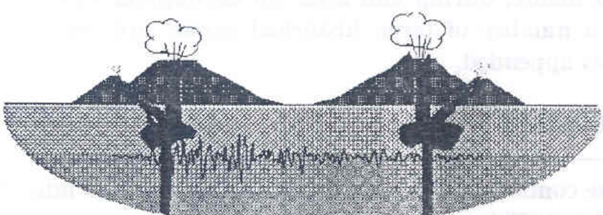
EARTHQUAKES AND VOLCANOES



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INTRODUCTION

The sudden and violent motions of earthquakes and the cataclysmic eruptions of volcanoes, may radically change our landscapes within a short time span. It is, therefore, not surprising that earthquakes and volcanoes have always been treated with healthy respect and even regarded in ancient religions as expressions of supernatural forces beyond the comprehension of mankind.

It has been said that if mountains had personalities, then volcanoes are schizophrenic - they have split personalities. Volcanoes are perhaps better known for their violent and often disastrous outburst than for anything else. In a similar way earthquakes have always inspired awe and fear because of their potential for tremendous loss of life and destruction of property.

This publication focuses on earthquakes and volcanoes. The processes involved in their generation are reviewed and a number of precautionary measures which should be taken before, during and after an earthquake are outlined. Some short notes on a number of large historical events are also itemised and a glossary of terms appended.

CONTINENTAL DRIFT

The idea that the continents had once been together but had later drifted apart was first mooted in 1858 by Antonio Snider of Paris. However, it was not taken seriously until the publication in 1915 of the text "The Origins of Continents and Oceans" by German explorer and meteorologist Alfred Wegener, in which he brought together all the scientific evidence for drift then available. This evidence included the striking parallelism between the Atlantic coastlines of South America and Africa, the similarity in rocks and geological structure occurring along the west coast of Africa and the east coast of South America, and the existence of certain identical fossils on continents now separated by oceans.

Wegener proposed that there existed just one supercontinent, Pangaea, 200 million years ago and that this split into smaller land masses which then drifted to their present positions. However, the debate for and against continental drift became a stalemate until the 1950s and 1960s when the existence of major submarine mountains encircling the Earth and of remanent rock magnetism was revealed.

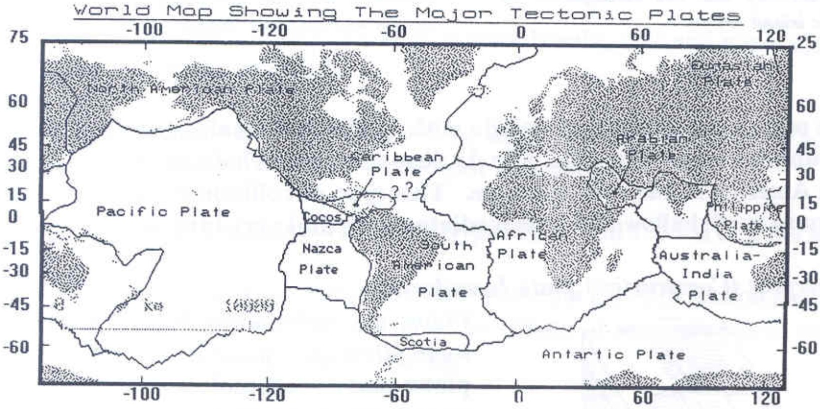
By the late 1960s, continental drift and sea floor spreading had been incorporated into the more encompassing phenomena of Plate Tectonics.

PLATE TECTONICS

The Earth's uppermost 100 km (***the lithosphere***), is cool and therefore, mechanically strong. Underlying the lithosphere is the ***asthenosphere*** which, because of relatively high temperature and pressure, has a viscosity low enough for flow to occur over geological time. The strong lithosphere can be considered to float on the weak asthenosphere.

The present existence and world wide distribution of earthquakes and volcanoes are mainly a direct result of the movement of crustal plates, a mechanism explained by the ***Theory of Plate Tectonics.***

FIGURE 1



The theory of plate tectonics holds that the lithosphere consists of a small number of large and semi-stable slabs called plates that are in constant motion relative to one another (Fig. 1). The relative movement of such tectonic plates causes strain to build up in crustal rocks. This strain is released periodically as rock formations rupture along zones of weakness (faults) causing earthquakes to be generated. Faulting in the earth's crust is particularly frequent in active zones associated with boundaries between tectonic plates.

There are three types of plate boundaries.

1. Convergent (Destructive) plate boundaries

Plates may move towards each other and collide. Two different features can result from such movement. In the first case, one plate can override the other causing the formation of subduction zones and island arc systems (Fig. 2a). At subduction zones, which are usually associated with deep trenches, lithosphere is being consumed by the earth's interior. The islands of the Lesser Antilles are one such example of an island arc system. More than 75% of the world's earthquakes occur at convergent plate margins.

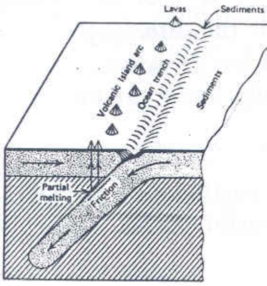


FIGURE 2a: Ocean-ocean convergent ate boundary with the development of anic island arc.

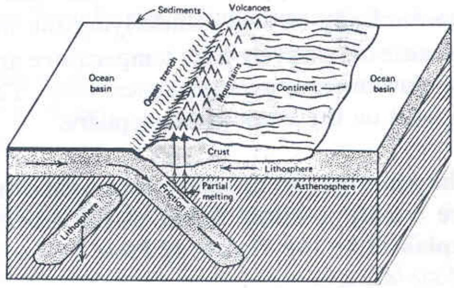


FIGURE 2b: Ocean-continental convergent plate boundary with the development of fold mountain ranges and volcanic chains.

In the other case, plates may collide with each other resulting in the formation of mountain ranges (Fig. 2b). The Andean mountain chain on the west coast of South America is one such example. This type of collision is characterized by earthquakes of shallow and intermediate depth and very little volcanic activity.

2. Divergent (Constructive) plate boundaries

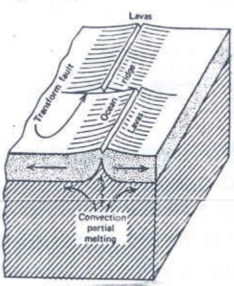


FIGURE 3: Divergent plate boundary with the development of oceanic ridges and conservative plate boundary with transform fault.

Plates can move away from each other to form divergent plate boundaries. As the plates move apart molten material from the earth's interior is extruded onto the surface to form new oceanic crust. This material becomes solid and is incorporated into each plate. Most of these boundaries and the volcanic eruptions associated with them are submarine. A good example of such a boundary is the Mid-Atlantic Ridge separating the North and South American Plates from the Eurasian and African plates (Fig. 3). The rate of earthquake occurrence at these boundaries is relatively low and focal depths are shallow. In Iceland, where the Mid-Atlantic Ocean Ridge is exposed above sea level, there are active volcanoes on land.

The giant rift valley which runs from Zimbabwe (south-central Africa) to Syria (Middle East) is considered to represent an early stage in the development of a

constructive plate boundary. Here, both volcanoes (e.g. Kilimanjaro) and tremors are frequent.

3. Conservative plate boundaries (transform faults)

At such boundaries, plates slide past each other and crustal material is neither created nor destroyed (Fig. 3). Earthquakes rather that volcanoes are produced. The San Andreas fault in California, which is the boundary between the Pacific and North American Plates, is one famous example of a transform fault.

EARTHQUAKES

As the plates move relative to each other, frictional resistance causes distortion at the boundaries and the build up of strain. This strain energy is released from time to time in the zones of weakness in the rocks. This sudden release of strain energy in the Earth's crust or upper mantle is called an earthquake.

The point in the Earth where the energy release occurs is called the focus or *hypocentre*, and its direct projection on the Earth's surface is called the *epicentre*. These foci may be located at depths up to 700 km beneath the Earth's surface although the majority have shallow (0-70 km) focal depths.

Wave types

There are two types of seismic (earthquake) waves - *body waves* which travel within the Earth and *surface waves* which are propagated along the earth's surface. Body waves consist of *primary (P) waves* and secondary or *shear (S) waves*. There are two types of surface waves - *Love and Rayleigh*.

Seismic waves differ in their velocities and in the ways in which the Earth's rock particles vibrate as the waves pass through. P waves travel about 1.7 times faster than S-waves which are in turn faster than the surface waves.

Earthquake waves are refracted and reflected as they encounter subsurface layers of different densities. This characteristic can be used to determine the physical properties of the layers in the Earth. For example, the boundary between the crust and the mantle,called the *Mohorovicic Discontinuity* (Moho), was revealed by a study of seismic waves.

Locating earthquakes

The difference in velocity between the P- and S-waves results in the P-wave arriving at a seismographic station earlier than the S-wave. For a shallow earthquake, this time difference is proportional to the distance from the station to the earthquake epicentre. Therefore, using a minimum of three

seismographic stations (triangulation), seismologists can determine the location of the earthquake hypocentre.

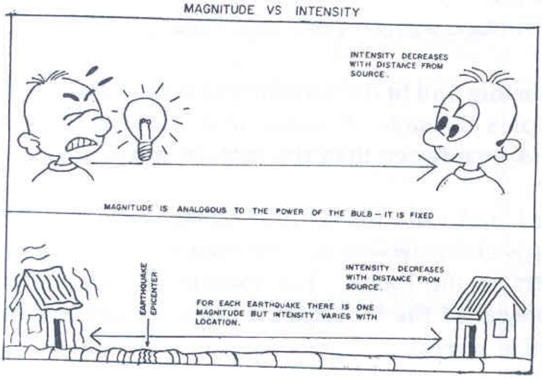
Where do earthquakes occur?

Most earthquakes occur along the plate boundaries because that is where distortion and strain accumulation is greatest. A plot of the global distribution of earthquake epicentres reveals very distinct zones of earthquake concentration, of which the most significant is the zone encircling the Pacific Ocean (Circum-Pacific ring). This zone accounts for about 70% of the world's total earthquake energy release.

However, large earthquakes do occur within the interior of plates (intraplate earthquakes) although these are not as easily explainable.

Earthquake size: magnitude vs intensity

Magnitude is an instrumental measure of the size of an earthquake. The first magnitude scale was devised in the 1930s by American seismologist Charles Richter in an attempt to quantify the size of southern Californian earthquakes. The open-ended Richter scale, as it is known, is not a physical scale. Richter determined the magnitude of a given event by measuring the amplitude of the largest swing on a recording of an earthquake on a special seismograph. The value obtained was substituted into an equation, the calculation of which yielded the magnitude. The scale is described as open-ended because there is no upper or lower limit. However, an earthquake cannot be infinitely large since there is a finite amount of energy which rocks can store.



Magnitude is actually a measure of the amplitude of the seismic waves radiated by the earthquake. The magnitude scale is not linear but logarithmic, such that each unit increase in magnitude corresponds to a ten-fold increase in the amplitude of the radiated waves. Since energy is related to wave size, magnitude can also be regarded as a measure of the energy released by an earthquake. In this case, each unit increase in magnitude represents a 32-times increase in released energy.

The largest earthquake that has occurred since the introduction of instrumental recording was the great Chilean earthquake of May 22, 1960, which was assigned a magnitude of about 9.0. This event, along with its foreshocks and aftershocks, ruptured about 1000 km of the southernmost section of the Nazca plate which is being subducted beneath South America along the Peru-Chile trench.

1	DETECTED ONLY BY INSTRUMENTS.
2	FELT BY PERSONS FAVORABLY PLACED.
3	FELT INDOORS. HANGING OBJECTS SWING.
4	FELT OUTDOORS. PARKED VEHICLES SWAY.
5	FELT BY ALL. UNSTABLE OBJECTS DISPLACED.
6	FELT BY ALL. CREATE'S PANIC. PERSONS WALK UNSTEADILY.
7	MODERATE DAMAGE TO STRUCTURES. SERIOUS DAMAGE TO POOR CONSTRUCTION.
8	LIGHT DAMAGE IN CONSTRUCTION OF GOOD DESIGN, CONSIDERABLY IN REGULAR AND HEAVY IN POOR.
9	GREAT DEAL OFDAMAGE TO STRUCTURE OF GOOD DESIGN AND REGULARS AND TOTAL DESTRUCTION OF POOR DESIGN.
10	SERIOUS DESTRUCTION TO PROPERLY CONSTRUCTED BUILDINGS.
11	FEW BUILDINGS REMAINS STANDING. FISSURES ALONG GROUND.
12	TOTAL DESTRUCTION. CATASTROPHE

Table 1: Effects defining different levels of the Modified Mercalli Intensity Scale.

The damage caused by an earthquake does not depend on its magnitude alone but also on such factors as the nature of the subsurface geology in the epicentral region, the quality of buildings and the population density in the area. Specification of the size of an earthquake in terms of its effects is done using an intensity scale. The one most commonly used in the Caribbean is the Modified Mercalli Intensity Scale (Table 1). This scale ranges from I to XII and reflects the effects on persons, structures and natural earth features subjected to the earthquake. The scale was devised by the Italian seismologist Guiseppe Mercalli in 1902, modified by the American seismologists Harry Wood and Frank Neumann in 1931 and further revised by Charles Richter in 1956.

Can earthquakes be predicted?

The emphatic answer to this question is NO, although it should be noted that scientists have managed to predict a few specific earthquakes. The search for a generally applicable prediction technique has failed and there are now very serious doubts as to whether this can ever be achieved at all.

The most successful prediction was that of the magnitude 7.3 earthquake which occurred in Haicheng, China, in 1975. Using observations of a large number of natural precursory phenomena, scientists were able to make a relatively accurate prediction of the location and time of the impending earthquake and an evacuation of people effectuated. This definitely contributed to the low number of deaths sustained (1,328) as opposed to a possible 1 million casualties. However, this success seems to have been unique because there was a failure to forecast the 1976 magnitude 7.8 Tangshan earthquake which caused the deaths of at least 240,000 people.

Earthquake risk

When an earthquake occurs, elastic waves are radiated outward from the focus. It is these vibrations that cause damage to structures. In general, most deaths or injuries during an earthquake are not directly caused by the earthquake but by the collapse of structures such as buildings.

The actual earth movement of an earthquake is seldom a direct cause of injury or death. Most casualties are caused by the following agents:

1. Falling brick and plaster.
2. Splintering glass.
3. Toppling furniture, collapsing walls, falling pictures and mirrors.
4. Rock slides on mountains and hillsides.
5. Fallen power lines.
6. Tsunamis or sea waves generated by earthquakes.
7. Fire from broken gas lines and spillage of gasoline and other flammables (aggravated by lack of water from broken water mains).
8. Drastic human actions resulting from panic.

Secondary effects and post-quake hazards may cause more suffering and damage than the earthquake itself. Such hazards include land subsidence, liquefaction, seismic sea waves or tsunamis. In addition, a number of socio-economic and health related problems may arise. Problems with sanitation, pestilence, lack of food and water, and stress may lead to political unrest.

Earthquake risk mitigation

To mitigate the effects of earthquakes, assessment of the hazard is necessary. Risk management is based on risk and vulnerability assessment. The resources available to the society are also an important factor. Although a disaster prevention and preparedness program reflects a country's needs, it must encompass all of the following elements:

1. A data collection and analysis system.
2. Information storage and data dissemination system.
3. Building codes of practice to regulate and inform construction.
4. A public land use system.
5. Efficient warning systems.
6. Tested evacuation strategy.
7. Recovery and reconstruction or relocation strategy.

Developing countries should be particularly vigilant to put in place such programs since their economies do not quickly recover from disasters. The declaration by the United Nations of the decade 1990-2000 as the "International Decade for Natural Disaster Reduction" (IDNDR), provides an appropriate setting for the establishment of such programs.

VOLCANOES

What are Volcanoes?

Volcanoes are vents in the earth's crust through which molten or solid materials and gas from the interior of the earth are extruded onto the surface. When magma works its way towards the earth's surface, the pressure decreases enabling dissolved gases to *effervesce* driving the magma upwards through the volcanic vent. The erupted materials often become solid and pile up around the vent to form a distinctively cone shaped mountain which is called a volcano.

The degree of violence (explosivity) of an eruption is determined mainly by the amount and rate of effervescence of the gases and the viscosity of the magma itself. Generally, increased silica (silicon oxide), content means increased viscosity of the magma and hence greater explosivity.

Volcanic settings

Volcanoes are not scattered randomly around the world. If one plots the sites of all the recently active volcanoes in the world on a map, one finds that several distinct, narrow chains exist, some of these running along the edges of continental land masses, some along island arcs and some of them through the sea.

There are approximately 20,000 volcanoes on the Earth with over 500 considered active. Indonesia has the largest number of known volcanoes (approx. 127). More than 80% of the world's active volcanoes lie north of 10°S and two-thirds are located around the so-called Pacific 'ring of fire'. The dominance of this belt is evidenced by the fact that about 82% of all volcanic eruptions ever recorded above sea level have occurred within this region.

Although most of the Earth's active volcanoes are located at plate boundaries, other settings for volcanic eruptions include areas where the Earth is being rifted or broken apart such as the Great East African Rift Valley and hot spots such as the Hawaiian volcanic chain which are expressions of persistent rising plumes of hot mantle material.

There is a general relationship between the location of volcanoes and eruption style. Generally volcanoes at divergent/incipient divergent plate boundaries (eg. the East African Rift valley), or mid-oceanic upwellings (eg. Hawaii), produce lava of a low viscosity which flows easily and may spread over large areas. In contrast, volcanoes of the great subduction zones found along convergent plate boundaries, usually erupt lava of high viscosity which tends to build up into domes or form relatively short, thick flows.

Although volcanoes at convergent plate margins erupt infrequently and are comparatively of short duration, they are generally characterized by more explosive eruptions. Eruptions at convergent plate margins are responsible for 84% of known eruptions and 88% of all eruption fatalities.

DO NOT SPREAD RUMOURS!

Volcanic activity

The categorization of volcanoes as 'active', 'dormant' or 'extinct' is generally unsatisfactory since: (a) it has a variable meaning as the 'historic period' is variable throughout the world; (b) some volcanoes erupt only once (they are monogenetic); (c) some apparently extinct volcanoes become active. For example, the 1973 eruption of

Heimay in Iceland was the first at this volcano for over 5,000 years and the devastating eruption of Mt. Lamington in Papau New Guinea in 1951 was probably the first for at least several thousand years.

Some volcanoes clearly have periods of dormancy which are much longer than the historic record for the local area, and in general, it seems longer intervals of quiescence commonly precede very explosive eruptions. This observation is of particular concern to us in the Caribbean since the vast majority of our volcanoes have been quiet for a very long time.

Types of eruptions

Generally, where volcanic activity is from a vent or pipe, cone building usually occurs, where activity is centred on a fissure - sheets of lava are normally produced. Several attempts have been made at classification of volcanic eruptions. The most commonly used forms are based on the names of volcanoes which exemplify that style of behaviour (eg. Strombolian, Peléean, Hawaiian, etc). All such classifications often suffer from the fact that these volcanoes may change their pattern of behaviour between eruptions, as an eruption progresses or even from place to place on the volcano.

Measuring the size of eruptions

The size of a volcanic eruption can be estimated in a number of ways. The total volume of erupted products (magnitude), the volumetric/mass rate at which the products left the vent (intensity), the area over which products are distributed (dispersive power), the explosive violence and the destructive potential of the eruption can all be used to give some indication of the scale of an eruption.

The total thermal energy released by eruptions, based on the volume of erupted material, have often been used to determine the size of eruptions. Moderately large eruptions can release between 10^{15} - 10^{18} joules of energy (a 1 kilotonne atomic explosion liberates about $4x10^{12}$ joules of energy). However, measures of energy liberated in a volcanic eruption are not always directly correlated with the degree of volcanic hazard. Degree of hazard is more related to the power of eruptions (ie. the rate at which the volcano's energy is expended), rather than the absolute energy released. For example, the eruptions of Mauna Loa in Hawaii in 1859 and 1959 were as 'big' in terms of total energy released as the Krakatau eruption of 1883, which is generally considered to be one of the largest eruptions to date.

A simple measure used to describe volcanic eruptions, *the Volcanic Explosivity Index* (VEI), was proposed by Newhall and Self in 1982. It combines estimates of the total volume of eruptive products with the height of the eruption cloud, the duration of the main eruptive phase and several other descriptive terms to give a relative measure of a volcano's explosivity on a scale of 0 to 8. Of all the historic eruptions, only the 1815 eruption of Tambora (Indonesia) has been assigned a VEI of 7 while none have a VEI of 8. More that half of the volcanoes for which data exist have had 'large eruptions' - ie. eruptions with VEI of 3 or greater.

Volcanic Hazard

A volcanic hazard may be defined as any potentially damaging or destructive volcanic event that could have a negative effect on human society. The hazardous effects of volcanic activity result either from the direct impact of volcanic events and their products, or from indirect influences associated with these events. *Primary hazards* result from direct eruptive activity and the immediate effects of such activity. The effects of volcanic events such as tremors, ashfalls, pyroclastic flows, mudflows and lava flows would all constitute primary hazards. *Secondary hazards*, in contrast, include not only the indirect effects of volcanic activity (eg. atmospheric disturbances), but also the environmental hazards posed by the deposits of past eruptions (eg. landslides) as well as the social and economic effects of volcanic activity. Pyroclastic flows (glowing avalanches) and tsunamis (giant sea waves), have been the greatest and mudflows and ashfalls the least important, destroyers of human life.

In the Lesser Antilles island arc (Saba in the north to Grenada in the south), there are at least 7 and possibly 27 active volcanic centres. The figure depends on the definition of "active" which is used and on the criteria used to decide how many of a number of closely spaced vents should be regarded as separate volcanoes.

Volcanism poses several hazards to life and property in the Eastern Caribbean. The volcanoes of the eastern Caribbean erupt only intermittently, often with gaps of hundreds, or even thousands of years between the eruptions. However, when they do erupt they often do so with tremendous violence posing a threat to lives and property which is far greater than the threat posed by any other natural hazard. At the present time there are over a quarter of a million people living on the flanks of active volcanoes in this region, half of them in the OECS states.

Volcanic Hazard Assessment

Due to the fertility of volcanic soils and the often spectacular beauty of volcanic landscapes, volcanoes have always attracted human settlement. In order to reduce the potential for destruction from volcanic eruptions, some preparedness measures must be considered in any area in which there is an active volcano.

DO NOT TIE UP THE TELEPHONE!

Volcanic hazard assessment involves estimation of the size, time-interval, frequency and spatial distribution of the volcanic events which have a potential to impact negatively on human society. Two basic questions must be asked in the assessment of volcanic hazard. Is the volcano going to erupt? If it erupts, how would it affect the people?

Hazard assessment usually involves two activities. Firstly, the effect both in terms of time and space, of the physical events triggered by the natural hazard must be defined. This involves a number of components: location of past events; determination of their physical impact; assessment of future levels of impact and determination of the average frequency. With these various components established, the physical effects are presented in a map format so as to aid the use of this information by decision makers and planners. Such individuals can then use these maps to implement emergency preparedness and mitigation measures and, to develop the ability to predict future events.

For long-term planning of human settlements and investment in volcanic areas, it is useful, and indeed essential, to have some knowledge of the volcanic hazard. Such knowledge can be obtained through geological studies of the past history of each volcano. The frequency of past eruptions and the extent of the areas devastated by them can be reconstructed by examining the sequence of deposits they created.

Hazard maps can therefore be prepared and estimates made of the probability of any particular area being affected by an eruption in a given period of time.

HISTORICAL EVENTS

The list presented below serves to illustrate the destructive nature of earthquakes and volcanic eruptions by highlighting a few of the most disastrous events which have occurred during human history. It is interesting to note that the Caribbean has not been spared from such disastrous events. At least 16,000 deaths have resulted from earthquakes in the Caribbean since the 1640s while 31,000 people have died as a result of volcanic eruptions.

EARTHQUAKES

26th Jan. 1556: Shansi province, China. **This event led to over 830,000 deaths. It is considered to have been the worst seismic disaster in recorded times.**

7th June 1692: Port Royal, Jamaica. **An earthquake which measured X on the Modified Mercalli Scale (MM X) destroyed 90% of Port Royal. Over 2,000 people were killed due to widespread liquefaction, tsunamis, surface fissures and post-event fever epidemics.**

1st Nov. 1755: Lisbon, Portugal. **30,000 of the 230,000 inhabitants were killed. A post-event tsunami (7m high) and a fire also contributed to the deaths.**

7th May 1842: Haiti & Dominican Republic. **An earthquake which measured MM IX killed over 5,000 in Haiti (pop. approx. 9500) which was reduced to ruins. In St. Domingo (pop. 2,000), 100-500 were killed. In Port de Paix, a tsunami killed 200 out of 3,000 inhabitants, and no building remained erect.**

8th Feb. 1843: Leeward Islands, Eastern Caribbean. **This is the biggest earthquake to have affected the Eastern Caribbean. It measured MM IX and was felt from St. Kitts to Dominica. In Antigua, the English Harbour sunk and all the stone houses were in a complete ruinous state. In Pointe-a-Pitre Guadeloupe, there was total destruction of all masonry. The number of deaths included 5000 in Guadeloupe, 30 in Antigua, 6 in Montserrat and 1 in Dominica.**

4th Dec. 1954: Trinidad & Tobago. **An earthquake which measured MM VIII killed one person, injured many and damaged unreinforced buildings in Port of Spain.**

31st May 1970: Chinbote, North Peru (25 km off coast). **An earthquake of magnitude 7.6 (Richter Scale) damaged 96% of all adobe structures. Avalanches and movement of ice masses which resulted killed 40,000-70,000 people.**

28th July 1976: Tangshan City, ESE of Beijing. **An earthquake which measured 7.8 on the Richter scale destroyed 94 % of houses, and 80% of industrial facilities. 242,000 people were killed out of a population of 1 million, most dying under collapsed buildings.**

7th Dec. 1988: Spitak, Armenia. **An earthquake of magnitude 6.9 (Richter Scale), killed 55,000, wounded 15,000 and left 530,000 homeless. Spitak was completely destroyed. The cost of destruction was put at US$ 210,098,857.**

29th Sept. 1993: Killari, Southern India. **An earthquake which measured 6.1**

(Richter Scale) was felt in large parts of central and southern India. It killed 9,748 people killed, injured approximately 30,000 and destroyed almost all the buildings in the village of Killari.

17th Jan. 1994: Northridge, California. An earthquake which measured 6.6 (Richter Scale), killed 57 people, injured 9,000 and left 20,000 homeless. Damage was estimated to be US$ 15-30 billion.

17th Feb. 1994: Sumatra, Indonesia. An estimated 200 people died while 2,749 were injured. Souh (a village perched precariously on a volcanic ridge) and surrounding villages with a total population of about 9,000 were all but flattened.

VOLCANOES

AD 79: Vesuvius, Italy. The towns of Pompeii, Herculaneum and Stabiae were completely buried and thousands died. The volcano has since erupted 50 times, the last being in 1944.

1669: Etna, Italy. 20,000 people were killed. Lava overran the western part of the city of Catania, 28 km from the summit.

19th May 1586: Kelud, Java, Indonesia. 10,000 people were killed with 9,000 houses destroyed and 1,571 cattle lost. Mudflows devastated arable land.

1815: Tambora, Indonesia. The explosion, followed by caldera collapse, is estimated to have produced about 40 km^3 of ash and blocks. 10,000 people were killed by the eruption and 80,000 starved to death in the resulting crop loss and famine.

1883: Krakatau, Indonesia. One of the largest natural explosions in recorded time. Sounds were heard up to 4000 km away, the emitted ash and pumice blocks totaled 18 km^3, the 6-km-diameter caldera collapsed and the resulting tsunami killed 36,000 people.

8th May 1902: Mt. Pelée, Martinique. A glowing avalanche (pyroclastic flow) from this eruption completely destroyed the town of St. Pierre and its 28,000 inhabitants. Only one person, a prisoner, survived.

1902: Soufriere, St. Vincent. An explosive volcanic eruption was preceded by approximately twelve months of earthquake activity. The eruption began on 6th May 1902 and continued up to the 30th March 1903. Pyroclastic flows, mudflows and ashfalls affected areas to the north-east, east and west of the volcano. 1565 people died and extensive damage was caused to agriculture in the areas around the volcano.

1980: Mt St. Helens, Washington, USA. **A directed blast levelled 500 km^2 of forest, and a major avalanche filled a valley for 25 km. The 2950 m high summit was lowered by 400 m. About 57 people were killed. Smoke and ash rose to 6000 m depositing ash 800 km away.**

13th Nov. 1985: Nevado del Ruiz volcano, Colombia. **Approximately 25,000 people were killed, 5,000 injured and 7,700 left homeless. Surrounding rural areas were covered with mud and ash and the town of Armero was nearly destroyed. Total damage was estimated at over US$ 1 billion.**

21st August 1986: Lake Nyos, Cameroon. **Toxic gas emissions asphyxiated 1,734 people and thousands of animals. 25,000-30,000 people suffered including 400-500 burned on the skin. This was the worst volcanic gas disaster ever recorded. Gas emission was estimated at 0.63-1.0 km^3.**

BEFORE AN

EARTHQUAKE

- BOLT DOWN OR PROVIDE STRONG SUPPPORT FOR WATER HEATERS AND GAS APPLAINCES, SINCE FIRE DAMAGE CAN RESULT FROM TOPPLED APPLIANCES AND BROKEN GAS LINES.
- PLACE HEAVY OBJECTS ON LOWER SHELVES OF CLOSETS AND STORAGE AREAS.
- BRACE OR ANCHOR HIGH OR TOP-HEAVY OBJECTS.
- WIRE OR ANCHOR OVERHEAD LIGHT FIXTURES.

DURING AN

EARTHQUAKE

FOLLOW THESE PRECAUTIONS

SAVE YOURSELF AND OTHERS FROM INJURY.

- REMAIN CALM AND REASSURE OTHERS. DON'T RUSH FOR EXITS.
- PROTECT HEAD AND FACE!
- IF INSIDE OR OUTSIDE, STAY THERE!
- IF INSIDE A BUILDING STAND IN A STRONG DOORWAY OR GET UNDER A DESK, TABLE,OR BED.
- MOVE AWAY FROM WINDOWS, GLASS DOORS, HEAVY MIRRORS PICTURES, BOOKCASES, HANGING PLANTS AND HEAVY OBJECTS.
- WATCH FOR FALLING PLASTER, BRICKS, LIGHT FIXTURES, AND OTHER OBJECTS.
- AVOID USING ELEVATORS AS POWER MAY FAIL.
- IF YOU'RE IN AN AUTOMOBILE, DON'T STOP UNDER OR NEAR ELECTRICAL POLES OR BUILDINGS FROM WHICH DEBRIS MAY FALL.
- IF YOU'RE IN A STORE OR SHOP, MOVE AWAY FROM DISPLAY SHELVES CONTAINING BOTTLES, CANS, OR OTHER OBJECTS THAT MAY FALL.

AFTER AN

EARTHQUAKE

FOLLOW THESE SAFETY ACTIONS

DO'S	DON'TS
CHECK FOR FIRES.	DON'T REMOVE SERIOUSLY INJURED PERSONS UNLESS THEY ARE IN DANGER OF FURTHER INJURY.
CHECK UTILITIES - shut off if necessary.	
CHECK YOUR HOUSE FOR SERIOUS DAMAGE - evacuate if there's threat of collapse.	DON'T LIGHT A MATCH OR TURN ON A LIGHT SWITCH. USE FLASHLIGHT
CHECK FOR INJURIES- administer first aid.	
BE PREPARED FOR ADDITIONAL SHOCKS.	DON'T TOUCH FALLEN POWER LINES.
CLEAR UP HAZARDOUS MATERIAL.	DON'T USE THE TELEPHONE EXCEPT IN REAL EMERGENCY.
ASSIST OTHERS.	
TURN ON A TRANSISTOR RADIO FOR EMERGENCY BULLETINS.	DON'T GO TO THE BEACH TO SEE BIG WAVES.
STAY AWAY FROM LANDSLIDE PRONE AREAS.	DON'T GO SIGHTSEEING. KEEP STREETS CLEAR FOR EMERGENCY VEHICLES.
STAY AWAY FROM WEAKENED BUILDINGS.	

STAY CALM!

GLOSSARY OF TERMS

Ashfalls
Fine pyroclastic fragments, down to dust size, that have fallen from an eruption cloud during an explosive volcanic eruption.
Amplitude
The vertical displacement of a seismic signal about a mean position.
Earthquake waves
A general term for a vibrational wave produced by an earthquake.
Effervesce
To give off bubbles of gas as a result of chemical action.
Epicentre
Point on the earth's surface vertically above the point where first fault rupture (hypocentre) and first earthquake motion occur.
Eruption column/cloud
The column of fragmented particles (ash, blocks, bombs, etc) and gases ejected by a volcano during an eruption.
Fault
A discontinuity along which rocks have been displaced. A fracture or fracture zone in the earth along which there has been movement.
Focal depth
Vertical distance between an earthquake hypocentre and the earth's surface.
Intensity
A discrete numerical ranking of earthquake effects, not given to frationalisation. A non-qualified numeric scale describing the effects of an earthquake on the earth's surface, on man, and on structures.
Island arc
A curving chain of volcanic islands formed at a compressional plate boundary.
Landslides
Falls, topples, slides and flows of rock and/or soil.
Lateral blast
A hot, low-density mixture of rock debris, ash, and gases, generated by an explosion, that moves at high speed along the ground surface.
Lava
Magma or molten rock that has reached the surface; or its resulting solid rock after cooling.
Liquefaction
Temporary conversion of soils into a medium that behaves like a fluid. This happens when seismic shear waves having high acceleration and long duration pass through such soils. This causes the void spaces to collapse. Fine sands are more susceptible than silts and gravel.
Magma
Molten rock material with dissolved gases that forms igneous rocks on cooling;

magma that reaches the surface is called lava.

Magnitude

A quantification of the total energy released by a quake at its source. It is determined from some feature of an earthquake recording - eg. amplitude or duration. Several scales exist

e.g. Mb - body wave (Magnitude)
Ms - surface wave (Magnitude)
Ml - local (Magnitude)

Microearthquake

An earthquake that is not felt but is detectable by a seismograph.

Pressure wave

A seismic wave with behaviour similar to ocean waves. A wave propagated such that particle motion is in the same direction as the wave travels.

Pyroclastic materials

Solid fragments formed by explosion or spraying from a volcanic vent; includes ash, bombs, or cinders.

Seismograph

A sensitive instrument used to detect seismic disturbances.

Shear wave

A type of earthquake wave. A wave propagated such that particle motion is at right angles to the direction of wave travel.

Subduction zone

The zone of convergence of two tectonic plates, one of which usually overrides the other.

Tephra

A general term for all fallout pyroclastics ejected from a volcano, sometimes used as a synonym for pyroclastics.

Tsunamis

Long period seismic ocean waves generated by the sudden vertical motion of a submarine earthquake or by a volcanic eruption.

Viscosity

A measure of resistance to flow in a liquid; water has a low viscosity while honey has a high viscosity. It is a measure of the stiffness of a lava flow - the ease with which it flows.

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