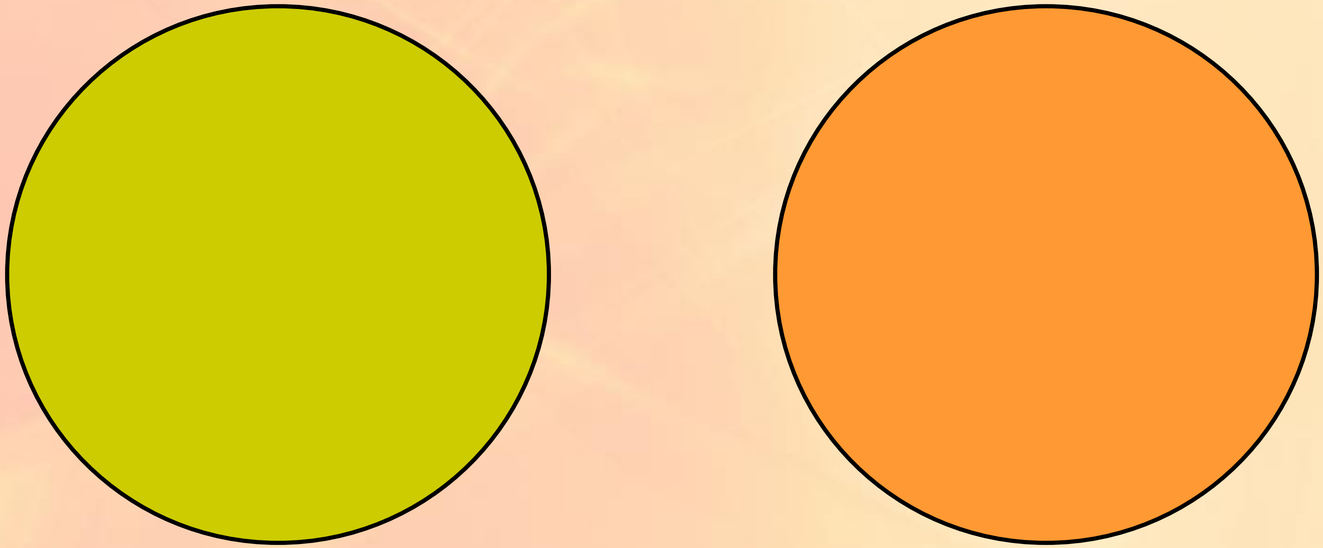
Model Earth – Plasticine™ spheres

- Two spheres, different colours - other differences?



- There are five possible theories

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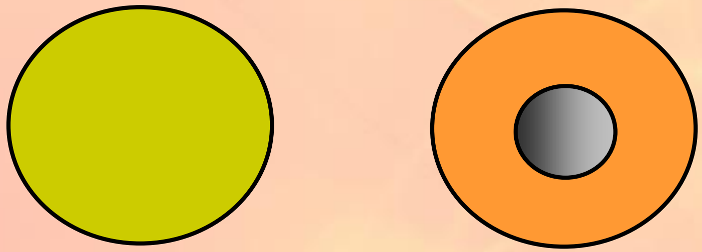
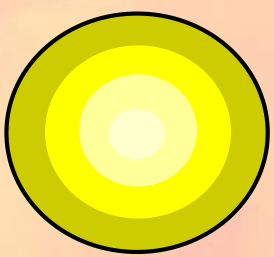
One feels heavier, and it is - reasons could be:

- something heavy in the centre of the heavy one

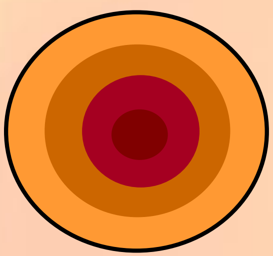


- something light in the centre of the light one

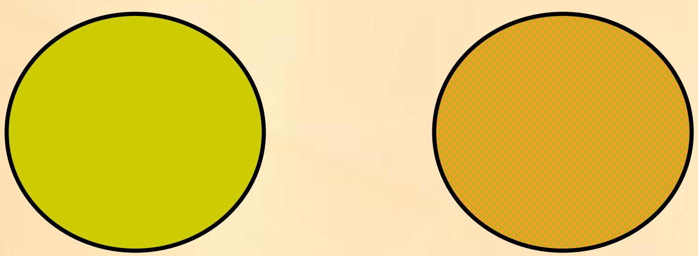
- one gets steadily lighter towards the centre



- one gets steadily heavier towards the centre



- one is made of heavier 'stuff' than the other



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How could you find out which is right - without destroying the ball?

- Stick a pin in
- Magnetism
- Inertia
- Ultrasound
- X-ray
- Ionising radiation (α, β, γ)

Which of these could you use on the Earth in an attempt to find out what is in the middle?

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Which of these could you use on the Earth to find in an attempt to find out what is in the middle?

- Stick a pin in - no, can’t drill that deep
- Magnetism - yes, measure and interpret effects
- Inertia - yes, measure and interpret effects
- Ultrasound - yes, lower frequency seismic waves
- X-ray - no, can’t penetrate that far
- Ionising radiation - no, can’t penetrate that far

Note: a copy of the article ‘King, C. (2002) The secrets of Plasticine balls and the structure of the Earth: investigation through discussion, published in *Physics Education,* 37 (6), 485 – 491, is available.

Have we just been learning about science or ‘doing’ science?

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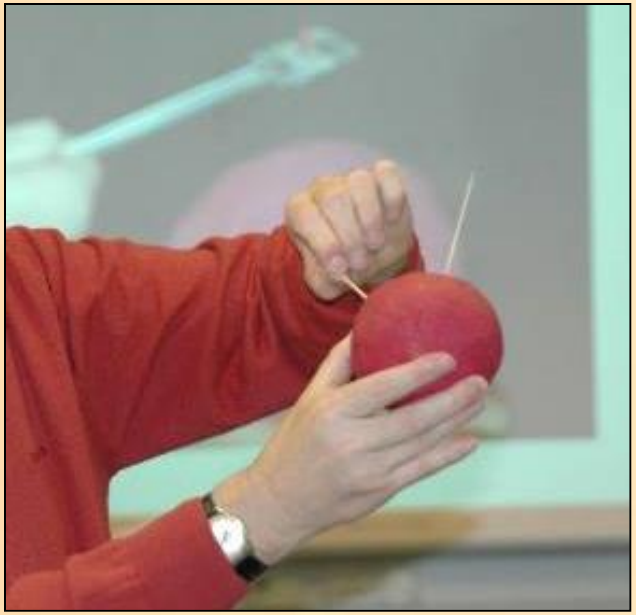
The magnetic evidence

From Magnetic Globe to Magnetic Rock Evidence



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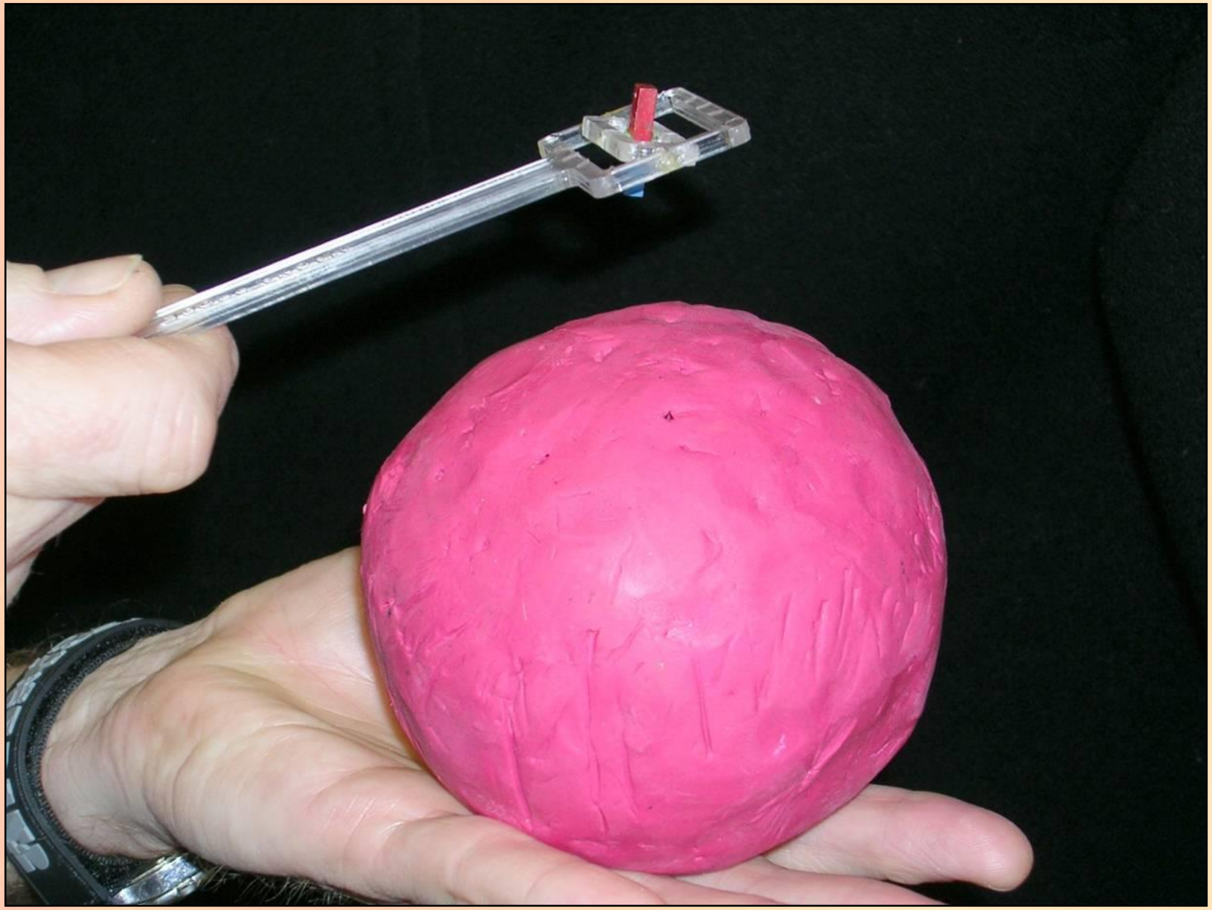
Model magnetic Earth



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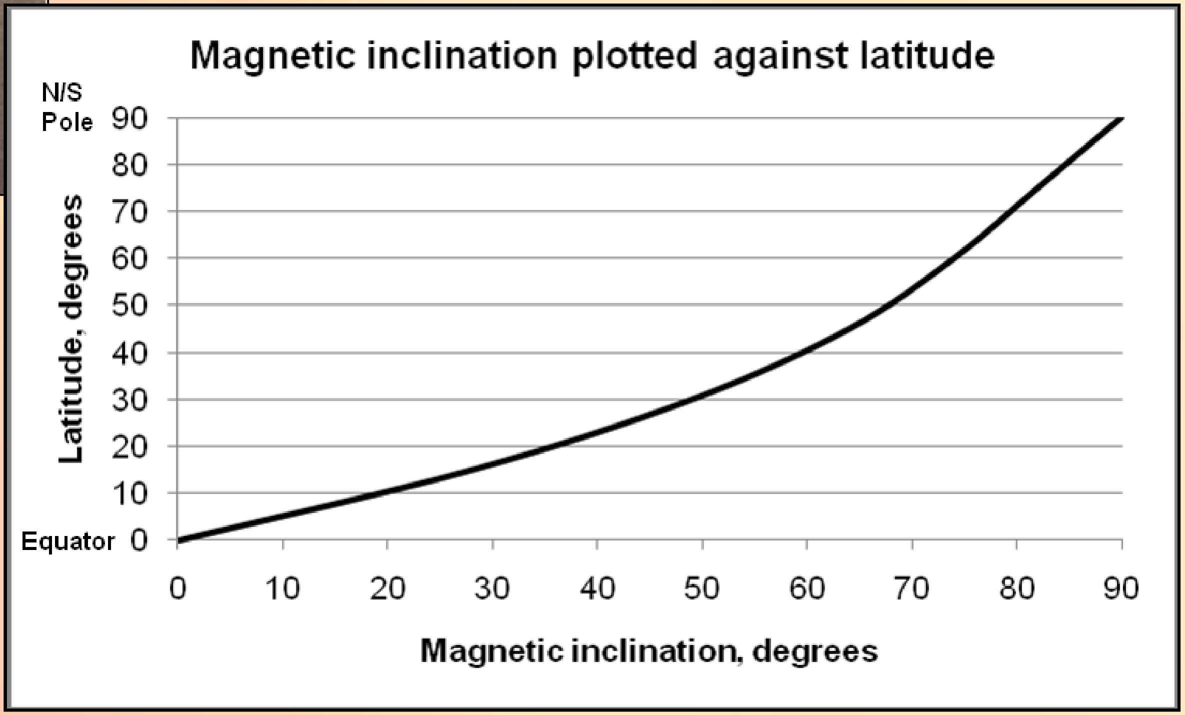
Preserving remanent magnetisation



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by Cochranes of Oxford

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Manufacturer recommended age: 36 Months and up

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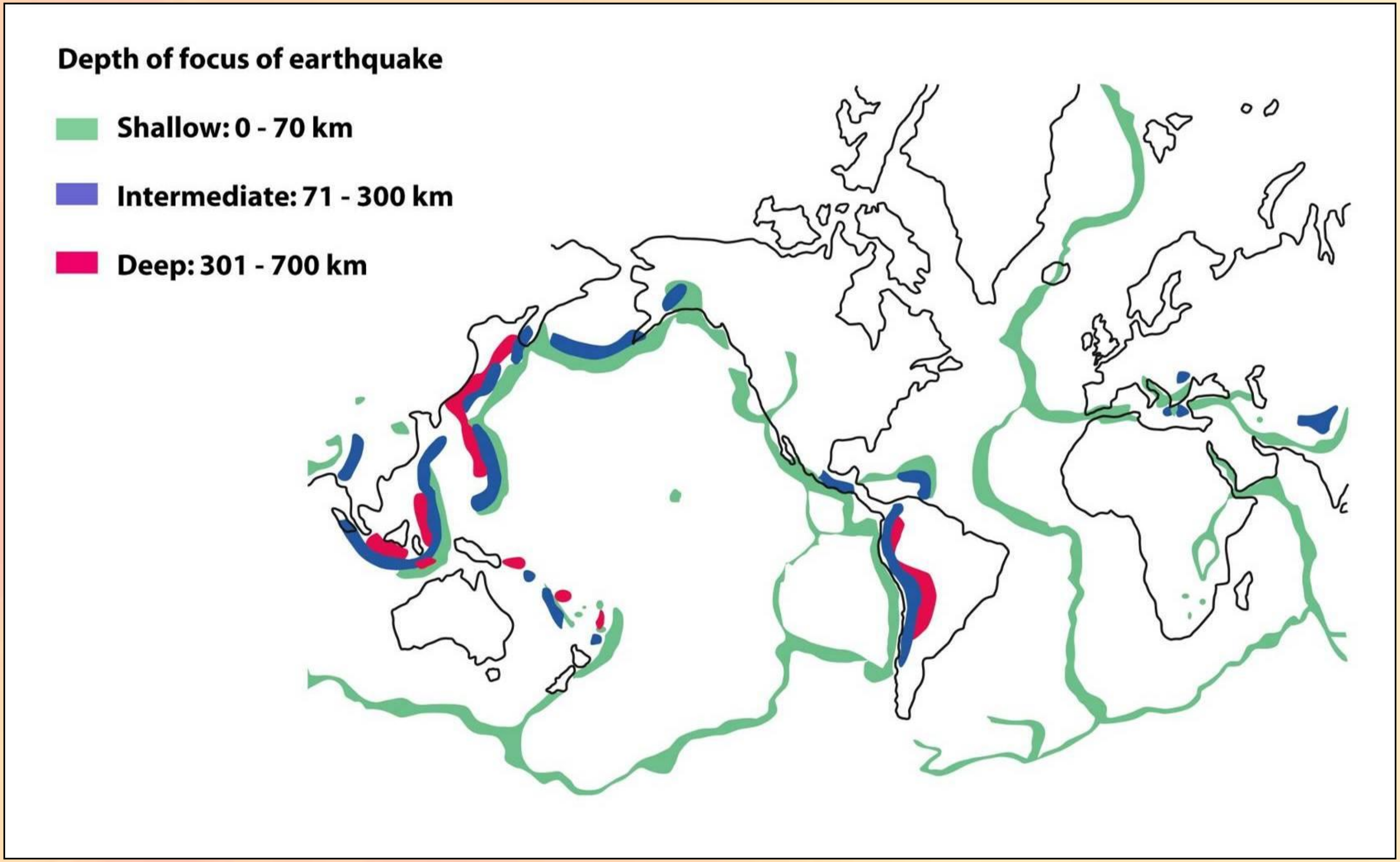
The earthquake distribution evidence

The Earth and Plate Tectonics

Distribution of earthquakes – what does the distribution show?



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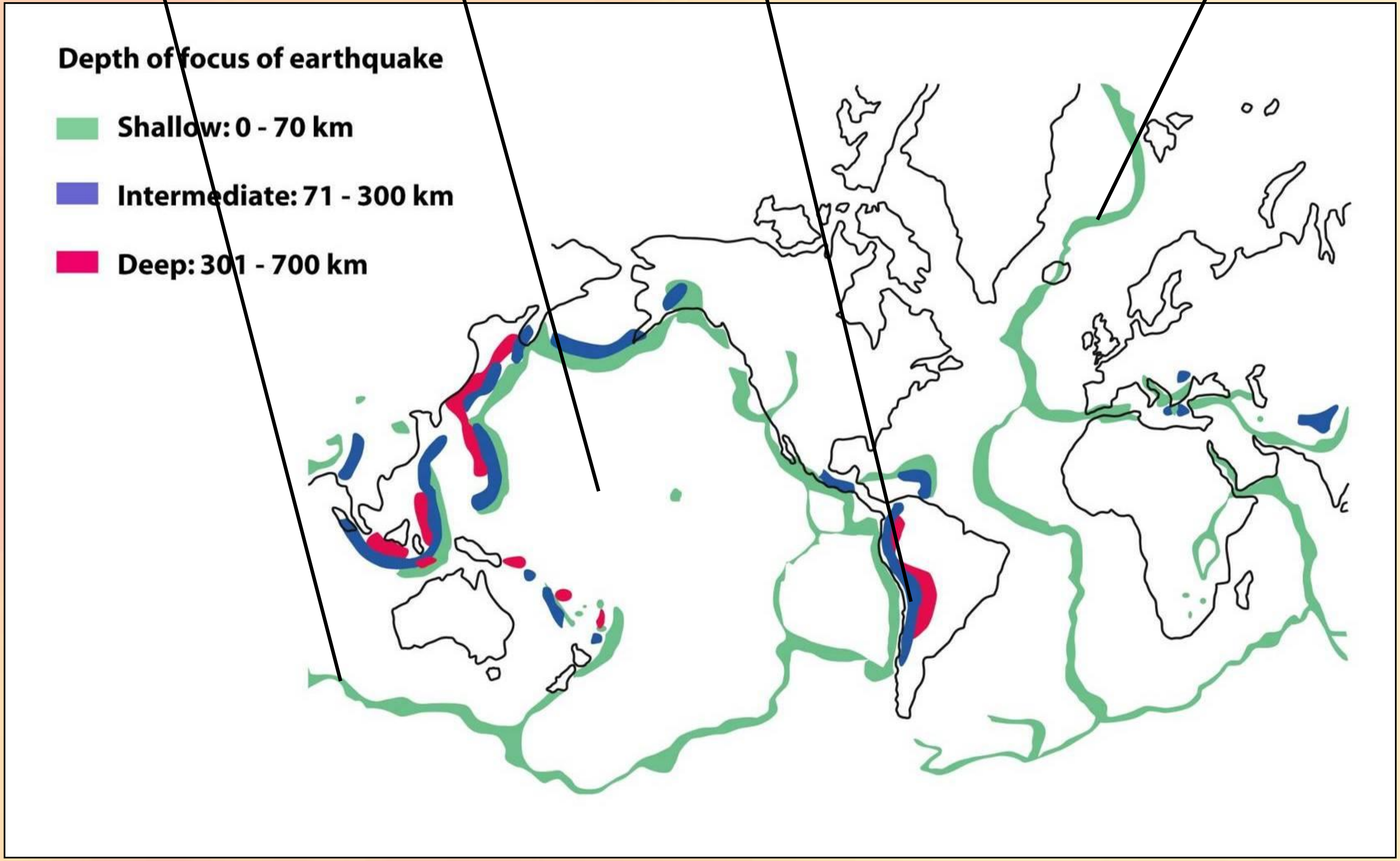
Distribution of earthquakes – what does the distribution show?

Plate margins – shown by earthquake distributions

Plate shapes

Deep focus earthquakes = subduction

Shallow focus earthquakes only = constructive margins



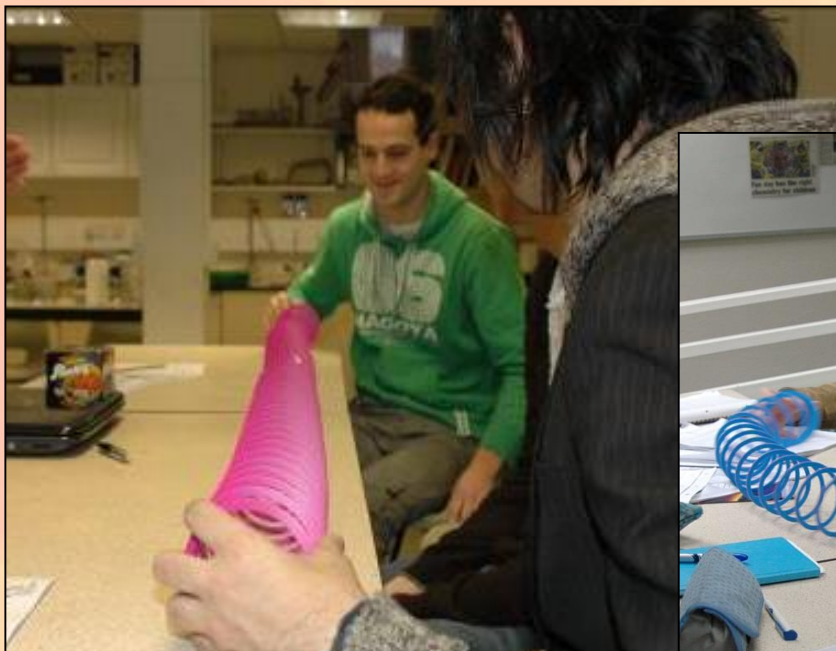
The Earth and Plate Tectonics

The earthquake that caused this damaged produced both **P**- and **S**-waves – but what are these waves?

The Earth and Plate Tectonics

Earthquakes – the slinky simulation

How earthquakes produce **P**- and **S**-waves



The Earth and Plate Tectonics

Earthquakes - the slinky seismic waves demo

How earthquakes produce **P**- and **S**-waves

The Earth and Plate Tectonics

Seismic wave summary

Wave type	**Primary wave**	**Secondary wave**
Name meaning	fastest wave, so arrives first, called primary	slower wave, arrives second, called secondary
Other names	longitudinal – travels by vibration along the material	transverse – travels by lateral movement
	push/pull wave; comPressional wave	shake wave; shear wave; sideways wave; slow wave
Transmission	through solids and fluids (liquids and gases)	through solids only

Earthquake damage is caused mainly by seismic **Surface waves**, and not by Primary or Secondary waves

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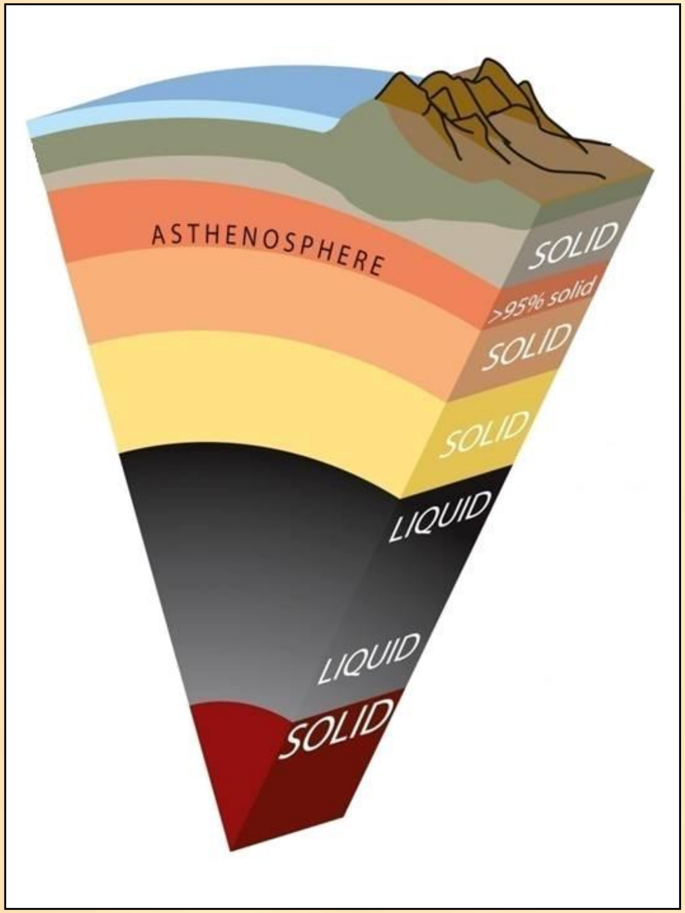
Wave motion – student molecules

How **P**- and **S**-waves are transmitted

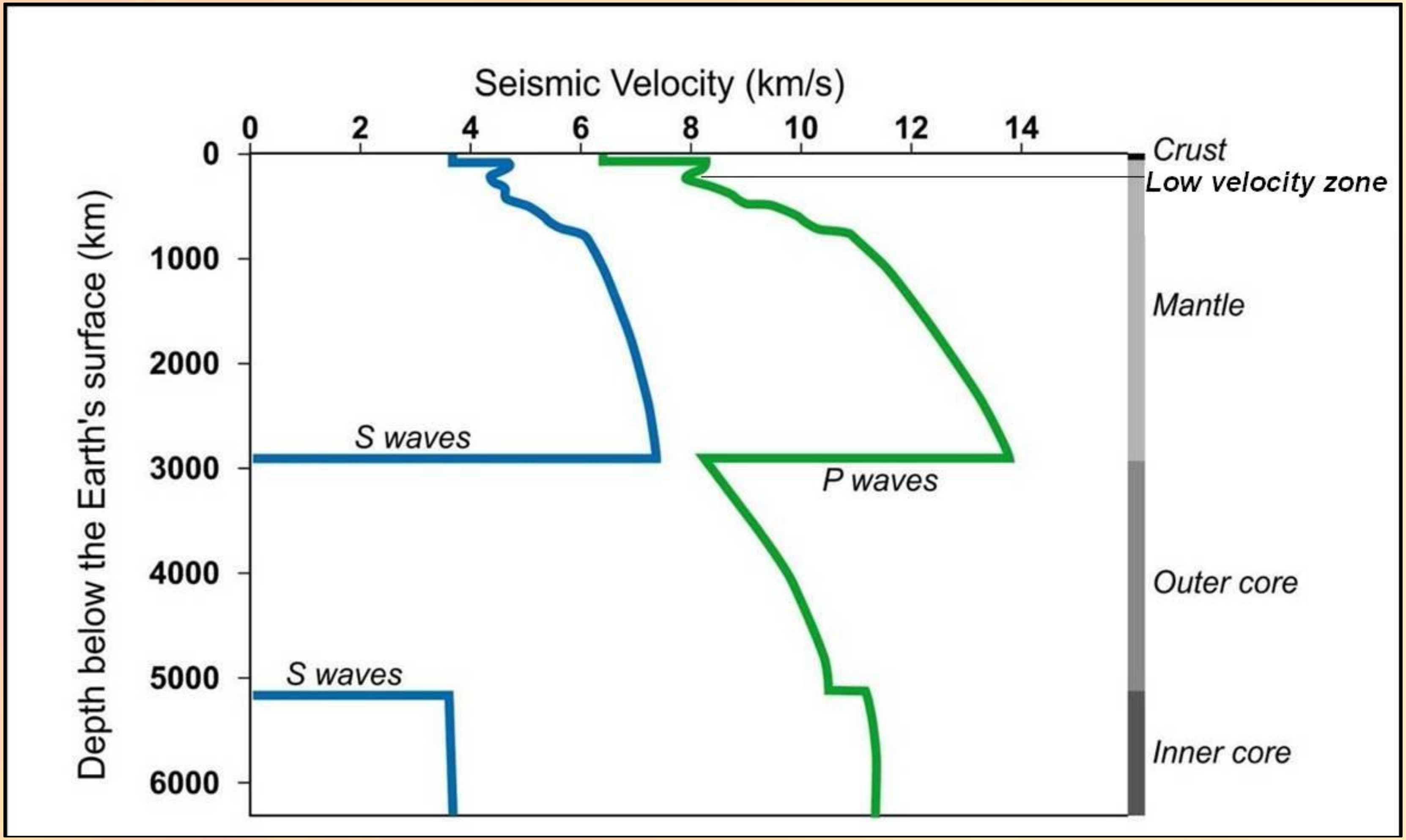
The Earth and Plate Tectonics

The seismic evidence for the structure of the Earth



The Earth and Plate Tectonics

Velocities of P and S waves as they travel into the Earth



The velocities of seismic waves in the Earth
Originally from The Earth Science Teachers' Association, 'Investigating the Science of the Earth 2: Geological changes – Earth's Structure and Plate Tectonics', redrawn by ESEU.

The Earth and Plate Tectonics

The structure of the Earth – from the seismic evidence

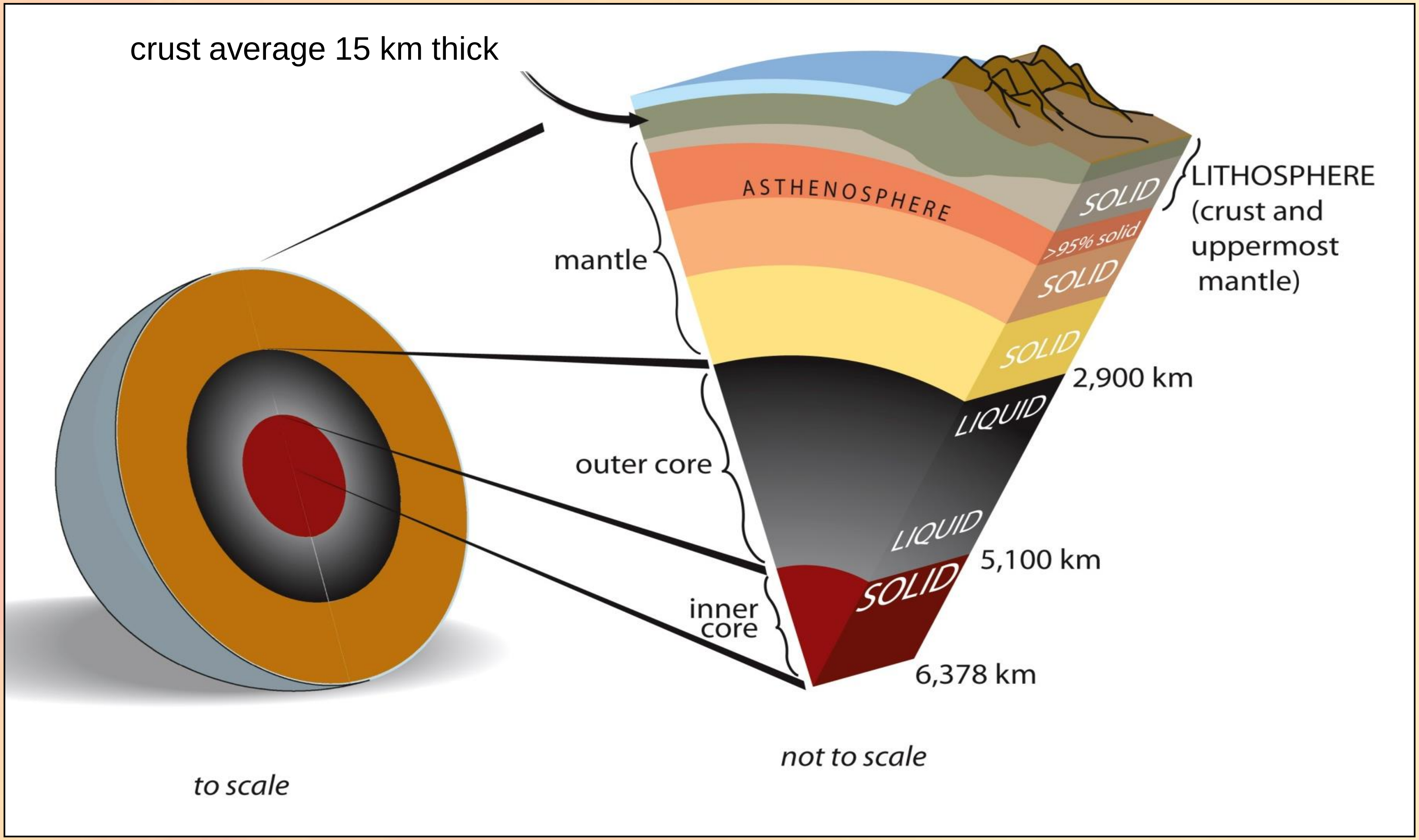


Diagram of the internal structure of the Earth, an example of a diagram showing the crust very much thicker than in reality. Reproduced with the kind permission of the U.S. Geological Survey, redrawn by ESEU.

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The lithosphere, asthenosphere and below:

Depth, km	Compositional (chemical) layering	Mechanical (physical) layering
0	Crust	Lithosphere
mean of 15	Mantle	
about 100		Asthenosphere
about 250		The rest of the mantle

Note. The crust has a mean thickness of 35 km beneath continents and 6 km beneath oceans giving an overall mean of about 15 km.

The Earth and Plate Tectonics

Modelling the lithosphere and asthenosphere (?)

The Earth and Plate Tectonics

Modelling the lithosphere and asthenosphere (?)

The crust – trainers	The extreme upper mantle – skate board	The asthenosphere - wheels

The asthenosphere (wheels) flows, carrying the plate of lithosphere = trainers (crust) + extreme upper mantle (skateboard) along

The Earth and Plate Tectonics

Why are the Earth’s tectonic plates called plates?

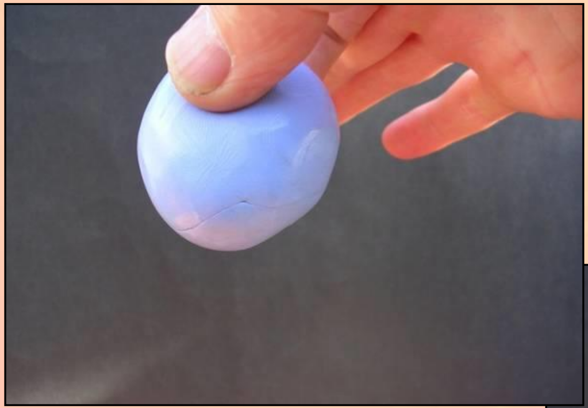
The Earth and Plate Tectonics

Properties of the mantle – Potty Putty™

Showing how the solid mantle can flow

The Earth and Plate Tectonics

Modelling the mantle



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CRAYOLA - The Original Silly Putty - 5" x 7"

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Bounce it, stretch it and snap it Stretch your imagination with this fun collection of silly putty. Ages four and up. Product may stick to fabric and other household surfaces. Made in USA.

- Silly Putty Original
- Non-hardening and non-toxic
- Mold into any shape
- Ages 4+
- This is a bouncy, stretchy, peculiar substance that bounces like rubber and stretches like taffy.

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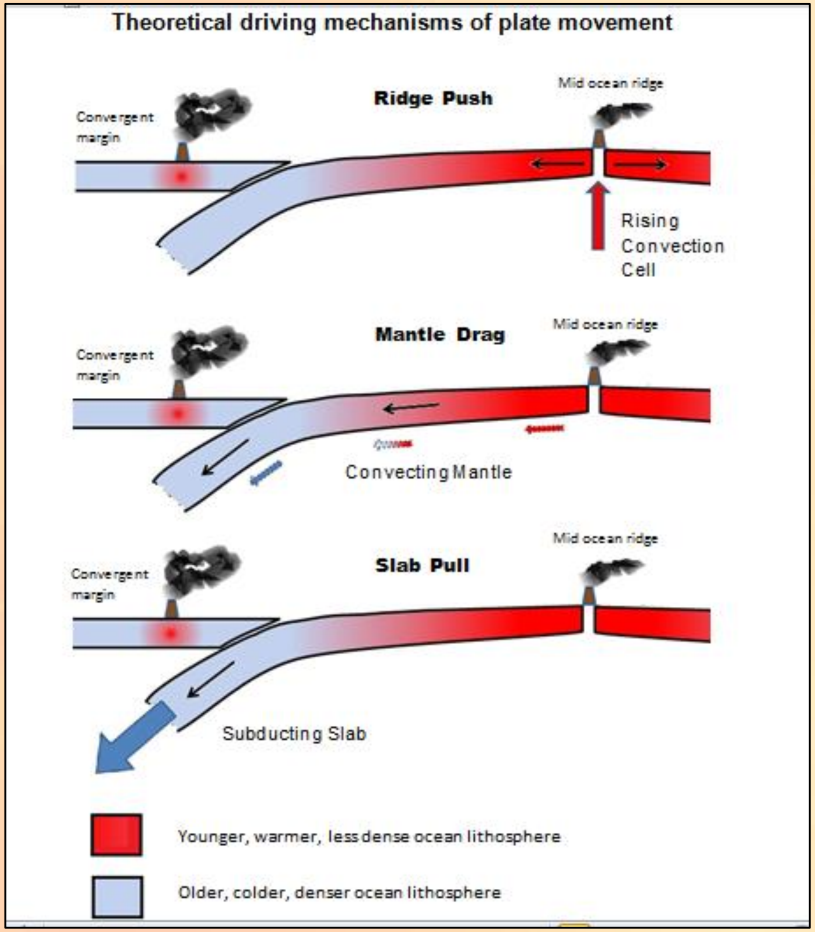
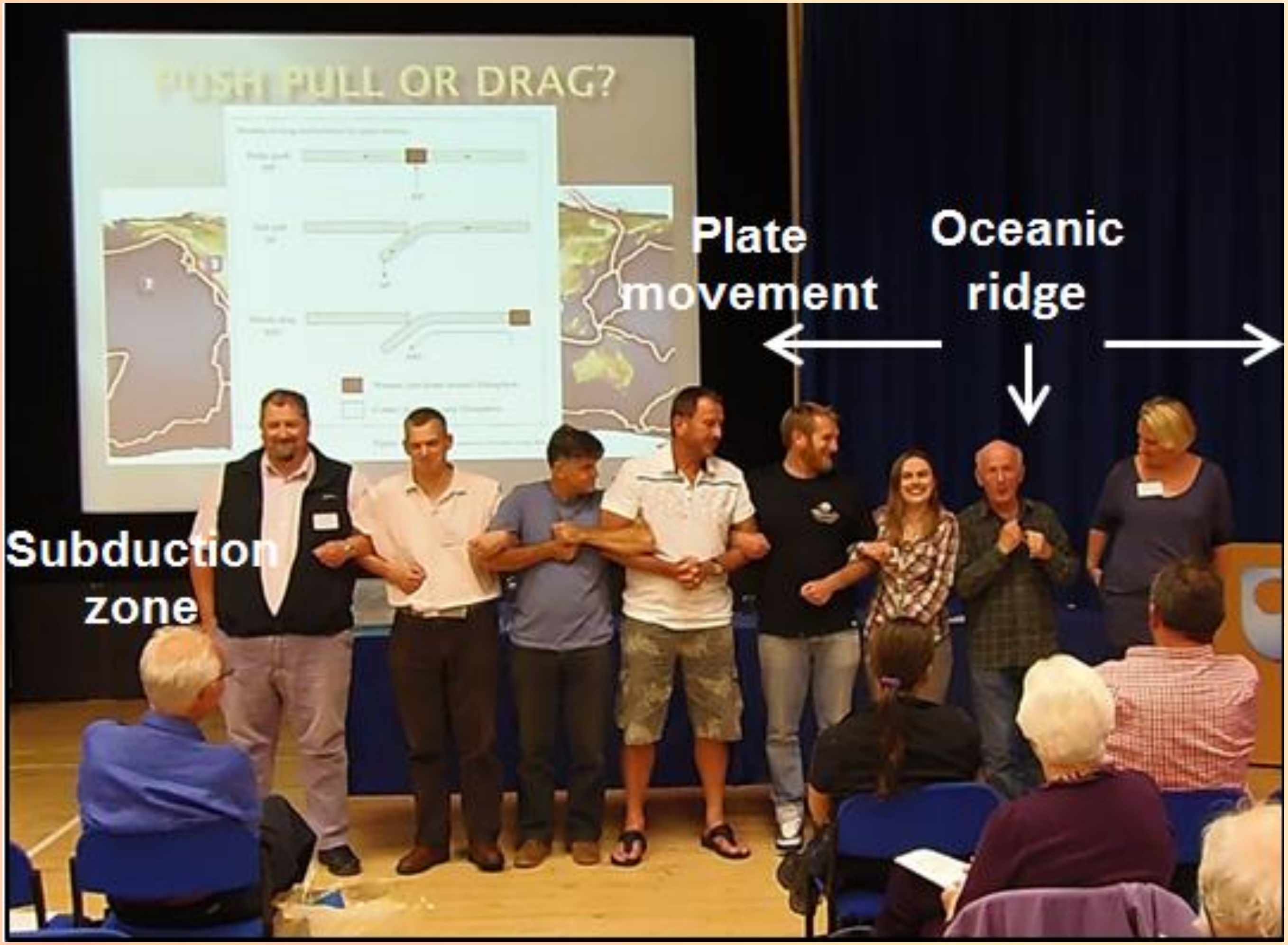
What drives the plates?



Theoretical driving mechanisms of plate movement © Pete Loader

The Earth and Plate Tectonics

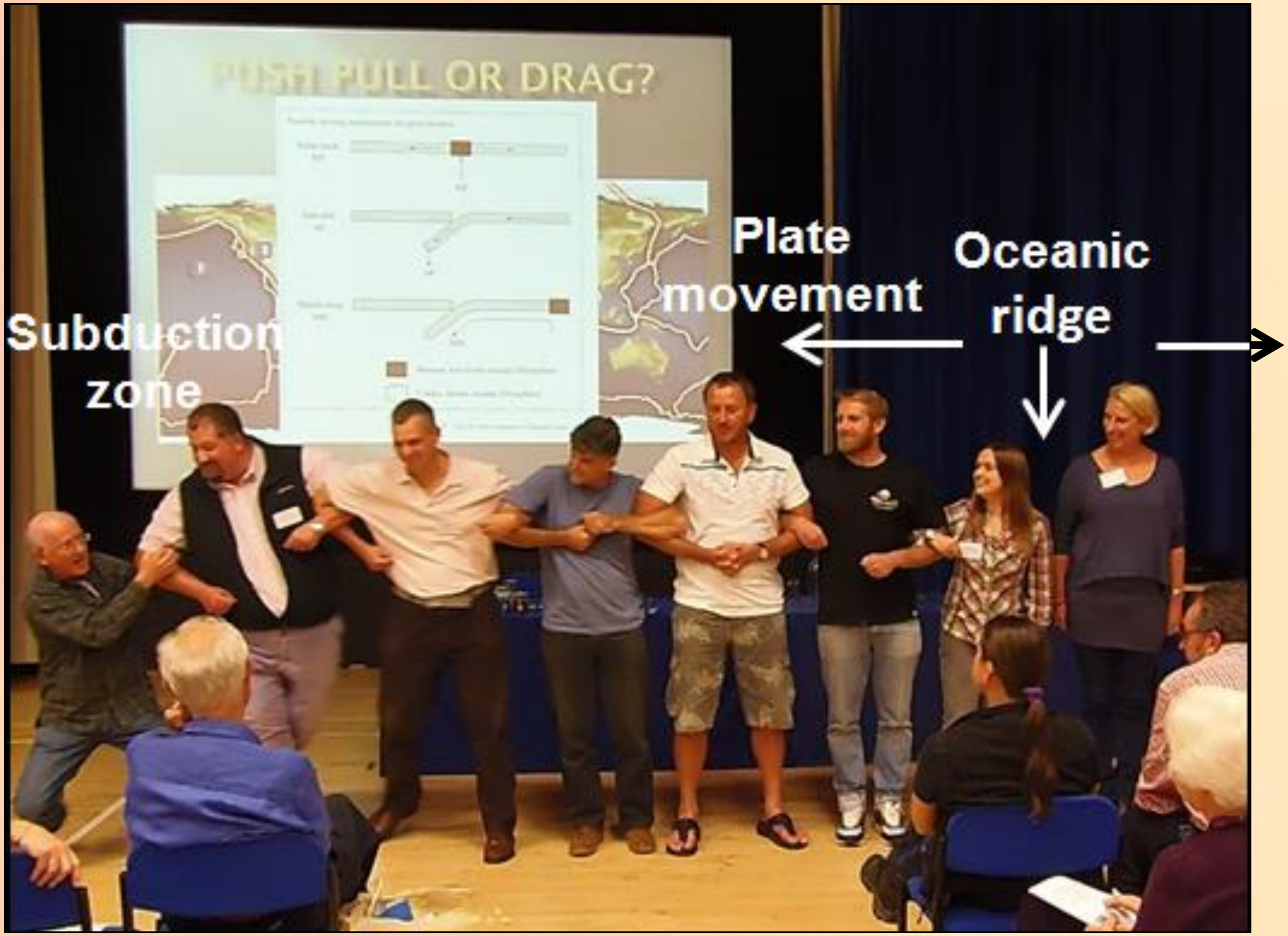
What drives the plates?



Stab pull © David Bailey

The Earth and Plate Tectonics

What drives the plates?

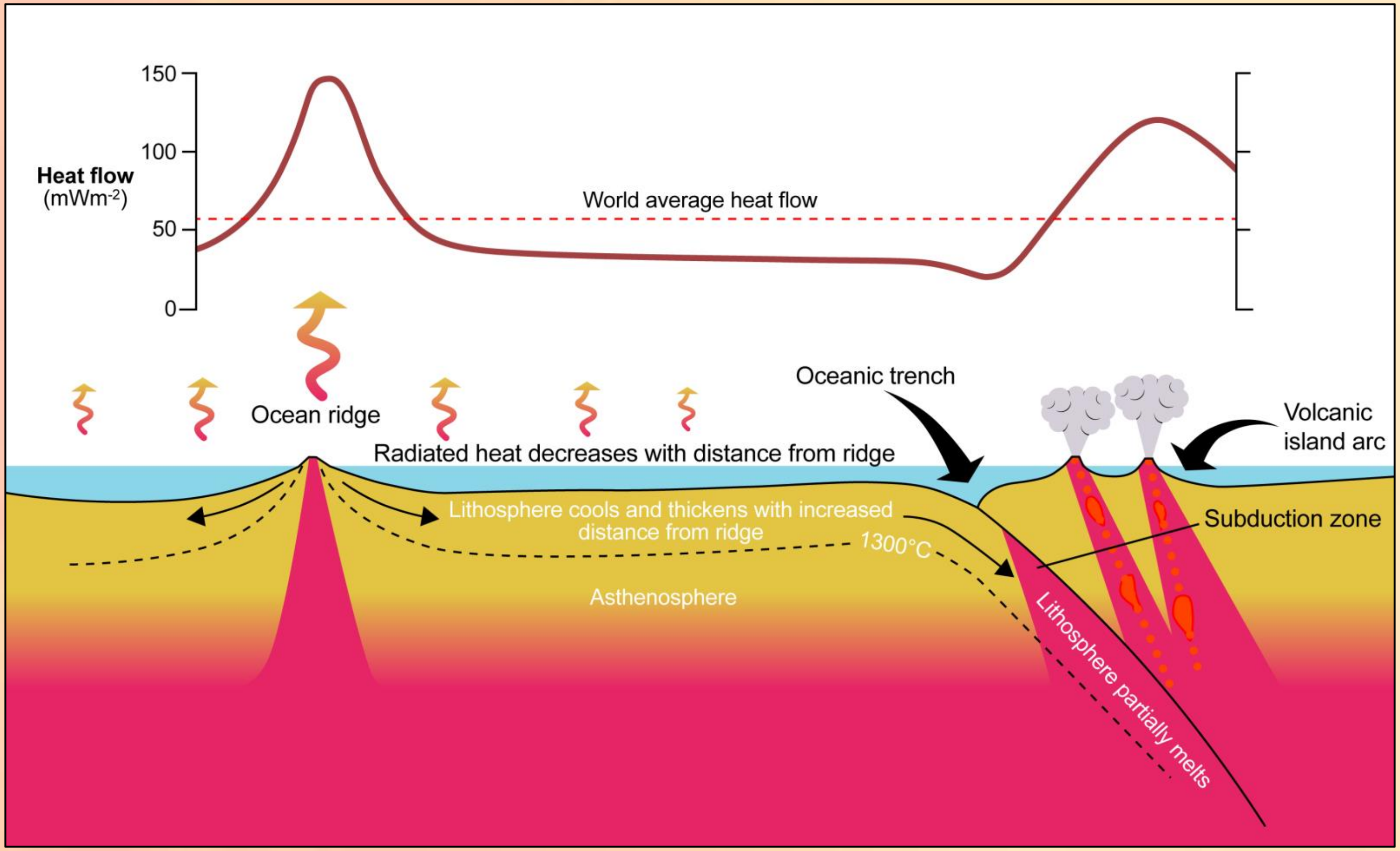


Stab pull © David Bailey

The Earth and Plate Tectonics

The heat flow evidence

The pattern of heat flow from the Earth



The pattern of heat flow out of the ocean floor and the upper part of the mantle and the crust © Chris King and Dee Edwards, redrawn by ESEU

The Earth and Plate Tectonics

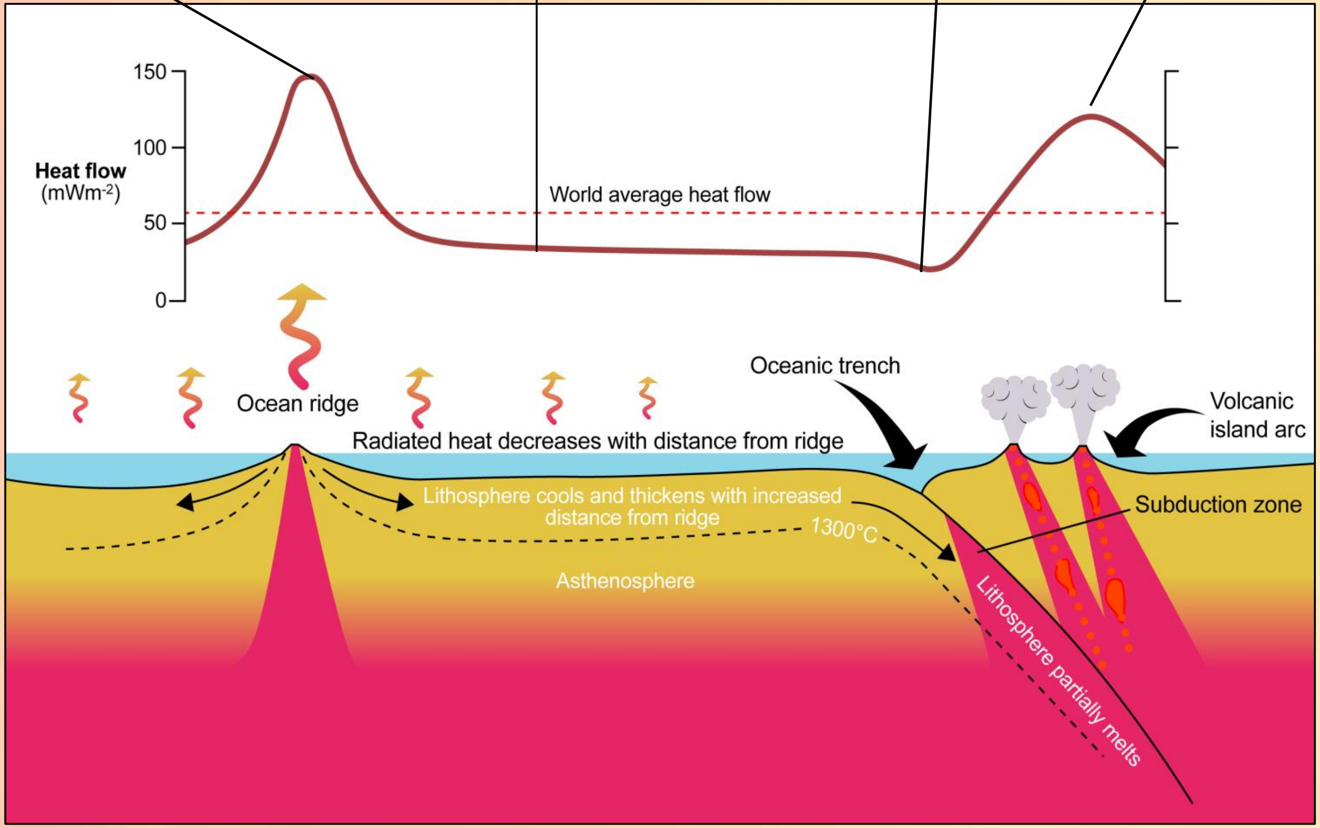
The pattern of heat flow from the Earth

High heat flow – from rising current at ridge

Heat flow reducing as plate cools

Lowest heat flow at trench

High heat flow from volcanicity



The pattern of heat flow out of the ocean floor and the upper part of the mantle and the crust © Chris King and Dee Edwards, redrawn by ESEU

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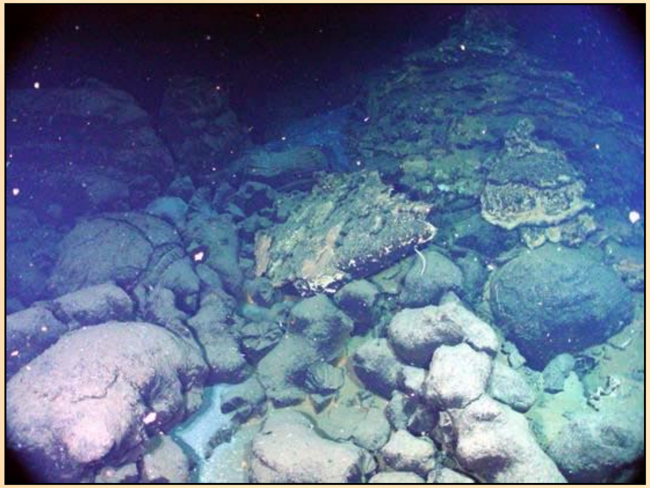
The age of the ocean floor evidence:
ocean floors are young where new plate is being formed, becoming older outwards



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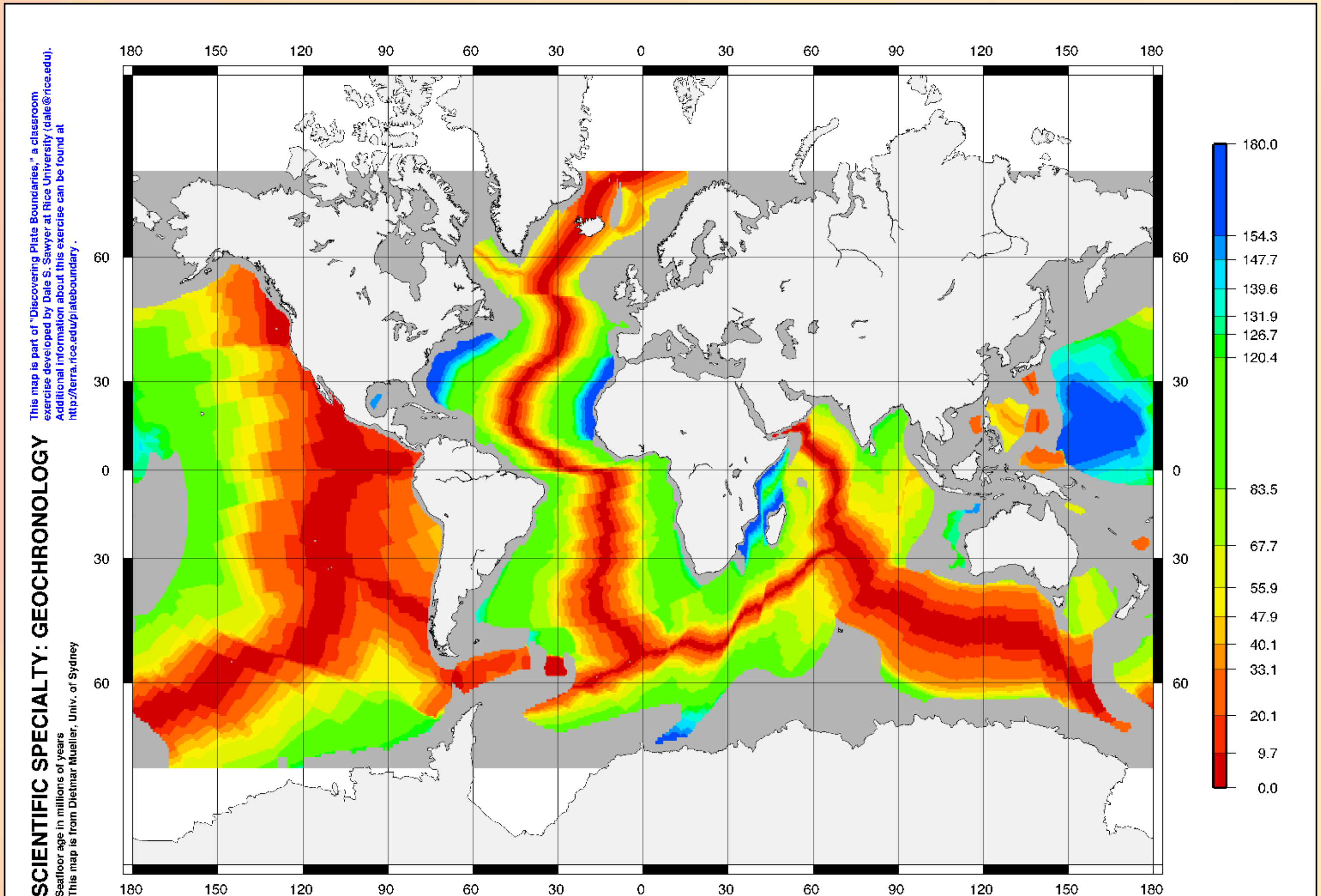
Evidence from the age of the sea floor



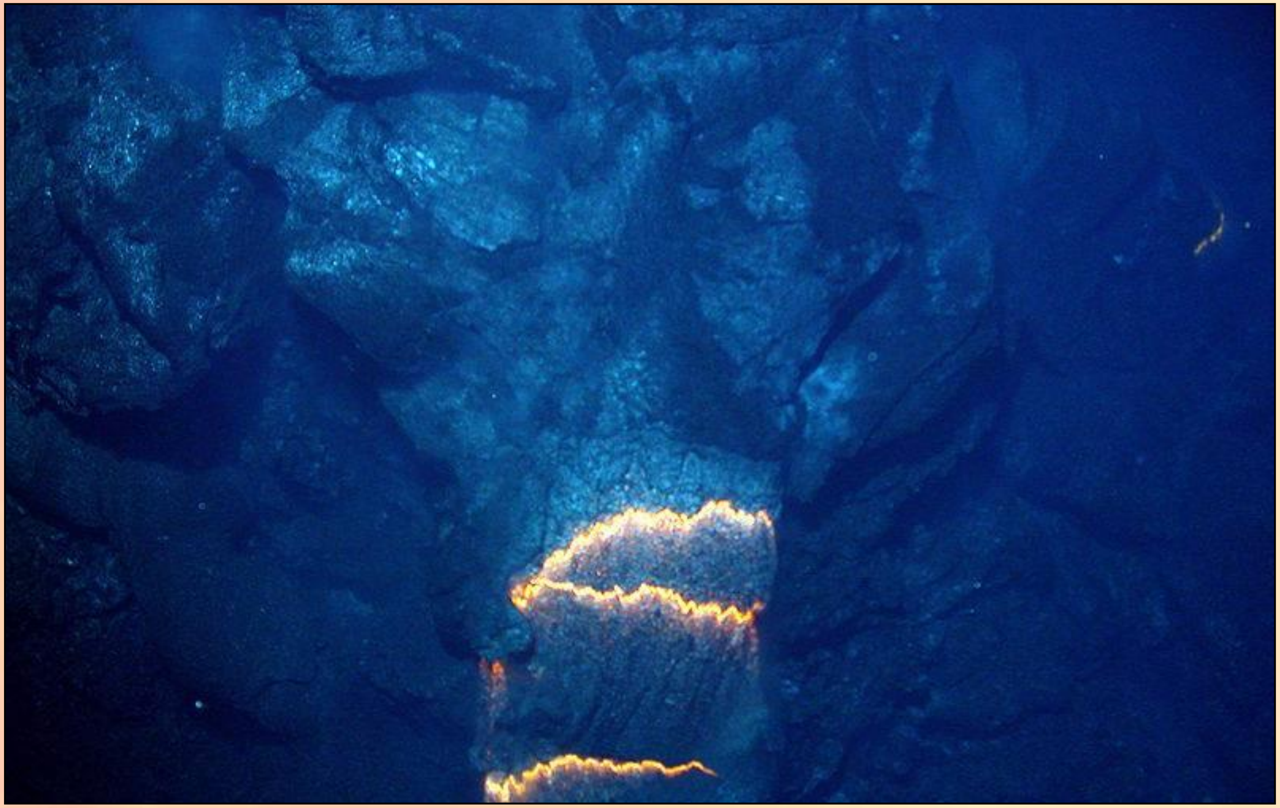
 http://zephyr.rice.edu/plateboundary/home.html

Age of the sea floor – youngest = red, oldest = blue

The Earth and Plate Tectonics

Constructive plate margins -

adding new plate material



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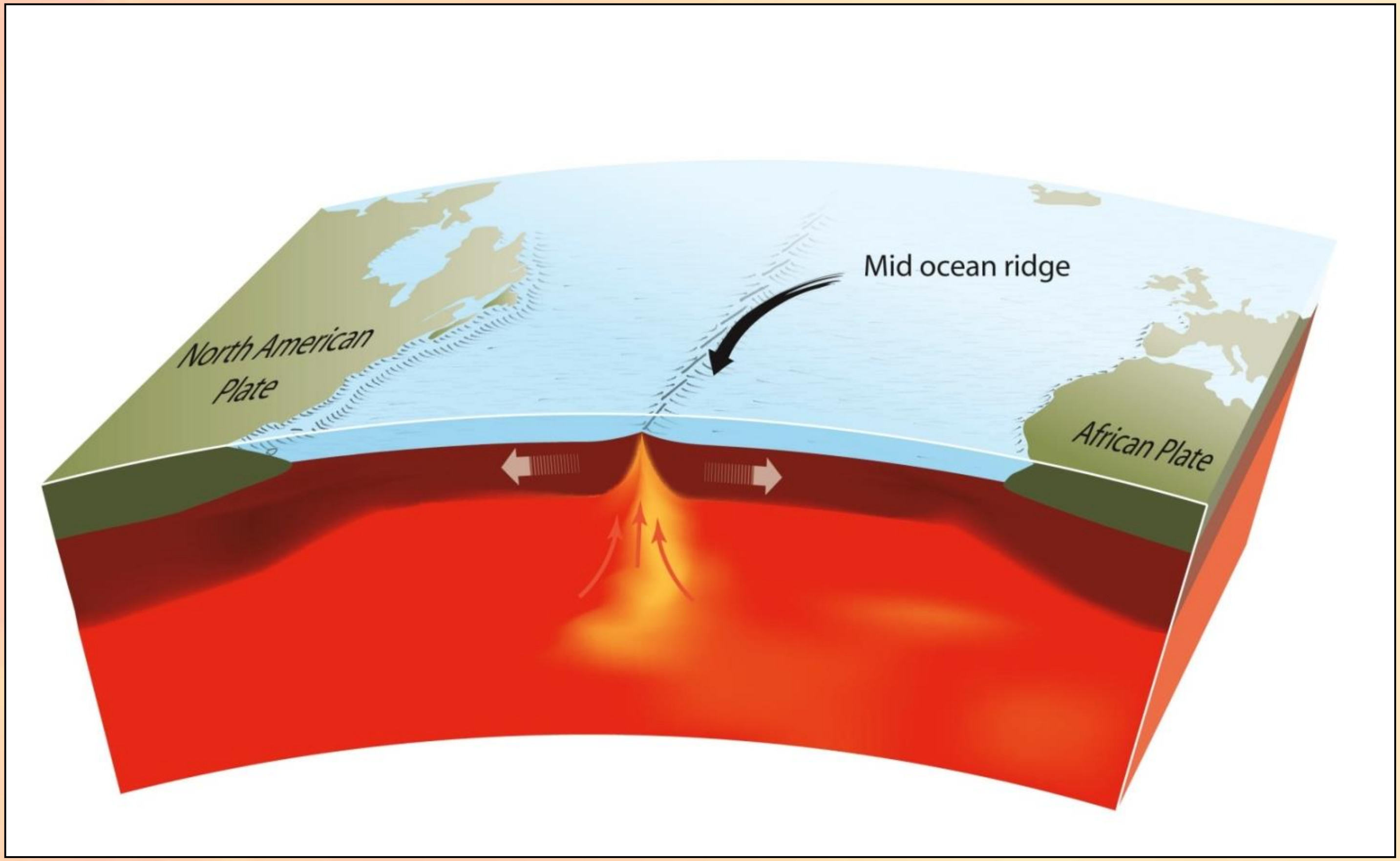
Activity at an oceanic ridge – a constructive plate margin



An oceanic ridge © Press & Siever, redrawn by ESEU

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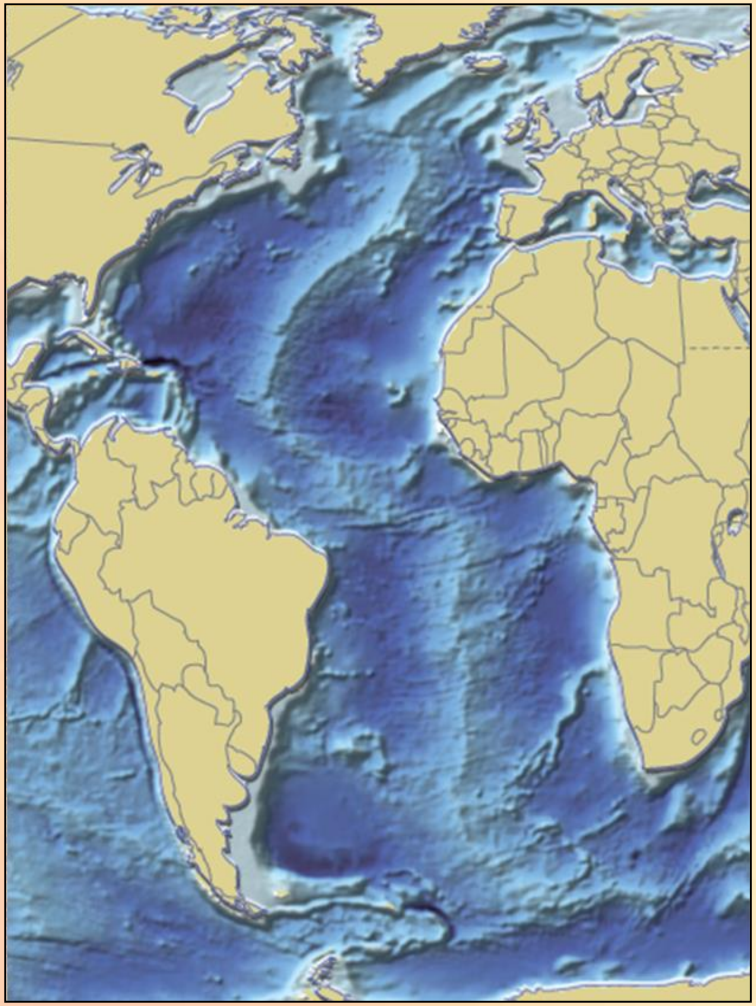
Mid-Atlantic ridge



http://maps.grida.no/go/graphic/world-ocean-bathymetric-map
(Hugo Ahlenius, UNEP/GRID-Arendal)

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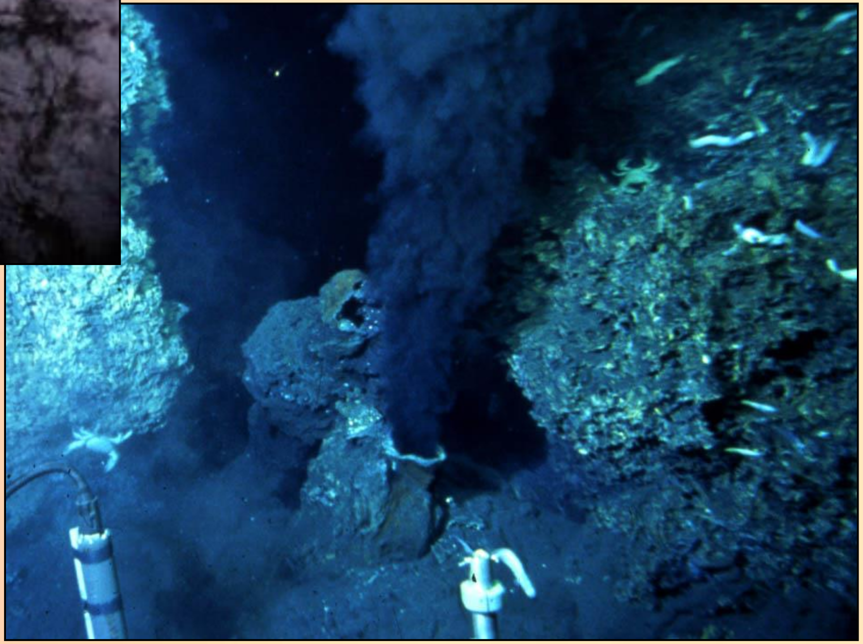
Black smoker activity



Black Smoker' by US National Oceanic & Atmospheric Administration (public domain)

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Icelandic-type eruption

Icelandic-type eruption - reproduced with kind permission of U.S. Department of Interior, USGS

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Ancient pillow lavas

Ancient Pillow lavas © Peter Kennett

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Faults in a Mars™ Bar

Modelling a constructive plate margin

Gap between the North American and Eurasian continental plates © Randomskk

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Faults in a Mars™ Bar

Faults in a Mars™ Bar (A rift valley) © Peter Kennett

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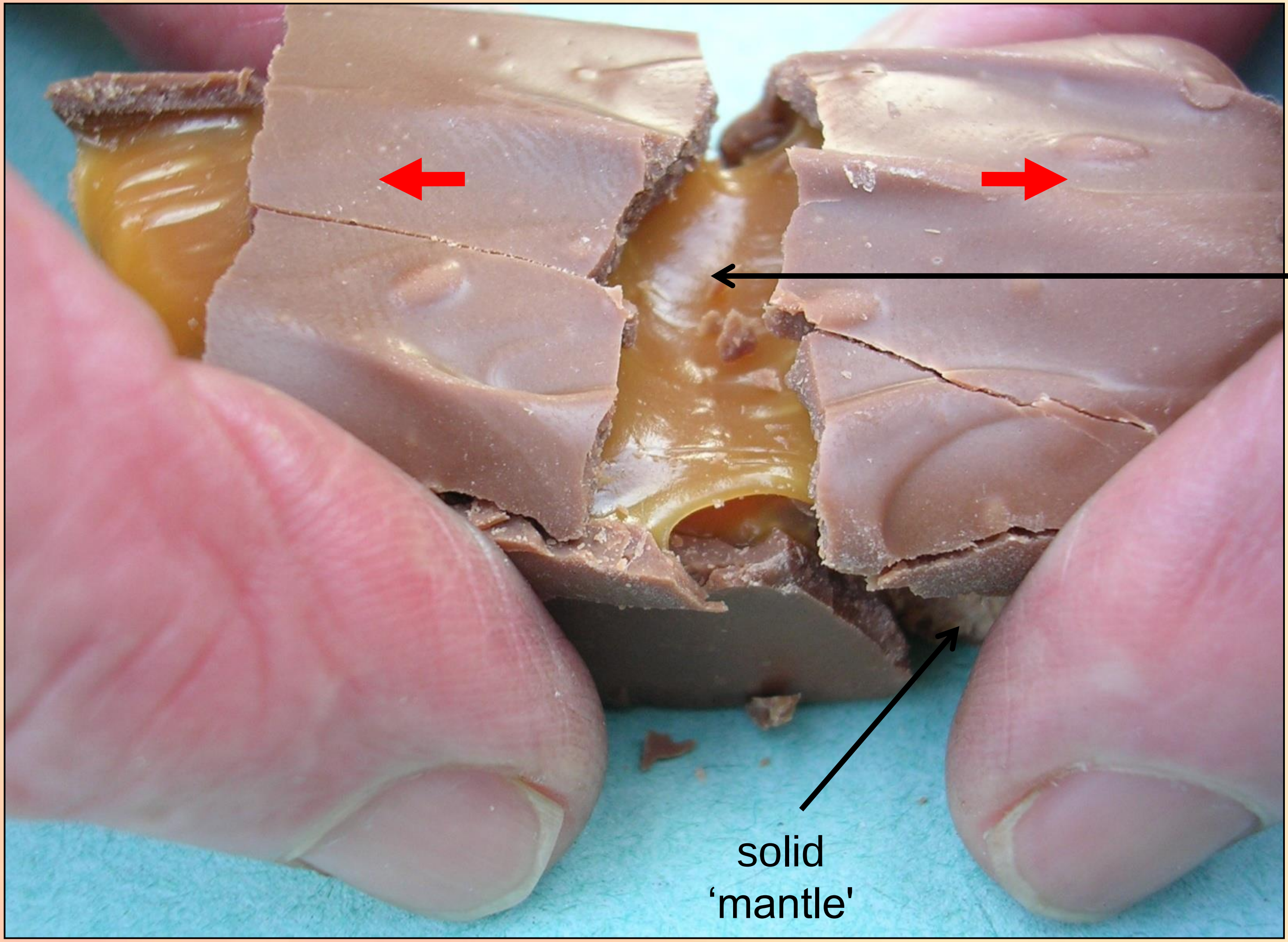
Faults in a Mars™ Bar

central ‘rift valley'

rigid ‘lithosphere’ moving left

rigid ‘lithosphere’ moving right

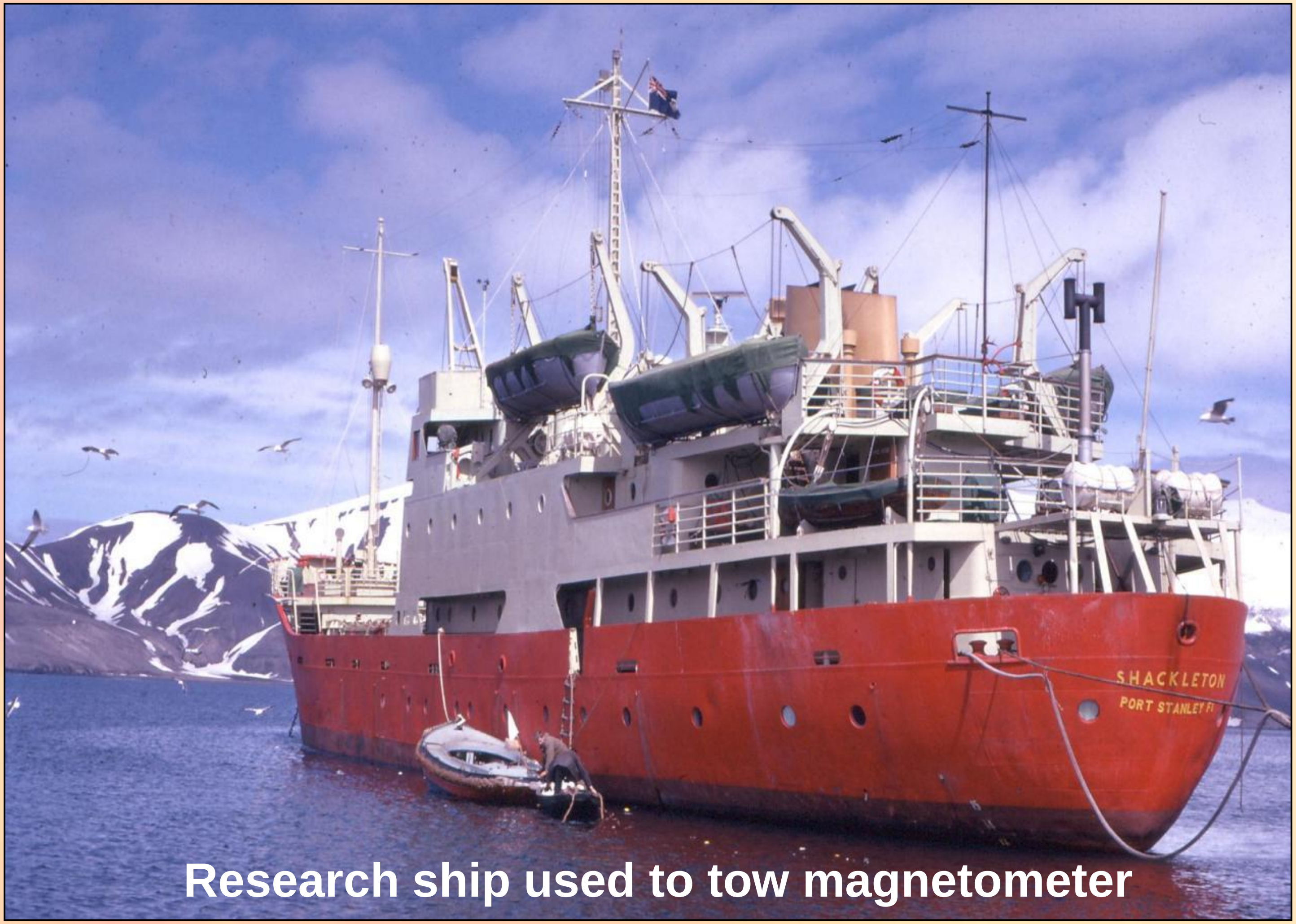


ductile flowing ‘astheno-sphere'

solid ‘mantle'

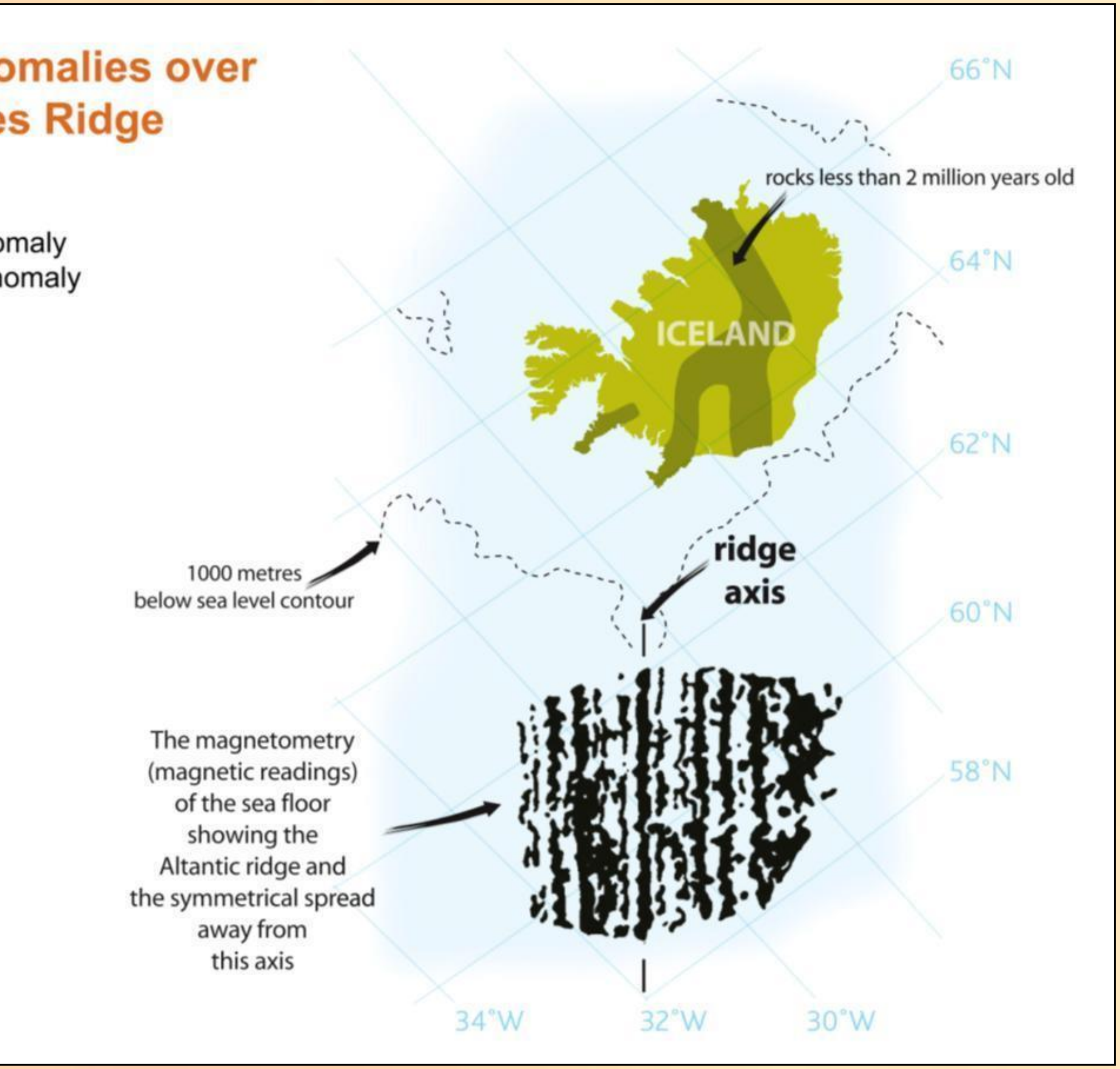
The Earth and Plate Tectonics

The magnetic stripes evidence



Research ship used to tow magnetometer

The Earth and Plate Tectonics



The equipment used to show magnetic anomalies © Peter Kennett

Magnetic anomalies over the Reykjanes Ridge © Geoscience, redrawn by ESEU

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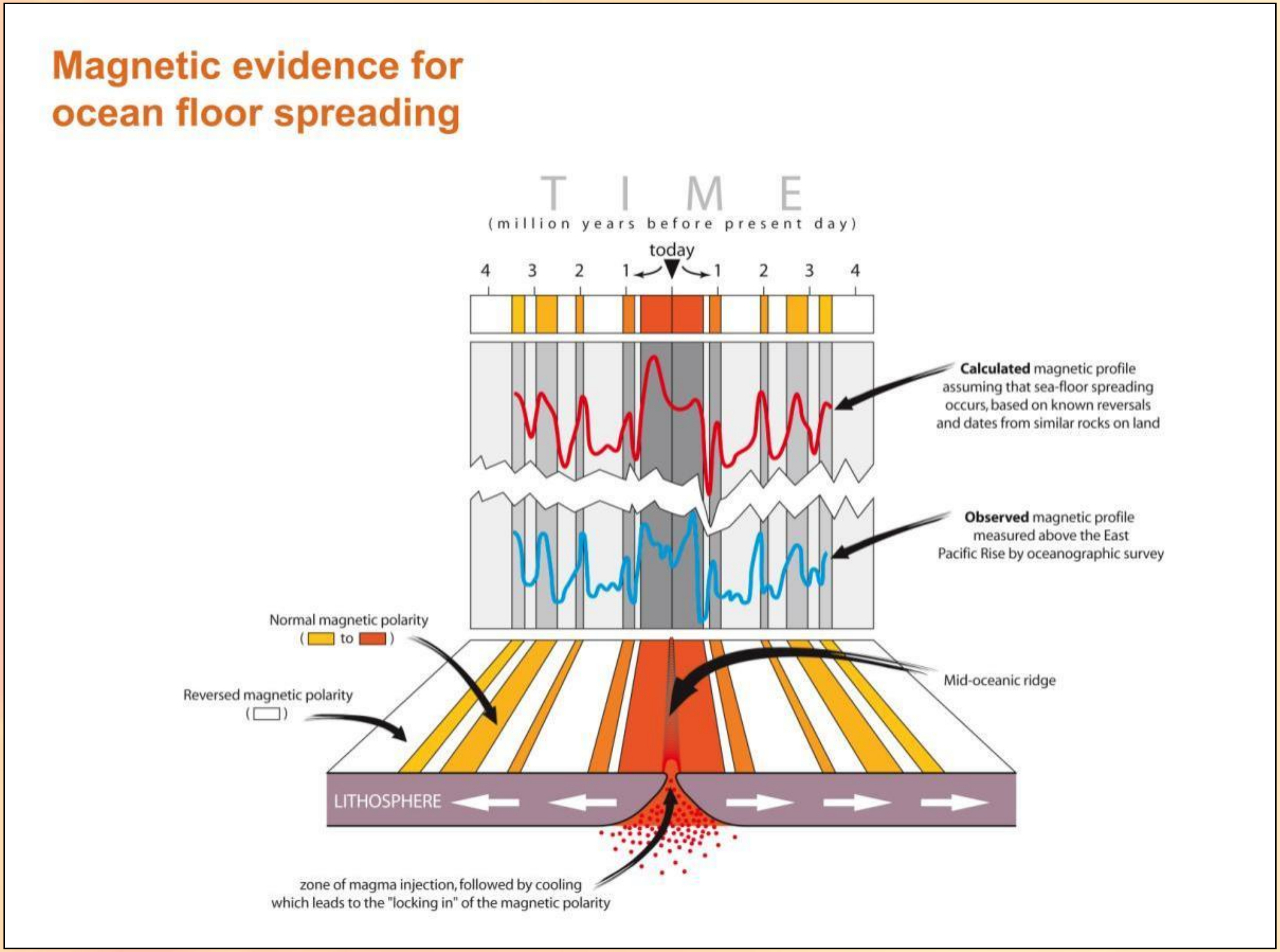

Magnetic evidence for ocean floor spreading © This Dynamic Earth: the Story of Plate Tectonics, USGS, redrawn by ESEU

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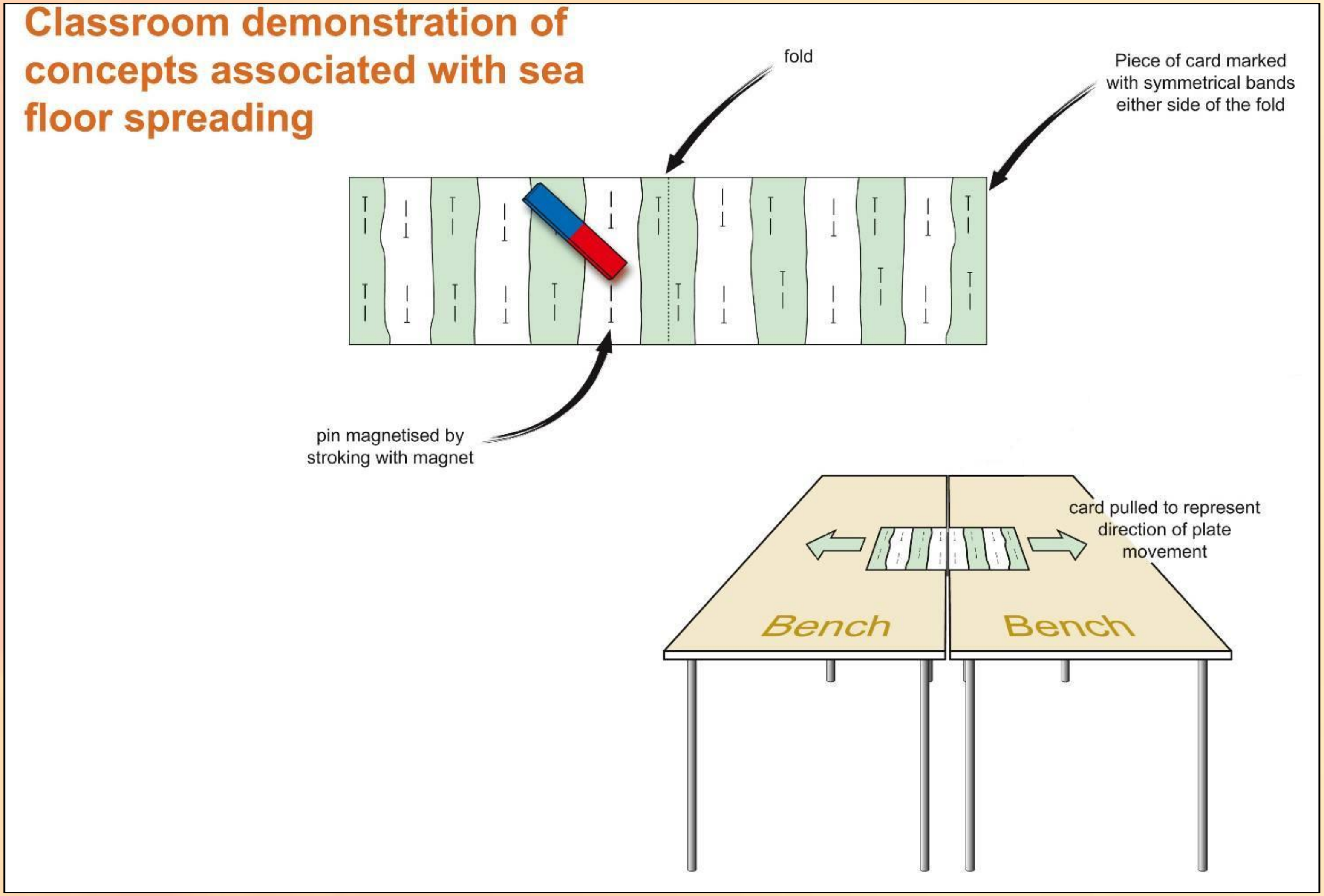
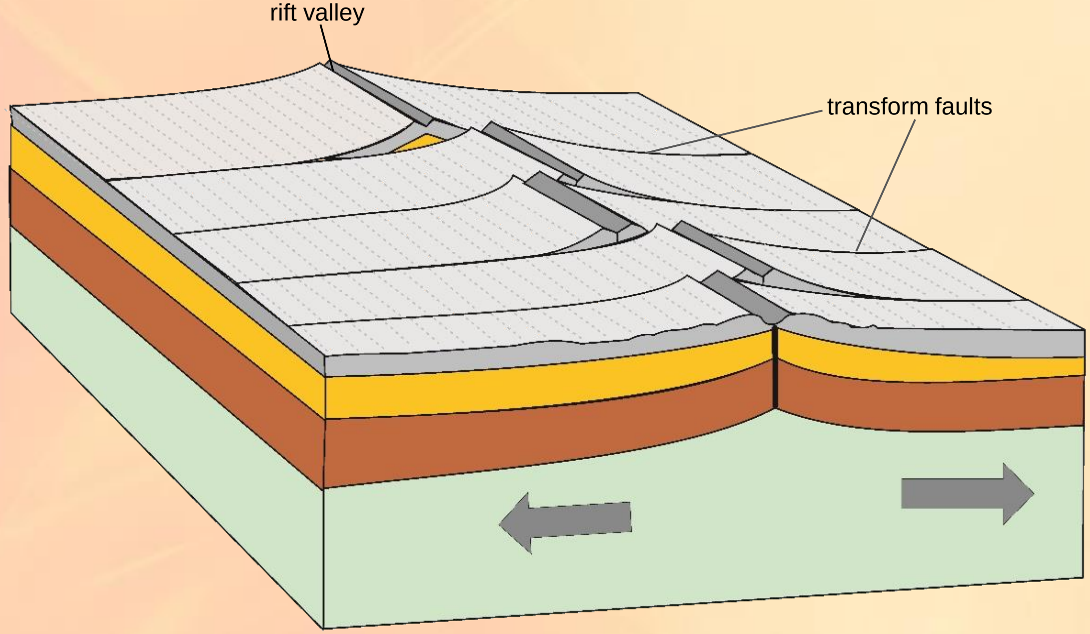


Classroom demonstration of concepts associated with sea floor spreading © ESTA redrawn by ESEU

The Earth and Plate Tectonics

Conservative plate margins - sliding



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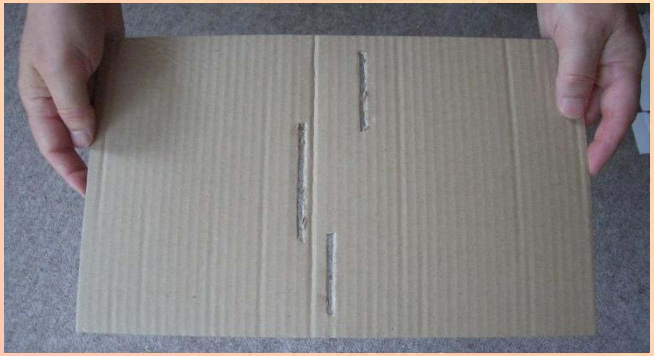
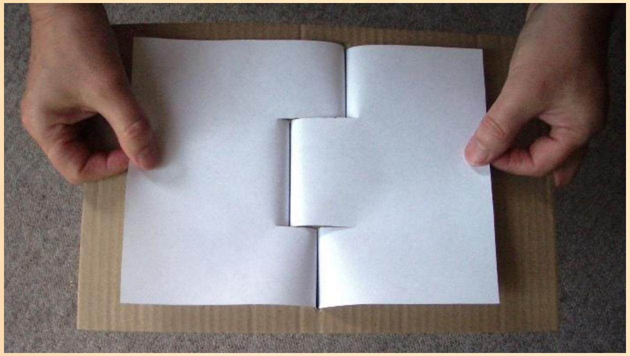
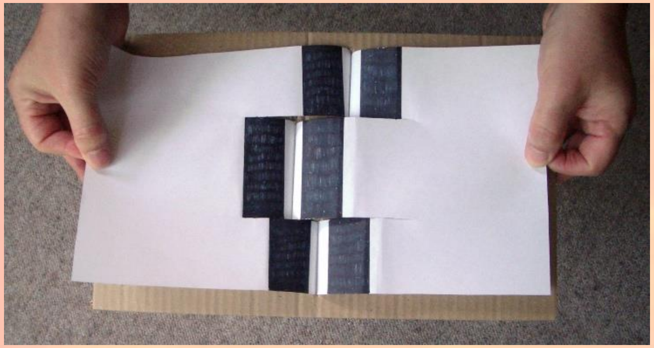
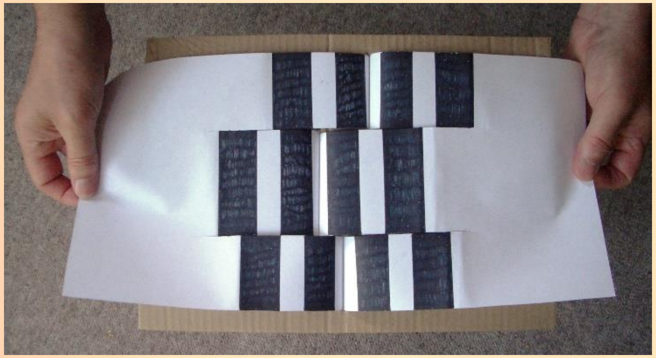
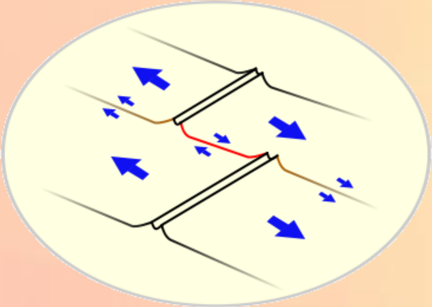
Conservative plate margins - sliding





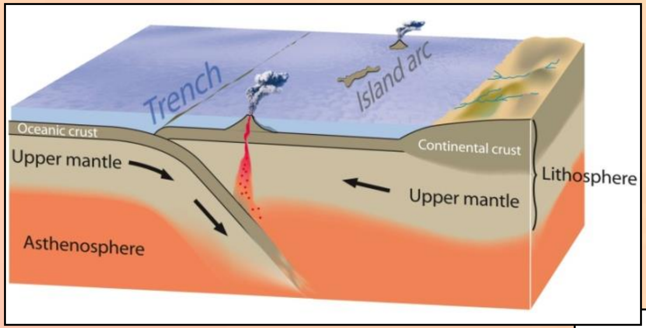


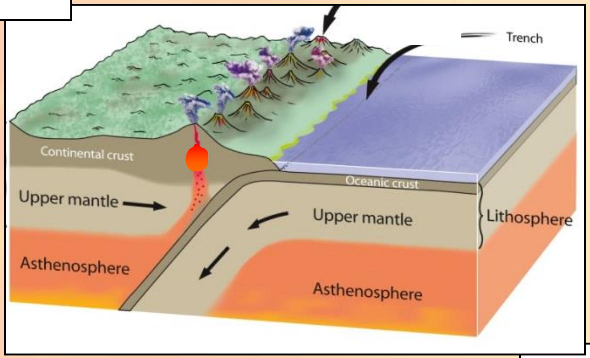


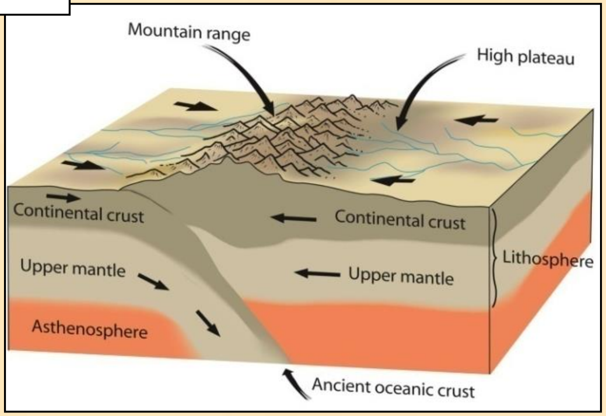


The Earth and Plate Tectonics

Destructive plate margins - recycling material







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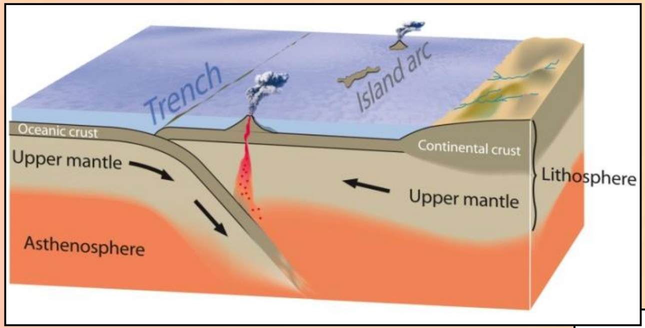
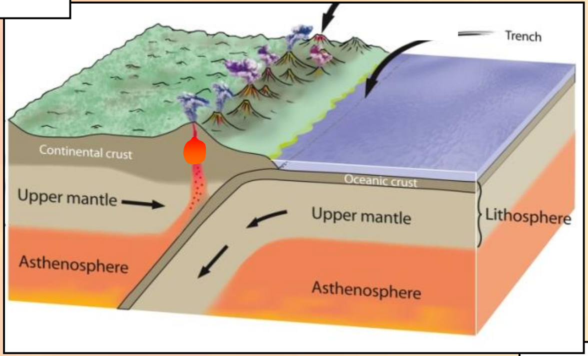
Destructive plate margins - recycling material

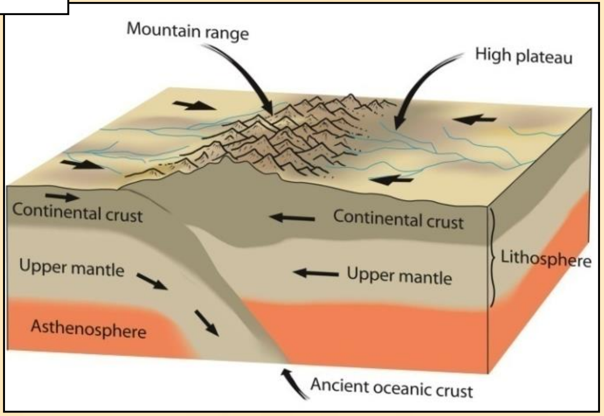


Ocean v ocean destructive plate margin – one oceanic plate subducted beneath another

Ocean v continent destructive plate margin – an oceanic plate subducted beneath a continental plate

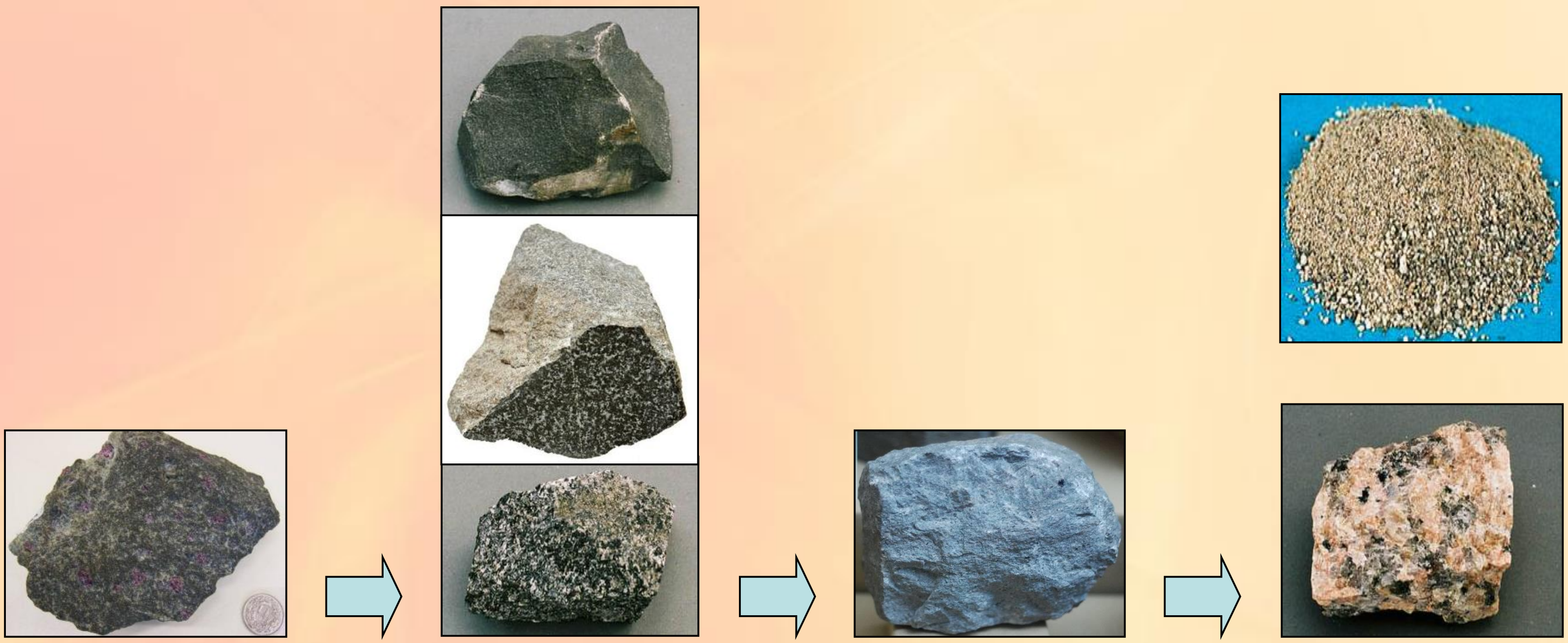


Continent v continent destructive plate margin – two continental plates colliding



The Earth and Plate Tectonics

Partial melting - producing new materials that are chemically different and of lower density



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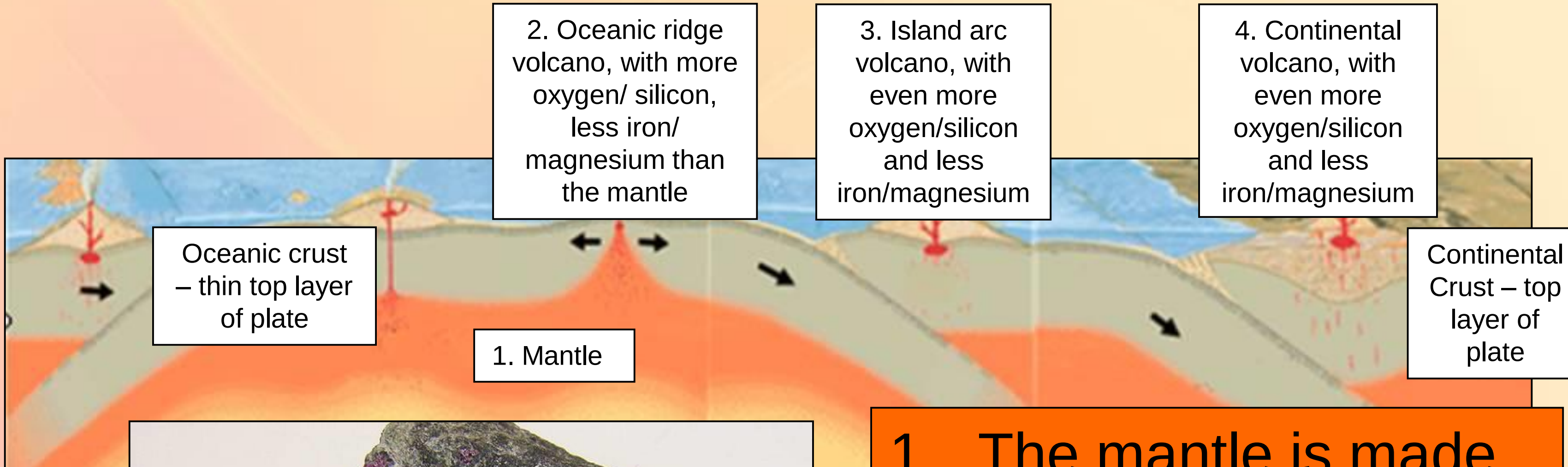
Partial melting

The Earth and Plate Tectonics

Magma composition evidence

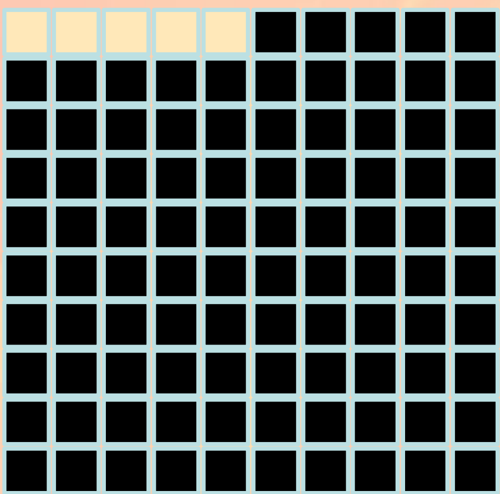


1. The mantle is made of peridotite – very rich in iron/magnesium-rich minerals, very poor in oxygen/ silicon- rich minerals (compared with crustal rocks)

The Earth and Plate Tectonics

1. **The mantle** is made of peridotite – very rich in iron/magnesium-rich minerals, very poor in oxygen/ silicon-rich minerals (compared with crustal rocks)

Peridotite: around 95% iron/magnesium-rich minerals, around 5% oxygen/silicon-rich minerals



Block of 100 squares – represents the percentage of minerals in rock

- Oxygen/silicon-rich mineral: pale in colour, relatively low density
- Iron/magnesium-rich mineral: dark in colour, relatively high density

The Earth and Plate Tectonics

2. **Beneath ocean ridges**, mantle peridotite partially melts producing basaltic magma (iron/magnesium-rich, oxygen/silicon-poor)

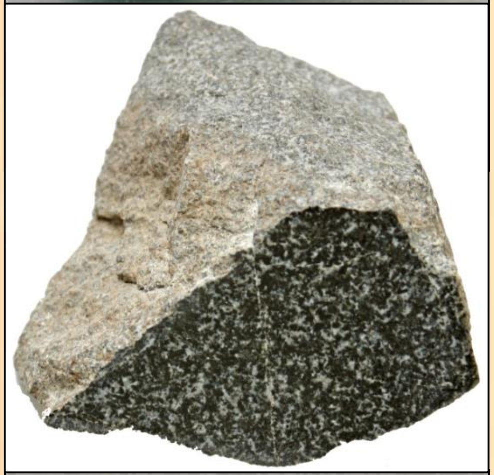
The mantle: very iron/magnesium-rich, very oxygen/silicon-poor rock (compared with crustal rocks)

Peridotite – very rich in iron/magnesium, very poor in oxygen/silicon (compared with crustal rocks)

Partial melting →

Oceanic crust: iron/magnesium-rich, oxygen/silicon-poor crustal rock

Basalt – fine-grained basaltic rock

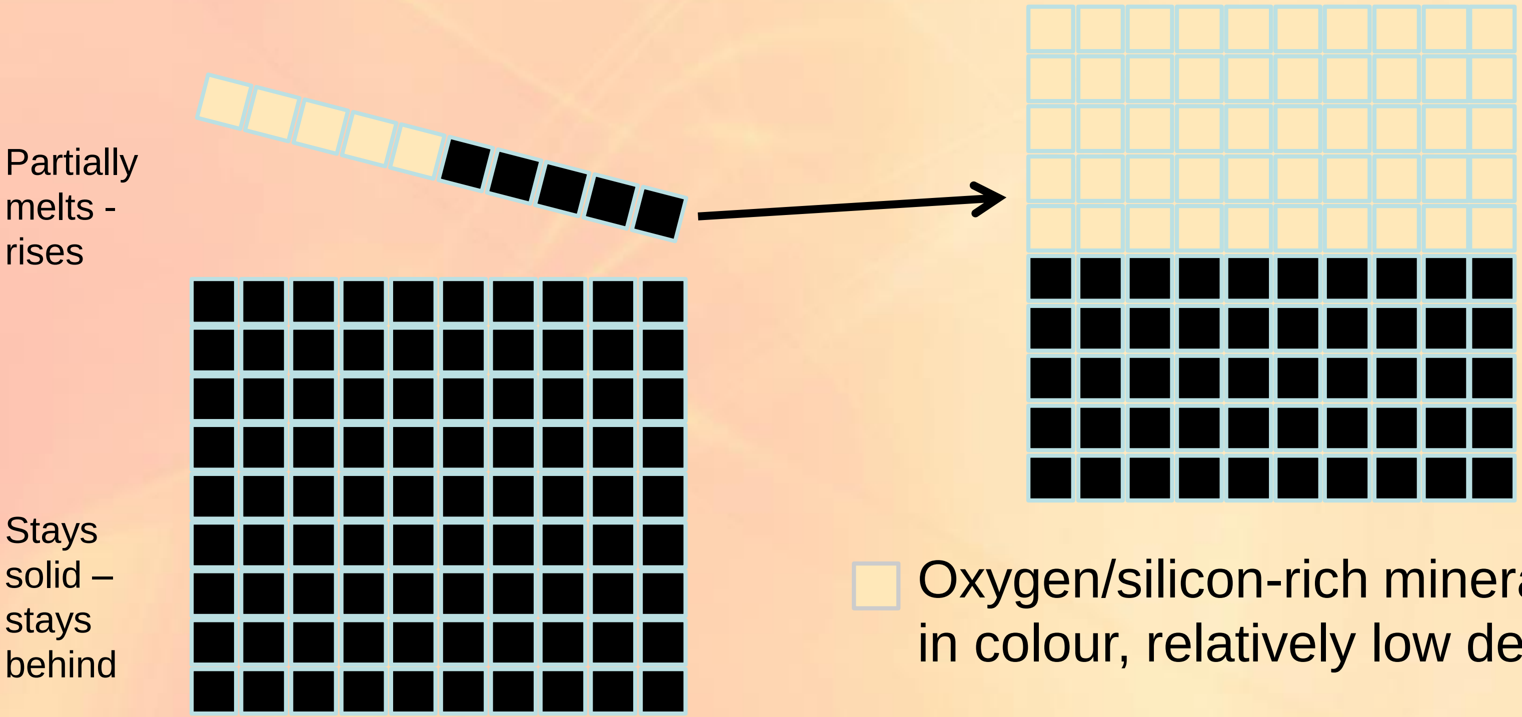


Dolerite – medium-grained basaltic rock

Gabbro – coarse-grained basaltic rock

The Earth and Plate Tectonics

2. **Beneath ocean ridges,** mantle peridotite partially melts producing basaltic magma (iron/magensium-rich, oxygen/silicon-poor)

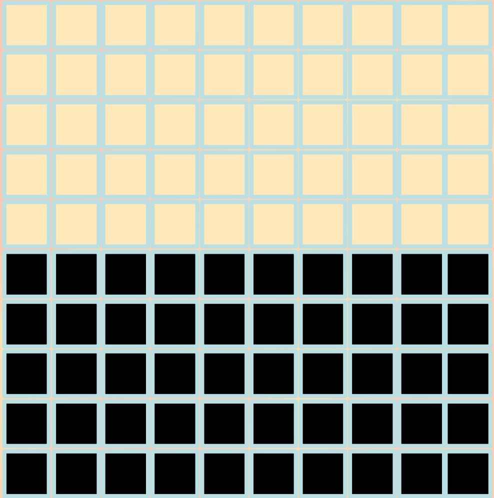


Oxygen/silicon-rich mineral: pale in colour, relatively low density

Iron/magnesium-rich mineral: dark in colour, relatively high density

The Earth and Plate Tectonics

2. **Beneath ocean ridges**, mantle peridotite partially melts producing basaltic magma (iron/magnesium-rich, oxygen/silicon-poor)



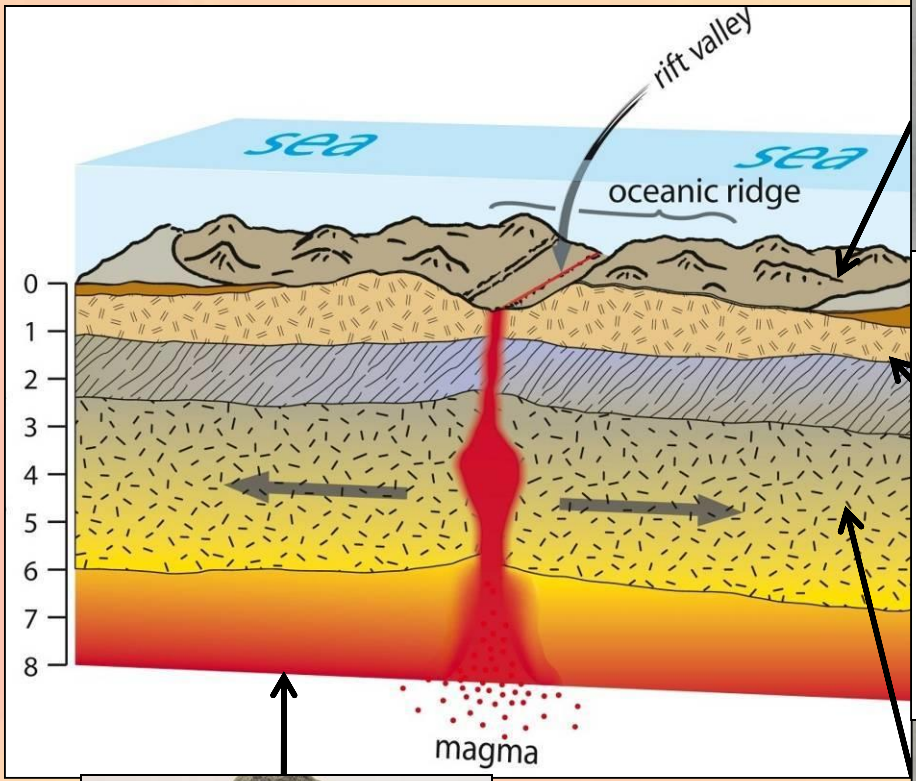
Basaltic magma: cools to produce rocks with around 50% iron/magnesium-rich minerals, around 50% oxygen/silicon-rich minerals.

- ☐ Oxygen/silicon-rich mineral: pale in colour, relatively low density
- ■ Iron/magnesium-rich mineral: dark in colour, relatively high density

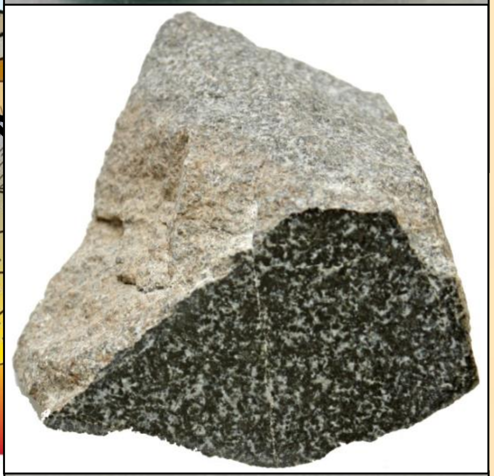
The Earth and Plate Tectonics

Oceanic ridge

Oceanic crust: iron/magnesium-rich, oxygen/silicon-poor crustal rock



Basalt – fine-grained basaltic rock



Dolerite – medium-grained basaltic rock

Gabbro – coarse-grained basaltic rock

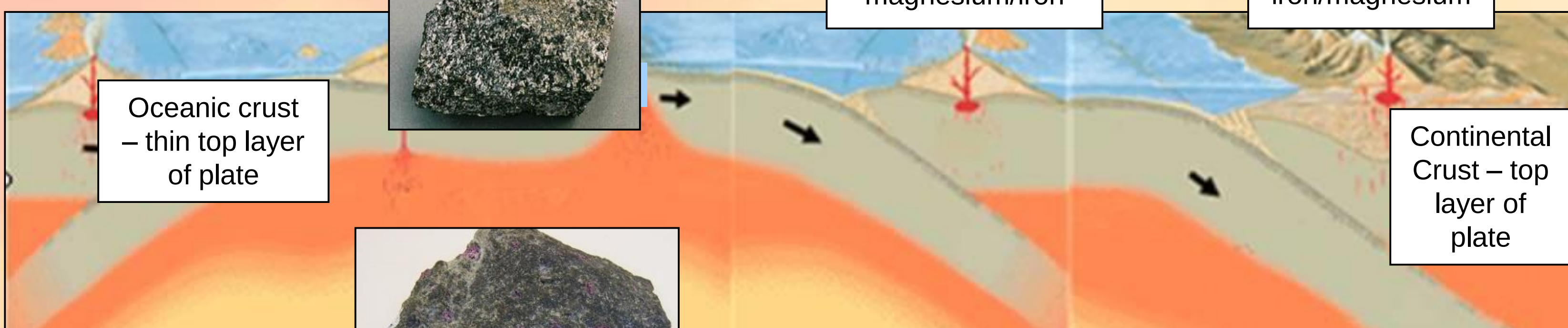
Peridotite – very rich in iron/magnesium, very poor in oxygen/silicon (compared with crustal rocks)

The Earth and Plate Tectonics

Magma composition evidence

Oceanic crust: iron/magnesium-rich, oxygen/silicon-poor crustal rock.

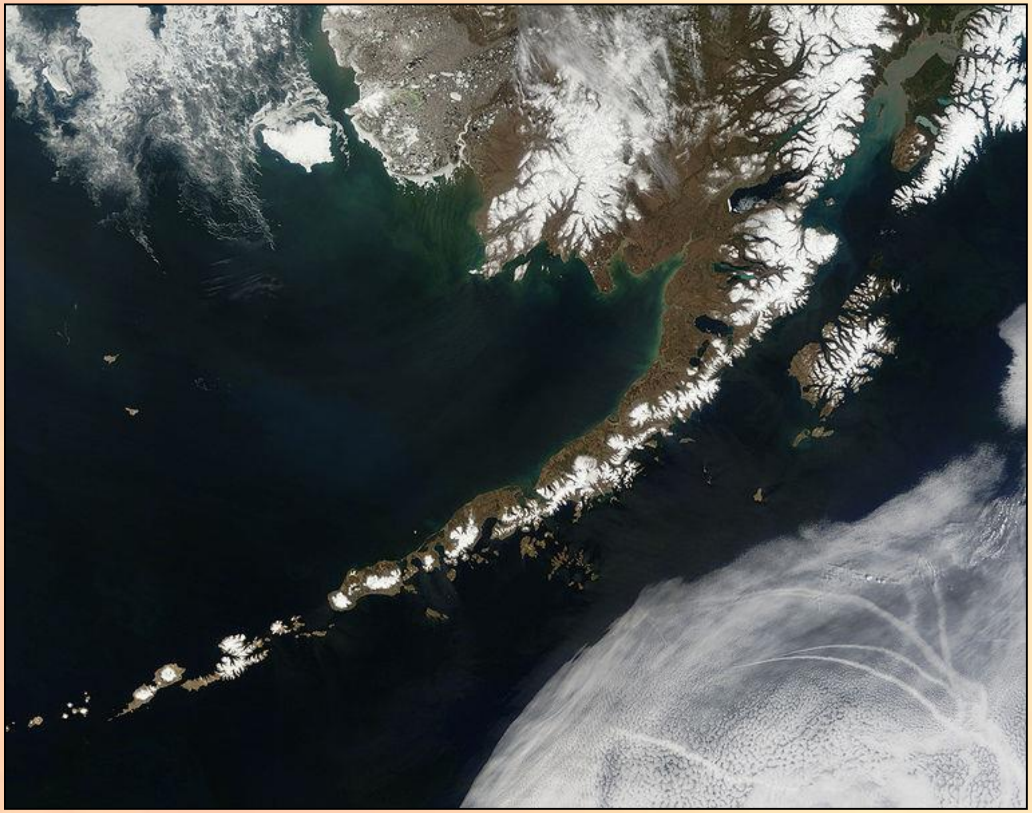
Gabbro with dolerite above, overlain by pillow basalt



The mantle: very iron/magnesium-rich, very oxygen/silicon-poor rock (compared with crustal rocks)

The Earth and Plate Tectonics

Destructive plate margins:
where plate material is recycled

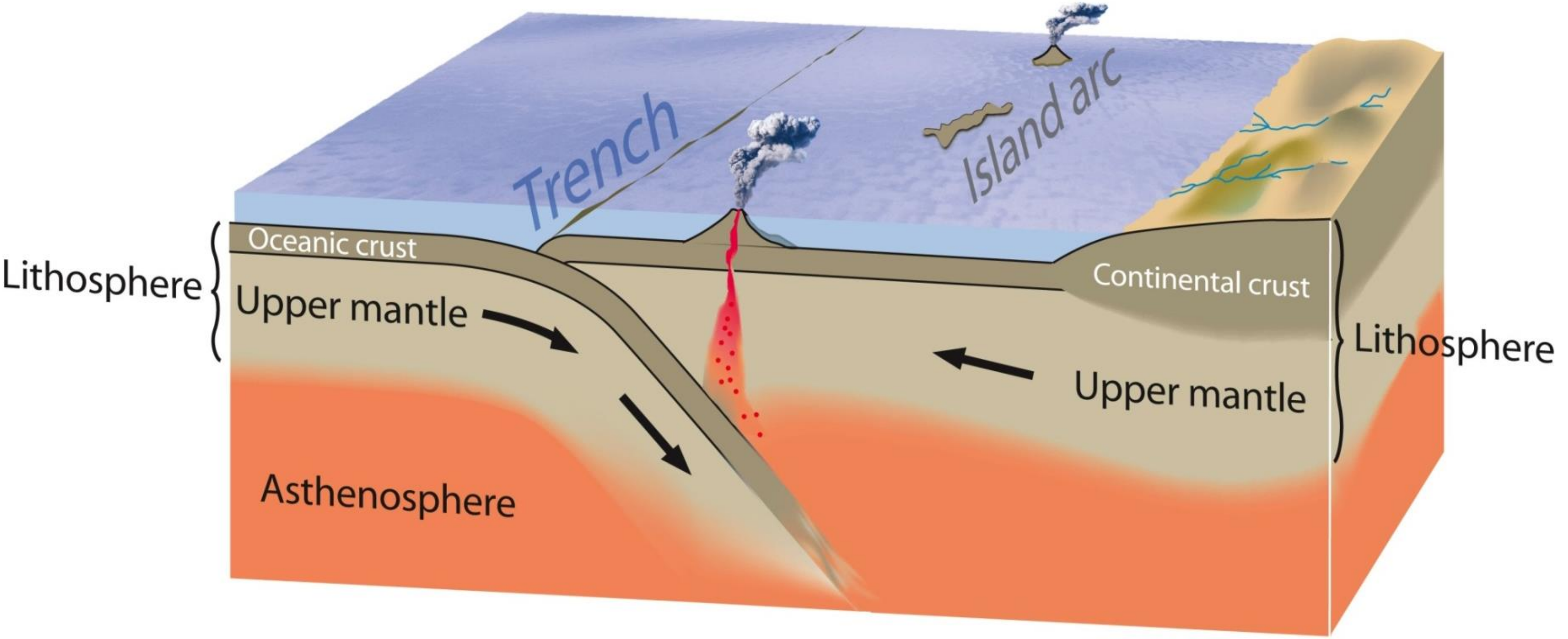


‘A satellite view of the Aleutian Islands, Pacific Ocean’ by NASA (public domain)

The Earth and Plate Tectonics

Ocean-ocean convergence

Two oceanic plates meet in the open ocean.
The denser plate is subducted into the mantle.
Partial melting produces magma which rises
to form an island arc.



Subduction zone ('partially melts and volcanoes are produced' 'molten rock cools down below the surface') - reproduced with kind permission of USGS, redrawn by ESEU

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Island arc volcanism

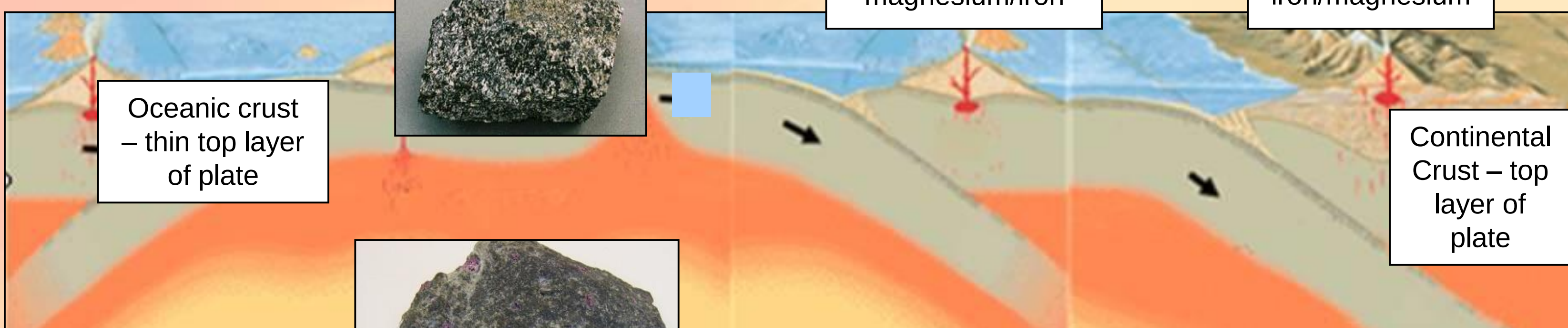
Zavodovski Island, South Sandwich Island, South Atlantic (Peter Kennett)

The Earth and Plate Tectonics

Magma composition evidence

Oceanic crust: iron/magnesium-rich, oxygen/silicon-poor crustal rock.

Gabbro with dolerite above, overlain by pillow basalt



The mantle: very iron/magnesium-rich, very oxygen/silicon-poor rock (compared with crustal rocks)

The Earth and Plate Tectonics

3. **Island arcs** – beneath island arcs, oceanic crust partially melts producing andesitic magma (iron/magnesium-moderate, oxygen/silicon-moderate)

Andesitic island arc volcanoes – iron/magnesium -moderate, oxygen/silicon-moderate rock

© Beatrice Murch from Buenos Aires, Argentina

Andesite – fine-grained andesitic rock

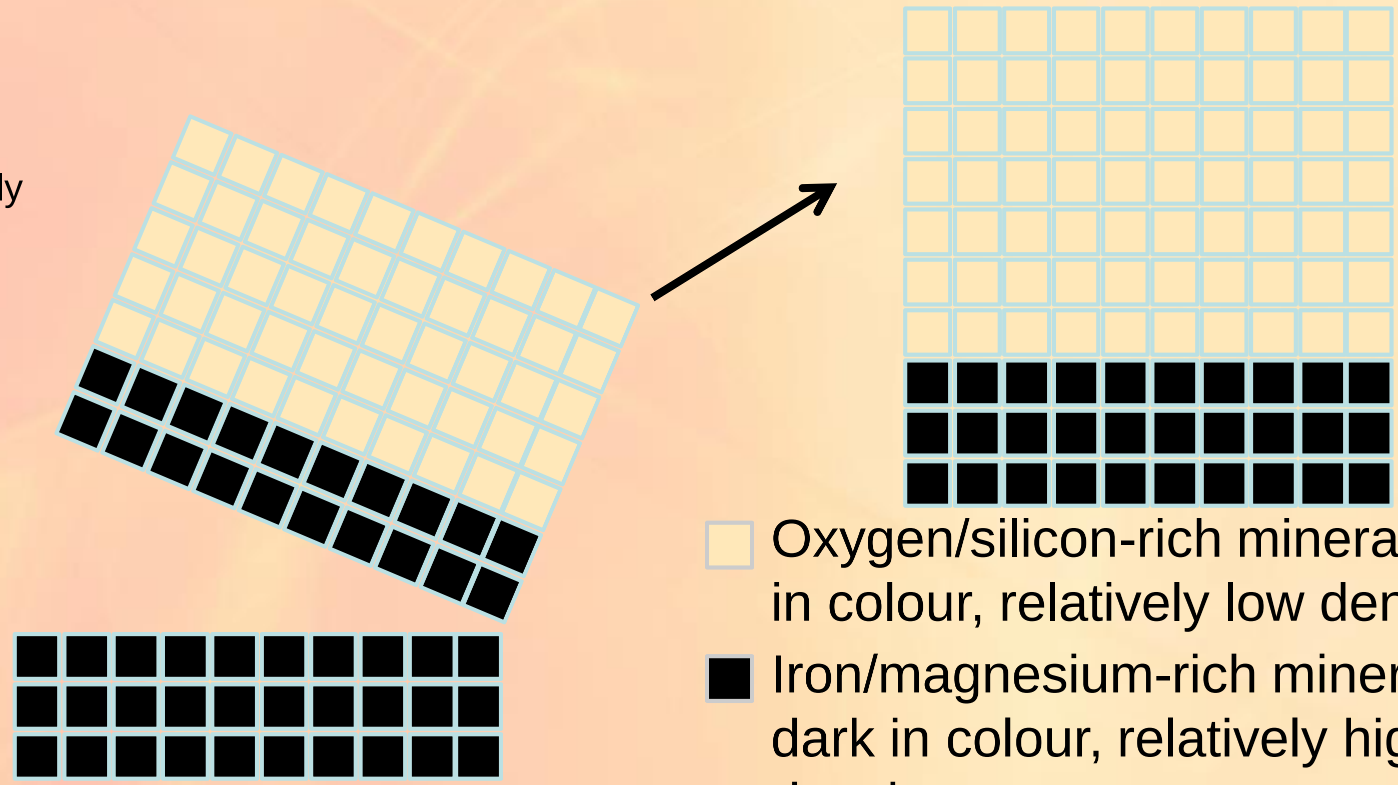
Partial melting

Oceanic crust: iron/magnesium-rich, oxygen/silicon-poor rock.

Gabbro with dolerite above, overlain by pillow basalt

The Earth and Plate Tectonics

3. **Magma composition evidence** – beneath island arcs, oceanic crust partially melts producing andesitic magma (iron/magnesium-moderate, oxygen/silicon-moderate)

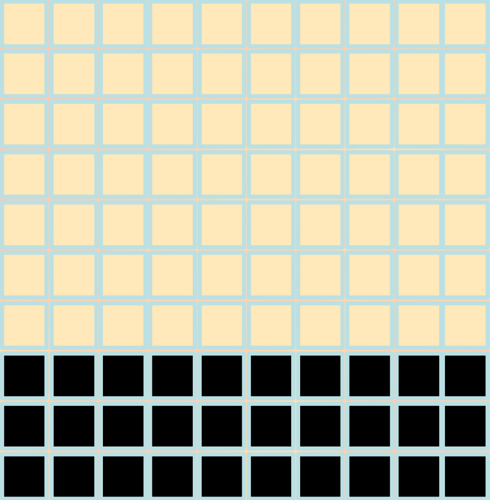


- Oxygen/silicon-rich mineral: pale in colour, relatively low density
- Iron/magnesium-rich mineral: dark in colour, relatively high density

The Earth and Plate Tectonics

3. **Island arcs** – beneath island arcs, oceanic crust partially melts producing andesitic magma (iron/magnesium-moderate, oxygen/silicon-moderate)

Andesitic magma: cools to produce rocks with around 30% iron/magnesium-rich minerals, around 70% oxygen/silicon-rich minerals.



- Oxygen/silicon-rich mineral: pale in colour, relatively low density
- Iron/magnesium-rich mineral: dark in colour, relatively high density

The Earth and Plate Tectonics

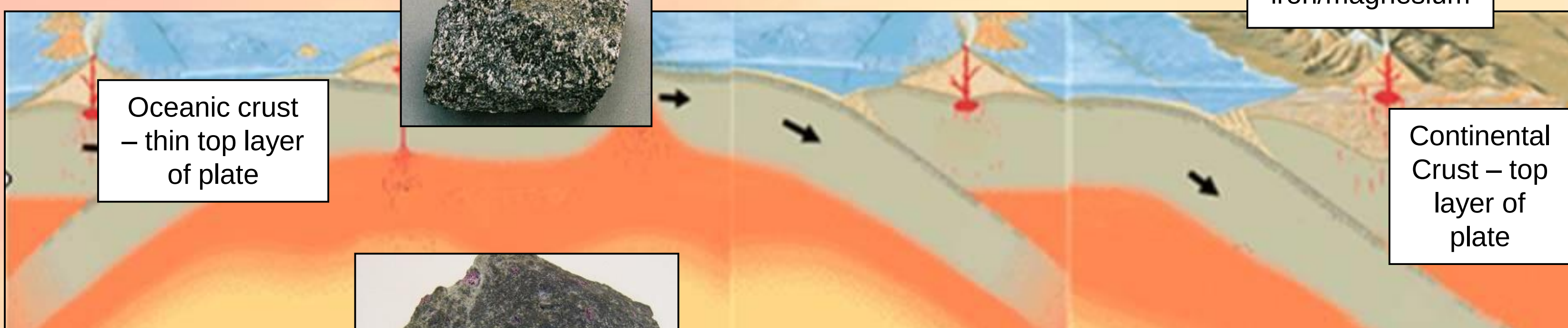
Magma composition evidence

Oceanic crust: iron/magnesium-rich, oxygen/silicon-poor crustal rock.

Gabbro with dolerite above, overlain by pillow basalt

© Beatrice Murch from Buenos Aires, Argentina

Andesitic island arc volcanoes – iron/ magnesium-moderate, oxygen/silicon-moderate rock

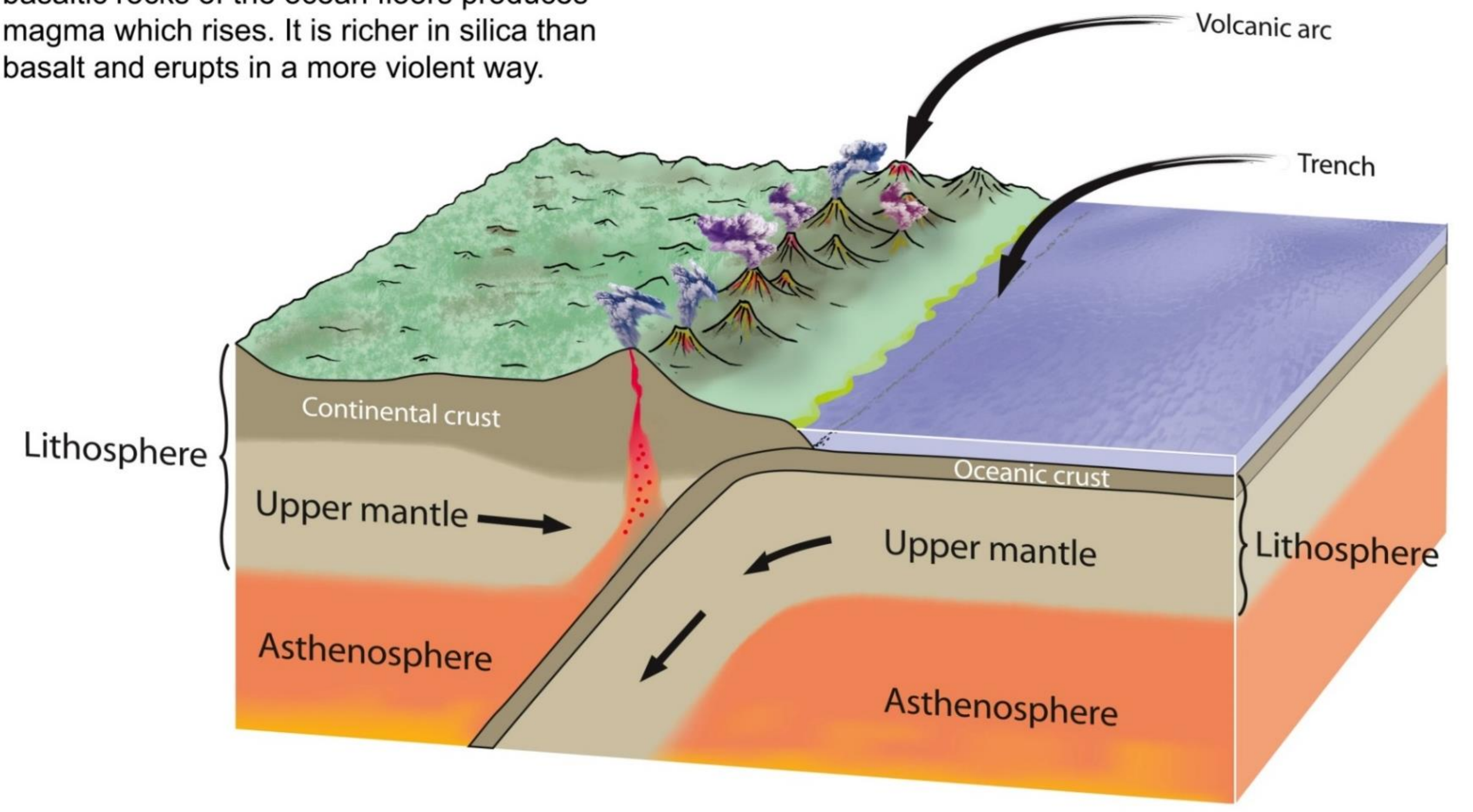


The mantle: very iron/magnesium-rich, very oxygen/silicon-poor rock (compared with crustal rocks)

The Earth and Plate Tectonics

Ocean-continent convergence

The dense oceanic plate descends below the lighter continental one. Partial melting of the basaltic rocks of the ocean floors produces magma which rises. It is richer in silica than basalt and erupts in a more violent way.



Subduction zone (‘partially melts and volcanoes are produced’ ‘molten rock cools down below the surface’) - reproduced with kind permission of USGS, redrawn by ESEU

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Ocean-continent convergence:
Mount St Helens

Mount St Helens © USGS/Cascades Volcano Observatory

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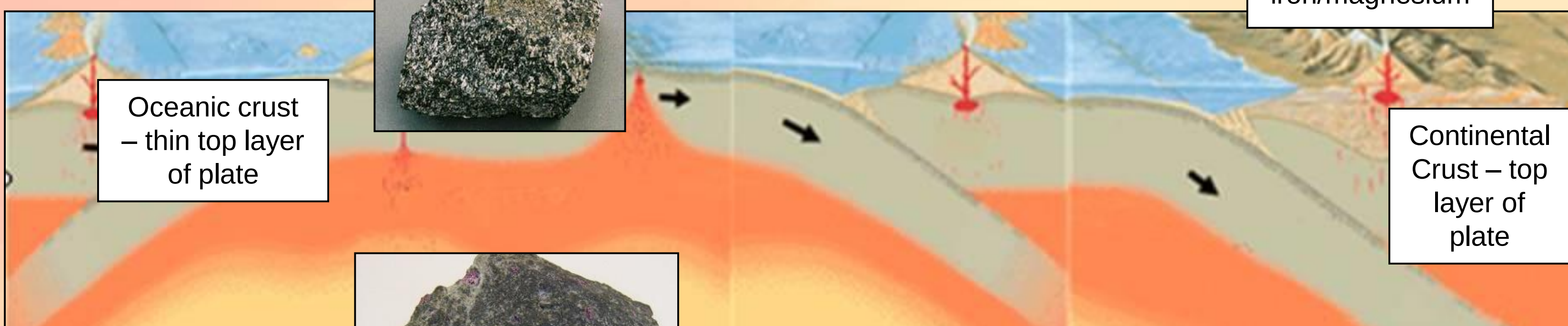
Magma composition evidence

Oceanic crust: iron/magnesium-rich, oxygen/silicon-poor crustal rock.

Gabbro with dolerite above, overlain by pillow basalt

Andesitic island arc volcanoes – iron/magnesium-moderate, oxygen/silicon-moderate rock

4. Continental volcano, with even more oxygen/silicon and less iron/magnesium



Oceanic crust – thin top layer of plate

Continental Crust – top layer of plate

The mantle: very iron/magnesium-rich, very oxygen/silicon-poor rock (compared with crustal rocks)

The Earth and Plate Tectonics

- **Continental crust** – beneath continents, material partially melts producing silicic magma (iron/magnesium-poor, oxygen/silicon-rich)

Continental volcanoes and intrusions: iron/magnesium-poor, oxygen/silicon-rich rock

Subducting plate (oceanic crust) and the base of the continent partially melt

Partial melting

Volcanic ash, often fine iron-poor, silica-rich ash

Granite – coarse-grained silicic rock

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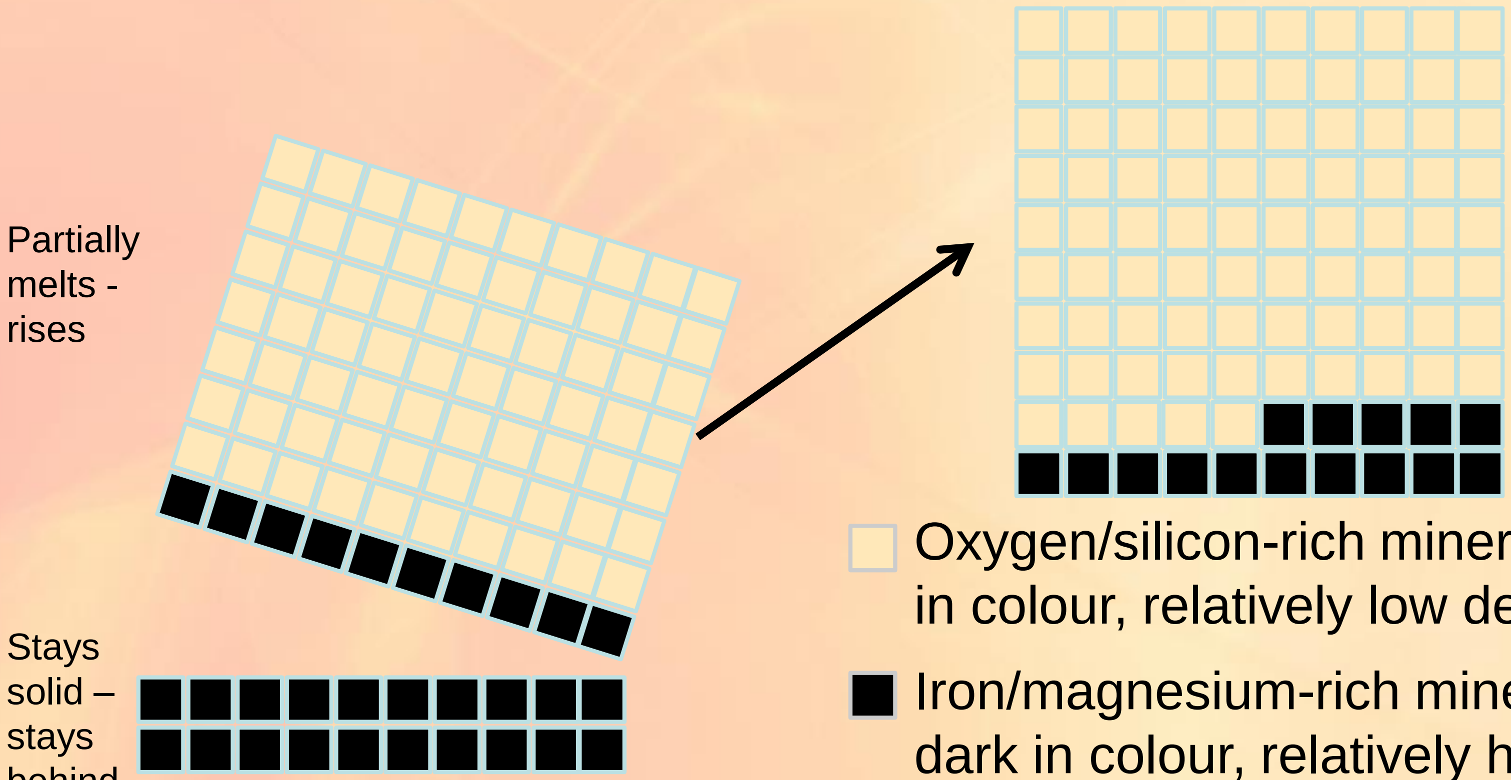
4. **Continental crust** – beneath continents, material partially melts producing silicic magma (iron/magnesium-poor, oxygen/silicon-rich)



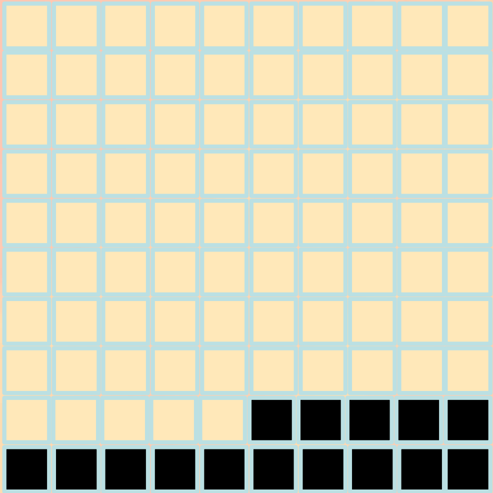
Oxygen/silicon-rich mineral: pale in colour, relatively low density

Iron/magnesium-rich mineral: dark in colour, relatively high density

The Earth and Plate Tectonics

4. **Continental crust** – beneath continents, material partially melts producing silicic magma (iron/magnesium-poor, oxygen/silicon-rich)

Silicic magma: cools to produce rocks with around 15% iron/magnesium-rich minerals, around 85% oxygen/silicon-rich minerals

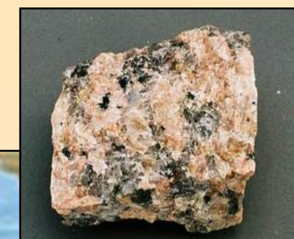


- Oxygen/silicon-rich mineral: pale in colour, relatively low density
- Iron/magnesium-rich mineral: dark in colour, relatively high density

The Earth and Plate Tectonics

The effects of partial melting: a summary

Continental volcanoes and intrusions – iron/magnesium-poor, oxygen/silicon-rich

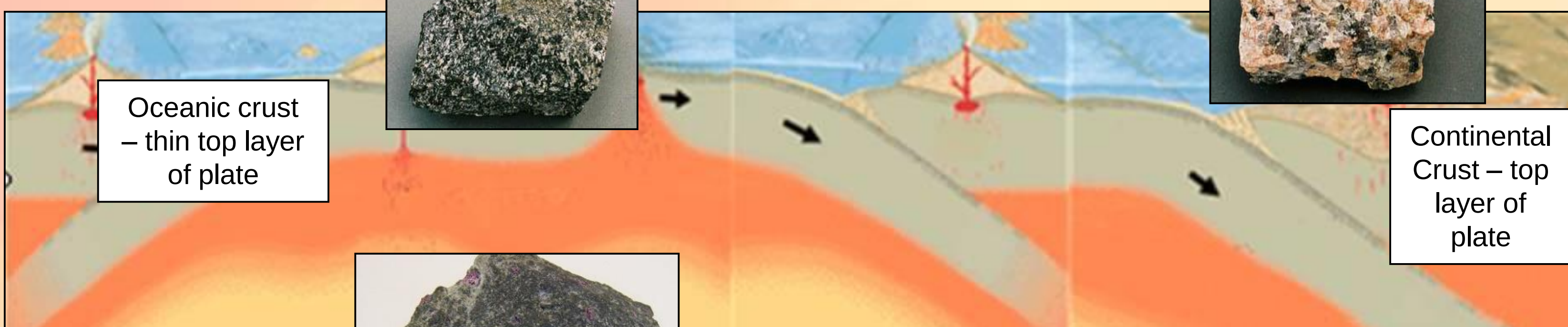


Oceanic crust: iron/magnesium-rich, oxygen/silicon-poor crustal rock.

Gabbro with dolerite above, overlain by pillow basalt

© Beatrice Murch from Buenos Aires, Argentina

Andesitic island arc volcanoes – iron/ magnesium-moderate, oxygen/ silicon-moderate rock



The mantle: very iron/magnesium-rich, very oxygen/silicon-poor rock (compared with crustal rocks)

The Earth and Plate Tectonics

The effects of partial melting – on density

Oceanic crust: iron/magnesium-rich, oxygen/silicon-poor crustal rock.

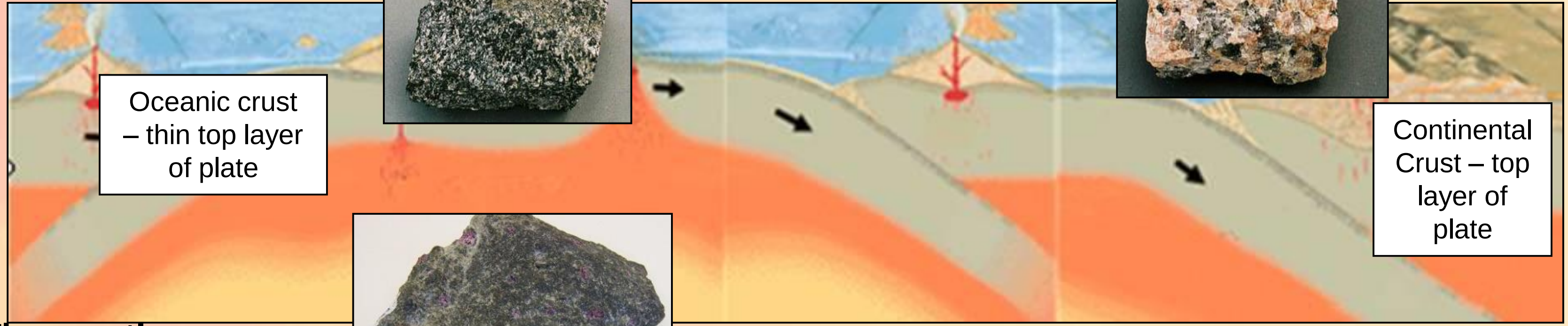
High density crustal rock – can be subducted

© Beatrice Murch from Buenos Aires, Argentina

Andesitic island arc volcanoes – iron/ magnesium- moderate, oxygen/ silicon-moderate rock – cannot be subducted

Continental volcanoes and intrusions – iron/magnesium-poor, oxygen/silicon-

Low density continental rock – can never be subducted



The mantle: very iron/magnesium-rich, very oxygen/silicon-poor rock (compared with crustal rocks)

Very high density rock (compared with crustal rocks)

The Earth and Plate Tectonics

Partial melting

SCIENTIFIC ACCURACY

- Whilst partial melting plays a major role in forming iron/magnesium-rich magmas from mantle peridotite,
- and oxygen/silicon-rich magmas from lower crustal melting beneath continents,
- recent research has confirmed that the formation of andesitic magmas (neither oxygen/silicon-rich nor iron/magnesium-rich) is much more complex, and partial melting only plays a small part in the formation of some of them

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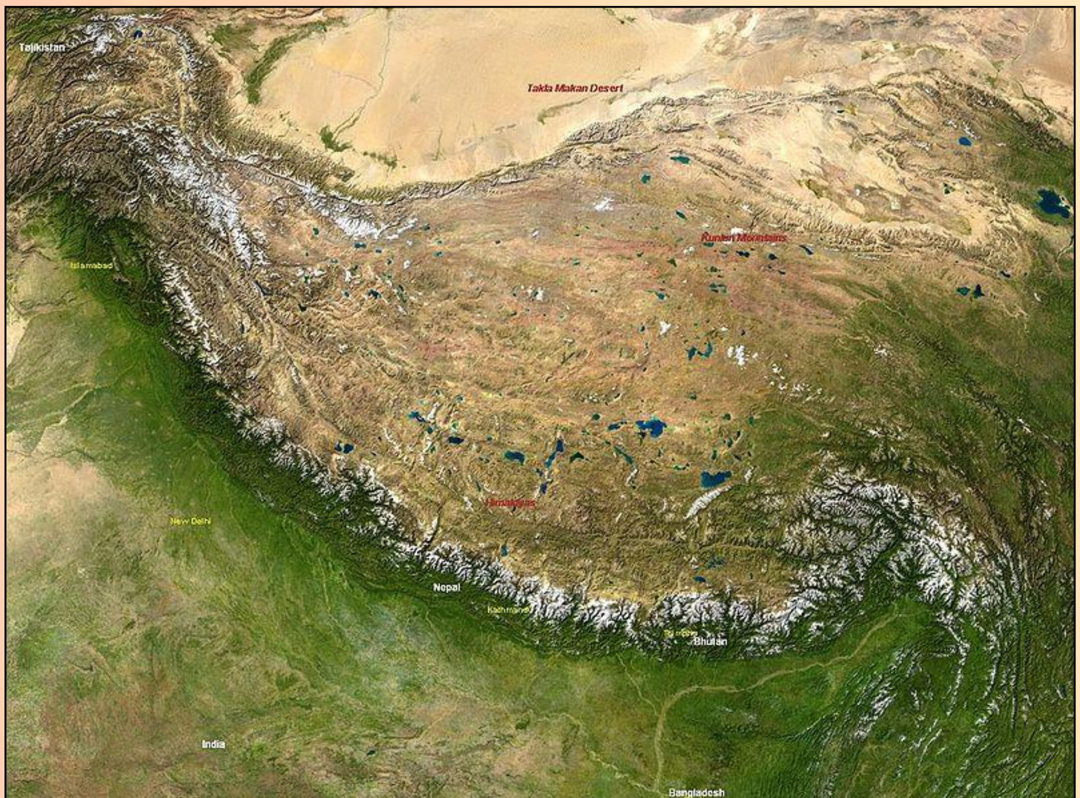
A volcano in the lab

Click to set the volcano off

The Earth and Plate Tectonics

Plates in motion – cardboard replica

A working model of how colliding continents produce mountain chains



‘The Tibetan Plateau, Himalayas’ by NASA – image in the public domain ‘The Tibetan Plateau, Himalayas’ by NASA (public domain)

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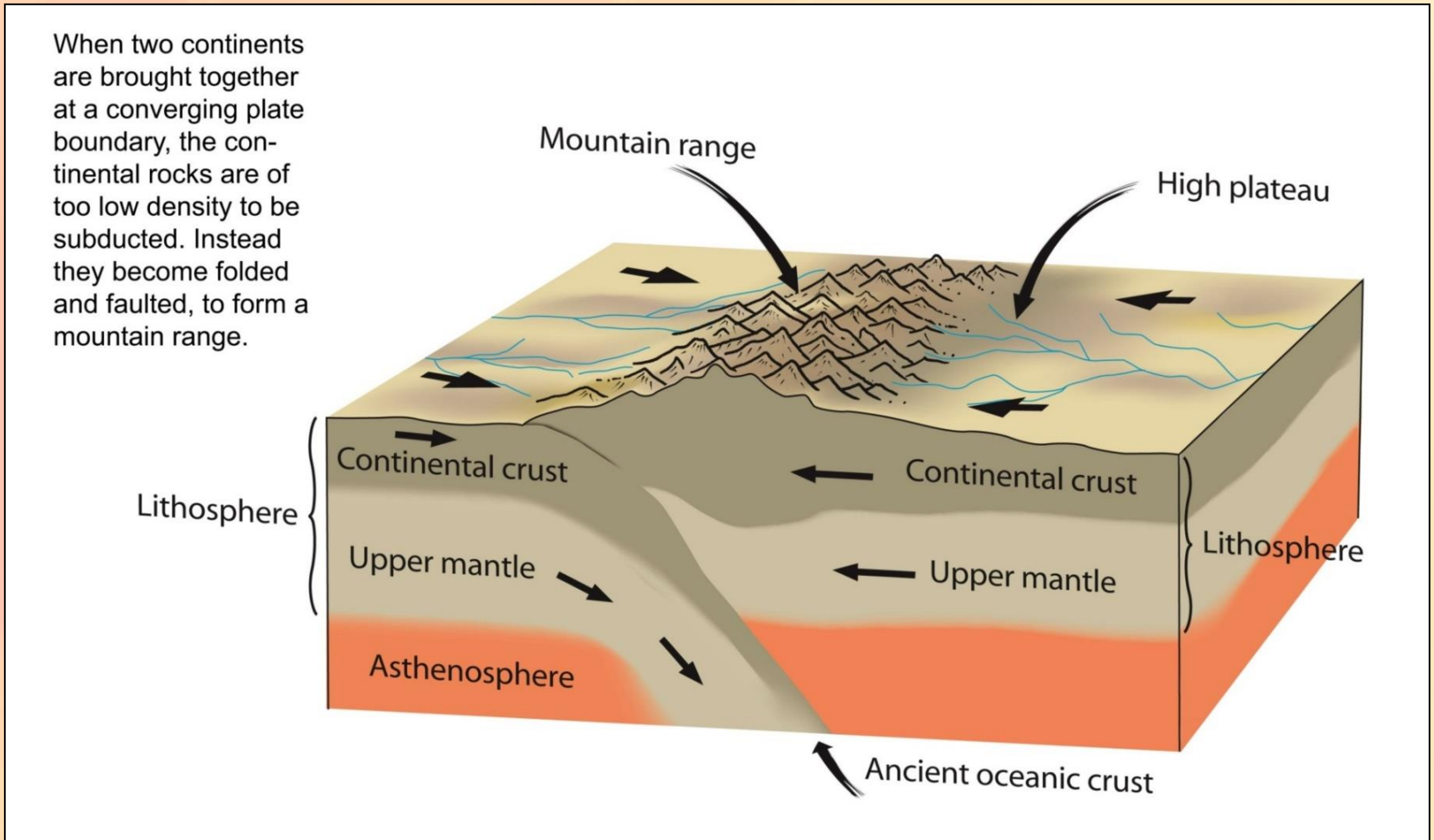
Continent-continent convergence



Continental plate collision zone. Reproduced with kind permission of USGS, redrawn by ESEU

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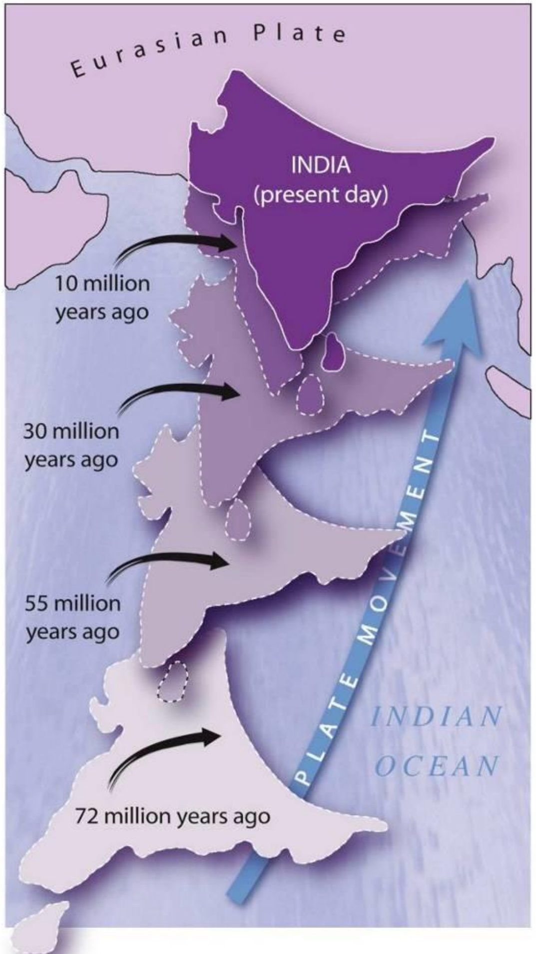
Continent-continent convergence

The rapid northward drift of the Indian plate (at 15-40cm per year) produced the Himalayas and Tibetan Plateau when it collided with the Eurasian plate.

Folds at Lhotse (Himalayas) by Michael Searle © University of Oxford



Eurasian Plate (India's movement) © This Dynamic Earth: the Story of Plate Tectonics, USGS, redrawn by ESEU

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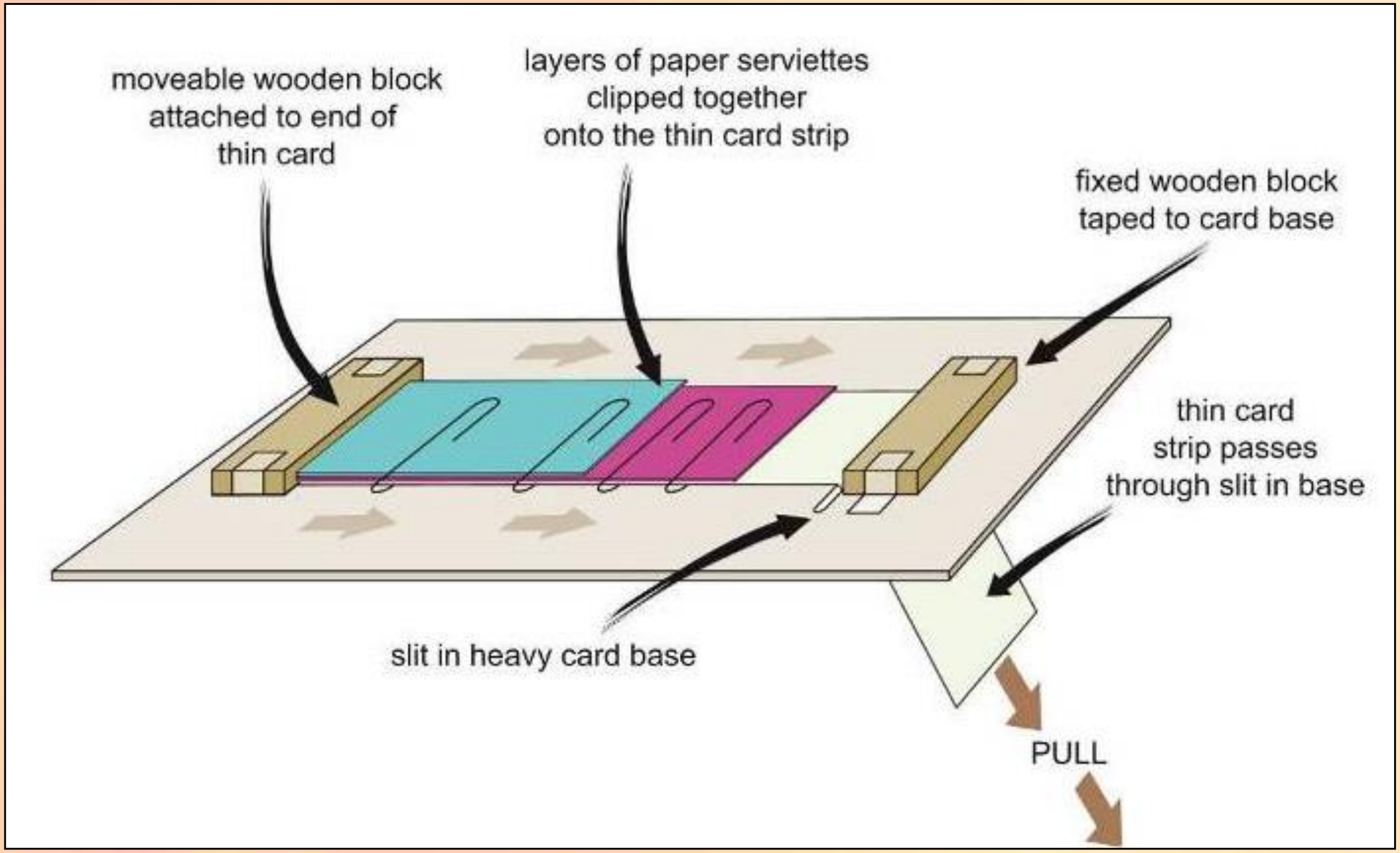
Plates in motion:
cardboard replica plates in motion

Cardboard replica of plates in motion (photograph) © ESEU

The Earth and Plate Tectonics

Plates in motion:
cardboard replica plates in motion



Cardboard replica of plates in motion (diagram) © ESTA, redrawn by ESEU

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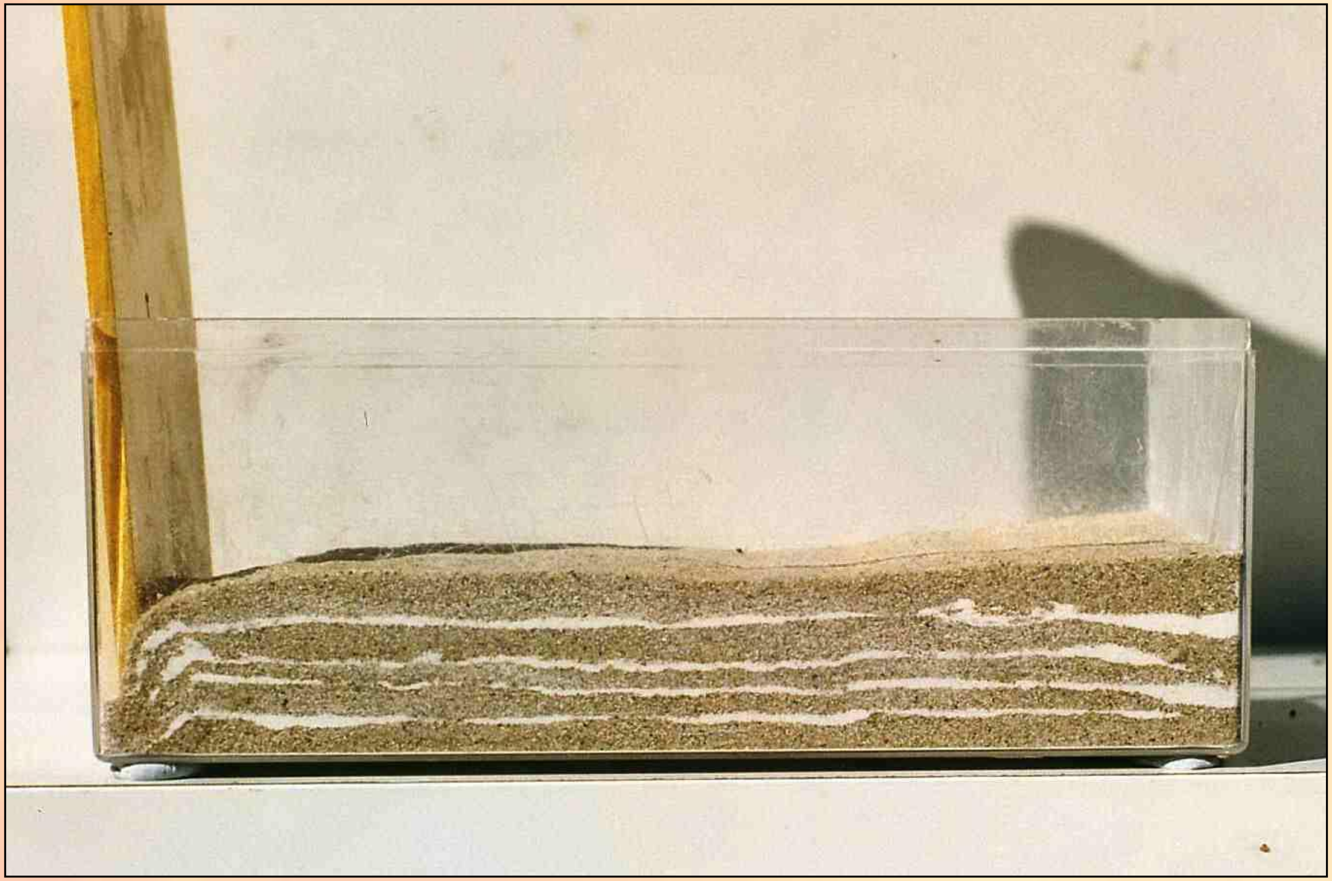
Fold mountains in a chocolate box



Fold mountains in a chocolate box © Peter Kennett

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Fold mountains in a chocolate box

Note: This activity forms part of the 'Dynamic Rock Cycle' ESEU workshop

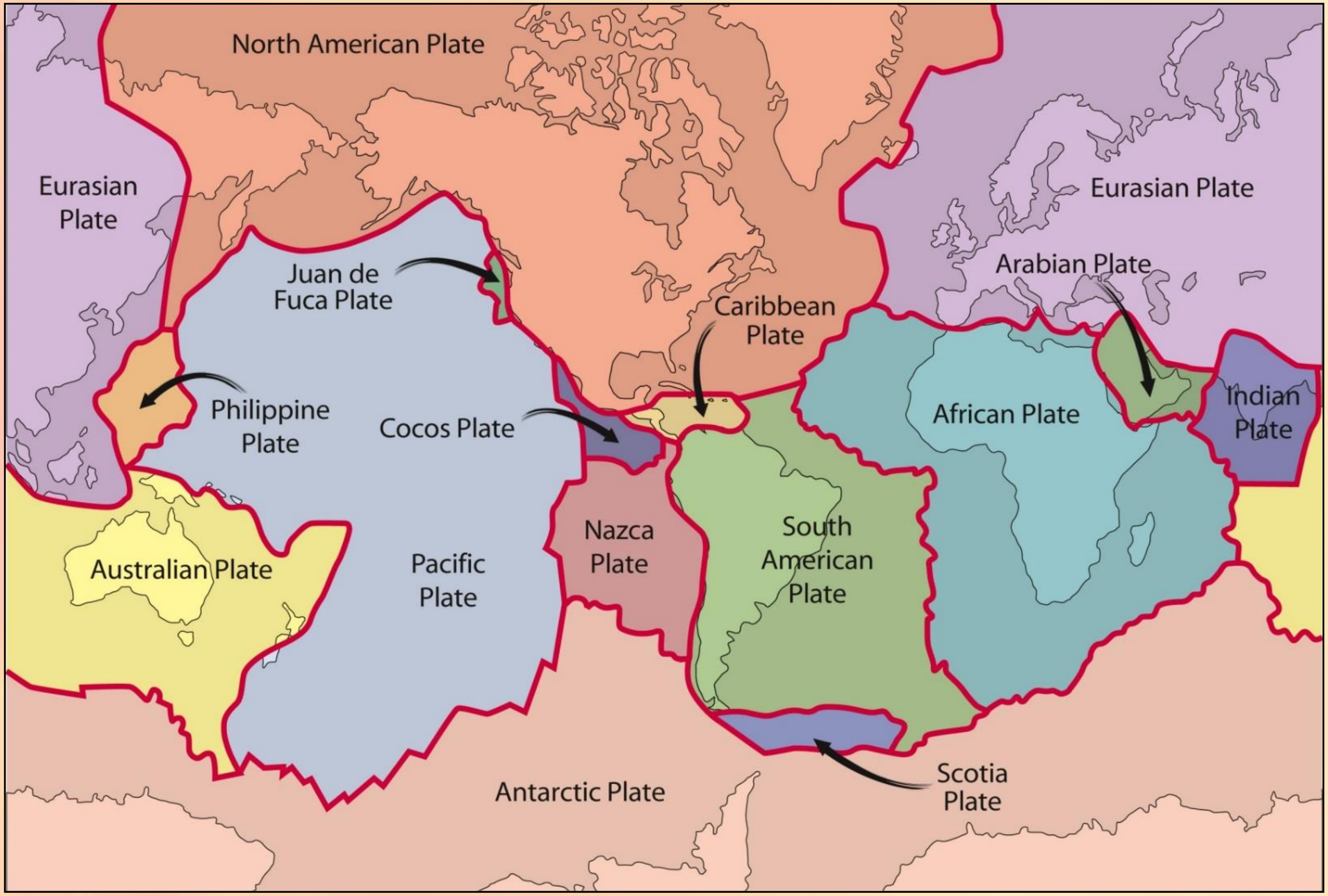
The Earth and Plate Tectonics

Fold mountains in a chocolate box

Note: This activity forms part of the ‘Dynamic Rock Cycle’ ESEU workshop

The Earth and Plate Tectonics

Map of plates



Map of Plates © This Dynamic Earth: the Story of Plate Tectonics, USGS, redrawn by ESEU

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Rate of plate movement

The Geological Map of the World © Open University

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What am I doing?

Published by Jim Henderson under the Creative Commons CC0 1.0 Universal Public Domain Dedication as File:30th St hiline balancing on rails jeh.jpg

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Plate-riding

‘Surfer’ by United States Marine Corps (public domain)

Image of the Earth © Noldoaran

The Earth and Plate Tectonics

Plate-riding

‘How fast am I going?’

‘In which direction am I travelling?’

‘What is happening behind me?’

‘What is happening in front of me?’

‘How can I tell I’m moving?’

The Earth and Plate Tectonics

Plate-riding

‘**How fast am I going?’**
(*as fast as our fingernails grow*);
‘In which direction am I travelling?’
(*towards the East*);
‘**What is happening behind me?’**
(*new plate material is being formed, as in Iceland*);

‘What is happening in front of me?’
(*I’m heading towards the Japanese subduction zone, with its earthquakes, volcanoes and mountains*);
‘How can I tell I’m moving?’
(*GPS measurements over several years, magnetic stripe evidence; evidence from the age of ocean floor sediments*.)

The Earth and Plate Tectonics

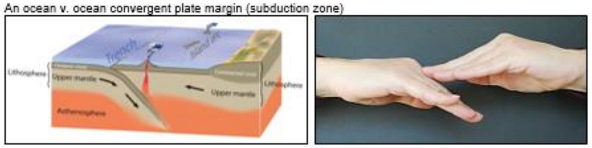
Plate margins and movement by hand

Plate margins and movement by hand
Modelling plate margins and plate movement with your hands

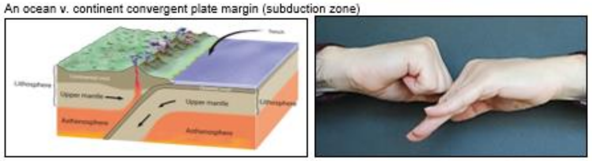
Ask your pupils to model each of the following with their hands:

A divergent plate margin:

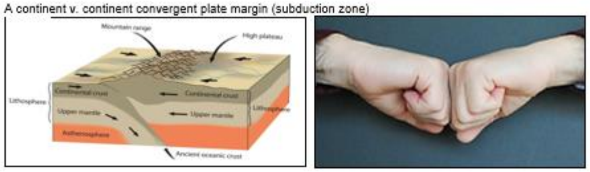
An ocean v. ocean convergent plate margin (subduction zone)



An ocean v. continent convergent plate margin (subduction zone)



A continent v. continent convergent plate margin (subduction zone)



A conservative (transform) plate margin

(Dave King)

Earthlearningidea – http//:www.earthlearningidea.com

The elastic rebound theory generating earthquakes at a fault, such as the San Andreas Fault

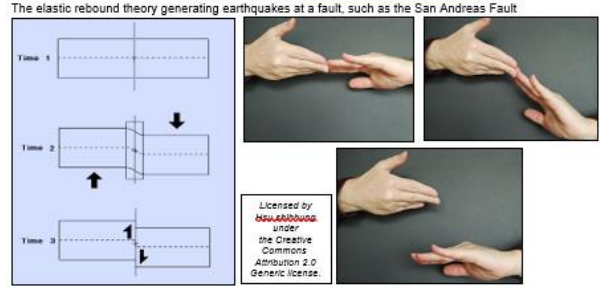


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Plate movement over a mantle plume

(Plate diagrams produced by the US Geological survey, redrawn by ESEU and used with permission.)

The back up

Title: Plate margins and movement by hand.

Subtitle: Modelling plate margins and plate movement with your hands.

Topic: A class activity to help pupils to visualise plate margins and movements through modelling with their hands.

Age range of pupils: 10 years upwards

Time needed to complete activity: 5 minutes

Pupil learning outcomes: Pupils can:
- describe different types of plate margin and movement;
- model them with their hands.

Context:
The educational advantages of using your hands to model geoscience features and processes have been explained in the Earthlearningidea, *Rock cycle at your fingertips.*

Participants in the GIFT Conference in Vienna, Austria, 2017, modelling plate margins with their hands. *(Filippo Camerlenghi).*

The Earth and Plate Tectonics

Prediction of earthquakes - ‘Brickquake’

How earthquakes work –

and how difficult they are to predict

Ground deformation after an earthquake © National Geophysical Data Center (NGDC)

Brickquake (ESEU)

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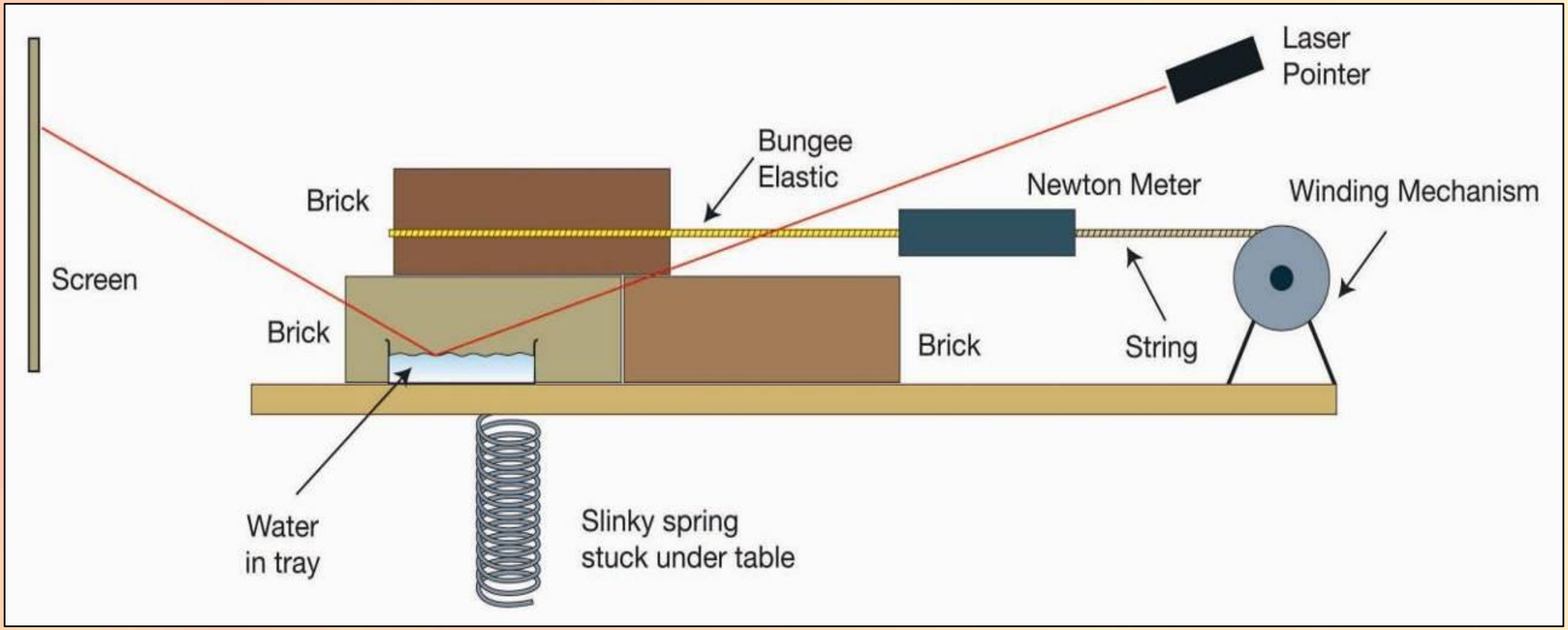
Brickquake – can earthquakes be predicted?

How earthquakes work –

and how difficult they are to predict



Brickquake – can earthquakes be predicted (diagram) © ESEU

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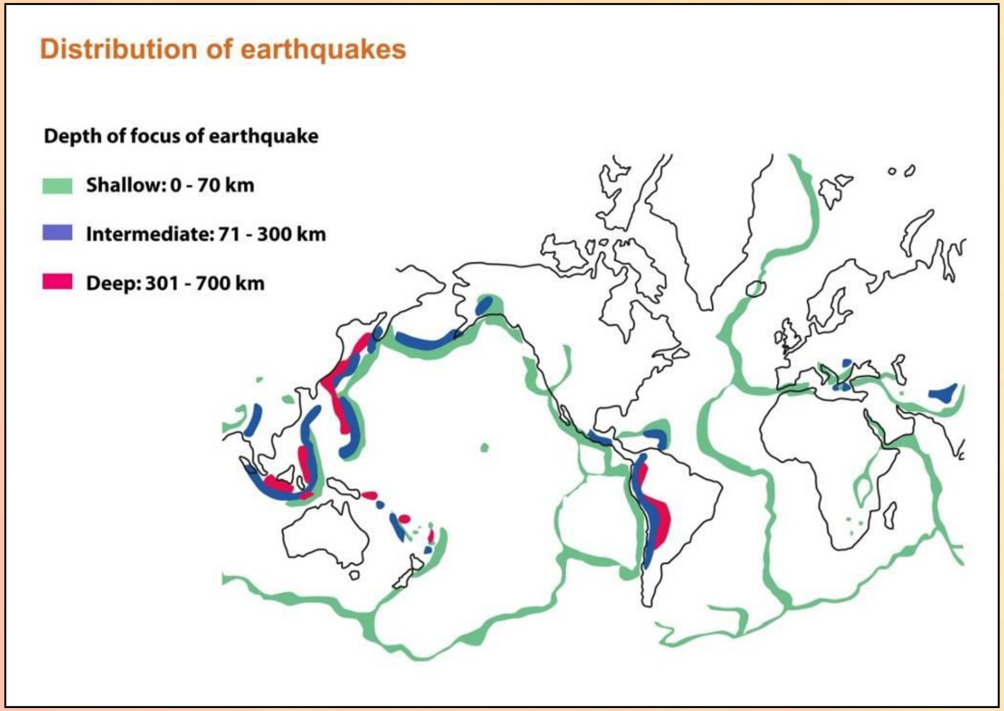

'Brickquake'

'Brickquake' results		
Distance moved (cm)	Force (Newtons)	Relative energy released
2	15	30
7.5	45	337.5
3.5	35	122.5
4	25	100

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Tsunami

- making waves

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Tsunami - making waves

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Earth Science for 11 – 16 year olds

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