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Rapid after shock deployment after the Mw=6.2 Aysen earthquake in Southern Chile

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Abstract

On February 23rd 2007, an earthquake M=5.2 took place in the Aysen Fjord, Southern Chile and started a sequence of earthquakes that culminated, at least in its critical phase, with the M=6.2 Aysen earthquake. The Aysen earthquake not only caused damage to buildings and installation, but also a significant number of casualties were reported. The aim of this study focuses on analysing the aftershock sequence of the main event in order to characterize the seismo-tectonics of this zone, which was formerly believed to have no significant seismic hazard. Up to now we determined accurate event locations by simultaneously inverting for station corrections and a 1D velocity structure. We also calculated preliminary fault plane solutions based on first motion polarities.
The results show that the aftershock seismicity is related to the main structure present in the area, the Liquiñe-Ofqui Fault Zone (LOFZ) and it is generated at shallow depths. Furthermore, fault plane solutions for some of the events indicate right strike slip faulting NNE trending which also coincides with the geometry and nature of this intra-arc transcurrent fault. Additionally, a new alignment of seismic events trending ENE has been observed in the region, which could be interpreted as a reactivation of an old structure or the rupture and development of a completely new fault subordinate to the main fault.

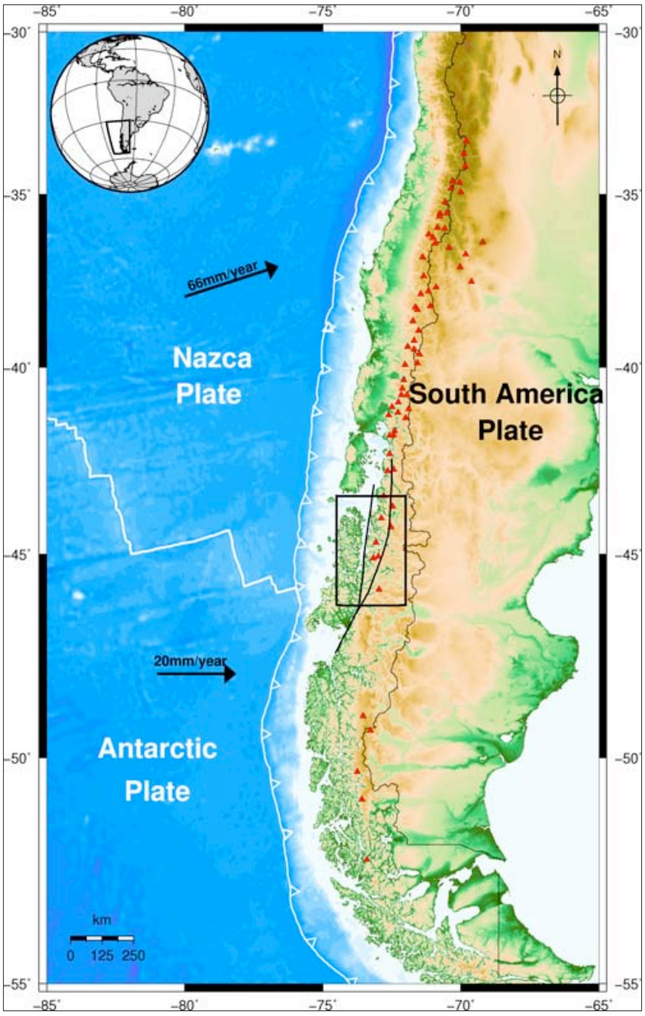
Background and survey procedure

Located in the South of Chile (see figure 1), the Aysen Region is of great tectonic interest since offshore the active Chile Ridge is currently being subducted (Herron et al., 1981; Cande et al., 1987) at the Chile triple junction. The oblique subduction between the Nazca and South America plates has caused the presence of the LOFZ, a +1000 km length strike-slip fault NNE trending located within the tectonic arc. The LOFZ accommodates part of the parallel component of the oblique convergence. While the northern edge of this fault system has been studied in great detail, the southern portion remains not very well understood. The present study will help to better understand and characterize this intra-arc fault, and will be a starting point for future studies in the region.
Recently, in early 2007, an earthquake sequence took place in this area, specifically at the Aysen Fjord as a result of the reactivation of the LOFZ, generating events of considerable magnitude and losses in resources and human lives. Seismic equipment was requested from SEIS-UK (urgency grant) in mid-2007 in order to record the aftershocks sequence of the main event, the Aysen earthquake of 21st of April 2007, which represents a unique opportunity to investigate this zone, which lacks of seismic studies due in part to its low seismicity and difficult accessibility.
In June-July 2007 we deployed a network of 5 three-component short-period seismic stations (SEIS-UK; see figure 2 and table 1) in the area around the Aysen fjord (see figure 2). Due to the severe weather conditions the remaining stations could only be deployed in the second half of September 2007. The recording period was extended to be able to still collect enough earthquakes for this study. All stations recorded continuously at a sampling rate of 50Hz for a period of nearly seven months. Unfortunately, only 13 stations produced data, one of those with timing problems. The deployment was especially difficult due to the weather conditions, accessibility, and the closure of the Fiord for all boat traffic, except Navy or Police boats during the whole deployment period. Navy or Police boats and 4x4 vehicles were used in order to reach the sites. The network was

unistalled in February 2008.

Data and processing

A visual examination of the waveforms was carried out using the software PQL (PASSCAL Quick Look), finding a total of 214 events. These events were processed using the GIANT software package (Rietbrock and Scherbaum, 1998), picking manually both P and S arrival times and assigning weights to each picking according to its quality. A total of 1535 P- and 1429 S- arrivals could be relaiable determined and HYPO-71 was used to get preliminary hypocentre location. After that, a selection of the best events in terms of number of observations (>6 P-wave arrivals), GAP (<180º) and RMS was done, giving a total of 47 high quality events. This selection was used as input for a simultaneous inversion of hypocentres, velocity model and station corrections using the software VELEST (Kissling et al., 1995) in order to improve the accuracy of the locations and to get a 1-D minimum velocity model for both P and S waves. Additionally, focal mechanisms were calculated for some events using first motion polarities processed (contained in the GIANT package's tools). Amplitude ratios were also used to better constrain the focal mechanisms.



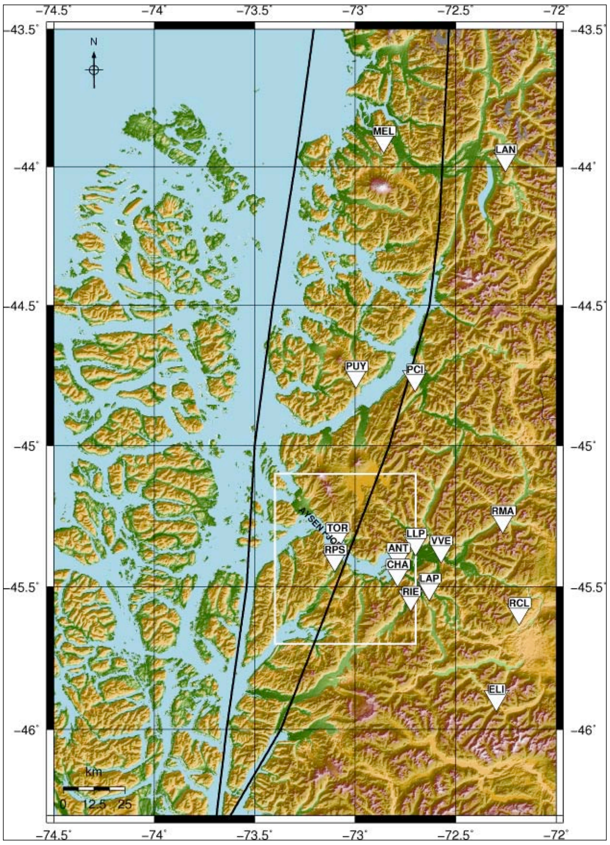


Figure 1 (left). Location and tectonic settings of Southern South America. LOFZ is shown in thin black line and red triangles correspond to Quaternary volcanism. Rectangle indicate study area. Velocity of the Nazca plate after Angermann et al. (1999) and velocity of Antarctic plate after Chase et al. (1978).

Figure 2 (above). Study area and distribution of stations around Aysen Fjord. Black line indicate LOFZ. White rectangle shows area in figure 3.

Name	Latitude	Longitude	ID	Installed/Removed	Name	Latitude	Longitude	ID	Installed/Removed
ANT	45.3926ºS	72.7855ºW	6030	27/06/07–16/02/08	PUY	44.7460ºS	72.9951ºW	6044	09/09/07-19/02/08
CHA	45.4505ºS	72.7890ºW	6102	30/06/07-16/02/08	RCL	45.5862ºS	72.1839ºW	6093	10/09/07-17/02/08
ELI	45.8890ºS	72.2971ºW	6188	No data	RIE	45.5366ºS	72.7228ºW	6071	04/07/07-16/02/08
LAN	43.9686ºS	72.2525ºW	6161	No data	RMA	45.2617ºS	72.2654ºW	6097	16/09/07-17/02/08
LAP	45.4999ºS	72.6317ºW	6051	01/07/07-01/02/08	RPS	45.3979ºS	73.1020ºW	6140	27/10/07-17/02/08
LLP	45.3411ºS	72.6993ºW	6217	12/09/07-16/02/08	TOR	45.3212ºS	73.0883ºW	6160	29/10/07-22/02/08
MEL	43.9009ºS	72.8583ºW	6178	24/07/07-19/02/08	VVE	45.3672ºS	72.5726ºW	6088	11/09/07-17/02/08
PCI	44.7580ºS	72.7023ºW		03/07/07-18/02/08					

Table 1. List of seismic stations deployed during this experiment.

Preliminary results and interpretations

Figure 4 shows the final 1-D velocity model obtained for both P- and S-waves, as was as for the vp/vs ratio. Dashed lines indicate range of starting models, grey lines indicate final models (best 5%) and the bold black line represents the best final model with the lowest overall RMS (0.04236s). Layers between 5 and 23 km depth are well resolved, but for the first 5 km a greater variability of the velocity models is observed. For the first 5 km depth, P-wave velocities between 4.99 and 5.18 km/s were determined. These values show concordance with the velocities expected for this area based on the geology, which corresponds mostly to granitic rocks from the Norpatagónico Batholit. At 5 km depth there is a significant jump of the velocities from 5.18 to 6.35 km/s probably due to the presence of mafic rocks beneath the granitic batholit. From 10 to 23 km depth the velocities are constant at ~6.6 km/s. For deeper layers (depth>23km) the velocity model for the Chiloe region (Lange et al., 2007) was used and not changed during the inversion due to the limited penetration depth of the seismic rays for the deployment.

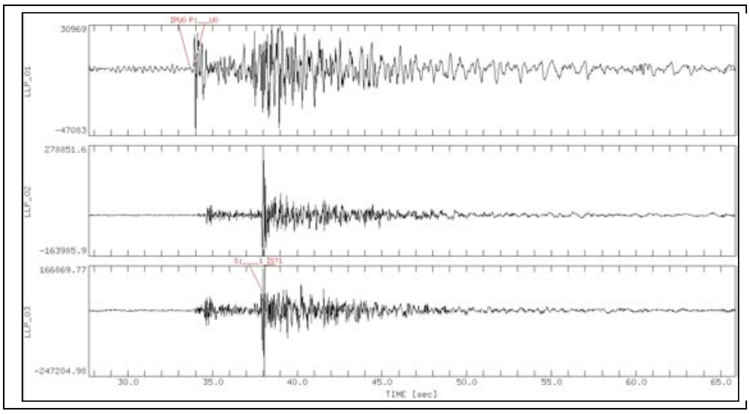


Figure 3 (above). Sample of the data obtained (vertical, N-S and E-W components) showing one event and both P and S arrivals picked. Bandpass filter 0.5-15 Hz.

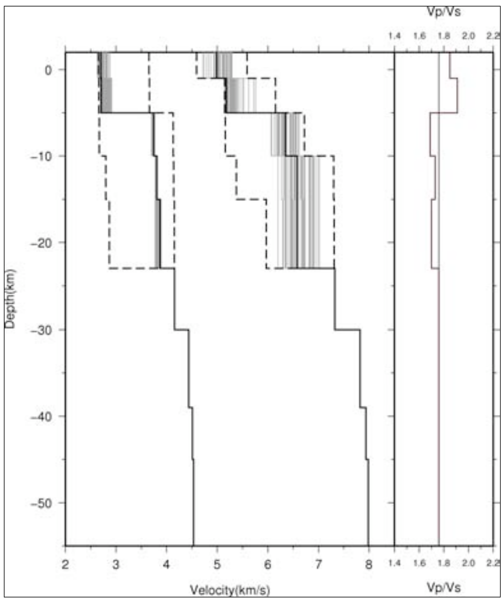


Figure 4 (right). Final 1-D velocity model for P and S velocities. See text for explanation.

Figure 5 shows the final locations for the processed aftershocks and the calculated focal mechanisms for a number of high-quality events. The aftershock events can be described as intra-arc seismicity at shallow depths, mostly located between 0-10 km depth. The main feature found corresponds to a NNE trending alignment of events that crosses the Aysen Fjord and coincides with one of the main strands of the LOFZ (see figure 5). A second cluster of events, very localized, is observed to the North of the area (~45.15º lat. S) with depths around 10 km. This cluster could correspond simply to an extension of the main fault or to a possible magmatic centre in development and activated by the main fault. No seismicity related to the Wadati-Benioff Zone for this area could be detected during the observation period.

The most interesting feature recognized corresponds to an alignment of events trending ENE observed to the East of the main alignment mentioned above (see figure 5). This strand of seismicity has not been recognized previously either from seismicity or geological studies. It could be consistent with either the re-activation of an old structure or the rupture and development of a completely new fault subordinate to the master fault (Liquiñe-Ofqui fault). The extension of the seismicity strand is around 10 km long, occurring mainly around 5 km depth, which is shallower than the seismicity related to the main fault (see figure 6a and 6b).

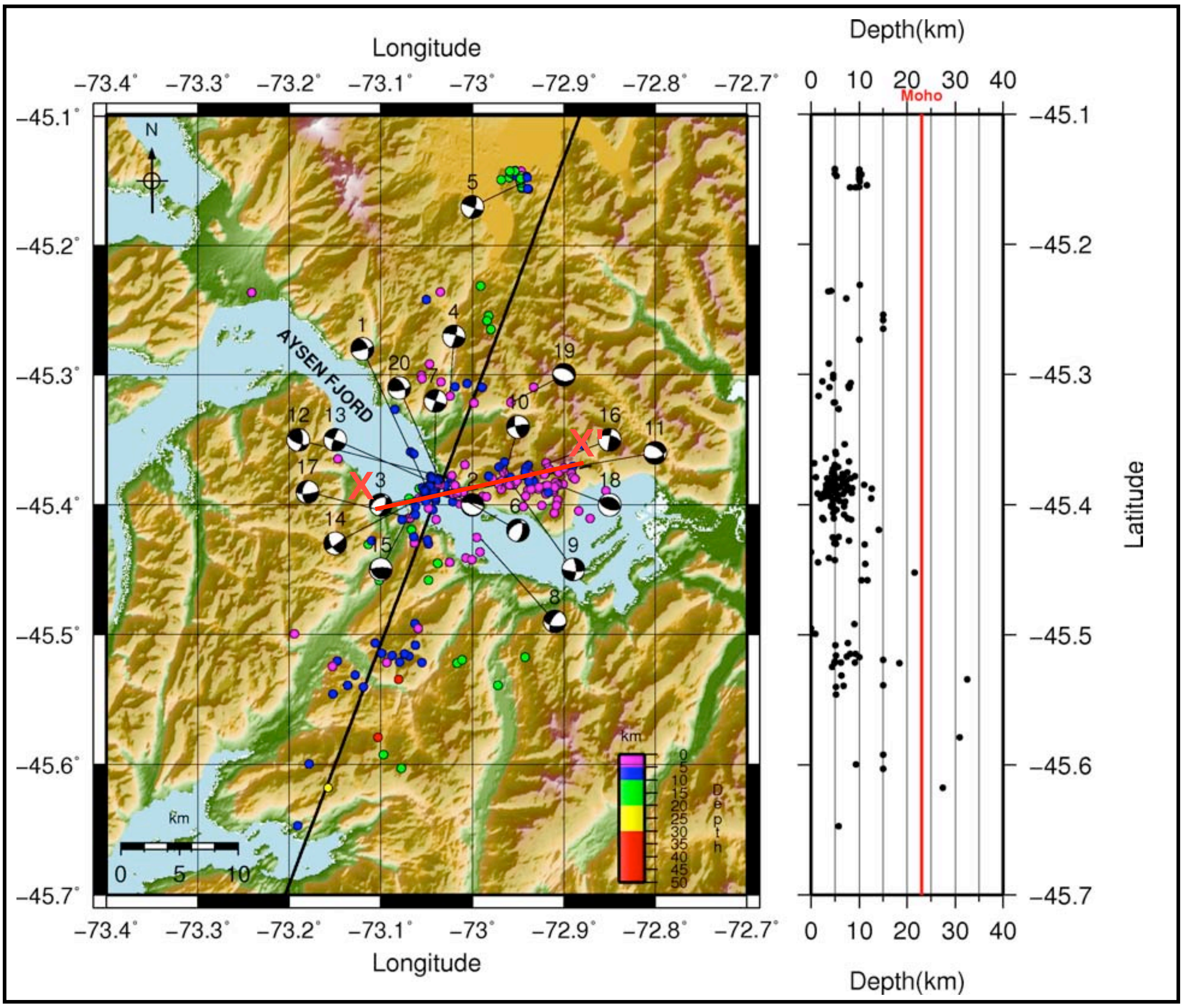


Figure 5. Final locations and focal mechanisms. Red line X-X' indicate profile in figure 6a.

The fault plane solutions calculated (see figure 5) show dextral strike-slip faulting for focal mechanisms number 4, 5, 7 and 13 with strikes ~NNE which coincides with the orientation of the main fault. In the secondary alignment of events, focal mechanisms number 9, 10 and 16 show strike-slip faults but with different orientation. Few other mechanisms show reverse and normal faulting as well. It is important to highlight that these focal mechanism are preliminary solutions and further attempts are necessary to get robust solutions.

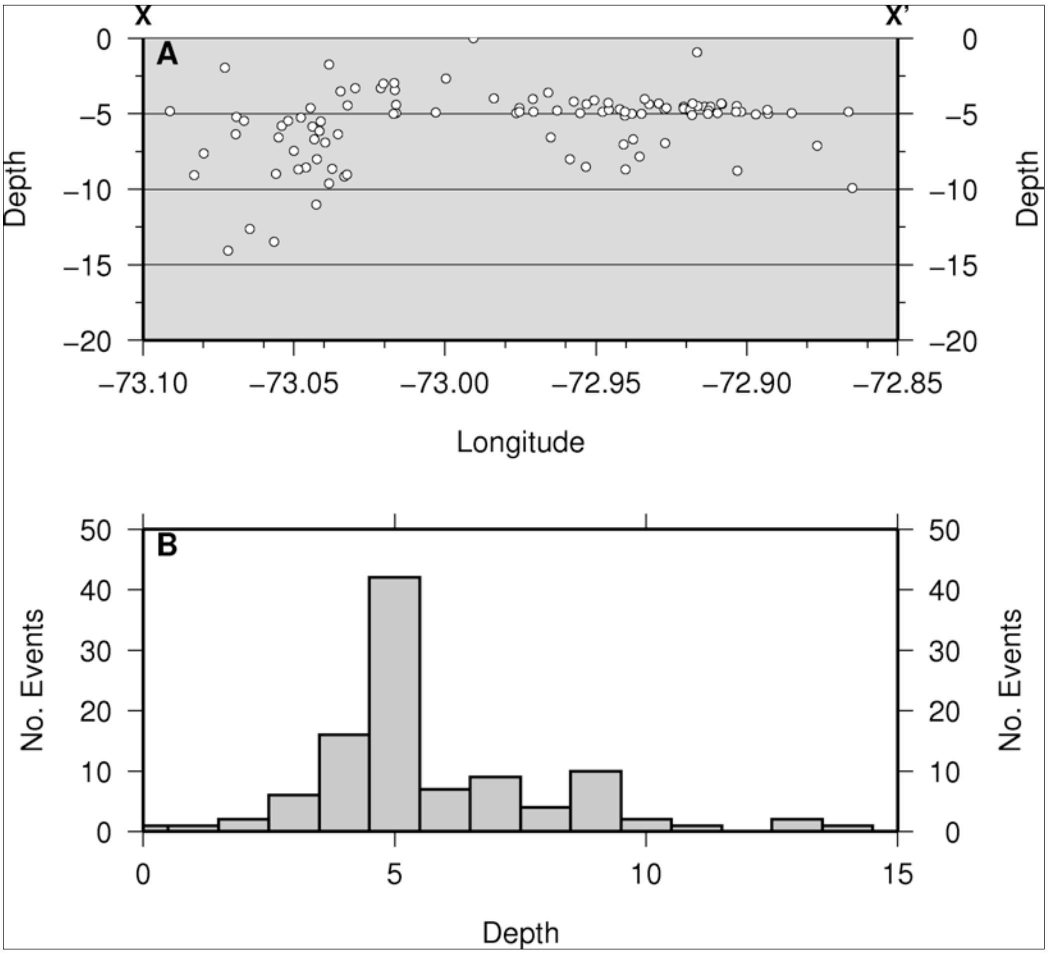


Figure 6. Selection of events belonging to ramification ENE in figure 5 (see text for explanation). **A.** Profile X-X' in depth. **B.** Histogram of depths for profile X-X'.

Conclusions and recommendations

The seismicity recorded in 2007-2008 is clearly related to the LOFZ and therefore, it shows that this fault is currently active. Moreover, the focal mechanisms suggest right-lateral strike slip faulting. The seismogenic zone in this area is confined to the upper 15 km since most of the events are located at shallow depth less than 10 km. The velocity model probable indicates the presence of fluids and fracturing in the upper 5 km of the crust deduced from the high Vp/Vs ratios. The Moho discontinuity would be located at approximately 23 km depth, although the uncertainty of this measurement has to be assessed. The nature of the seismcity strand trending ENE will be further investigated. Future work in this zone should contemplate the deployment of an amphibious seismic network in order to get a better coverage of the area and continue monitoring this interesting region.

Publications

Agurto ,H., Rietbrock, A., Bataille, K. 2010. Analyzing the seismo-tectonic structure in the Aysen Region, Southern Chile by using aftershocks recordings from the Mw=6.2 Aysén earthquake. In prep.

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