The seismogenic potential for large earthquakes at the southernmost Pampean flat-slab segment (Argentina) from a geologic perspective

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INTRODUCTION

The most prominent geologic provinces distinguished accross the Pampean flat-slab in Argentina between 31°S and 33°S are from West to East: the Andean orogen, where the Cordillera Principal, Cordillera Frontal and Precordillera, are the morphostructural units resulting from mountain building processes during the Neogene (Ramos, 1988, 1996), and the Sierras Pampeanas, a Neogene uplifted broken-foreland blocks. The current active orogenic front is located between the Eastern foothills of the Precordillera and the western boundary of the Sierras Pampeanas. This dynamic interaction is highligthed by a clustered intraplate seismicity and by the occurrence of the most destructive earthquakes in the country of the 20th century (M 7.4, 1944 San Juan and M 7.3 1977, Caucete). It concentrates also the most striking quaternary deformation.

This contribution focuses on some characteristics and challenges that this area poses for a more realistic estimation of the capability of seismic sources, when evaluating the regional seismic hazard on a long-term basis. The issues here discussed are related to the time-dependant seismic cycle of potential seismogenic structures as well as paleoseismic implications of the deformation style of neostructures at surface.

It is considered that the characterization of the seismic hazard in many areas has been biased by using only or mainly the short-term catalog of historical and instrumental seismicity , which in the best cases has a maximum temporal penetration of $4x10^2$ years. This contrasts with the common seismic cycle of intraplate faults for producing large earthquakes (10^3-10^5 years) and has led the seismic hazard to be in many cases underestimated or misunderstood.

Enlarging the seismic data by studying the deformation record in recent sediments allow sometimes to find evidences of large pre-historic earthquakes which might testify about the damaging potential of structures not adequately imaged by both historical or instrumental seismicity. But paleoseismological studies can also lead to misleading conclusions if the neotectonic environment and the mechanisms of faulting were not properly considered .

QUATERNARY ACTIVE STRUCTURES IN THE PRECORDILLERA

The Precordillera fold and thrust belt is a paleozoic orogen where neogene deformation resulted in different structural styles controlled by previous anisotropies. The Precordillera Occidental and Precordillera Central shows East-verging thrusts affecting different quaternary alluvial and piedmont levels (Bastías et al., 1984, Bastías et al., 1990) South of 32° 15'S the Andean structure and quaternary deformation are controlled by former normal faults of inverted Triassic halfgrabens (Ramos and Kay, 1991; Dellapé and Hegedus, 1995). Despite this typical compressive setting, the most notorious quaternary structure as for its landscape imprint, is the El Tigre fault a strike-slip structure where horizontal movements with a dextral component have been documented (Bastías et al., 1984, Siame et al, 1997).

Quaternary displacements observed along these precordilleran settings are basically concentrated along the fault planes, without noticeable distributed deformation through secondary structures or folding. This fact has a great paleoseismological significance because it makes feasible to apply the empirical relationships such as those developed by Wells and Coppersmith (1994). These data relate the reconstructed surface rupture length and coseismic displacement of prehistoric earthquakes with parameters of historically documented events. Thus, it is possible to reconstruct paleomagnitudes and enlarge, even if with less accuracy, the seismic record at least to Holocene-Late Pleistocene times.

In contrast, the main neostructures at the Eastern Precordillera are basement-cored west-verging thrusts (Rolleri, 1969, Ortiz y Zambrano, 1981, Comínguez and Ramos, 1991, Zapata and Allmendinger, 1996, , Siame et al., 2002). The main displacements as for relief-building significance is concentrated along the thrust surfaces, such as the Villicum-Zonda thrust. However, several holocene-active faulting areas are located at the back-limb of the main thrusts and concentrate the most conspicuous features linked to historical seismicity. From North to South these areas are Blanquitos, La Laja, Marquesado and Cerro Salinas fault systems. Such structures are characterized by several bedding-controlled linear fault scarps interpreted as interbedding-slip or flexural-slip faults (Costa et al., 1999, Krugh and Meigs, 2001, Krugh, 2003).

During a seismic event, this style may produce a wide distribution of the original displacement related to the primary shock source into several secondary flexural fault planes. Conversely, the size of the paleoearthquake responsible for the resulting individual rupture lengths and vertical displacements on these secondary fault, might be underestimated according to the commonly used empirical relationships (i.e. Wells and Coppersmith, 1994).

QUATERNARY ACTIVE STRUCTURES IN SIERRAS PAMPEANAS

The Sierras Pampeanas are regarded as a broken foreland adjacent to the Andean orogen, as well as another characteristic geologic feature of the flat-slab subdution segment (Jordan et al., 1983; Jordan and Allmendinger, 1986, Ramos et al., 2002). These blocks are bounded by commonly West-verging reverse faults dipping 30°-55°E. where Quaternary deformations are concentrated.

Small to moderate earthquakes (≤ M 6.4) have shocked the region during historical times. But except for the 1977 M 7.4 Caucete earthquake and probably for the 1934 M 6.0 Sampacho earthquake, neither direct relationships between epicentral locations and major Quaternary faults nor historical surface faulting have clearly been documented. Accordingly, the Sierras Pampeanas have traditionally been considered as an area with a seismic potential for large earthquakes considerably lower than the Andean belt. This consideration has been based on instrumental and historical seismicity (INPRES, 1977). However, a suitable analysis on the capabilities of intraplate faults, with low deformation rates and long seismic cycle, for producing large earthquakes is far beyond the time span provided by the seismic catalogs.

However, in these intraplate settings involving structures with long-recurrence interval, the most "active" fault (i.e. the fault where the most recent movement was recorded) might not be the most hazardous in terms of being the next one for producing a large earthquake (Machette, 1996, Costa, 2004). In this sense, a better picture on the long-term behavior of a capable structure can be obtained by analyzing the prehistorical record of movements.

Many earthquake-related evidences have been found along several neotectonic structures in the Sierras Pampeanas, such as primary surface ruptures (Comechingones, Sierra Chica, Sierra de San Marcos and Velazco faults), large rock-avalanches (San Luis fault) and paleoliquefaction features (Las Lagunas fault). These phenomena have no historical analogs in the region, but they testify for the occurrence of large earthquakes ($M \geq 7.5$) since Late Pleistocene.

Despite the long-term recurrence interval characterizing any individual neostructure, the evidences so far recognized highlight that many of these faults or fault segments gave rise to large earthquakes with surface signature and hence with a damaging potential similar to many structures located at the Andean belt.

CONCLUSIONS

The progress during the last years of studies focused on the dating and reconstruction of prehistorical seismic events (paleoseismology), have been stimulated by the necessity of lengthening the short chronologic record provided by both historical and instrumental seismicity as suggested by modern trends in seismic hazard assessment. Accordingly, the wide variety of paleoseismic scenarios resulting from different neotectonic settings implies different strategies to gather data and interpret information.

Empirical relationships linking some rupture parameters (length, coseismic displacement) with magnitudes of prehistoric earthquakes is a robust tool in paleoseismology and it has proved to be useful in many areas where coseismic deformation is concentrated along the main fault plane. However, where deformation resulting from the primary source is distributed through flexural slip or folding, the surface rupture pattern may show characteristics in terms of rupture lengths and fault slip mismatching the relations predicted by empirical data. It is considered that this is the case in many areas of recent faulting at the Eastern Precordillera. For instance, the 30 cm of instantaneous coseismic slip as well as the recognized surface ruptures at La Laja fault during the 1944 M 7.4 earthquake are minor than predicted by the relations proposed by Wells and Coppersmith (1994). They only would account for a maximum earthquake size ranging from 5.9 to 6.3.

The seismic problem in the Sierras Pampeanas highlight the necessity of enlarging the seismic data by studying the prehistoric deformation recorded in the quaternary stratigraphy, which might have been resulted from earthquake-related ruptures. Many evidences gathered at the Sierras de Córdoba and San Luis suggest that prehistoric seismic crisis have produced surface faulting and large landslides compatibles with seismic sources of magnitudes $M \geq 7.5$. This consideration contrasts with the maximum size of events recorded since historical times in the region ($M \leq 6.2$) and suggest the importance of including paleoseismological data in seismic hazard studies.

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