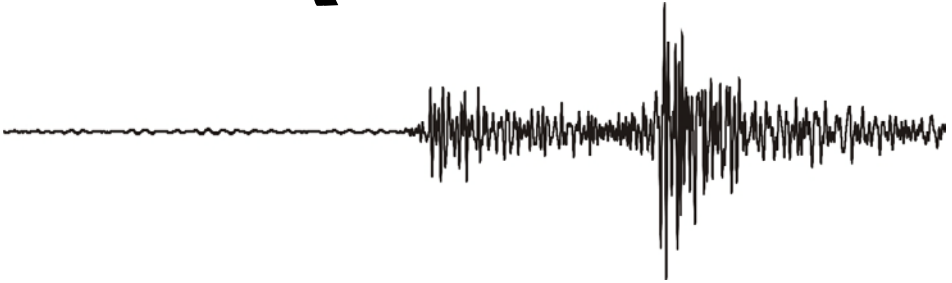




**British
Geological Survey**
NATURAL ENVIRONMENT RESEARCH COUNCIL

EARTHQUAKES



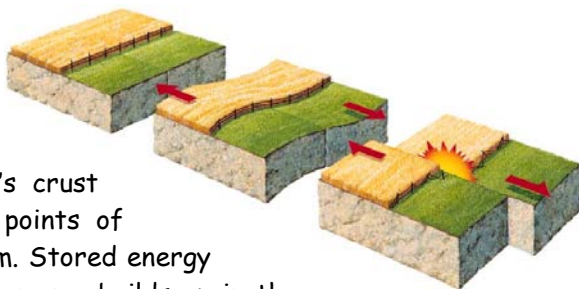
Turkey, 17 August 1999, magnitude 7.6

Introduction

Earthquakes are among the most deadly natural hazards. There are around 100 earthquakes each year of a size that could cause serious damage. They strike without warning and many of the Earth's earthquake zones coincide with areas of high population density. When large earthquakes occur in such areas the results can be catastrophic, with terrible loss of human lives and untold economic cost.

Seismology is the study of earthquakes and seismic waves. The seismograph records the seismic waves generated by earthquakes, allowing the seismologist to determine where, and how deep, a particular earthquake is. Also, the seismic waves from earthquakes can be used to image the deep interior of the Earth, providing vital clues to the internal structure of our planet.

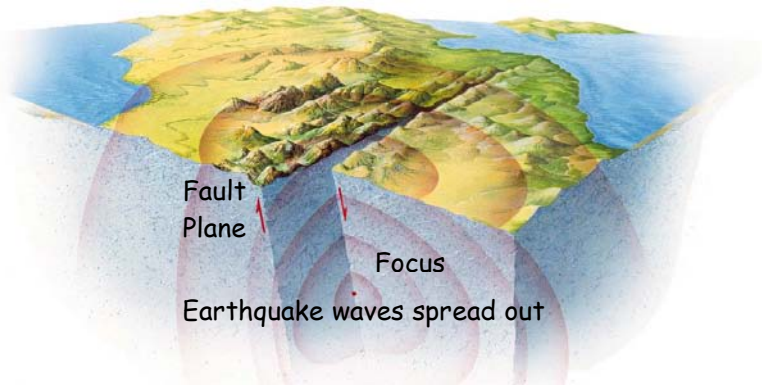
This booklet will explain: what an earthquake is; why and where they occur; how the vibrations from an earthquake travel as waves through the Earth; how we measure them; the Earth's largest and most damaging earthquakes; and, earthquakes in the UK.



What is an earthquake

Movements within the Earth's crust cause stress to build up at points of weakness, and rocks to deform. Stored energy builds up in the same way as energy builds up in the spring of a watch when it is wound. When the stress finally exceeds the strength of the rock, the rock fractures along a fault, often at a zone of existing weakness within the rock. The stored energy is suddenly released as an earthquake.

Intense vibrations, or seismic waves, spread out from the initial point of rupture, the focus, like ripples on a pond. These waves are what makes the ground shake and can travel large distances in all directions. Near the focus, the waves can be very large, making them extremely destructive.

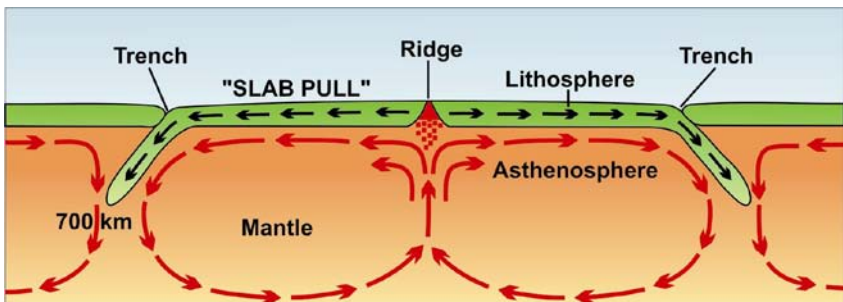


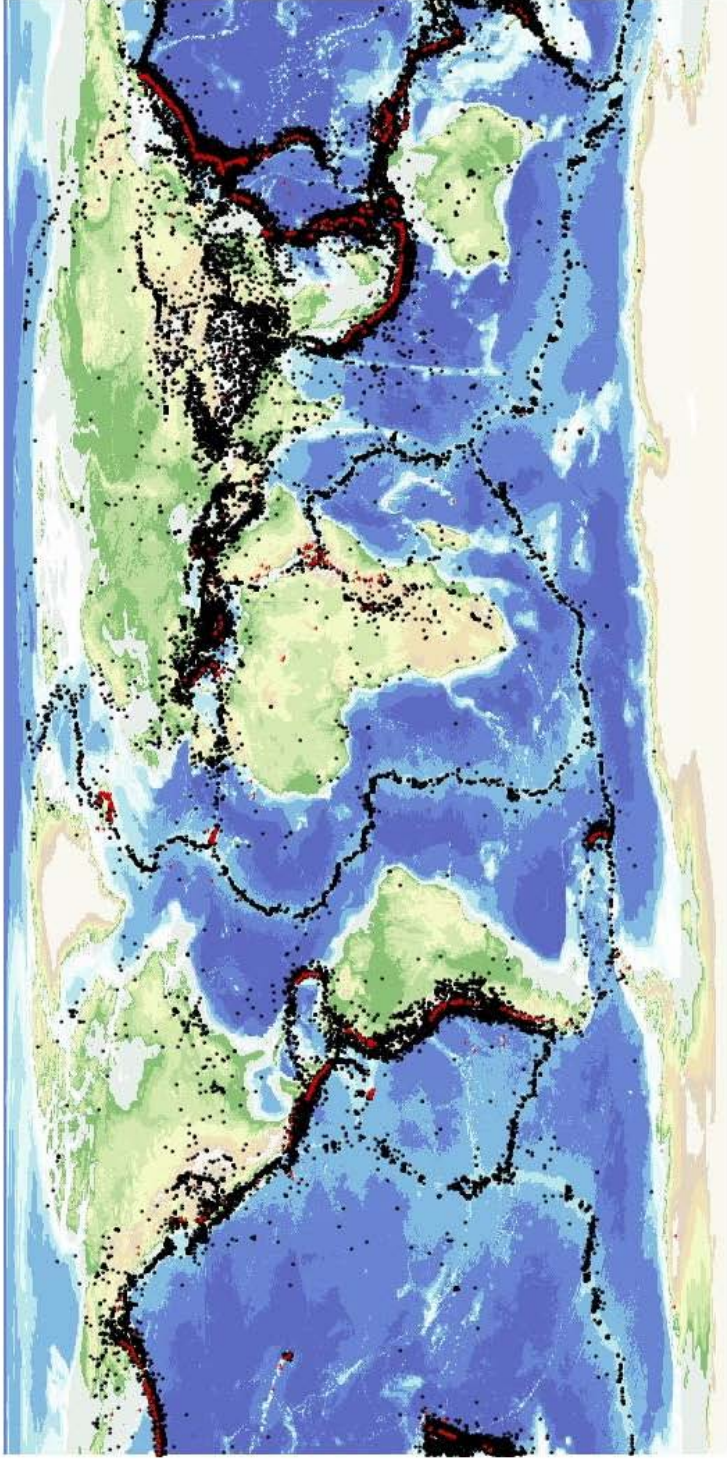
Why and where

If we look at the pattern of where earthquakes occur around the world, it is clear that most of the earthquake activity is concentrated in a number of distinct earthquake belts. For instance, around the edge of the Pacific Ocean, or in the middle of the Atlantic Ocean. These earthquake belts provide an important clue in the development of the theory of plate tectonics.

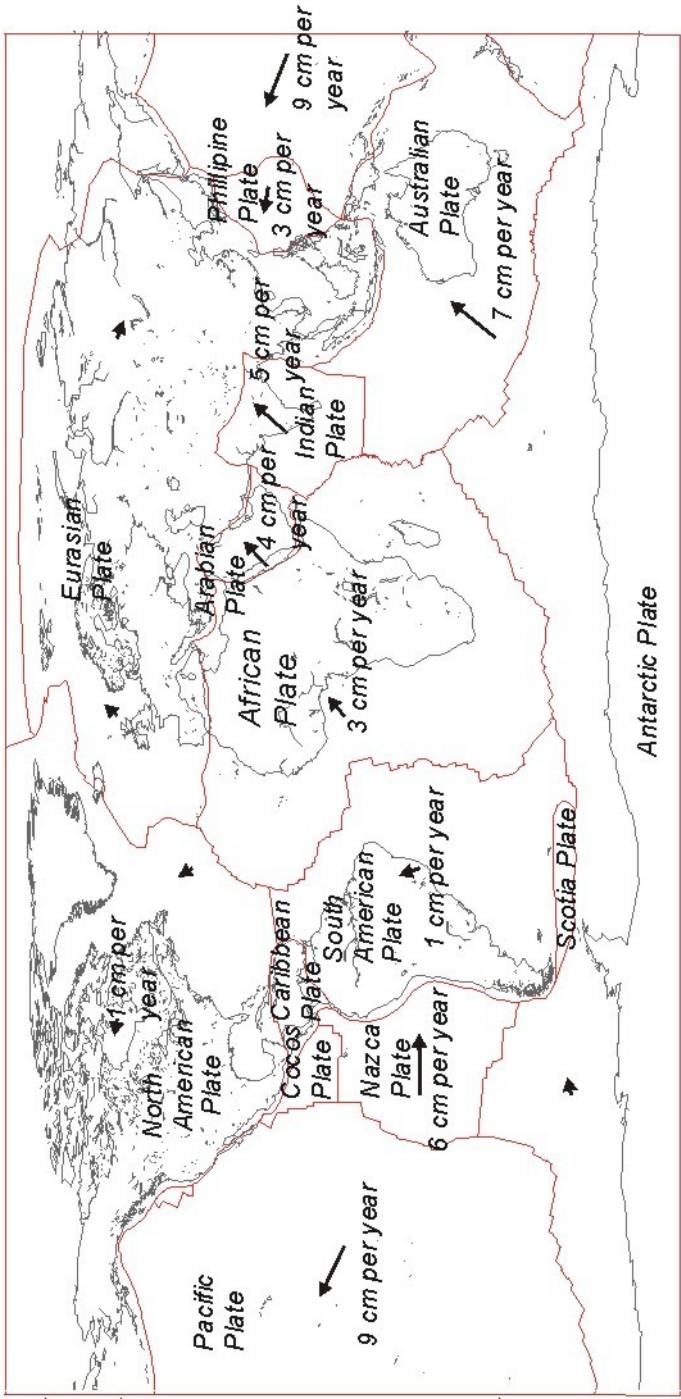
The outer shell of the Earth, or Lithosphere, is made up of a number of rigid segments called tectonic plates. These plates are continually moving at rates of a few centimetres per year (about as fast as your fingernails grow), driven by forces deep within the Earth. Below the Lithospheric plates, lies the Earth's Asthenosphere. The Asthenosphere behaves like a fluid over very long time scales, allowing it to convect. Convection acts like giant conveyor belts, moving the overlying plates around.

At the boundaries between the plates, where they are moving together, apart or past each other, tremendous stresses build up, and are where most earthquakes occur.





A map of the world's earthquakes shows that most of them lie in narrow zones, often around the edges of the continents, or in the middle of the oceans

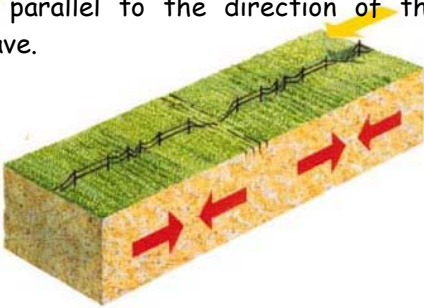


At the plate boundaries (red), the plates are either colliding, moving apart, or past one another. This means huge stresses build up, causing earthquakes.

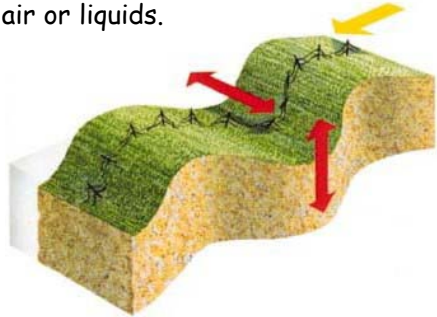
Seismic Waves

Two different types of seismic waves are generated by the sudden movement on a fault: P-waves and S-waves. A third type of seismic wave is generated by the interaction of the P- and S-waves with the surface and internal layers of the Earth. The speed of the waves depends on wave type and the properties of the rock; the denser the rock, the faster the waves travel. In the Earth's crust P-waves travel at around 6-7 km/s, while S-waves travel at around 3.5-4 km/s.

P-waves travel fastest. They consist of successive contractions and expansions, just like sound waves in air. The motion of the particles in the rocks that the waves travel through is parallel to the direction of the wave.

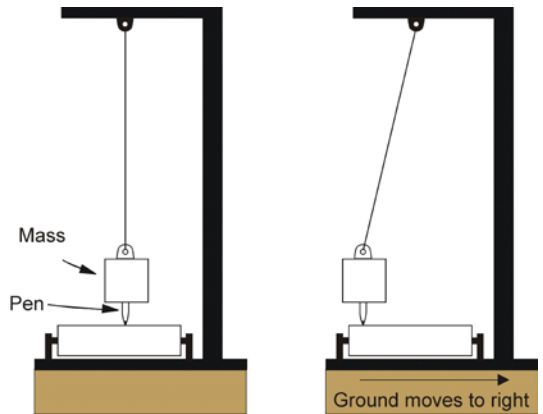


S-waves are slower than P-waves. They are transverse waves, which means that the particle motion is at right angles to the direction of travel. S-waves cannot travel through air or liquids.



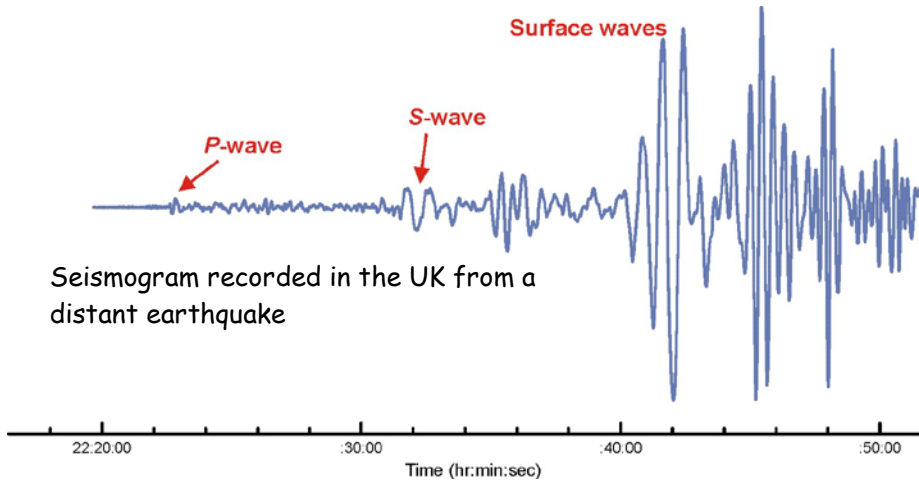
How we measure them

A seismogram is a record of the seismic waves from an earthquake. A seismograph or seismometer is the measuring instrument that creates the seismogram. Almost all seismometers are based on the principle of inertia: a suspended mass tends to remain still when the ground moves. The relative motion between the suspended mass and the ground will then be a measure of the ground's motion.



Because of its inertia the mass tends to stay still when the ground moves. The pen records the relative motion.

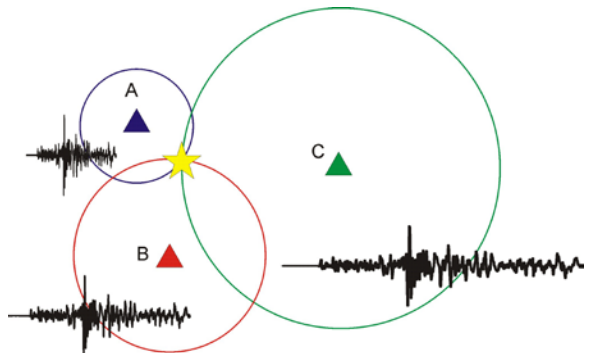
On a seismogram from an earthquake, the P-wave is the first signal to arrive, followed by the slower S-wave, then the surface waves. The arrival times of the P- and S-waves at different seismographs are used to determine the location of the earthquake. Given that we know the relative speed of P- and S-waves, the time difference between the arrivals of the P- and S-waves determines the distance the earthquake is from the seismograph.



Locating Earthquakes

By looking at the seismograms from different recording stations we can find out the epicentre of the earthquake. The signals arrive first at the closest station and last at the one furthest away. The time difference between the P- and S-waves tells us the distance the earthquake is from the seismograph. By measuring this at three stations we can work out where the epicentre is.

We need measurements from at least three stations to find the epicentre. The intersection of the circles whose radius is equivalent to the distance from the earthquake gives the epicentre.

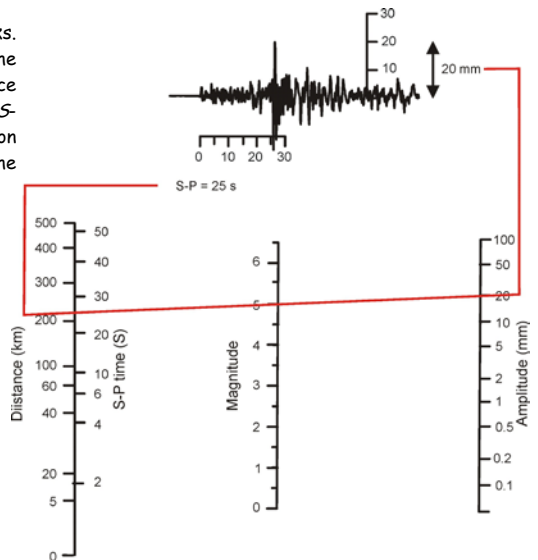


Measuring the size of an earthquake

We can determine how big an earthquake is by measuring the size of the signal directly from the seismogram. However, we also have to know how far away the earthquake was. This is because the amplitude of the seismic waves decreases with distance, so we must correct for this.

In 1932 Charles Richter devised the first magnitude scale for measuring earthquake size. This is commonly known as the Richter scale. Richter used observations of earthquakes in California to determine a reference event; the magnitude of an earthquake is calculated by comparing the maximum amplitude of the signal with this reference event at a specific distance. The Richter Scale is logarithmic, that means that the amplitude of a magnitude 6 earthquake is ten times greater than a magnitude 5 earthquake.

How the Richter's magnitude Scale works. The amplitude is measured from the seismogram, as is the time difference between the arrival of the P and S waves. A line connecting the two values on the graph gives the magnitude of the earthquakes.



Since then, a number of different magnitude scales have been developed based on different seismic wave arrivals observed on a seismogram. Body wave magnitude, m_b , is determined by measuring the amplitude of P-waves from distant earthquakes. Similarly, surface wave magnitude, M_s , is determined by measuring the amplitude of surface waves.

However many magnitude scales tend to underestimate the size of large earthquakes. This led to the development of the moment magnitude scale M_w . The advantage of M_w is that it is clearly related to a physical property of the source, since the seismic moment is a measure of the size of an earthquake based on the area of fault rupture, the average amount of movement, and the force that was required to overcome the friction holding the rocks together.

Magnitude	TNT equivalent	Example
1.0	30 lb	Construction site blast
2.0	1 ton	Large quarry or mine blast
3.0	29 ton	
4.0	1 kiloton	Small atomic bomb
5.0	32 kiloton	Nagasaki atomic bomb
6.0	1 megaton	Double Spring Flat, NV Quake, 1994
7.0	32 megaton	Largest thermonuclear weapon
8.0	1 gigaton	San Francisco, CA Quake, 1906
9.0	32 gigaton	Indian Ocean quake 2004

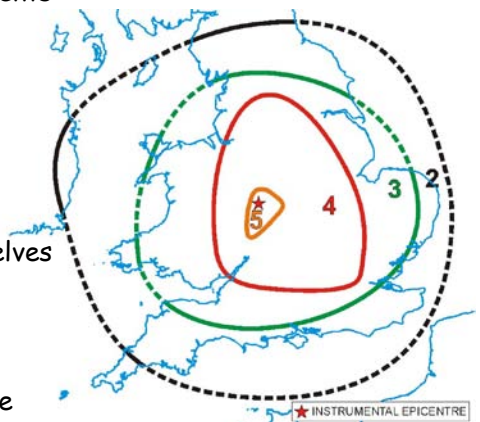
Intensity

Intensity is a measure of an earthquake determined from the observed effects, especially damage. For a given earthquake, intensity normally decreases with distance from the epicentre. The observations can then be compiled to make macroseismic maps showing lines of equal intensity.

The European Macroseismic Intensity Scale

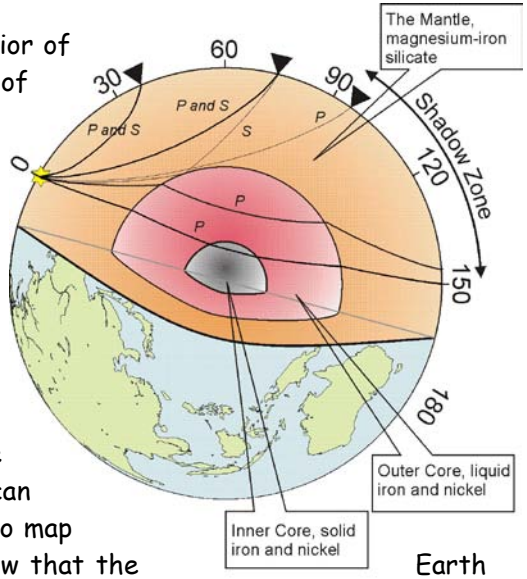
- 1 Not felt - detected by seismic instruments only
- 2 Very weak - felt by very few people
- 3 Weak - felt by a few people indoors
- 4 Noticed by many people, windows and doors rattle
- 5 Strong - some small objects fall over
- 6 Slightly damaging - objects fall off shelves
- 7 Damaging - parts of chimneys fall
- 8 Very damaging - large cracks in walls
- 9 Destructive - some houses collapse
- 10 Very destructive - many houses collapse
- 11 Devastating - most ordinary buildings collapse
- 12 Completely devastating - Practically all structures above and below ground are heavily damaged or destroyed

Macroseismic map for the magnitude 4.7 ML Dudley Earthquake 2002



The Structure of the Earth

Most of what we know about the interior of the Earth comes from the study of seismic waves from earthquakes. Seismic waves from large earthquakes pass throughout the Earth. These waves contain vital information about the internal structure of the Earth. As seismic waves pass through the Earth, they are refracted, or bent, like rays of light bend when they pass through a glass prism. Because the speed of the seismic waves depends on density, we can use the travel-time of seismic waves to map change in density with depth, and show that the Earth is composed of several layers.

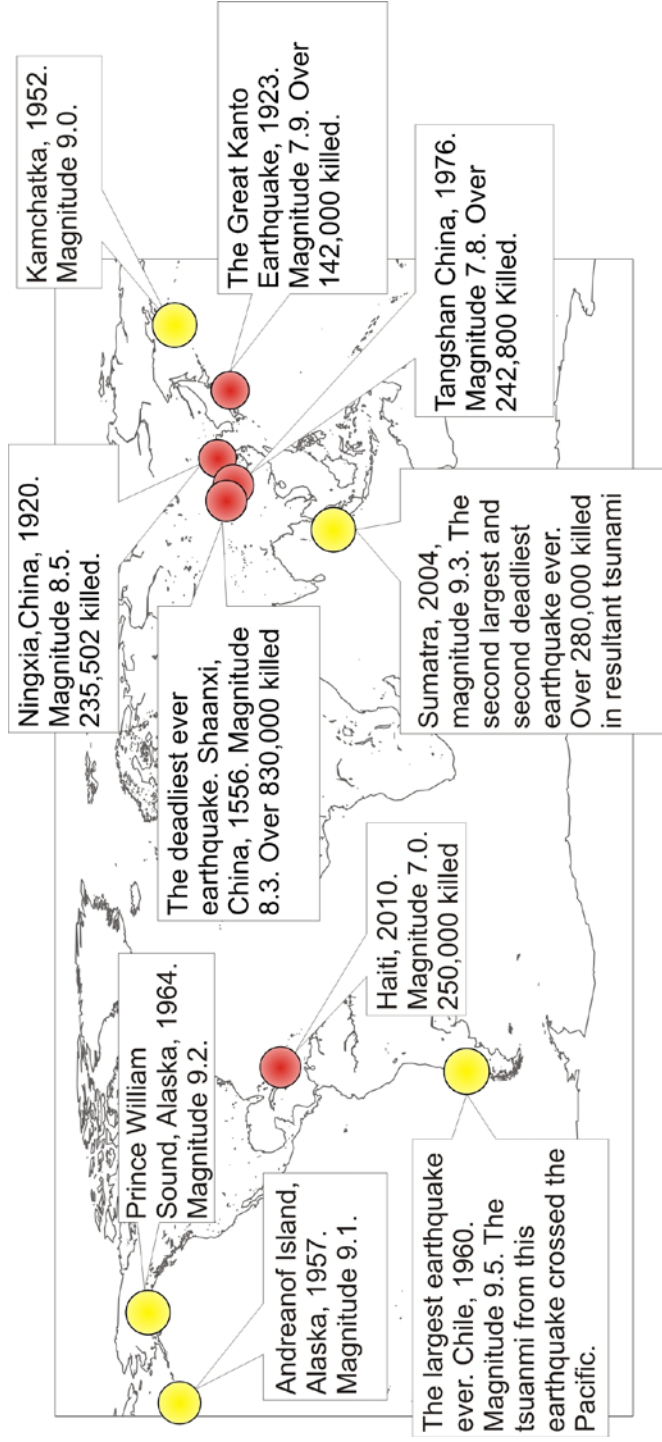


The Crust: this brittle outermost layer varies in thickness from 25 to 60 km under continents, and from 4 to 6 km under the oceans. Continental crust is quite complex in structure and is made from many different kinds of rocks.

The Mantle: below the crust lies the dense Mantle, extending to a depth of 2890 km. It consists of dense silicate rocks. Both P- and S-waves from earthquakes travel through the mantle, demonstrating that it is solid. However, there is separate evidence that parts of the Mantle behaves as a fluid over very long geological times scales, with rocks flowing slowly in giant convection cells.

The Core: at a depth of 2890 km is the boundary between the Mantle and the Earth's Core. The Core is composed of Iron and we know that it exists because it refracts seismic waves creating a "shadow zone" at distances between 103° and 143°. We also know that the outer part of the Core is liquid, because S-waves do not pass through it.

The Biggest and the Deadliest....



Yellow circles show the biggest earthquakes ever recorded and red circles show the deadliest.

Earthquakes in the UK

The UK is not generally associated with earthquakes, however, between twenty to thirty earthquakes are felt by people each year, and a few hundred smaller ones are recorded by sensitive instruments. Most of these are very small and cause no damage. However, some British earthquakes have caused considerable damage, although nothing like the devastation caused by large earthquakes in other parts of the world.

The Largest

The largest known British earthquake occurred near the Dogger Bank in 1931, with a magnitude of 6.1. Fortunately, it was 60 miles offshore but was still powerful enough to cause minor damage to buildings on the east coast of England. The most damaging UK earthquake was in the Colchester area in 1884. Some 1200 buildings needed repairs, chimneys collapsed and walls were cracked.

How often? - How large?

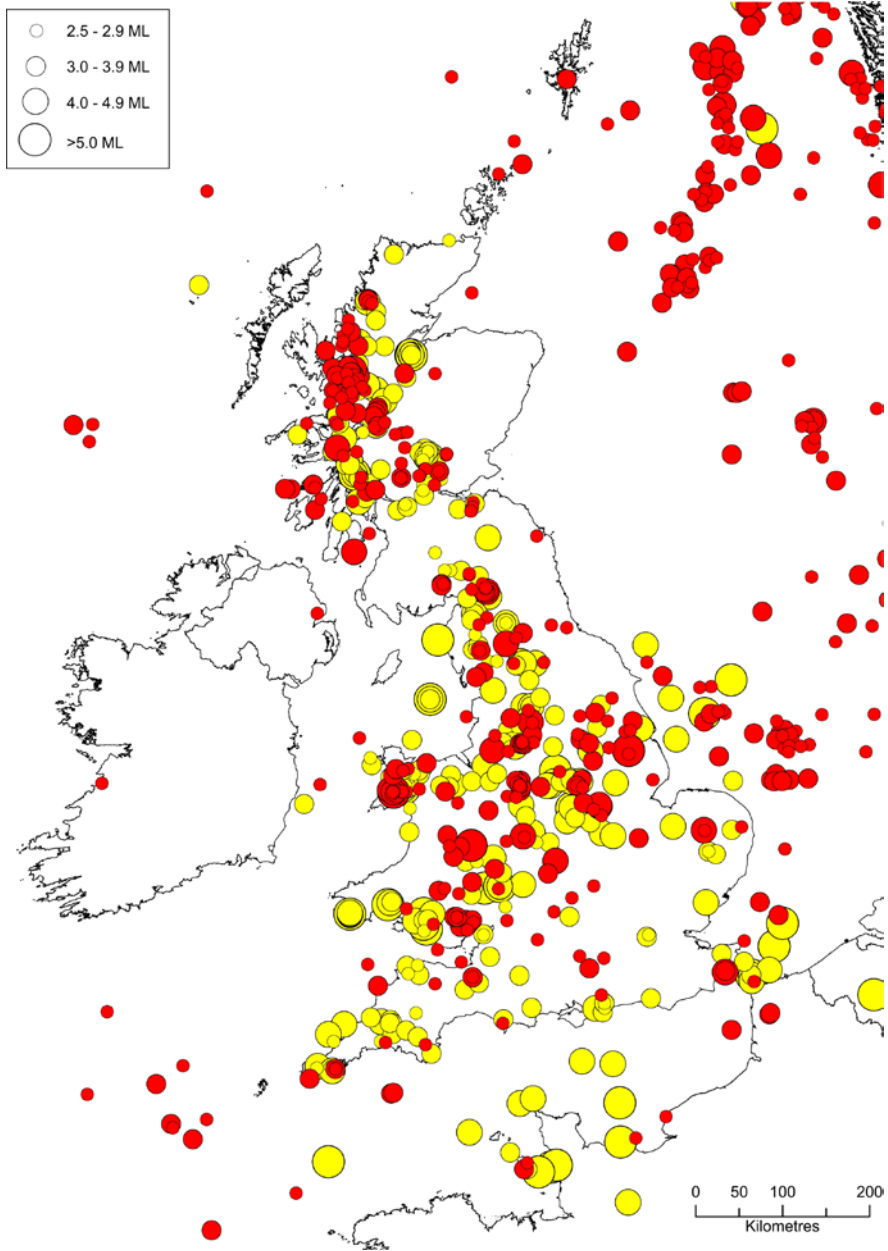
A magnitude 4 earthquake happens in Britain roughly every two years. We experience a magnitude 5 roughly every 10-20 years. Research suggests that the largest possible earthquake in the UK is around 6.5.

Where do they occur?

A map of earthquake activity in the UK shows a number of regional variations. Most earthquakes occur on the western side of the British mainland. Earthquakes are almost completely absent from eastern Scotland and north east England. Similarly, Ireland is almost completely free of earthquakes. The North Sea is more active than the mainland.

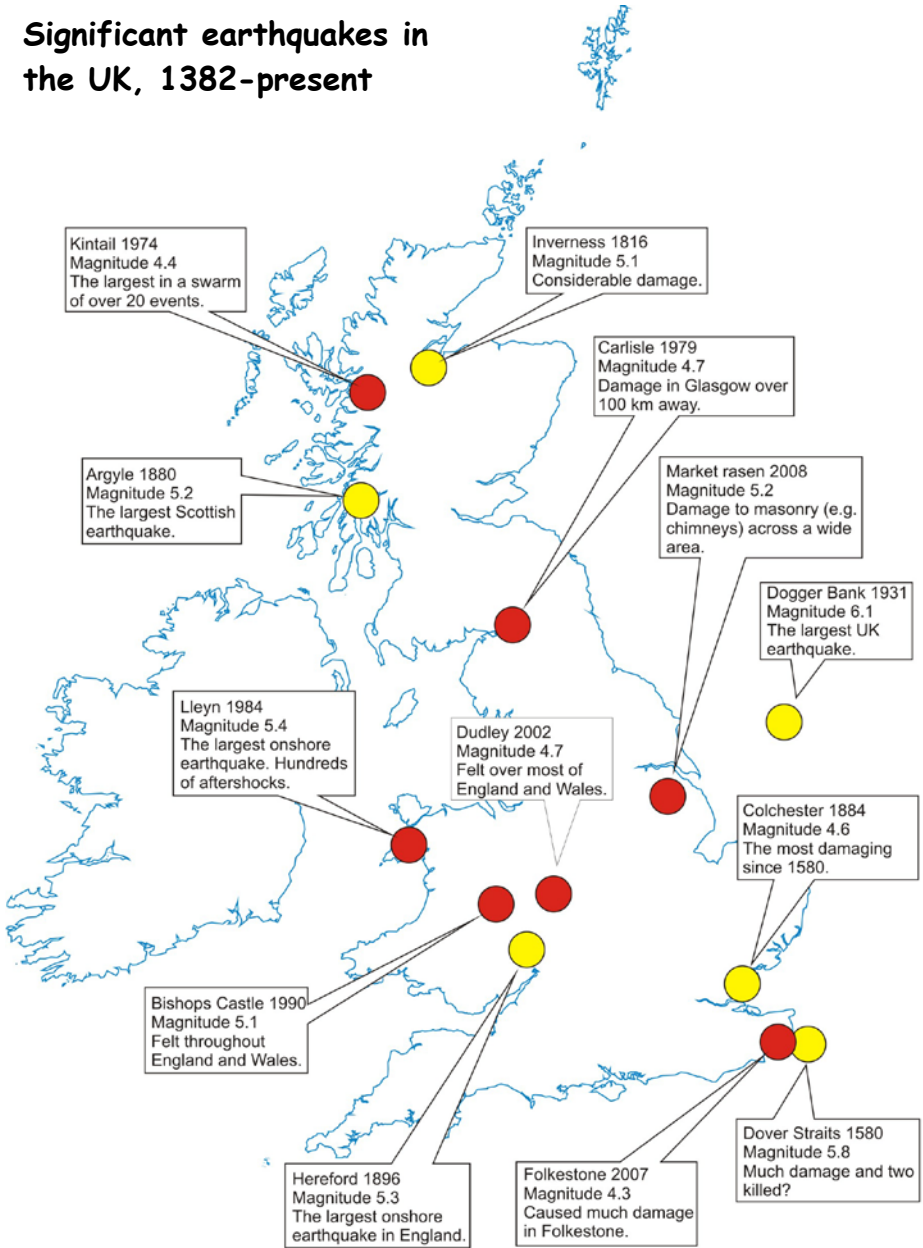
Why do we get earthquakes in Britain?

The Earth under our feet has many faults caused by our turbulent geological past. Some of these faults can be observed at the surface and mapped by geologists, others are hidden many kilometres below the surface. These faults are places where earthquakes can occur. The driving forces for earthquake activity in the UK are unclear; however they include regional compression caused by motion of the Earth's tectonic plates, and uplift resulting from the melting of the ice sheets that covered many parts of Britain thousands of years ago.



Historical seismicity of the UK (yellow) from 1382 to 1970 and instrumental seismicity (red) from 1970 to present, for earthquakes of magnitude 2.5 ML and above.

Significant earthquakes in the UK, 1382-present



Red circles show instrumentally recorded earthquakes. Yellow circles show historical earthquakes

About Us

The British Geological Survey, part of the Natural Environment Research Council, is the United Kingdom's premier centre for earth science information and expertise. The Survey operates the UK-wide earthquake-monitoring network of over 140 seismograph stations. Our aims are to provide a near-immediate response to the occurrence, or reported occurrence, of significant seismic events in the UK, and also to develop a database of seismic activity in the UK for use in seismic hazard assessment. The project is supported by NERC and a customer group that includes central and local government, the regulatory bodies for the oil and nuclear industry, and private sector companies in the oil, nuclear and water industries.

Website Links to Seismology Information

IDEERS web site at Bristol University. This site has a range of educational information to which BGS is contributing - www.ideers.bris.ac.uk.

Virtual Coursework on Earthquakes. Online tutorial on how to calculate the epicentre and magnitude of an earthquake.
www.sciencecourseware.org/eec/Earthquake.

USGS education site for children gives an excellent introduction to all elements of seismology - <http://earthquake.usgs.gov/learning/kids/>

BGS recent earthquakes list (UK region only) -
www.earthquakes.bgs.ac.uk/recent_events/recent_events.html

European-Mediterranean Seismological Centre (world) - www.emsc-csem.org/index.php?page=home

IRIS Seismic Monitor (world) - www.iris.edu/seismon

USGS NEIC near-real time earthquake bulletin. List and map of recent world earthquakes -
http://earthquake.usgs.gov/eqcenter/recenteqsww/Quakes/quakes_all.php

Contact: Seismology, British Geological Survey, West Mains Road, Edinburgh, EH9 3LA
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Seismograph stations operated by the British Geological Survey

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