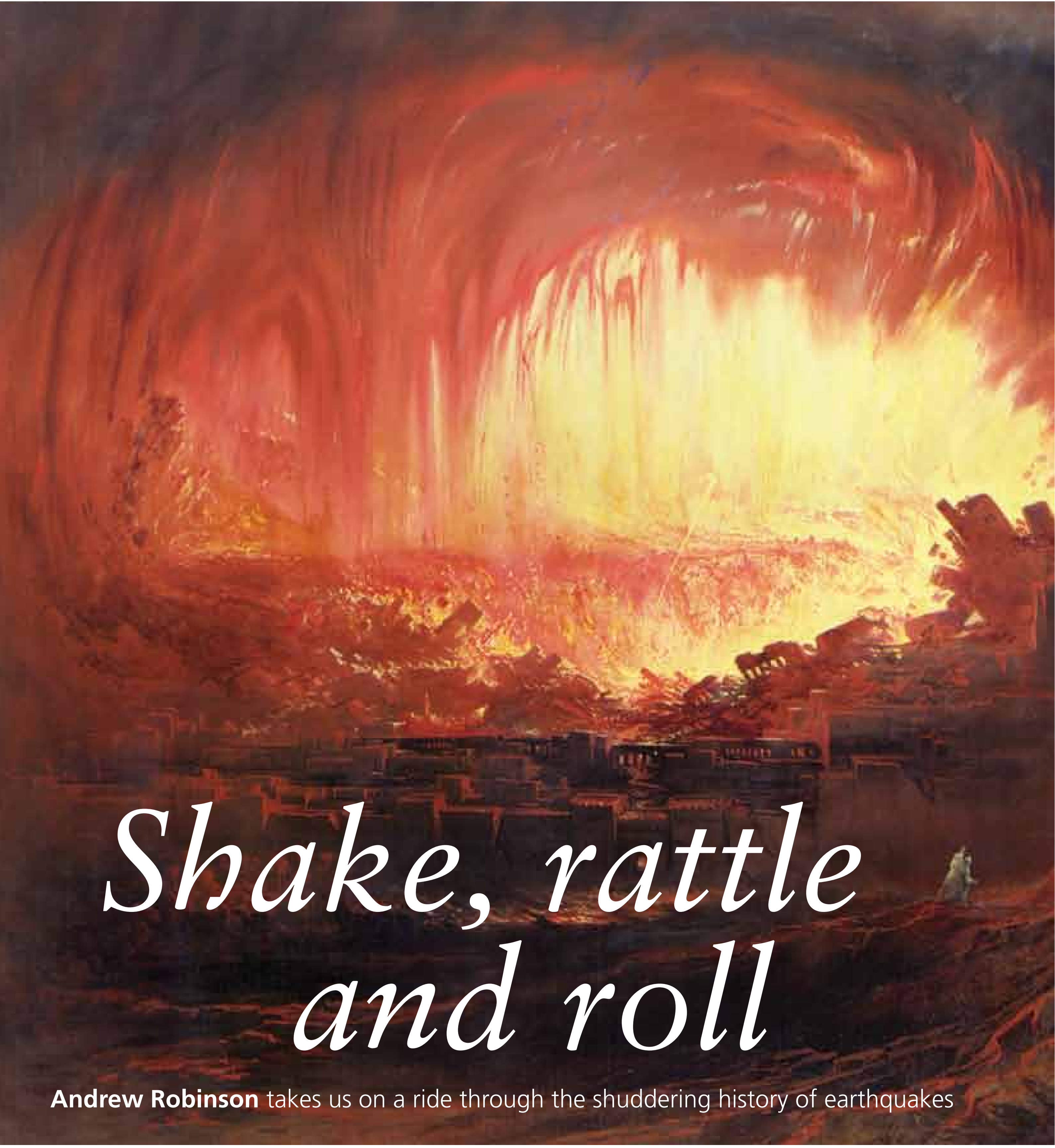

Shake, rattle and roll

Andrew Robinson takes us on a ride through the shuddering history of earthquakes

Modern visitors to the Colosseum in Rome cannot help but notice that only part of the external wall of the oval amphitheatre remains standing. But they are usually unaware of the reason why the northern section survived while the southern collapsed. The cause was an earthquake.

In AD 1349, a millennium after the fall of ancient Rome, the city was struck by a quake that produced widespread damage, and even more serious damage in the Alban Hills some 20 kilometres to the south. A seismic study of the foundations of the Colosseum conducted in 1995, using sound waves to create images of the subsurface structure, revealed that the southern half of the Colosseum rests on alluvium – accumulated sediment filling the prehistoric bed of a tributary of the River Tiber that is now extinct. The northern, undamaged half stands on the riverbank where the ground is older and more stable.

1. In *The Destruction of Sodom and Gomorrah*, 1852, (oil on canvas) by John Martin (1789-1854), a bolt of lightning strikes Lot's wife, turning her into a pillar of salt, while her daughters and her husband escape. Laing Art Gallery, Newcastle-upon-Tyne, UK/ © Tyne & Wear Archives & Museums/The Bridgeman Art Library.

In Classical antiquity – instead of our modern conception of moving tectonic plates – Poseidon, the Greek god of the sea, was usually considered to be responsible for earthquakes. Presumably this was a tribute to the destructive power of earthquake-induced *tsunamis* in the Aegean and the Mediterranean. Poseidon was said to cause earthquakes while striking his trident on the ground when he was angry.

However, some Greek philosophers proposed natural, rather

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than divine, explanations for earthquakes. Thales, for example, writing around 580 BC, believed that the earth was floating on the oceans and that the movement of the waters was responsible for earthquakes. By contrast, Anaximenes, who also lived in the sixth century BC, proposed that rocks falling in the interior of the earth struck other rocks and produced reverberations. Anaxagoras, during the 5th century BC, regarded fire as the cause of at least some earthquakes. A century or so later, Aristotle believed there was a 'central fire' inside caverns in the earth from which flames, smoke and heat rapidly rose and burst violently through the surface rocks, causing both volcanic eruptions and earthquakes. As the subterranean fires burned away the rocks, the underground caverns would collapse, causing earthquakes.

2. A 16th-century drawing by artist Jean Cousin the Elder shows the destruction and chaos wrought by an earthquake – people flee, buildings collapse and smoke billows across the sky.

Aristotle even classified earthquakes into types according to whether they shook structures and people in mainly a vertical or a diagonal direction, and whether or not they were associated with escaping vapours. Much later, the Roman philosopher Seneca, inspired in part by an Italian earthquake in AD 62 or 63, proposed that the movement of air – rather than smoky vapours – trapped and compressed within the earth, was responsible for both the violent storms and the destructive rock movements.

The Chinese, who recorded earthquakes as far back as 1831 BC, were equally perplexed by their origin. But they adopted a more scientific approach than the Greeks and Romans to the measurement of seismicity. The earliest seismometer was invented in China in AD 132 by the astronomer and mathematician Chang Heng. His device consisted of eight dragon-heads facing the eight principal directions of the compass. They were mounted on the outside of an ornamented vessel said to resemble a wine jar of approximately two metres (six feet) diameter. Around the vessel's base, directly beneath the dragon-heads, were eight squatting toads with open mouths. In the event of an earthquake, a bronze ball would drop from a dragon-head into a toad's mouth with a resonant clang; the direction of the earthquake was probably indicated by which dragon-head dropped its ball, unless more than one ball dropped, indicating a more complex shaking.

The precise mechanism inside Chang Heng's seismometer is unknown. It must have comprised some kind of pendulum as the primary sensing element, which was somehow connected to lever devices that caused the bronze balls to drop. At any rate, according to a Chinese history called *Gokanjo*, in AD 138 the seismometer is said to have enabled Chang Heng to announce the occurrence of a major earthquake at Rosei, 650 kilometres (400 miles) to the northwest of the Chinese capital Loyang – two or three days before news of the devastation arrived by messengers on galloping horses. This prediction apparently restored the faith of those who had doubted the efficacy of the seismometer, and led the imperial government to appoint a secretary to monitor the behaviour of the instrument, which remained in existence for 400 years.

Over the centuries, in earthquake-prone countries, much has been learnt about earthquake-resistant construction by trial and error. Hence, the evolution of the complicated wooden joints that support the roofs of Japanese pagodas.

In Turkey, and also in Kashmir, architects and builders have long recognised creaks and cracks as an effective defence against earthquake damage, because these imperfections help to prevent a building from destructive swaying.

'Traditional architecture in these regions incorporates a patchwork quilt of wood elements and masonry infill, producing buildings that are able to dissipate shaking energy in a million little internal shifts and shimmies', notes the US seismologist Susan Hough. At Hagia Sophia in Istanbul (formerly Constantinople), the greatest of the Byzantine churches, the architect-engineers of the 6th century AD used a flexible cement to allow the walls of the building to 'give' a little during earthquakes.

3. The effects of an earthquake depicted in a woodcut in *The Illustrated Bartsch*, printed before 1500.

4. A modern-day reconstruction of the dragon-headed seismometer designed in China in AD 132 by the astronomer and mathematician Chang Heng (AD 78-139).

5. The Throne Room in the Palace of Knossos on Crete, as recreated by Arthur Evans, the archaeologist who excavated the site in the 1920s. The original Minoan city may well have been destroyed by an earthquake.

They added volcanic ash or other silica-rich materials to their mortar of limestone and crushed brick. This reacted with the limestone and water and produced a calcium silicate matrix – similar to that found in modern Portland cement – that can absorb seismic energy.

Nonetheless, the destructive power of earthquakes, coupled with the fires that follow them, has always been, and still remains, awesome. Pompeii, less than two decades before its destruction by Mount Vesuvius, was so badly damaged by the Italian earthquake of AD 62 or 63 that the Roman emperor Nero, after a visit, recommended the city be abandoned. Antioch, a trading and pleasure city on the shores of Asia Minor, was devastated four times by earthquakes in 115, 458, 526 and 528. Even in Britain, the vaulted roof of the celebrated medieval cathedral at Wells in Somerset was thrown down by an earthquake in 1248.

In modern times, major cities including Antigua Guatemala, Lisbon, Managua, San Francisco and Tokyo have all been ruined by earthquakes. But in each case, the city was rebuilt on the same site as before, and flourished. The only major city in the historical record to have been more or less abandoned after an earthquake and *tsunami* is Port Royal in Jamaica, much of which slid under the sea in 1692.

So, how influential have earthquakes really been in human history? Certainly less influential than Charles Darwin imagined in the midst of his *Beagle* voyage after examining the ruins of Concepción in 1835, when he darkly contemplated in his journal what would happen to England in the event of a major earthquake: 'Earthquakes alone are sufficient to destroy the prosperity of any country.'

That said, a reasonable case can be made for a long-term decline in Portugal's power and influence as a consequence of the destruction of its capital Lisbon in 1755; and also for the massive cost of rebuilding Tokyo and Yokohama in the 1920s as a key factor in the economic stress that led to the militarisation of Japanese society and, eventually, to Japan's entry into the Second World War.

At a much earlier period in history, it is possible, though unproven, that earthquakes played a greater role in the decline of cities and civilizations. It is quite likely that an earthquake destroyed the biblical cities of Sodom and Gomorrah, judging from the description of their fate in the book of *Genesis*; but there is no certainty, as the cities' archaeological sites have yet to be discovered.

Earthquakes may also have been a factor in the catastrophic end of the Bronze Age civilizations in Turkey, Greece and Crete during a period of around 50 years in the late second millennium BC. These include the fall of Troy, Mycenae, Knossos, and other cities, which left behind substantial archaeological sites. There is also tantalising evidence for a seismic role in the fall of Armageddon (Megiddo) and Jericho in Israel, Petra in Jordan and Teotihuacan in Mexico.

However, opinion is divided on the importance of earthquakes in the development of civilisation. Most present-day archaeologists say that earthquakes have had little to do with historical demises. They prefer to attribute the collapse of civilizations to human agency: war, invasion, social oppression, environmental abuse and so on. The conventional explanation of the Bronze Age collapse involves maritime invasion by the mysterious Sea Peoples, whose identities have long eluded scholars. 'When a city is destroyed for no apparent reason, archaeologists are far more comfortable ascribing the destruction to the vagaries of an unknown enemy than to the whims of nature', writes the US geophysicist Amos Nur in his fascinating study, *Apocalypse: Earthquakes, Archaeology, and the Wrath of God*, published in 2008.

There were notable exceptions of academics during the first half of the 20th century who were sympathetic to the idea that earthquakes could crush civilizations. These include the English archaeologist Arthur Evans, the first excavator of Knossos, the American archaeologist Carl Blegen, who excavated Troy, and the French archaeologist Claude Schaeffer, who excavated Ugarit in Syria and was the author of a controversial book on the comparative stratigraphy and chronology of western Asia published in 1948. But the majority have always been sceptical. For instance, in *The End of the Bronze Age: Changes in Warfare and the Catastrophe ca. 1200 BC*, published in 1993, Robert Drews took pains to quash any explanations involving earthquakes, and in *Collapse: How Societies Choose to Fail or Succeed*, published in 2005, Jared Diamond made no mention of earthquakes or volcanic eruptions. If earthquakes really have had so great an influence, the sceptics ask, then where is the hard evidence?

6. Skeleton of a victim killed in an earthquake in Jericho, *circa* 1400 BC. It has been decapitated by subsequent fault movement indicated by the crack running across the ground.

7. Map by the Royal Society of London showing the extent of the Neapolitan earthquake of 1857 and the seismic bands of the Mediterranean.

8. Map showing the tectonic plates of the world and the directions of their movement.

This is what Nur attempts to provide in *Apocalypse*. Drawing upon evidence from archaeological sites, especially in his native Israel, he demonstrates how earthquakes can be detected in the archaeological record, by analysing geological formations, faults, structural movement, human remains, the collapse of pillars and walls, and inscriptions. In Jericho, for example, he points out that excavators found grain and the skeletons of two people under its collapsed walls. Had the city simply been conquered by an enemy, without the prior collapse of its walls due to an earthquake, the valuable grain would have been seized by the invaders. In Mycenae, she notes that the immense stone blocks of the city's outer wall are built on top of a fault scarp, created by a major earthquake.

By superimposing upon a map of the Bronze Age sites in the eastern Mediterranean that were destroyed in 1225-1175 BC a second map of the maximum intensity of seismic ground motion during AD 1900-1980, which overlaps remarkably with the first map, Nur postulates that strong seismic ground motion in ancient times, too, may have helped to destroy these Bronze Age cultures. While none of his evidence is conclusive, it is more than merely suggestive. In the ancient world, as in the modern, such earth-shattering forces of nature were surely, at least sometimes, influential in changing the course of human history. ■

***Earthquake: Nature and Culture* by Andrew Robinson is published by Reaktion Books, at £14.95.**