Monitoring Volcanoes

These workshop notes are designed for use along with the accompanying slides which contain further notes.

Year Group: S1-S3

Length: ~50 minutes [10 mins introduction, 30* mins activity, 10 mins on monitoring techniques]

** depending on the party poppers/speed of the group, this can take up to 40/45 mins*

Set-up Time: 20 minutes (+ preparation time to tie party poppers – see below)

Room requirements: A classroom space with desks for students (ideally groups of 4)

Summary: This interactive session gives students the chance to discover the science of volcano monitoring and prediction, using the work of an interdisciplinary research team on the island of Montserrat as a case study. Party poppers are used to simulate a volcanic eruption and, from the data gathered, pupils form an evacuation plan and repeat the experiment to demonstrate how tricky it is to predict such volatile processes.

Equipment:

- Large plastic cups (2 per group)
- Party poppers (2 per group)
- Clamp stands (1 per group)
- Weights/bolts*
- Worksheet/paper to record data

** or anything else that can be placed, one at a time, in to a cup to weigh it down*

Preparation: make a small hole near the rim of each cup and carefully attached a party popper by tying the string through the hole using <u>three basic knots</u> so that it holds when weighted!

Content:

When asked to picture a volcano, most people imagine a cone-shaped mountain (a stratovolcano), but in reality volcanoes come in a much bigger range of different shapes and sizes.

The form of a volcano depends on the type of lava that is erupted – runny lava spreads out easily and forms a volcano with gently sloping sides (shield volcano) whereas thicker, stickier lava builds up more of a cone shape. The type of lava is partly to do with where the tectonic setting of the volcano. Plate Tectonics – the movement of the earth's crust – occurs because of convection in the mantle and results in these different settings.

Volcanoes form at subduction zones (the boundary of two tectonic plates where one is being pulled down underneath the other), spreading margins/rift zones (where two tectonic plates are spreading apart) and at hot spots (areas where there is excess heat in the mantle underneath the crust). Hot spots are not that common, so most volcanoes are found at the edges of tectonic plates, and a map of currently active volcanoes (as shown on the slides) matches nicely with a map showing the boundaries of the tectonic plates.

There are more volcanoes at spreading margins/rift zones than any other type. These can be underwater eruptions (mid-ocean ridges) or on land often form spectacular lava fountains and lava lakes, with curtains, flows and pools of glowing red-hot molten rock. Eruptions from these types of volcano are generally *effusive* (pouring out runny lava).

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The most violent and dangerous volcanoes are the ones that form at subduction zones. These can look much less stunning (for example lava domes which typically appear as piles of rubble/rock) but they are extremely important to study as they can be very unpredictable and large explosive eruptions may trigger one of the most dangerous volcanic hazards – *pyroclastic flows*.

Mt. St. Helens, Mt. Pinatubo, Krakatoa and Mt. Vesuvius are all famous examples.

Case Study: Montseratt (Soufrière Hills Volcano)

The island of Montseratt is located on a subduction zone, where the North American Plate is being dragged under the Caribbean Plate. The added water from the subducted plate makes it easier for the mantle to melt, and the resulting magma is less dense than the surrounding rocks and begins to rise until eventually it reaches the surface and erupts forming, in this case, a volcanic island.

Montseratt is a relatively small island (10 miles long by 7 miles wide) and the main vent of the volcanic system is to the south of the island. Plymouth, in the south west, is the technical capital of Montseratt but it has been abandoned since 1997 (making it the only ghost town that serves as the capital of a political territory).

Prior to its evacuation, there were approximately 4,000 inhabitants living in Plymouth, served by Bramble Airport (to the east) which was also destroyed in 1997.

Eruption timeline:

July 1995 – a series of eruptions with ash falls across southern Montserrat, including Plymouth

August 1995 – *tephra* (small particles/fragments of rock ejected by a volcano) falls on Plymouth

December 1995 – evacuation of Plymouth

Early 1996 – residents allowed to return to Plymouth

June 1997 – huge eruption creating pyroclastic surges (19 people killed), Plymouth evacuated again

August 1997 – series of large eruptions, approximately 80% of Plymouth destroyed

Late 1997 – Plymouth officially abandoned, southern half of Montseratt declared an exclusion zone

Time lapse video

Cameras set up to take a picture every day for 6 months, show the volcano growing over time and can be used to predict when the volcano is likely to erupt or collapse. Estimated growth rate for the timelapse video in slides is $7m^3/s$ or approximately 7 fridges worth of material every second!

The rapid growth of the volcano indicates that fresh magma is being supplied, the volcano becomes very unstable, and significant pressure builds up inside.

What happens when pressure builds?

The best comparison for pressure building up inside a volcano is a bottle of Irn Bru … Magma is similar to Irn Bru as they are both *liquids* containing *dissolved gases* (pupils will often point out that they are also similar in colour, which is fair enough considering the orange-ish glow that magma gives off because it is so hot!). Most people are familiar with what will happen if gas pressure builds up in a bottle of Irn Bru because it is shaken – if the lid is taken off the Irn Bru will be forced out of the bottle as the gas tries to escape, creating a huge mess.

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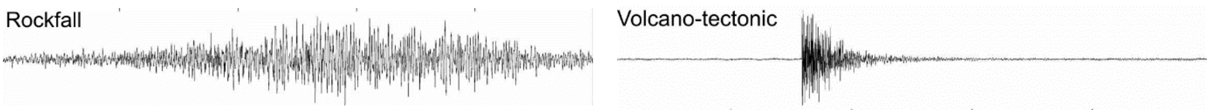
In magma, the dissolved gases (mostly carbon dioxide, water vapour & sulphur gases) also act as a driving force but instead of a lid being opened to release the pressure the volcano will erupt when the force can no longer be contained.

Pyroclastic flow:
Can reach speeds of up to 400mph and temperatures of 700-900°C, carrying large chunks of rock, clouds of ash and deadly gases.

[Practical activity works well here as a demonstration of how hard it is to predict eruptions, then continue by discussing the techniques mentioned and their relative strengths/weaknesses. There are a lot of slides explaining the different techniques and depending on how long the activity takes there may not be time to go through them all]

Seismic Network:
The seismic network (also used for monitoring earthquakes) records the shaking of the ground. In a volcanic setting, different signals can be recorded.

1. Rockfall signal – not very helpful in predicting danger as it is only seen when a collapse or even pyroclastic flow has already occurred
2. Volcano-tectonic – a sharp signature which then tails off, this is more useful as it indicates rock fracturing inside the volcano as a result of magma moving



Scientists can set up a number of seismic recording stations around the volcano, allowing them to track the movement of magma - if the signals originate from deep beneath the volcano there is less cause for concern, but as it rises to shallower than around 1km an eruption may be more likely.

The main problem with monitoring using the seismic network is identifying a clear signal – everything from heavy machinery or vehicles to people to small animals scurrying past can cause shaking and add noise to the signal making it messy.

[Various phone/tablet seismometer apps are available that can be used to demonstrate these signals. For the rock fall have the pupils gently jogging on the spot and then have them increase speed gradually and die down again – similar to rockfall as more shaking occurs as it builds up momentum and eventually dies off as it slows down. For volcano tectonic – have the class all jump but have to land at the same time. A sharp burst of energy which then tails off.]

The Electromagnetic Spectrum:
Scientists monitoring volcanoes are interested in the infrared part of the spectrum, which can be used to measure heat signatures (pupils will often point out that it's used in crime dramas in searching for missing people and it also makes an appearance in the popular game 'Call of Duty'). Being able to identify areas where more heat is being released by the volcano is useful as it indicates areas where fresh magma is being supplied (and sometimes erupted). Pyroclastic flows are also very hot and show up clearly on infrared cameras.

The main problem with infrared is that the signal can easily be blocked, particularly by water. This means that when there is a lot of cloud around infrared is essentially useless as it can't see through the water vapour droplets in the clouds. The video in the slides shows a good examples of this.

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You can search videos of infrared cameras on YouTube for examples – point out that the white/yellow areas are hotter than the blues/blacks

[The following link is a good example of infrared not being able to see through water – note that the man's hand goes dark as he puts it into the water suggesting it is colder than it really is https://www.youtube.com/watch?v=lAM-sLYCoXs]

Radar:

Radar can be used to 'see through' cloud. Pulses of radio waves are sent out and hit the target object, some is scattered away but most is reflected back to the source. The speed/distance/time equation V=D/T is then used to calculate how far away the object is (V is known – radio waves travel at the speed of light, 3×10^8 m/s, and T is known – the time between when the pulse was sent and when it returned).

The problem with radar is that is only able to image solid objects and therefore it can only image the front part of the volcano that the signal is pointed at.

Working with a team at the Montserratt Volcano Observatory, scientists from the University of St Andrews successfully combined infrared and radar in order to get temperature readings through cloud and to produce 3D images of changes in the volcanoes surface and temperature, helping them to predict which areas are most likely to collapse (more rapid growth and hotter areas = unstable so more likely to collapse).

Sources of supporting information:

BGS resource on different types of volcano:
https://www.bgs.ac.uk/discoveringGeology/hazards/volcanoes/types.html

BGS information on Montserrat:
https://www.bgs.ac.uk/discoveringGeology/hazards/volcanoes/montserrat/home.html

Oregon State University introduction to volcanoes:
http://volcano.oregonstate.edu/volcanoes-0

Suggested links/extensions:

Introduce the different types of igneous rocks formed in volcanic environments (see ***FUNdamentals of Rocks*** for descriptions and sample information).

Visual demonstration of the power of trapped gas – fill a film canister half full of water and quickly add half of an effervescent vitamin C tablet before putting the lid on tightly and turning the canister upside down … after a few seconds the gas will build up and the canister will 'pop', flying in to the air (full instructions/notes in ***Plate Tectonics***).

Expand on the evacuation aspect of the activity by getting pupils to consider what they would take as their survival essentials if they had to evacuate in a hurry. The American Department of Homeland Security gives some advice for being prepared - https://www.ready.gov/volcanoes.

There is also a first-hand experience book written about the Montserratt eruption: *'The Volcano, Montserrat and Me: Twenty years with an active volcano' by Lally Brown*

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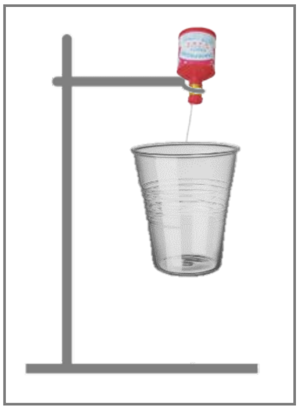
Activity:

Try to predict the eruption (of a party popper) and evacuate at the right time to save everyone, using only knowledge of previous eruptions.

The party popper represents the volcano, with the cup hanging underneath it representing the interior system and the magma chamber. Each weight added to the cup represents one day of pressure building up inside the volcano.

Set-up:

Each group should clamp their first party popper in to the stand by the narrow neck of the popper (to ensure it can't fall through), ensuring that the clamp is only loosely tightened and the party popper can still move slightly (so that the string inside isn't trapped, preventing an eruption).



Once set up and checked (see notes below), groups can start adding weights to the cup. Weights should be added one at a time (to represent each day) and must be counted as they go in – you may not get through all of the workshop if they have to re-count, also they have probably lost some due to the weights rolling! A tally space is provided on the worksheet overleaf.

Once the first party popper for each group has gone off, pupils should record how many days each of the volcanoes has taken from 'first activity' to 'eruption' (usually between 40 – 100 days, depending on the weights used). Discuss the minimum and maximum values and calculate an average (mean) for the data set.

Things to look out for: hands under cups (injury when cup falls), hands or faces over party popper (injury when party popper pops), clamp stand arm not over clamp stand base (toppled sideways).

[NB: occasionally the cup becomes completely full of weights without the party popper going off (or the group runs out of weights) – at this point tell the pupils that the volcano is going to release some pressure with an earthquake and get them to count to three and all bang on the table with their hands (take care to make sure they don't knock the stand over, this should only be done with an adult at the table) until the party popper goes off.]

This is the data collection stage – the pupils have collected information from a number of different volcanoes (of the same type – party poppers came from the same packet) and calculated the average number of days before an eruption occurs.

Each group now represents the science team advising the town of Plymouth when an evacuation should be carried out. The volcano has just started to show signs of activity again (ash is appearing etc.) and they need to make sure everyone is safe before the eruption occurs, but not remove everyone too soon. This is because people don't like to be away from home, and if they are evacuated too far in advance of the eruption and see that nothing happens, then they are likely to ignore advice, move back home, and be in danger!

Taking this in to account, each group should decide on and write down an evacuation day (remember it takes time to evacuate everyone!) based on all of the information collected so far.

The activity should now be repeated, with each group setting up their second part popper and trying to get past their evacuation date before the eruption. They should continue putting weights in the cup even after their evacuation date, until the party popper pops by itself.

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Each group can calculate the number of days between their evacuation and the eruption and compare using the table below to find out how many people they managed to save.

DAYS BETWEEN EVACUATION & ERUPTION	OUTCOME
Number of days > 60	**ALL EVACUATED, BUT 25% KILLED RETURNING TO HOMES AND CROPS** *(people have been away from home for so long they don't trust the scientists, aren't scared, move home, get caught in the eruption)*
60 > number of days > 14	**ALL EVACUATED, BUT 5% KILLED RETURNING TO HOMES AND CROPS** *(less time = fewer people moving back, snowball effect as 1 person moves back, tells friends and family its safe, they move back etc. … closer to 60 = closer to 25% killed)*
14 > number of days > 3	**ALL POPULATION EVACUATED** **NO FATALITIES!**
Number of days = 2	**EVACUATION STARTED, BUT 10% KILLED** *(not enough time, especially as can't fly out due to volcanic ash in the atmosphere)*
Number of days = 1	**EVACUATION STARTED, BUT 40% KILLED** *(as above, but less time so fewer people have had a chance to escape)*
Number of days < 1	**DISASTER!** **OVER 90% FATALITIES**

Even if the eruption happens before the evacuation and catches everyone by surprise, not everyone will be killed. Some people will have chosen to evacuate on their own (but it can be very expensive without government help for transport, accommodation) and some may just get lucky (in a different part of the island, on holiday).

It's hard to predict volcanic eruptions based on just previous observations – instead scientists use a range of different techniques to try to understand how volcanoes work and how best to keep people living near active ones safe.