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Earth's Dynamic Systems: Earthquakes

The Shaking Planet

Aira Astralis

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Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

An earthquake, also called a quake, tremor, or temblor, is the shaking of the Earth's surface resulting from a sudden release of energy in the lithosphere that creates seismic waves. Earthquakes can range in intensity, from those so weak they cannot be felt, to those violent enough to propel objects and people into the air, damage critical infrastructure, and wreak destruction across entire cities.

The seismic activity of an area is the frequency, type, and size of earthquakes experienced over a particular time.

The seismicity at a particular location in the Earth is the average rate of seismic energy released per unit volume. In its most general sense, the word earthquake is used to describe any seismic event that generates seismic waves. Earthquakes can occur naturally or be induced by human activities, such as mining, fracking, and nuclear weapons testing.

The initial point of rupture is called the hypocenter or focus, while the ground level directly above it is the epicenter.

Earthquakes are primarily caused by geological faults, but also by volcanism, landslides, and other seismic events. Significant historical earthquakes include the 1976 Tangshan earthquake in China, with over 300,000 fatalities, and the 1960 Valdivia earthquake in Chile, the largest ever recorded at 9.5 magnitude. Earthquakes result in various effects, such as ground shaking and soil liquefaction, leading to significant damage and loss of life.

When the epicenter of a large earthquake is located offshore, the seabed may be displaced sufficiently to cause a tsunami.

Earthquakes can trigger landslides. The occurrence of earthquakes is influenced by tectonic movements along faults, including normal, reverse (thrust), and strike-slip faults, with energy release and rupture dynamics governed by the elastic-rebound theory. Efforts to manage earthquake risks involve prediction, forecasting, and preparedness, including seismic retrofitting and earthquake engineering to design structures that withstand shaking.

The cultural impact of earthquakes spans myths, religious beliefs, and modern media, reflecting their profound influence on human societies.

This book follows the subject from its outermost effect to its deepest cause. It begins with how earthquakes were discovered and understood, moves through their measurement and their characteristic effects, then places them in their cultural context, and finishes with the modern science of warning, engineering

and preparation that turns knowledge into survival. A closing pair of chapters looks forward: at the research directions of the coming decades, and at what the shaking of the ground finally tells us about the planet and our place on it.

Chapter 1: The Discovery of Earthquakes

In its most general sense, an earthquake is any seismic event—whether natural or caused by humans—that generates seismic waves. Earthquakes are caused mostly by the rupture of geological faults but also by other events such as volcanic activity, landslides, mine blasts, fracking and nuclear tests. An earthquake's point of initial rupture is called its hypocenter or focus. The epicenter is the point at ground level directly above the hypocenter.

The seismicity of a spot in the Earth, in the technical sense, means the average rate at which it releases seismic energy per unit volume. One of the most devastating earthquakes in recorded history was the 1556 Shaanxi earthquake, which occurred on 23 January 1556 in Shaanxi, China. More than 100,000 people died, with the region losing up to 730,000 people afterwards due to emigration, plague, and famine.

Most houses in the area were yaodongs—dwellings carved out of loess hillsides—and many victims were killed when these structures collapsed.

The 1976 Tangshan earthquake, which killed between 240,000 and 655,000 people, was the deadliest of the 20th century. The 1960 Chilean earthquake is the largest earthquake that has been measured on a seismograph, reaching 9.5 magnitude on 22 May 1960. Its epicenter was near Cañete, Chile.

The energy released was approximately twice that of the next most powerful earthquake, the Good Friday earthquake (27 March 1964), which was centered in Prince William Sound, Alaska.

The ten largest recorded earthquakes have all been megathrust earthquakes; however, of these ten, only the 2004 Indian Ocean earthquake is simultaneously one of the deadliest earthquakes in history. Earthquakes that caused the greatest loss of life, while powerful, were deadly because of their proximity to either heavily populated areas or the ocean, where earthquakes often create tsunamis that can devastate communities thousands of kilometers away.

Regions most at risk for great loss of life include those where earthquakes are relatively rare but powerful, and poor regions with lax, unenforced, or nonexistent seismic building codes. Tectonic earthquakes occur anywhere on the earth where there is sufficient stored elastic strain energy to drive fracture propagation along a fault plane.

The sides of a fault move past each other smoothly and aseismically only if there are no irregularities or asperities along the fault surface that increases

the frictional resistance.

Most fault surfaces do have such asperities, which leads to a form of stick-slip behavior. Once the fault has locked, continued relative motion between the plates leads to increasing stress and, therefore, stored strain energy in the volume around the fault surface. This continues until the stress has risen sufficiently to break through the asperity, suddenly allowing sliding over the locked portion of the fault, releasing the stored energy.

This energy is released as a combination of radiated elastic strain seismic waves, frictional heating of the fault surface, and cracking of the rock, thus causing an earthquake. This process of gradual build-up of strain and stress punctuated by occasional sudden earthquake failure is referred to as the elastic-rebound theory. It is estimated that only 10 percent or less of an earthquake's total energy is radiated as seismic energy.

Most of the earthquake's energy is used to power the earthquake fracture growth or is converted into heat generated by friction. Therefore, earthquakes lower the Earth's available elastic potential energy and raise its temperature, though these changes are negligible compared to the conductive and convective flow of heat out from the Earth's deep interior.

There are three main types of fault, all of which may cause an interplate earthquake: normal, reverse (thrust), and strike-slip.

Normal and reverse faulting are examples of dip-slip, where the displacement along the fault is in the direction of dip and where movement on them involves a vertical component. Many earthquakes are caused by movement on faults that have components of both dip-slip and strike-slip; this is known as oblique slip.

The topmost, brittle part of the Earth's crust, and the cool slabs of the tectonic plates that are descending into the hot mantle, are the only parts of our planet that can store elastic energy and release it in fault ruptures. Rocks hotter than about 300 °C (572 °F) flow in response to stress; they do not rupture in earthquakes.

The maximum observed lengths of ruptures and mapped faults (which may break in a single rupture) are approximately 1,000 km (620 mi).

Examples are the earthquakes in Alaska (1957), Chile (1960), and Sumatra (2004), all in subduction zones. The longest earthquake ruptures on strike-slip faults, like the San Andreas Fault (1857, 1906), the North Anatolian Fault in

Turkey (1939), and the Denali Fault in Alaska (2002), are about half to one third as long as the lengths along subducting plate margins, and those along

normal faults are even shorter.

Normal faults occur mainly in areas where the crust is being extended such as a divergent boundary.

Earthquakes associated with normal faults are generally less than magnitude 7.

The science grew out of the disasters themselves.

Earthquakes acquired names the way storms never did, mostly by place and date, and the names carry history. The Good Friday earthquake, the Great Kanto earthquake, the Boxing Day tsunami, the Wenchuan earthquake: each name fixes a calendar mark on a whole society, and in countries that quake often the shorthand does the work of a national memorial. Seismologists, who need precision, use the coordinates instead, but even their catalogs keep the human names alongside. After the Lisbon earthquake of 1755, John Michell, a Cambridge clergyman, studied the accounts of shaking and arrival times, proposed that earthquakes were waves spreading from an origin deep in the ground, and effectively invented the idea of the epicenter, decades before instruments existed to confirm him. Robert Mallet, an Irish engineer, mapped the 1857 Naples earthquake in the field, ranked its damage by zones and gave the young discipline its name, seismology.

Instrumental records followed quickly once the tools existed. In the 1880s John Milne and his colleagues in Japan built reliable seismographs, and in the 1890s Milne's global network recorded distant quakes so routinely that the interior of the Earth began, for the first time, to be mapped. The great step came from the aftermath of San

Francisco 1906: the painstaking investigation led by Andrew Lawson, with Harry Fielding Reid's analysis of the surveyed displacements, concluded that the crust had snapped back elastically after decades of accumulating strain, the elastic-rebound theory that still anchors every model of the earthquake cycle.

The catalog of great historical earthquakes continues to be revised as historians and paleoseismologists work.

The global instrumental era has its own turning points. In the early 1960s the United States deployed the World-Wide Standardized Seismograph Network, over a hundred identical stations on every continent, built to monitor nuclear tests but destined to become the backbone of plate-tectonics research: the uniform data let seismologists compare earthquakes worldwide for the first time, and the seismic maps that proved the new theory were drawn largely

from its records.

The magnitude scale that gave the era its common language was born in Pasadena from practical need. Charles Richter, working with Beno Gutenberg in the 1930s, wanted a way to compare southern California earthquakes at a glance, borrowed a logarithmic idea from Kiyoo Wadati's Japanese work, and produced a number simple enough for newspapers and rigorous enough for science. Richter himself spent decades gently correcting people who called it a gauge of an earthquake's totality; it was, he said, a ruler for one kind of shaking in one kind of region, and its worldwide success was the accident that followed. Modern studies of Chinese and Mediterranean archives, of tsunami sand deposits and of offset stream terraces keep adding events, and keep showing that the instrumental record, barely a century and a quarter old, has not yet seen the worst a fault can do.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.