27 February 2010 Concepcion, Chile Earthquake – Status on scientific information

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Christophe Vigny
« Directeur de recherches » at CNRS
« Laboratoire de Géologie » de l'ENS, UMR8538 of CNRS
On behalf of direction of International associate Laboratory (LIA) «Montessus de Ballore» [3]

Saturday, 27 February 2010, at 6h34 UT, an Earthquake of magnitude 8.8 occurred on the Chilean subduction near the cities of Concepcion, Constitucion and Valparaiso. This event takes place in a long list of earthquakes which have been occurring all along the Chilean subduction zone for centuries.
From North Patagonia to Southern Peru, this seismic prone area is quite simple: it is simply the boundary between two tectonic plates, converging towards each other (figure 1). Here, it is the Nazca plate which moves towards the South American plate at a rate around 7 cm/year. The motion is slightly oblique but is entirely absorbed on a single fault at sea. Along this fault line, the Nazca plate goes under the South American plate and dives into the earth mantle, in what geologist call subduction.

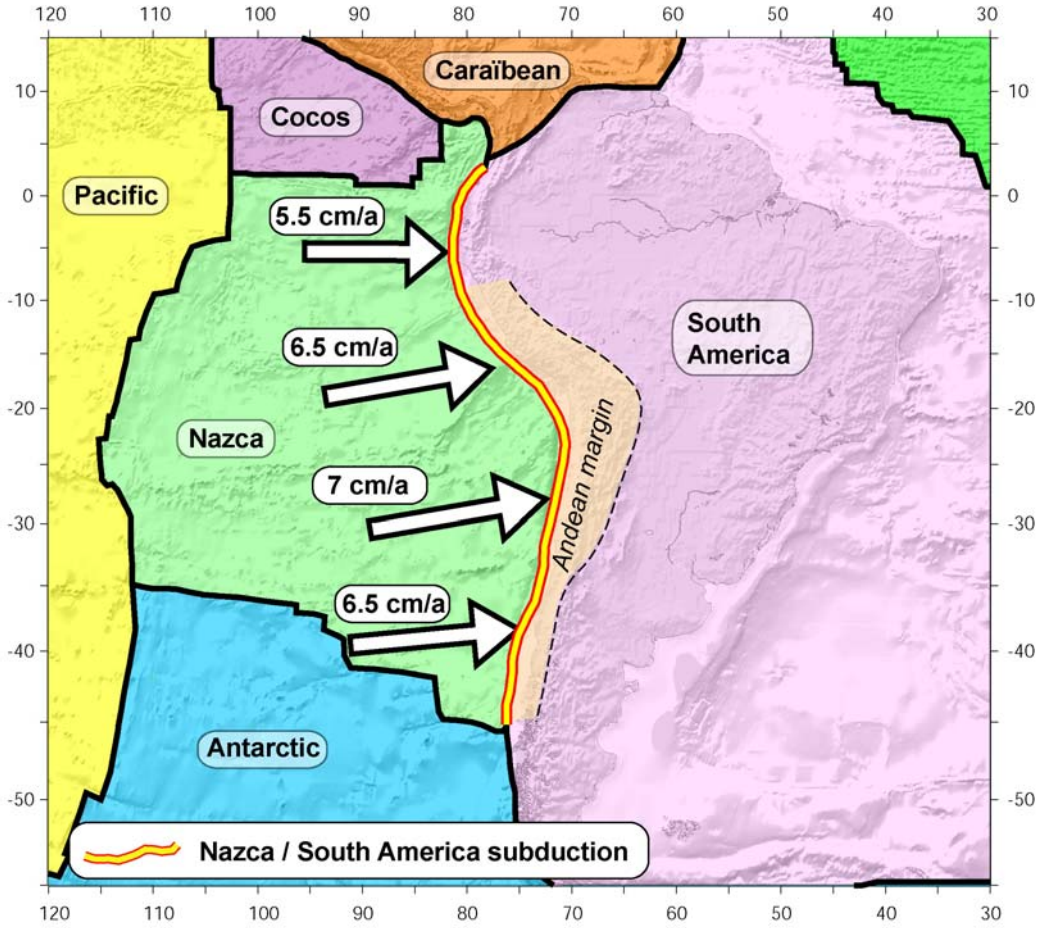

Figure 1 : plate tectonics in the Andes. The thick red/yellow line shows the subduction of Nazca plate under South America. The dashed line shows the deformed Andean area inside the plate. Arrows depict direction and velocity of plate convergence determined by GPS.

Seismicity in Chile and 27-02 Eq.

Because of the rapid Nazca-South America convergence, the chilean subduction has a strong seismic activity, with a magnitude 8 earthquake every decade on average and a Mw > 8.7 earthquake at least every century. In addition, the largest earthquake ever recorded since the modern era of seismology and seismographs (Mw 9.4-9.5) occurred in Chile in 1960, just south of Concepcion.
Following the studies we conducted in Chile over the last decades, and following others, we indentified at least 2 seismic gaps in North and South/central Chile, which seemed mature for an imminent earthquake (areas circled in red on figure 2). The Arica gap in he north, where a giant earthquake occurred in 1877 and which started to brake partially with the 2007 event of Tocopilla; and precisely this seismic gap of Concepcion, where an Earthquake with magnitude significantly larger than 8 occurred in 1835 and was described by Darwin on his Beagle trip. This gap was delimited to the south by the giant rupture of 1960 and to the north by the more recent earthquakes of Valparaiso in 1906 and 1985. In this region, our GPS measurements showed that elastic accumulation was "normal", with full locking on the subduction plane and no aseismic creep of any kind. In 175 years and at 7 cm/years, it is at least 12 meters of deformation that were accumulated on this 400km long segment. Consequently, in a recent publication in PEPI, we indicated the gap was a likely spot for a major [magnitude-8.0 to 8.5] subduction earthquake in the coming decades.

The epicentre of the 27- February earthquake (red star on figure 2) is right in the middle of the Concepcion gap. Its depth and focal mechanism leave no doubt that it is a normal subduction earthquake, occurring on the interface between the two plates (figure 3). As aftershocks distribution shows, the rupture propagated symmetrically both North and South, so that to rupture the entire length of the seismic gap. They also show that the rupture may be slightly longer because aftershocks also occur north of Constitucion and up to the latitude of Valparaiso, possibly meaning a reactivation of this segment, which could in turn explain the large magnitude of this earthquake (with respect to the 1835 event). The fact that the epicentre is not shallow (35-40 km) can also explain the relatively moderate amplitude of the triggered Tsunami: around 5 meters though, possibly slightly more locally, following the empirical and simple 1-to-1 relation between inundation maximum levels (run-up) and maximum slip on the fault. Starting deep, the rupture would reach the surface weakly and generate a moderate ocean bottom displacement. However, this locates the hypocenter very close to the cost line (rather than farther of shore), which on the opposite would generate a higher level of destruction on coastal cities like Concepcion or Constitucion, and even farther inland like at Cauquennes.

The distribution of the first aftershocks raises a question. They seem to indicate a long rupture, around 600 km, which would on one hand explain the large 8.8 magnitude, but on the other hand, is much longer than the Concepcion seismic gap. It also does not seem to be compatible with the first source models inversion made by G. Hayes (NEIC), which indicate a rupture length of only 350 km, which in turn perfectly fits the 1835 gap (figures 5).

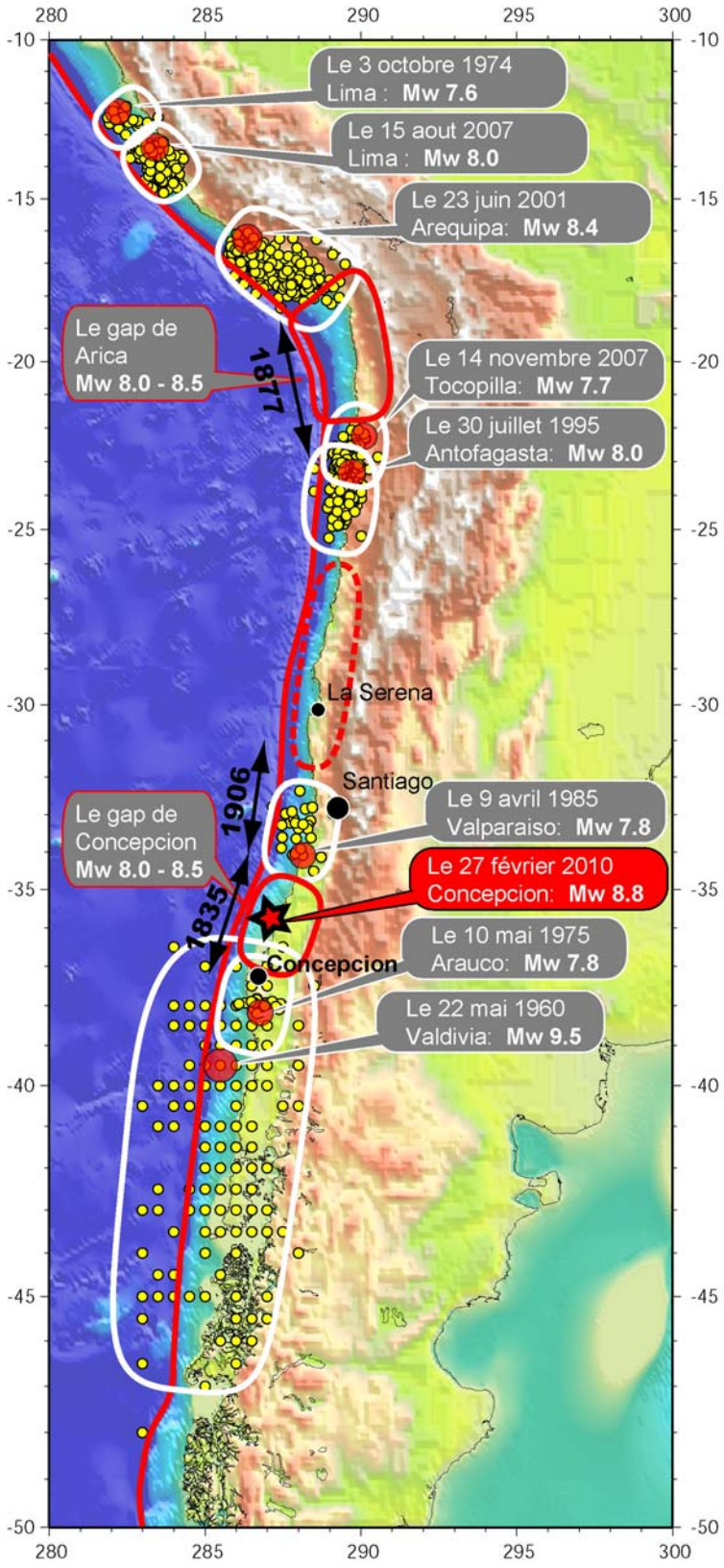

Figure 2 : Chilean earthquakes and the epicentre of 27-feb event. Large red dots show large earthquake epicentres, small yellow dots show their aftershocks. These depict the surface of the main shock rupture, and then circle by a white line. Red "ellipses" depict the areas which did not produce any significant earthquake for a long time… until yesterday. They are seismic gaps. He red star shows the epicentre of 27 February earthquake near Concepcion.

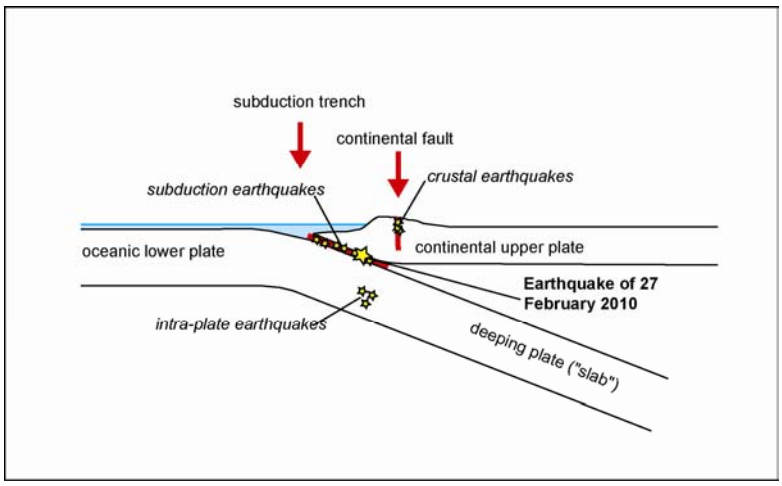

Figure 3 : schematic detail of a cross cut section of the subduction, and earthquake type depending on their depth and distance to the trench.

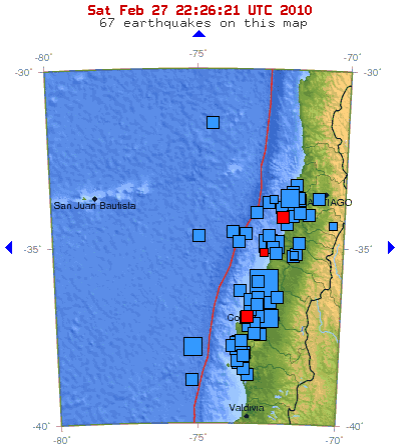

Figure 4 : First series of aftershocks localised by USGS-NEIC (blue rectangles). They clearly show a rupture extending over almost 600 km, much longer than the 350-400 km length of the Concepcion gap.
http://earthquake.usgs.gov/earthquakes/recenteqsww/Maps/10/285_-35.php

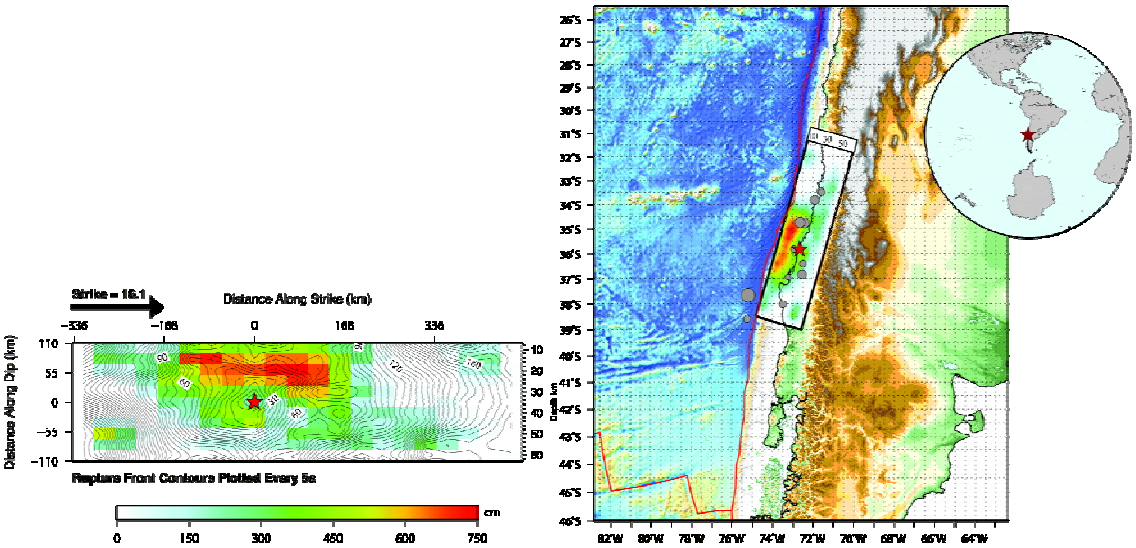

Figure 5 : preliminary rupture models made by Gavin Hayes (NEIC-USGS), indicating an epicentre around 35-40 km depth, perfectly localised on the subduction plane, and a rupture length limited to around 350 km.
http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/finite_fault.php

Some important questions hold now :

- Did the earthquake of 27 February release all the elastic deformation accumulated since 1835 ? If yes, then aftershocks will happen, but smaller and smaller and less and less frequently. Otherwise, we should expect other large earthquakes in this same area, now fragilized by this first rupture.
- Can strain and stress increase at both ends of this rupture trigger other earthquakes North and South of it ? To the South, this seems not very likely because it was there that the giant earthquake of 1960 occurred and this segment did not even start to re-accumulate elastic deformation since. To the north, it is still possible, the events of Valparaiso (1906 and 1985), La Serena (1943) and Vallenar (1922) having released only a fraction of the accumulated deformation since the last very large earthquake of 1730 there.
- Why do aftershocks show a rupture length of 600 km, in contradiction with first estimations of the source slip distribution ? The latest fitting well the size of the 1835 gap with a 350-400 km long rupture. Did a slow earthquake (a-seismic) occurred in this area ?
- Why are there aftershocks south of the Arauco peninsula ? Are they really aftershocks?

Geodetic and seismologic measurements allow quantifying and understanding some aspects of these earthquakes, and thus bring answers. In particular, continuous GPS stations installed in the area allow to determine how much deformation was released by the quake which just happened (all or part of what was available), if deformation is released slowly and silently (good news), or if on the contrary everything is locked. In the later case, one should get ready for a future earthquake and the latest the larger (bad news). Seismological networks, localising micro-seismicity and aftershocks, allow to draw the rupture fault plane. The whole feeds stress transfer computation with precise geometric elements (rupture size, direction, amount of slip, etc….)

Our team[(1)], in cooperation with Chilean institutes[(2)], makes geodetic (GPS) measurements in since 1996 in the area. In the framework of the international associated laboratory (LIA) "Montessus de Ballore" [(3)], we will re-measure the network of existing geodetic benchmarks to quantify precisely the crustal deformation inflicted by this earthquake, and visit and maintain our cGPS stations, among which some may have suffered (in particular the one installed in Constitucion and San Javier). We will also participate to the installation of a temporary network of seismographs dedicated to the precise locations of aftershocks and monitoring of this ongoing crisis.

More info : http://www.geologie.ens.fr/~vigny/chili-f.html

(1) Le laboratoire de Géologie de l'ENS et l'Institut de physique du globe de paris, UMR 8538 et 7154 du CNRS : P. Bernard, A . Fuenzalida, M. Lancieri, A. Lorme, R. Madariaga, M. Métois, S. Morvan, J.C. Ruegg, S. Ruiz, A. Socquet, J.P. Vilotte, C. Vigny

(2) University of Chile at Santiago and University of Concepcion : J.C. Baez, S. Barrientos, K. Bataille, J. Campos, S. Peyrat.

(3) Le LIA « Montessus de Ballore » is an international structure created in 2006 by University of Chili at Santiago and CNRS/INSU. It includes reasearchers and investigators from french and Chiean laboratories and its main objective is the study of active seismo-tectonics in Chile. More info on the LIA at : https://www.lia-mb.net/