Volcano Island: Montserrat, West Indies 1995 to 2001

This resource was principally created for pupils aged 11-16 taking courses in geography, geology and science. The resource accompanies a video, together they tell the story of the eruption on Montserrat, explain major volcanic processes, introduce modern methods of monitoring an active volcano and consider the impact of volcanic activity on a small island community. This resource contains additional information including a history of the eruption, a glossary of terms, maps and references for further reading plus a set of twelve worksheets.

The resource and accompanying video explains

- **the plate tectonic origin of volcanoes**
- **the nature of magma**
- **lava dome growth**
- **pyroclastic flows**
- **volcanic explosions**
- **volcanic ash and pumice**
- **volcanic blasts**
- **lahars (volcanic mudflows)**
- **volcanic hazards**
- **methods of monitoring volcanoes**

Volcano ISLAND

A study of an active volcano

David Lea lives on Montserrat and has documented the eruption in film from its beginnings in 1995. His spectacular video images provide the backdrop for this unique study.

Professor Steve Sparks FRS of Bristol University wrote the script of the film and this educational resource that explains ideas about volcanoes and their hazards.

Further copies of the video and resource (priced £15 inc p&p) may be ordered from:
ASE, College Lane, Hatfield Hertfordshire, AL10 9AA. Tel: 01707 283001 Fax: 01707 266532

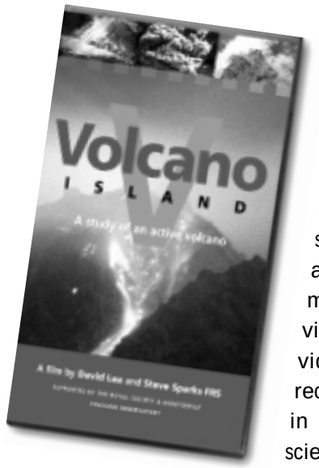
THE ROYAL SOCIETY

The Royal Society is pleased to support the production of this video and resource as part of its work in science education. Founded in 1660, the Royal Society is the independent scientific academy of the UK, dedicated to promoting excellence in science. Further information about the Society can be found at www.royalsoc.ac.uk

An educational resource

by David Lea and Steve Sparks FRS

Supported by the Royal Society and Montserrat Volcano Observatory.



Montserrat's Andesite Volcano

Use of the video for teaching

The video can be used at a variety of levels in schools. The narration is focused on the Earth science content in the Science, Geography and Geology National Curricula at Key Stage 3 and 4. Thus the terms and concepts in the video are those that are commonly introduced to students at this stage. The video is rich in visual and factual information and the student will benefit from some preparatory and follow-up material to get the most out of the video's content. It will help the viewer to be familiar with the geography of Montserrat. Although the video tells the story of the eruption and explains some scientific terms we recommend that students also read over the brief account of the eruption in this resource and familiarise themselves with the more important scientific terms in the glossary.

The richness of information allows the video to be shown more than once. The video has been broken into sub-sections so that individual segments can be extracted to focus on a particular subject or issue. For example the sections showing volcanic explosions could be shown initially to give a class a basic idea of how pyroclastic flows form and could then be studied in more detail, after appropriate lessons and reading. One suggested strategy is to show the video in its entirety after some basic preparation and then repeat each section on a particular phenomenon as the basis for a segment of the course. The amount of preparation will of course depend strongly on the background of the students and purpose of the course.

The video does not attempt to explain everything. Indeed many aspects of volcanism are not fully understood. The inquisitive student will no doubt identify many unanswered questions and puzzles, which can form the basis for further study and reading.

ISBN No. 0 85403 567 2

Introduction

Volcanic eruptions are one of the great spectacles of nature and remind us that we live on a dynamic and ever-changing planet. Volcanoes can also be very dangerous and pose threats to the people who live next to them. Studying volcanoes is thus important both to understanding how the Earth works and to practical problems of living with an active volcano. This video, made with the support of the Royal Society and the Montserrat Volcano Observatory, provides a case study of the eruption of a volcano on the Caribbean island of Montserrat. The eruption of the Soufrière Hills Volcano (1995-2001) displayed a remarkable range of volcanic phenomena. Almost every kind of major volcanic process occurred. The eruption was recorded on video by producer David Lea. His remarkable collection of images forms the basis for a video study of the eruption and major volcanic processes. The video introduces the student to the ideas of plate tectonics and why most volcanoes occur at the boundaries between plates. The video describes the modern techniques of monitoring an active volcano. The video also shows the impact of a major volcanic eruption on an island society.

The video study is aimed principally at school children in the 11 to 16 years range taking courses at Key Stages 3 and 4 in the Science, Geography and Geology curricula. Students taking Advanced level Geography should also find the video useful. A broader audience will find the video entertaining, educationally valuable and instructive. Volcano enthusiasts, be they amateur or professional, will find some outstanding images of volcanic phenomena and will learn something new from watching the unique footage. Some of the images of the eruption are spectacular and beautiful so much of the video can be simply enjoyed.

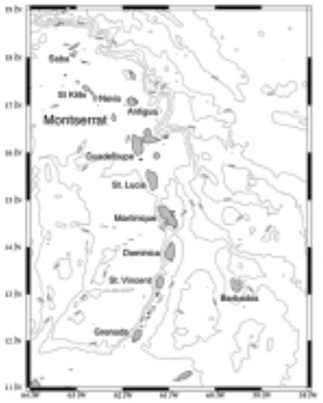
The Soufrière Hills volcano on the southern end of Montserrat is a collection of lava hills and is seen steaming.

The video is designed as an aid to teaching and learning about volcanoes in secondary schools.
This resource provides some ancillary information including a brief background to the island, a map of the Caribbean, a map of Montserrat, a history of the eruption and an explanatory glossary. Worksheets are provided for teachers to develop some of the themes and topics explored in the video. Suggestions are made on how the video might be used as a teaching aid on the inside cover.

History and Geography of Montserrat

Montserrat is one of eleven islands with an active volcano in the Caribbean that make up the Lesser Antilles *(Figure 1, also see Worksheet 8).* The island is about 100 square kilometres in area and is about 16 km from north to south and about 8 km at its widest from east to west. The climate of Montserrat is tropical and warm throughout the year. There is with a wet season and a dry season, although there can be a lot of rain any time of the year. There are often tropical storms and hurricanes in the Caribbean during the wet season from July to October. In 1989 a huge hurricane called Hugo swept through Montserrat and destroyed many homes.

Figure 1. See Worksheet 8 for large size format of map



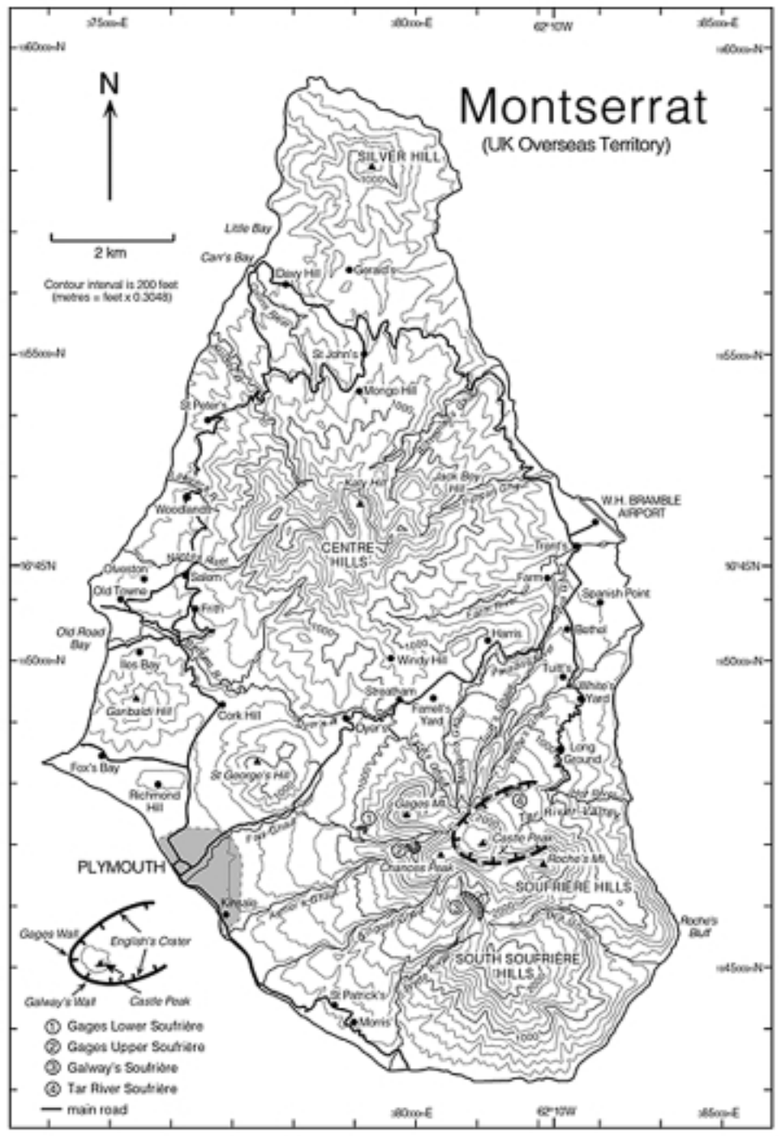


Figure 2. Map of Montserrat.

Volcano ISLAND

Montserrat is a rugged island *(Figures 2, 3a and 3b)* with several high hills and rather few beach areas. The Silver Hills and Centre Hills are old extinct volcanoes and the Soufrière Hills is the active volcano. The Soufrière Hills is made up of several peaks, such as Chances Peak, Gages Mountain and Perches Mountain. Each of these hills is in fact a large lava dome from a prehistoric eruption. The activity of the volcano goes back for over 180,000 years. About 4000 years ago there was an immense landslide. A large area of the volcano slid into the sea to the east. A large horseshoe-shaped depression known as English's crater formed at the top of the volcano. The flanks of the Soufrière Hills volcano are cut by deep river valleys known locally as ghauts.

Like many Caribbean islands Montserrat was inhabited by Carib Indian people for well over one thousand years before European people arrived in the sixteenth century. The island was uninhabited when Irish people settled there in 1632. The island eventually became a British colony. Many of the place names on Montserrat *(Figure 2)* reflect this Irish and British history. During the seventeenth and eighteenth centuries Montserrat's economy developed principally around sugar plantations and slave labour. After slavery was abolished the island continued as a colony sustained mainly by agriculture. However, towards the end of the twentieth century the importance of agriculture declined and the island became increasingly dependent on other activities such as tourism.

Before the eruption in 1995 Montserrat had a successful economy. In addition to tourism there was a rice mill, an American Medical school and several cottage industries. Wealthy people from the UK and North America Montserrat retired and bought luxury villas on Montserrat, making an important contribution to the economy. The island had become well known in the world of pop music in the 1970's when famous rock'n'roll groups and stars, such as the Beatles, Elton John and the Rolling Stones, came to Air Studios to record. The population was about 12,000 people in 1995 when the eruption began. Most of the people lived in the south on the flanks of the volcano, which was the most attractive part of the island. About half the people lived in the capital of Plymouth.

The island's status is now as an Overseas Territory of the UK. There is a local democratically elected government and several members of parliament with a Chief Minister. There is also a British Governor, who represents the Queen and is responsible for external matters such as foreign policy.

Figure 3a. Plymouth and the Soufrière Hills volcano from the north-west.

Figure 3b. The Soufrière Hills volcano viewed from the north-west.

Brief account of the eruption

The eruption of the Soufrière Hills volcano began on 18 July 1995 after three years of earthquake activity. The eruption was the first eruption of the volcano since the island was settled in 1632. In 1896-97, 1933-37 and 1966-67 there were thousands of small earthquakes on the island. However there was no eruption in these periods of numerous earthquakes so the people on the island did not realise that the earthquakes from 1992 to 1995 would lead up to a major eruption.

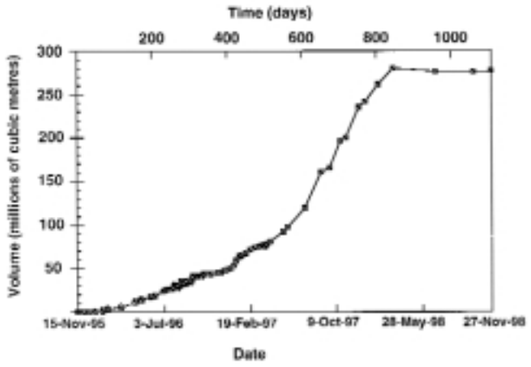


Figure 4. The chart shows the volume of magma erupted with time.

Figure 5a. The dome during the day in 1997 is a pile of broken grey rock.

One of the most important measures of the size of a volcanic eruption is the volume of erupted magma. Volume is usually measured in millions of cubic metres or cubic kilometres. By 2001 over 400 million cubic metres or two-fifths of a cubic kilometre of magma had erupted. Try and imagine a cube of rock with sides of 750 m to get an idea of the enormous amount of erupted magma. A chart of the volume of magma erupted over the first 3 years of the eruption is given in *Figure 4*. The rate at which magma erupts is a measure of how active the volcano is. Scientists usually record this rate as cubic metres of magma erupted every second. To help the public on Montserrat understand the activity of the volcano these rates were described by the scientists as the number of domestic fridges or cars erupted every second. A fridge has a volume of about 1 cubic metre and a car has a volume of about 5 to 7 cubic metres. In the first few months of the eruption magma was erupting at about half a cubic metre every second. During 1996 the rate of eruption increased to about 3 cubic metres per second and in the last 6 months of 1997 the rate of eruption increased to about 7 cubic metres per second. There are 86,400 seconds in a day so the volcano at the height of its activity in 1997 was erupting the equivalent volume of 100,000 cars every day!

In the first four months of the eruption jets of steam and small explosions were observed from vents in English's Crater. There were also many earthquakes and some of these were large enough to shake the ground in Plymouth. People were scared. On 21 August 1995 a cloud of black ash from an explosion moved into Plymouth and most of the people evacuated the town.

Volcano ISLAND

The magma reached the Earth's surface on 15 November 1995 and a dome of red-hot andesite lava started to grow in English's Crater *(Figure 5a and 5b*). In March 1996 the lava dome became sufficiently big that parts of the dome collapsed. Avalanches of hot lava rock flowed down the side of the dome and into the Tar river valley *(Figure 6a and 6b)*. These avalanches are called pyroclastic flows. The dome continued to grow through 1996 with collapses of increasing size taking place. Pyroclastic flows reached the sea in May 1996 and a delta of new land built out beyond the old coastline. A major part of the lava dome collapsed on 17 September 1996 and was followed by the first major explosion, which formed a 14 km high cloud. Lumps of pumice with sizes of several centimetres, fell onto the roofs of houses in villages near the volcano. Rocks of over a metre in diameter were thrown by the force of the explosion to the village of Long Ground to the east of the volcano *(Figure 2)*. A few houses were destroyed and many caught fire. Fortunately nobody was hurt because the village had already been evacuated.

After a period of slow dome growth from October to December 1996 there followed an increase in the rate of growth of the lava dome and more large pyroclastic flows reached the sea on the east coast. By the end of March 1997 the dome had almost filled English's Crater. Up to this time the dome collapses had sent pyroclastic flows down the Tar River valley to the east, the open side of English's Crater. Now the lava dome built over the south-western wall of English's Crater and pyroclastic flows moved down the White River valley nearly reaching the sea.

Figure 5b. The dome at night in April 1996 is red hot.

Figure 6a. A small pyroclastic flow moves down the side of the dome.

The focus of lava dome growth switched in May 1997 and the northern flanks became threatened *(Figure 7)*. By this time the whole of the south of Montserrat had been evacuated. On 25 June 1997 about 5 million cubic metres of lava collapses and pyroclastic flows swept over the northern flanks of the volcano at speeds of over one hundred kilometres per hour. Unfortunately some farmers and villagers had come back to this area despite the danger. 19 people lost their lives.

Lava dome growth was now three times faster than in 1996 (the volume of a car every second rather than a fridge). The dome built over the walls of English's Crater facing Plymouth in early August. Pyroclastic flows from large collapses of the dome swept into Plymouth on 3 August, destroying the central parts of town. Immediately following this collapse a period of large volcanic explosions occurred from 3 to 12 August 1997 *(Figure 8)*. These explosions were quite regular, with one occurring every 12 hours. Some of the explosions generated pyroclastic flows full of lumps of pumice by the process of fountain collapse.

Lava dome growth through August and September 1997 ended in another large collapse of about 9 million cubic metres of lava on 21 September 1997. The pyroclastic flow covered the north-eastern flanks and destroyed the Bramble airport terminal. There then followed a month of 75 spectacular explosions, with one explosion taking place about every 9 hours. Many of the explosions formed pumice-rich pyroclastic flows. Growth of the lava dome resumed on 22 October 1997 in the 300 m diameter crater formed by the explosions.

Figure 6b. A large pyroclastic flow has moved down the Tar River valley and has formed a large cloud of ash and hot air above the flow.

Figure 7. The lava dome in June 1997 has grown so large that it has filled English's crater. The lava dome has built over the northern crater wall (to the right). On 25 June the lava at the summit collapsed down the volcano in a large pyroclastic flow.

Lava dome growth switched to the south in early November 1997 and large pyroclastic flows entered the sea down the White River on the west coast on 4 November. The dome continued to increase in size in November and in December reached its greatest height (1030 m) and largest volume (110 million cubic metres) by Christmas Day.

On Christmas Day 1997 numerous earthquakes were recorded on seismographs in the Observatory and at 3 am on 26 December the largest eruptive event of the whole eruption occurred. The lava dome had been growing over an area of weak rocks. These rocks failed in a large volcanic landslide, which swept down the White River valley reaching to within 100 m of the sea. The landslide undermined the lava dome and about 60 million cubic metres of the dome collapsed to form a violent volcanic blast, which devastated 10 square kilometres of south-western Montserrat. The eruption only took 15 minutes and the volcanic blast had a speed of about 300 kilometres per hour. The entire village of St Patricks was completely destroyed. Many of the houses broke apart and were swept into the sea. Nobody was hurt because the village had been evacuated the year before.

The volcanic blast of 26 December 1997 was followed by further lava dome growth. Surprisingly the lava dome stopped growing quite abruptly in early March *(Figure 4)*. This ended the eruption of magma. However volcanic activity continued during 1998 and 1999 with further collapses of the still hot lava dome generating pyroclastic flows and some small explosions. There was high rainfall in the 1998 wet season, in particular during the passage of Hurricane George in September, with generation of lahars (volcanic mudflows) and flash floods, which transported large amounts of volcanic debris onto the lower flanks of the volcano. The centre of Plymouth became buried underneath this debris (*Figure 9)*. In November 1999 the lava dome started to grow again and has continued into 2001.

The effects of the eruption on Montserrat have been profound. The only safe part of the island is in the north. There were not enough houses in the north to

Volcano
ISLAND

accommodate the people escaping from the volcano, and so many people had to leave Montserrat altogether and had to start a new life in another country. Most of these people went to Britain, North America and other Caribbean countries. By 1999 there were only about 4000 people remaining of the original 12,000 people. The economy of the island suffered greatly, because most of the businesses and activities such as farming were in Plymouth and the south. An assessment of economic losses by the British Government gives a cost of about one billion US dollars. Despite the severe problems and hardship the people of Montserrat are now rebuilding the island society and learning to live with an active volcano.

Figure 8. An explosion of the volcano in August 1997.

Figure 9. A telephone box in the centre of Plymouth shows how the town has been buried by the deposits of pyroclastic flows and lahars.

Glossary

Andesite Andesite is the name given to volcanic rocks that form at volcanoes like the Soufrière Hills where tectonic plates collide. Andesite magma is very stiff and flows very slowly.

Ash Ash is defined as volcanic particles less than 4 mm in diameter.

Ash fall Ash fall occurs when volcanic clouds full of volcanic ash are blown by winds across the island. The ash falls to the ground and covers everything.

Basalt Basalt is the name given to volcanic rocks that form at volcanoes where tectonic plates pull apart, and also in some volcanoes in the middle of the ocean like Kilauea on Hawaii. Basalt flows easily and volcanic gases can escape. Basalt magma is much hotter (1200°C) than the andesite magma at Montserrat (850°C).

Blast: see volcanic blast.

Crater A Crater is a volcanic depression often caused by explosions which blow out a hole in the ground around the vent.

Cloud A volcanic cloud is a mixture of volcanic ash, gas and air that can quickly rise to heights of many kilometres above the volcano. Volcanic clouds can be formed by explosions and by pyroclastic flows mixing lots of hot ash into the air as they move down the sides of the volcano.

Deformation Deformation describes how a volcano changes shape as the pressure inside changes. In many eruptions the large pressure inside the volcano due to the pushing of magma causes the volcano to swell. The volcano increases in size and points on the ground move apart. The tiny movements of the ground are detected by instruments that measure the position of the ground very accurately.

Dome: see Lava dome.

Dormant A dormant volcano is a term used for a volcano that has not erupted for a long time, but is still capable of future eruptions. The last eruption before the 1995-2001 eruption on Montserrat was over 500 years ago. Thus the Soufrière Hills volcano was regarded as dormant before 1995.

Earthquakes Earthquakes are caused by breaking rock that releases energy in the form of vibrations which shake the ground.

Explosions Volcanic explosions occur when magma containing a lot of dissolved volcanic gas reaches near the Earth's surface. Bubbles of gas form in the magma with very high pressures causing the magma to explode.

Extinct An extinct volcano is one that is no longer able to erupt. The Centre Hills on Montserrat is an example of an extinct volcano.

Flash floods Flash floods occur when intense rain causes a rapid increase in river discharge. Flash floods are very effective in mobilising loose volcanic debris. See lahar.

Fountain collapse Fountain collapse is the process that forms pyroclastic flows in volcanic explosions. A mixture of volcanic gas, pumice and ash is blown by the explosion into the atmosphere above the vent. The mixture is denser than air and forms a huge fountain over the volcano. The mixture then flows down all sides of the volcano (see also pyroclastic flow). The video of the Soufrière Hills Volcano shows some excellent examples of this process.

Hazard A volcanic hazard is any volcanic event that is dangerous to humans or is destructive (for example to houses).

Igneous rocks Igneous rocks are formed from magma when it solidifies. Magma that erupts and solidifies at the Earth's surface is volcanic rock. Magma that solidifies underground is called plutonic rock.

Island arcs The boundaries of plates in ocean areas occur where one plate is pushed back into the interior of the Earth below the other plate. Island chains of active volcanoes form at the boundary as exemplified by the Lesser Antilles island arc in the Caribbean.

Lahar A lahar (an Indonesian word) is a flow of volcanic rock, ash and water. Lahars form when there is a lot of rain, as has been the case on Montserrat, or when there is a sudden release of a lot of water, such as a melting glacier. Lahar formation often occurs after a major eruption because there is a large amount of loose rock and ash on the volcano. A lahar is also called a volcanic mudflow.

Lava Lava is a flow of magma along the ground at the Earth's surface.

Lava dome A lava dome is a large mound of lava. In volcanoes like the Soufrière Hills the magma is very stiff and can only flow very slowly. The lava piles up around the vent to form a mountain of red-hot lava.

Magma Magma is liquid rock, which often contains some solid crystals and gas bubbles.

Magma A magma chamber is a region of magma, usually within the Earth's crust, which supplies magma to the volcano. At the Soufrière Hills volcano the andesite magma comes from a chamber estimated to be about 5 to 6 km below the volcano.

Monitoring Monitoring is the scientific term for watching what happens at the volcano and measuring the volcanic activity, such as earthquakes, deformation of the ground and release of volcanic gas.

Ocean ridges Ocean ridges are the boundaries between plates that are pulling apart. They mostly occur on the ocean floor. As the plates move apart basalt volcanoes erupt and a ridge of volcanic rock forms on the floor of the oceans.

Plate tectonics Plate tectonics is the idea that the Earth's surface is broken up into a series of large plates of solid rock and that these plates both push together and pull apart. Volcanoes form at the boundaries between the plates. See ocean ridges and island arcs.

Prehistoric Prehistoric refers to any volcanic eruption that occurred before an area was inhibited by humans and the activity of the volcano recorded. On Montserrat prehistoric refers to before the year 1632 when the island was first settled by Europeans. Carib Indians lived on the island hundreds to thousands of years ago but there is no written record of their history on the island.

Pumice Pumice is a volcanic rock containing a lot of gas bubbles. Pumice is foamy rock and is very light so that pumice floats on water. Pumice forms when magma full of dissolved volcanic gas rises to the Earth's surface and explodes.

Pyroclastic Pyroclastic is a general term for pieces of volcanic rock erupted by a volcano. The pieces of rock can be any size from the size of a car to tiny pieces of dust.

Pyroclastic flow Pyroclastic flow is a concentrated flow of hot volcanic fragments. There are two main kinds of pyroclastic flow on Montserrat. One kind forms by collapse of a dome and is made of lava blocks and ash. The other kind forms from a volcanic explosion to form a flow of pumice and ash (see also fountain collapse).

Pyroclastic surge Pyroclastic surge: see volcanic blast.

Risk Risk is the situation when a volcanic hazard threatens people or material things such as houses. The level of risk depends both on the kind of the hazard and other factors such as the number of people in the threatened area. If nobody lives in an area threatened by a volcanic hazard then there is no risk.

Seismograph A seismograph is an instrument that displays the vibrations of the ground measured by a seismometer. Usually a drum covered in paper slowly turns and a pen makes a continuous mark on the paper. When there is an earthquake the vibrations of the ground are recorded by the seismometer and transmitted to the Observatory where earthquake vibrations are converted into vibrations of the pen on the seismograph.

Seismometer A seismometer is an instrument that records the vibrations of the ground caused by an earthquake.

Steam vents Steam vents are formed where very hot water reaches the Earth's surface and boils violently to form a jet of steam from a vent. Such activity is common in the early stages of an eruption. The inside of a volcano is soaked in water in a tropical island and the magma heats water as it moves to the Earth's surface.

Tectonic Tectonic is a term used to describe the movements of the rocks near the Earth's surface, which are largely caused by movements of the plates.

Vent A vent is the surface opening through which volcanic materials (magmas and gases) are emitted at the earth's surface.

Volcanic blast A volcanic blast is a very violent pyroclastic flow that moves at high speed. A blast typically moves at speeds of hundreds of kilometres per hour and devastates everything in its way. Sometimes volcanic blasts are also called pyroclastic surges.

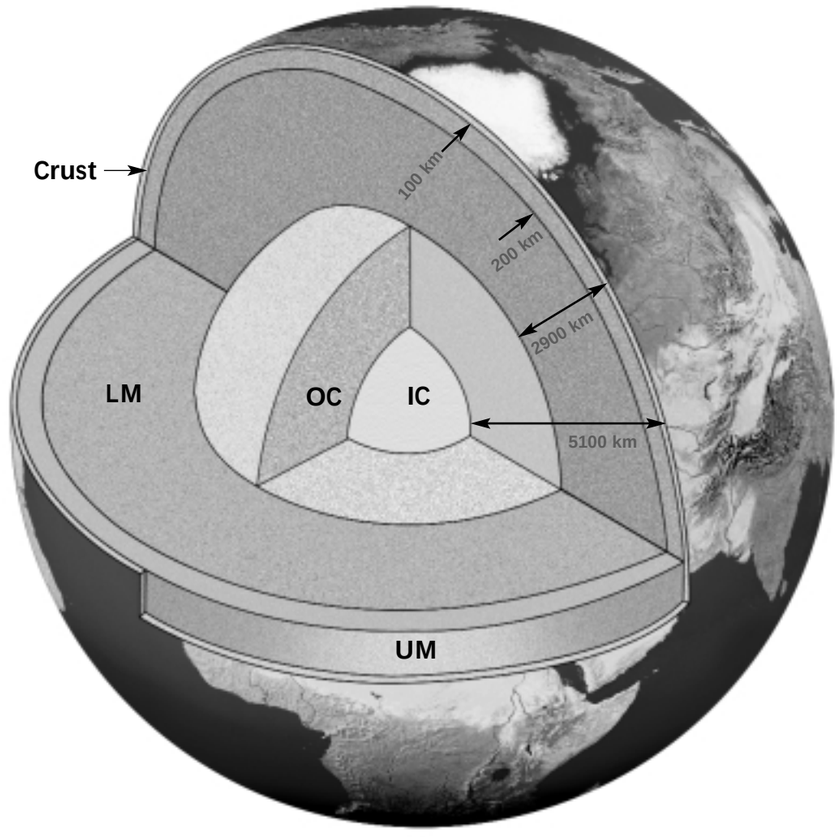
Volcanic gas Volcanic gases are dissolved in the magma at depth in the chamber where the pressure is very high. The gas is released by the growth of bubbles in the low pressure environment of the Earth's surface (see also pumice). The main volcanic gas is usually water with minor amounts of sulphur dioxide (SO_2), carbon dioxide (CO_2) and halogen gases such as chlorine and fluorine.

Volcanic mudflow. See lahar.

Worksheet 1

THE LAYERS OF THE EARTH

The Earth is divided into several layers. In the middle of the Earth is a **core** of iron. The inner core at the centre of the Earth is solid metal. It is surrounded by a layer of liquid metal. Most of the Earth is made of very hot rocks. This is called the **mantle.** These rocks are made of minerals containing a lot of the chemical elements. These include silicon, oxygen, magnesium and iron. The mantle is divided into a lower and upper part. A thin outer layer of rocks, called the **crust,** is made of rocks which are lighter than the mantle.



Cross section of Earth showing the main layers:

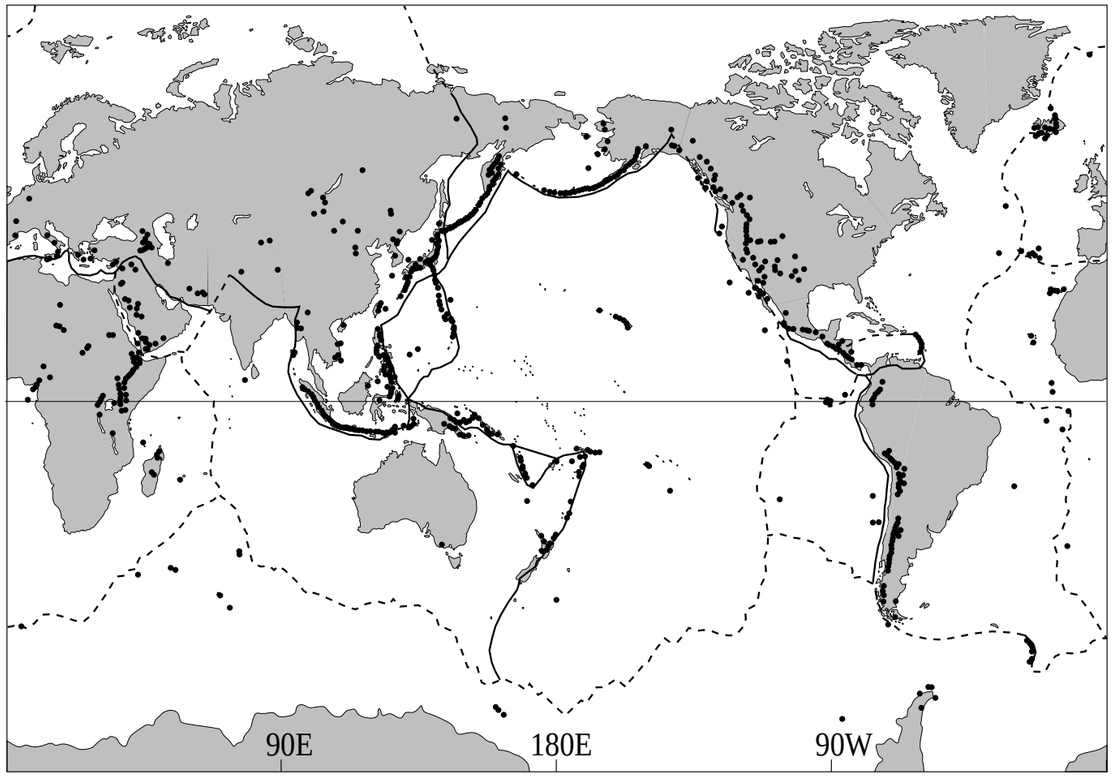
***UM** is upper mantle;*
***LM** is lower mantle;*
***OC** is outer liquid metal core and*
***IC** is inner solid metal core.*

Volcano
ISLAND

Worksheet 2

PLATE TECTONICS I

The outer 100 km or so of the Earth is made of solid rocks. These are cold and rigid. This rocky layer is broken up into large areas called **tectonic plates.** The plates fit together like a jigsaw. Deeper in the Earth the rocks are so hot that they can flow like plastic. The plates move around. Where the plates pull apart is called an **ocean ridge.** Where the plates collide is called a **subduction zone.** The boundaries between tectonic plates are where earthquakes occur and active volcanoes are found.



Map of the Earth's tectonic plates showing boundaries and the distribution of active volcanoes.

The movement of tectonic plates is very slow. Speeds are typically a few centimetres every year. This is about the same speed as your fingernail grows.

Volcano
ISLAND

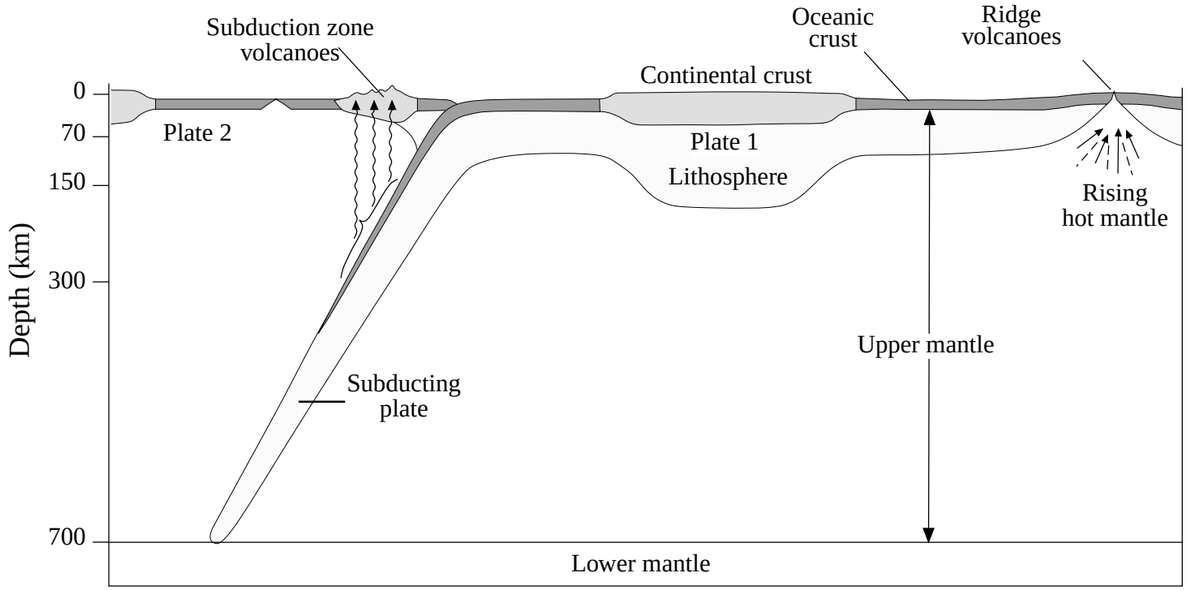
Worksheet 3

PLATE TECTONICS II

Plates are made of cold rock. They form a layer around the outside of the Earth. The layer is called the **lithosphere.** It is about 100 kilometres thick. Rocks deeper in the Earth below the plate are so hot that they flow like plastic. The lithosphere has two parts:

(1) An upper layer called the **crust** this is made of low density rocks.
(2) A thicker lower layer of high density rocks. This is also part of the mantle.

The continents are parts of the plates. They are places where the crustal layer is thick (about 30 kilometres). In the oceans the crustal layer is thin (about 6 kilometres).



Cross-section through tectonic plates showing the main kinds of boundary: ocean ridges and subduction zones

At ocean ridges plates pull apart and volcanoes erupt on the sea floor. At subduction zones the plates collide and one of the plates is pushed down into the interior of the Earth. This plate causes melting of the hot rocks deep in the Earth. Volcanoes erupt in the zone where the plates collide.

Volcano
ISLAND

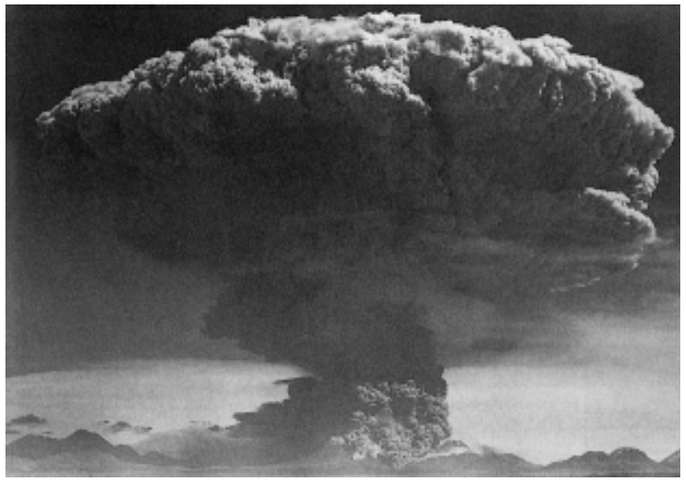
Worksheet 4

TYPES OF ERUPTIONS

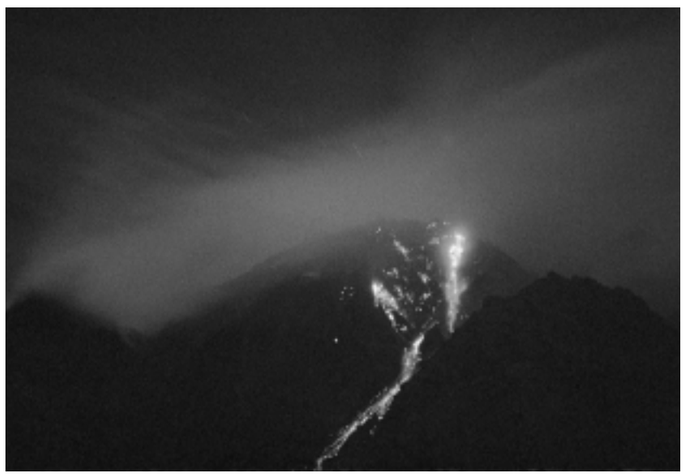
Volcanoes can erupt in two different ways:

(1) as lava flows
(2) in violent explosions

If the magma moves to the Earth's surface slowly the volcanic gas can escape. So the magma erupts quietly as lava. If the magma moves to the Earth's surface too fast then the volcanic gas cannot escape. The magma explodes. The volcanic gas is dissolved in the liquid rock (magma) at the great pressures deep in the Earth. People who make fizzy drinks dissolve gas in the liquid under high pressure. When you open your can of fizzy drink lots of gas bubbles form. In the same way magma forms lots of bubbles when it arrives at the Earth's surface.



Explosion at Lascar volcano, Chile. Eruption cloud is 25 kilometres high.



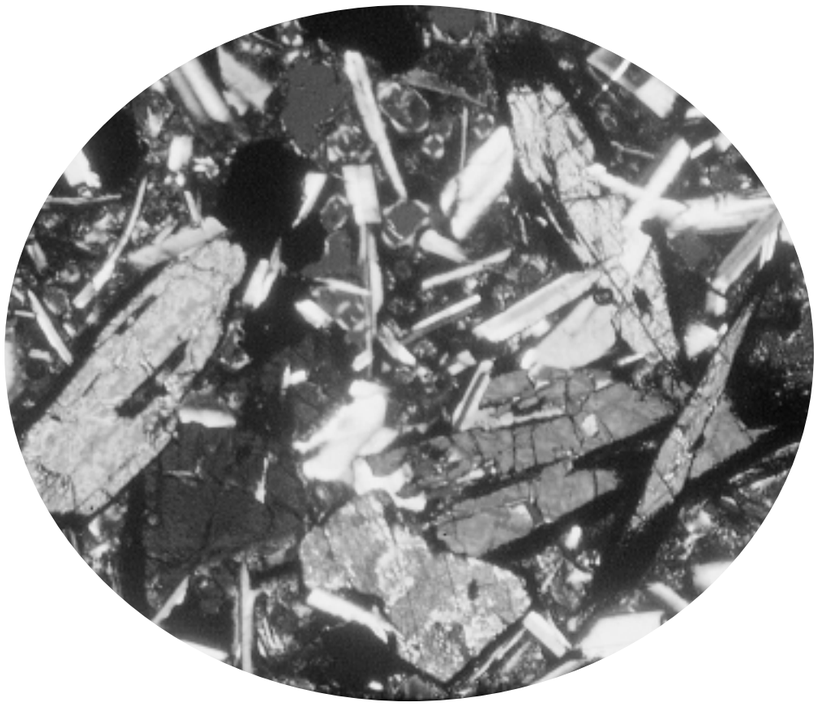
The lava dome on Montserrat glows red hot at night.

Volcano
ISLAND

Worksheet 5

MAGMA

Magma is the scientific name of liquid rock. A solid such as ice or wax turns into a liquid at the melting temperature. Rocks melt at very high temperatures of 800-1200 degrees centigrade. These temperatures are much hotter than you can get in a kitchen oven (about 250 degrees centigrade). Although magma is mostly made of liquid rock it also commonly contains quite a few solid crystals and bubbles. The magma at the Soufrière Hills volcano has a temperature of 850 degrees centigrade. Magma on Hawaii has a temperature of 1200 degrees centigrade.



Photograph of microscope slide

Very thin transparent slices of volcanic rock can be studied with a microscope. The crystals in the magma can be seen. The dark areas were originally liquid rock.

Volcano
ISLAND

Worksheet 6

BASALT VOLCANOES

The most common kind of magma on Earth is called **basalt.** The volcanoes on the sea floor at the ocean ridges erupt basalt. The huge volcanoes of Hawaii also erupt basalt. Basalt magma is very hot (1200 degrees celsius) and is very runny. Bubbles of gas easily escape from the magma so basalt eruptions are not usually very explosive. Basalt lava runs quickly down the sides of the volcano at speeds up to one metre per second (or about 2 miles per hour).

Basalt lava on the island of Surtsey near Iceland

Volcanic islands form when eruptions occur in the sea. In the photo explosions occur as hot basalt lava meets the sea to form the new volcanic island of Surtsey, south of Iceland

Volcano
ISLAND

Worksheet 7

ANDESITE LAVA DOMES

The volcanoes at subduction zones tend to erupt magma which is much colder than basalt magma and contains more volcanic gas. The magma is known an **andesite** after the Andes mountains in South America where andesite lavas are common. At Soufrière Hills the andesite lava is very stiff and flows extremely slowly so that it piles up around the vent. Such a pile of lava is called a **dome.**

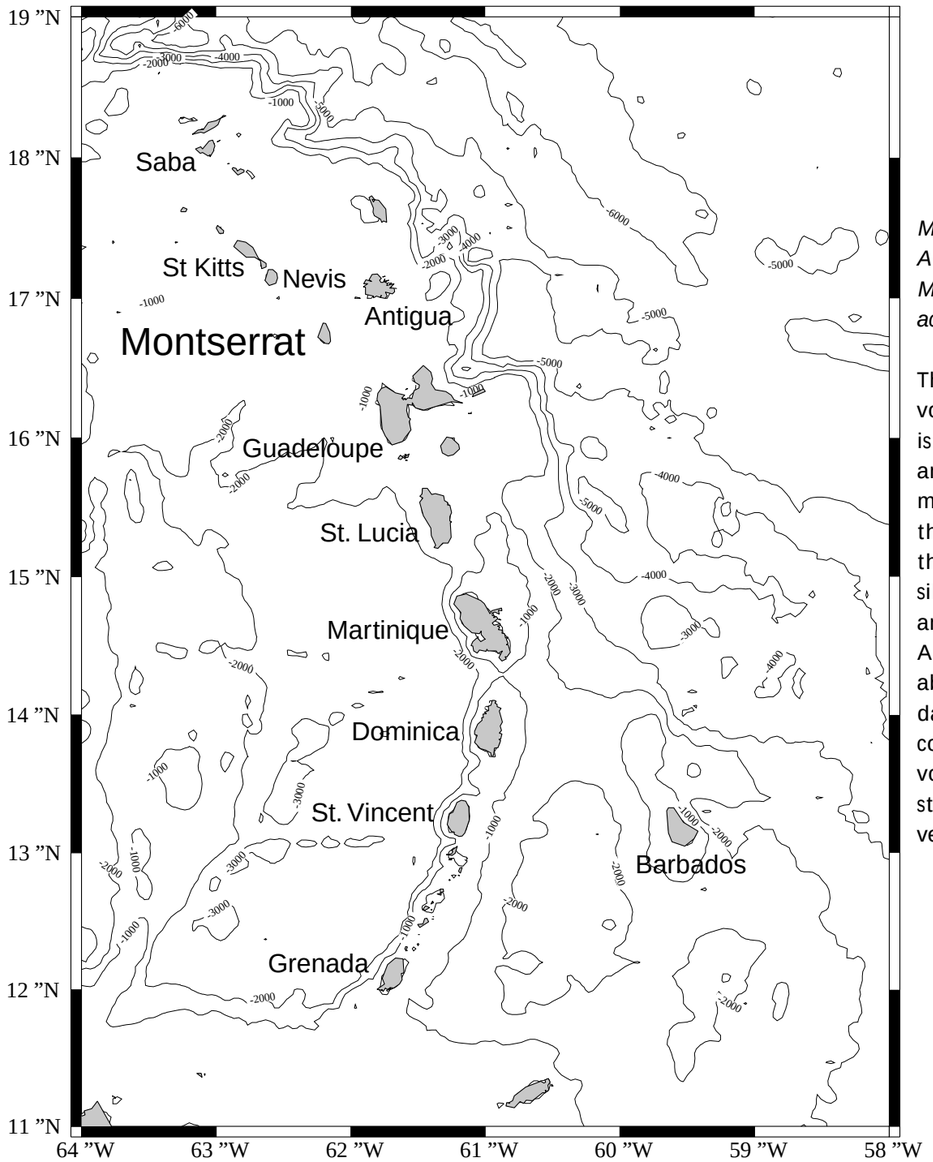
Photograph of andesite lava dome, Soufrière Hills volcano, Montserrat.

Volcano ISLAND

Worksheet 8

The Lesser Antilles Island Arc

The volcanoes at subduction zones typically form a chain of volcanic islands known as an **island arc.** In the Caribbean the Atlantic plate is being pushed below the Caribbean plate at about 3 centimetres per year. The chain of active volcanoes is called the Lesser Antilles Island Arc.



Map of the Lesser Antilles Island arc. Most of the islands are active volcanoes.

The Soufrière Hills volcano on Montserrat is a typical volcano is an island arc. The magma (liquid rock) that erupts is rich in the chemical element silicon. It is very stiff and flows very slowly. A typical speed is about 10 metres per day. The magma also contains a lot of volcanic gas (mostly steam). This makes it very explosive.

Volcano ISLAND

Worksheet 9

VOLCANIC GAS

Deep in the Earth hot rocks melt to form liquid rock (magma). They also dissolve gas because of the great pressure. The most important gas is steam (water), but there are also gases like carbon dioxide and sulphur dioxide. In a subduction zone the plate that is pushed down into the Earth has been soaked in sea water. This water is dissolved in the magmas that erupt in island arc volcanoes like Soufrière Hills. The large amount of steam in the magma makes it very explosive.

A cloud of steam above the lava dome on Montserrat is formed by gas escaping from the lava.

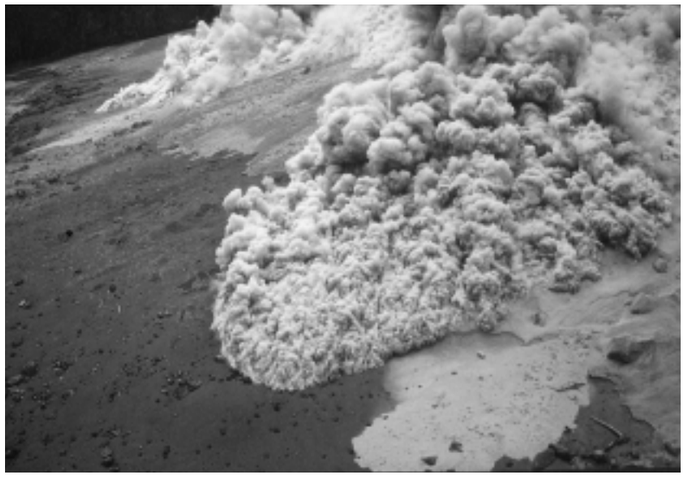
Pumice is a volcanic rock full of bubbles formed from gas escaping from the liquid rock

Volcano
ISLAND

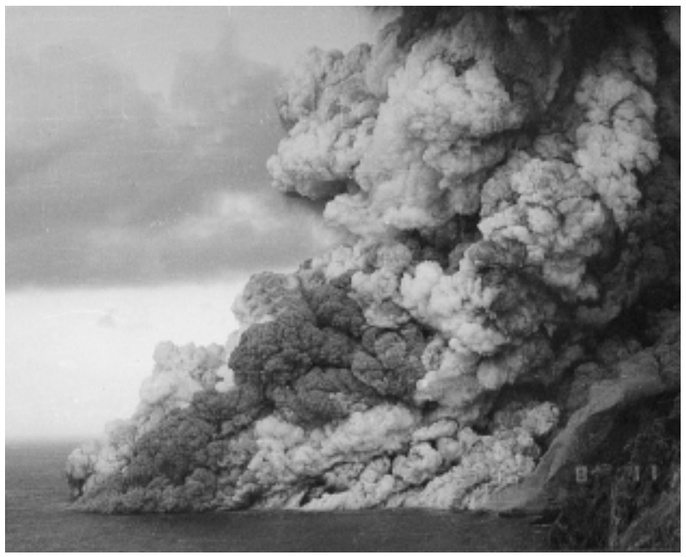
Worksheet 10

PYROCLASTIC FLOWS

Pyroclastic flows are clouds of hot lava rock and volcanic ash. They flow down the side of a volcano. They can move at speeds of over 150 kilometres an hour and are very hot. They burn and destroy everything in their way. Nobody can survive being caught by a pyroclastic flow. At Soufrière Hills volcano pyroclastic flows formed in two ways: by explosions and by large pieces of lava dome breaking away.



A pyroclastic flow moves down the side of the Soufrière Hills volcano as a billowing cloud



A pyroclastic flow enters the sea on east coast of Montserrat

Volcano
ISLAND

Worksheet 11

EXPLOSIVE ERUPTIONS

There are two kinds of explosive eruptions. In the first kind the explosion forms a column of volcanic ash and hot gas in the atmosphere. These can reach heights of 10 to 40 kilometres. Volcanic ash falls out of the high cloud. In the second kind the explosion makes a fountain of volcanic ash and hot gas. The fountain is a few hundreds of metres high. It falls onto the volcano to form pyroclastic flows.

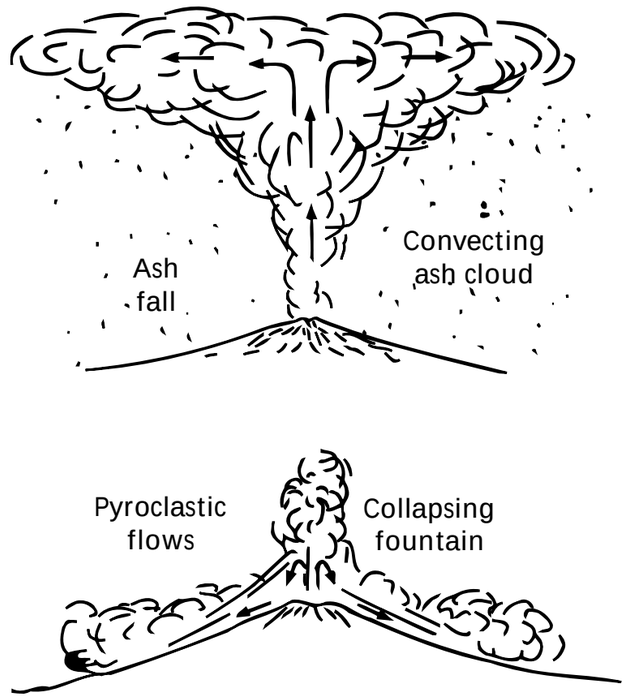


Diagram to show the two kinds of phenomena caused by volcanic explosions

Volcano
ISLAND

Worksheet 12

VOLCANIC HAZARDS

Volcanoes can be very dangerous. Three of the main hazards at a volcano are illustrated below.

Clouds of volcanic ash are blown by the wind from the volcano on Montserrat.

House destroyed by pyroclastic flow on Montserrat. The trees are knocked over and burnt.

The fall of volcanic ash. The weight of ash on a roof can make it collapse and injure people inside the building.

Volcano
ISLAND

Acknowledgments

The following organisations and individuals are thanked for their help in the making of the video: the Montserrat Volcano Observatory and, in particular, the many members of MVO staff involved in the scientific work of the Observatory, the Department for International Development, the Natural Environment Research Council, National Geographic and BBC for permission to use their film and graphics, Ricky Herd of the British Geological Survey, Dave Rothery of the Open University for help with securing cartoons of plate tectonics, Ka'lo Productions Hawaii, Steve Wessells of CVO, Lynn Stevenson, Henry Fortrie, the pilots of St Lucia and Bajan helicopter companies, and members of the Lea family. We thank Arrow for permission to use his music track of "Hot Hot Hot" and Summy Lea for composing Volcano jam especially for the video. The Royal Society are thanked for supporting the production of this video.

We acknowledge the help of Peter Kokelaar who provided the Montserrat map displayed in this pamphlet. The video production benefited greatly from reviews of draft versions by Chris Bedford, Mike Brooks, Dee Edwards, Angus Gregson, Julie Jordan, Chris King, Ros Rathouse, Jim Sammons, and Paul Wilcox. Kirsty Brown of the Royal Society is thanked for her help in the preparation of the notes and worksheets.

Suggested further reading

Pyle, David (1998) Volcanoes, Oceana Books

Francis, Peter (1992) Volcanoes: a planetary perspective, Oxford University Press

Visit the web site of the Montserrat Volcano Obsevatory
www.mvo.ms

Other useful websites

http://vulcan.wr.usgs.gov/Volcanoes/framework.html

http://www.volcano.si.edu/gvp/volcano/index.htm

http://volcano.und.nodak.edu/vwdocs/current_volcs/current.html

http://www.geo.mtu.edu/volcanoes/world.html

http://www.acclaimscientists.org.uk