- Earthquakes

SPECIAL

# MEGA QUAKE

Feel the force of the world's biggest earthquakes and discover how these seismic events rock our cities and settlements

WORDS SCOTT DUTFIELD









**DID YOU KNOW?** Japan has around 1,500 noticeable earthquakes every year

With the power to topple towers and bring entire cities to their knees, earthquakes are one of the most destructive forces in nature. To understand why the ground shakes, you must first look at Earth's outermost layer, the crust. Also known as the lithosphere, the crust is a 25-mile-thick layer of solid rock that's split up into 15 tectonic plates that fit together in one Earth-sized jigsaw puzzle. However, the plates aren't static and are continually on the move. Driven by heat emanating from Earth's centre, the plates, along with everything on top of them, move at around 1.5 centimetres each year. But where are they moving to?

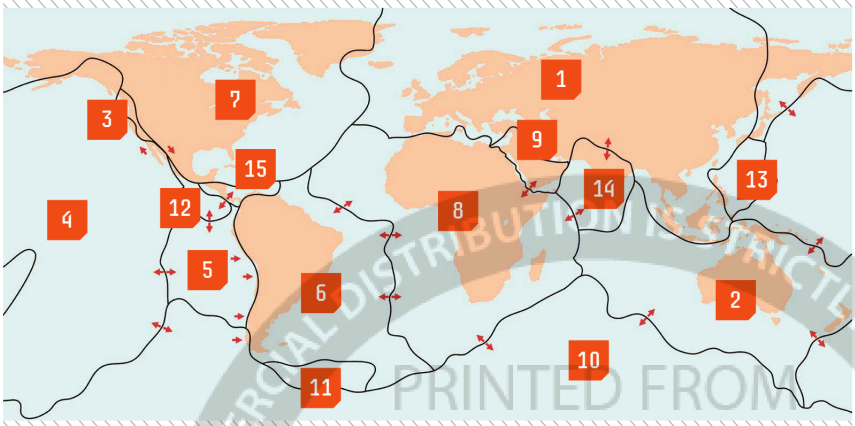
At the boundary where two plates meet, one will subduct under the other. The heat and pressure generated by the collision cause the crust to melt and drive it back towards the core. At the same time that plates are being destroyed at this boundary, more crust-forming rock is being released along other plate boundaries called oceanic ridges. This creates a kind of crust-forming conveyor belt. However, the motion of tectonic plates creates a great deal of 'stress' between them. Tectonic stress, also known as shear stress, is the force between two plates that causes them to deform. Over time, shear stress can build between the two plates, until one day the pressure becomes too much and rocks suddenly slip past one another. The waves of seismic energy released from the slip can be strong enough to shake the ground, causing an earthquake.

**Did you know?**
The San Andreas fault is around 800 miles long

In 2024, researchers studying the most powerful earthquake in Japan's history, the magnitude 9.0 to 9.1 Tōhoku earthquake, calculated that the shear force at the plate boundary was equal to around 100 megapascals. For comparison, one megapascal is around the same force exerted by a 100-tonne rock resting on an area of one square metre. The force of the quake itself not only brought widespread destruction, but also created one of the most

**"Where two plates meet, one will subduct under the other"**

## WHERE ARE THE WORLD'S FAULT LINES?




1 EURASIAN PLATE
2 AUSTRALIAN PLATE
3 JUAN DE FUCA PLATE
4 PACIFIC PLATE
5 NAZCA PLATE
6 SOUTH AMERICAN PLATE
7 NORTH AMERICAN PLATE
8 AFRICAN PLATE
9 ARABIAN PLATE
10 ANTARCTIC PLATE
11 SCOTIA PLATE
12 COCOS PLATE
13 PHILIPPINE PLATE
14 INDIAN PLATE
15 CARIBBEAN PLATE

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In 2004, a nine-metre-tall tsunami hit the shorelines of islands in Indonesia following a magnitude 9.1 earthquake

devastating side effects of an earthquake: a 40-metre-high tsunami. The waves of the Tōhoku tsunami were created by the sudden movement of the ocean floor, which in turn displaced enormous amounts of water. Earthquakes are isolated to plate boundaries, but also occur where two rocks press against one another, divided by a crack or 'fault'. These fault lines are commonly found following plate boundaries, but can also be in the middle of a plate – the 2008 magnitude 7.9 quake in Sichuan, China, was generated at an intraplate fault line.

At the start of each year, the Japanese Meteorological Agency calculates the probability of a major Nankai Trough earthquake in the next 30 years. The Nankai Trough is a region of the Philippine plate that is subducting underneath Japan into the Eurasian plate. The fault line that underlies the trough is called the Nankai megathrust, and it has been the source of some of Japan's most devastating earthquakes. The nation is currently gearing up for another 'megaquake', which is typically any earthquake with a magnitude of 8.0 or more.

2025's predictions saw a rise in the likelihood of a magnitude 8.0 to 9.0 earthquake rising from between 70 to 80 per cent last year to around 80 per cent. The most recent Nankai Trough earthquake occurred in 1946, when a magnitude 8.1 quake generated a 6.9-metre tsunami, killing 1,300 people. In 2013, the Japanese government's disaster prevention team estimated that a magnitude of 9.1 at the Nankai Trough could generate a ten-metre-tall tsunami within minutes, potentially killing more than 300,000 people and smashing around 2 million buildings to the ground. The likelihood of a Nankai Trough earthquake is estimated

## HOW THE GROUND SHAKES

There are many seismic waves that can cause chaos following a major earthquake




**Did you know?**

Over 70 per cent of tsunamis are caused by earthquakes

**6 LOVE WAVES**

A surface wave that produces horizontal movement in the ground during a quake.

**7 RAYLEIGH WAVES**

These are surface waves that move through the ground with a similar motion to an ocean wave.



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**DID YOU KNOW?** Earth's crust makes up just one per cent of our planet's mass


Seismic reinforcements being constructed for a building in Tokyo, Japan

**2 EPICENTRE**
The point on the surface that is directly above the hypocentre.

**3 P WAVES**
Primary waves are fast moving pressure waves that push and pull rock particles apart, and are also known as compressional waves.

**5 SURFACE WAVES**
Unlike P and S waves, which move through the body of the Earth, surface waves are trapped at the surface.

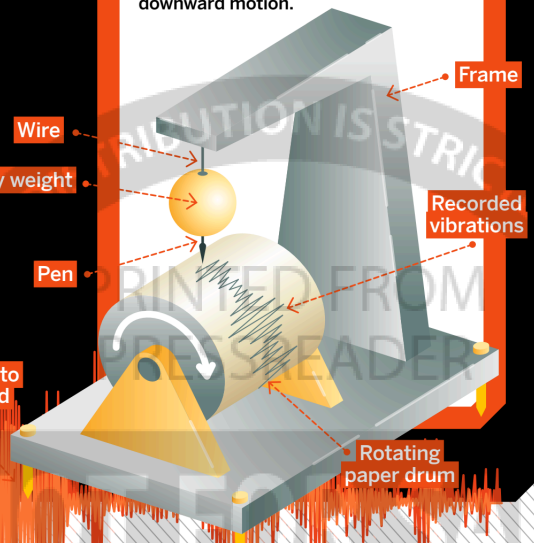
**1 FOCUS**
The point at which the earthquake emanates, also known as the hypocentre.

**4 S WAVES**
Secondary waves, or shear waves, are slower moving pressure waves that move rock particles up and down and from side to side.

## FEELING THE FORCE

Since around 132 CE, people have been recording the motion of earthquakes using a tool that became known as the seismograph in the late-19th century. The device uses a pendulum or a similar mass mounted on a spring, along with an attached pen, to record the relative motion on the paper below. When the ground shakes, the seismic waves cause the device to shake too – except for the pendulum. Due to a phenomenon in physics called inertia, the pendulum remains still while the device shakes. As the paper passes the static pen, it picks up the ink and inadvertently records the primary, secondary and surface waves of an earthquake.

These devices are only able to record the side-to-side motion of an earthquake, so over the years seismometers have evolved to include electrical sensors for upward and downward motion.

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from earthquake activity data since 2013. However, predicting a time and date for when an earthquake is likely to strike is a near-impossible feat.

In 2023, up to 66,900 people lost their lives as a result of an earthquake and its secondary impacts, including tsunamis. How many of those deaths might have been avoided if we were able to predict when an earthquake will erupt? While the probability of frequent minor tremors is fairly simple to estimate, according to the United States Geological Survey (USGS), "neither the USGS nor any other scientists have ever predicted a major earthquake."

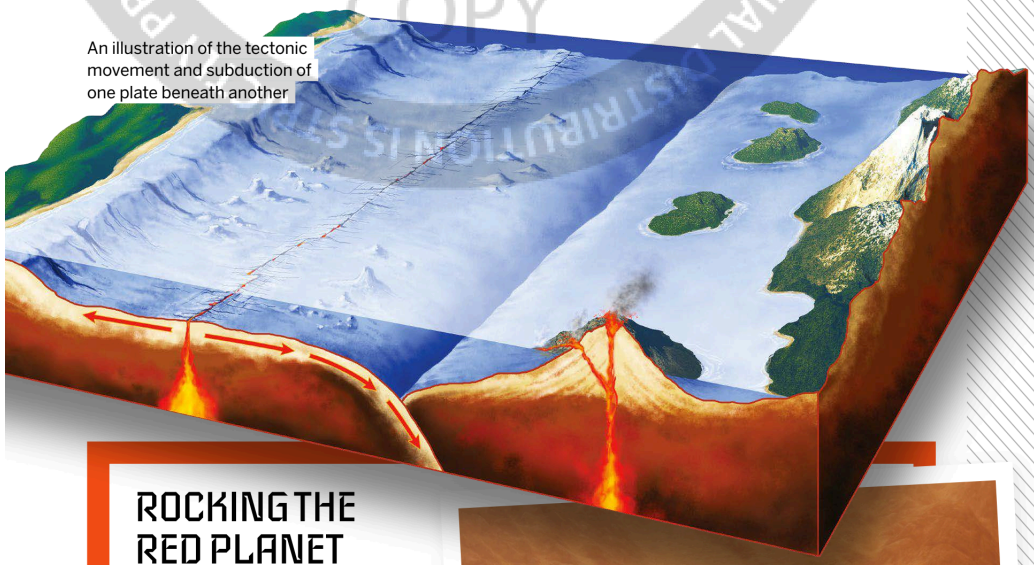
There are some signs and signals that scientists can interpret to create early warning systems for an imminent quake. By detecting fast-moving P waves and slower S waves, some warning systems can determine the location of earthquakes and roughly how intense the quake might be. However, the warning period these systems provide is extremely short. For example, the Canadian Earthquake Early Warning (EEW) system, launched in 2024, provides seconds to tens of seconds of notice before a strong quake arrives. Something



Destroyed buildings in Fukushima, Japan, after the 2011 earthquake

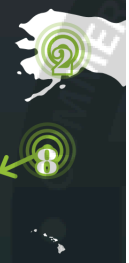
**Did you know?**

Alaska is the most earthquake-prone US state



An illustration of the tectonic movement and subduction of one plate beneath another

## TEN OF THE LARGEST EARTHQUAKES



1 VALDIVIA, CHILE
Date: 1960
Magnitude: 9.5

2 ALASKA, US
Date: 1964
Magnitude: 9.2

3 SUMATRA, INDONESIA
Date: 2004
Magnitude: 9.1

4 TŌHOKU, JAPAN
Date: 2011
Magnitude: 9.1

5 KAMCHATKA, RUSSIA
Date: 1952
Magnitude: 9.0

6 MAULE, CHILE
Date: 2010
Magnitude: 8.8

7 OFF THE COAST OF ECUADOR AND COLOMBIA
Date: 1906
Magnitude: 8.8

8 RAT ISLANDS, ALASKA, US
Date: 1965
Magnitude: 8.7

9 TIBET-INDIA BORDER
Date: 1950
Magnitude: 8.6

10 SUMATRA, INDONESIA
Date: 2005
Magnitude: 8.6

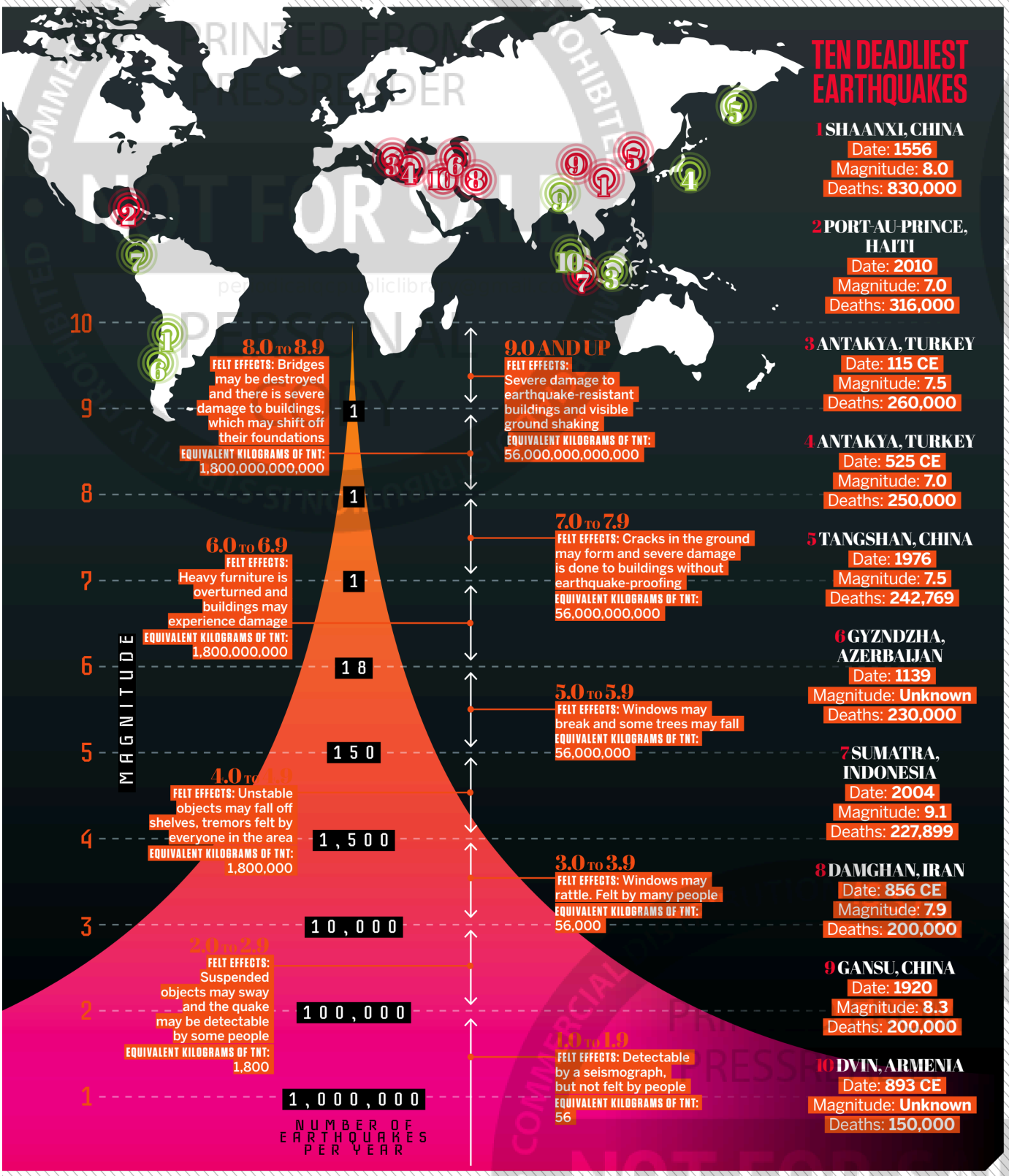
## ROCKING THE RED PLANET

**Earth isn't the only planet to feel the force of a quake. Despite a lack of tectonic plates, Mars still experiences seismic events called 'marsquakes'. These tremors are caused by several factors, including the planet's surface contracting under extremely cold temperatures, underground pressure generated by internal magma and meteorite impacts. The largest recorded marsquake was picked up in 2022 on the surface of Mars by NASA's InSight lander. The quake is estimated to have had a magnitude of 5.0, the highest in over 1,300 quakes the lander detected after landing on the Red Planet in 2018.**



An illustration of InSight on the surface of the Red Planet

**DID YOU KNOW?** Japan's Noto Peninsula experienced 2024's most extreme earthquake, at magnitude 7.6




## TEN DEADLIEST EARTHQUAKES

**1 SHAANXI, CHINA**
Date: **1556**
Magnitude: **8.0**
Deaths: **830,000**

**2 PORT-AU-PRINCE, HAITI**
Date: **2010**
Magnitude: **7.0**
Deaths: **316,000**

**3 ANTAKYA, TURKEY**
Date: **115 CE**
Magnitude: **7.5**
Deaths: **260,000**

**4 ANTAKYA, TURKEY**
Date: **525 CE**
Magnitude: **7.0**
Deaths: **250,000**

**5 TANGSHAN, CHINA**
Date: **1976**
Magnitude: **7.5**
Deaths: **242,769**

**6 GYZNDZHA, AZERBAIJAN**
Date: **1139**
Magnitude: **Unknown**
Deaths: **230,000**

**7 SUMATRA, INDONESIA**
Date: **2004**
Magnitude: **9.1**
Deaths: **227,899**

**8 DAMGHAN, IRAN**
Date: **856 CE**
Magnitude: **7.9**
Deaths: **200,000**

**9 GANSU, CHINA**
Date: **1920**
Magnitude: **8.3**
Deaths: **200,000**

**10 DVIN, ARMENIA**
Date: **893 CE**
Magnitude: **Unknown**
Deaths: **150,000**

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seismologists can predict is the improbability of a future earthquake with a magnitude of 10.0 or higher. The magnitude of an earthquake is directly related to the length of a fault line. Generally, the longer the fault line, the larger the earthquake. According to the USGS, there are no known fault lines long enough to generate a magnitude 10.0 earthquake.

But can human activity also cause an earthquake? In short, yes. From constructing cities to digging quarries, humans have engaged in activities that have shaken the ground as 'induced earthquakes'. One of the most prolific activities that can bring about a quake is fracking and oil recovery.

During the process of extracting natural resources such as gas and oil, enormous volumes of wastewater are produced and disposed of by pumping it back deep underground. Cracks and faults in the rock can then become lubricated by the water, triggering them to slip past one another and release built-up shear force as an earthquake. One of the largest induced earthquakes occurred in Oklahoma in 2016. The Pawnee earthquake had a magnitude of 5.8 and was the result of injecting wastewater into the ground.

According to a database called the Human-Induced Earthquake Database (HiQuake), created by geophysicists at Durham University and Newcastle University in the UK, there are currently 1,320 industrial projects around the world that have induced earthquakes. Around 32 per cent of those projects relate to fracking. Other industries making the ground move include nuclear testing, groundwater extraction and deep-penetrating bombs.

**Did you know?**
The first recorded earthquake occurred in 1831 BCE


Fracking can cause earthquakes

# MAKING THE GROUND SHAKE

How human activity can induce an earthquake outbreak




**1 WASTEWATER**
The wastewater produced from both fracking and oil drilling is pumped deep underground through a network of pipes.

**2 OIL DRILLING**
Water is used to help lubricate drill bits cutting through rock to reach deep oil reserves.

**3 FRACKING**
High-pressure water is injected into rock to create cracks and extract natural gas.

**5 STRESS**
Each section of the rock adjacent to the fault line is experiencing shear forces, or 'stress', in opposing directions.

**6 FILLING WITH WATER**
When wastewater is pumped into deep rock, it fills up all the available pores and cracks in the rock.

**7 SLIP**
The wastewater lubricates the crack and allows the two sections of rock to slip past one another, causing an earthquake.

**4 FAULT LINE**
A fault line is two sections of rock pushing against one another either side of a crack.

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**DID YOU KNOW?** Britain experienced its biggest earthquake, a magnitude 6.1, in 1931

# STRONG AND STABLE

Buildings can be constructed using special earthquake-proofing techniques and materials to prevent them toppling during a tremor

**5 SHEAR WALLS**
Similar to the horizontal diaphragm, a shear wall helps stabilise the building during a quake.

**2 PENDULUM DAMPER**
A suspended mass at the tip of the skyscraper automatically swings in the opposite direction to the building as it shakes, which can absorb the kinetic energy and reduce the building's movement.

**1 FLUID DAMPER**
A piston surrounded by pressurised fluid. During an earthquake, the fluid damper converts kinetic energy into heat energy.

**3 CROSS BRACES**
Structural X-shaped steel rods help reduce the swaying motion of the building during an earthquake.

**4 HORIZONTAL DIAPHRAGM**
A solid interior wall stiffens the building and helps resist the sideways-moving forces of an earthquake.

**"Generally, the longer the fault line, the larger the earthquake"**

**6 BASE ISOLATION SYSTEM**
A system of isolated foundations for the building to sit on top of.

**8 LEAD CORE**
A stiff central bearing combats the vertical forces of an earthquake.

**7 STEEL DISCS**
Alternating layers of rubber and steel discs absorb horizontal forces.

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