**Script/lesson plan**

Things highlighted as optional are intended to be done only when workshop is delivered by external demonstrator, but could be done by internal teachers if relevant (e.g. if the teacher in question were a geoscientist/had done a geoscience degree).

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| **Slides** | **Leader instructions** | **Approx. time** | **Student activities/purposes** |
| 1 | Icebreaker/opener  ***EXPERIMENT 1 – Silly Putty****.* | *4 mins* | *Students think about behaviour of silly putty on different timescales, and how it can deform like either a fluid or a solid.* |
| 2-3 | Right, can I have the silly-putty back? *[Collect in the silly putty, and put a blob at the top of a sloped board.]* Don’t forget this, we'll need it later.  Set ground rules of how the session is going to work.  [**Optional:** Introduce yourself, what you do, and where you're from.]  In this workshop we're all going to have a go at being geoscientists as we investigate what the deep insides of the Earth is like. | *2 mins* | *Students meet the workshop leader and understand a bit about the background of a geoscientist.* |
| 4 | Before we start, can you spend a minute discussing in groups what you think a geoscientist is like and what they do and then write down 7 words to describe this?  What words did you get?  Does anyone know a geoscientist in real life? | *2 mins* | *Students think about examples of geoscientists they're heard of, and what they think geoscientists are like. They write a list of words to decide which aspects are the most important.*  *Personally involving any students who might know something about geosciences and using their knowledge to help inform the class.* |
| 5-15 | So, one of the main things that geoscientists do is study the Earth. This includes the atmosphere, oceans, plants and animals, rocks on the surface and the structure of the deep Earth right to its centre. | *2 min* | *Students are reminded of the diversity of disciplines and subject areas in geosciences.* |
| 16-17 | Has anyone seen or read anything about the deep insides of the Earth?  Follow up: What does it say that it's like?  *[collect responses on the board: hopefully some of these ideas will be accurate and others not so (e.g. Journey to the Centre of the Earth)]*  Prompt if stuck: For example: a film, TV series, book, magazine article?  Do we think these can all be accurate pictures of the deep Earth?  Why might there be lots of contradictory ideas?  In order for us to understand which of these pictures is the accurate one, we have to start with a few experiments. The first one was the silly putty, which you did earlier. For the second one we need to gather round this tank. | *3 mins* | *Students consider pop-culture visions of the inside of the Earth and evaluate whether these are likely to be accurate, and which are more likely to be accurate than others. Think about the prevalence of misinformation in pop-science and why.* |
| 18-21 | ***EXPERIMENT 2 – Convection***  This is a tank of water heated from below, but cool at the top. I'm going to add some colouring so that we can see where the water is moving.  Can someone describe what is happening?  Why is this happening?  Can anyone think of any other examples of convection in real life? | *5 mins* | *Students consider the movement of water up from the hot base and down from the cool top. Students work out/possibly already know what's happening and explain it. They generalise this to other cases of convection (hot rises, cold sinks).* |
| 22-27 | Okay, back to the Earth. Let's start with what we already know. Working in small groups you have a minute to draw a cross-section through the Earth as best you can.  Once you've done that, can you each mark onto your cross-section the depth to which we've drilled into the Earth.  Can the groups share what they remembered? *[also draw this structure on the board to make sure students know]* | *3 mins* | *Students should recall the basic layered structure of the Earth. If not, drawing it on the board will help get students up to the same level of knowledge.* |
| 28 | How do you think we know this? And more generally, how might we 'see' inside the solid Earth to see the structures inside it? Try to think of some different ways that we might be able to do it. Talk about this in groups for 3 minutes and then I'll get each group to feedback to the class.  [*Go around the class. If they're stuck, or only think drilling, suggest to them to think about how we 'look' inside other solid things.]*  Right, what ideas do we have?  *[Briefly discuss ideas, we will talk more about drilling later.]* | *4 mins* | *Students recall anything they might already know about Earth imaging, and analogise with other things we use to 'see' when we can't actually see e.g. medical imaging, to make a guess at how we might look inside the Earth. They discuss this in groups.* |
| 29-42 | We can look inside the Earth using something called 'seismic tomography'. This is a bit like a CAT scan at the hospital where they take multiple X-rays and put them together to make a 3D image, but using sound instead of light (x-rays). We place sound-detecting receivers all around the surface of the Earth, and use them to detect sounds/vibrations in the Earth.  Take 30 seconds to discuss some possible sources of sound in the Earth? [*Earthquakes, waves, 'cultural noise' are all things we actually use]*  Usually, we used Earthquakes, which release a lot of sound energy (we can see this from the shaking damage they cause).  The vibrations received carry information about the material in the path between source and receiver, just like in an x-ray the intensity of light hitting any point on the screen tells you about how solid the material between there and the x-ray gun is. In seismic tomography we look at how much later or earlier rays arrive than we would expect, which tells us if there's a slow or fast patch which that ray passed through. Computer geoscientists then combine these lines of information to make a 3D image.  In order to understand this better, we can 'do' it ourselves! | *8 mins* | *Students consider how seismic tomography works by comparison with x-rays, something they are likely familiar with.*  *Students discuss processes in the Earth which might cause vibrations/sound and make suggestions from their groups.*  *They think about how geoscientists are involved with collecting data and producing these images in a variety of ways.* |
| 44-49 | ***EXPERIMENT 3 – Seismic tomography experiment***  Then use remaining slides to explain seismic tomography. | *10 mins* | *Students participate in actually doing 'seismic tomography' in a physical way, aiding understanding and making it more memorable and engaging.*  *Get un understanding of how passing through a 'slow patch' makes the seismic wave arrival later.* |
| 48-49 | In these images, red signifies slow patches and blue shows fast patches. One of the things that controls wave speed is temperature.  Take 30 seconds to discuss how temperature might affect the speed of sound passing through a material? Do you think waves will pass through a hot solid faster of slower than a cold solid? | *2 mins* | *Students consider how temperature affects how waves move through materials, and how this relates to particle vibration and expansion with temperature.* |
| 50 | In order to understand how temperature affects wave speed, we can have a race.  ***EXPERIMENT 4 – Wave-speed and temperature experiment***  Which 'wave' got to the end first? *[should be the cold one]*  Let's do it with groups A and B switched to check the reliability of our result. Was it the cold one again? *[yes]*  So, thinking back to experiment 3, would a wave travelling through cold mantle arrive sooner or later than we'd expect if it were a normal temperature? What about hot mantle?  Having a look at these tomographic images, then, which colour means hot mantle, and which means cold mantle. | *10 mins* | *Students physically engage with the meaning of hot or cold in terms of particle motion.*  *Students consider the importance or repeatability in experiments and why they must do it both ways round.*  *Students gain a physical intuition of how temperature affects sound wave-speed.*  *Students relate this difference in speed to tomography form experiment 3.* |
| 51-52 | Right. In light of this, I'd like you to have a look at these tomographic images and see if you can work out what's happening in them? Have a look at the temperature distribution, and then think back to experiments 2, 3, and 4. Discuss in your groups for a few minutes, then I'll ask you for your ideas.  *[Hand out tomographic images. During this, go around the class and check they are on the right track. If they are struggling, tell the class to think back to experiment 2. Suggest they look at where it's hot and where it's cold..]*  What are our ideas?  *[hopefully at least someone suggests convection]*  Okay, so we think that it looks like there is convection going on in the mantle. Do we agree?  This convection transfers heat from the core to upper layers of the Earth.  Which of the descriptions of the mantle which we wrote on the board at the start do we think is right? Why? | *5 mins* | *Students discuss tomographic images and use their knowledge of what the images mean in terms of temperature, plus what they saw in the convection tank, to work out (hopefully) that the mantle is convecting.*  *This might lead them to predict that the mantle is liquid like suggested in e.g. The Core, as only fluid things convect.* |
| 53-59 | The mantle convects by hot plumes rising towards the base of the tectonic plates, and tectonic plates subducting at subduction zones.  Can you discuss in groups what you know about tectonic plates?  Ask feedback.  *[Give as much background to plate tectonics as the particular group needs]*  The cold crust and upper mantle of the Earth are broken into tectonic plates, like a broken eggshell on a boiled egg. These plates move around the Earth compared to one another (we can measure this using GPS satellites). Where two plates are moving together we get subduction; where one plate is forced down under the other, and deep into the mantle. This brings cold material from the surface downwards – convection! | *3 min* | *Students recall what they know about tectonic plates in order to understand how subduction (a plate-tectonic process) is the downwelling part of the convection of the mantle.* |
| **N/A** | **Suggested place for an optional break in the workshop, if needed.** | *5-15 min* |  |
| 60-63 | We can see evidence of mantle convection at the Earth's surface! Did anyone spot Hawaii in these images? You can see how it is directly above some hot, rising mantle. 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 compared to where this hot plume is over time, so we get a whole chain of little islands which used to be volcanoes when they were on top of the hotspot.  ***EXPERIMENT 5 – Making hotspot tracks*** | *8 mins* | *Students think about relevancy of mantle convection to phenomena they have probably heard of in the news – Hawaiian volcanoes.*    *Students develop their thought on plate tectonics, and how we can see/measure plates moving.* |
| 64-78 | Some of you might have noticed I said that the heat makes 'some of the mantle melt'. And that is because the mantle is entirely solid apart from some very small blobs of magma near the surface.  Not only is the mantle solid, we can actually hold a bit of the mantle. It's made of this: a green rock made of solid crystals of a few specific minerals *[Olivine, Pyroxene and Garnet, if they ask].*  *[Bring out a hand specimen of peridotite or, if not available, an image of someone holding the peridotite. If a sample, pass it round and let the students hold it.]*  Pass it round and have a look at it – if you don't get a chance or want to look at it more, you can do so at the end of the lesson.  Where do you think we got this?  We didn't get it from drilling! The deepest we've ever drilled is only 12 km into the crust – this is the Kola Superdeep borehole in Russia. It’s not that we're not trying, it's just really difficult because it gets very hot and high-pressure down there!! A second MoHole project, drilling in the oceans is ongoing at the moment, so maybe in the next 10 years? Maybe one of you might be involved in it!  We actually got this from a kimberlite pipe, which is a special type of very deep volcano which erupts from the mantle, and so rips-off and brings-up bits of the mantle with it. A Kimberlite pipe is also the kind of place where diamonds are found. Anyone know why?  Knowing the mantle is like this, do we have a problem? | *5 mins* | *Students get to actually see what the mantle is made of, potentially challenging their expectation that it would be liquid.*  *Students get perspective on 1) how difficult deep Earth exploration is and 2) how big the Earth is. Students are also reminded of a relevant use of geosciences (diamond exploration).* |
| 79 | Take a few minutes to discuss how the mantle can be solid when we see it e.g. here in the classroom, but also be convecting.  *[Walk around the class to check they're on the right track. If not, remind the class of the silly putty by pointing it out – by this point it should be some way down the sloped board. This will hopefully help.]*  Any ideas?  *[Students might have other ideas which could be discussed e.g. it's hotter down there (true, and does affect it, but it's still SOLID when it moves), or it's under more pressure down there (true, and the reason that it's hotter). In this case, you can tell them that we know it is solid because a type of sound wave called as s-wave can go through it and we know s-waves can't move through liquids.]* | *3 mins* | *Students try to reconcile the two pieces of information they have discovered about the mantle. They should realise, after having seen the silly putty earlier on, that things can be both solid and fluid, just over different timescales. Students attempt to generalise this to the mantle, how it can be solid on timescales that we can see, but act in a fluid way over a longer timescale.* |
| 79 | The mantle is like many solids, it behaves like a fluid over a very long time.  Can anyone think of any other solids which act like fluids over a long time?  *[useful examples include ice in glaciers, or custard/oobleck. Although this isn't the same thing as being a non-newtonian fluid! Glass in windows does flow, but not on the timescales that people think, it's much slower, so this misconception about old windows should be cleared up.]* | *2 mins* | *Students consider some alternative relevancies for the idea of solids behaving as fluids, and try to relate it to more familiar phenomena to aid understanding.* |
| 80 | Solids can flow by creep, the summation of lots of tiny motions to produce overall big movements. Crystals in the rock slide past each other, or dissolve in some places and re-grow in others to overall make the rock move.  We can have a race to demonstrate how creep of solids works.  ***EXPERIMENT 6 – Creep*** | *10 mins* | *Students get a physical understanding of how small motions of crystals can add up to make solids move, and see how lineation can be produced by creep.* |
| 81-88 | In the experiment we saw that creep caused alignment of crystals parallel to the direction the solid was moving. We can see this in real life too. Field geoscientists can see alignment and banding in rocks showing how they flowed (e.g. in Cornwall), or in the lab people can see crystals lined up by the flow in thin-sections (very thin slices of rock which you look at with a microscope).  Glaciers are solid but flow over time, you can see alignment in the ice in glaciers too. Glaciologists (a type of geoscientist) sometimes measure the speed of glacier flow using wooden sticks in the top of the ice. It is useful to know how glaciers move because then we can work out how old the ice is at different depth, and use ice-core records to see how climate changed in the past e.g. past CO2 in air bubbles in ice. This helps us understand modern climate change. | *4 mins* | *Students get a view of a different field of geosciences with a direct relevance to modern challenges of climate change.*  *They also are shown several examples of how geoscientists unwrap past motions form present patterns in rocks.* |
| 89-91 | So, the mantle must be moving really slowly, but quite how slow is it?  Suggest some things that move at different speeds and we can put them on the timescale timeline to see how fast the mantle really moves.  *Explain the logarithmic scale on the timeline.*  *[Make sure fingernail growth goes up there. This is quite open-ended and can take as long as you like. See fact-file for speeds, or look-up/estimate unusual things. This can also be done as an individual worksheet-style activity if you want]* | *2 mins* | *Students get a more physical understanding of the timescales involved by thinking about and comparing the speeds of everyday phenomena.* |
| 92-94 | Why is mantle convection useful? Any ideas?  *[They might not have any, but it's good to make them think. Go through list of applications and scientists using the idea in the power-point with the students.]* | *2 mins* | *Students get shown relevancy of the entire session to other problems and aspects of science, and hopefully are helped to appreciate the interdisciplinary nature of geosciences.* |
| 95-106 | Overview of everything we've learned during the session. | *3 mins* | *Students are told what they were told to improve retention of knowledge and make the overall "story" clear.* |
| 107 | 'What is a geoscientist like?' Take two | *2 mins* | *Students (hopefully) reconsider their views on geoscientists, in light of this workshop.* |
| 108 | **[Optional:** "Ask a geoscientist". Students can ask the demonstrator about geosciences, or their degree/career as appropriate.] | *10 mins* | *Students get a more detailed understanding of who geoscientists are and are given a real-life role-model.* |