Palaeoseismicity as a complement to earthquake catalogues

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A course on the **Present and future of seismic prevention: lessons learned from the latest destructive earthquakes. Insurance as a means towards reconstruction** was held in El Escorial (Madrid, Spain) during the last week of July 2000 as part of the prestigious Summer Courses run by the Universidad Complutense General Foundation and sponsored by the Consorcio de Compensación de Seguros of Spain.

Following a series of earthquakes in 1999 with great economic and social impact, in Colombia, Turkey, Taiwan and Greece, this course tackled the urgent need to revise and extend earthquake catalogues as a primary information source of obvious importance for seismic hazard and risk research, and the suitability of the specifications in local seismic building codes.

Experts from New Zealand, Spain and the states of Nevada and California in the USA, outlined the basics of a relatively new scientific approach: **palaeoseismicity.** The idea is to search for evidence of the effects of major earthquakes in changes in the geomorphology of the landscape and the stratigraphic record. Since earthquake catalogues become increasingly less accurate as we go back in time, an interesting proposal was made to standardise the splitting of earthquake catalogues into four parts: instrumental, with records compiled from instrument data; historical, with data based on documentary research, **archaeological,** using evidence from archaeological remains; and **geological,** which includes major events identified via palaeoseismicity.

These indirect or proxy methods enable us to confirm what happened during a significant seismic event, including the study of dislocated river terraces, watercourse displacements and disruptions of stratigraphic levels, or where there is evidence of fluidification, among other phenomena. Significant earthquakes with long return periods such as those of Lisbon in 1755 or New Madrid in 1811 and 1812 would not have been identified if they had not actually occurred, having a decisive influence on the hazard maps for the Iberian Peninsula and the US Midwest, respectively. Thus the importance of identifying significant seismic events with the aid of geomorphology and stratigraphy is brought to the fore, in an attempt to prevent any “major absences”.

Certain parts of the Earth crust, which in principle are seismically stable, have been poorly mapped, with traces of past earthquakes that are difficult to locate because they act at a different pace than the erosion of the landscape. These areas have the potential to generate strong earthquakes, with the added problem of the lack of implementation of suitable seismic buildings codes and very low attenuation rates, so that the area that could be seriously affected is usually very large. In general, these earthquakes have hypocentres at a depth of less than 10 kilometres, return periods of between 10,000 and 100,000 years and episodic occurrence exhibiting clusters. This creates a need for an in-depth study of many parts of the Earth surface, following the criteria outlined above, because of the potential impact on human beings and their settlements.

In this context, blind thrusts, one of which was responsible for the Northridge earthquake in 1994, are cause for considerable concern among Californian experts. We must add to this the importance of faults associated with a main fault together with the seismic-gap theory, as in the Chi-chi (Taiwan) earthquake in 1999. In other words, secondary faults that have not broken for 30 years or so but remain active or are associated with an active system, will tend to break some time soon.

However, the seismic-prediction field is still hindered by the lack of progress when it comes to confirming reliable parameters with a degree of accuracy applicable to the human scale. In Parkfield, California, where the US federal government agreed to invest in an advanced monitoring network of the barely perceptible movements of the borders of the San Andreas fault system, a seismic gap was believed to have been located since the last earthquake in 1966. It was also thought that a pattern had been discovered for return periods in the area. Consequently an earthquake was expected to occur around 1988 if a 22 year return period was considered. However, since that earthquake never happened, the human and financial resources devoted to the project have been cut, and the experiment has been written off as a failure.

Insofar as the Iberian Peninsula is concerned, the most hotly debated topic was the previous rating of the seismicity in the region as "moderate". This classification makes little sense in the context of seismic activity on a global scale. The most important earthquakes that have been properly documented in the Spanish seismic catalogue are as follows:

Year	Epicentre	maximum intensity/magnitude*
1373	Ribagorza (Huesca-Lleida)	X
1396	Tabernes (Valencia)	IX
1428	Queralps (Gerona)	IX
1504	Carmona (Sevilla)	IX
1518	Vera (Almería)	IX
1522	Mar de Alborán	IX
1531	Baza (Granada)	IX
1645	Alcoy (Alicante)	IX
1680	Alahurín el Grande (Málaga)	IX
1748	Montesa (Valencia)	IX
1755	SW Cape San Vicente	XI-XII
1804	Dalías (Almería)	IX
1806	Pinos Puente (Granada)	VIII-IX
1829	Torrevieja (Alicante)	X
1884	Arenas del Rey (Granada)	IX-X
1954	Dúrcal (Granada) Depth = 650 km	V/7,0
1986	Albolote (Granada)	VIII/5
1969	SW Cape San Vicente	VII/7,3

* Intensities measured according to the MSK scale.

Of particular interest here is the earthquake of 1755, known as the "Lisbon earthquake", which is today conceived as a multiple earthquake, being composed of at least 3 ruptures. The earthquake occurred at 10 a.m. (local time) on All Saints Day, and lasted some 7–8 minutes in all. The Mw magnitude of the earthquake has been calculated as being 8.5, with an intensity at the epicentre of between XI and XII. In Portugal the maximum intensity must have been X, while for both Spain and Morocco the maximum EMS´98 intensity has been estimated as being VIII. It is thought that around 12,000 people were killed in Portugal –10,000 in the city of Lisbon itself– with at least 1,000 deaths caused by the tsunami generated by the earthquake. In Spain there were 51 people crushed by collapsing structures, 4 people were trampled to death, 6 were killed by panic and over 1,000 died as a result of the tsunami. In Spain alone, the economic losses have been calculated at the equivalent of 127 billion pesetas (ESP) at current values. If this earthquake occurred today, the economic cost has been estimated at ESP 500 billion.

It is also very interesting the earthquake in Dúrcal (Granada) in 1954, which had a magnitude of 7 but occurred at depth of 650 kilometres, limiting the surface effects. The explanation for this is still uncertain, with an relict subduction zone in the southeastern Iberian Peninsula being suspected but still not confirmed.

Seismicity in Spain can be roughly grouped into five categories:

- Major earthquakes with a magnitude of over 7, such as those occurring on the Azores-Gibraltar fault, with return periods of over 200 years.
- Destructive earthquakes with a magnitude of 5.5–7, which normally occur in the south and south-east of the Iberian Peninsula and the Pyrenees.
- Seismic series with a magnitude of 4.0–5.5 in southern and south-eastern Spain, the Pyrenees and Galicia, which are usually followed by many aftershocks.
- Clusters of earthquakes with magnitude of less than 4, separated by short periods of time, recorded throughout the Peninsula.
- Individual isolated epicentres with a magnitude of 4.5, which are found all over the Peninsula.

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These observations must be framed within geotectonic contexts of well identified activity, where palaeoseismicity offers a potential major contribution.

Society in the 21st century will continue to face the effects of a seismicity obviously related to the current configuration of the external layers of the Earth crust. Only intensive and extensive research will enable us to establish suitable building codes to attenuate the destructive effects that earthquakes have on modern life. With the aid of the different insurance schemes, we can soften the economic blow and make progress in the rational reconstruction of devastated areas. ■