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Supporting the Professional Learning of School Leaders and Teachers

Geological Survey Suirbhéireacht Gheolaíochta Ireland | Éireann

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iCRAG SFI RESEARCH CENTRE IN APPLIED GEOSCIENCES

EARTHQUAKE FACT SHEET
CASE STUDY 1: JAPAN

Location	Japan off the coast in the Pacific Ocean	Date and time	11/03/2011 at 05:46 UTC
Magnitude (Richter scale)	9.1	Nearby population center	Miyako in the Tōhoku region
Type of earthquake	Convergent plate boundary cause megathrust earthquake and tsunami	Epicenter	43 miles east of Tōhoku at a depth of 20 miles

Scale of damage and socio-economic impacts

This earthquake is known as the “Great East Japan Earthquake”. It was the most powerful earthquake ever recorded in Japan, and the fourth most powerful earthquake recorded in the world since modern seismography began in 1900.

Case study: Tohoku, Japan

On 11 March 2011, a massive 9.0 earthquake occurred off the Japanese coastline at 14:46.

The epicentre ⓘ was 43 miles east of Tohoku at a depth of 20 miles.

The earthquake lasted 6 minutes and caused a tsunami ⓘ wave that reached heights of over 40 metres.

Earthquake destruction in Japan

The plates involved

Japan is located in one of the most active earthquake zones on earth.

The Philippine plate and the Pacific plate are moving towards the much bigger continental Eurasian and North American plates.

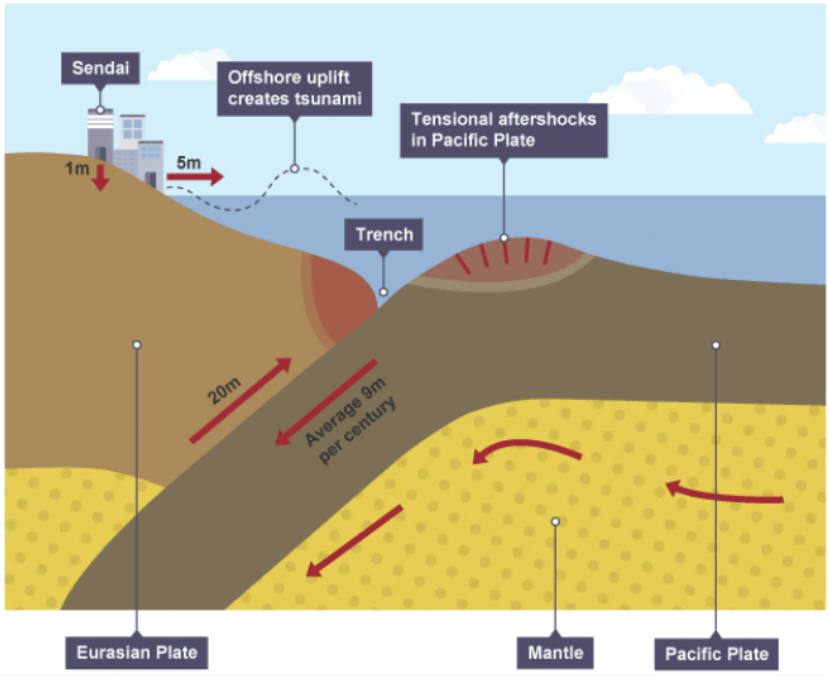
The movement can be up to around 9cm each year.

This is a destructive plate margin ⓘ where a subduction zone ⓘ has formed.

The thin, oceanic Pacific plate is being forced (subducted) underneath the much thicker continental Eurasian plate.

Friction has built up over time and when released this caused a massive 'megathrust' earthquake.

The amount of energy released in this single earthquake was equivalent to 600 million times the energy of the Hiroshima nuclear bomb.



Cross section of Tohoku earthquake

Short-term impacts

Impacts on people	Impacts on the environment
Death and injury - 15,894 people died, 6,152 people were injured, 130,927 were displaced and 2,562 people remain missing.	**Fore and aftershocks** - Scientists estimate that over 800 earthquakes of magnitude 4.5 or more were recorded following the main earthquake.
Nuclear crisis - A 9m high wave flooded the plants generators and electrical wiring. People lost energy immediately.	**Tsunami** up to 40 m high devastated entire towns and resulted in the loss of thousands of lives. This caused a lot of damage and pollution up to 6 miles inland.
Flood defence disaster - Japan spent billions of dollars building anti-tsunami defences at heights of 12 m. The tsunami washed over them, rendering them totally ineffective.	**Land fall** - some coastal areas experienced land subsidence as the earthquake dropped the beachfronts in some places by more than 50 cm.
Damage - 332,395 buildings, 2,126 roads, 56 bridges and 26 railways were destroyed or damaged. 300 hospitals were damaged and 11 were totally destroyed.	
Blackouts - Around 4.4 million households in North-East Japan were left without electricity.	

Long-term impacts

Impacts on people	Impacts on the environment
Economy - The economic cost was US$235 billion, making this the most expensive natural disaster in world history.	**Land movement** - The quake moved parts of North East Japan 2.4 m closer to North America.
Tsunami - Only 58% of people in the coastal areas followed the tsunami warnings and headed for higher ground. The waves hit 49% of those who did not follow the warning.	**Coastal changes** - A 250 mile stretch of coastline dropped by 0.6 m, allowing the tsunami to travel further inland.
Nuclear power - The damage caused by the earthquake resulted in the meltdown of seven reactors. Radiation levels at one point were over eight times normal levels.	**Plate shifts** - Geologists estimate that the Pacific plate has slipped westwards by between 20 and 40 m.
Transport - Japan's transport network suffered huge disruptions. Sections of the Tohoku Expressway were damaged.	**Seabed shift** - The seabed near the epicentre shifted by 24 m and the seabed off the coast of the Miyagi province has moved by 3 m.
Aftermath - The 'Japan move forward committee' thought that young adults and teenagers could help rebuild parts of Japan devastated by the earthquake.	**Earth axis moves** - The earthquake moved the earth's axis by between 10 and 25 cm, shortening the day by 1.8 microseconds.
	Liquefaction occurred in many of the parts of Tokyo built on reclaimed land. 1,046 buildings were damaged

Japan earthquake and tsunami of 2011

Japan earthquake of 2011

Map of the northern part of Japan's main island of Honshu depicting the intensity of shaking caused by the earthquake of March 11, 2011.

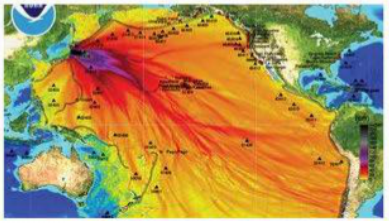
Japan earthquake and tsunami of 2011

A massive tsunami, generated by a powerful undersea earthquake, breaching the seawall at Miyako, Japan, March 11, 2011.

The earthquake and tsunami

The magnitude-9.0 earthquake struck at 2:46 PM. (The early estimate of magnitude 8.9 was later revised upward.) The epicentre was located some 80 miles (130 km) east of the city of Sendai, Miyagi prefecture, and the focus occurred at a depth of 18.6 miles (about 30 km) below the floor of the western Pacific Ocean. The earthquake was caused by the rupture of a stretch of the subduction zone associated with the Japan Trench, which separates the Eurasian Plate from the subducting Pacific Plate. (Some geologists argue that this portion of the Eurasian Plate is actually a fragment of the North American Plate called the Okhotsk microplate.) A part of the subduction zone measuring approximately 190 miles (300 km) long by 95 miles (150 km) wide lurched as much as 164 feet (50 metres) to the east-southeast and thrust upward about 33 feet (10 metres). The March 11 temblor was felt as far away as Petropavlovsk-Kamchatsky, Russia; Kao-hsiung, Taiwan; and Beijing, China. It was preceded by several foreshocks, including a magnitude-7.2 event centred approximately 25 miles (40 km) away from the epicentre of the main quake. Hundreds of aftershocks, dozens of magnitude 6.0 or greater and two of magnitude 7.0 or greater, followed in the days and weeks after the main quake. (Nearly two years later, on December 7, 2012, a magnitude-7.3 tremor originated from the same plate boundary region. The quake caused no injuries and little damage.) The March 11, 2011, earthquake was the strongest to strike the region since the beginning of record keeping in the late 19th century, and it is considered one of the most powerful earthquakes ever recorded. It was later reported that a satellite orbiting at the outer edge of Earth's atmosphere that day had detected infrasonics (very low-frequency sound waves) from the quake.

The sudden horizontal and vertical thrusting of the Pacific Plate, which has been slowly advancing under the Eurasian Plate near Japan, displaced the water above and spawned a series of highly destructive tsunami waves. A wave measuring some 33 feet high inundated the coast and flooded parts of the city of Sendai, including its airport and the surrounding countryside. According to some reports, one wave penetrated some 6 miles (10 km) inland after causing the Natori River, which separates Sendai from the city of Natori to the south, to overflow. Damaging tsunami waves struck the coasts of Iwate prefecture, just north of Miyagi prefecture, and Fukushima, Ibaraki, and Chiba, the prefectures extending along the Pacific coast south of Miyagi. In addition to Sendai, other communities hard-hit by the tsunami included Kamaishi and Miyako in Iwate; Ishinomaki, Kesennuma, and Shiogama in Miyagi; and Kitaibaraki and Hitachinaka in Ibaraki. As the floodwaters retreated back to the sea, they carried with them enormous quantities of debris, as well as thousands of victims caught in the deluge. Large stretches of land were left submerged under seawater, particularly in lower-lying areas.



tsunami wave height model

Map prepared by the U.S. National Oceanic and Atmospheric Administration depicting the tsunami wave height model for the Pacific Ocean following the March 11, 2011, earthquake off Sendai, Japan.

The earthquake triggered tsunami warnings throughout the Pacific basin. The tsunami raced outward from the epicentre at speeds that approached about 500 miles (800 km) per hour. It generated waves 11 to 12 feet (3.3 to 3.6 metres) high along the coasts of Kauai and Hawaii in the Hawaiian Islands chain and 5-foot (1.5-metre) waves along the island of Shemya in the Aleutian Islands chain. Several hours later 9-foot (2.7-metre) tsunami waves struck the coasts of California and Oregon in North America. Finally, some 18 hours after the quake, waves roughly 1 foot (0.3 metre) high reached the coast of Antarctica and caused a portion of the Sulzberger Ice Shelf to break off its outer edge.

Aftermath of the disaster

Casualties and property damage

Initial reports of casualties following the tsunami put the death toll in the hundreds, with hundreds more missing. The numbers in both categories increased dramatically in the following days as the extent of the devastation—especially in coastal areas—became

wreckage from Japan earthquake and tsunami of 2011

Fishing boat lying amid the wreckage in Ōfunato, Iwate prefecture, Japan, after being washed ashore by the tsunami that struck the city on March 11, 2011.

known and rescue operations got under way. Within two weeks of the disaster, the Japanese government's official count of deaths had exceeded 10,000; more than one and a half times that number were still listed as missing and presumed dead. By then it was evident that the earthquake and tsunami constituted one of the deadliest natural disasters in Japanese history, rivaling the major earthquake and tsunami that had occurred off the coast of Iwate prefecture in June 1896. As the search for victims continued, the official count of those confirmed dead or still missing rose to about 28,500. However, as more people thought to be missing were found to be alive, that figure began to drop; by the end of 2011 it had been reduced to some 19,300.

Coastal cities and towns as well as vast areas of farmland in the tsunami's path were inundated by swirling waters that swept enormous quantities of houses, boats, cars, trucks, and other debris along with them. As the extent of the destruction became known, it became clear how many thousands of people were missing—including, in some cases, half or more of a locality's population. Among those who initially were unaccounted for were people on a ship that was washed away by the tsunami and passengers on several trains reported as missing in Iwate and Miyagi prefectures. The ship was later found (and the people on board rescued), and all trains were located as well.

Ultimately, the official total for the number of those confirmed dead or listed as missing from the disaster was about 18,500, although other estimates gave a final toll of at least 20,000. Of those, fewer than 100 were from prefectures other than Iwate, Miyagi, and Fukushima. Miyagi prefecture suffered the greatest losses, with some 10,800 killed or missing and another 4,100 injured. The great majority of those killed overall were drowning victims of the tsunami waves. In addition, more than half of the victims were age 65 years or older.

Although nearly all of the deaths and much of the destruction was caused by the tsunami waves along Japan's Pacific coastline, the earthquake was responsible for considerable damage over a wide area. Notable were fires in several cities, including a petrochemical plant in Sendai, a portion of the city of Kesennuma in Miyagi prefecture, northeast of Sendai, and an oil refinery at Ichihara in Chiba prefecture, near Tokyo. In Fukushima, Ibaraki, and Chiba prefectures thousands of homes were completely or partially destroyed by the temblor and aftershocks. Infrastructure also was heavily affected throughout eastern Tōhoku, as roads and rail lines were damaged, electric power was knocked out, and water

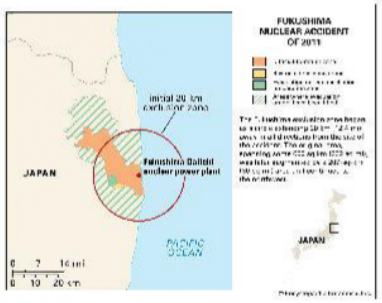
and sewerage systems were disrupted. In Fukushima a dam burst close to the prefectural capital, Fukushima city.

Northern Japan's nuclear emergency

damage at Fukushima Daiichi power plant

Two of the damaged containment buildings at the Fukushima Daiichi nuclear power plant, northeastern Fukushima prefecture, Japan, several days after the March 11, 2011, earthquake and tsunami that crippled the installation.

Of significant concern following the main shock and tsunami was the status of several nuclear power stations in the Tōhoku region. The reactors at the three nuclear power plants closest to the quake's epicentre were shut down automatically following the temblor, which also cut the main power to those plants and their cooling systems. However, inundation by the tsunami waves damaged the backup generators at some of those plants, most notably at the Fukushima Daiichi ("Number One") plant, situated along the Pacific coast in northeastern Fukushima prefecture about 60 miles (100 km) south of Sendai. With power gone, the cooling systems failed in three reactors within the first few days of the disaster, and their cores subsequently overheated, leading to partial meltdowns of the fuel rods. (Some plant workers, however, attributed at least one partial meltdown to coolant-pipe bursts caused by the earthquake's ground vibrations.) Melted material fell to the bottom of the containment vessels in reactors 1 and 2 and burned sizable holes through the floor of each vessel, which partially exposed the nuclear material in the cores. Explosions resulting from the buildup of pressurized hydrogen gas in the outer containment buildings enclosing reactors 1, 2, and 3, along with a fire touched off by rising temperatures in spent fuel rods stored in reactor 4, led to the release of significant levels of radiation from the facility in the days and weeks following the earthquake. Workers sought to cool and stabilize the damaged reactors by pumping seawater and boric acid into them.



Because of concerns over possible radiation exposure, Japanese officials established an 18-mile (30-km) no-fly zone around the facility, and an area of 12.5 miles (20 km) around the plant was evacuated. The evacuation zone was later extended to the 18-mile no-fly radius, within which residents were asked to leave or remain indoors. The appearance of increased levels

evacuation and exclusion zones of the Fukushima nuclear accident of 2011

of radiation in some local food and water supplies prompted officials in Japan and overseas to issue warnings about their consumption. At the end of March, seawater near the Daiichi facility was discovered to have been contaminated with high levels of radioactive iodine-131. The contamination stemmed from the exposure of pumped-in seawater to radiation inside the facility; this water later leaked into the ocean through cracks in water-filled trenches and tunnels between the facility and the ocean.

In mid-April Japanese nuclear regulators elevated the severity level of the nuclear emergency at the Fukushima Daiichi facility from 5 to 7—the highest level on the scale created by the International Atomic Energy Agency—placing the Fukushima accident in the same category as the Chernobyl accident, which had occurred in the Soviet Union in 1986. Radiation levels remained high in the evacuation zone, and it was thought that the area might be uninhabitable for decades. However, several months after the accident, government officials announced that radiation levels in five towns located just beyond the original 12.5-mile evacuation zone had declined enough that they could allow residents to return to their homes. Although some people did come back, others stayed away, concerned about the amount of radioactive materials still in the soil. Attempts were made in several of those areas to remove contaminated soil. In December 2011 Japanese Prime Minister Noda Yoshihiko declared the Fukushima Daiichi facility stable after the cold shutdown of its reactors had been completed.

In the years following the accident, numerous leaks at the facility occurred at the site where contaminated reactor cooling water was stored. A significant leak occurred in August 2013 that was severe enough to prompt Japan's Nuclear Regulation Authority to classify it as a level-3 nuclear incident.

Relief and rebuilding efforts

Japanese Ground Self-Defense Force, Ōfunato, Iwate prefecture, Japan

Members of the Japanese Ground Self-Defense Force in rescue and

In the first hours after the earthquake, Japanese Prime Minister Kan Naoto moved to set up an emergency command centre in Tokyo, and a large number of rescue workers and some 100,000 members of the Japanese Self-Defense Force were rapidly mobilized to deal with the crisis. In addition, the Japanese government requested that U.S. military personnel stationed in the country be available to help in relief efforts, and a U.S. Navy aircraft carrier was

recovery operations in Ōfunato, Iwate prefecture, Japan, after the city was devastated by the March 11, 2011, earthquake and tsunami.

dispatched to the area. Several countries, including Australia, China, India, New Zealand, South Korea, and the United States, sent search-and-rescue teams, and dozens of other countries and major international relief organizations such as the Red Cross and Red Crescent pledged financial and material support to Japan. In addition, a large number of private and nongovernmental organizations within Japan and worldwide soon established relief funds to aid victims and assist with rescue and recovery efforts.

The rescue work itself was hampered initially by the difficulty in getting personnel and supplies to the devastation zone; compounding the difficulty were periods of inclement weather that curtailed air operations. Workers in the disaster zones then faced widespread seas of destruction: vast areas, even whole towns and cities, had been washed away or covered by great piles of mud and debris. Although some people were rescued from the rubble in the first several days following the main shock and tsunami, most of the relief work involved the recovery of bodies, including hundreds that began washing ashore in several areas after having been swept out to sea.

temporary shelter near Sendai, Miyagi prefecture, Japan

U.S. government officials (right) visiting a temporary shelter near Sendai, Miyagi prefecture, Japan, for victims of the March 11, 2011, earthquake and tsunami.

In the immediate aftermath of the disaster, several hundred thousand people were in shelters, often with limited or negligible supplies of food or water, and tens of thousands more remained stranded and isolated in the worst-hit areas as rescuers worked to reach them. Within days the number of displaced people in the Fukushima area grew as the situation with the nuclear reactors on the coast deteriorated and people left the quarantined area. Gradually many people were able to find other places to stay in the Tōhoku area, or they relocated to other parts of the country. Some quarter million people were still in hundreds of shelters in the region two weeks after the quake, but in the ensuing months that number gradually was reduced. Two years after the disaster, a small number of people still remained in emergency centres. However, more than 300,000 displaced residents were living in tens of thousands of prefabricated temporary housing units that had been set up in Sendai and other tsunami-damaged locations or were in some other type of domicile, such as hotels, public housing units, or private homes. Four years after the disaster, some 230,000 people were still displaced, a large number of them because of the continuation of the evacuation zone around the Fukushima plant.

In the weeks following the disaster, much of northern Honshu's transportation and services infrastructure was at least partially restored, and repairs continued until train lines and major highways were again fully operational. However, the region's power supply continued to be affected by the ongoing situation at the Fukushima plant, resulting in temporary power outages and rolling blackouts. The loss of businesses and factories from earthquake and tsunami damage, as well as the uncertainties surrounding the power supply, severely reduced the region's manufacturing output in the months following the disaster. Industries most affected included those producing semiconductors and other high-technology items and automobiles. By late summer, however, the economy was again growing briskly, as many of the affected businesses were able to resume at least limited production. In the first months of 2012, industrial output essentially reached the level it had been at before the disaster.

In 2011 first the Kan and then the Noda administration proposed and pushed through the legislature three disaster-related supplemental budgets. The third and largest of these, approved in November, provided some $155 billion, the bulk of the funds earmarked for reconstruction in devastated areas. In addition, in February 2012 the government established a cabinet-level Reconstruction Agency to coordinate rebuilding efforts in the Tōhoku area. The agency was scheduled to be in operation for 10 years, the length of time it was projected to completely restore the region. In early 2015 the agency reported that nearly all the disaster debris had been removed. In addition, it noted that work had started on about three-fourths of the planned coastal infrastructure (e.g., seawall) construction in the affected areas and was at least under way on nearly all the higher-ground sites designated for rebuilding away from low-lying coastal areas.

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EARTHQUAKE FACT SHEET
CASE STUDY 2: DONEGAL

Location	Near Glenveagh National Park in northwest Donegal, Ireland	Date and time	06/05/2023 at 00:32 UTC
Magnitude (Richter scale)	2.5 At a depth of approx..10 km	Nearby population center	Donegal
Type of earthquake	Fault	Epicenter	

Scale of damage

People living nearby reported a booming sound that woke them from their sleep, according to comments on facebook.

Many said they presumed it was thunder or an explosion.

One woman in the village of Church Hill said: "Heard it indeed and it shook the house."

The INSN has received reports that the event was also “felt throughout the Donegal area”.

Socio-economic impacts

BBC

Largest earthquake for 10 years shakes Donegal

Donegal is the seismically most active region in Ireland

Matt Fox
BBC News NI

7 May 2023

A 2.5 magnitude earthquake was recorded in County Donegal in the early hours of Saturday morning, experts have said.

The Irish National Seismic Network (INSN) reported that the quake occurred at 01:32 local time near Glenveagh National Park.

It is understood to be one of Ireland's largest onshore earthquakes since records began.

The INSN previously detected a 2.5 magnitude quake on 26 January 2012 on the Fanad peninsula, also in Donegal.

It is operated by the Geophysics section at Dublin Institute of Advanced Studies (DIAS) with support from the Geological Survey Ireland.

Dr Martin Möllhoff from DIAS told BBC NI that Donegal is, seismically, the most active region in Ireland.

"Overall Ireland is seismically relatively quiet, a felt earthquake occurs on average about every two years," he said.

"For yesterday's event we received over 100 felt reports and more are still coming in."

'It shook the house'

People living nearby reported a booming sound that woke them from their sleep, according to comments on the **Donegal Daily Facebook page.**

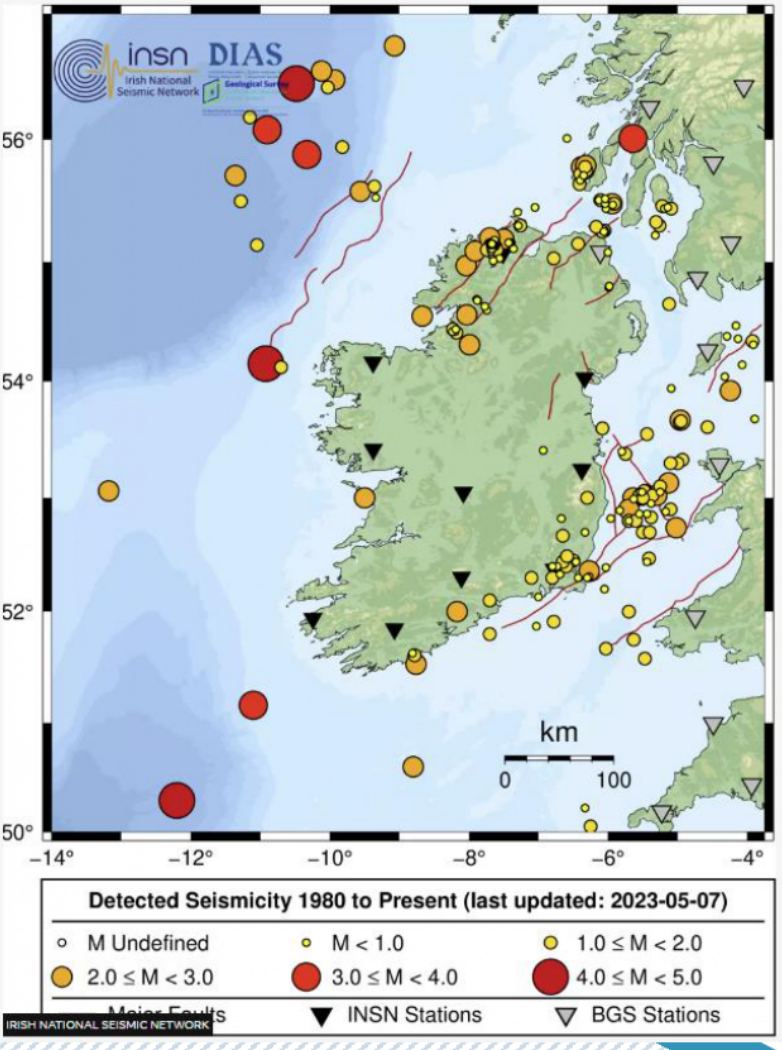
Many said they presumed it was thunder or an explosion.

One woman in the village of Church Hill said: "Heard it indeed and it shook the house."

- **Earthquake-hit historic Argyll site to partly reopen to visitors**

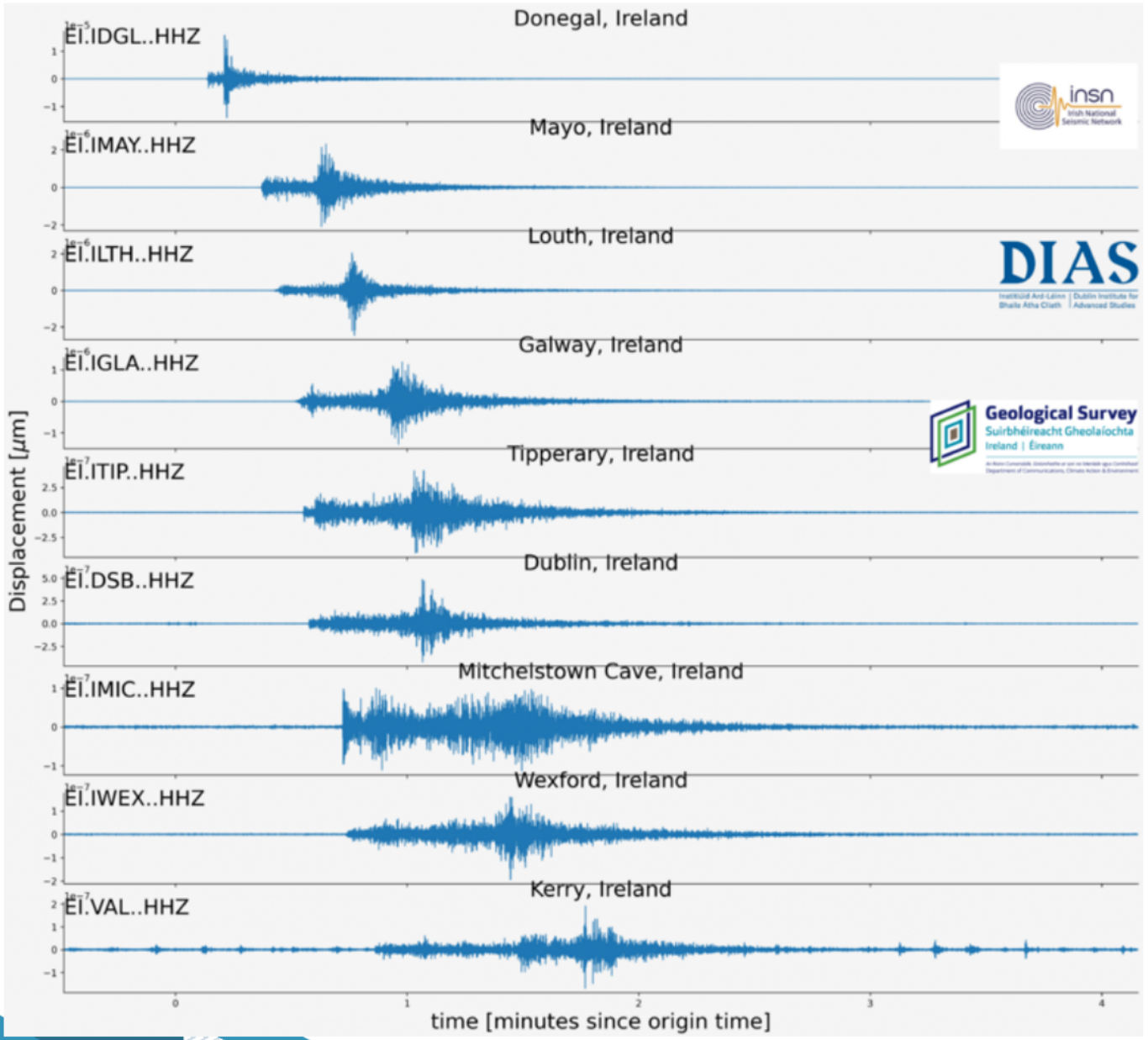
The earthquake was also detected by several Raspberry Shake seismometers operated by citizens and schools in counties Antrim, Dublin and Sligo.

Dr Möllhoff said reports from the public gave "valuable information" and urged people who may have felt the earthquake to make a report on their website.



Community Seismology Project (CSP)

The earthquake was also detected by several Raspberry Shake seismometers operated in Ireland by citizens and schools.



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EARTHQUAKE FACT SHEET
CASE STUDY 3: MOROCCO

Location	Morocco	Date and time	08/09/2023 at 22:11 UTC
Magnitude (Richter scale)	6.8-6.9	Nearby population center	Marrakesh-Safi region
Type of earthquake	as a result of shallow oblique-thrust faulting beneath the mountain range	Epicenter	73.4km southwest of Marrakesh

Scale of damage and socio-economic impacts

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The Guardian
Article from Sun 10 Sep 2023, Ruth Michaelson

Morocco earthquake: mourning begins as rescue continues with death toll over 2,000

Villagers bury their dead while Red Cross warns recovery may take years and other countries offer aid

How have you been affected by the earthquake in Morocco?

Morocco earthquake: drone footage shows scale of destruction in village of Moulay Brahim – video

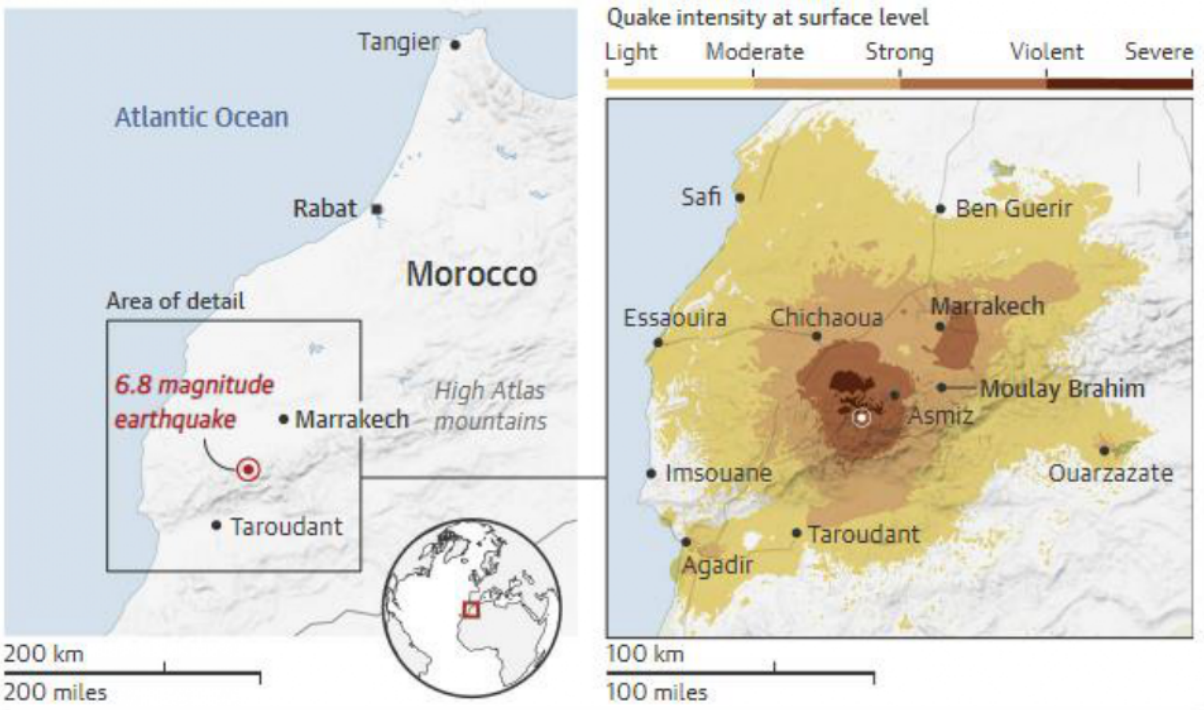
Rescuers in Morocco were trying to find survivors in the rubble of collapsed buildings on Sunday as the country began three days of mourning for victims of a disaster that killed more than 2,000 people and left many more injured and homeless.

Friday's 6.8-magnitude quake, Morocco's deadliest in more than six decades, had an epicentre below a remote cluster of mountainous villages 45 miles south of Marrakech, and shook infrastructure as far away as the country's northern coast.

The government reported that at least 2,122 people were killed and more than 2,421 injured, many of them critically. In Marrakech, many people slept outside on pavements and in squares, fearing returning to their homes.

Military forces and emergency services rushed to reach remote villages where many more victims were feared trapped.

Morocco's King Mohammed VI chaired an emergency disaster response meeting on Saturday afternoon and declared three days of national mourning. Civil protection units were deployed to increase stocks in blood banks and ensure the supply of resources including water, food, tents and blankets to affected areas, the palace said.



Omar Bajjou, from a village near Asni at the foot of the Atlas mountains, 30 miles south of Marrakech, said the force of the earthquake threw him out of bed, terrifying him and his wife.

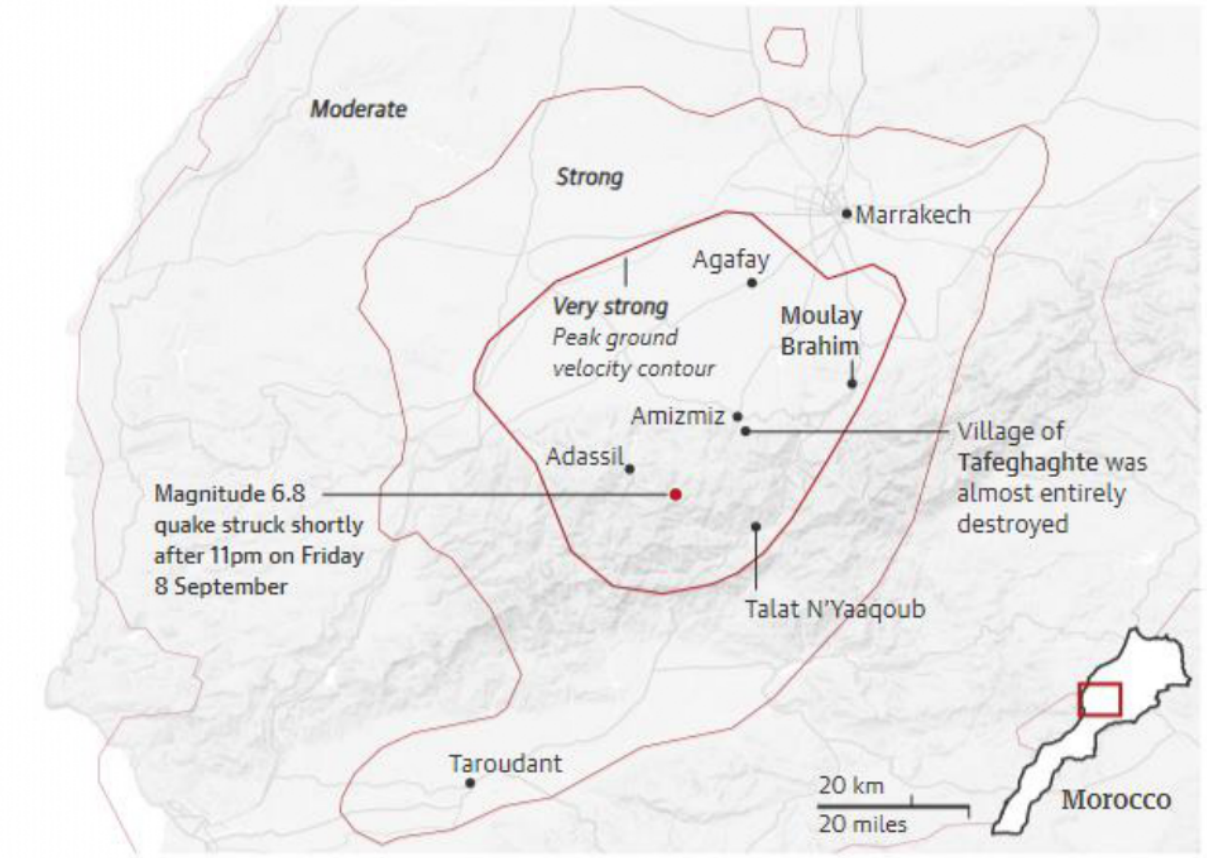
"I initially thought it was an airplane that had somehow fallen on the roof of our building," he said. Fleeing outside, they found chaos in their village. "All of the surrounding houses, especially the mud-brick ones, had crumbled, and the others had huge cracks in them, fatal cracks, like they could collapse at any moment. There was dust everywhere, and the sound of screams," he said.

Bajjou and the other villagers began to try to dig their neighbours out from under their homes. "We managed to rescue several people who were buried under the rubble, we saved some but others were already dead, like my neighbour. Another lost both of their children, and his wife was injured. In total, there were five dead from our building."

Terrified and cold, the residents of the village remained outside for two days without water or electricity, too scared to return to their homes for fear of further aftershocks or crumbling buildings.

Samia Errazzouki, an expert in the history and governance of the Moroccan state at Stanford University in California, said: "Roads and access to this region are already difficult, before you compound that with difficulties like rubble or problems with the roads. It's going to take a miracle to get immediate aid there."

Members of Morocco's marginalised Amazigh community, sometimes known as Berbers, live among the villages in the earthquake zone. "These regions have historically been hit with earthquakes, but they have also been marginalised," Errazzouki said.



Guardian graphic. Source: USGS. Note: times are local

Several countries including Israel, France, Spain, Italy and the US have offered aid. Neighbouring Algeria, which has had difficult relations with Morocco, opened its airspace, which had been closed for two years, to flights carrying humanitarian aid and the injured.

Al-Haouz province, above the epicentre of the earthquake, recorded the most deaths, 1,293, followed by the province of Taroudant with 452.

Kamal, who declined to give his surname, from the town of Skoura, an oasis west of Marrakech at the base of the Atlas, said homes across the town had sustained damage but villages higher up in the hills had fared even worse.

"We felt the violent tremors but everyone managed to get out of their houses in time. Thankfully we are yet to count any deaths, but many of the clay homes here completely collapsed. However, the villages further up in the mountains have been seriously affected - there are many dead and we are completely unable to reach them," he said.

People across the country described their terror at being unable to contact their loved ones in villages across the earthquake zone, where telephone networks have been patchy and in some cases continue to be unable to function after the earthquake.

"I wasn't at home at the time, I was in Casablanca but even there we still felt the violent shaking and stayed outside the entire night," said Toufik, also from Skoura. "I managed to contact my family by phone that night, but for a period after that it became impossible, the network wasn't functioning. I began to panic as I didn't know what had happened to them, whether there had been further aftershocks that had affected them. Thankfully after several hours I managed to speak to them and everyone was OK."

Powerful earthquake strikes Morocco, killing more than 1,000 - video report

While the country mourned, some questioned the speed of the emergency response. The king has long been quietly accused of governing from his residence in France. Despite him returning to chair the emergency response meeting, some said vital hours may have been lost due to a need for the palace's approval and control.

"Ultimately, nothing in the country gets done with the green light from the palace ... so much time was lost because [the king] was physically not there," said Errazzouki, the Stanford academic. "Fundamentally, this is a reflection of how ineffective Moroccan governance has been due to the fact it relies entirely on an authoritarian structure of a figure who is absent."

She added: "There's a cloud of opacity surrounding communications, and this becomes an impediment to the state being able to effectively carry out emergency operations ... every second counts in these moments, every minute it takes to get approval, to double-check all these tedious time-consuming steps - people are dying. Lives could have been saved."

Residents of Marrakech, the biggest city nearest to the epicentre, said some buildings had collapsed in the old city, a Unesco world heritage site. Video showed the city's famous 12th-century Koutoubia mosque, which stands over the central Djemaa el-Fna marketplace, quaking with the force of the initial tremors, as people fled into the open area to seek safety.

The Red Cross said repairing the damage wrought by the powerful earthquake could take years. Unesco pledged to help repair damage to heritage in historic Marrakech, but the prospect of rebuilding in inaccessible remote towns and villages appeared even more challenging.

"It won't be a matter of a week or two ... We are counting on a response that will take months, if not years," said the Red Cross Middle East and north Africa director, Hossam Elsharkawi.

Philippe Vernant, a specialist in active tectonics, particularly in Morocco, at the University of Montpellier, told Agence France-Presse that even though the quake did not hit in Morocco's most active seismological region, aftershocks could be expected. "Even if they are less strong, they can lead to the collapse of buildings already weakened by the earthquake. Traditionally, we tend to say that aftershocks diminish in intensity," he said.

The prime minister of Morocco's cross-strait neighbour Spain, Pedro Sánchez, expressed his "solidarity and support to the people of Morocco in the wake of this terrible earthquake ... Spain is with the victims of this tragedy," he said.

The French president, Emmanuel Macron, said he was "devastated" and that "France stands ready to help with first aid".

Algerian state television broadcast a message from the presidency, declaring that the state would open its airspace to allow the transport of humanitarian aid to Morocco as well as offering aid resources, a significant shift after the rupture in diplomatic relations between the two nations that has lasted for two years.

Morocco has regularly experienced earthquakes along its northern coastline, notably a 6.3-magnitude quake near the town of Al Hoceima in 2004, which killed more than 600 people. Friday's earthquake was one of the more destructive since the 1960 quake that destroyed Agadir and killed 15,000 people, a third of the city's population at that time.

Errazzouki said: "Obviously we can't prevent earthquakes, and loss of life is unfortunately inevitable with something of this magnitude. But what can be controlled is how we respond to it and how we deal with it. It takes a crisis, a disaster like this to shed light on the day-to-day realities of people who live in the margins."

Agence France-Presse, Reuters and Associated Press contributed to this report

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EARTHQUAKE FACT SHEET
CASE STUDY 4: SAN FRANCISCO

Location	San Francisco	Date and time	18/04/1906 at 05:12am local time
Magnitude (Richter scale)	7.9	Nearby population center	San Franciso, Santa Rosa. Sebastopol, San Bruno, San Jose, Point Arena and many more
Type of earthquake	Slipping in the San Andreas Fault	Epicenter	Off coast at the San Andreas Fault

Scale of damage and socio-economic impacts

More than 3,000 people died, and over 80% of the city was destroyed. The event is remembered as the deadliest earthquake in the history of the United States.

San Francisco earthquake of 1906

San Francisco earthquake of 1906

Crowds watching the fires set off by the earthquake in San Francisco in 1906, photo by Arnold Genthe.

San Francisco earthquake of 1906

Map of northern California depicting the intensity of shaking caused by the earthquake of April 18, 1906.

San Francisco earthquake damage

Aftermath of the San Francisco earthquake of 1906.

San Francisco earthquake of 1906, major earthquake with a magnitude of 7.9 that occurred on April 18, 1906, at 5:12 AM off the northern California coast. The San Andreas Fault slipped along a segment about 270 miles (430 km) long, extending from San Juan Bautista in San Benito county to Humboldt county and from there perhaps out under the sea to an unknown distance. The shaking was felt from Los Angeles in the south to Coos Bay, Oregon, in the north. Damage was severe in San Francisco and in other towns situated near the fault, including San Jose, Salinas, and Santa Rosa.

San Francisco had experienced earthquakes in 1864, 1898, and 1900 but nothing like the 1906 event. Just after 5:00 AM on April 18, a noise "like the roar of 10,000 lions" rose as the entire city began to tremble and shake. Cable cars abruptly stopped, City Hall crumbled, and the Palace Hotel's glass roof splintered and littered the courtyard below.

The quake was followed by a massive fire that swept from the business section near Montgomery Street and the South of Market district toward Russian Hill, Chinatown, North Beach, and Telegraph Hill. The blaze continued for four days, until its smouldering ashes were ultimately extinguished by rain. In the process, more than 500 blocks in the city centre—covering some 4 square miles (10 square km)—were leveled. The inferno destroyed some 28,000 buildings, and the total property value loss was estimated at $350 million.

Some 700 people originally were thought to have died in the disaster, but the death toll is now believed to

San Francisco earthquake of 1906

Damage from the San Francisco earthquake of 1906.

San Francisco earthquake of 1906

San Francisco after the 1906 earthquake.

Panama-Pacific International Exposition

Fountain of Energy and Festival Hall at night, mirrored in the broad lagoon of the South Gardens, Panama-Pacific International Exposition, San Francisco, California, 1915.

Bernard Maybeck: Palace of Fine Arts

have exceeded 3,000. Moreover, about 250,000 were left homeless; survivors camped in Golden Gate Park and dunes west of the city or fled to outlying towns. Within a short time, relief shipments of food and clothing reached the city, and several tens of millions of dollars in financial aid arrived from foreign sources, including Europe, Japan and China, and other parts of the Americas. Although insurance payments in the neighbourhood of $300 million were forthcoming, the long task of reconstruction was sustained by local courage and persistence.

Much of the city was rebuilt to be earthquake- and fire-resistant. New plans for civic development made headway as the debris of the old city vanished. In 1915 San Francisco invited the world to see the results of its efforts at the Panama-Pacific International Exposition.

Geologic field studies of this earthquake led to the detailed formation of the theory that elastic rebound of strained faults causes the shaking associated with earthquakes. *See also* uplift; Harry Fielding Reid.

The Editors of Encyclopaedia Britannica This article was most recently revised and updated by John P. Rafferty.