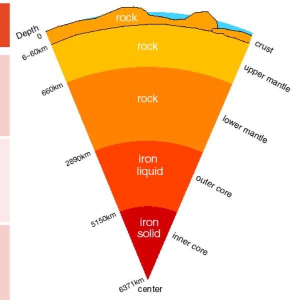
Dynamic Landscapes: Tectonic Processes & Hazards

The Structure of the Earth

The Crust	Varies in thickness (5-10km beneath the ocean). Amounts to less than 1% of the Earth's total mass. Made up of serval major plates.
The Mantle	Widest layer (2900km thick). The heat and pressure means the rock is in a liquid state that is in a state of convection.
The Inner and outer Core	Hottest section (5000 degrees). Mostly made of iron and nickel and is 4x denser than the crust. Inner section is solid whereas outer layer is liquid.



What is a Tectonic Plate?

A tectonic plate is a **massive, irregularly shaped slab of solid rock**, composed of both **continental** and **oceanic** lithospheres. These tectonic plates move in various ways against each other on areas know as plate margins.

Theory of Plate Tectonics

In 1912, Alfred Wegener proposed the theory of continental drift. He suggested the existence of Pangaea and that continents drift. Evidence for this includes;

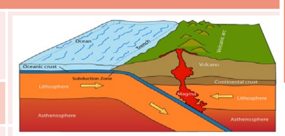
1	Geology- Rock sequences and jigsaw fitting of the world's continents.
2	Fossil records –Fossil remains of reptiles found in different continents.
3	Living species – Some species found on different continents are similar.
4	Climatology- Glacial deposits on the Equator suggests plate movement.

Vine and Matthews's theory included the Palaeomagnetism – Record of the Earth's polarity on erupted lava.

Types of Plate Boundaries

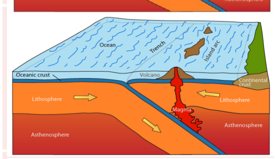
Divergent/Destructive Plate Boundaries

Oceanic – Continental: Subduction of an ocean plate at oceanic and continental plate margins leads to fold mountains & volcanoes.



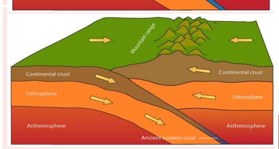
Andean Mountain Range, Peru and Chile

Oceanic – Oceanic: When two oceanic plates collide the older and denser plate subducts. The process here creates volcanic island arcs such as those found in the Lesser Antilles.



Aleutian Island, Alaska USA

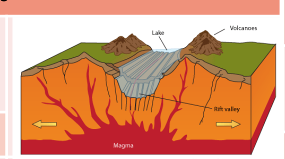
Continental - Continental: Involves two plate margins that are both continental and neither subducts. As these two plates are similar in density, the two plates collide to uplift and fold the crust.



Himalayan Mountain Range, Nepal and China

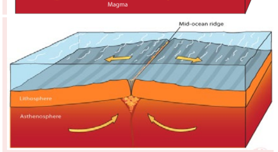
Divergent/Constructive Plate Boundaries

Continental – Continental: Caused by geologically recent mantle plume splitting a continental plate to create a new ocean basin. It can cause Basaltic volcanoes and minor earthquakes.



African Rift Valley, Ethiopia

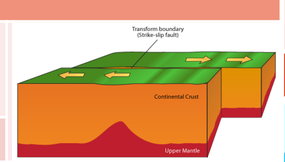
Oceanic – Oceanic: New lithosphere forms at constructive margins, where rising plumes of magma stretches the crust to create intense volcanic activity on the ocean floor.



Mid-Atlantic Ridge, Atlantic Ocean

Conservative Plate Boundary

Oceanic – Continent: Two plates slide past each other in either different directions or the same direction but at different speeds. As they shear past they can cause powerful earthquakes.



San Andreas Fault, California USA

Volcanic Hotspots

A concentration of radioactive elements inside the mantle may cause a hotspot to develop. From this, a plume of magma rises to melt through into the plate above. Where lava breaks through to the surface, active volcanoes can occur above the hot spot.

Intra-plate Earthquake

An intra-plate earthquake refers to an earthquake that occurs within the interior of a tectonic plate.

Global Distribution of Tectonic Hazards

Earthquakes

Earthquakes occur throughout the world but predominately on **plate boundaries**. For example the San Andreas Fault, a conservative plate margin. Furthermore, earthquakes also occur on the constructive plate boundaries of the Mid- Atlantic Ridge, although these are not as severe when compared to conservative, collision and especially destructive plate margins.

Volcanoes

Volcanoes are most likely to occur along **subduction zones** where oceanic plates dive under continental plates. Volcanic activity can also be found along **constructive plate margins** such as the Mid Atlantic ridge. There are, however, exceptions. The Hawaiian Islands, which are entirely volcanic in origin, formed in the middle of the Pacific Ocean. This is explained by the **'hotspot' theory**.

Tsunamis

The global distribution of tsunamis is fairly predictable, with around 90% of all events occurring **within the Pacific Basin**, associated with activity **at plate margins**. Most are generated at **subduction zones**, particularly off the Japan-Taiwan island arc, South America and the Aleutian Islands.

What is the Asthenosphere?

The upper layer of the earth's mantle, below the lithosphere, in which there is relatively low resistance to plastic flow and convection is thought to occur.

Mechanism of Plate Movement

The lithosphere is divided into tectonic plates. The processes that cause their movement are still debated. Below are some of the up-to-date theories surrounding reasons why plates move.

Slab Pull	Newly formed oceanic lithosphere at mid ocean ridges is less dense than the asthenosphere, but becomes denser with age as it cools and thickens. This causes it to sink into the mantle at subduction zones (Mariana Trench), pulling slabs of lithosphere apart at divergent boundaries and resulting in sea floor spreading or rifting. This process linked to driving convection currents within the mantle.
Ridge Push	As the lithosphere formed at divergent plate margins is hot, and less dense that the surrounding area, it rises to form oceanic ridges (Mid Atlantic Ridge). The newly-formed plates slide sideways off these high areas, pushing the plate in front of them resulting in a ridge-push mechanism.

Types of Lithospheric Plates

Continental	Oceanic
• Thick (10-70km) • Buoyant (less dense than oceanic crust) • Old sedimentary & metamorphic rock	• Thin (-7 km) • Dense (sinks under continental crust) • Young basalt (igneous) rock

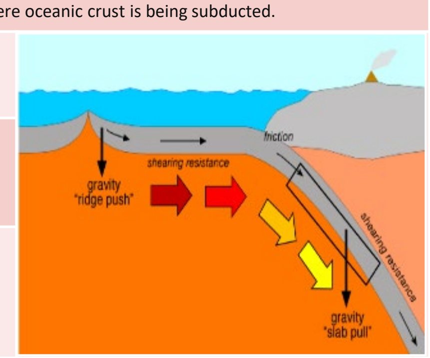
Benioff Zone and Subduction Processes

The Benioff Zone is an inclined zone in which many deep earthquakes occur, situated beneath a destructive plate boundary where oceanic crust is being subducted.

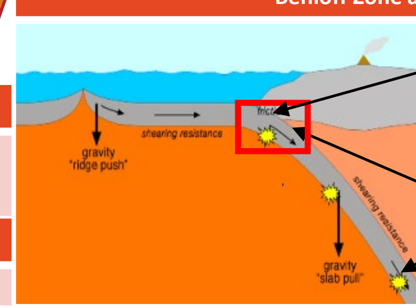
As the **asthenosphere** and **lithosphere** at the ridge are heated, they expand and become elevated above the surrounding sea floor.

At a **subduction boundary**, one plate is denser and heavier than the other plate. The denser, heavier plate begins to **subduct** beneath the plate that is less dense.

The subducting plate is **much colder and heavier** than the mantle, so it continues to sink, pulling the rest of the plate along with it. The force that the sinking edge of the plate exerts on the rest of the plate is called **slab pull**.



Benioff Zone and Earthquakes



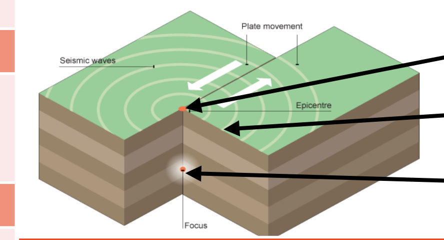
When plates become stuck, they will lock together. When the **frictional stress** exceeds the given threshold, a sudden failure occurs causing a **shallow focus earthquake** .

Where **faults** may become stressed over long periods of time as they drag the plate further along with it. When the pressure is released, the result is a **'mega-thrust event'.**

When pressure/heat exceeds the strength of the subducted plate, **deep-focus earthquakes** occur.

How do Earthquakes happen?

Earthquakes (shallow focus – less than 70km) happen when two plates become **locked** causing **friction** to build up. From this **stress**, the **pressure** will eventually be released, triggering the plates to move into a new position. This movement causes energy in the form of **seismic waves**, to travel from the **focus** towards the **epicentre**. As a result, the crust vibrates triggering an earthquake.

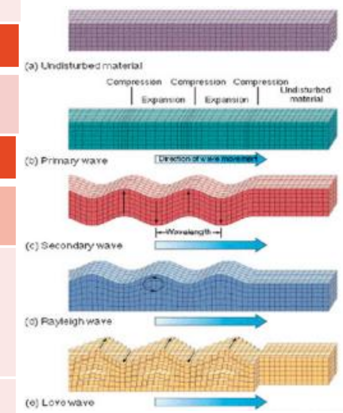


The point directly above the focus, where the seismic waves reach first, is called the EPICENTRE.

SEISMIC WAVES (energy waves) travel out from the focus.

The point at which this pressure is released is called the FOCUS.

Types of Seismic Waves



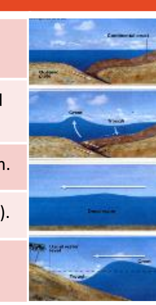
P Waves	Travel through solids and liquids. Shakes the Earth in the same direction as the travelling wave Fastest type of wave.
S Waves	Travel through solids only. Shakes the Earth vertically (90°angle to the travelling wave). Most damaging type of wave.
Surface waves	They can occur closest to the surface. They travel slower than P and S waves but are more destructive. Love waves Travel through solids only. Shakes the Earth in the same direction as the travelling wave Rayleigh waves Travel through solids and liquids. Shakes the Earth in a rolling motion (like an ocean wave).

Earthquake Secondary Earthquakes

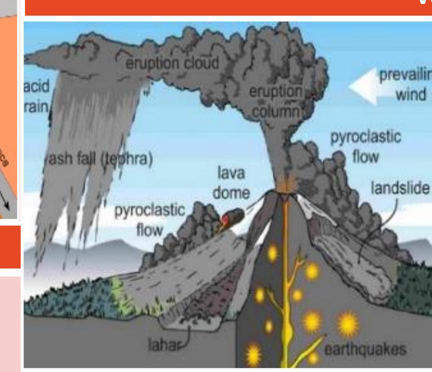
Liquefaction	Solid material changed into a liquid state. Damage to building foundations, results in them sinking.
Landslides and Avalanches	Earthquakes in mountainous regions often cause landslides and avalanches. Steep, unstable slopes are notoriously unstable and vulnerable to landslides.
Tsunamis	Earthquakes occurring underwater can cause the seabed to rise, leading to the displacement of water, producing powerful waves which spread out from the epicentre.

Formation of Tsunamis

1	Large waves caused by the displacement of water triggered by underwater earthquakes, submarine landslides and volcanic eruptions.
2	In the open ocean, the wave can travel at 500-950km/h and has a wavelength of 200km and a small amplitude (wave height) of 1m.
3	Closer to land the water gets shallower, causing the waves to increase in size but slow down.
4	Just before the tsunami reaches the coast, The water withdraws down the shore (drawback).
5	In Japan 2011, when the tsunami waves reached inland, in some places the waves were 20 metres high. Overall, the tsunami destroyed 200,000 buildings, and killed 19,000 people.



Volcanic Hazards



Ash cloud	Small pieces of pulverised rock and glass which are thrown into the atmosphere.
Gas	Sulphur dioxide, water vapour and carbon dioxide come out of the volcano.
Lahar	A volcanic mudflow which usually runs down a valley side on the volcano.
Pyroclastic flow	A fast moving current of super-heated gas and ash (1000ºC). This travels at 450mph.
Volcanic bomb	A thick (viscous) lava fragment that is ejected from the volcano.
Jökulhlaup	A massive flood that occurs when water trapped in a glacier breaks free due to a volcanic eruption.

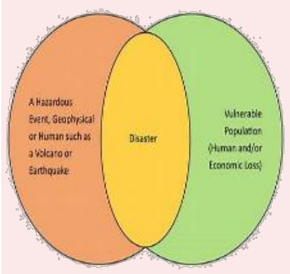
Main Types of Volcanoes

Shield	This type of volcano is almost entirely composed of **fluid lava flows**. They are found in **hot spots** or along **constructive plate margins**. Their eruptions are mostly **effusive** and **predictable**.
Composite	Composite volcanoes are created by **layers of ash and viscous lava**. They can be found along **destructive margins** and are often **steep-sided**. They are extremely **explosive** and **unpredictable**.

Hazard or Disaster?

Hazard	Disaster
A perceived natural event that has the potential to threaten both life and property.	The reality of a hazard happening; when it causes a significant impact on a vulnerable population.

The Degg's Model



The Degg's Model shows that a natural disaster only occurs if a vulnerable population is exposed to a hazard. For example, if the magnitude of the hazard is large, such as a magnitude 9 earthquake, but there is little infrastructure of population density near the epicentre, then no one will experience the hazard and the disaster is small and weak.

Understanding Risk

There is a complex relationship between risk, hazards and people. This is due to several factors as shown below:

1. **Unpredictability – many hazards are not predictable and people can be caught out by timing or magnitude.**
2. **Lack of Alternatives – People stay in hazardous areas for a multitude of reasons.**
3. **Dynamic Hazards – the threat from hazards fluctuates and human influence can play a role.**
4. **Cost-Benefit – the benefit of staying in a hazardous location may outweigh the risk (perception of risk plays a role here)**
5. **Russian Roulette Reaction – the acceptance of the risk as something that will happen whatever you do, that is, one of fatalism.**

Hazard-Risk Equation

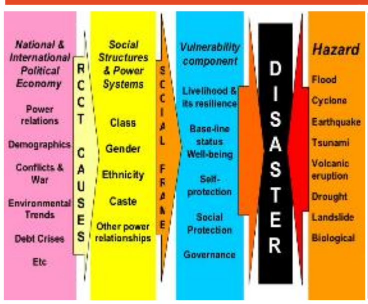
The hazard-risk equation attempts to capture the various components that influences the amount of risk that a hazard may produce for a community or population.

$$Risk = Hazard \times Exposure \times \frac{Vulnerability}{Manageability}$$

Perception of risks can also drive a population to the point where they have to adjust to the presence of the risk. People and populations also vary in terms of resilience.

According to the **United Nations Office for Disaster Risk Reductions (UNISDR)** the resilience of a community is generally based on resources, governance and level of organisation before and during disasters.

The Pressure and Release Model



The Pressure and Release Model (**PAR Model**) is a model that helps understand risk in terms of vulnerability analysis in specific hazard situations. **PAR** is a tool that shows how disasters occur when natural hazards affect vulnerable people.

Tectonic Measurements

Earthquakes: Richter Scale

- The Richter scale measures earthquakes **magnitude**.
- It is determined by the **logarithm** of the amplitude of seismic waves.
- In all, this is a scientific measurement for understanding the **seismic effect**.

Earthquakes: Mercalli Scale

- The Mercalli scale measures **earthquake's intensity**, i.e. the impact of an earthquake on people and structures.
- The measurement is **observational**.
- The scale goes from **1 to 12**. 1 is instrumental and **12 is catastrophic**.

Volcanoes: VEI Scale

- The **Volcanic Explosivity Index (VEI)** is a relative measure of the **explosiveness** of volcanic eruptions.
- No modern human has experienced a **VEI 8 supervolcano**. These are rare caldera eruptions such as Yellowstone and Toba.

Social and Economic impacts of tectonic hazards

Economic impacts are roughly proportional to the land area exposed to the hazard. But economic hazards need to take into account:

1. **Level development** in the region or country.
2. **Insured impacts** vs non-insured losses.
3. **Total numbers of people** affected and the speed of economic recovery following the event.
4. **Degree of urbanisation** and value of land
5. Absolute versus relative **impacts on GDP**; higher relative impacts are more devastating.

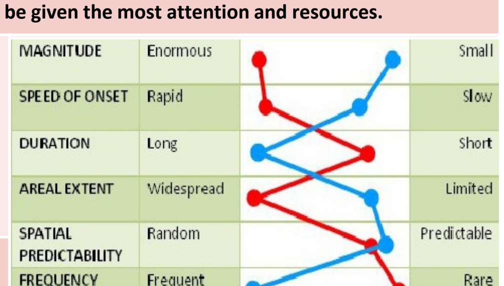
Key Point: Tectonic hazards that happen in a wealthy location are often more costly because the infrastructure is more developed and the loss of business is more significant.

Tectonic Hazard Profiles

A hazard profile compares the physical processes that all hazards share and helps decision makers to identify and rank the hazards that should be given the most attention and resources.

- Hazard profiles are useful for comparing the same hazard in different locations (for example, the Sichuan Earthquake to the Haiti Earthquake)
- However it is difficult to compare different hazards (volcanoes, tsunamis, earthquakes) without a certain degree of accuracy.

Profile shows comparison of 2004 Asian Tsunami and ongoing eruption of Kilauea in Hawaii.



CASE STUDY: Haiti Earthquake 2010

Causes

- On a conservative plate margin, involving the Caribbean & North American plates.
- The magnitude 7.0 earthquake was only 15 miles from the capital Port au Prince. With a very shallow focus of 13km deep , Haiti (the poorest county in the western hemisphere) became more vulnerable.

Short-Term Effects	Long-Term Effects
• 230,000 people died and 3 million affected. • 250,000 homes and 30,00 business had collapsed or were damaged. • Rubble blocked roads & ports shut.	• 1 in 5 jobs were lost. • Millions became homeless. • The spread of disease became a big risk due to sanitation damage and unburied corpses.

Immediate Management	Long-term Management
• Individuals tried to recover buildings and people. • Many countries responded with appeals or rescue teams.	• Heavily relied on international aid. E.g. $330 million from the EU. • 6 months after, 98% of the rubble still remained.

CASE STUDY: Japan, Tohoku Tsunami 2011

Causes

- Measuring 9.0, the epicentre occurred 100km east , where the Pacific plate subducts beneath the North America plate.
- A segment slipped suddenly to thrust upwards causing tsunami waves.

Short-Term Effects	Long-Term Effects
• 500km2 coastal plains hit, destroying farmland, settlements and communications. • Explosions at the Fukushima nuclear power plant. • 20,000 were killed.	• Electricity lost in 6 million homes, 1 million had no running water. • Many people not allowed to return due to radiation. • Triggered an economic slowdown and issues in energy supplies.

Immediate Management	Long-term Management
• 100,000 Japanese soldiers sent out to search and rescue. • Exclusion zone set up around Fukushima; People evacuated.	• Re-building, re-construction. e.g. Port facilities were rebuilt. • Tsunami defence system reconsidered and extended.

Predict Plan and Protect

Earthquakes

Predict: Scientists can deduce where earthquakes will happen but not WHEN!

Example methods include:

Satellite surveying (tracks changes in the earth's surface)
Radon gas sensor (radon gas is released when plates move so this finds that)
Water table level (water levels fluctuate before an earthquake)
Scientists also use seismic records to predict when the next event will occur.

Prepare
Training for emergency services.
Practising earthquake drills
Emergency kits that include first-aid items, blankets and tin food.

Protect
Building earthquake-resistant buildings
Raising public awareness
Improving **earthquake prediction**

Tsunamis

Predict
Like any earthquakes, there's no way of predicting when a tsunami-causing earthquake will strike, but thanks to **early warning systems**, it's now possible to get word out about an approaching tsunami within minutes.

Prepare
Evacuation routes on the coastlines indicated by signs & signalled by sirens .
DART (Deep-ocean Assessment and Reporting of Tsunami) buoys moored to sensors on the sea floor can monitor passing tsunamis.

Protect
Buildings designed with **raised, open foundations** and made of strong materials such as **concrete**.
Tsunami walls have been built around settlements to protect them.

Volcanic Eruption

Predict
Seismometers to detect earthquakes.
Thermal imaging can be used to detect heat around a volcano.
Gas samples may be taken and chemical sensors used to measure sulphur levels.

Preparation
An **exclusion zone** around the volcano.
Emergency kit of key supplies.
Having **evacuation routes**.
Trained **emergency services** with good **communication systems.**

How can Governments use Hazard Profiles?

- Implement **land-use zoning** to keep danger areas clear.
- Use **hazard-resistant designs**. Improved buildings and infrastructure.
- **Educating local people** about disasters and ensuring **community preparedness.**
- **Management strategies** to reduce losses; insurance and aid deployment.

Governance and Hazard Vulnerability

Governance and its impact goes from local to international scales and has three major components.

Poor political governance increases vulnerability and is linked to:

- Population density/Rapid rise in unstable urbanisation.
- Geographic isolation and accessibility.
- Ineffective services such as law enforcement, healthcare and education.

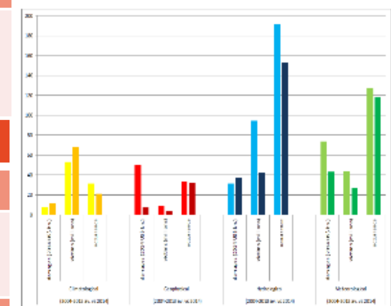
Interactions of Governance

Economic governance is how decisions affect economic activities and relationships with other economies. Affects equity, poverty and quality of life.

Administrative governance is how policy is implemented. It requires good building codes, land use planning, environmental risk and vulnerability monitoring.

Political governance is the process of making policy including disaster risk planning. This brings together state, non-state and private-sector players and stakeholders.

Trends & Patterns in Global Hazard



Trends since about 1960

- The total number of recorded hazards has **increased**.
- Number of **deaths is falling**, but spikes with mega-events.
- Economic costs have **increased significantly**.
- Total number of **people affected is rising**.
- The number of tectonic hazards has remained **fairly stable**.

Reasons behind Patterns & Trends

- Improvements in **monitoring and recording events**.
- Improvements in **technology** allow for more **reporting**.
- The **global population has increased** by 4.3 billion since 1960.

Tectonic Mega-Disasters

Mega-disasters are a large scale (in spatial scale or in impact) event. They pose problems for effective management and require a coordinated, usually international, response. They are High Impact, Low Probability (HILP) events.

Multiple Hazard Zones

Some places are vulnerable to multiple hazards; we call these places 'hazard hotspots'.

- They are **hotspots due to their geography and location**.
- They usually experience **volcanic eruptions, earthquakes and tsunamis** as well as their secondary hazards.
- Good examples of hazard hotspots would be **California (USA), Philippines and Japan**.

Hazard Management Cycle

The theoretical model shows hazard management as a continuous four stage cycle.

Recovery
Getting back to normal.
This focuses on people's immediate needs, so it overlaps with the response phases. However, it also has long term focuses such as aiming to improve systems for next time.

Mitigation
Preventing hazard events or minimising their effects.
Identifying potential natural hazards and taking steps to rescue their impact. The main aim is to reduce loss of life and property.

Response
Responding effectively to a hazard event.
The main aims are to save lives, protect property, make affected areas safe and reduce economic loss.

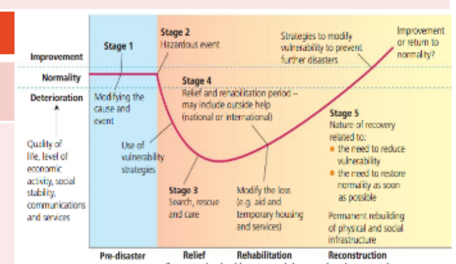
Preparedness
Preparing to deal with a hazard event. Minimising loss of life and property whilst also facilitating response and recovery. Plans are implemented by emergency planners.

The Park's Model

The Park Model plots the quality of life after a disaster against the time since the disaster has occurred.

The Park model takes into account:

- That hazards are **inconsistent**. Things such as the magnitude, development and aid received change over time.
- All hazards have **different impacts and responses**.
- **Wealthier countries** have different curves as they recover faster. They have well-equipped services with technology.



Players: The Role of Aid Donors

Emergency Aid	Short-Term Aid	Long-Term Aid
Immediate help such as food, clean water and shelter for people displaced by a disaster event.	Restoring water supplies to affected areas, providing temporary shelters for displaced people.	Rebuilding infrastructure, redeveloping economy and managing to reduce the impact of future events.

Key Players in Modifying Disaster Losses

Communities	Insurers	Governments	NGOs
When a disaster strikes, its local people who are the first to respond and who often play an important role in recovery	Provides individuals and business with the money they need to repair, rebuild and recover.	In industrialised countries, insured losses are low. In developing countries this disaster insurance is often unaffordable.	NGOs can play a crucial role where the local government is struggling to respond, or doesn't have the resources to do so.