EARTHQUAKE WAVES

TYPES OF WAVES

Type/Location	Name	Motion	Speed	Travels through	Time
Surface (L) Waves	Rayleigh waves	Vertical movement (elliptical motion)	Slowest	Just below earth surface (so probably solid only)	Arrive last
	Love Waves	Horizontal movement (transverse)			
Body (P/S) Waves	S-Waves	Transverse		Solid only	
	P-Waves	Longitudinal	Fastest	Solid + Liquid	Arrive first

SURFACE WAVES (L WAVES)

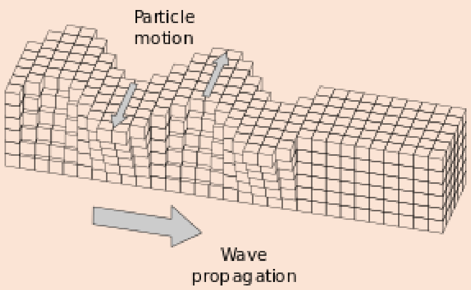
These surface waves travel **just below the Earth's surface**. They are the most **destructive** type of wave because:

1. **Long duration** (energy dissipates slower)
2. **Low frequency**
3. **Large amplitude**
4. Shear forces **horizontal (love waves**) and **vertical (Rayleigh waves**) at the surface

 # A Love wave is a surface wave having a horizontal motion that is transverse (or perpendicular) to the direction the wave is traveling

The 3 terms:

Long – the wavelength is longer than for P and S waves

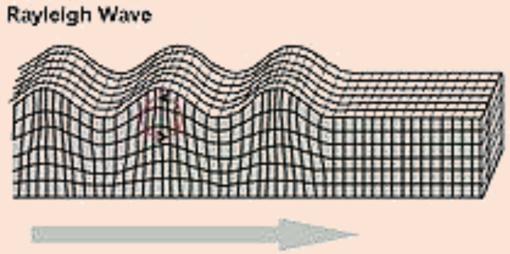


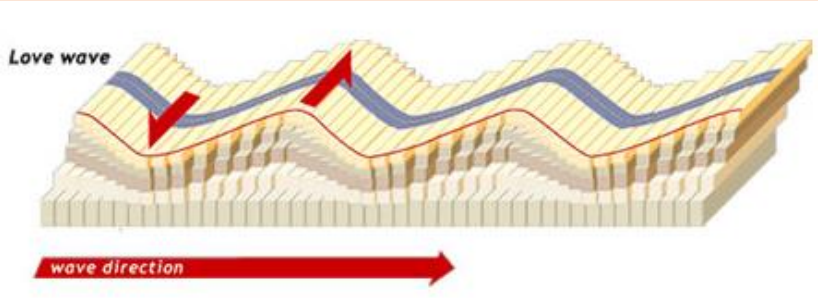
- **Love waves** are **slower than P & S** waves but **faster than Rayleigh** waves.
- Love waves lose their energy exponentially with depth as they are **confined to the surface**. However, their **amplitude (horizontal/ transverse motion)** decays more slowly with distance from epicentre compared to body waves. They can travel several times around the Earth before dissipating. = **Long duration**
- The Love wave is a **result of the** interference of many shear waves (**S–waves**) guided by an elastic layer.
- Have largest amplitude

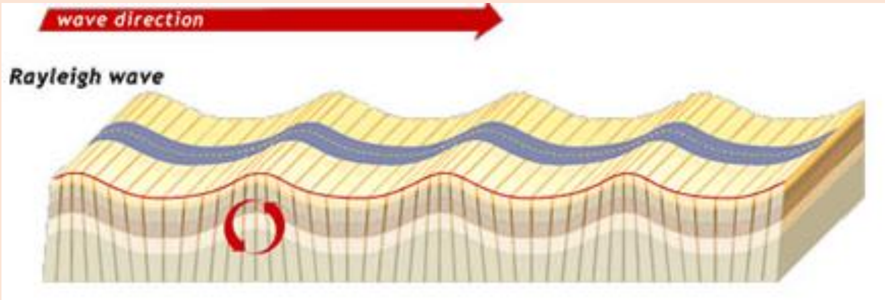
Good description of a Rayleigh wave = The particle motion of this wave is confined to a vertical plane containing the direction of propagation and retrogrades elliptically.

 # A Rayleigh wave is a seismic surface wave causing the ground to shake in an elliptical motion, with no transverse, or perpendicular, motion.

- Rayleigh waves are a **surface acoustic wave**, travelling **along the surface of solids**. Said to includes both longitudinal and transverse motion but it is summarised as **elliptical motion in vertical plane.**
- These waves cause the surface particles to **move in ellipses** in planes normal to the surface and parallel to the direction of propagation – the **major axis of the ellipse is vertical.**
- They are the **slowest** type of wave
- **Circular oscillations** means energy is lost quicker with distance from epicentre.







Surface waves (L waves) have oscillation in a **circular motion** so the waves **lose energy quickly with distance** away from the epicentre (duration is still LONG !!!!). L waves are confined to the surface layers of the Earth and they **cause damage to buildings.**

BODY WAVES A) P-WAVES

P- Waves

They can an travel through both solid and liquid.

Primary – Arrive first out of all waves

Push – are longitudinal or compressional waves so vibration of rock particles is parallel and particles move back and forth. They can pass through any type of material

Pressure – particles alternately move together (compression) and apart (rarefaction) in the direction parallel to the propagation/energy transfer direction.

The properties that govern how fast a P-wave travels are:

- **Density (p):** The denser to rock medium the lower the velocity. This is because there are more particles in a given volume so it becomes harder for a wave to pass through (more energy for undulation/oscillation).
- **Incompressibility (k)**: P wave energy causes rapid compression, then the material rebounds (springs pack) and passes the energy along. The faster the material rebounds, the faster the seismic waves can travel through it. Therefore, a material with high incompressibility will rebound quicker and p waves will travel faster.
- **Rigidity (μ): is the same as shear strength or how much a material resists a bending force. A liquid has zero rigidity.**

BODY WAVES B) S-WAVES

<u>S waves take their name from:</u>

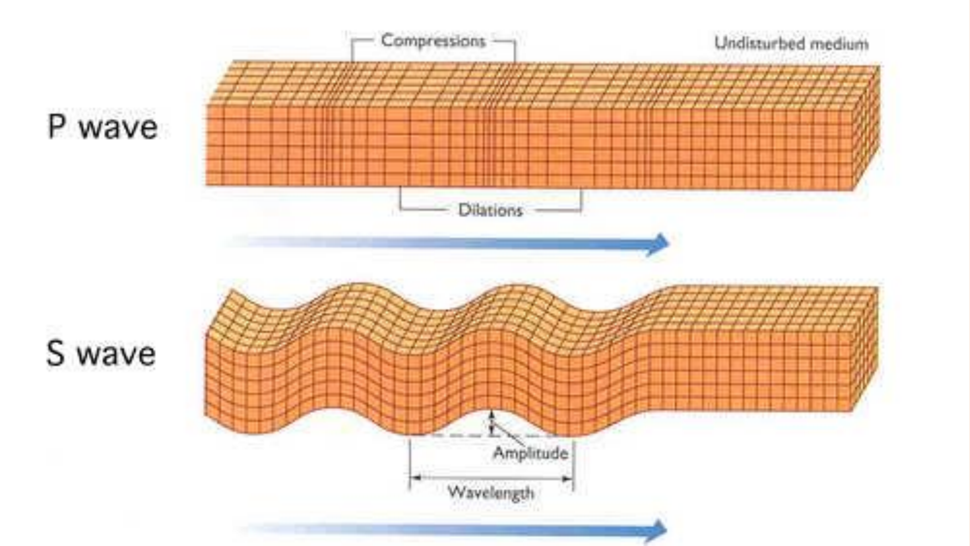
Secondary – travel slower than P waves – about 60% of the P wave velocity and so arrive second, after P waves.

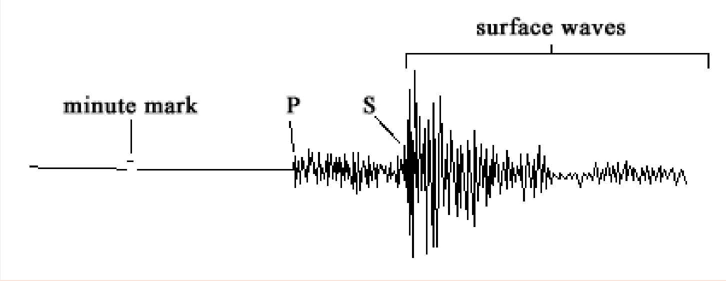
Shear – the movement of the particles is at right angles to the direction of wave travel, sideways in a shearing motion. This is a transverse wave as the ground moves alternately to one side and then the other.

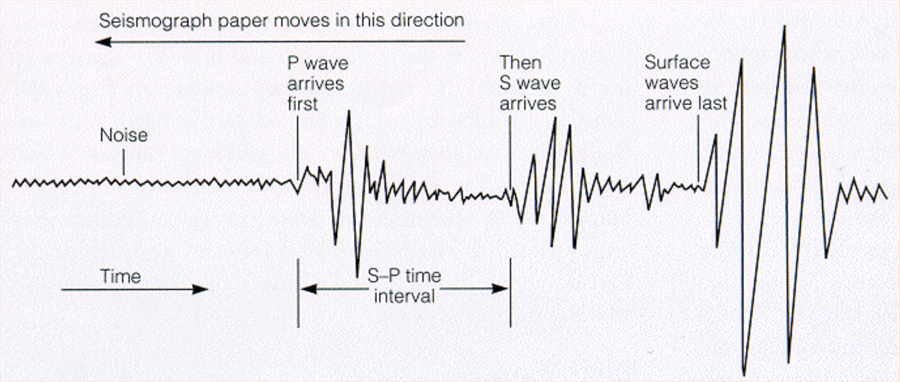
Several - times larger in amplitude than P waves.

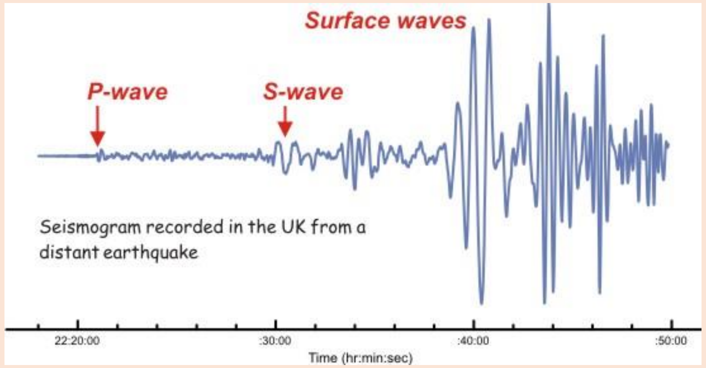
S -wave velocity depends on **ONLY density** and **Rigidity** (NOT incompressibility).

P-wave velocity depends on **incompressibility, density** and **Rigidity**









GENERAL DEFINITIONS FOR EARTHQUAKES

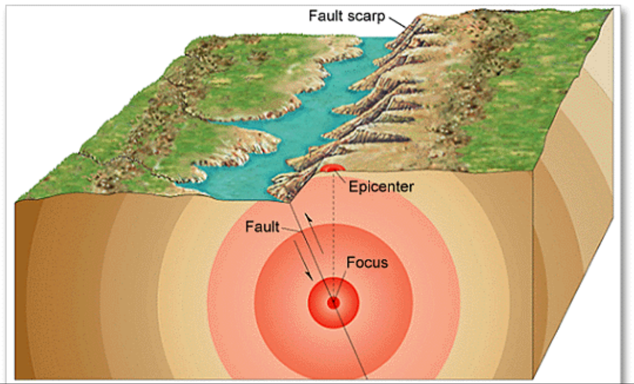
 # An earthquake = A vibration in the rocks of the crust and upper mantle (lithosphere) cause by a sudden dislocation of the rocks along a fault. Seismic waves are produced.

 # A seismic wave = a wave that travels through the Earth as particles of rock vibrate one another, transmitting energy from one particle to the next away from the source (focus). Generally caused by tectonic earthquake but may be due to a nuclear bomb.

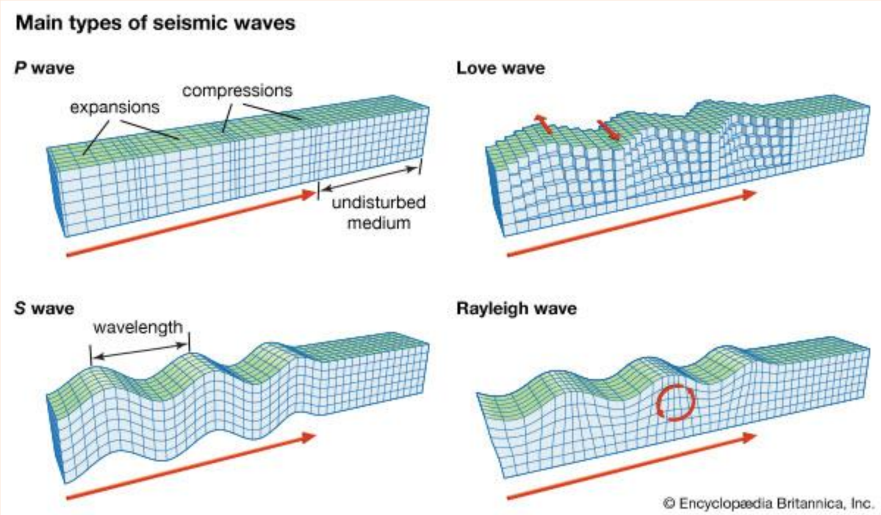
#Epicentre =

#Focus = The point within the Earth (below surface) form which an earthquake originates.

#Benioff zone = a sloping plane of the boundary between an oceanic and continental plate at a subduction zone, along which increasingly deep-focus earthquakes occur.



The epicentre is the pin point on the earth's surface that is directly above the focus where the earthquake originates form. This is marked on (aerial) maps to show focus. Greatest damage most likely to occur here.



How do earthquakes form?

The focus of an earthquake is where the earthquake originates form. Seismic waves are produced since there are **frictional forces along a fault plane** where part of the **crust moves alongside** another part.

Vibrations may also occur at deep foci where there is partial melting of the outer edges of the ocean crust while the **centre remains colder and more rigid** so outer **edges move more easily**.

The oceanic plate always sub ducts as it is made of denser basalt (avg. den. 2.9 g/cm^3) compared to the lighter continental crust of granitic composition (avg. den. 2.7 g/cm^3).

What is the Benioff zone (from further on in book – pg39)

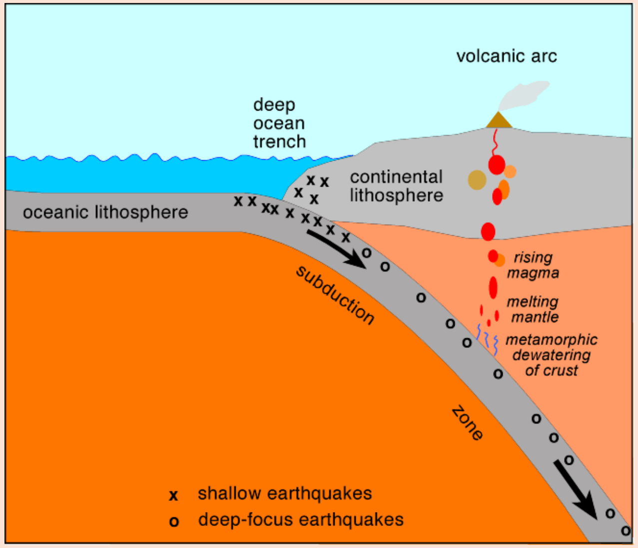
With distance from the trench (towards continent) the oceanic plate sub ducts down and the Benioff zone shows a sloping plane of earthquake foci.

Further in land, the depth of earthquake focus will increase.

At higher levels in the crust, where subduction begins, the earthquakes are generated along the boundary itself due to friction of rocks.

Further down, the foci occur within the plate itself, the interior part remains colder and more rigid, while the edges heat up and move more easily. It is the difference in motional speeds of subduction that causes vibrations (deep focus earthquakes).

Above the deep focus Benioff zone there is a point where the oceanic crust partially melts and the rising magma that forces its way up through the lithosphere and continental crust – this causes earthquakes but we don't tend to mention these **(less significant).** Magma can rise up to a volcanic arc (on continent!)



WHERE DO EARTHQUAKES FORM

Oceanic-continental **(destructive subduction)**	Nazca plate colliding with South America to form Andes
Oceanic-Oceanic **(destructive subduction)**	Collision of pacific plate with Eurasian plate (and Philippines) in Japan.
Continental-Continental **(convergent collision)**	The collision of Indo-Australian plate with Eurasia to form the Himalayas
Oceanic-Continental 2 **(conservative)**	1300km vertical strike slip fault (San Andreas Fault) where North American and Pacific plates slide past each other. Both move North westerly but pacific plate faster.

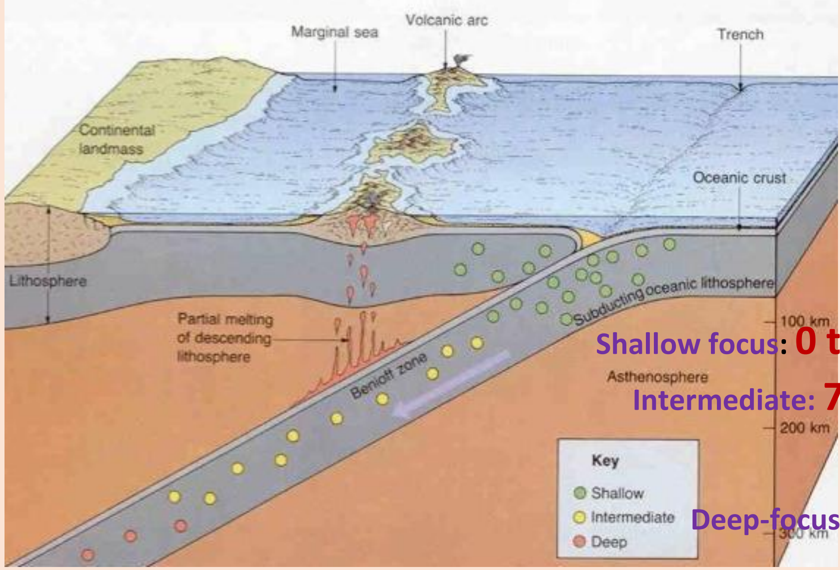
***Shallow focus earthquakes** may also occur at a MOR (mid ocean ridge) due to rising magma along fault planes and also either side of the spreading ridge as transform faults (different rates of plate movement) occur.*

Linking this to island arcs

Note: A volcanic arc is a chain of volcanoes parallel to a oceanic trench. They can be on continents, like in the Andes or in the Rockes (Cascade mountain range), or in the ocean (volcanic island arc) like the Japanese islands.

Note: Volcanic island arcs (in ocean) may also form at no subduction zone such as to the west of North America where the Hawaiian islands have formed due to a mantle plume or hot spot in the lithosphere.

DEPTH OF FOCUS



Shallow focus: 0 to 70 km

Intermediate: 70 to 300 km

Deep-focus: 300 to 700 km

Earthquakes do not originate below a depth of ~ 720km as the warmer, deeper rocks are not brittle enough to fracture.

Finding epicentre (and so focus) from isoseismal maps.

The **epicentre will be in the centre of the area of greatest intensity.**

Maps showing area of equal intensity are compiled – either from observations form humans or readings from seismometers, at different locations across the area.

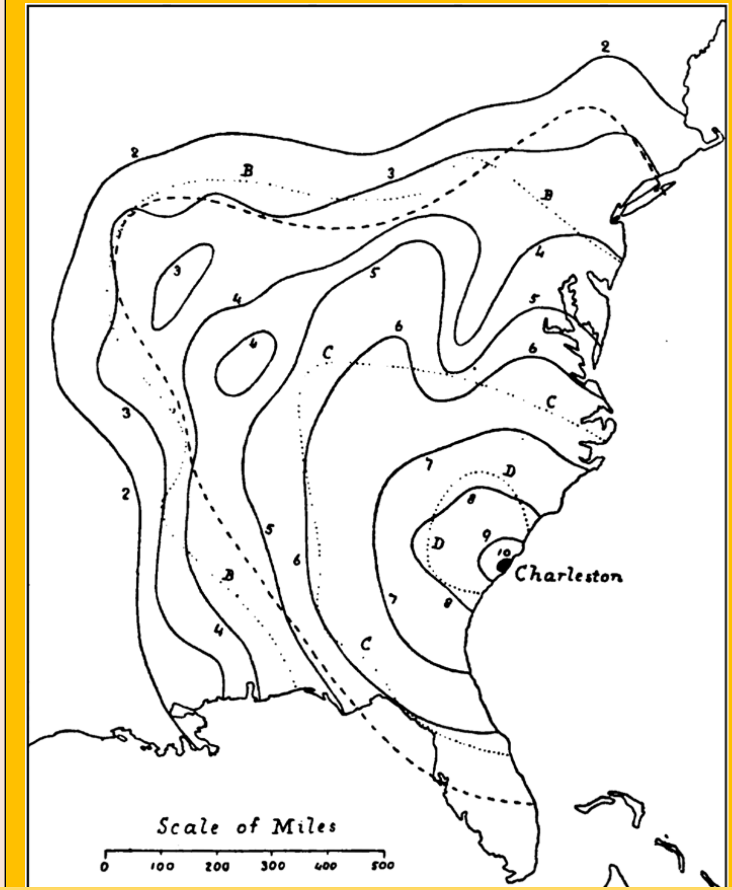
An isoseismic line = a line on a map joining up points of equal intensity, separating zones of different intensities.

REFER to page 16 bottom diagram

The pattern should be roughly concentric.

For a values of say 5, **ensure all numbers less than 5 are one side** outer side form epicentre) and **all the values that are 5 or above** are **on the other side** (facing epicentre).

Try to keep these as straight as possible (don't do dot to dot) Go around the points to keep curving gentle and circle singular isolated points.



How do sub-surface deposits play a role on determining earthquake sale of damage?

For any given intensity, the rock deposits of the area determine the amount of damage caused.

- **Solid competent rocks** (like **granit**e or **limestone**) allow vibrations to pass through **easily** and the seismic waves are transferred **without causing much damage.** The rock and the structures built on rock suffer less damage, the **amplitude of L waves** is c**omparativel**y **low.**
- **Weaker rocks** such as **clay** or **poorly cemented sandstone** will **absorb some of the energy** and may be deformed. Buildings built on weaker rocks are more damaged.
- **Unconsolidated sands** and **gravels** can **oscillate freely**. The **L wave amplitude** is **higher and damage** is far is **greater** compared to rigid competent/consolidated rock.

The physical effects

When the crust fractures, **elastic energy is released** and **transfereed by high amplitude L waves** travelling through the surface layers of the Earth. The most destructive effect of this energy are felt at the epicentre. Typically surfce waves come from shallow focus earthquakes and nuclear bombs.

Ground movement	Earthquake vibrations travel through he ground and cause **little permanent damage** when **intensities are low.**
	Stronger, **larger amplitude** earthquakes cause **shear, lateral motion** of the ground surface. Earthquakes of a **magnitude 12** on the **Mercalli scale** make "the ground surface move as a **series of waves**, with **cracks o**pening at the cr**ests** and **closing a**t the **troughs**" This adds a vertical component. When **acceleration of ground up** is greater than that **acceleration of gravity**, **loose objects are thrown bodily upwards**.
Damage to structures	Movement of ground separates structures…….. ▪ **Bricks and stonework** separate **along mortar = walls collapse** ▪ **Floors separate** from **supporting walls** so they `**pancake**' on top of each other. ▪ **Bridges** built in **sections separate** from their **supporting piers**. ▪ Sections of **gas, water** and **drainage pipes** separate and leak. Damaged **electrical cables can spark** and **ignite** such gas leaks while split drainage pipes **contaminates drinking water** and environment (can cause **disease**).

Aftershocks	**The main movement** along the **fault releases** the **majority** of the energy, but s**ubsequent** movements (minutes/hours/days/weeks) cause **aftershocks.** Already **weakened structures will collapse**. **Rescue efforts** can be **delayed** and **trapped** people **killed**
Landslips	On **steep slopes**, especially with **unconsolidated or porous material** (saturated in water)/ made **unstable by rain infiltration**, the **vibration** may trigger **landslides of mudflows**. This can be **assisted by liquefaction**. **Burial** results in **loss of lives** and **rescue attempts are hampered**.
Liquefaction	**Vibrations in the bedrock** are **transmitted t**o the **superficial** (=at surface) **deposits at the surface**. In wet sand, and other **unconsolidated deposits**, the **water separates** from the solid particles and **rises to the surface**. **Structures built** on such **alluvial deposits** can suddenly be **standing in** large amounts of **water** causing damage. The ground behaves as a liquid **losing its rigidity** so L waves have larger amplitude and **ground may sink/subside underweight**.
Tsunamis	A large section of the **crustal sea floor is displaced** by an earthquake (epicentre in or near ocean) and results in the **bodily displacement** of a **large volume**/column of water (typically upwards). This forms a tsunami wave (set up at **same time as earthquake** but **NOT a seismic wave**). A tsunami may also occur due to a **landslip into the ocean** (when flank of volcano collapses into the sea and displaces water). A tsunami wave in open water has **amplitude: ~ 1m** and **wavelength: several hundred Km s** **Speed: <700km/hr** As it **approaches the shallow waters** of the coast, the **height** of the wave **dramatically increases**, **surging across low-lying areas** with devastating effect. A more immediate **warning** is given as the **sea drains away** from the shore-line immediately before.

Landslip Ground subsidence

Damage to structure

Tsunami wave

Liquefaction

SOME CONSIDERATIONS FOR COUNTRIES AFFECTED BY EARTHQUAKES

Before the earthquake	**Frequency** and **magnitudes** of earthquakes
	Quality of forward planning and **training** and **wealth**
During earthquake	**Population density** and number of **people affected**
	Magnitude of earthquake and **proximity** to epicentre
	Amount of **damage** caused
The rescue	**Quality of emergency services**: search teams, fire and rescue services, policing and hospitals.
	Availability of **medical services** and supplies
	Availability of **emergency food and shelter** and sanitation
	Viability of **communications**
The aftermath	**Healthcare, hygiene** and s**anitation**
	Restoration of water and electricity and gas
	Rebuilding costs, materials and labour
	Employment opportunities

The social and economic effects of earthquakes

Earthquakes **seldom kill** – it is the indirect effects of it such as **fires, collapsing buildings, landslides, tsunamis, disease, famine that can cause hundreds of thousands of casualties.**

Housing and industrial buildings damaged   Transport networks damaged and disturbed

Communications dislocated   Services disrupted   Homes and schools destroyed

The effects may last for several years before a solution is implemented and life is back to normal. The **local economy also suffers** at just the time when the **money is needed for rebuilding** after the earthquake. Countries respond differently depending on:

wealth, infrastructure, geography and climate.

ELASTIC REBOUND THEORY

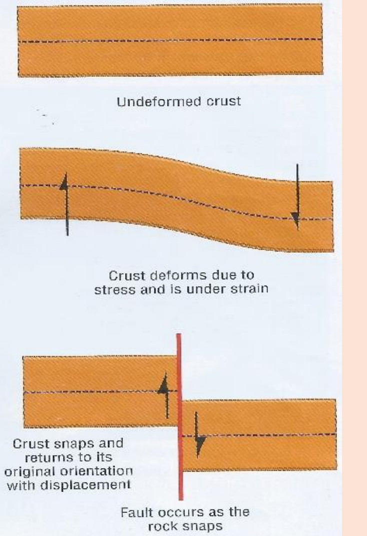


Figure 1 The elastic rebound theory

This is how earthquakes cause seismic waves

1. Two parts of a body of rock are **put under stress** due to opposing forces of friction acting on the rock.
2. The opposing **forces** are often due to **tectonic plates** with movement in **opposing directions.**
3. The body of rock is slowly **deformed under strain**
4. **Energy applied** to **deformed rock** is stored as **potential or strain energy** within the rock.
5. The **deformation continues** until **the stress overcomes** the **strength** of the rock and **it fractures**.
6. Two parts of rock **move relative** to each other and there is **displacement along a fault**.
7. The **strain energy** which had been stored **is released** during this action, causing the **ground to vibrate** as an **earthquake**.

Incompetent or plastic rocks bend (experience **strain more easily)** when stress is applied. They can undergo more stress without brittle fracture by bending or **showing plastic flow** and so **rocks do not fracture** to create an earthquake. Such rocks are hot **metamorphic rocks, clay, shale or mudstone**.

EARLY WARNING SYSTEMS FOR TSUNAMIS

Tsunamis can have a catastrophic effect. A tsunami may reach an area affected by an earthquake up to several hours after the shocks were first received for distant epicentres. The **Indian Ocean Tsunami Warning system** has been set up by **UNESCO** after 230, 000 people died following the Sumatran earthquake of 2004. Countries which can afford expensive equipment paired with good communication system can place mid-ocean detectors out at sea linked to the land.

Other ways in which tsunami effects are avoided/dampened are:

- A wall of trees and vegetation alogn a coast lien to absorb wave enrgy
- Buildign houses on raised land and away from the coast line
- Tsunami alarm systems

SOCIAL CONSEQUENCES OF EARTHQUAKE PREDICTION

It is not only hard to predict the exact date, magnitude and location of an earthquake, but human nature causes unwanted reactions when a predicted earthquake does not strike. There is controversy over when the public should be warned before an earthquake (could this affect behaviour/jobs).

Improved building practices are expensive but will reduce risk to people.

Planning	1. The likely number and **magnitudes** of future earthquakes are **predicted** where possible. 2. **Local authorities** can **ban building on fault** line itself or on areas of **alluvial deposits** which suffer from liquefaction and/or landslides. 3. **Red lining zones** for infrastructure near the **shore line** means buildings must be **built further inland** where they are **safer from Tsunamis.** 4. **Planting vegetation** along the coastline **to absorb wave energy**. 5. **Tsunami warning** systems out at sea connected to land **communication**.
Building designs	1. Although it is too expensive to stop all damage, we can protect buildings form **collapse, falling structures** and **broken glass**. 2. **Wooden structures** are **flexible** and can **withstand a certain amount of strain**. 3. **Larger buildings** use **steel reinforced concrete** (strong compression and tension properties). This is **safer** (less brittle) **than bricks/masonry with concrete.** 4. **Foundations reinforced** by **injecting liquid cement** into a network of **micro pile**s drilled into the ground beneath the building.
Ground or base isolation	1. Buildings can rest on **large rollers, springs or sliders coated** with **non-stick Teflon** (reduce friction). The **inertial mass** of the structure combined with **non-stick base** means the building can **stay stationary as the ground beneath it moves** or vice versa (reducing damage). Older buildings can have this system inserted in it for future protection (e.g. Utah State Capitol)
Resisting shear forces	1. **Diagonal bracing**, using **cables or girders**, creates a **strengthened exoskeleton framework**; each part of the structure is **connected to another part.** 2. **Large open spaces are not** included and **floors are fixed to supporting walls** to add **rigidity** and prevent `**pancaking'.** 3. **Shear walls**, extending the **full height of the building without** any **openings** add to the rigidity.
Absorbing sway	1. **Tall buildings** are designed to **sway**, **absorbing the energy** through **flexible supports** and **materials made**, for example, of **rubber**. 2. **Hydraulic systems** can be used, sometimes **computerised, to dampen movement** – shock absorbers. 3. **Flexible connections** between different parts of the building **help counter movements**.
Services	**Flexible piping using PVC/PEX/HDPE** is strong and **resists fracturing** unlike brittle metal/stone piping. This can prevent gas/water and electric links leaking and **causing fires.**

The Utah State Capitol is a large open-spaced building supported by only external columns (no internals). Improvements can be made to the structure to reduce the effects of a magnitude 8 earthquake, at a cost of ~ £100 million.

- Replace a slice of each **base column with a base isolation unit** made of **laminated** layers of **rubber** and **steel plates** surrounding an **energy absorbing lead core.**
- **Insert sliders** made of **Teflon-coated pads** that rest on **stainless steel plates** under the columns **bearing less load**. This will allow for **sideways movement** of up to 60cm without damage.
- Build-new **concrete load-bearing walls to add strength** to the building. The **extra weight** of the building will then **mean micro piles are injected** into the soil for support.

HOW TO DETECT EARTHQUAKES

- **Stress** = the force acting per unit cross sectional area on or within a body (similar to pressure)
- **Strain** = the change in shape of a body in response to stress (deformation).
- **Seismometer** = a sensor device that receives seismic vibrations, converting them into a signal that is transmitted and CAN BE recorded (onto a seismogram).
- **Seismogram** = the paper or electronic record made by a seismograph or seismometer.
- **Seismograph** (another name for seismometer once connected to its recording unit) = this consists of the seismometer device that receives the vibrations and converts them to a signal which is recorded on a seismogram.

<u>The seismometer is made up of two parts.</u>

1. A **tracer attached** to **large mass suspended by a cable (pendulum)**.
2. The **mainframe/structure** connected to the ground that can **move freely.**

The relative movement between the two parts is recorded on a seismogram.

Nowadays seismometers use the **relative movements** between a **magnet and coil of wire (electromagnetic induction)** so **digital c**ircuits record motion. Movements smaller than **1nm** (10^{-9}m) are detected.

Data form seismometers can be collected automatically, analysed by **algorithms remotely** and distributed to communications. **Seismometers are sensors** placed in the earth to detect the vibrations, **together with the unit recording signal is a seismograph**.

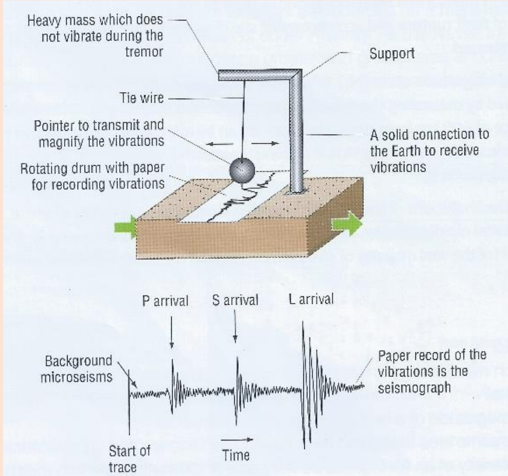


Figure 2 Seismometer and seismogram

Interpreting a seismogram:
Commonly, three groups of waves are seen (with exceptions of shadow zones): **P, S and then L waves**.

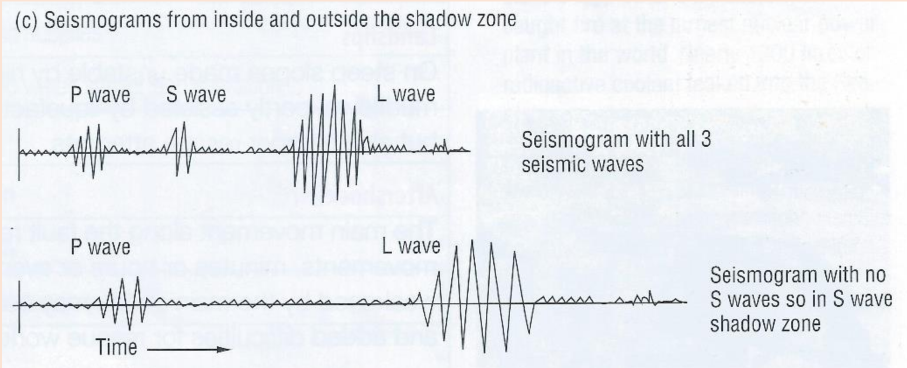
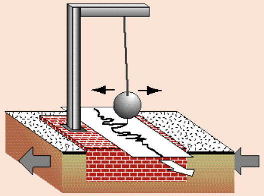
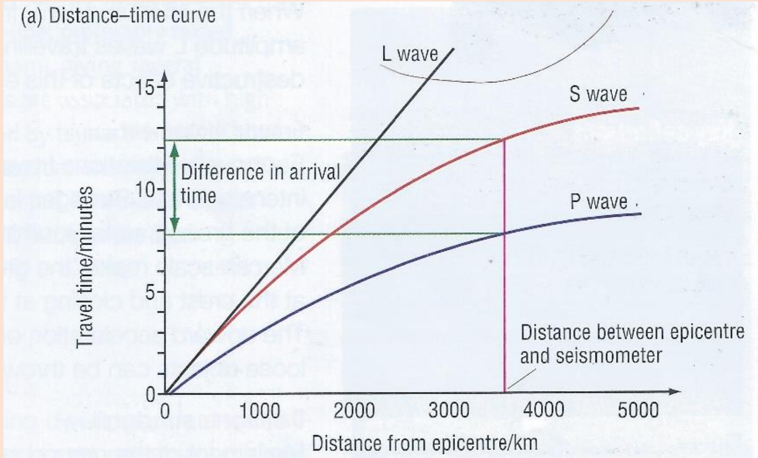


Figure 3 Finding the epicentre

Shadow zones affect seismograms ! (Seismic wave shadow zones @ 103 to 142 for P/S waves an d 142 to 142 for S waves).



We may plot arrival times against distances from epicentres for the three types of waves to **calculate their speed** (time-distance graph). Note: gradient is reciprocal of speed so calculate 1/gradient to obtain speed (i.e. **distance/time = speed**).

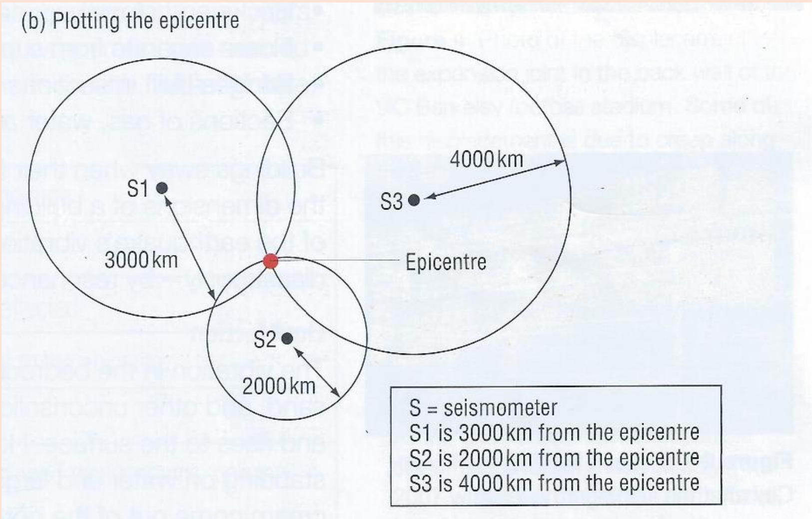


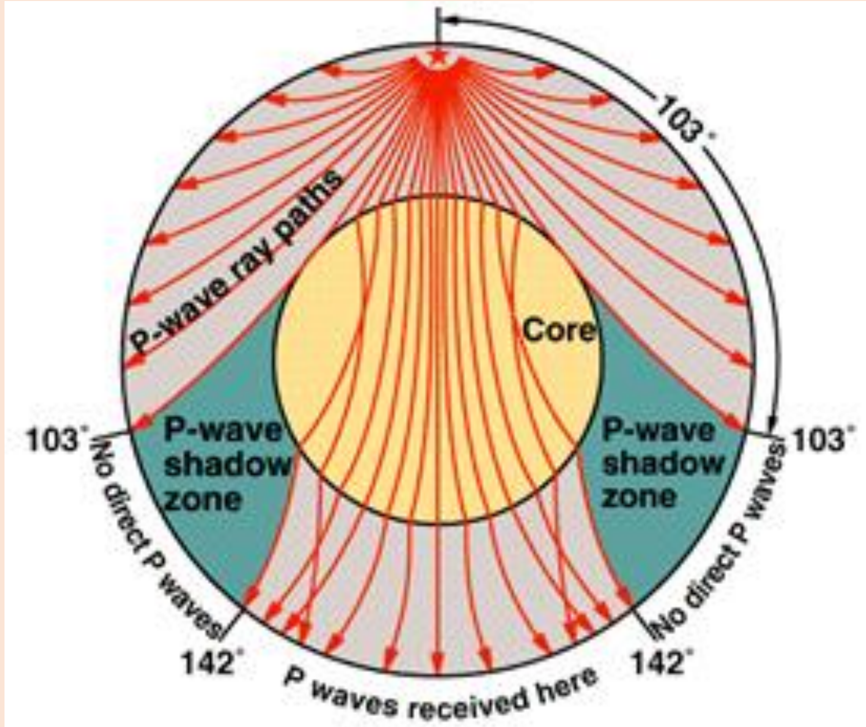
Using the **known velocities** of seismic waves form a graph, we can use a **speed-time graph** and a **time interval** between say a **P and an S wave**. The time interval will **only fit at a certain point between the two curves**, a line drawn down from this gives the **distance from the epicentre** on the x-axis.

Time gap between P and S waves increases with distance form an epicentre. This only tells us **how far (scalar)** away the epicentre is and so we need at least **3 seismomet**ers seismogram recordings at different locations. We use a **protractor with loci to find intersection point**.

If the 3 curves cross but not at a single point the epicentre is placed as a dot in the centre of the area bound by the 3 curves.

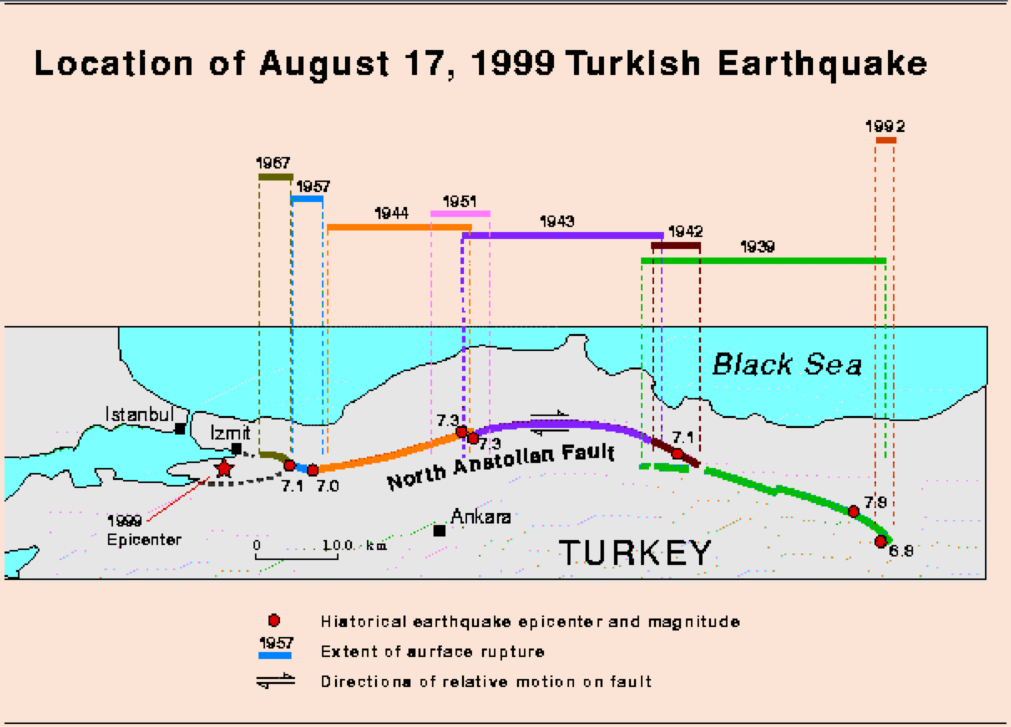
A seismogram will only show **magnitude/amplitude** of the seismic waves at the station (**not the epicentre**). By **comparing** numerous seismograms of different distances form the epicentre we can use c**alculation** to predict what the actual magnitude was. The **Richter scale does this.**





CAN EARTHQUAKES BE PREDICTED?

Seismic gap theory



This is based on the idea that we can analyse **historic earthquake patterns** along a **fault line** to predict which **sections have the most built up stress** and so which sections will have the **next high magnitude earthquake**.

The **gap between active sections** along a fault – the **quiet areas**- have **the most stress** built up since there has not been any displacement to release strain energy (**active sections dissipate strain energy frequently**). Provided the **pattern is regular** of **periodic displacement**, the **date** and l**ocatio**n on the fault of the next earthquake is predicted. Quiet sections have **stress locked away** and are ready for a high magnitude earthquake.

This pattern does rely on the regularity of periodic displacement along a fault. Unfortunately patterns are **not very regular on a human time** frame to be useful.

This method also assumes that frictional properties and deposits of the rocks along a fault are consistent – which they are not.

a. **Stress**

Many **minute cracks develop** within a rock under **stress, increasing its volume** and allowing the **inward percolation of water and gases**. These change properties of rocks and the change is detected.

b. **Detailed measurements of gases**

Radon gas, a **radioactive** gas, originates form **uranium in granite**. Vibration of earthquakes and built up **stress develop micro cracks** so radon gas an **percolate up** to the surface. This is detectable with a **Geiger counter** due to the radioactivity. Radon gas is a **heavy gas** so also **accumulates in water wells**. Before an earthquake, radon gas levels increase as more stress makes more cracks and **pathways** for the gas to percolate up.

c. **Changes in water levels**

Before an earthquake the built up stress develops more **micro cracks so water**, **especially in wells**, **percolates through** them and water levels may **decrease**. The water levels will **restore before an earthquake occurs**.

d. **Changes in ground levels**

The area around the **focus may tilt slightly** due to the **deformation** and **swell due to micro cracks**. **Tilt meters**, using **laser technology and GPS**, measure the **slope** of the ground level **very accurately**. **Strain gauges** in **boreholes measure the deformation** and therefore an increase in stress.

e. Physical properties

- The number of **foreshocks** before an earthquake event will **increase.**
- The P**–wave velocities decrease**, **then increase** again before the quake.
- **Water increases** the **electrical conductivity** of the ground, **lowering its resistivity**.
- **Coloured lights** in the sky may be seen due to the **changes in electrical properties** of **quartz** and **other minerals** under **stress** (piezo electric effect).

f. Magnetism and animal behaviour

- Research in China confirms that animals show **disturbed behaviour** before an earthquake. **Dogs may bark** (although they do this for other reasons too), **snakes can leave their burrows,** fish may leap out of the water and **birds perch in trees**.
  It is thought animals may be able to **detect slight changes** in the **Earth's magnetic field** or feel the **very small vibrations** of **foreshocks.**

HOW ARE EARTHQUAKES COMPARED AND MEASURED

- **#Intensity** = the measure of the surface damage of an earthquake
- **#The Mercalli Scale** = measures the intensity of an earthquake based on the effects that are felt in an area.
- **#Magnitude** = a measure of the strain energy released by an earthquake.
- **#The Richter scale** = measures the **magnitude** of an earthquake (so its strain energy) by recording the **amplitude** of the seismic waves of the earthquake waves (from a seismogram).
- **#Amplitude** of a seismic wave represents the maximum extent of oscillation/vibration from equilibrium position. This represents how much energy it transfers.

The Mercalli scale (intensity)

We use **isoseismic lines** to join up points of equal seismic intensity, separating zones of different seismic intensities. The liens should be kept as a straight and regular pattern with few sharp bends. The pattern should be **concentric** roughly.

The intensities are observed at many different localities and recorded on a map. As waves travel away forma focus the energy is dissipated over a greater area so intensity decreases. Intensity is greatest in the centre of the isoseismic pattern – where the epicentre is located.

Earthquake i**ntensity (= the noticeable effects** on an area) depends on:

- The s**trength** of the earthquake at its focus
- The **distance** the area is to the focus and epicentre
- The nature of the **rocks and sediments** that the buildings are **constructed on.**
- The standard **design** of the buildings.

This is a useful scale for localities where sophisticated instruments aren't available. A simple scale is easy to understand and implement.

	Intensity	Modified Mercalli intensity scale summary descriptions	Likely magnitude
1	Instrumental	Not normally felt. Birds and animals uneasy	Less than 3.5
2	Feeble	Felt only by a few persons at rest	3.5–4.0
3	Slight	Vibrations like large lorry passing. Felt by people at rest	
4	Moderate	Felt indoors by many. Cars rock	4.0–5.0
5	Rather strong	Sleepers wakened. Some windows broken	
6	Strong	Small bells ring. Trees sway. Loose objects fall	5.0
7	Very strong	Difficult to stand up. People run outdoors. Walls crack	5.5
8	Destructive	Partial collapse of ordinary buildings. Chimneys fall	6.0
9	Ruinous	Ground cracks, buildings shift off foundations. Pipes break	6.5
10	Disastrous	Landslides, buildings damaged. Many buildings destroyed	7.0
11	Very disastrous	Few buildings stand, bridges destroyed, landslides	7.5
12	Catastrophic	Damage total. Waves formed on ground surface	Over 8.1

The Mercalli scale was devised in the 19th century as a 10 point scale of increasing intensity, this was updated to a 12 point scale later on.

The scale is an **arbitrary scale** meaning it has **no numerical base** and instead depends on the **opinions of the observer** (very subjective). Some observers may exaggerate the effects and many people will disagree on the description of intensity.

Typically larger intensity earthquakes are a 7 or above on the Mercalli scale (around magnitude 6 on Richter).

The intensity 12 (highest) is catastrophic when there is total damage, waves form on the ground surface, cracks open at crests and close at troughs adding a dangerous vertical component that buildings can't withstand.

The Richter Scale (measuring magnitude)

After 1904, a mathematical (numerical based) and objective scale was put in place to more accurately assess the energy released by an earthquake. The Richter scale measures the magnitude and energy of the earthquake itself not the observed effects. It is a quantitative logarithmic scale and is obtained by recording the maximum amplitude using a seismometer at a distance of 600km from the epicentre.

The range in energies released by different earthquakes is so large that the scale has to be logarithmic. And increase in 1 means that the energy released is around a factor of 30 times as great.

No theoretical limit to the amount of strain energy released but the maximum ever recorded was around 9.5 (Great Chilean Earthquake, 1960).

Richter scale is widely accepted universal, accurate and objective and is also understood and sued by the media/public. It can also be calculated rapidly and catalogues of data dating back many years used this.

The downside is that this can be affected by saturation at higher magnitude values – meaning that it underestimates the magnitude of larger events above magnitude 6.

Modern scale – Seismic moment magnitude scale

Seismologists now use a more accurate scale that is more complicated. It is based on the idea of a moment or leverage developed on the two sides of the fault, which move in opposite directions. The seismic moment magnitude scale (Mw) was introduced in 1979. In particular for very large earthquakes as this gives the most reliable estimate. This is because it is derived from the concept of moment in physics and therefore provides clue to the physical size of an earthquake – the size of the rupture and accompanying slip displacement – as well as the amount of energy released.