ARTÍCULOS

**Física de la Tierra**
ISSN-e: 1988-2440

http://dx.doi.org/10.5209/FITE.57690

EDICIONES COMPLUTENSE

# The Large Earthquakes of the XV Century in Catalonia. Clues for the Regional Seismic Hazard

Josep Batlló[1]; Janira Irizarry[2], Antoni Roca[3]

Recibido: 26/07/2017 / Aceptado: 16/10/2017

**Abstract.** Catalonia, in the NE part of the Iberian Peninsula, was shaken by large earthquakes in the XV Century. As these are the largest events consigned in the regional catalogues of seismicity, a proper knowledge of their epicentral parameters and their effects is essential for any further analysis of regional seismic hazard and risk. We review the present knowledge of these important events and some applications of the obtained results for the calculation of scenarios and other products really useful for civil protection for present earthquakes.
**Key words:** Eastern Pyrenees seismicity; Earthquake focal parameters; Historical seismicity; Seismic hazard evaluation.

## [es] Los grandes terremotos del siglo XV en Cataluña: Claves para la peligrosidad sísmica regional

**Resumen.** Cataluña, situada en el NE de la Península Ibérica, se vio afectada por grandes terremotos en el siglo XV. Debido a que se trata de los mayores eventos consignados en los catálogos regionales de sismicidad, es esencial un conocimiento fidedigno de sus parámetros epicentrales y de sus efectos para cualquier análisis de peligrosidad o riesgo sísmico regional. Presentamos el conocimiento actual de estos importantes eventos y algunas de las aplicaciones de los resultados obtenidos para el cálculo de escenarios sísmicos y otros productos de utilidad para la protección civil frente a posibles terremotos.
**Palabras clave:** Sismicidad del Pirineo Oriental; Parámetros focales de terremotos; sismicidad histórica; Evaluación de la peligrosidad sísmica.



**Cómo citar:** Batlló, J., Irizarry, J., Roca, A. (2017). The Large Earthquakes of the XV Century in Catalonia. Clues for the Regional Seismic Hazard. *Física de la Tierra,* 29 (2017), 85-99.

## 1. Introduction

The seismicity of Catalonia, in the NE part of the Iberian Peninsula, is moderate. Geologically, Iberia is a microplate with a complex evolution (Dewey et al., 1989; Roest

[1] Institut Cartogràfic i Geològic de Catalunya (Spain).
E-mail: josep.batllo@icgc.cat
[2] Institut Cartogràfic i Geològic de Catalunya (Spain).
E-mail: janira.irizarry@icgc.cat
[3] Institut Cartogràfic i Geològic de Catalunya (Spain).
E-mail: antoni.roca@icgc.cat

and Srivastava, 1991) and the present structural framework of the NE of the Iberian Peninsula is situated within the context of Mediterranean continental collision on the convergence of African and European tectonic plates (Olivera et al., 2003). As a consequence of this situation, the regional seismicity is diffuse, concentrating mainly along the Pyrenees and the Mediterranean coast (both inland and offshore).

Fault palaeoseismic studies point to the possible occurrence of large earthquakes, with magnitudes on the order of M7, on geological times (Santanach et al., 2010; Perea et al., 2003). If so, the recurrence time for such an event should be long, much more that 500 years. The instrumental record shows just two damaging earthquakes occurred in the XX century (19th November 1923, with maximum intensity VIII and 12th March 1927, intensity VII). Nevertheless, from the macroseismic record it is known that destructive earthquakes occurred in the past, mainly in the late Middle Ages, with intensities VIII and even IX (EMS98) (Olivera et al., 2006). A big earthquake, with Imax VIII-IX (EMS98) occurred on 3rd March 1373. Present knowledge points to an epicentre near the Aran Valley, in the Pyrenees, althoug the available sparse records introduce large uncertainties in the results. This is not the case of the three large events on 19th March 1427 (Imax VIII), 15th May 1427 (VIII) and 2nd February 1428 (IX), occurred within a short period of time and clustered in space in the triangle Amer-Olot-Puigcerdà.

As these are the largest earthquakes in the NE Iberian region for which information of their effects on the territory is available, it is of great interest obtaining the most accurate seismological information about them. This will improve our knowledge of the regional seismicity. Moreover, this information is really valuable for present evaluation of the regional seismic hazard and risk and for more specific products as shakemaps (Bertil et al., 2012) or seismic scenarios (Goula et al., 2008).

The throughout report of Olivera et al. (2006) on the analysis of these earthquakes, published a decade ago, is the latest comprehensive work on the medieval earthquakes occurred in the NE of the Iberian Peninsula. Based on this report, on the next sections we will describe how these earthquakes have been studied, the present knowledge about them, and their contribution to the assessment of regional seismic hazard and risk.

## 2. The memory of the earthquakes

The construction of our present knowledge about these earthquakes has been a long way. Memory of their occurrence remained in general chronicles and historical accounts, usually just as short mentions. Locally, on the damaged area, the memory of such events remained stronger and mention to them can be found on local accounts since their occurrence up to the present. But coming back to the seismological point of view, it can be said that the early seismic catalogues almost skip them. The Perrey (1847) catalogue for Iberian earthquakes presented them as a unique event (even he wrote “les secousses furent fréquentes”). To our knowledge, was Cazurro (1906) in an almost forgotten primal work the first one to identify the main events of the series (this is, 15 March 1427 —date slightly mismatched—, 15 May 1427 and 2 February 1428). This information was used by Mengel (1909) in his much more known catalogue for the Eastern Pyrenees. Galbis (1932), in his Iberian catalogue, collected and assembled intensity data points assigned by several authors. It looks like the first one to assign a

magnitude to these events was Munuera (1963). Fontserè and Iglesies (1971) presented a throughout revision of the available sources. Their work was a turning point in our knowledge about these events. They reviewed the whole series of earthquakes, adding new earthquakes and removing fake events and assigned new macroseismic intensities for the different villages affected for each event. Using this information, Banda and Correig (1984) made the first modern research. They try to obtain seismic source parameters from the intensity data and, for the first time, they suggest for the main shock on 1428 an epicentre near Queralbs (between Puigcerdà and Camprodon) instead that near Olot assumed for long time.

The seismic catalogue compiled by Suriñach and Roca (1982), assembling the available information previously published, contributed to show up the gaps about contemporary knowledge of the whole series of events. On 1984, short after its creation, the Servei Geològic de Catalunya (SGC, now integrated on the Institut Cartogràfic i Geològic de Catalunya —ICGC) realized the need for a throughout revision of these earthquakes, the largest ones occurred in Catalonia and key events for the assessment of regional hazard and risk and plans for this task were devised and implemented. It has been a long way, more than twenty years, as a lot of archive work has been necessary. The work was done in several steps and gave origin to several publications. The final results were summarized in the book of Olivera et al. (2006), the most complete and up to date compilation and evaluation of these events and main source of the review here presented.

## 3. Methodology used for the analysis of historical earthquakes

Research on historical earthquakes is not an easy task. Several issues not directly related to seismology should be accounted for (Guidoboni and Ebel, 2009). For earthquakes occurred in the late medieval period, tight collaboration of historians, archivists and geophysicists is needed. As backgrounds of the involved professionals are really different the "tuning" of the team requires time and patience. Vogt (1993) gives a glimpse on the specific issues such a research involves.

In this case, the study undertaken by the SGC was divided into three main steps:

— A critical review of Fontserè and Iglésies (1971) catalogue. Even being a milestone, the work of Fontserè and Iglésies (1971) has an important drawback, it relies heavily on printed sources and most of them are not primary sources (this is, contemporary documents written by witnesses). The reliability of those accounts and its sources was reviewed.
— Retrieval of sources contemporary to the events used by former compilers and search for new original documents. Such a research should confirm information contained in secondary sources and increase the number of sources.
— Evaluation of the available sources from a seismological point of view. This is, to transform the information from medieval sources and other accounts into seismic data useful for the determination of the earthquake seismic source parameters.

These steps involved other related issues. Among them, it should be taken into account that the proper review of contemporary sources implies the evaluation/knowl-

edge of many related topics: the organization of land, population and settlement, the political and socio-economic context, etc.

Another issue was dealing with a series of earthquakes distributed on time (several years) and space (more than 50 km). Thus, some precautions should be adopted to avoid mixing macroseismic effects of the different events. The most evident, but not always possible, is, when dealing with a specific event, to use sources written between the date it occurred and previous to the date of the next big event.

Finally, as these earthquakes occurred near the present border between France and Spain and affected also French territory (they were felt as far north as Cahors and Avignon), coordination with the French researchers was essential for a comprehensive study of such events. Collaboration was established with the Service d'Aménagement et Risques Naturels at BRGM (Bureau de Recherches Géologiques et Minières) in order to carry out a joint analysis and evaluation of all the recovered data (Lambert, 1993).

The revision task was favoured by the existence of a large amount of contemporary sources of the late medieval period in Catalonia. The Archives of the Crown of Aragon[4] preserve a large amount of the documentation generated by the government at that time. The public notary archives of Catalonia[5] are also preserved (they are the largest collection on the world of such documents). Other local and foreign archives preserve documents about these earthquakes. Among them, two documents never analysed before merit mention. One is the Pastoral Visit to the Diocese of Girona in 1432, manuscript preserved at the Diocese Archive. The other is a chronicle of the earthquakes written in Girona in Hebrew. It is preserved at the Bavarian State Library and was studied and translated by Del Valle (1994). Figure 1 shows the reproduction of the first page of the Hebrew chronicle. As it can be seen, the study of old earthquakes involves sciences considered far away from seismology as philology or palaeography.

The progress of the research was presented in several publications (Olivera et al., 1991; Riera-Melis et al., 1993; Olivera et Roca, 1999) and its final results synthetized in Olivera et al. (2006). Part of the obtained results were already included in the *Seismic Atlas of Catalonia* (Susagna and Goula, 1999).

## 4. The series of earthquakes

As a result of the undertaken studies our understanding of the NE Iberian earthquakes in the XV century has changed dramatically. Summarizing the results consigned in Olivera et al. (2006), now we know that the series of earthquakes was extended on time and, much more interesting, also in space. The series is characterized by three main groups of events (see fig. 2), with approximate epicentres at Amer, Olot and Queralbs (small village between Camprodon and Puigcerdà), each one with a main event occurred on the 19th March 1427, the 15th May 1427 and the 2nd February 1428 respectively (as figure 2 is reproduced from an early study of the series, the first date, 19th March appears on the figure as 15th March, as it was believed in previous studies). Each group has a different location and the general trend of the seismicity moved approximately from SE to NW. A four group of events, smaller in size and not reviewed here, occurred on June 1427

[4] https://www.mecd.gob.es/cultura-mecd/en/areas-cultura/archivos/mc/archivos/aca/portada.html

[5] http://arxiu.notarisdecatalunya.org/AdminPaginas/FonDig/058b78e6-19ef-4ec4-8e50-47d3a084afc7

to the SE of the main groups, around the village of Caldes de Malavella. Table 1 shows chronologically the events of the series and their main characteristics.

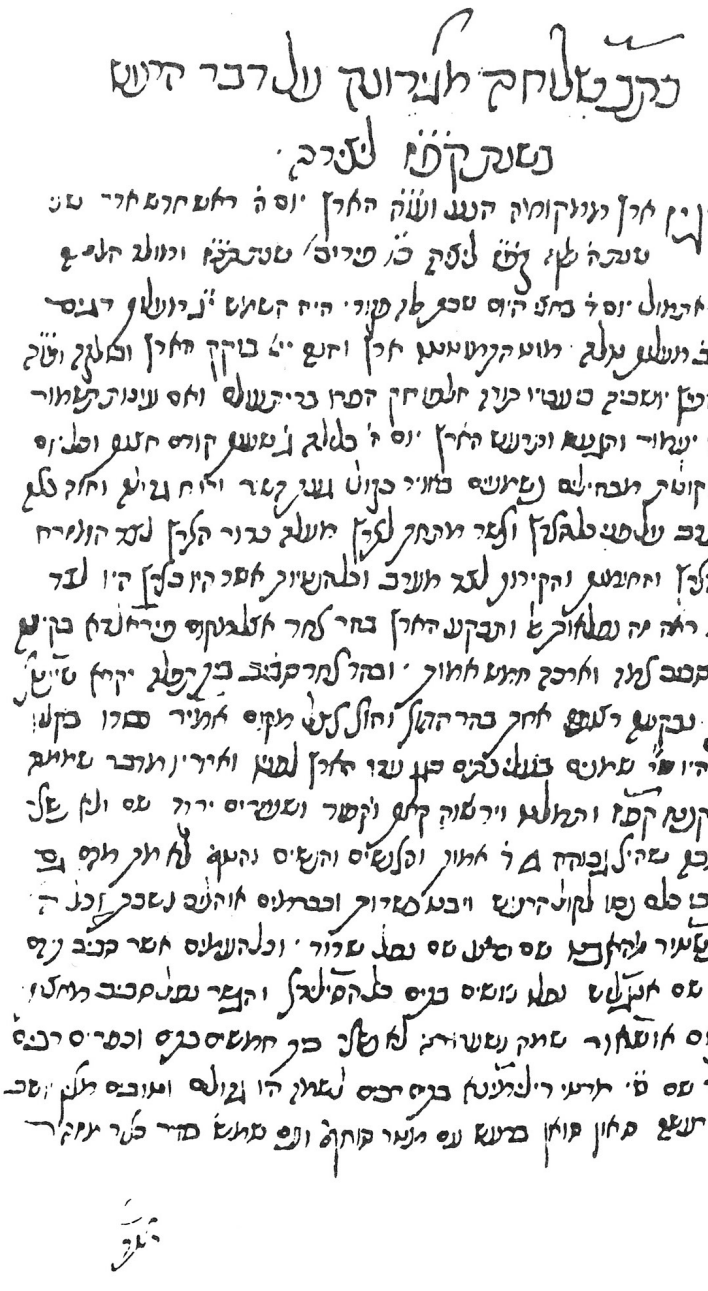

Figure 1. First Page of the Hebrew Chronicle on the earthquakes occurred on 1427 written in Girona and now preserved at the Bavarian State Library. From del Valle (1994)

Table I. Final list of earthquakes for the series occurred on 1427-28 in the NE of the Iberian Peninsula with their epicentral parameters. Those events with a "Map" indication on the column "Felt at" can be retrieved at «http://www1.igc.cat/midop/query_eq/» (last accessed on 30 May 2017). Column Qe shows the epicentral quality. B stands for epicentre within 10 km of the given coordinates. C stands for epicentre within 20 km of the given coordinates.

| Date | Time | Felt at | Epicentral Zone | Lat. | Lon. | Qe | Io |
|---|---|---|---|---|---|---|---|
| 1410.03.30 | 4-5 h | Barcelona | ? | | | | |
| 1410.07.27 | | Girona | ? | | | | |
| 1410.08.05 | 1-2 h | Barcelona | ? | | | | |
| 1425.02. before 9 | | Barcelona | ? | | | | |
| 1427.02.end | | Girona | Near Amer | 42º 02' | 2º 35' | C | <IV |
| 1427.03.02 | 21 h | Girona, Barcelona | Near Amer | 42º 02' | 2º 35' | C | V |
| 1427.03.03 | 1-2 h | Girona, Barcelona | Near Amer | 42º 02' | 2º 35' | C | V |
| 1427.03.13 | 11 h | Map | Near Amer | 42º 02' | 2º 35' | C | VI-VII |
| 1427.03.14 | 12 h | Map | Near Amer | 42º 02' | 2º 35' | C | VI |
| 1427.03.15 | 23 h | Map | Amer | 42º 02' | 2º 35' | B | VI |
| 1427.03.19 | 21 h | Map | Osor-Amer | 41º 59' | 2º 35' | B | VIII |
| 1427.03.21 | 12 h | 7 places | Osor-Amer | 41º 59' | 2º 35' | C | IV-V |
| 1427.03.22 | 13 h | 7 places | Osor-Amer | 41º 59' | 2º 35' | C | IV-V |
| 1427.04.13 | 1-24 h | Map | Osor-Amer | 41º 59' | 2º 35' | C | <VI |
| 1427.04.22 | 22 h | Map | Lloret Salvatge | 41º 59' | 2º 35' | B | VI-VII |
| 1427.04.23 | 11 h | Map | Lloret Salvatge | 41º 59' | 2º 35' | B | VI |
| 1427.05.15 | 15-16 h | Map | Vall d'en Bas-Olot | 42º 10' | 2º 26' | B | VIII |
| 1427.05.16/06.04 | | Girona | Vall d'en Bas-Olot | 42º 10' | 2º 26' | C | <IV |
| 1427.06.8 | | Girona | Caldes de Malavella | 41º 51' | 2º 49' | C | V |
| 1427.06.12 | 1-24 h | Map | Caldes de Malavella | 41º 51' | 2º 49' | C | <VI |
| 1427.06.14 | 8 h | Map | Caldes de Malavella | 41º 51' | 2º 49' | C | VI-VII |
| 1427.06.15/08.31 | | Girona | Caldes de Malavella | 41º 51' | 2º 49' | C | <V |
| 1427.12.25 | | Barcelona | ? | | | | |
| 1428.02.02 | before 8 h | Girona | Near Camprodon | 42º 18' | 2º 20' | C | <VI |
| 1428.02.02 | 8-9 h | Map | Near Camprodon | 42º 18' | 2º 20' | B | IX |
| 1428.02.03/08 | | Osona, Puigcerdà | Near Camprodon | 42º 18' | 2º 20' | C | <V |
| 1430.01. before 12 | | Puigcerdà | ? | | | | |

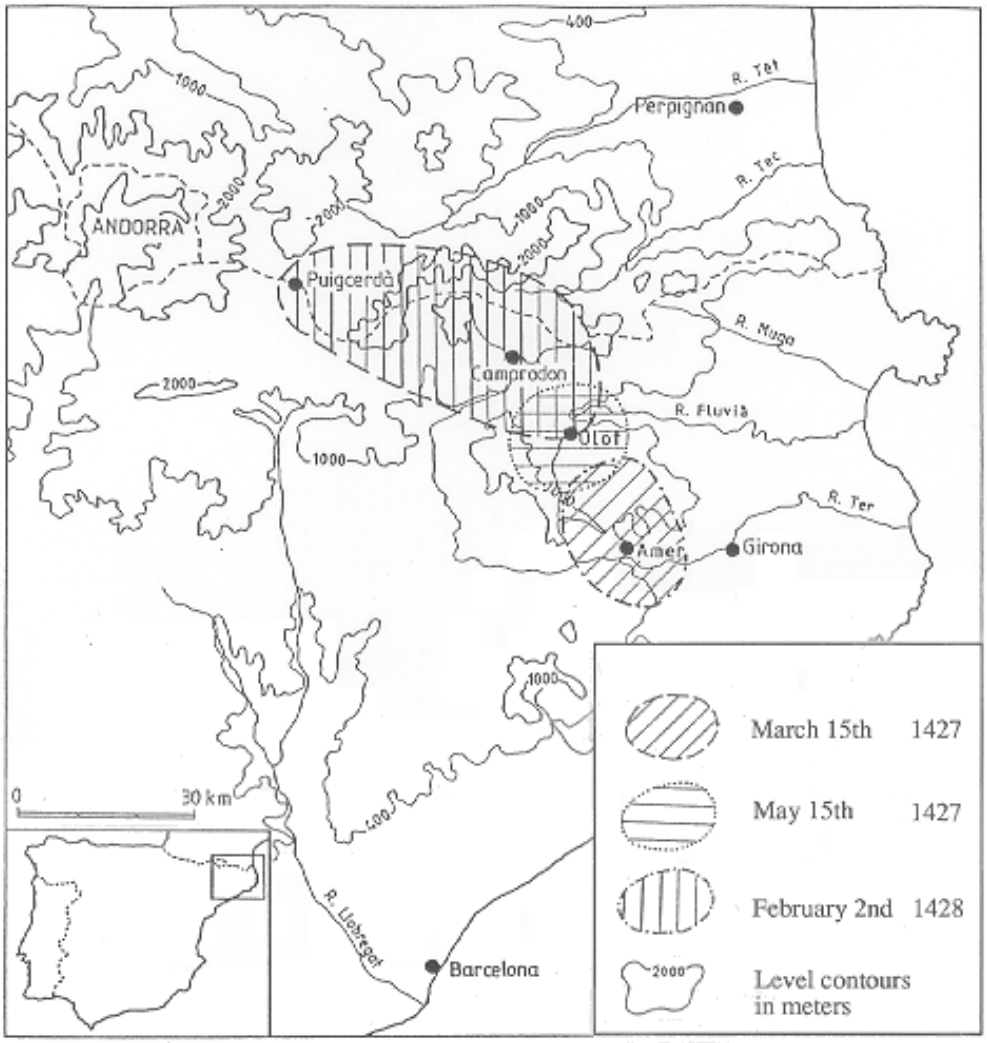


Figure 2. Sketch of the zones of damage for the three main events of the series of earthquakes occurred in Catalonia in the years 1427-28. The real date of the first main event is 19th March; but it appears as 15th March in the figure, as it was believed when the figure was made. From Riera-Melis et al., (1993)

## 4.1.The seismic sequences of 1427

The sequences of earthquakes occurred in 1427 were, prior to the recent study of Olivera et al. (2006), less well known, probably because they have been overshadowed by the earthquake on 2 February 1428, which was more destructive. Despite the difficulties encountered (the effects of the big 1428 earthquake mask those of the previous ones), the assessment of the seismic parameters of the 1427 sequences

are useful for two reasons. First, cataloguing the earthquakes of these sequences is important because of their destructiveness itself and, also, to complete the catalogue. Second, an analysis of the effects of these sequences in some localities subsequently affected by the earthquake of 1428 is important in order to make a correct evaluation of this last earthquake.

Given the amount of new documentation that had not been considered in earlier studies, the evaluation of the earthquakes presented in Olivera et al. (2006) is more complete and more reliable than any previous one since it provides an epicentre and epicentral intensity for each event, with a quality index for each earthquake of the sequence (see table 1). The analysis of the descriptions provided in Olivera et al. (2006) indicates that the chronology shown in table 1 is reliable. The epicentres proposed have an uncertainty of up to a maximum of 20 km. Table 1 also shows the epicentral intensities, which were obtained taking into account the extension of the area of perception and the degree of perception of the earthquakes at some localities.

Hence, all doubts concerning the duplication of the earthquake of 15 March and 15 May, existing in previous studies, are now dispelled. The compiled records allow obtaining accurate dates and times of the two main events of the series. Now, it is known than on 15 March an earthquake damaged the Amer monastery. This became the focus of considerable attention because of its symbolic significance although the earthquake was less intense (VI, EMS-98) than others of the sequence and for a long time it was regarded as the main shock of the series occurred near Amer.

But the most important earthquakes of the sequence occurred on 19 March with an epicentre in the area between Osor and Amer and on 15 May, located between Vall d'en Bas and Olot, the two locations asserted with quality B (uncertainty around 10 km). Both earthquakes reached an epicentral intensity of VIII, with quality C. Using the relationships proposed by Johnston (1996a, 1996b), the energy released by the 19 March earthquake corresponds to a seismic moment Mo of $8.43 \times 10^{17}$ N·m and a moment magnitude Mw of 5.9 and the energy released by the 15 May earthquake corresponds to a seismic moment Mo of $6.31 \times 10^{17}$ N·m and a moment magnitude Mw of 5.8

### 4.2. Earthquake of 2 February 1428

The earthquake of 2 February 1428 wrought heavy destruction in Catalonia and France and claimed more than 1000 lives. It is the largest event occurred in the whole Pyrenean region in historical times. This earthquake was studied by Cadiot (1979) and by Banda and Correig (1984).

Although the results by Olivera et al. (2006) do not differ greatly from those of Banda and Correig (1984), the following new issues incorporated in Olivera et al. (2006) help us to describe better this earthquake:

— Data from some French localities were incorporated. But the review and analysis of the records from the French archives led Olivera et al. (2006) to exclude some other towns, i.e. Bordeaux, Clayra, Libourne, Montpellier and Le Puy, that had been included in earlier studies. This is an important finding when evaluating the extension of the area of perception, which did not affect

more than 300 km. Cadiot (1979) proposed an epicentral intensity of X-XI, basing himself on a larger area of perception. Now this area is reduced.

— The previous destructive effects caused by the earthquakes of 1427 in some localities were considered. Given that the epicentral zones of the earthquakes of 1427 and that of 1428 do not coincide, it was possible to evaluate the epicentral intensities independently because it was possible to separate the destructive effects of both earthquakes. By contrast, for certain localities devastated in March 1427 (Vall d'Amer and Vall d'en Bas) and those affected by the earthquake on 15 May 1427 (Vall d'en Bas, Olot, Castellfollit…) the descriptions record the accumulated effects of the earthquakes of 1427 and 1428. After the final revision, some of these localities were not assigned intensity values because of the impossibility of discriminating between the effects of the different earthquakes. Only destruction (D) or probable damage (PD) is indicated in such cases.

— Olivera et al. (2006) was the first time that a review of the contemporary accounts of the earthquake of 1428 has been carried out. It was also the first time that an interpretation of this earthquake has been made, bearing in mind the reappraisal of the seismic sequence of 1427 and that of the earthquake of the 25th May 1448, smaller and occurred to the SE and not analysed here.

— The studies of Cadiot (1979) and Banda and Correig (1984) propose an epicentral area for the 1428 earthquake between Puigcerdà and Camprodon. The two localities were assigned almost the same intensity value, X-XI according to Cadiot, and IX-X according to Banda and Correig. An accurate analysis of the records shows that the destruction was more widespread at Camprodon (I = IX) than at Puigcerdà (I = VIII). Accordingly, an epicentral intensity of IX (EMS-98) with quality C was assigned to the earthquake of 2 February 1428. The epicentral zone was located in the vicinity of Camprodon, 42º18'N and 2º20'E with quality B (uncertainty around 10 km). The focus of the earthquake, using Sponheuer (1960) method, was estimated to be located in the crust at a depth of about 9 km and the energy released corresponds to a seismic moment Mo of 5.95 × 1018 N·m and a moment magnitude Mw of 6.5.

— As already pointed, the report of Olivera et al. (2006) on the analysis of these earthquakes is the latest comprehensive work on the medieval earthquakes occurred in the NE of the Iberian Peninsula. Additional primary sources have not been found since its publication. Thus, some new evaluations of the seismic source of these events published on the last years relay on the set of intensity data points published by Olivera et al. (2006). This is the case of the SHEEC catalogue[6] (Stucchi et al., 2013), or the latest actualization of the French database SISFRANCE[7]. In the first case, new epicentre locations were calculated using the BOXER algorithm. They differ slightly, not more than 3 km, from those of Olivera et al. (2006). Magnitudes are much lower, Mw 5.6, 5.5 and 6.0 respectively. Such differences arise from the intensity attenuation model used.

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6 www.emidius.eu/SHEEC/sheec_1000_1899.html

7 www.sisfrance.net

## 5. Regional seismic hazard and risk

The accurate analysis of the series improved the regional seismicity catalogue as the uncertainty of its largest events was reduced. Moreover, together with a proper catalogue of seismicity, another item needed for the assessment of seismic hazard is an attenuation law.

As acceleration data for NE Iberia are scarce and those available are from small earthquakes, many hazard assessments studies rely on macroseismic intensity data. In such case the intensities of the 1427-1428 series are essential to define such attenuation law for high intensity degrees. An attenuation relationship of the Sponheuer (1960) type was adjusted to the observed intensity data as presented in the results of Secanell (1999).

Thus, the study of the large earthquakes occurred in the XV Century in Catalonia contributed to the evaluation of the effects of present earthquakes. A database with the intensity data points has been created and is accessible at http://www.icgc.cat/en/Public-Administration-and-Enterprises/Services/Earthquakes/Seismic-information-and-maps-collections/Catalan-Macroseismic-Database (last accessed on 30 May 2017). As an example, figure 3 shows the intensities probably felt in the region of Catalonia according to the simulation of the 1428 Ripollès earthquake using the methodologies developed in the ISARD project (Goula et al., 2007). The earthquake was characterized by an epicentral intensity of IX, a moment magnitude (Mw) of 6.5 and a depth of 9 km.

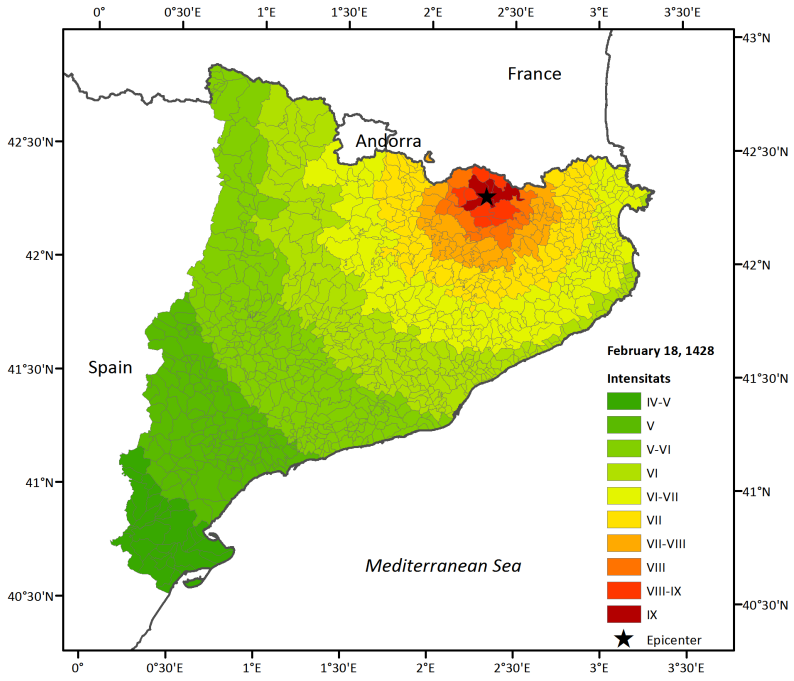


Figure 3. Simulation of intensities probably felt in Catalonia due to the 1428 Ripollès earthquake. It has been obtained using the methodologies developed in the ISARD project (Goula et al., 2007).

The results from intensity attenuation relationships also contribute to the development of seismic damage scenarios. Scenarios based on historical earthquakes with a high maximum intensity are extremely useful as allow evaluating the impact that earthquakes like these would have if they occurred nowadays. Such scenarios are needed by civil protection services to develop emergency plans and carry out simulation exercises.

Figure 4 shows the expected felt intensities due to an earthquake similar to the May 15th 1427 Olot earthquake characterized by an epicentral intensity of VII, a moment magnitude (Mw) of 5.5 and a depth of 5 km. This simulation was developed using the *Escenaris* software that is part of the automatic detection and damage scenarios generation service that the ICGC offers to the civil protection services of Catalonia (Batlló et al., 2016). This software integrates an intensity attenuation relationship adjusted to the historical intensities observed in the region which allows estimating the intensity felt in each municipality so an expected damage distribution can be obtained based on damage probability matrices and the statistical distribution of the vulnerability.

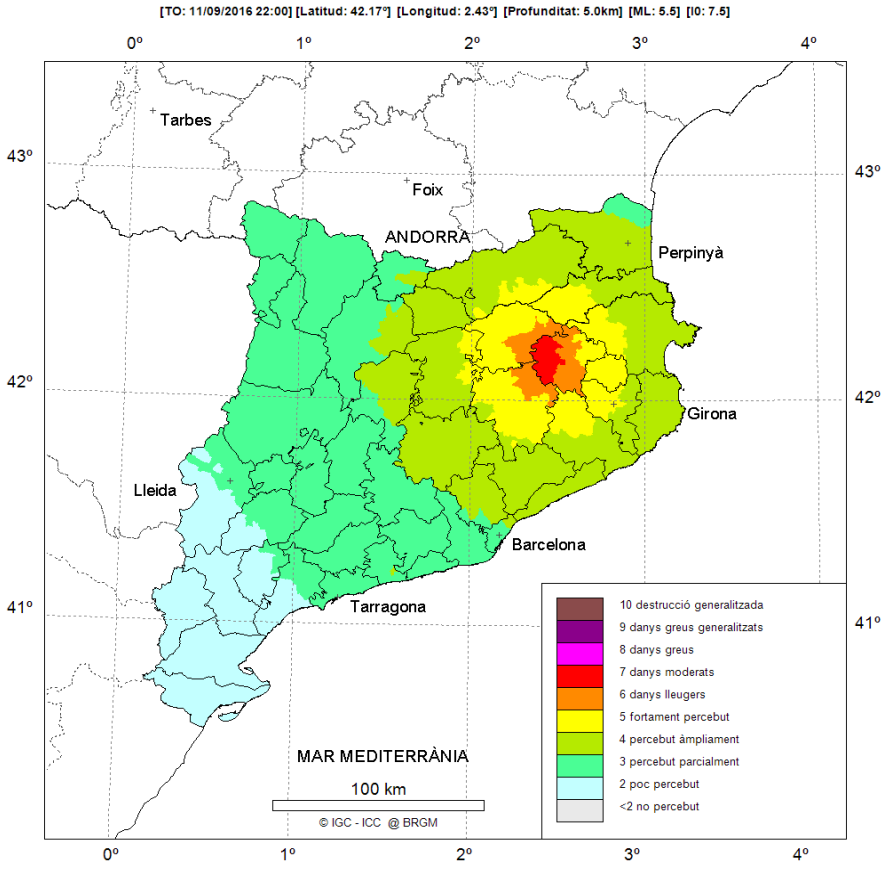


Figure 4. Simulation of probably felt intensities in Catalonia, Andorra and the French department of Pyrénées Orientales due to an earthquake like the Olot earthquake occurred on May 15th 1427. It has been obtained using the *Escenaris* software (Batlló et al., 2016)

Thanks to the intensity attenuation relationship adapted for Catalonia civil protection services can have simulations of what could be expected if the historical earthquakes would happen again today. These simulations include the estimations of the seismic damage distribution expected for each municipality, number of buildings that could be uninhabitable and an approximation of the number of persons that could be directly affected by the earthquake. Figure 5 presents an example of these estimations: the map of the number of uninhabitable buildings expected due to an earthquake similar to the 1427 Olot earthquake. As can be seen uninhabitable buildings would be expected to be reported as far as the city of Girona and in French territory near the border.

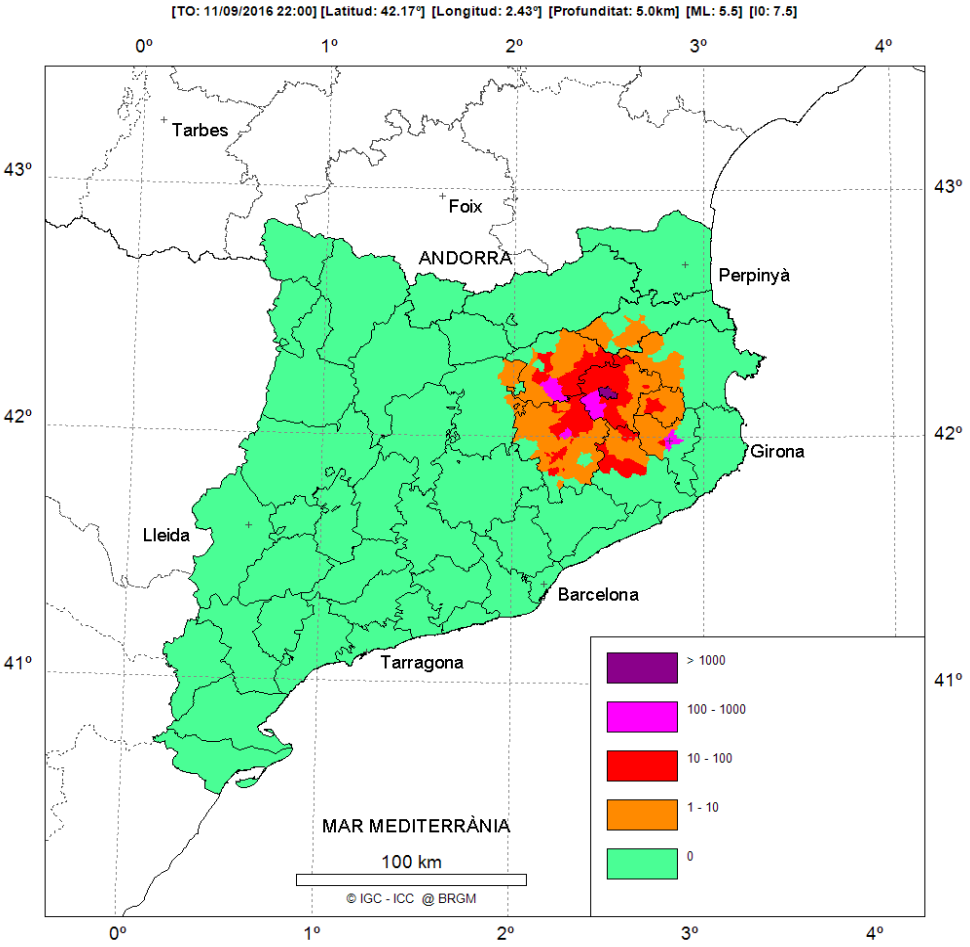


Figure 5. Simulation of the number of uninhabitable buildings that can be expected in Catalonia, Andorra and the French department of Pyrénées Orientales due to an earthquake like the Olot earthquake. It has been obtained using the *Escenaris* software (Batlló et al., 2016).

## 6. Conclusions

We presented the main results of the analysis of the large earthquakes occurred in the NE of the Iberian Peninsula in the XV Century. This has been a long project where collaboration of the present ICGC with the Department of Medieval History of the Barcelona University and the French BRGM was crucial.

The existence of contemporary sources of the late medieval period in Catalonia allows to study these earthquakes in more detail. The good state of preservation of old documents and the wealth of description of the events enabled to make a relatively reliable reconstruction of these events. It is not common, when dealing with medieval earthquakes, to get such level of detail as attained in this case.

In regions of absence of data of recent high intensity earthquakes, studying the large historical earthquake is essential as it provides valuable information to be integrated to seismic hazard analysis. This is the case of Catalonia, where the in deep study of the XV Century series of earthquakes allowed a more realistic evaluation of the regional seismic hazard. Furthermore, with the development of damage probability functions based on intensity, the macroseismic studies of theses earthquakes provide the data to adjust intensity attenuation relationships needed to generate the seismic damage scenarios currently being delivered to civil protection services in Catalonia.

## 7. Acknowledgements

We thank E. Suriñach and an anonymous reviewer for their insight comments contributing greatly to improve this paper.

## 8. References

Banda, E. and A. Correig (1984). The Catalan earthquake of February 2, 1428, *Eng. Geol*., **20**, 89-97.

Batlló, J.; Frontera, T.; Irizarry, J.; Romeu, N.; Jara, J. A.; Goula, X. (2016). Operational Procedures of Contributing Agencies: The Catalan Seismic Network, *Bulletin of the ISC*, 50 (1), 72-94 (available online at www.isc.ac.uk/iscbulletin/agencies/MRB-ops.pdf).

Bertil, D., Roviró, J., Jara, J.A., Susagna, T., Nus, E., Goula, X., Colas, B., Dumont, G., Cabañas, L., Antón, R. and Calvet, M. (2012). ShakeMap implementation for Pyrenees in France-Spain border: regional adaptation and earthquake rapid response process, Proceedings of the 15th World Congress on Earthquake Engineering, Lisbon, Portugal. (available online at http://www.iitk.ac.in/nicee/wcee/article/WCEE2012_2078.pdf. Last accessed: 30 May 2017).

Cadiot, B. (1979). Le séisme nissart de 1564. Les effets en France du séisme catalan de 1428. In: Vogt J. (Editor), *Les tremblements de terre en France*, BRGM Mémoire 96, Orléans, pp. 166-171; 172-174.

Cazurro, M. (1906). Terremotos de la región volcànica de Cataluña, *Memorias de la Real Sociedad Española de Historia Natural*, **IV**, 288-307.

Del Valle, C. (1994). *Los terremotos de Girona de 1427 en la fuente hebrea*, Aben Ezra Ediciones / Ajuntament de Girona. Girona, 133 p.

Dewey, J. F.; M. L. Helman, S. D. Knott, E. Turco, and D. H. W. Hutton (1989). Kinematics of the western Mediterranean, Geological Society, London, Special Publications, 45: 265-283, doi: 10.1144/GSL.SP.1989.045.01.15

Fontserè, E. and Iglésies, J. (1971). *Recopilació de dades sísmiques de les terres catalanes entre 1100 i 1906*, Fundació Salvador Vives Casajuana, Barcelona, 547 pp.

Galbis, J. (1932). Catálogo sismico de la zona comprendida entre los meridianos 5°E y 20°W de Greenwich y paralelos 45°N y 25°N, Tomo I, Instituto Geografico Catastral y de Estadistica, Madrid, 807 pp.

Guidoboni, E., and Ebel, J. (2009). *Earthquakes and Tsunamis in the Past: A guide to Techniques in Historical Seismology*, Cambridge, Cambridge University Press, xii + 590 p.

Goula, X., Dominique, P., Colas, B., Jara, J.A., Roca, A. and Winter, T. (2008). Seismic rapid response system in the Eastern Pyrenees, Proceedings of the XIV World Conference on Earthquake Engineering. Beijing.

Goula, X. and the SISPYR team. (2007). Proyecto ISARD: Información Sísmica Automática Regional de Daños, Memorias del 3er Congreso Nacional de Ingeniería Sísmica, Girona (Spain), 1513-1526.

Johnston, A. C. (1996a). Seismic moment assessment of earthquakes in stable continental regions-I. Instrumental seismicity, *Geophis. J. Int*., **124**, 381-414.

Johnston, A. C. (1996b). Seismic moment assessment of earthquakes in stable continental regions-II. Historical seismicity, *Geophis. J. Int*., **125**, 639-678.

Lambert, J. (1993). The Catalonian (1428) and Alpine (1564, 1644) Earthquakes: Review of Research in France. In: M. Stucchi (Editor), Materials of the CEC project "Review of Historical Seismicity in Europe", 1, Milano, CNR, 145-159.

Mengel, O. (1909). Monographie des "terratrèmols" de la Región Catalane, *Bull. Soc. Ramond*, vol. 44, 66-85.

Munuera, J. M. (1963), A study of seismicity on the peninsula Iberica area, Technical note n.1 'Seismic Data', Inst. Geográfico y Catastral, 93p.

Olivera, C., Banda, E. and Roca, A. (1991). An outline of historical seismicity studies in Catalonia, *Tectonophysics*, **193**, 231-235.

Olivera, C. et Roca, A. (1999). Les grans Séismes Catalans, dans Marichal, R. (dir.): Archeosismicité et Sismicité Historique, Perpignan, Groupe APS, 183-194.

Olivera, C., J. Fleta, T Susagna, S Figueras, X. Goula and A. Roca (2003). Sismicidad y deformaciones actuales en el NE de la Península Ibérica, *Física de la Tierra*, **15**, 111-144. Online at: https://revistas.ucm.es/index.php/FITE/article/view/FITE0303110111A. Last accessed: 30 May 2017.

Olivera, C.; Redondo, E.; Lambert, J. Riera, A. i Roca, A. (2006). *Els terratrèmols dels segles XIV i XV a Catalunya*, Institut Cartogràfic de Catalunya, 407 p.

Perea, H., Figueiredo, P. M., Carner, J., Gambini, St., and Boydell, K. (2003). Paleoseismological data from a new trench across the El Camp Fault (Catalan Coastal Ranges, NE Iberian Peninsula), *Ann. Geophys*., 46, 763-774.

Perrey, A. (1847). Sur les tremblements de terre de la Peninsule Iberique, *Annales des Scien. Phys. et Naturelles, d'Agric. et d'Indus. Lyon*, T. X, p. 461-513.

Riera-Melis, A., A. Roca and C. Olivera (1993). Analysis of the Pastoral Visit of 1432 to the Diocese of Girona for the study of the seismic series 1427-1428 in Catalonia. In: M. Stucchi (Editor), *Materials of the CEC project "Review of Historical Seismicity in Europe"*, 1, Milano, CNR, 161-172.

Roest, W. R., and S. P. Srivastava (1991). Kinematics of the plate boundaries between Eurasia, Iberia, and Africa in the North Atlantic from the Late Cretaceous to the present, Geology, June, v. 19, 613-616, doi:10.1130/0091-7613(1991)019<0613:KOTPBB>2.3.CO;2

Santanach, P., E. Masana and H. Perea (2010). The El Camp fault revisited: A 300 ka long paleoseismic history of a low-slip normal fault in northeastern iberia. In: Contribución de la geología al análisis de la peligrosidad sísmica, Primera reunión ibérica sobre fallas activas y paleosismología (Insua-Arevalo, J.M. & Martín-González, F. eds.), Sigüenza, Guadalajara: 23-26.

Secanell, R. (1999). Avaluació de la perillositat sísmica a Catalunya: anàlisi de sensibilitat per a diferents models d'ocurrència i paràmetres sísmics, Ph. D. Thesis, Universitat de Barcelona, 335 p.

Sponheuer, W. (1960). "Methoden zur Herdtirefenbestimmung in der Makroseismic". Freiberger Forschungshefte, C88, 117 pp.

Stucchi, M.; A. Rovida; A. A. Gomez Capera; P. Alexandre; T. Camelbeeck; M. B. Demircioglu; P. Gasperini; V. Kouskouna; R. M. W. Musson; M. Radulian; K. Sesetyan; S. Vilanova; D. Baumont; D. Faeh; W. Lenhardt; K. Makropoulos; J. M. Martínez Solares; O. Scotti; M. Zivcic; P. Albini; J. Batlló; C. Papaioannou; R. Tatevossian; M. Locati; C. Meletti; D. Viganò; D. Giardini (2013). The SHARE European Earthquake Catalogue (SHEEC) 1000-1899, *Journal of Seismology*, **17**, 523-544. Doi: 10.1007/ s10950-012-9335-2.

Suriñach, E. and A. Roca (1982). Catálogo de Terremotos de Cataluña, Pirineos y zonas adyacentes, 1100-1979, Universidad Complutense, Cátedra de Geofísica, Publicación Técnica No.190, 9-106.

Susagna, T. and X. Goula (1999). *Atles sísmic de Catalunya*, vol. 1, Barcelona, Institut Cartogràfic de Catalunya, 436 p.

Vogt, J., (1993). Historical seismology. Some notes on sources for seismologists. In M. Stucchi (editor): *Materials of CEC Project "Review of Historical Seismicity in Europe"*, CNR, Milano, vol. 1, 15-24.