of the technique allowed detection of higher dopa-iron content within cuticular granules as opposed to the continuous cuticular matrix.

An earlier observation that cuticle hardness is reduced by ~50% upon chelation of iron by EDTA (*3*), along with the observation by Harrington *et al*. of a disappearance of Raman spectroscopic signal of dopa-iron, suggested a connection between dopa-iron complexes and mechanical properties (*3*). The authors propose a model whereby dopa-iron complexation contributes both hardness and extensibility to the thread cuticle. Additional detailed experiments will likely be necessary to further elucidate the chemomechanical basis for these properties. However, single-molecule experiments have demonstrated substantial bond-rupture forces between dopa and metal oxide surfaces (*6*). These results, together with the successful use of catechols as anchors for grafting molecules onto metal oxide surfaces (*7–11*), leave little doubt that dopa-metal coordination interactions of the type spectroscopically detected by Harrington *et al*. can impart mechanical stabilization.

Evidence is accumulating for metal coordination as a biological strategy for fabricating mechanically competent organic tissues in which there is little or no inorganic mineral present. For example, in the case of the hard load-bearing jaws of polychaetes, a type of annelid worm, coordination complexes between histidine and copper or zinc are suggested to play an important role in mechanical performance of the tissue (*12*). By contrast, in the dopa-iron complexes of the byssal thread cuticle, metal coordination occurs entirely through catechol.

Metal coordination bonds acting as cross-links in polymer and protein systems are expected to behave quite differently under applied force than covalent cross-links do. For example, coordination bonds can be considered sacrificial, in that they can break under an applied load, but then re-form when the load is withdrawn. It will be interesting to see if this molecular behavior proves to be the underlying basis of the macroscopic observations of self-healing in byssal threads. Synthetic materials scientists exploiting dopa-iron complexes will likely be inspired by this study. Indeed, one report exists of self-assembly and stabilization of collagen-like peptides mediated by catechol-iron interactions (*13*).

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Movie S1

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GEOPHYSICS

Central Chile Finally Breaks

It has been known for 10 years that the site of the Maule mega-earthquake of 27 February 2010 was fully locked and ready to break.

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Chile is the site of some of the largest earthquakes in the world: On average, a magnitude 8 earthquake occurs there every 10 years or so. These earthquakes take place in the subduction zone, either as interplate ruptures at the interface between the South American and Nazca plates or as intraplate events within the subducted Nazca plate. A few times in every century, massive plate-interface earthquakes break several hundred kilometers in a single shock. This is what happened on 27 February 2010, when a major earthquake (magnitude 8.8) occurred in the Maule and Biobío regions in central Chile (see the first figure). This region had last experienced a major subduction earthquake in 1835, when Darwin (*1*) visited the area as part of his voyage on the Beagle. His description of the earthquake inspired many seismologists and historians of Chilean earthquakes (*2*, *3*).

In the early 1970s, Kelleher proposed that Chilean earthquakes occurred on "gaps" left from previous large events (*4*). At the time, the Maule region was not identified as a gap, because a very large earthquake (magnitude 7.8) had occurred there on 25 January 1939 (*5*); the deadliest event in Chile to date, it claimed some 20,000 lives (*3*). In the 1990s, seismologists found that the 1939 earthquake was not a subduction earthquake but the largest intraplate event ever recorded in Chile (*6–9*).

Once the region between Concepción and Constitución in Chile was identified as seismic gap, a group of Chilean and European researchers decided to take a closer look into the area (*10*). They discovered that the plate interface was completely locked (coupled), so that stress was building up at the fastest possible speed. Interpretation of the geodetic data obtained by several groups (*11–16*) showed that coupling along the Chilean subduction zone changes widely from south to north but is largest in the most ancient gaps.

In the second figure, we show the plate coupling in the area of the Maule earthquake derived from all available GPS data. The red areas

Tsunami damage. Shortly after the Maule mega-earthquake, a tsunami hit nearby coastal areas, such as the village of Penco (near Concepción), shown here.

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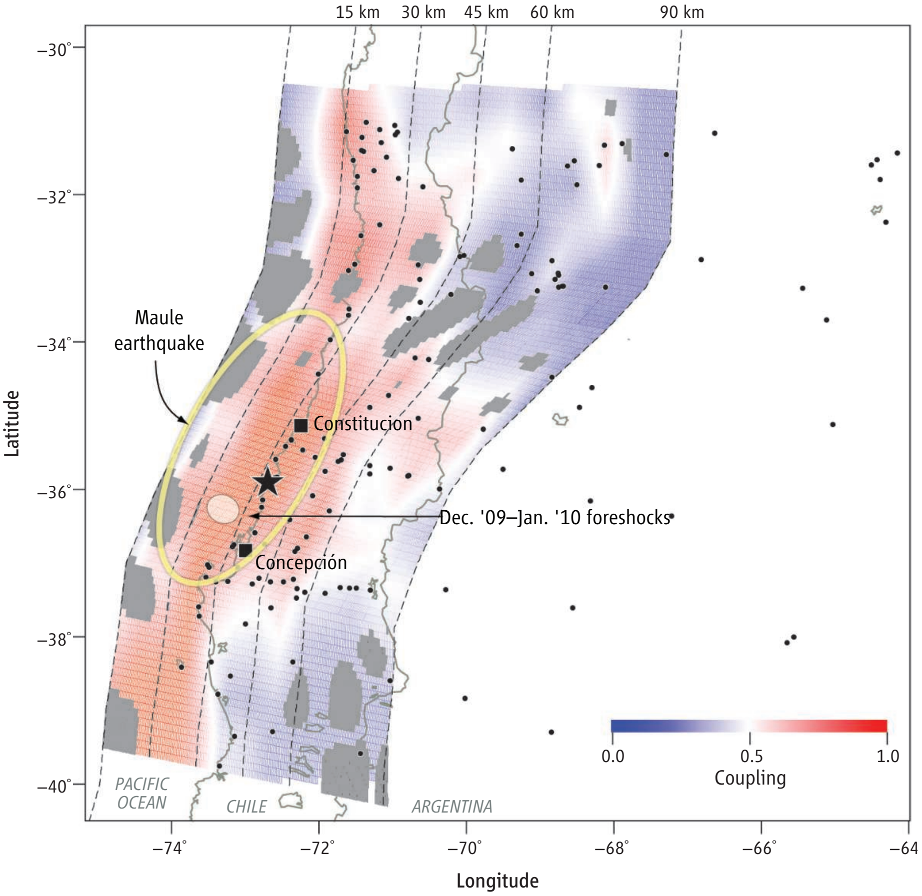

Stress accumulation in central Chile before the Maule earthquake on 27 February 2010. The figure shows the degree of coupling (or locking) of the plate interface between the Nazca and South American plates. The dark red areas coincide very well with the rupture zone (yellow ellipse). Dots are the GPS sites used to generate the image. The large black star is the epicentre of the earthquake. The small ellipse is the area where foreshocks were observed from December 2009 to January 2010.

of the plate interface are those where the two plates have been completely locked since at least 2000. A detailed seismic study of the area was unfortunately not possible because its seismicity was weak and very few seismometers recorded it. According to earthquake catalogs, only 10 earthquakes of magnitude greater than 5 occurred in the Maule and Biobío regions in the 10-year lapse before 29 December 2009. On that date, a series of events started to break the elliptical zone plotted in the figure, less than 30 km from the future epicenter of the Maule earthquake.

The Maule earthquake caught Chile without a seismic network capable of recording large earthquakes. A few accelerometers in Chile and Argentina recorded the earthquake; this is the first mega-earthquake for which digital strong motion data from near the source is available. Geodetic data of the main event are more abundant: The earthquake took place inside campaign GPS networks deployed by several groups (*13*–*16*). A continuously recording GPS receiver in Constitución recorded a peak oceanward displacement of more than 4 m. Because of the lack of a continuously recording strong-motion network, the Chilean government had no reliable information about the earthquake and could not prepare for the tsunami that hit the coastal cities near the earthquake less than an hour after the main shock (see the first figure). There was no earthquake-proof communication network, hampering the emergency response.

Despite its magnitude, the Maule shock had an official toll of fewer than 500 victims—a small number compared to several recent events. The reason is the good performance of modern earthquake-resistant building designs and the rapid reaction of the population that escaped from the tsunami in spite of the hesitation of authorities. At the epicenter, the earthquake produced horizontal ground accelerations of up to 6 m/s^2 (that is, about 60% of the acceleration of gravity, the unit used by earthquake engineers), but accelerations were lower in the more populated central Valley of Chile. These peak accelerations are within the earthquake design requirements of the Chilean seismic code. Well-built structures sustained some heavy damage, but very few collapsed, in sharp contrast to some doomsday scenarios disseminated a few years ago by geographers in the Chilean press.

Studies farther north along the Chilean coast show that a similar stressing of the plate interface is occurring between the Mejillones Peninsula and the boundary between Chile and Peru. This region, known as the Tarapacá gap, last had major earthquakes in 1868 and 1877, with magnitudes close to 8.7 (*2*–*5*). Chilean, European, and American researchers have deployed a network of seismic and geodetic instruments in Northern Chile. The Tarapacá region is showing signs of renewed activity: A large earthquake of magnitude 7.8 occurred in November 2007 at the southern end of the gap, and since last year, the city of Iquique has experienced several magnitude 6 events. It is urgent that the data from this network is processed in real time in Chile to provide early warning when the next large earthquake strikes in the next few decades.

The main lesson from the Maule earthquake is that the sites of rare catastrophic events can be identified in advance, but it remains impossible to predict when these events will occur (*17*). Mega-earthquakes are rare events that require a long-term public policy of enforcement of building regulations. In Chile, buildings resisted well, but communication networks failed. Tsunami alarm could also work if the appropriate instruments—continuous accelerometers like those of northern Chile—are used together with an earthquake-proof communication network in order to compute almost-real-time location and magnitudes in Chile.

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