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Seismic hazard assessment in the Peru-Chile border region

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Introduction

Very large destructive earthquakes, with magnitude close to Mw 9.0, have occurred in Peru-Chile Border Region in 1604, 1868, and 1877. Those earthquakes had their epicenters in front of Arica elbow, and affected seriously the southern Peruvian region, the first two events, and the northern of Chile, the third earthquake. They also provoked tsunamis that completed the destruction of Arica port and of other towns located in the seaside up to 400 km from Arica. Those tsunamis reached other places of the Pacific Ocean such as California, Hawaii, Yokohama, Philippines, Sydney, and New Zealand.

From those earthquakes, the one occurred on August 13, 1868 has been well reported and abundant macroseismic information exists in Barriga (1951), and Silgado (1978). Maximum intensity XI MM was felt in Arica and its epicenter was in front of Arica just to the north of latitude 18.5° S. This earthquake with 8.8 Mw determined by Dorbath et al (1990), destroyed almost completely southern Peruvian cities like Tacna, Moquegua, Torata, and Arequipa. In this city, located around 300 km from the epicenter, the earthquake provoked ground undulations that difficult the people to stand during almost 10 minutes, causing the collapse of more than 80% of the buildings. In Lima the earthquake was felt during 5 minutes. A large tsunami arrived in Arica 52 minutes after the earthquake, in the form of a 12 m high wave completely destroying the port, followed by a 16 m high wave that arrived 73 minutes later, and then 20 minutes later came the most violent wave, which stranded three ships anchored in the port for almost 800 m inside the continent.

Seismic catalogue

Reliable information for historical earthquakes in Peru-Chile Border Region exists since 1582, most of it compiled in Silgado (1978) and SISRA (1985) catalogues, however, they are not complete and continuous catalogues. This kind of catalogue exists only for the interval beginning in 1964 until recent years, such as Engdahl et al. (1998) relocations, upgraded later on until the end of 1999 (personal communication). This relocations present good quality hypocentres, compatible with selected ISC determinations, which can be obtained for earthquakes occurred until the end of 2002.

Method for seismic hazard evaluation

Seismic hazard evaluation was performed in this work through ZMAP software (Wiemer, 2001), which executes statistical determinations of seismicity parameters, elaborating automatically epicentral maps, cross sections, histograms with spatial and temporal distribution, frequency/magnitude single and cumulative distributions, defining the *b*-value with Gutenberg & Richter (1954) (GR), and Maximum Likelihood (Utsu, 1996) (ML) approaches. The following steps were carried out:

1. From the Engdahl catalogue (C1) were selected 2471 earthquakes occurred between 16° -26°S and 62°-79°W, with $m_b \geq 4.0$ and depths between 0 – 200 km. Historical and more recent seismic information is available for temporal distribution of Andean seismic activity.
2. After analyses of seismicity maps and cross sections, two seismogenic sources were determined from C1, the first one Seismogenic Source 1 (SS1) in northern Chile with 96 earthquakes, and the second one Seismogenic Source 2 (SS2) in southern Peru with 261 earthquakes (Fig. 1).
3. Frequency/magnitude relations were obtained for SS1 and SS2. For both seismogenic sources were calculated the parameters for single (GR) and cumulative (GR and ML) distributions, which are shown in Fig. 2.
4. Recurrence intervals were determined for each seismogenic source, especially for earthquakes with the maximum magnitude occurred in each seismogenic source (Fig. 3).
5. Seismic hazard will be estimated considering the social development for some important cities in Peru-Chile Border Region.

Results

Two seismogenic sources were determined in this study based in the earthquake spatial distribution shown in Fig. 1, SS1 in northern Chile with 261 events, and SS2 in southern Peru with 96 events, occurred between 1964-1999. The frequency/magnitude curves for both seismogenic sources are shown in Fig. 2, and their main seismicity parameters are listed in Table 1.

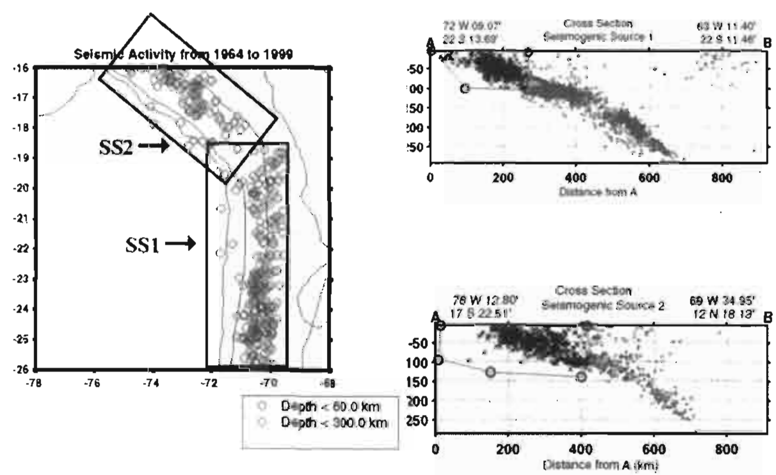


Figure 1. Seismicity map and cross sections in Peru-Chile Border Region showing spatial distribution of earthquakes, and selected horizontal and vertical portions to define SS1 (Northern Chile), and SS2 (Southern Peru)

Considering the relatively short interval of C1 (36 years), it is not possible to obtain realistic curves for cumulative magnitudes relationships (GR and ML) for larger magnitudes earthquakes than those occurred during the interval considered in C1. To calculate reliable frequency/magnitude cumulative curves historical earthquakes have to be considered. In this case we have to use the single magnitude distribution curve for each source and calculate the return period (see Fig. 3) of the maximum magnitude earthquake occurred in each source, assuming this value should be the same than the calculated with the proper cumulative relation, for the maximum magnitude earthquake.

The largest historical earthquake occurred in SS1 was in May 09, 1877 with Mw 8.6, converted to m_b 6.9 using Mw/m_b relationship determined by Zamudio (1998). The return period (RP) for this largest magnitude earthquake in SS1 is 135 years, which means an earthquake like the one of 1877 could occur in northern Chile around the year 2012.

For SS2 the maximum magnitude earthquake (Mw 8,8) occurred in August 13, 1868. That magnitude converted as above, results in m_b = 7.0. Its return or recurrence period (RP) is 258 years, consequently an earthquake with magnitude Mw 8.8 could occur in Southern Peru around the year 2126.

Seismogenic Source 1	***Seismogenic Source 2***
Log N = 5.026-1.04m_b	Log N = 6.269 – 1.20 m_b
RP = 133 years for m_b 6.9	RP = 258 years for m_b 7.0

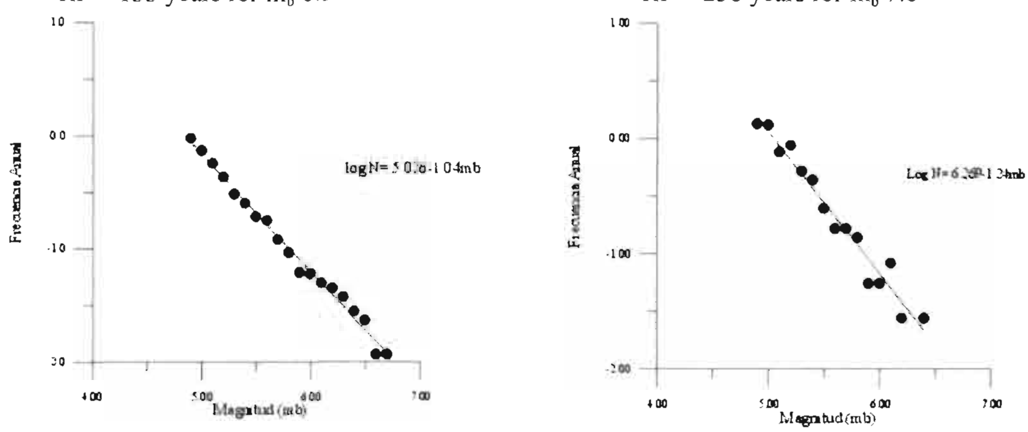
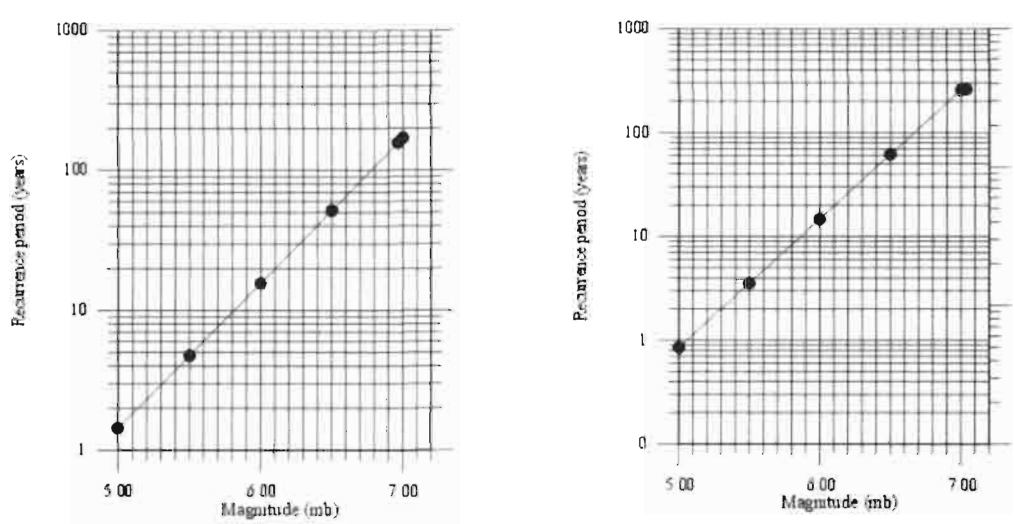


Figure 2. Single frequency/magnitude distribution relations for SS1 and SS2. The data of SS1 has been rearranged passing it 5 times through a Hanning window.



SS1 **SS2**

Figure 3. Recurrence period (RP) for SS1 and SS2, using the frequency/magnitude single distribution relation.

Conclusions

Seismic activity is the most important natural phenomena in Peru-Chile Border Region, spatial distribution of that activity shows the existence of two seismogenic superficial sources associated to the subduction process, were occur the more dangerous earthquakes in that region.. Results of this work indicate the probable occurrence of a very large earthquake with Mw 8.6 in the northern Chile portion of Peru-Chile Border Region, around the year 2010, and in the southern Peruvian portion of that region may occur a large earthquake with Mw 8.8, around the year 2126. Considering the 1868 and 1877 earthquakes destroyed several cities next to the epicentral area and caused many deaths, it is probable that similar magnitude earthquakes could provoke a larger quantity of casualties because the great number of inhabitants that live now in cities like Arequipa, Camana, Ilo , Mollendo, in southern Peru, and Arica, Antofagasta, Iquique, in northern Chile.

During the last 128 years two earthquakes with magnitude larger or equal than 6.7? m_b (Mw 8.0) have occurred in Peru-Chile Border Region: July 30, 1995 (Mw 8.0) in Antofagasta SS1, and June 23, 2001 (Mw 8.4) in Ocoña SS2, the last one damaged some Peruvian towns and cities, which were partially destroyed by the seismic event and by a tsunami generated by that earthquake. Those large earthquakes are considered by some authors premonitory events of a larger catastrophic earthquake in the Arica elbow, like Delouis et al. (1996), Spence et al. (1999), and Berrocal et al (2004).

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