Geofile Online
SEPTEMBER 2011
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CHILE'S 2010 EARTHQUAKE – DAMAGE AND RECOVERY

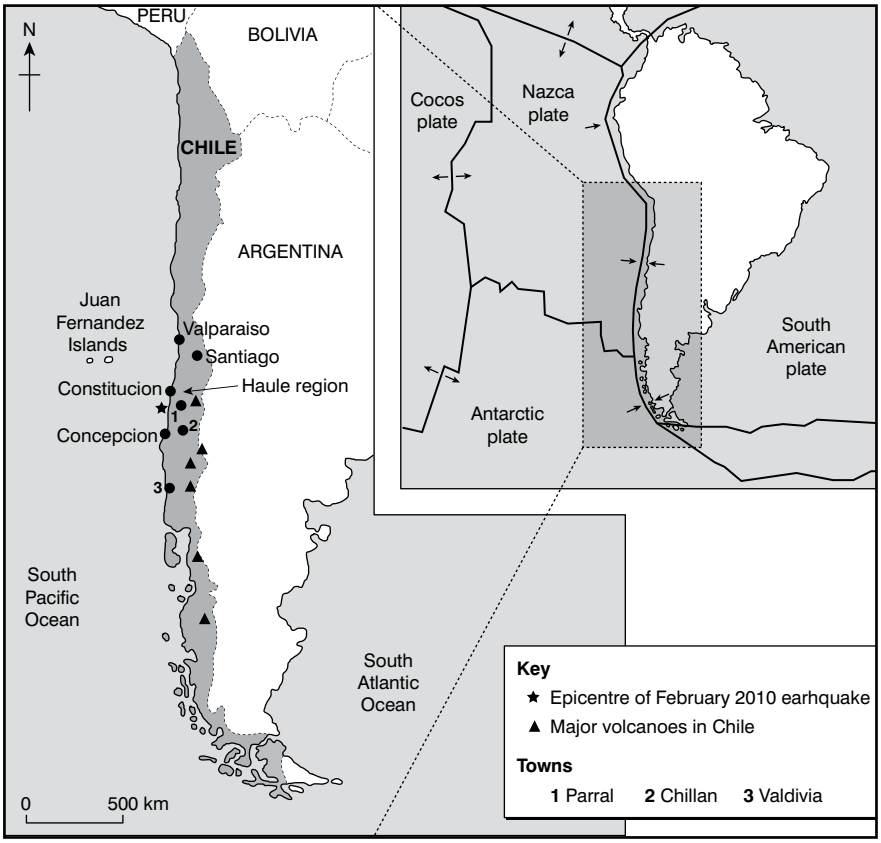
Earthquakes are a sudden, often violent shaking of the ground. An earthquake took place in Chile on Saturday 27 February 2010. Its epicentre lay 115 km north east of Concepcion, a town in the Maule region of Chile, and 325 km south west of Santiago, the capital city of Chile (Figure 1). The earthquake measured 8.8 on the Richter scale. An earthquake of this level of magnitude is classified as 'Great', and it would be expected to occur only once in the world every 10–20 years. It is the sixth biggest earthquake ever recorded (the earthquake in Japan in March 2011 measured 8.9). It has been estimated that the earthquake was so powerful that it moved Concepcion 3.04 m to the west, and caused the earth's axis to move temporarily by 8 cm. The earthquake was followed by a series of aftershocks (earthquakes of lesser magnitude). By 6 March more than 130 of these had been recorded, including 13 above magnitude 6.0.

The coast of Chile has seen 13 earthquakes of magnitude 7.0 or more since 1973. Figure 2 gives some information about some of these earthquakes and the damage they caused. In 1960 the Valdivia earthquake in southern Chile measured 9.5 on the Richter scale, the largest magnitude ever recorded in the world.

The nature of the seismic hazard

When rocks come under stress due to movement in the earth's crust, they bend until a breaking point is reached, and then stored energy is released as an earthquake. The energy released moves through the rock in waves. The focus of an earthquake is the place in the earth's crust where movement takes place. The epicentre is the point on the earth's surface, often directly above the focus, where the earthquake is first felt. The energy produced by an earthquake decreases with distance from the focus and the epicentre. Following an earthquake, aftershocks occur, as the stresses in the adjacent rocks are redistributed.

Figure 1: Chile, showing the situation of tectonic plates off the western coast of South America



The earth consists of a crust, below which are the mantle and then the core. The crust is made up of continental crust and oceanic crust. The crust and the top, rigid layer of the mantle are called the lithosphere. The rest of the mantle below the lithosphere is called the asthenosphere. Here, the rocks are semi-molten. The lithosphere consists of seven, very large tectonic plates as well as many smaller ones which 'float' on the asthenosphere. Major earthquakes take place at the boundaries or margins of these tectonic plates. There are three types of plate margin:

- Constructive plate margins, where two tectonic plates are moving away from each other. An example of this is the Mid-Atlantic Ridge in the Atlantic Ocean where new oceanic crust is being created as the Eurasian plate moves eastwards and the North Atlantic plate moves westwards.
- Conservative plate margins, where two plates are moving sideways against each other, eg the San Andreas fault in California where the Pacific plate is moving against the North American plate.
- Destructive plate margins, where two plates meet, as is the case off the western coast of South America. In this case, when an oceanic plate meets a continental one, the result is a subduction zone.

A destructive plate margin – the example of the western coast of South America

A common location for earthquakes is where oceanic and continental plates converge or meet. This is called a destructive plate margin because as the plates move towards each other and meet (driven by convection currents in the asthenosphere), the oceanic crust is forced downwards into the earth's upper mantle. This process is called subduction. This takes place because the oceanic crust is denser than the continental

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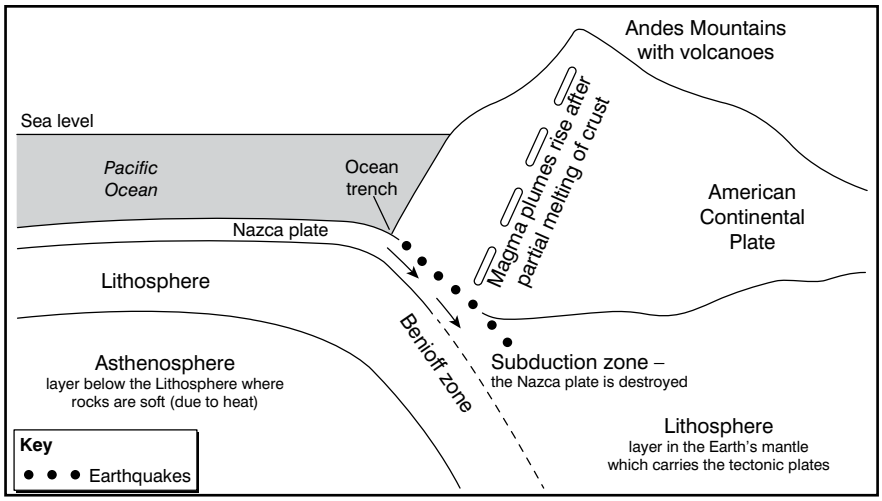
Figure 2: Information about recent earthquakes in Chile. Fortunately several of these earthquakes took place in sparsely populated areas, so the amount of damage they caused to people and property was relatively slight

Date	Magnitude (Richter scale)	Location	Damage
14 November 2007	7.7	Northern coast of Chile	2 deaths and 45 people injured. Considerable damage to hospitals, schools and other public buildings.
13 June 2005	7.8	Andes mountains in northern Chile and southern Peru	11 killed and 100 injured. 80 houses destroyed. Considerable damage to roads caused by landslides following the earthquake.
8 August 1987	6.8	Arica	4 killed and 350 injured. 120 buildings destroyed or damaged. The coastal highway closed for five days by landslides again brought about by the earthquake.
3 March 1985	7.8	The coast of Chile, south west of Valparaiso	147 killed and 2,000 injured. The port facilities in Valparaiso were damaged. Water supplies in the area were hit particularly hard – the aqueduct which supplies water to Valparaiso was severely damaged. The pumping station moving water to the town of San Antonio was also destroyed.

Figure 3: The plate boundaries off the western coast of South America



crust. Friction between the colder, more brittle oceanic crust and the continental crust causes stresses. The release of these stresses results in earthquakes. The pressure that builds up at this type of plate margin tends to be greater than that at the other two types of plate margins, so earthquakes here often have a greater magnitude. Also, at a destructive plate margin, the continental crust and the sediments which have built up on the seabed are forced upwards and folded into a fold mountain range. Figure 1 shows the situation of tectonic plates off the western coast of South America. Just off the coast of Chile, the Nazca plate is being destroyed as it moves underneath the continental South American plate, at a speed of 7 m per century. Figure 3 shows the situation at this plate boundary in more detail. Here, subduction begins with a deep ocean trench, which is 8000 m deep in parts. One wall of this trench is formed by the subducted plate, whilst the other wall is formed from the edge of the continental plate. As the plate moves downwards, it moves in a series of jerks and this too can generate earthquakes. It is believed that when the earthquake took place on 27 February 2010, the continental South American plate was moved 10 m west.

The name given to the subduction zone at the boundary between the crustal rocks and the subducting plate is the Benioff zone. Earthquakes can take place anywhere in this zone, from the surface to about 700 km down.

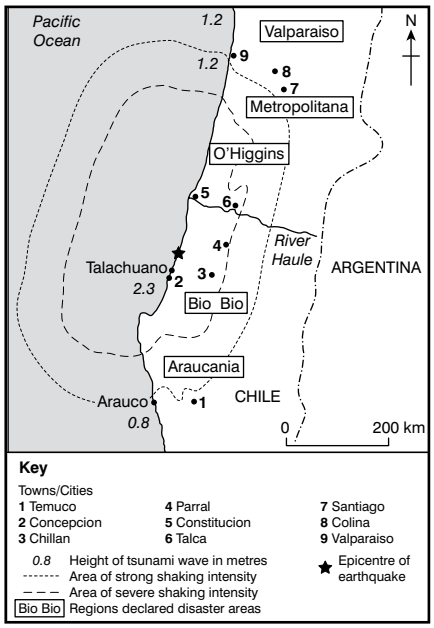
As well as the earthquakes, there are a series of volcanoes, formed from magma created at the melting edge of the Nazca plate where it is being subducted. As the magma rises through the continental crust it comes under great pressure, as this crust is very thick and there are few routes to the surface. As a result, when an eruption does take place, it is usually very explosive.

Impact of the February 2010 earthquake

Figure 4 shows the areas of Chile which were affected by the earthquake. Six regions, stretching from Valparaiso in the north to Temuco in the south, felt a strong shaking intensity. 80% of the country's population was affected. The earthquake caused both uplift and subsidence along the coast of Chile. The area surrounding Arauco was uplifted and tilted gently to the east, with about 2 m of uplift. In a 50 km coastal zone close to Constitucion, the land subsided. Tremors from the earthquake were felt further away as well – up to 2400 km away in southern Peru, as well as in Buenos Aires in Argentina. The effects of the earthquake included:

- 521 people were killed, with 56 people missing. 12,000 people were injured. Deaths and injuries were caused by collapsing buildings trapping people inside. Buildings also collapsed onto cars, killing their occupants.
- All over the affected area, the infrastructure suffered considerable damage and road transport became difficult because of blockage by landslides and because bridges were brought down. For several days this made it very difficult for the government to bring aid to the affected areas.
- 1.5 million homes were damaged, displacing 0.8 million people. The

Figure 4: Main areas affected by the Chile earthquake



Source: US Geological Survey/Department of the Interior

homes which suffered the most damage were those made of adobe. In urban areas, many people were forced to sleep in tents, in parks or on the streets because their houses were uninhabitable and because they feared the effects of aftershocks. 4,013 schools and 79 hospitals were also damaged.

- In the capital, the Fine Arts Museum and National Library were damaged. A fire caused by the earthquake led to damage to a chemical plant on the outskirts of the city. Both the international airports in Santiago and Concepcion (which together handle over two-thirds of Chile's air traffic) were closed, and it was estimated that this cost Chile's international airline, LAN, approximately $25 million in lost local passenger traffic alone. Most of Santiago was left without water or electricity, but four days later 90% of the city had these services restored. There was a great deal of damage to houses and property in the city. Figure 5 is an account of what happened during the earthquake, provided by Richard Fletcher, a resident of Santiago, and it illustrates what it is like to experience an earthquake as well as the damage it can cause to homes and property. Figure 5 shows a photograph taken in Mr Fletcher's house showing some of the damage caused by this earthquake.
- The Maule region was most seriously affected by the earthquake. Many buildings in Constitucion, Chile's second largest city, were destroyed, and one apartment building toppled over trapping 80 people, of whom 13 were rescued. Telephone and power cables were brought down and roads severely damaged in places. In the tourist city of Talca, many historic buildings were destroyed, including nearly all the buildings in the city centre.
- Overall, it was estimated that it would cost £20 billion to restore the damage done to the country by the earthquake.

Tsunami (Japanese for 'harbour wave')

As shown by the 2011 Japanese earthquake, earthquakes can have important secondary effects which can cause considerable damage. These include landslides, tsunamis and soil liquefaction. Tsunamis are tidal waves. These are caused when the epicentre of an earthquake is close to the coast or on the seafloor. This can lead to enormous underwater landslides. Water then falls into the area where subsidence has taken place, which results in water at the coast retreating away from the land. However, about 15 minutes later the water returns as a huge wave, followed by a series of other waves, some of which can be higher than the initial one. These waves can spread very quickly out into deeper water, where they can travel at speeds of 500 to 950 km per hour (the speed of a jet plane), but they don't show themselves until they reach shallow water again. At this point they slow down and become much higher. When they eventually break, their height can also be affected by the coastal topography and aspect, so some places can receive higher waves than other places close by.

Immediately after the earthquake, the Pacific Tidal Warning Centre issued a tsunami warning, suggesting that waves would cause destruction along nearby shores. Approximately 30 minutes after the first shock, a series of waves did hit Chile's coastal towns. Eyewitnesses observed three or four distinct waves, with the third or fourth usually being the highest. Figure 4 shows the highest wave heights recorded at places along the coast of Chile. The single largest loss of life caused either directly or indirectly by the earthquake was on La Isla Orrego, an island in the River Maule, when a tsunami flooded

Figure 5: An eyewitness account of the earthquake

'It was one hell of a shake and not one I want to live through again. We were woken by the sound of rumbling and creaking of the house and the bed started to shake. We have gone through this before, but this time as the seconds passed it got stronger and stronger, until the bed was shaking harder and harder. We could hear the crash of falling objects. I yelled to my wife to get into the safety triangle by the bed and we rolled off the bed onto our respective sides onto the floor to lie adjacent to the bed (if the ceiling comes down, the theory is that a triangle or wedge of safe area will be formed where you can survive). The noise continued, now also deafening with the continued crashes and tinkling of pictures falling to the floor, china crashing onto the tiled kitchen floor having "walked" across and out of the cabinets, and falling furniture, and the whole building was shaking and moving as if it was in the hand of a giant or a dice shaker. It seemed to go on for ever –approximately a minute and a half, but it seemed like an eternity. The shaking and the noise finally subsided and stopped with one final crash as the barbecue fell over, and we struggled to our feet, trembling with nervousness.'

Source: Richard Fletcher

a campsite packed with people on holiday during the weekend of 27 and 28 February. Several ports on the coast were affected. The port of Talcahuano was hit by a wave 2.3 m high (the tsunami waves caused by the March 2011 earthquake in Japan reached up to 37.9 m in height). This flooded the main square, leaving behind a large fishing boat. Small fishing villages on the coast were also similarly affected. The port of Valparaiso was closed for a day due to damage caused by the tsunami. Robinson Crusoe Island, the largest

of the Juan Fernandez Islands, located 660 km off the coast of Chile, was struck by a wave which killed four people, with 11 others reported as missing.

The Pacific Tidal Warning Centre also predicted that a wave 4.8 m high could hit the Hawaiian Islands. A series of tsunami waves did reach these islands at noon on 27 February, but they were just under a metre high and caused little damage. As a precaution, a partial evacuation was ordered on Easter Island, 3,510 km from the coast of Chile. Warnings were also issued in 53 other countries with coastlines along the Pacific Ocean. Thousands of people in Japan left their homes in case of flooding, and there were reports of damage in Peru, Nicaragua, French Polynesia, with waves 1.8 m high. In Mexico and Hawaii, damage was only on a small scale. A tsunami warning was issued to places on Australia's east coast, predicting that large waves were possible for several hours during the Sunday following the earthquake, which led to the closure of several beaches. Waves of between 10 and 50 cm were recorded, but there was little damage.

Soil liquefaction
This is a process where soil loses its solidity and strength due to the stresses applied to it by forces like earthquake shockwaves. The process is especially common in sandy soils which are waterlogged, and can cause soil to flow like a liquid, hence the term liquefaction. It can explain why on a local scale, some places can see more damage from earthquakes than others. For example, in Concepcion, four eight-storey residential buildings were severely damaged. They had been built on a site composed of compacted sand. And all four bridges over the Bio Bio river near the same town were damaged, due to collapse as a result of liquefaction.

Management and response to the earthquake

In January 2010, Haiti was hit by an earthquake which killed 220,000 people. The 2010 Chilean earthquake was 500 times stronger than the one in Haiti, but resulted in only 521 deaths.

The difference in the death toll partly reflects lessons learnt as a result of the Valdivia earthquake, in May 1960, which struck in the same area as the 2010 earthquake. Then, 1,655 people died and two million people were left homeless. After this, the government developed an improved design code for new buildings to enable them to better withstand earthquakes. This requires the framework of buildings to be constructed of heavily reinforced concrete columns which can resist the forces resulting from an earthquake. This did seem to help to prevent widespread building collapse in Chile, whereas in Haiti, many deaths were due to people being buried under collapsed buildings.

Immediately after the earthquake the President of Chile, Michelle Bachelet, declared a state of catastrophe and declared six regions of the country – Valparaiso, Metropolitana, O'Higgins, Maule, Bio-Bio and Araucania – disaster areas. Soldiers were sent to the worst affected regions of Maule and Bio-Bio to prevent looting of food and electrical goods. These troops took control of these regions and imposed a curfew, in some cities restricting residents to only six hours outdoors during the day. Troops delivered basic supplies to houses.

The government also reached an agreement with the major super-markets to give basic foodstuffs to people affected by the earthquake. At first the government did not call for international help, but when the full extent of the damage was realised, assistance was requested in the form of field hospitals, water purification plants, temporary bridges, and expert damage assessment. The United States provided water, food and satellite communications equipment. The UK's Lancashire Fire and Rescue Service donated a 'trapped person locator', which uses microphones to detect noise and vibrations, making it easier to locate people who are trapped in collapsed buildings. Non-government organisations like the Red Cross also helped. $58 million was raised by a 24-hour telethon on Chilean television.

Five days after the earthquake, some 400 lorries had been sent to the worst-affected areas, carrying 16,000 tonnes of emergency aid. To provide accommodation for people who had lost their homes, 12 emergency housing areas were set up, composed first of tents and then wooden huts 2 x 5 m in size for individual families. Six months on from the earthquake, some residents in affected areas were critical that more had not been done to rebuild housing, but the government argued that new building could not take place until detailed surveys had been made to ensure that potential land for building was safe for housing in the event of another earthquake.

In the longer term, the government set up a special fund to pay for the rebuilding of houses, hospitals, roads and schools.

Focus Questions

1. (a) Identify the main processes of tectonic activity found at destructive plate margins.
(b) Describe the landforms found at destructive plate margins.
(c) What are the processes at destructive plate margins which produce the landforms found there?

2. (a) What is the difference between conservative and destructive plate margins?
(b) Why is it particularly dangerous to live near destructive plate margins?

3. Using the February 2010 earthquake as an example, suggest how far the impact of an earthquake is dependent on its magnitude.

4. (a) Identify the physical characteristics of tsunamis.
(b) What causes tsunamis?