Topic 1B Hazardous Earth: Tectonics

Layers of the Earth

The Crust—The thinnest layer. There are two types - oceanic crust and continental crust. Oceanic crust is relatively thin (5-8km). It is made of basaltic rock, so is slightly denser than continental crust, Continental crust is thick on average (30-40km), but its thickness varies and can reach 70km under some mountain ranges such as the Himalayas. It is lighter as it is granitic with is less dense.

The Mantle—This is the thickest layer - nearly 2900km. Its temperature ranges from 1000⁰C near the crust to 3700⁰C near the core. It is divided into two layers. The upper mantle is mostly solid, but some melting occurs at hotspots and plate boundaries. As these locations the mantle moves slowly. The mantle becomes hotter and denser with depth. As the pressure is increased the lower mantle is solid despite the high temperatures.

The upper mantle is further divided into the lithosphere and asthenosphere.

1. The lithosphere—includes the crust and the top layer of the upper mantle which is made of peridotite. The lithosphere is 80-100km thick, although it is thinner under the oceans and in volcanically active continental areas. It is broken up into tectonic plates (lithospheric plates) of varying size which move on the asthenosphere.
2. The Asthenosphere—this is a denser, mobile layer in the upper part of the mantle, about 100-300km deep. The temperatures in the asthenosphere is high (above 1300⁰C) and the pressure, while still high is low enough that rocks can still move.

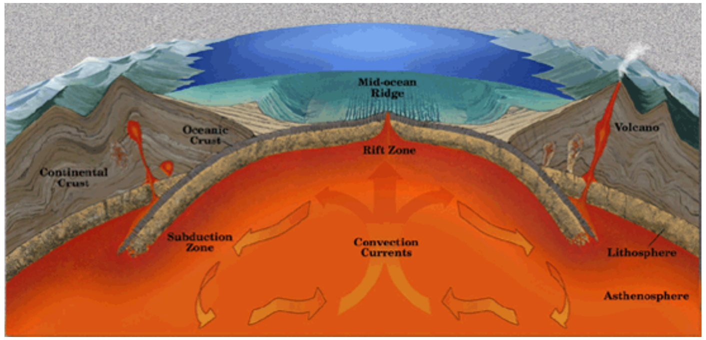
The Core—This is the centre of the Earth. It is very hot and dense. It has two layers. The outer core is made of liquid iron and nickel the temperature is between 4500-5500⁰C The inner core is up to 6000⁰C. It is a dense solid ball of iron and nickel. It cannot melt due to the pressure.

Convection currents

The plates are continually moving on the asthenosphere due to rising hot currents called convection currents in the mantle. Rock heated in the lower mantle by the core, rises slowl towards the crust. As it rises, it cools. When it reaches the asthenosphere it is forced sidewa as it is blocked by the lithosphere above. It then sinks slowly towards the core and is forced sideways due to the dense iron and nickel.

The heat generated to create convection currents comes from radioactive decay (such as uranium) and residual heat (heat left from the earths formation 4.6billion years ago).

Convection currents exert a weak 'pull' on the plate above. This causes the plates to move apart or slide past each other. The movement impacts on plate boundaries leading to earthquakes and volcanoes.

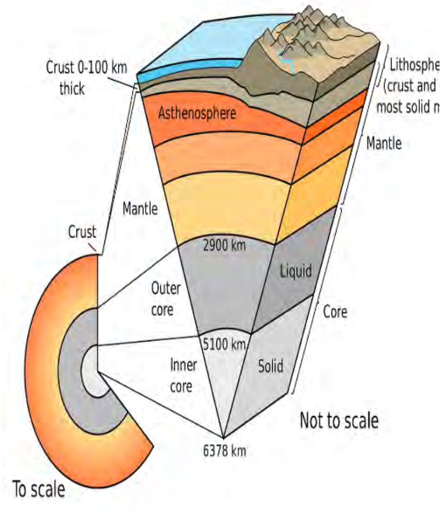


Exam questions

1. State 2 differences between oceanic and continental crust (
2. Explain how convection curren cause tectonic plates to move (
3. Identify and describe the layers of the earth (4)

Key Terms

Convergent
Subduction zone
Trench
Magma
Composite volcano
Fold mountains
Ocean trenches
Faults
Rift Valley
Shield volcano
Mid-ocean ridge
Conservative plate boundary
Divergent plate boundary



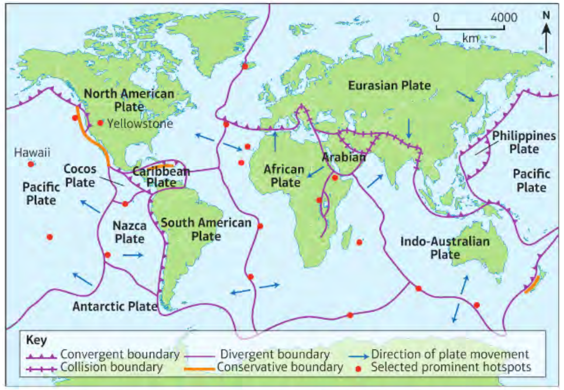
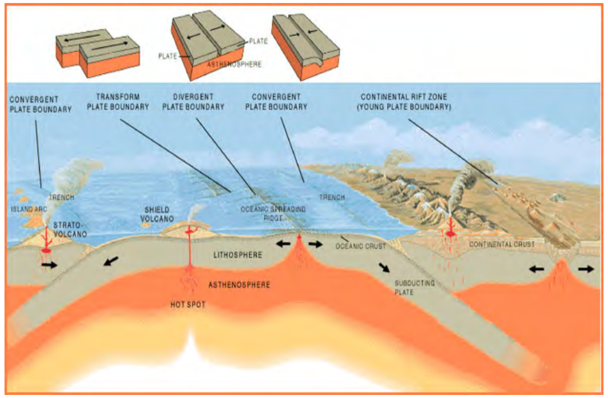


Figure 2 Global distribution of tectonic plates, boundaries and hotspots



Exam questions

Explain the differences between convergent and a transform plate boundary (4)

Describe the distribution of earthquakes and volcanoes (5)

Describe and explain the characteristics of a convergent plate boundary (5)

Type of plate boundary	Description	Features produced	Example plates and countries
Convergent (Oceanic and Continental crust)	Convection currents in the mantle cause the plates to move towards each other. The oceanic plate subducts beneath the continental plate as it is denser into the asthenosphere. As it subducts the increase in temperature due to friction and pressure force the crust to lose impurities into the asthenosphere which begins to melt. This creates magma, which can lead to volcano.	Trench Composite volcano Oceanic trench	Peru-Chile Trench, Andes Mountains. Involving the Nazca Plate and South American Plate
Collision (Continental vs Continental)	Convection currents in the mantle move the plates towards each other. As the plates are the same there is no subduction, the collision causes the boundaries to crumble forming fold mountains. As there is no subduction there is not volcanic activity here. However major earthquakes do occur due to the pressure of the colliding plates which causes rocks to fault.	Fold mountains	Himalayas, Tibetan Plateau
Divergent plate boundaries	Convection currents cause the plates to move away from each other. This mainly occurs under the oceans. As the plates break apart, rising heat and a reduction in pressure causes the asthenosphere to melt, forming magma. The magma rises to fill the rift valley between the two plates creating oceanic lithosphere. Where the magma breaks through to the earth's surface a shield volcano is created. A mid-ocean ridge can then be formed if the process continues. Earthquakes also occur here.	Shield volcano Rift Valley	Iceland—Eurasian plate and North American plate
Transform plate boundary	Convection currents cause the plates to slide past each other. The plates can move in opposite directions or in the same direction but at different speeds. In both examples, the plates tend to get stuck, increasing tension and pressure. The pressure builds until one plate jerks and causes an earthquake.	Fault lines	San-Andreas fault, California, USA—North American plate and the Pacific Plate

Exam questions

1. Define Magnitude (1)
2. Explain how hotspot volcanoes are formed (4)
3. Explain how a composite volcano is formed (4)
4. What measures earthquakes (1)
5. Explain what causes an earthquake (4)

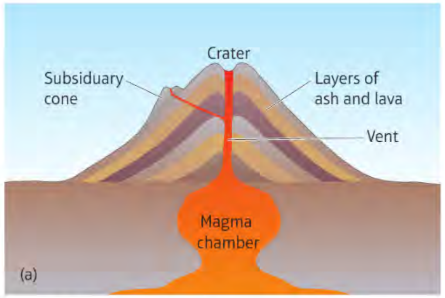
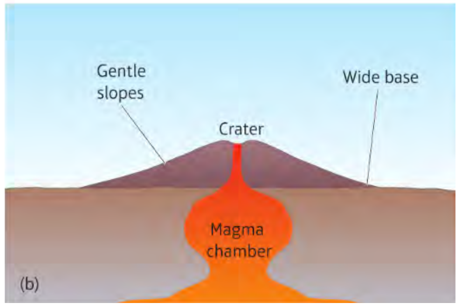


Figure 7 (a) Composite volcano and (b) Shield volcano



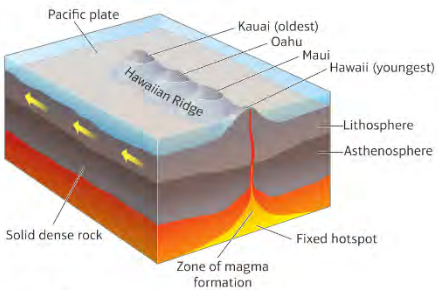


Figure 8 Hawaiian hotspot volcanoes

Types of volcanoes

Volcanoes are formed when molten rock from a magma chamber inside the Earth erupts through a vent in the lithosphere. Molten rock is called magma below the surface and lava when it erupts. As well as lava, volcanoes erupt steam, gas and ash from the crater. There are two main types of volcanoes:

Composite volcanoes—These are formed along convergent plate boundaries. They are steep sided, tall and conical shaped with a narrow base. They are made of alternate layers of ash and lava. Andesitic lava is erupted from these volcanoes. It has a high silica content making it more viscous so it flows slowly and travels short distances before cooling. Eruptions tend to be infrequent but violent, as the vent becomes blocked with lava so pressure builds up. During explosive eruptions the lava shatters into pieces producing, lava bombs and very hot flows of gas (pyroclastic flows). These are a primary hazard. A secondary hazard from these volcanoes is a lahar (hot mudflow).

Shield volcanoes—These are formed along divergent plate boundaries and over hotspots. They are gently sloping domes with a wide base. They are made of lava only, which in many shield volcanoes, erupts from fissures as well as the crater. Basaltic lava is erupted from shield volcanoes. It has a low silica content so it is less viscous meaning it is runny and flows long distances before cooling. Eruptions tend to be frequent but gentle. Whilst lava flows destroy property and crops they rarely kill people.

Hotspots— These are volcanoes that are formed away from plate boundaries. They are formed by a 'plume' of superheated rock (not magma) rising slowly through the mantle. Once it reaches the upper mantle, it causes the asthenosphere and base of the lithosphere to melt. The magma produced then rises through weaknesses in the crust and erupt at the surface. Oceanic hotspots erupt basaltic lava, creating shield volcanoes such as Mauna Loa in Hawaii. Continental hotspots erupt viscous granitic lava. These can erupt explosively e.g. Yellowstone Supervolcano in the North American plate.

Earthquakes

Earthquakes are intense vibrations within the Earth's crust that make the ground shake. They are sudden events.

At a convergent plate boundary great stresses build up in the subduction zone as the edge of one plate sinks below the other. Energy builds up until the rock fractures along a fault and the energy is released. The point of rupture is called the focus. Shockwaves or seismic waves radiate out from this point. These make the earth shake. The epicentre is the point on the ground surface directly above the focus. Earthquakes also occur along conservative and divergent plate boundaries. They are caused as the plate moves and get stuck.

Measuring Earthquakes

The size of an earthquake is recorded using a seismometer. The magnitude (size) is then given according to the Richter scale which gives a value between 1 and 10. The scale is logarithmic, Another scale is the moment magnitude scale (Mw) is frequently used. It is similar to the Richter scale but it works over a wider range of earthquake sizes and is more accurate.

The amount of damage an earthquake creates depends on several factors:

1. The scale of the event in terms of energy, area & duration
2. The depth of the focus
3. The density of human settlements in the area
4. The time of day/week
5. The degree to which the country and people are prepared
6. The level of development

Tsunamis

These are usually triggered by earthquakes and are a secondary hazard. A tsunami is a series of giant ocean waves that send surges of water onto land. When a powerful earthquake occurs under the sea, the seafloor at the boundary either rises or falls suddenly displacing the water above it and setting off rolling waves that build to tsunamis. They can reach speeds of 800kmh. As they approach land, they slow down, grow in height and gain energy. When they crash onto the shore they cause widespread destruction.

Tectonic hazards affect people and are managed differently at contrasting locations

Impacts -Primary impacts are the immediate damage caused by the volcano or earthquake such as injury or loss of life. Secondary impacts are the ‘knock on’ effects from primary impacts such as shortage of clean water, diseases spreading.

Response— Emergency responses take place immediately after the event such as rescue teams. Long term responses include restoring the area back to normal and managing the area by predicting, protecting and preparing for future hazards. The ability to respond depends on the country’s economic wealth.

Predicting volcanoes and earthquakes

Sensitive instruments can measure earths movements such as a seismometer as usually foreshocks occur before a major earthquake and earthquakes occur before volcanic eruptions so scientists and volcanologists can monitor this. A hazard map can be made to show local people areas that would be the most vulnerable. Despite this, earthquakes are extremely difficult to predict compared to volcanic eruptions as they are so sudden. Volcanoes have other features that can be a sign of an eruption such as gas emissions, warnings can be given if air pollution levels increase, snow melt and bulging can be monitored via satellites that can indicate a change in a volcanoes behaviour. Tiltmeters can be installed to measure ground/rock deformation.

Preparing for volcanoes and earthquakes

Earthquake proof buildings can be built as most deaths are caused by falling buildings. These buildings have features such as cross-bracing, shock absorbers and reinforced concrete to reduce the motion of earthquakes.

Education—government agencies, schools and councils can educate locals about the hazards so that they can be prepared for the hazard and its effects such as earthquake drills, evacuation drills. Leaflets can be distributed.

Emergency services—can prepare to respond to a hazard with food, water, shelter and medical aid. Send search and rescue teams and communicate so that the areas that need the most help get it.

Exam questions

1. Explain how earthquake can impact people and the environment (4)
2. Describe one way in which people can predi volcanic eruptions (2)
3. Assess the effectivenes of the management of one tectonic hazard event (8+4)
4. Explain one short term and one long term impact of an earthquak event (4)
5. Explain how the responses to a volcanic hazard can vary betwee countries at different levels of development (

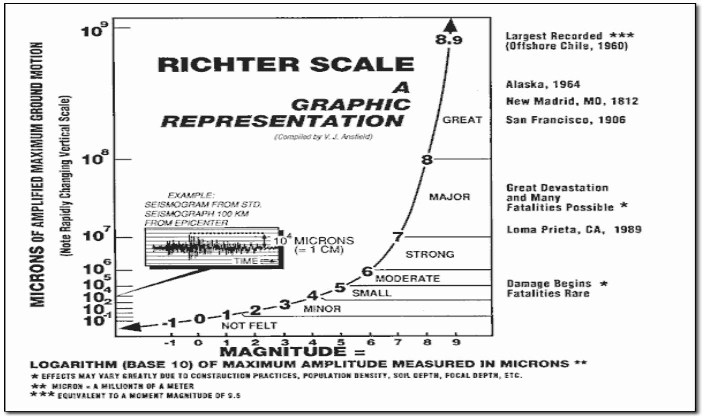
Protection — volcanoes and earthquakes

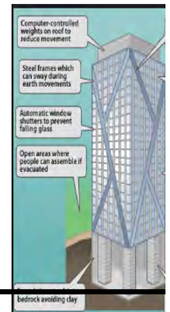
Infrastructure can be built to protect people from buildings collapsing through design. Earthquake proof buildings have features such as:

- Shear wall—Reinforced concrete walls provide strength and resist earthquakes
- Shear core—Reinforced concrete with steel rods to strength the centre of a building.
- Moat—A gap between the ground and foundations so that the shock waves can move through the base isolators
- Cross bracing—Diagonal steel bars to reinforce the walls
- Base Isolators—Like shock absorbers they dampen the impact of movement.

Hazard proofing homes:

- Remove heavy items from the walls
- Secure chimneys with metal brackets
- Fasten bookshelves and cabinets with L-shaped brackets
- Bolt the house to its concrete foundation to prevent it from slipping off.
- Strap heaters and boilers to the walls to prevent them falling
- Learn how to turn the gas, water and electrics off
- Use metal connectors to strengthen joints in the house
- Use plywood to strengthen walls and ceilings.





Key Term

Primary impac
Secondary imp
Emergency res
Long term resp
Vog
Volcanologists
Tiltmeters
Liquefaction
Retrofitted

CASE STUDY—Kilauea, Hawaii, USA—Developed country

It is one of 5 shield volcanoes in Hawaii. It is extremely active, and has been erupting continuously since 1983. It was created due to being on top of a hotspot and its eruptions are effusive basaltic lava flows.

Primary impacts: Since 1983, lava from Kilauea has covered 100km² of land and destroyed 200 homes and community buildings, damaged utilities and blocked roads. In 1990, Kalapana village was buried beneath 15-24m of lava. In 2014, Villagers from Pahoa were evacuated when lava fountains erupted near to the village. The lava reached the sea which causes it to explode which endangers people's lives.

Secondary impacts—In 1986, Kilauea began releasing up to 2000 tonnes of sulphur dioxide a day. This is potentially lethal within a 1km radius of the volcano. This has led to persistent air pollution known as volcanic fog (Vog) and acid rain. This damages crops, vehicles, buildings and contaminates water supplies. However, a positive impact is that over 2.6 million tourists visit Hawaii Volcanoes National Park each year, which generates income for local business. The lava also makes the soils very fertile to grow commercial food crops like sugarcane and pineapples worth US$30million per year to the local economy.

Response—Although it is not generally a threat to human life, the dangers still need to be managed. The Hawaiian Volcano Observatory is located close to the crater and volcanologists monitor the volcanoes and issue warnings about possible eruptions and evacuations. They have 17 webcams and satellite data to monitor activity, gas emissions are monitored and warnings are issued about air pollution levels and seismometers measure any tectonic activity caused by moving magma. However weak planning laws and a growing population have resulted in building in areas at risk from the volcano. There is evidence that historically Kilueau has had explosive eruptions which have not been prepared for.

CASE STUDY—Mount Pinatubo, Philippines 1991— Emerging country

It is one of many composite volcanoes on the island of Luzon. Here the Eurasian plate is subducting beneath the Philippine plate. After more than 600 years of inactivity Pinatubo erup on the 12th June 1991. Its andesitic lava is thick and full of gas causing explosive eruptions. A cloud of steam and ash was sent 30km up into the atmosphere, and pyroclastic flows descend from the crater at speeds of more than 200km per hour.

Primary impacts—Volcanologists predicted the eruption and advanced warnings allowed thousands of people to evacuate. However, 847 people were killed mainly from pyroclastic flo the ash cloud made the region cold and dark which stopped rescue teams, 5000 homes were destroyed and a further 70,000 damaged. Many buildings collapsed and many people were displaced to shanty towns in the capital Manila. Power supplies were cut and roads and bridge were unusable. Local water supplies were contaminated.

Secondary impacts—As winds dispersed the ash cloud (10 million tonnes of sulphur dioxide), global temperatures dropped by 0.5^{o}C temporarily. Hundreds of people died from disease mai measles, pneumonia and diarrhoea in evacuation camps. Crops were destroyed as ash coverec 800km² of rice fields and around 800,000 farm animals were killed, with the cost to farmers estimated at 1.5 billion pesos (£20 million). Lahars were created up to 3m high. After wet ash destroyed many buildings, US air forces base at Pinatubo closed and relocated to Singapore. Many Filipinos lost their jobs and local trade suffered.

Response—Several techniques were used to predict the eruption. The Philippine Institute of Volcanology and Seismology (PHIVOLCS) detected swarms of earthquakes beneath the volcanc March 1991, indicating magma movement. Tiltmeters detected rock deformation. Helicopters with gas measuring technology flew over Pinatubo daily. Geologists mapped previous lava flov and lahars to estimate areas at most risk. Warnings were issued and locals were evacuated in advance. Vaccinations were given against measles to prevent outbreaks. International emerge aid was provided after the eruption and lahars.

With the help of international development agencies the Luzon authorities have established lc term initiatives to better protect people and their properties including: building dykes and dan to protect against lahars and flash floods, establishing new farms and employment away from danger area, redeveloping the old US air base into Clark International Airport, where tax free trading attracts businesses employing 47,000 people and New towns and villages have been bu outside the danger area.

CASE STUDY—Tohoku earthquake, Japan 2011—Developed country

At 2.47pm on 11 March 2011, an earthquake with a magnitude 9.0Mw shook North-east Japan and triggered a tsunami. The Pacific plate thrust under the Eurasian plate at the Japan Trench. The focus was relatively shallow (30km) and the epicentre was 130km east of Sendai. Hundreds of aftershocks occurred measuring between 6.0 and 7.0Mw. The earthquake triggered a tsunami that raced outwards from the epicentre at speeds of 800km per hour. Waves were up to 10m high hit the east coast and travelled as far as 10km inland. **Primary impacts—**Between 667—1479 deaths occurred as a direct result of the earthquake caused by buildings collapsing. Many buildings and railways were damaged. Electric power and sewer systems were disrupted. Reclaimed land in Tokyo suffered liquefaction and more than 1000 buildings were damaged.

Secondary impacts—The vast majority of deaths (over 17,000) were due to drowning. More than half the victims were aged 65 and older. A further 5000 were injured or reported missing. Over 127,000 buildings collapsed and 1.2 million were severely damaged. More than 2000 roads, 56 bridges and 26 railway lines along the entire east coast of Honshu Island were destroyed. The Fukushima nuclear power plant dam burst and the power supply to the station was cut. The waves also hit the back-up generator, causing a nuclear meltdown as the cooling systems failed. The World Bank estimated the damage would cost in excess of US$300 billion in Japan alone.

Immediate and long-term response— Advanced warnings of the earthquake and tsunami gave people time to get outside and reach higher ground. The Pacific Tsunami Warning Centre warned the coastal communities in Japan and around the world of the tsunami. Rescue workers and Japanese soldiers were mobilised to deal with the crisis. The government requested international aid and Australia, China, India South Korea and the USA sent search and rescue teams. The Red Cross and Red Crescent provided support as did private companies and NGOs. Rescue efforts were hampered due to blocked roads and lack of communication, as well as bad weather. More than 130,000 were displaced with many in shelters with limited supplies of food, water and aid. A further 140,000 were evacuated from a 20km radius around the Fukushima plant. The following weeks over 10,000 prefabricated temporary houses were set up in Sendai. Honshu's communications and transportation systems were partially restored. The power supply took longer to come back online reducing the regions manufacturing and business output even further. By late summer the economy was growing again. In February 2012, the government sent up an agency to rebuild in the Tohoku region, which is expected to take 10 years. By early 2015, it was reported nearly all the debris from the disaster had been removed and work had started on a new sea wall.

Reducing the impact—Earthquakes cannot be predicted. Therefore, emergency services are being trained to be more effective, schools, business and organisations practice drills. 1st September each year us a National Disaster Prevention day. New buildings are built according to strict building codes to ensure they are able to stay up during an earthquake and older buildings are being retrofitted to be stronger.

CASE STUDY—Haiti earthquake 2010—Developing country

At 4.53pm, on 12th January 2010 an earthquake with a magnitude 7.0 str
Haiti. It was caused by the conservative plate boundary between the Nor
American Plate and the Caribbean plate. The Epicentre was 25Km South-
of the capital Port-au-Prince. The focus was very shallow (3km). Aftersho
ranged between 5.5 and 6.0.

Primary impacts — 316,000 died, 300,000 injured estimated by the Haiti
government, 3 million were affected by the earthquake. 1.5 million, were
made homeless and more than 180,000 homes were destroyed. These
people were forced into squalid camps with limited supplies. All 8 hospita
were destroyed, around 5000 schools were damaged or destroyed and al
universities collapsed. One prison collapsed and 4000 inmates escaped. T
port at Port-au-Prince was severely damaged and the airport control tow
collapsed hindering the response and aid. Electricity, water, sanitation an
communications were badly disrupted.

Secondary impacts—Cholera spread throughout the aid camps. The cam
provided little protection during the hurricane season. Factories closed a
tourism stopped decreasing the economy. Looting and crime increased a
government and police force collapsed.

Response—Haiti is one of the poorest countries in the Caribbean. It was
unprepared for the event and could not respond adequately. In the first f
days after the event, aid workers reported no one seemed to be in charg
International aid in terms of search and rescue teams were flown in. Foo
water, shelter and medical supplies were brought in by the USA and
Dominican Republic. American engineers and divers cleared the port so t
waiting ships could unload the aid. The UN and US troops provided secur
to maintain law and order and distribute aid. The UK's Disasters Emergen
Committee (DEC) raised £100 million, which was used to provide emerge
shelters, medication, bottled water, purification tablets and sanitation. In
weeks and months to come (long-term responses) the government move
235,000 people from Port-au-Prince to less damaged cities. Many wante
leave. 3/4 of the damaged buildings were inspected and repaired. Earthq
resistant techniques were used in some cases such as using old tyres,
bamboo and straw bales which help take the impact of seismic waves.
200,000 people were paid or received food for public work, such as cleari
debris. The World Bank cancelled Haiti's debt repayments for 5 years.
However, by 2013, less than half the US$4.5 billion pledged had reached
Haiti. Oxfam estimated that by 2015 there was still 500,000 homeless pe
without water, sewage systems or electricity. A cholera epidemic began 1
months after the earthquake killing over 8000 people and infecting 6% o
Haitians.