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Devastating earthquakes strike Haiti and Chile

The earthquakes that caused devastation in Haiti on 12 January 2010 and in Chile on 27 February 2010 have reminded us once more of the tremendous destructive power of nature. The magnitude 7 Haiti earthquake is believed to have claimed 230,000 lives; in contrast current estimates of fatalities caused by the magnitude 8.8 Chilean earthquake stand at less than 1,000, even though the earthquake released 500 times the energy of the Haiti event. However, in both countries there has been destruction of homes, businesses and infrastructure on a huge scale, creating a human and economic catastrophe that will take years to recover from.

What caused the earthquakes?

Both earthquakes occurred at the boundary between two of the tectonic plates making up the Earth's surface. The plates are constantly in motion and where plates meet some parts of the boundary between them can lock, rather than creep past each other, and just as forces increase as a spring is compressed or stretched, stresses build up in the rocks as they are strained by the forces driving the plate motions.

Plate boundaries may be hundreds or thousands of kilometres long and major earthquakes happen when a locked section of the boundary suddenly gives way, slipping and releasing the strain energy that may have accumulated over hundreds of years. In the Haiti earthquake a 70 km section of the boundary between the Caribbean and North American plates ruptured; in the Chile earthquake the rupture 'unzipped' over a length of around 700 km and this took about 120 seconds. The rupture area and slip determines the earthquake magnitude and energy release.

Why weren't the earthquakes predicted?

It seems that after every damaging earthquake the question is asked "Why didn't scientists predict the earthquake?" To start to answer this question a definition of a successful prediction is needed. Firstly a prediction must demonstrate some level of skill. There are around 900 earthquakes of magnitude 5 or more each year, so 'predicting' that one will happen somewhere in the world tomorrow is unlikely to be wrong. However, with around only 20 earthquakes each year of magnitude greater than 7, giving odds of 17:1 against, predicting one correctly clearly requires skill, and the ability to do so is of great interest since earthquakes of this size have the potential to cause considerable damage.

A simple view is that a successful earthquake prediction should give the location, magnitude, and timing of the earthquake, with each parameter having a stated range or uncertainty. However, the commonly-held idea of an earthquake location being the epicentre which acts as a point source of energy release is quite wrong for large magnitude earthquakes as energy release is distributed along the length of the associated rupture. The epicentre is simply the point where the earthquake starts. So a complication is that a successful prediction needs to describe in some detail the process of rupture and energy release as this will strongly influence the impact of the earthquake. And to be useful, an earthquake prediction must be made sufficiently far in advance that decisions can be made to implement measures to reduce the impact of the event.

Even given a prediction with a high degree of confidence, in practical terms there are limitations to what can be done. It is unrealistic to consider evacuating a city with a population of several million inhabitants given a prediction made a few days or weeks in advance of a destructive earthquake, especially in poorer countries, many of which have huge cities in vulnerable locations. And to give a false alarm, where no earthquake happened within a narrow time window around the predicted time, would be intolerable if a major evacuation had been carried out.

What does modern science have to offer?

Earthquake prediction is clearly a formidable problem and many scientists contend that the processes involved in earthquake generation are inherently unpredictable. This is not to say that science cannot help; it definitely can.

Quite simple calculations can be carried out for plate boundary earthquakes. If one plate moves relative to another at 5 cm/year and if there is evidence from past events that locked sections of the plate boundary rupture when strain has accumulated to prevent 5 m of slip, then this leads to an earthquake cycle of around 100 years. This kind of statistic is a rough indicator of the frequency of earthquake recurrence and is one of the lines of evidence used by scientists in recent publications who identified the epicentral areas of the Haiti and Chile earthquakes as ‘hotspots’. However, these publications were not predictions, rather warnings pin-pointing areas of high earthquake hazard.

Very useful results can be found by taking a probabilistic approach to seismic hazard assessment, based on evidence of past and current earthquake behaviour from fieldwork and historical accounts. Seismic hazard maps most usually give estimates of the probability of a given level of ground acceleration being experienced at a site of interest within a certain time. These estimates are used in risk assessments in combination with data on the distribution of vulnerable elements exposed to the shaking, including people and built infrastructure. To refine estimates, local ground shaking, local geology and ground conditions must be considered in detail; the effects of an earthquake on buildings built on solid rock will be quite different to those built on soft sediments which may have a more ‘jelly-like’ response. Seismic hazard assessments are essential in informing the choice of locations for structures and for developing building regulations.

Today we have networks of seismometers recording earthquakes worldwide and giving the ability to monitor and model stress changes in the solid Earth. GPS and satellite observations are capable of detecting slow ground deformations (but not beneath the oceans). Such observations allow ground deformation on land following earthquakes to be measured accurately, and this information can be used to show where the hazard has increased and decreased. Advances in both observation and theory are enabling science to improve earthquake hazard maps and to monitor how hazard changes with time.

Outlook

Future potentially damaging earthquakes in regions close to many of the world’s major cities including Tokyo, Istanbul, Tehran, San Francisco, Lima, and Port-au-Prince again, are inevitable. It’s a case of ‘when’ rather than ‘if’. Modern science can readily identify the areas at risk and methods for engineering earthquake-resistant buildings are well established and add very little to overall construction costs. Ways to improve the earthquake resistance of existing buildings by retro-fitting structural supports are also well understood. However, this knowledge is useless unless it is applied to develop appropriate building regulations that are then enforced. Impacts can also be reduced simply by providing the public with advice on how to act when an earthquake happens. Earthquake drills in schools are an effective method for earthquake education. Plans must be developed to ensure an effective response is made to the immediate emergency situation following a damaging earthquake, and also for the longer term recovery phase where displaced people have to be cared for and buildings and infrastructure need to be repaired or rebuilt.

Given the continuing growth of mega-cities in earthquake-prone areas in poorer countries, many seismologists are fearful of a future earthquake disaster with more than a million casualties. Disasters and the ensuing human tragedies cannot be prevented entirely, but application of current scientific and engineering knowledge can dramatically reduce their scale. It is generally well appreciated that, in purely monetary terms, the costs of disaster recovery can be very significantly reduced by investment in disaster preparedness and mitigation. This understanding has translated into policy in some countries but not in others. The comparative number of deaths in Haiti and Chile illustrates this point.

In summary, to reduce the consequences of future earthquakes it is more pertinent for societies, planners and decision makers in earthquake-prone regions of the world to ask “Are we sufficiently prepared for the next major earthquake”, and to seek scientific and engineering advice on this question rather than ask whether the next major earthquake can be predicted.

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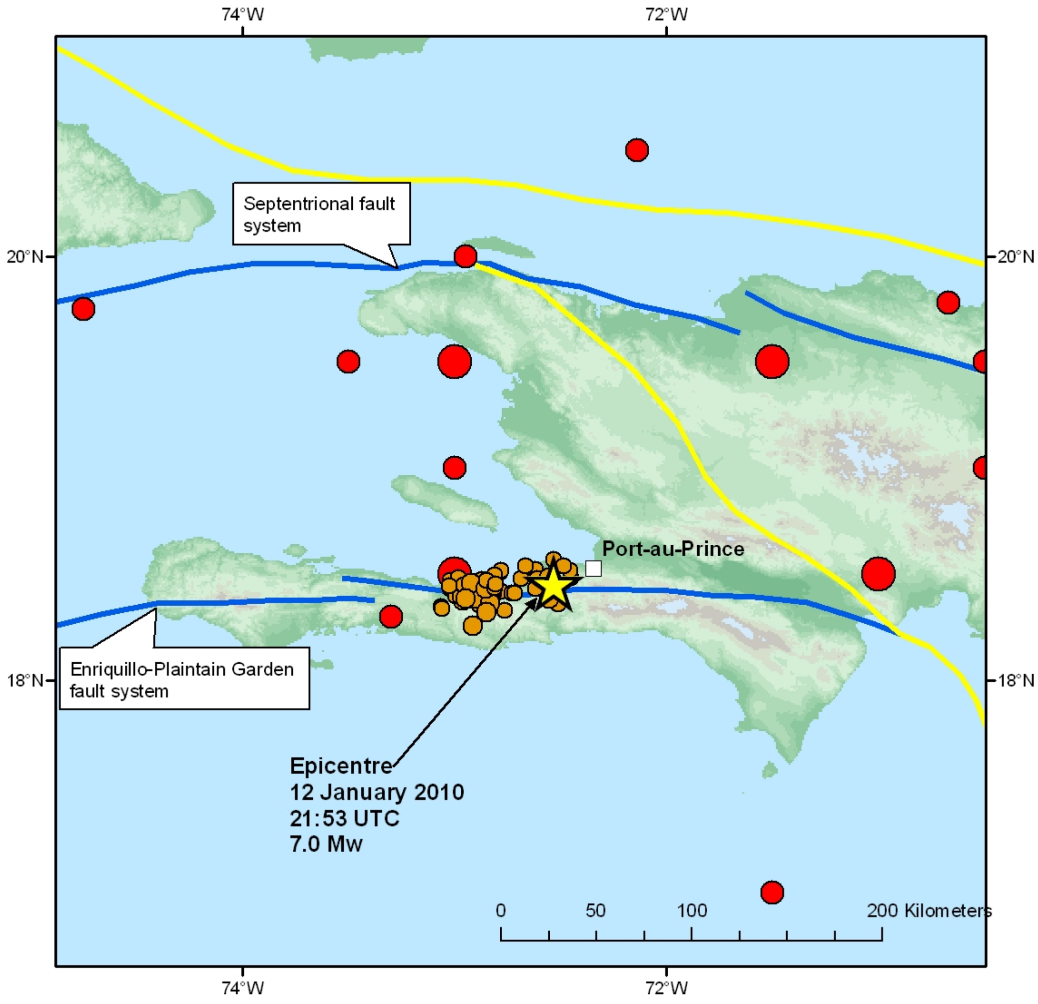

Fig. 1. The epicentre of the 12 January 2010 earthquake in Haiti (yellow star) was around 25 km west of the capital Port-au-Prince and the distribution of aftershocks (orange circles) reveals rupturing along the plate boundary over about 70 km.

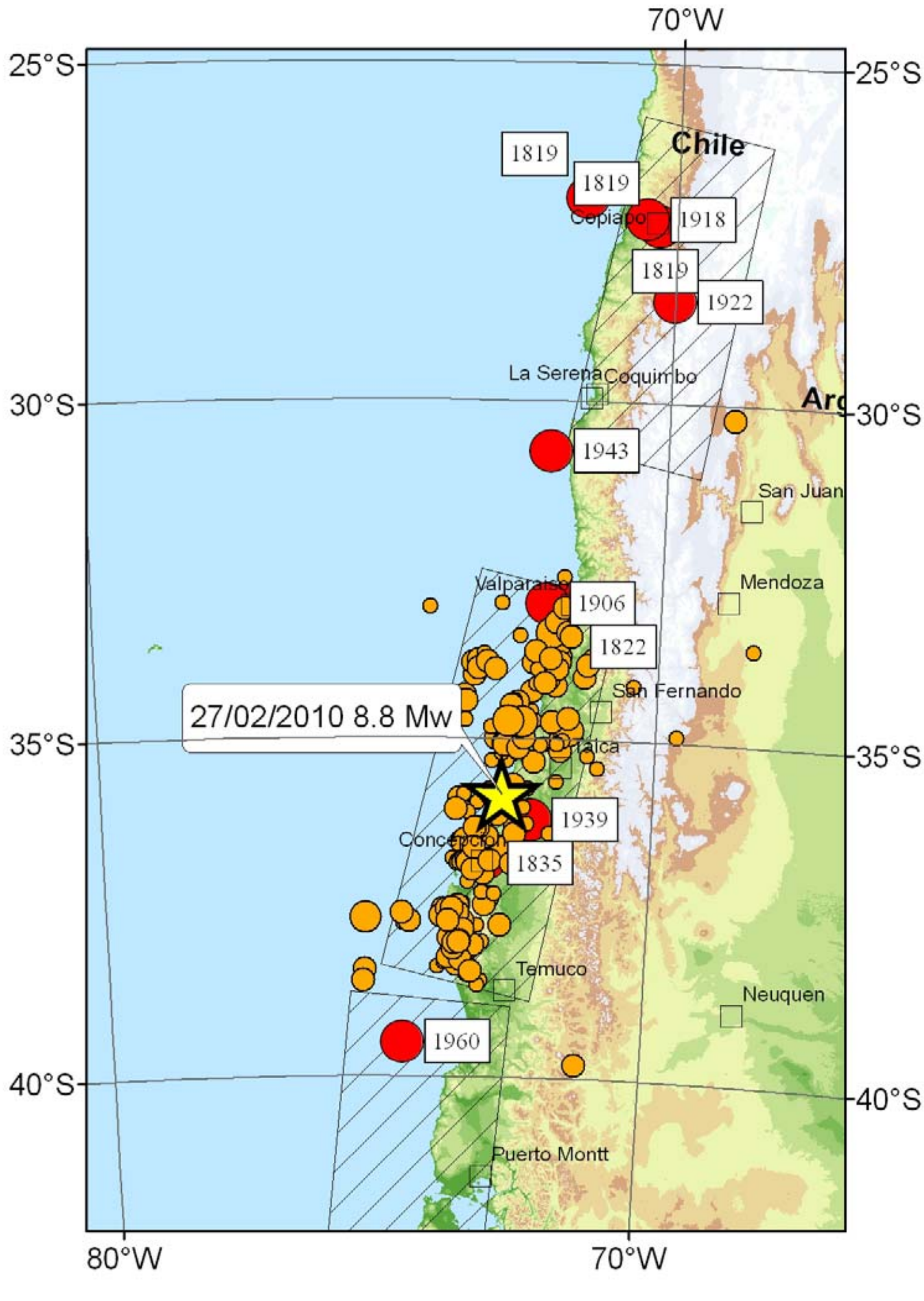

Fig. 2. The epicentre of the earthquake offshore Chile on 27 February 2010 (yellow star) was around 100 km north east of the city of Concepcion and 300 km south west of Santiago. The earthquake rupture was over 700 km long, as mapped out by the aftershocks (orange circles).