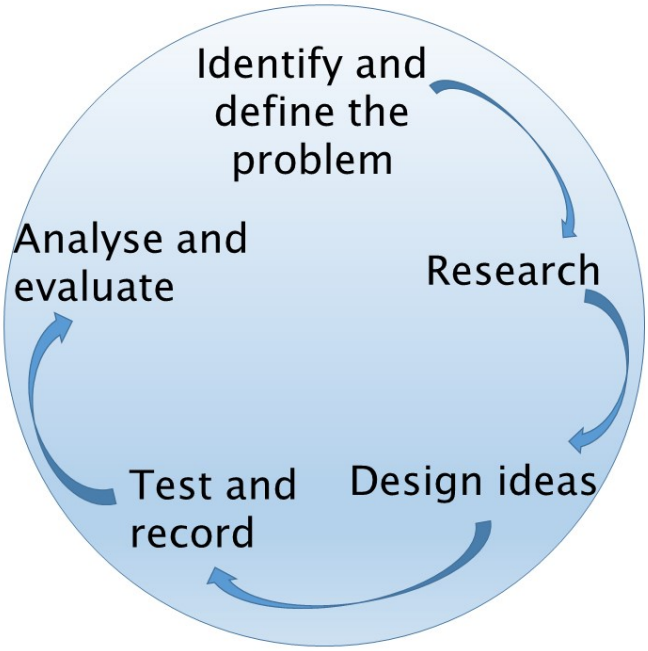
Volcanic Hazards – Student Booklet

The Challenge

Understanding the type and eruption history of a volcano is vital in understanding potential volcanic hazards. Volcanoes behave very differently depending on their type and location. The extent of the damage they cause will also depend on their proximity to populations. Your role is to investigate the behaviour of volcanoes and come up with an engineered solution which will help minimise the potential damage of a chosen volcano to local populations, explaining why it is a suitable solution for that area.



Background Information

Volcanoes are awesome yet powerful forces of nature, which were vital in the creation of Earth's current atmosphere and are important in the production of new, fertile soils, but they can also cause cataclysmic damage. In 1815 Mount Tambora, in Indonesia, erupted causing the 'year without a summer' as the large volume of ash and dust that entered the atmosphere filtered out a large portion of the Sun's rays.

Figure 1. Mount Tambora volcano on Indonesia's Sumbawa Island was the site of the world's largest historical eruption in April 1815. This NASA Landsat mosaic shows the 6-km-wide caldera truncating the 2,850-m-high summit of the massive volcano. Pyroclastic flows during the 1815 eruption reached the sea on all sides of the 60-km-wide volcanic peninsula, and the ejection of large amounts of tephra caused world-wide temperature declines in 1815 and 1816 (NASA, 2009).

An initiative supported by Woodside and ESWA

Over 71,000 deaths have been attributed to the eruption – the largest number of (human) deaths ever recorded to a volcanic eruption. Even with the best engineering solutions it would have been difficult to prevent death and injury from many of the hazards caused by the Mount Tambora volcano. Less violent eruptions can be easier to manage and predict, however.

In 1973 an eruption on the island of Heimaey caused a large lava flow that threatened to close off the harbour – the island's main income source by means of its fishing fleet. By pumping sea water onto the advancing lava flow, it was possible to cool the lava enough to halt its course and save the harbour. Other solutions to minimising the damage caused by volcanoes include creating man made channels to direct the flow of lava or landslides caused by eruptions.

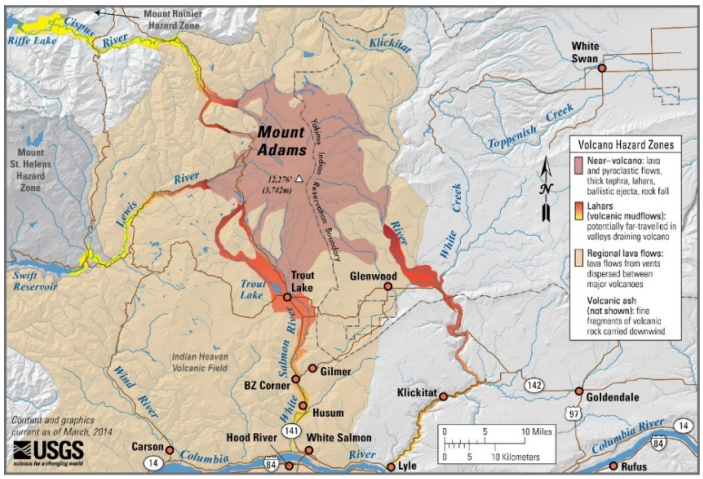


Figure 2. Mount Adams, Washington simplified hazards map showing potential impact area for ground-based hazards during a volcanic event (USGS, 2013).

A more simple solution can be creating a hazard map, using information known about the volcano and the topography of the region, to show areas that may be at risk and to not allow future building in these areas.

Volcanologists will investigate numerous factors to try to predict if, and when, a volcano may erupt again. The historic pattern of activity is a key indicator of when a volcano may erupt again, so by studying the frequency of previous eruptions it may be possible to forecast when one is due. Visible signs of a possible imminent eruption could include ground deformation – where it starts to swell due to rising lava – satellites are used to track this along with temperature changes. The swelling and ground movement can also cause small earthquakes which are tracked using seismometers. An increase or change in the type of gas being released is also an indicator that there is movement below ground and an eruption may be pending.

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Background Research

1. How many people have been killed by volcanoes since 1900?
2. Which countries have had the most fatalities caused by volcanoes since 1900?
3. What is the gross domestic product (GDP) per capita of each of these countries?
4. Is there any relationship between the GDP per capita and the number of fatalities?
5. What are the key differences between stratovolcanoes and shield volcanoes?
6. What are the hazards that can be caused by volcanic eruptions? How are these caused?
7. What are the different monitoring methods used to predict eruptions, and how do they work?
8. What are the common causes of death by a volcano (give specific examples).
9. What are the benefits of volcanoes, and why would people want to live near them?

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Where in the World?

Objective

To use Geographical Information Systems (GIS) to find the relationship between eruption styles/types of volcanoes and their tectonic location.

This investigation can be completed using paper maps or Google maps. Choose the equipment list and method suited to you.

Option 1: Paper Maps

Equipment

- List of recent volcanic eruptions with information on their location (longitude and latitude) and the type of volcano that produced it
- Map of the world with longitude and latitude lines on it
- Sticky dots or different coloured pens
- Map of tectonic boundaries

Method

1. Locate the position of each volcanic eruption on the map using the latitude and longitude coordinates. (+ Latitude = North, - latitude = South. + longitude = East, - Longitude = West)
2. Place a sticky dot/draw a dot on the map where the volcanic eruption was, using a different colour dot to show if it was from a stratovolcano or a shield volcano.

Option 2: Google maps

Equipment

- Computer
- Access to Google maps
- Excel

Method

1. Create two spreadsheets in Excel (one for stratovolcanoes and another for shield volcanoes) with the following headings: Volcano name, Latitude, Longitude and Elevation (m) (elevation is optional).
2. Carry out an internet search to find a list of shield and stratovolcanoes that have erupted in recent history – your teacher may guide you to a particular site.
3. Enter the information into the correct spreadsheet, ensuring you have at least 25 of each type.
4. Save each spreadsheet as a CSV file.
5. Open Google maps and click on the menu tab. Then select “My Places.”

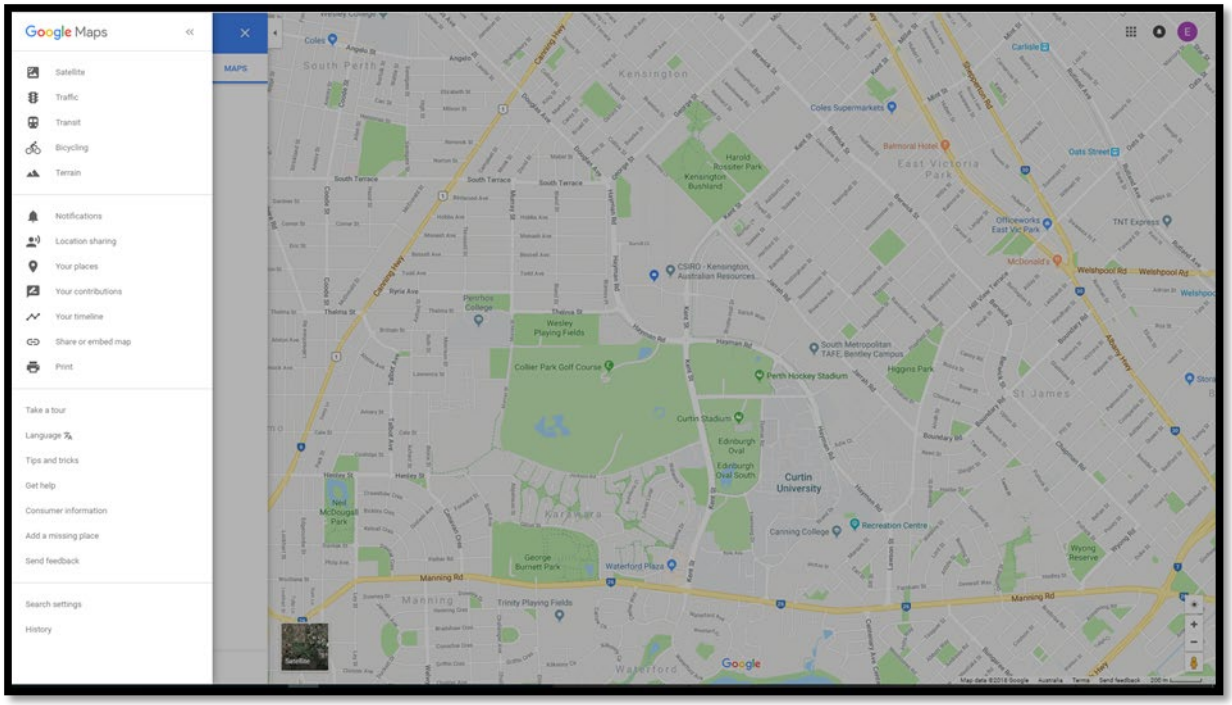


Figure 3. Screen shot of Google maps showing the menu bar.

6. Next select Maps -> create map.

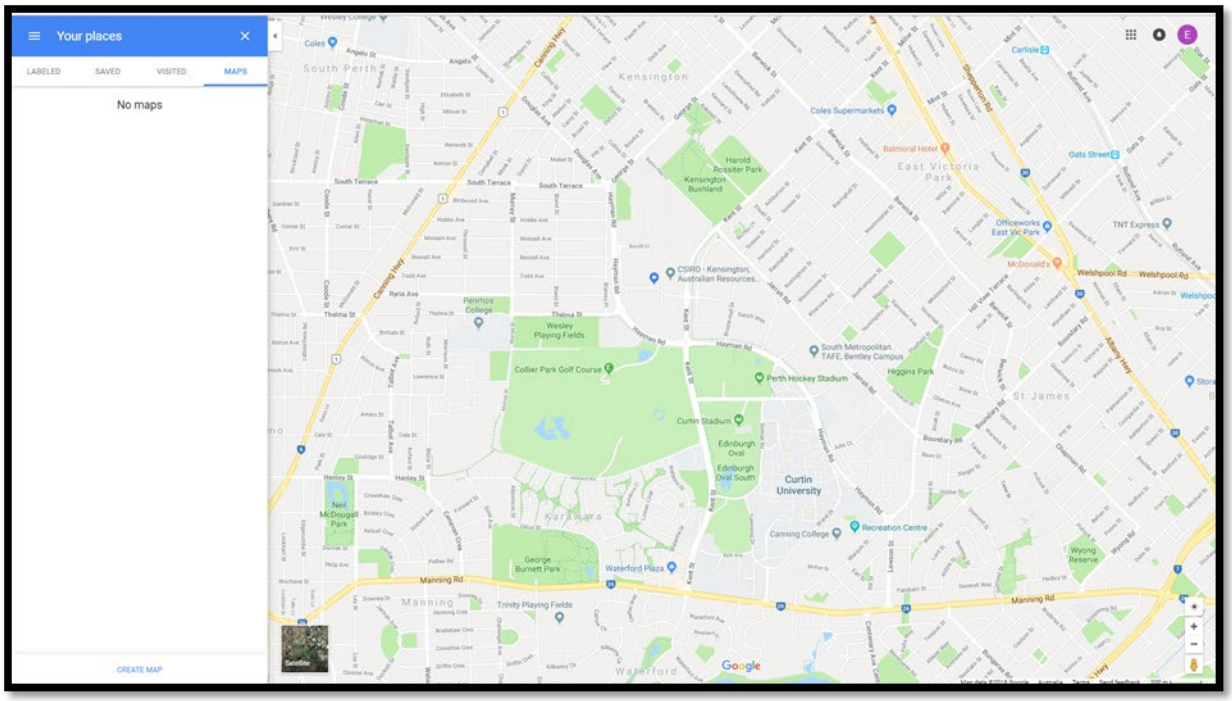


Figure 4. Screenshot of Google maps, select MAPS on the top bar, then CREATE MAP at the bottom of the menu bar.

7. Now you can either individually add each data point one at a time by selecting "add marker" tool (highlighted in yellow circle) OR you can import data directly from your spreadsheet by selecting "import".

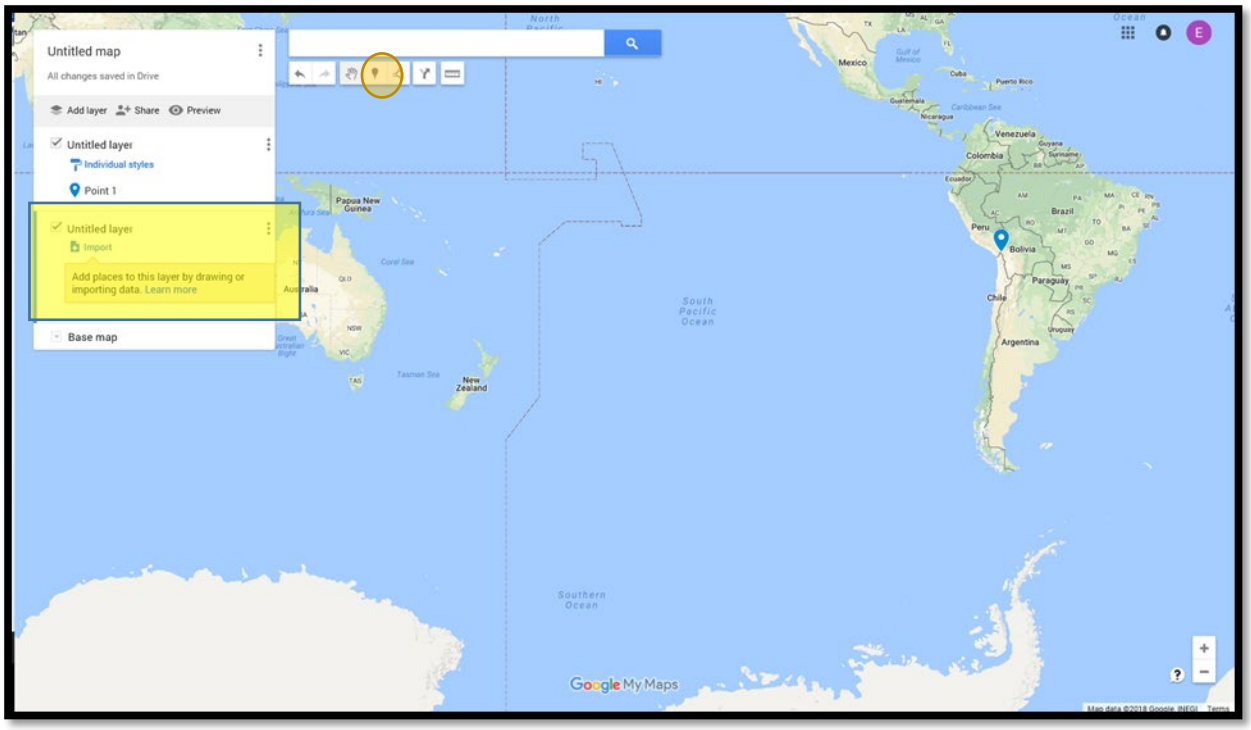


Figure 5. Screenshot highlighting where to select if you wish to add individual data points manually, or where to select if you wish to import a whole CSV file.

8. You can now edit your data points, by giving them different colours to highlight the different volcano types.

Results and Analysis

1. Compare your map to a tectonic map. Is there any relationship between the location of shield volcanoes and tectonic boundaries?
2. Compare your map to a tectonic map. Where are most stratovolcanoes found, at convergent (destructive) or divergent (constructive) boundaries?
3. Research the two types of volcanoes to find out more about their relationship with their tectonic setting.

How Fast will it Flow?

Three major factors can impact how fast a lava will flow: temperature, slope and viscosity. Design investigations for each.

Investigation 1: Temperature and Lava Flow

Objective

To determine how temperature impacts lava flow.

Method

1. Design an investigation to determine how temperature impacts lava flow using common laboratory equipment.
2. Create an equipment list, method and results/observations table and have these checked by your teacher before you conduct your investigation

Results and Analysis

1. Plot a scatter graph of your results and work out the formula for your line of best fit.
2. What happens to the time taken for the liquid to flow between the two points as its temperature increases?
3. What could this mean in terms of diverting flows and managing hazards?

Evaluation

1. Were there any potential sources of error in your investigation?
2. How could your improve this investigation?
3. What future experiments could you do to improve your conclusions?

Investigation 2: Angle of Slope and Lava Flow

Objective

To determine how the angle of a slope impacts lava flow.

Method

1. Design an investigation to determine how the angle of a slope impacts lava flow.
2. Create an equipment list, method and results/observations table and have these checked by your teacher before you conduct your investigation

Results and Analysis

1. Plot a scatter graph of your results and work out the formula for your line of best fit.
2. What happens to the time taken for the liquid to flow between the two points as the angle of slope increases?
3. What could this mean in terms of diverting flows and managing hazards?

Evaluation

1. Were there any potential sources of error in your investigation?
2. How could your improve this investigation?
3. What future experiments could you do to improve your conclusions?

Investigation 3: Viscosity and Lava Flow

Objective

To determine how the viscosity of a lava impacts its flow rate.

Background Research

1. What is viscosity a measure of in liquids?

_____

_____

2. Give three examples of highly viscous liquids compared to low viscosity liquids.

Highly viscous liquid	Low viscosity liquid

Method

1. Design an investigation to determine how the viscosity of a lava impacts its flow rate.
2. Create an equipment list, method and results/observations table and have these checked by your teacher before you conduct your investigation

Results and Analysis

1. Plot a histogram to show your results. Why would a line graph not be a suitable way to present your results?

2. What happens to the time taken for the liquid to flow between the two points as viscosity increases?

3. Was this what you predicted?

4. What could this mean in terms of lava flows and volcanic hazards?

Evaluation

1. Were there any potential sources of error in your investigation?
2. How could your improve this investigation?
3. What future experiments could you do to improve your conclusions?

VEI Scale

Objective

To create visual representations to make comparisons of the explosivity of historic eruptions, using the VEI scale.

Background Information

The Volcanic Explosivity Index (VEI) is a relative measure of the explosiveness of volcanic eruptions. It was devised by Chris Newhall of the United States Geological Survey and Stephen Self at the University of Hawaii in 1982.

Method and Results

VEI	Ejecta volume	Description	Plume	Frequency	Example	Occurrences in last 10,000 years*
0	< 10,000 m³	non-explosive	< 100 m	constant	Mauna Loa	many
1	> 10,000 m³	gentle	100-1000 m	daily	Stromboli	many
2	> 1,000,000 m³	explosive	1-5 km	weekly	Galeras (1993)	3477*
3	> 10,000,000 m³	severe	3-15 km	yearly	Cordón Caulle (1921)	868
4	> 0.1 km³	cataclysmic	10-25 km	? 10 yrs	Eyjafjallajökull (2010)	421
5	> 1 km³	paroxysmal	> 25 km	? 50 yrs	Mount St. Helens (1980)	166
6	> 10 km³	colossal	> 25 km	? 100 yrs	Krakatoa (1883)	51
7	> 100 km³	super-colossal	> 25 km	? 1000 yrs	Tambora (1815)	5 (+2 suspected)
8	> 1,000 km³	mega-colossal	> 25 km	? 10,000 yrs	Taupo (26,500 BP)	0

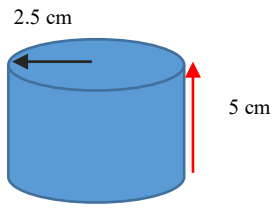
Figure 6. Volcanic Explosivity Index (Chegg Study, unknown).

1. Now convert all ejecta volumes into scientific notation

VEI	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Ejecta Volume (m^3)									

2. From VEI 3 onwards, how much more ejecta is released for each increase in index?

3. a) A student wanted to make a scale model to represent the volume of ejecta released as a classroom display. They intended to use a cylindrical eraser with a radius of 2.5 cm and height of 5 cm to represent a magnitude 2 VEI eruption. Calculate the volume and surface area of this cylinder and then the volume and surface area of the next 3 larger cylinders the student would have to create to keep the scale the same.
   b) Suggest what other cylindrical objects they could use for each VEI.
   c) Explain the difficulties with this idea.



The atmosphere contains many layers and stretches far beyond what most people realise. Each layer carries out an important role which influences our daily lives. Below is a table of information regarding the layers of the atmosphere.

Layers of the Atmosphere		
Layer name	**Extent of height above Earth's surface (km)**	**Information**
Troposphere	14.5	This part of the atmosphere is the densest. Almost all weather is in this region.
Stratosphere	50	The ozone layer, which absorbs and scatters solar ultraviolet radiation, is in this layer.
Mesosphere	85	Meteors burn up in this layer
Thermosphere	600	Aurora and satellites occur in this layer.
Ionosphere	48 - 965	The ionosphere is an abundant layer of electrons and ionized atoms and molecules that stretches from about 48 kilometres) above the surface to the edge of space at about 965 km, overlapping into the mesosphere and thermosphere.
Exosphere	10,000	This is the upper limit of our atmosphere.

Figure 7. Layers of our atmosphere (data from NASA (2018)).

4. Create a diagram to represent the first three layers of the atmosphere, ensure you have a clear scale and add any additional information you feel is important.

5. Add diagrams of volcanoes onto your diagram to show the maximum plume height for each index. You may want to research the example volcanoes given on the VEI scale so that you can also draw them to scale – or add pictures of them and further information, for example location and dates of historic eruptions.

Analysis

1. How much bigger on the VEI scale was the Krakatoa eruption in 1883 compared to the Galeras in 1993?
2. How much higher was the maximum plume height of the Tambora eruption of 1815 compared to the maximum plume height reached by Mauna Loa?
3. Which type of volcanoes typically have a higher VEI, stratovolcanoes or shield volcanoes?
4. Where are the more effusive and least explosive eruptions occurring, at convergent boundaries, divergent boundaries or at hot spots? Why do you think this is so?

Explosivity V Gas Content

Objective

To investigate if there is a relationship between the gas content of a liquid and explosivity, to relate this to volcanic eruptions.

Method

1. Design an investigation to determine if there is a relationship between the gas content of a liquid and explosivity.
2. Create an equipment list, method and results/observations table and have these checked by your teacher before you conduct your investigation

Results and Analysis

1. Produce a table and graph of your results.
2. What is the relationship between gas content and eruption distance of a liquid?
3. What could this mean in terms of lava flows and volcanic hazards?
4. What are the difficulties of mitigating and managing volcanic hazards caused by highly explosive volcanoes?

Evaluation

1. Were there any potential sources of error in your investigation?
2. How could your improve this investigation?
3. What future experiments could you do to improve your conclusions?

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Probability of Eruption

Objective

To use historical data to determine the likelihood of a volcanic eruption of a particular size occurring.

Background Research

1. What is the Volcanic Explosivity Index (VEI)?

_____

_____

2. Use Wikipedia, or another website, to find out the frequency of volcanic eruptions in relation to their VEI.

VEI	Frequency
0	
1	
2	
3	
4	
5	
6	
7	
8	

Method and Results

1. Use the data you have collected to calculate:
    a. The probability of an eruption with a VEI of >3 occurring today?
    b. The probability of an eruption with a VEI > 3 NOT occurring today?
    c. The probability of an eruption with a VEI > 3 NOT occurring today considering it didn't occur yesterday?

Volcanoes tend to have similar eruptions each time they erupt, due to their tectonic setting. We can predict the probability of a volcano erupting in a particular region if we know about its past. You can use the database on the Smithsonian Institution Global Volcanism Program website: http://volcano.si.edu/ or another means to find the number of eruptions that have occurred in a particular country in the past. Select a country that you know has been geologically active in the past 100 years (e.g. Iceland, Indonesia…) and download the dataset on that country – or research it and create a spreadsheet with the following headings:

- Date of eruption
- VEI
- Number of years from present day

2. Create a stem and leaf plot to display the VEI against number of years from present day for each eruption.
3. Calculate the mean and median VEI of the eruptions for that country.
4. Create box and whisker plots to show the interquartile range of the VEI.
5. Calculate the mean and median length of time between each eruption.
6. What is the range in the length of time between each eruption?

Analysis

1. Can you give a rough prediction of when the next eruption may be due and what VEI magnitude it may have? Justify your answer.

2. Suggest any further statistical analysis that could be done to give you a more accurate answer to the one above.

Building a 3D Volcano

Objective

To use topographic maps to create a 3D model of an active volcano, to investigate probable routes of a lava/lahar flow and create a basic hazard map.

Method

1. Design an investigation to investigate probable routes of a lava/lahar flow, using a 3D model of an active volcano, to create a basic hazard map.
2. Create an equipment list, method and results/observations table and have these checked by your teacher before you conduct your investigation

Results and Analysis

1. Did the 'lava/lahar' flow the same way for each trial?
2. Was it a good representation of the type of material your chosen volcano is likely to erupt?
3. Looking at your volcanic hazard map where would you recommend banning new construction? Why?

Evaluation

1. How realistic is your model volcano?
2. What improvements would you make to:
   a) The model
   b) The experiment
   to make it a more realistic test?

Designing a Diversion

Objective

To design an engineered solution for a chosen volcano which will help minimise the potential damage to local populations, explaining why it is a suitable solution for that area.

Background Research

1. Choose an active volcano/area near a volcano that you think would most benefit from volcanic hazard mitigation. Research more about the area such as:
    - The Gross Domestic Product (GDP) of the country
    - The population intensity
    - How frequently eruptions occur in the location
    - The maximum and average magnitude of eruptions in the location (VEI)
    - What type of volcano it is
    - The tectonic setting
    - The risk of lahars/landslides/avalanches/lava flows in the location if there is an eruption

2. Use the internet to find out more about current or historic ideas which have been designed to minimise the potential damage to populations living near volcanoes, to complete and add to the table below. Consider their strengths and weaknesses ***in relation to your chosen location*** by **critically analysing factors, including social, ethical and sustainability considerations.**

Method

1. Brainstorm your own ideas to minimise the damage from an eruption of your chosen volcano, comparing the pros and cons of them – add diagrams (use CAD if possible.)

If you are considering an idea such as creating earth barriers or lahar channels you may wish to make a model of your volcano in 3D and then cut out channels to test where they will be most effective.

2. If you plan to make a model of your hazard mitigation solution create an equipment list, method and results/observations table and have these checked by your teacher before you conduct your investigation

Evaluation

1. What were the strengths and weaknesses of your design?

2. What improvements could you make to your design? Explain why these suggestions would improve the design. Complete a labelled diagram of your modified design – highlighting the modifications.