DEEP EARTH EXPLORERS – WHAT IS THE INSIDE OF THE EARTH LIKE?

This is a home-learning worksheet about the interior of the Earth. There is a glossary on page 7 of helpful key words, which are highlighted in bold in the text.

Spoiler alert: It's important you do this worksheet in order. Try not to skip ahead and look at the next section before you've answered the questions in the section you're on – sometimes doing that will ruin it for you!

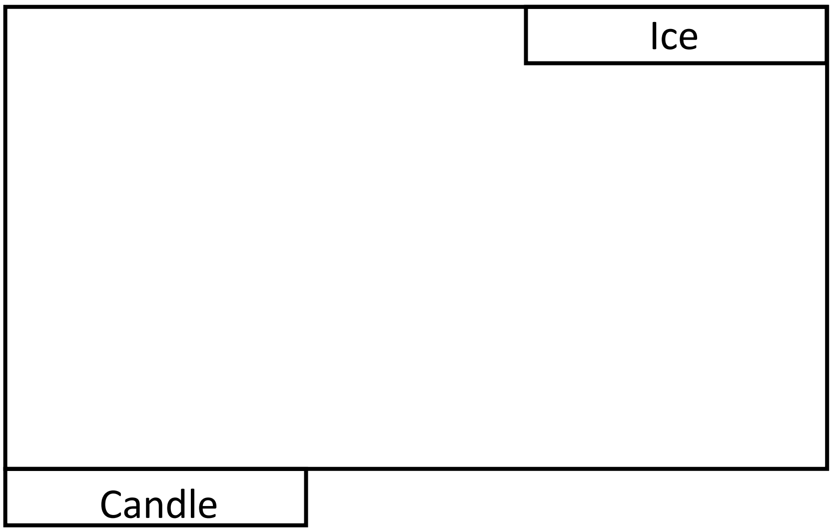
Experiment 1 – Silly Putty

Follow at the instructions on the first page of 'Experiment Instructions' to do the experiment. If you can't do the experiment, watch this video instead: https://youtu.be/sMKJvYSYiOs.

What are the material properties of silly putty? (hint: how does it behave differently over short timescales compared to long timescales e.g. seconds vs hours?)

Experiment 2 - Convection

Follow at the instructions on the second page of 'Experiment Instructions' to do the experiment. Then, complete the diagram to show what happened. If you can't do the experiment, watch this video instead: https://youtu.be/7xWWowXtuvA



Why did you see this pattern? (hint: if you're stuck, try thinking about how hot air balloons work)

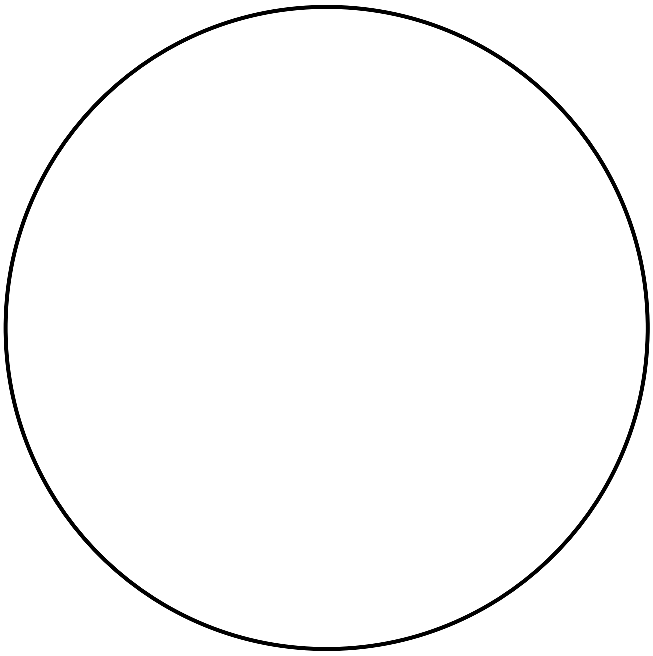
This phenomenon is called **convection**. In left hand side of the box the water was heated up by the candle and became less dense, so rose up. In the right of the box it was cooled down by the ice and became denser, so sank. Water had to flow from left to right to replace the sinking water at the top, and from right to left to replace the rising water at the bottom.

*What other examples of **convection** in real life can you think of?*

Which states of matter usually convect: solids, liquids, or gases?

THE INSIDES OF THE EARTH

Complete and label this diagram with the structure of a cross-section(slice) through the Earth. (If you haven't learnt this yet, or you have forgotten, you can look it up on the National Geographic website: https://www.nationalgeographic.org/media/earths-interior/#earths-interior.)



How do you think we know this? How might we 'look' inside the solid Earth? (hint: how do we look inside other solid things e.g. people?)

Now, have a look at the 'Seeing inside the Earth' fact file on the next page (page 3) to read about how geoscientists look inside the Earth.

FACT FILE: SEEING INSIDE THE EARTH

How do we look inside the Earth?

Geoscientists do something similar to 'x-raying' the Earth to look inside of it. Instead of using x-rays, they use sound waves passing through the Earth. These vibrations, called **seismic waves**, can be caused by explosions, waves in the sea, or even cars, but usually geoscientists use waves generated by earthquakes.

Just like in an x-ray gives information about what kind of material it's passed through, e.g. bone or muscle, **seismic waves** can give information about the Earth material they have passed through. In a medial CT (computer **tomography**) scan, x-rays are taken from all directions around a part of the body, and then combined to make a 3D image. Similarly, if we record lots of seismic waves going in different directions, we can computationally combine them to make 3D seismic **tomographic images** of the Earth.

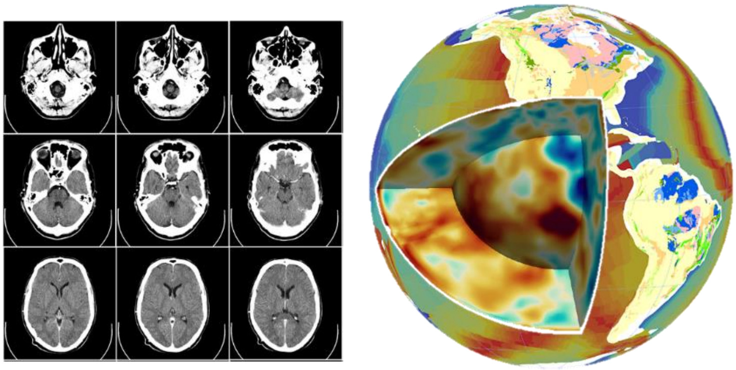


Figure 1 - (left) x-ray slices through a 3D CT-scan of a skull and (right) a 3D tomographic image of the Earth made in a similar way

What does the image show us?

In an x-ray, the colours show us how strongly different areas absorb x-rays. **Seismic tomography** is a little different.

What the image shows is the difference between the actual speed of the **seismic waves** in an area, and the speed of seismic waves we would expect. We can work this out by looking to see if rays passing through that area are moving faster or slower than we would expect. If they arrive late, then we know that seismic waves move more slowly in the area they've passed through (and the opposite for waves arriving early).

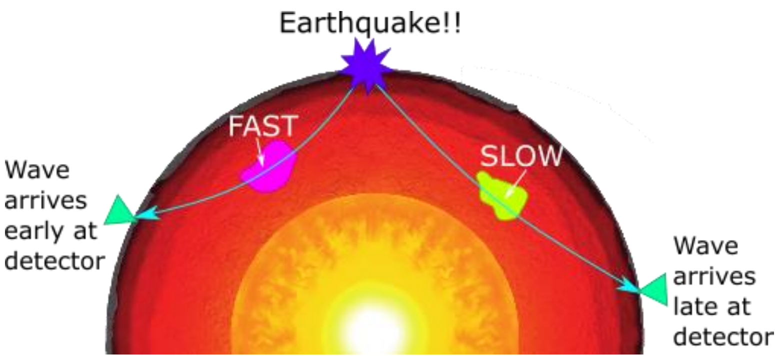


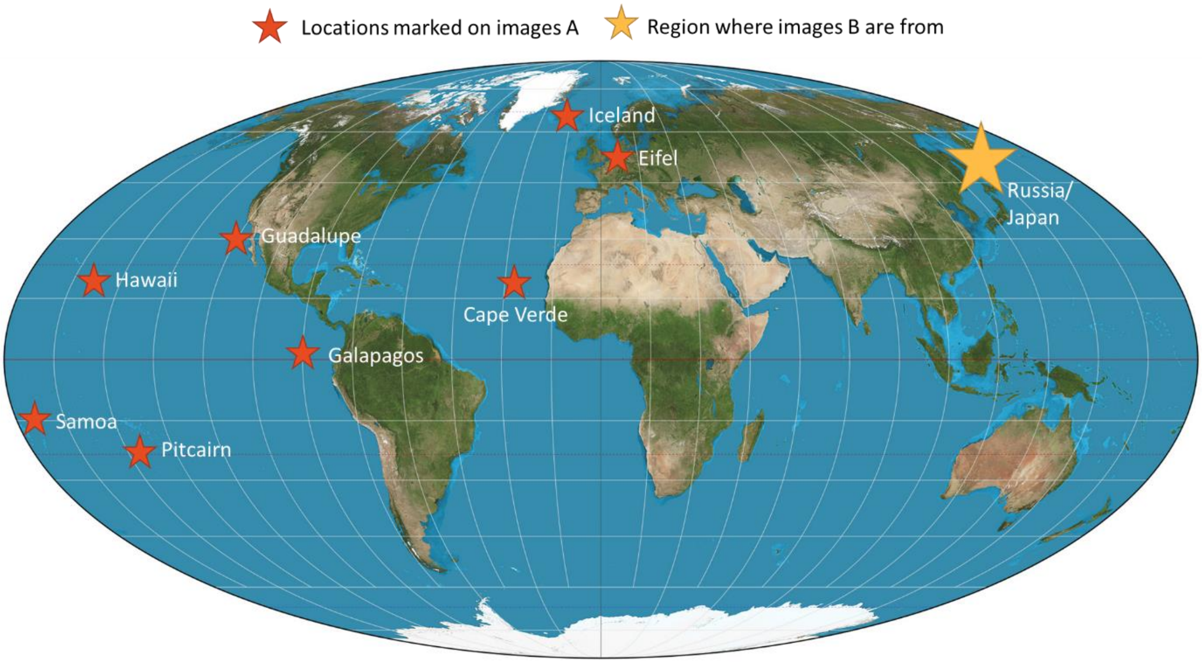
Figure 2 - Example of two waves moving through the Earth, showing how we can tell seismic wave speed from whether waves arrive early or late

What affects how fast seismic waves travel?

Lots of things! For example: the type of rock, or the size of the crystals in the rock. But the most important factor is **temperature**. When materials are hot, their particles are further apart and moving more. This means that it takes longer to pass a vibration between them, so sound moves slower through warmer material. Imagine a line of people. Will it take longer to pass a message down the line if everyone is standing still, or if everyone if running from side-to-side? It'll clearly take longer if everyone is moving all the time.

We can, therefore, say that ***faster*** *seismic wave speeds usually mean* ***colder material,*** *and* ***slower*** *seismic wave speeds mean* ***hotter material.*** (In the image in figure 1, red is hot, and blue is cold.)

Now look at sheet 1. On it are shown some real **tomographic** images of the Earth's **mantle** which were all made in the past few years. Within images A and B, each individual picture is part of a different cross-section through the Earth. The locations of the places marked on images A and B are shown on the map below.



Use the images on sheet 1 to answer the following questions.

*In the **tomographic images**, are red areas hotter or colder than the surrounding mantle?*

What about blue areas?

Sketch and label the important patterns in the images.

For the images in A, sketch the shapes that the hot areas of the mantle make.	For the images in B, sketch the shapes that the cold areas of the mantle make.

Which direction do you think the hotter patches in mantle are moving?

What about the colder patches?

What might this mean for what is going on in the ***mantle****? (hint: think back to experiment 2)*

Experiment 3 – Making hotspot tracks

We can see evidence of **mantle convection** at the Earth's surface! Did you spot Hawaii in image A on sheet 1? Have a look - you should see how it is directly above some hot, rising mantle (a **mantle plume).** Because it's hotter than usual under Hawaii, it makes a small amount of the mantle melt, which is why Hawaii is essentially a big volcano!

The crust has moved over time (compared to the **mantle plume**), so we get a whole chain of little islands which used to be volcanoes when they were on top of the hotspot. We call this a hotspot track.

Follow the instructions on the fourth page of 'Experiment Instructions' to make your own hotspot track!

Meeting the mantle

Have a look at the rock in the picture on the right. The solid green rock made of crystals is called **Peridotite**; The whole **mantle** is made of **solid Peridotite**. Here it is surrounded by a grey rock, which is the basalt (cooled lava) made in the volcano which erupted out this piece of mantle. Bits of **peridotite** are ripped up and carried off by magma moving through the mantle, from special deep volcanoes called **kimberlite pipes**.

Importantly, this rock tells us that *the* ***mantle*** *is* ***solid.***

*How can you reconcile the **mantle** being **solid Peridotite** and also convecting (i.e. flowing like a **fluid**)? (hint: think back to experiment 1)*

Flowing solids

Solids like the **mantle** can have the properties of a **solid** on a short timescale, but over a long timescale they can flow like a **fluid**. This is due to something called **creep**. During **creep**, tiny movements of crystals and particles in the **mantle** add up to produce overall motion of the mantle over a very long time.

*Can you think of any other examples of **solids** which behave as **fluids** on a long timescale?*

Experiment 4 – Creep

Follow the instructions on the fifth page of 'Experiment Instructions' to do the creep experiment.

One example of **creep** is the ice in glaciers; the ice crystals slide past each other, and dissolve and re-grow in order to let the glacier move downhill towards the ocean. Sometimes geoscientists can see evidence for movement by creep in a rock or ice; creep causes crystals to align to make bands or stripes in the material.

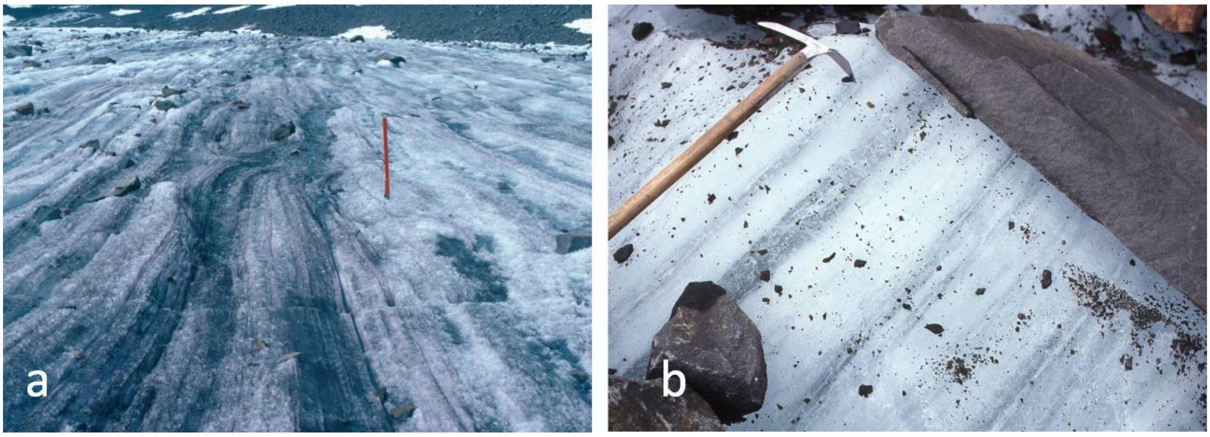


Image from: P.J. Hudleston *JSG* **81**, 1-27 (2015) doi:10.1016/j.jsg.2015.09.003

In the images above, these stripes and bands can be seen in a glacier.

Which direction do you think the glacier is moving?

But how slow?

To understand how slow the **mantle** is moving, we need to compare it to the speeds of everyday things. Write down at least four everyday things which move/grow/travel at a variety of speeds: for example, the rate of fingernail growth, the rate of grass growth, or the speed of an aeroplane.

Thing	Speed with units

Look up what speed they move at, and add them to the table. Now look at Sheet 2 - Timescales timeline.

On the timeline are two scales. One is **linear** (going up in even steps, probably like most scales you've seen before). The other is **logarithmic**, which means that each time you move one along the scale the speed gets ten times faster. You can see this if you look at the speeds all in m/s. Scientists often use this type of scale for things with very wide ranges of numbers, like our speeds.

If you tried plotting your speeds on both axes you would find that on the **linear scale** a lot of the speeds are squished together near zero, whereas on the l**ogarithmic scale** they are better spread out, and easier to compare. The green lines connect points on the two scales of the same speed, showing how all the small speeds are much more clumped together on the **linear scale**.

Mark the speeds from your table onto the timeline to compare to the speed of mantle flow (already marked on).

Extensions/Questions to think about and research

1) **Kimberlite pipes** are special for another reason. Apart from being where we get bits of **peridotite** from, there is something valuable which we almost only ever find in **kimberlite pipes**. What is this? Why do you think we find this thing in the same place as **mantle peridotite**?

2) In Hawaii, the crust has moved compared to the mantle plume because of plate tectonics. What is plate tectonics? Where are the boundaries between Earth's tectonic plates?

3) The part of **mantle convection** which is cold mantle sinking down is called **subduction**; look up what **subduction** is. Lots of famous earthquakes and tsunamis were due to **subduction**; which ones were? Why do you think they are so famous?

4) We can sometimes spot **mantle plumes** in the shape of the surface of the sea floor. What 3D shape do you think they make on the sea floor? A bump, a hole, something else? Why?

5) ***Have a look at the document "More activities to try"!!***

GLOSSARY

Solid A state of matter (like liquid or gas), where the particles in the material have fixed, and typically ordered, positions which they vibrate about.

Fluid A material, in any state, which can flow.

Geosciences A subject concerned with the workings of the Earth and other planets. It includes study of the climate, oceans, atmosphere, life and evolution, volcanoes, rocks, earthquakes, the deep interior or the Earth, and these same phenomena on other planets.

Convection The transfer of heat by the movement of hot material upwards and cold material downwards.

Mantle The second layer of the Earth, below the crust and above the outer core, which makes up 84% of the Earth's volume and is made of solid rock.

Seismic waves Vibrations (sound) which pass through the solid Earth, typically produced by earthquakes.

Seismometer A sensitive instrument which measures the vibrations of the Earth's surface caused by seismic waves.

Tomography The production of 3D images and 2D slices of the inside of a 3D solid by measuring rays passing through the solid; for example, medical tomography of the body using x-rays or seismic tomography of the Earth using seismic waves.

Mantle plume An area of hotter than usual mantle which rises upwards, and causes melting of the mantle beneath the base of the crust, resulting in volcanoes. Famous examples are beneath Hawaii and Iceland. This movement upwards of hot mantle is part of the convection of the mantle.

Subduction The downwards movement of a cold plate of the Earth's crust and upper mantle into the warmer mantle, below another plate. The movement of the cold mantle and crust downwards is part of the convection of the mantle.

Peridotite The green rock which makes up the Earth's mantle. It is made of crystals of the minerals Olivine and Pyroxene.

Kimberlite pipe A volcano with a magma source from melting deep in the mantle. They frequently bring up pieces of peridotite in their magma.

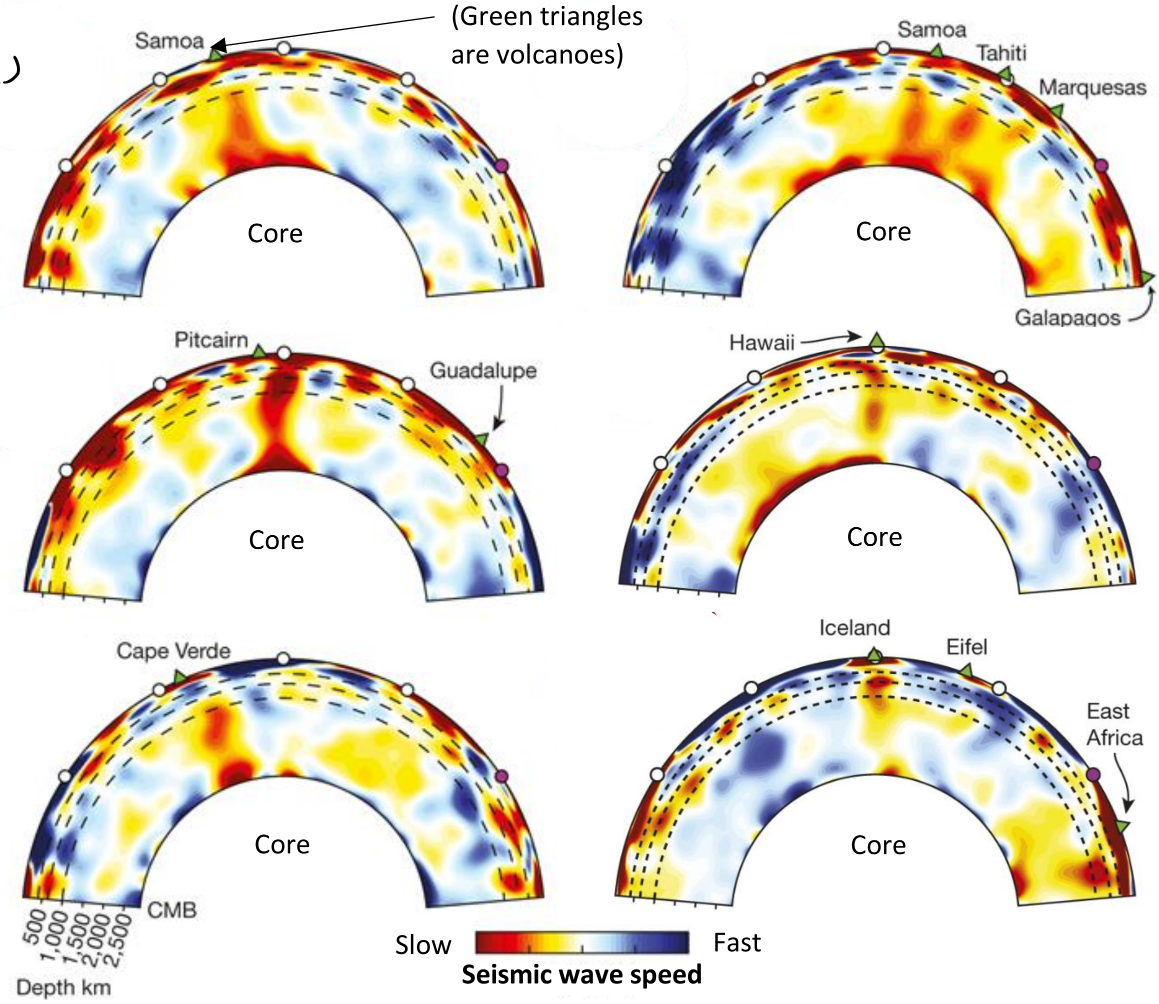
Creep The gradual flow of solids, caused by the addition of many tiny movements of the particles which make up the solid, for example crystals sliding past each other, or dissolving and re-crystallising.

Linear A scale which goes up in even steps.

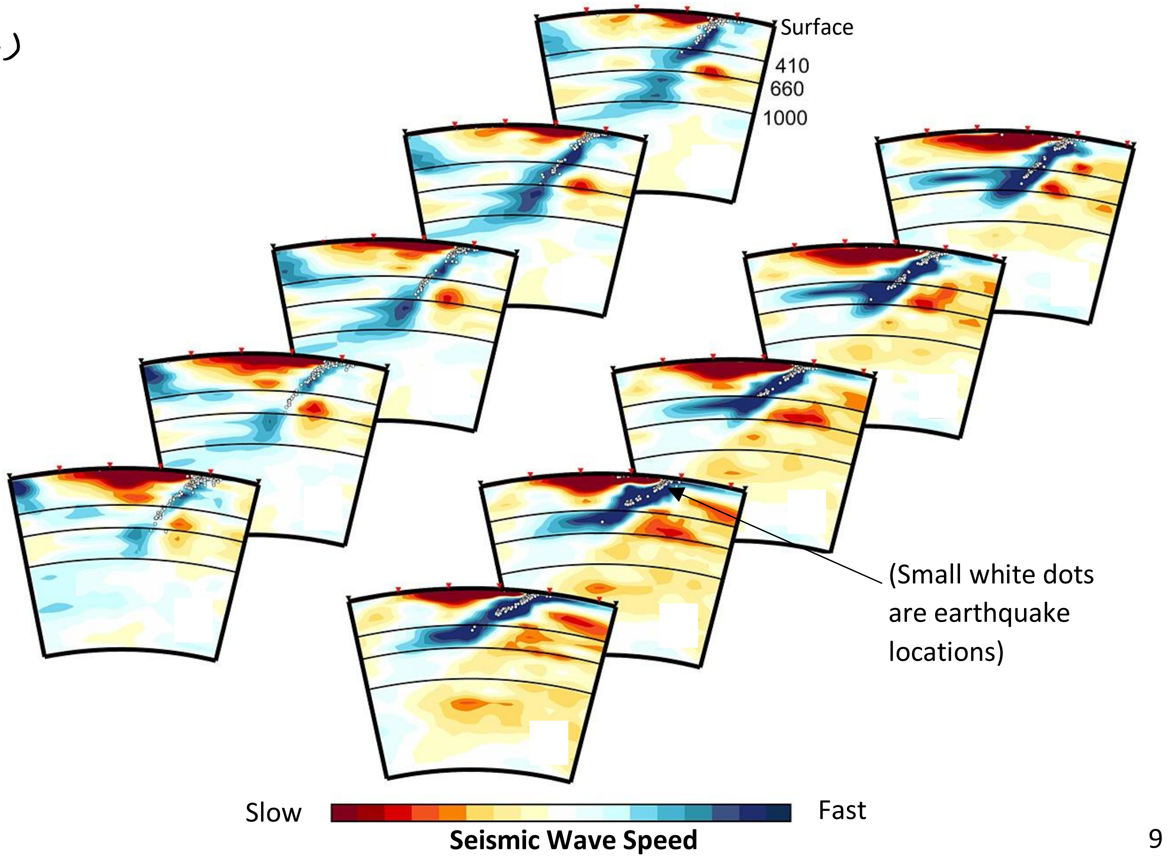
Logarithmic A scale where each time you go up one along the scale the number gets ten times bigger.

SHEET 1 – SEISMIC TOMOGRAPHIC IMAGES OF THE EARTH'S MANTLE

A)



B)



Figures adapted from: SW French *et al. Nature* **525**, 95-99 (2015) doi:10.1038/nature14876, and Y Fukao *et al. JGR* **118**, 5920-5938 (2013) doi:10.1002/2013JB010466

SHEET 2 – TIMESCALES TIMELINE