EARTHQUAKES

Giant returns in time

Sergio Barrientos

The behaviour of a seismic fault in Chile seemed to confound predictions of how often giant earthquakes should recur. Examination of a 2,000-year record of tsunami deposits in the region clarifies matters.

In May 1960, south-central Chile experienced a huge earthquake, the largest since instrument records began. The consequences were felt not only in Chile, but also in Hawaii, the Philippines, Japan and other locations across the Pacific, which were all hit by the ensuing tsunami. But this giant seismic event has long puzzled seismologists, because the energy released by the earthquake should have taken several centuries to build up, through the accumulation of stress on the fault concerned, as the Nazca and South American tectonic plates converge at a rate of 8–9 centimetres per year. Yet the immediately preceding events are historically documented as occurring not only in 1575, which would fit expectations, but also in 1737 and 1837.

As they describe on page 404 of this issue[1], Cisternas *et al.* have revisited this puzzle by examining records of land movement and tsunamis left in buried layers of sand and soil in an estuary that runs across the central part of the fault zone (see Fig. 1 of the paper, page 404). With these records, and earlier ones (Fig. 1), the history of activity on this fault can be rewritten.

Since the inception of instrumental recording in the late 1800s, the largest earthquakes have all occurred in subduction zones[2], where one tectonic plate is being driven beneath another. These earthquakes involve ruptures on the order of a thousand kilometres long by a couple of hundred kilometres wide, with fault displacements of tens of metres. Hundreds of years are necessary to accumulate the stresses released in these giant events, which leave traces of their consequences that can later be identified.

Thanks to the work of Cisternas *et al.*[1], we now have more insight into the seismic cycle in south-central Chile. The earthquake of May 1960 resulted from a rupture, about 1,000 km long and 150 km wide, along the north–south-trending fault where the Nazca plate dives beneath South America. Earthquakes of this size saturate the recorders of the seismic waves that are usually used to estimate earthquake magnitude and which are reported in terms of the familiar Richter scale. Instead, a measure known as seismic moment is used[3]. This is now more commonly applied to seismic events in general, and is calculated by multiplying the area of the rupture zone by the fault displacement and a quantity reflecting the rigidity of the volume in which the rupture takes place. The moment magnitude, derived from this quantity, reflects the real size in terms of the elastic energy release of an earthquake.

The 1960 earthquake measured 9.5 on the moment-magnitude scale. It has a special place in seismological history, because it provided experimental confirmation of the idea that earthquakes can cause free oscillations of the Earth[4] — that is, set the Earth ringing. The observed changes in land elevation ranged from 6 m of uplift to 2 m of subsidence; these displacements have been modelled[5,6] as the elastic response of the Earth to an average dislocation of 20 m along the fault, with localized peaks of more than 30 m. Even now, in 2005, post-seismic readjustments continue to be observed in the area[7].

Cisternas *et al.*[1] undertook a detailed examination of a local stratigraphic record of earthquakes in south-central Chile, as produced by the associated tsunamis and seen in layers of intercalated sand and soil extending horizontally for nearly a kilometre close to the mouth of the Río Maullín. This region subsided approximately 2 m as a consequence of the 1960 event, but the stratigraphy has been preserved because of long-term net tectonic uplift. Overall, the authors were able to identify a sequence of eight large earthquakes that have occurred over the past 2,000 years, with an average recurrence interval of about 300 years.

But what about the apparent recurrence sequence of 1575, 1737, 1837 and 1960, which does not fit this pattern? The consequences of the 1575 event are evident both from carbon dating and in documents written by the Spanish conquistadors, which tell of effects that were similar to those seen in 1960. Documentation of the earthquakes of 1737 and 1837 is less clear, but they are frequently cited in the seismological histories of the region as being large (estimated magnitudes of 7.5 and 8.0, respectively)[8].

Cisternas *et al.*, however, find that although the 1575 earthquake appears clearly in their tsunami stratigraphic record, those of 1737 and 1837 do not. A tsunami was associated with the event of 1837, reaching Hawaii with an amplitude of 6 m. But Cisternas *et al.* suggest that it originated outside their study area, to the south, and they conclude that the earthquake of 1737 was too small to generate a sizeable tsunami. All in all, they propose that much of the fault dislocation that occurred in 1960 stemmed from a release of energy that had remained 'locked in' since 1575 — that is, the earthquakes that occurred between those times had expended comparatively little of the accumulated stress.

The relevance of these studies is underlined by the more recent occurrence of a huge earthquake elsewhere in the world. In December 2004, and again in March 2005, the eastern Indian Ocean was seriously affected by tectonic movement at a subduction zone. The giant December event stemmed from a displacement of up to 30 m along a rupture 1,100 km in length[9], which produced the devastating tsunami that swept across the Indian Ocean — a startling reminder of the need to learn more about the behaviour of giant earthquakes. ■

Figure 1 | Spot the surveyor. In this print, produced in 1874, the figure of Francisco Vidal Gormaz can be seen at work in the coastal village of Carelmapu in southern Chile. Here he surveys part of the region that will be hit by the 1960 earthquake; his records have helped in interpreting the earthquake.

Sergio Barrientos is at the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization, PO Box 1200, A-1400 Vienna, Austria.
e-mail: sergio.barrientos@ctbto.org

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