

## **Problems in assessing focal parameters to earthquake sequences from historical investigation: the 1427 earthquakes in Catalonia**

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### **Abstract**

The problem of separation of effects of the individual events of an earthquake sequence together with the scarcity of detailed damage description are discussed through a thorough analysis of both new and previously available sources providing information in the near and far field. This has permitted a new interpretation of the 1427 earthquakes in Catalonia. Epicentral intensities of the individual events of the March sequence do not exceed 8 (EMS-92) while for the 15<sup>th</sup> May earthquake in Olot do not exceed 8-9. A previously non catalogued event in June 17<sup>th</sup> with epicenter near Caldes de Malavella has an epicentral intensity of 7-8.

### **1. INTRODUCTION**

The earthquake sequence that took place in the 1427-28 period affecting an important area of Catalonia (N.E. Spain) and Eastern French Pyrenees constitutes the most destructive seismic episode in the region. Consequently, the study of this sequence for achieving an accurate knowledge of its individual events is of great importance for a correct assessment of the earthquake hazard (figure 1).

Starting from the information available from previous works (Fontserè and Iglèsies, 1971; Banda and Correig, 1984) a research of historical sources contemporary to the 1427-28 series was undertaken. The main problem of earthquakes series in general is that of the superimposition of effects from the various individual events. The primary objective of this investigation was to separate, through an accurate analysis of the sources, the effects of the different earthquakes; for this reason there were selected only the primary documentary sources produced before the 2<sup>nd</sup> of February, 1428 earthquake which is clearly the most destructive of the whole 1427-28 period. The analysis of these data allowed an interpretation of the 1427 to be undertaken (Olivera et al., 1994).

The availability of new found pieces of information —archive documents and recently published specific studies— lead to a new interpretation of the 1427 sequence that will also modify the ongoing assessment of the 2<sup>nd</sup> of February, 1428 earthquake.

## SOURCES USED FOR THE STUDY OF THE 1427 SEQUENCE

Various types of sources have been analyzed for the study of the 1427 earthquakes. First, already known sources have been re-evaluated and second, new sources have been searched. The already known sources are the following:

- *Baluze 238*: Collection of letters received by and sent from the Jurors of the city of Girona. This source is commonly known as *Flosculi*, which are kept at the Paris National Library.
- Letters from the *Archive of the Aragon Crown*: records from the *Cancelleria Reial* and *Batllia* sections.
- Engagement book (*Dietari*) of the *Generalitat* which are kept in the *Archive of the Aragon Crown*.
- *Dietari* from *Joan Toralles*. Transcription from Moliné i Brases (Original document disappeared).
- Municipal books with assorted information from different municipalities: *Dietari de l'Antich Consell Barceloní (Novells Ardits)* and *Rúbriques de Bruniquer* from the City of Barcelona, *Manual d'Acors* from Girona, *Llibre de Privilegis* from Olot, *Manual del Consell* from Manresa, *Llibre de Consells* from Cervera, *Llibre de Consells* and *Llibre del Batlle* from Terrassa, *Llibre d'Acords de l'Arxiu Municipal* from Vic and *Petit Thalamus* from Montpellier.
- Local chronicle (*Memòries de la Comunitat de Sant Jaume*) from Perpignan.
- Notary's office from Amer: various documents.
- Pastoral Visits from the Girona Bishop of 1432.

The new considered sources are listed below:

- Some letters from the *Cancelleria Reial* and *Batllia* and some records from the *Dietari de l'Antich Consell Barceloní (Novells Ardits)* not considered in previous studies.
- Documents from the *Arxiu Històric Comarcal d'Olot* reporting the effects in Olot and Besalú towns (Puigvert, 1996; 1998).
- Hebrew Source: Chronicle-like document by a contemporary Jew of Girona who finished to write it on June 18<sup>th</sup>, 1427. This manuscript, which is kept in the Baviera National Library (Ms. 307), has been transcribed and translated by del Valle (1994).
- *Registre de les deliberacions del Consell Municipal* from the city of Pamiers (France).

Some sources give a relatively good description of damage but do not provide the chronology of the events. Some other sources give a highly accurate timing but they only report that the event was felt in relatively distant places such as Barcelona and Pamiers (figure 1), with no information of damage.

**CHRONOLOGY OF THE 1427 EARTHQUAKES FROM THE NEW SOURCES**

In the above mentioned previous work (Olivera et al., 1994) the most damaging earthquakes in 1427 were considered to be those of 15<sup>th</sup> of March and 15<sup>th</sup> of May (see table 1). This result was obtained from the analysis of the sources nearby the epicentral area. These sources record damage descriptions but do not give reliable dating.

Date	Fontseré-Iglèsias 1971		IGN 1991		Olivera et al. 1994		This revision		
	lo MSK	Felt Area	lo MSK	Epicentral area	lo MSK	Epicentral area	lo EMS-92	Epicenter $\lambda, \phi$	Epicentral area
1420		Amer		Amer		FALSE			FALSE
1421		Tortosa, Olot		Olot		FALSE			FALSE
1424.03.04		Catalunya				FALSE			FALSE
1426.03.03	VII	Catalunya	VII	Catalunya		FALSE			FALSE
1427.02.02		Olot, Amer				FALSE			FALSE
1427.02.23	II	Amer, Olot		Olot		Amer			<i>FALSE</i>
<b>1427.02.(26-28)</b>							-	-	<i>Amer</i>
1427.03.01		Catalunya				FALSE			FALSE
1427.03.02	IV	Barcelona, terres Girona		Olot		Amer	-	-	Amer
1427.03.03		Barcelona, terres Girona		Olot		Amer	-	-	Amer
1427.03.07	II	Vic		Olot		FALSE			FALSE
1427.03.13	V	Barcelona, Olot		Olot		Amer	<b>7-8</b>	<b>42.0°, 2.6°</b>	Amer
1427.03.14	VI	Barcelona		Olot		Amer	<b>7-8</b>	<b>42.0°, 2.6°</b>	Amer
1427.03.15	VIII-IX	Amer	VIII	Amer	VIII-IX	Amer	<b>7</b>	<b>42.0°, 2.6°</b>	Amer
1427.03.19	V	Barcelona		Olot		Amer	<b>8</b>	<b>42.0°, 2.6°</b>	Amer
1427.03.21	V	Barcelona		Olot		Amer	-	-	Amer
1427.03.22	V	Barcelona		Olot		Amer	-	-	Amer
<b>1427.04.12</b>									<i>Amer</i>
1427.04.22	V	Barcelona		Olot		Amer	<b>7-8</b>	<b>42.0°, 2.6°</b>	Amer
1427.04.23	VI	Lloret Salvatge		Amer		Amer			<i>FALSE</i>
1427.05.15	IX	Olot	IX	Olot	IX	Olot	<b>8-9</b>	<b>42.2°, 2.5°</b>	Olot
<b>05.15/06.04</b>							-	-	<i>Amer</i>
<b>1427.06.08</b>							-	-	<i>Amer</i>
<b>1427.06.12</b>							-	-	<i>Amer</i>
<b>1427.06.17</b>							<b>7-8</b>	<b>41.8°, 2.8°</b>	<i>Caldes de Malavella</i>
1427.12.25	VIII	Montpeller, Barcelona	VIII	Olot	<VI	Olot, Amer?	-	-	Olot, Amer?

**Table 1.** Earthquake sequence of 1427 from different studies. New results are in italics.

The new documents that have been found in the archives of the town of Pamiers (France), constitute an important contribution. These documents considered together with the chronicles from Barcelona may significantly modify former interpretations. The far field sources of Barcelona and Pamiers, which are independent one to the other, agree in the date and time of the felt earthquakes on 13<sup>th</sup> and 19<sup>th</sup> of March (the latest felt with higher intensity) in both cities. However the earthquake of March 15<sup>th</sup> is not mentioned in these two sources. Consequently it is conjectured that the events in March with higher intensity are those occurred the 13<sup>th</sup> and the 19<sup>th</sup>. These events are probably those reported as felt in Montpellier by the other source above mentioned that do not supply accurate chronology.

A thorough analysis of the descriptions in the near field sources (in particular the letters of the Jurors of Girona, the documents from the Amer Notary's office and Hebrew Chronicle source) together with the chronology provided by the far field sources from Barcelona and Pamiers, leads to consider that the Amer area was already damaged by the earthquakes on 13<sup>th</sup> and 14<sup>th</sup> of March. The effects of the March 15<sup>th</sup> event on the Monastery of Santa Maria in Amer is described in detail by the abbot in a Notary's document. It is related that "due to the earthquake, a fourth of the battlement of belfry of our monastery fell upon the vault of the church". This stones downfall produced a partial destruction of the building. It is then clear that it is not needed a very strong ground shaking to explain this destruction, and so the March 15<sup>th</sup> earthquake had probably lower intensity than other events of the sequence. However, this event was very sound because of the importance of the Amer Monastery. In the following days some more events occur, the cumulative effect of which produced devastation in the town Amer and surrounding area. In particular the 19<sup>th</sup> of March earthquake (felt in Pamiers and Barcelona at about 9 hours in the evening) must have had an important role in completing the destruction.

The next important earthquake was that of 22<sup>nd</sup> of April that produced effects on surface as smokers and ground cracks in Lloret Salvatge and damaged the village of Sant Julià del Llor (see figure 2). The Hebrew source coincides on the date and time of this earthquake with the Barcelona chronicle; the previously catalogued event of 23<sup>rd</sup> of April can be declared as fake quake.

The new sources considered basically confirm the former interpretation (Olivera et al., 1994) of the 15<sup>th</sup> of May earthquake. Although a document written on 5 April 1427 (Puigvert, 1996) describes some damages on March in Besalú (see figure 2) the exhaustive review of the documents in the archive of Olot show that the normality of life in this town was never discontinued before the May 15<sup>th</sup> (Puigvert, 1998), so the March earthquakes did not affect Olot. For the Olot May 15<sup>th</sup> earthquake we must consider that the description of damage were probably exaggerated for well known economical interest. The fact that this event is not reported in the Barcelona Chronicle *Novells Ardits* could be explained by a change in the handwriting in this source between April and May that can mean a scribe change.

Concerning June, the Hebrew source allows several new events to be catalogued, in particular that of June 17<sup>th</sup>.

## SEISMOLOGICAL PARAMETERS ASSESSMENT

Through the above chronology analysis has been possible to identify the various individual earthquakes of the sequence but their individual effects, in particular those of March, are difficult to separate. This is a general problem in earthquake sequences that appears even at present, as seen in the September 1997, Umbria-Marche region (Italy). Thus, figure 2 shows with different symbols the intensities (EMS-92) assigned to the various localities for the March sequence (cumulative effects) and for the April 22<sup>nd</sup>, May 15<sup>th</sup> and June 17<sup>th</sup> earthquakes.

In order to assess earthquake parameters (epicenter location, epicentral intensity  $I_0$ , etc...) from macroseismic data it is necessary to have assessed site intensities for individual events and to follow non subjective procedures (Stucchi, 1994). In this study the above mentioned problems of separation of effects of individual events are encountered making impossible the strict application of these procedures. In spite of this difficulty it is necessary to catalogue these events for providing to seismic hazard evaluators with the necessary data. Different solutions can be proposed to explain the data (damage and chronology) extracted from the historical sources. It is proposed here a solution compatible with the near and far field data (table 1). Epicentre and  $I_0$  is assigned only to those events for which significant and reliable data is available. Events in table 1 without intensity assignment are considered to have lower values of  $I_0$  (less than 7).

With respect to the March events the cumulative intensities in the various localities shown in figure 2, in particular the degree 8-9 in Amer, are considered to be the superimposition of the effects of all the listed events, with epicentre near Amer, four of them with  $I_0$  from 7 to 8.

The epicentral intensity of the 22<sup>nd</sup> April earthquake (7-8) has been assessed according to the point intensity on Sant Julià del Llor (figure 2); it is not possible to assign point intensity, based only on ground effects, to Lloret Salvatge (question mark in figure 2), where descriptions of damage on buildings are not available.

An epicentral intensity of 8-9 is assigned to the 15<sup>th</sup> of May earthquake with epicentre in Olot. It has been partially considered the possible exaggeration or effects by the population of Olot. This, together with the consideration of probable local effects might allow us to still decrease this assigned epicentral intensity of this earthquake. This would also be consistent with the fact that the earthquake was recorded only in near field sources.

Finally, a new earthquake on June 17<sup>th</sup>, 1427, of  $I_0 = 7-8$  with epicentre in Caldes de Malavella is presented. This assessment is based on the description in the Hebrew source; this event occurs just the day before this chronicle is written, so the information seems to be reliable. This event could be related with two other previous pieces of informations: 1) damage at Sant Feliu de Guíxols described in a letter from the king, and 2) descriptions referred to some churches (see figure 2) from the Pastoral Visits of 1432; some of these damages can be associated to this event; however, it has to be indicated that in the Visits there are reported some other churches without any damage in the same area (Riera et al., 1993).

The epicentres show a geographical alignment from SE to NW (figure 3) which corresponds with the Amer-Brugent fault system.

## CONCLUSIONS

The analysis of all the available documentation, which includes contemporary descriptions corresponding to both near and far to the epicentral area, has permitted to modify former interpretations proposed for the 1427 earthquakes.

Assigning site intensities for individual events presents a double difficulty: lack of detail in descriptions in the contemporary sources and impossibility to separate the effects from different earthquakes. With all these difficulties discussed, date, location and epicentral intensity of the studied events are proposed in table 1 and figure 3.

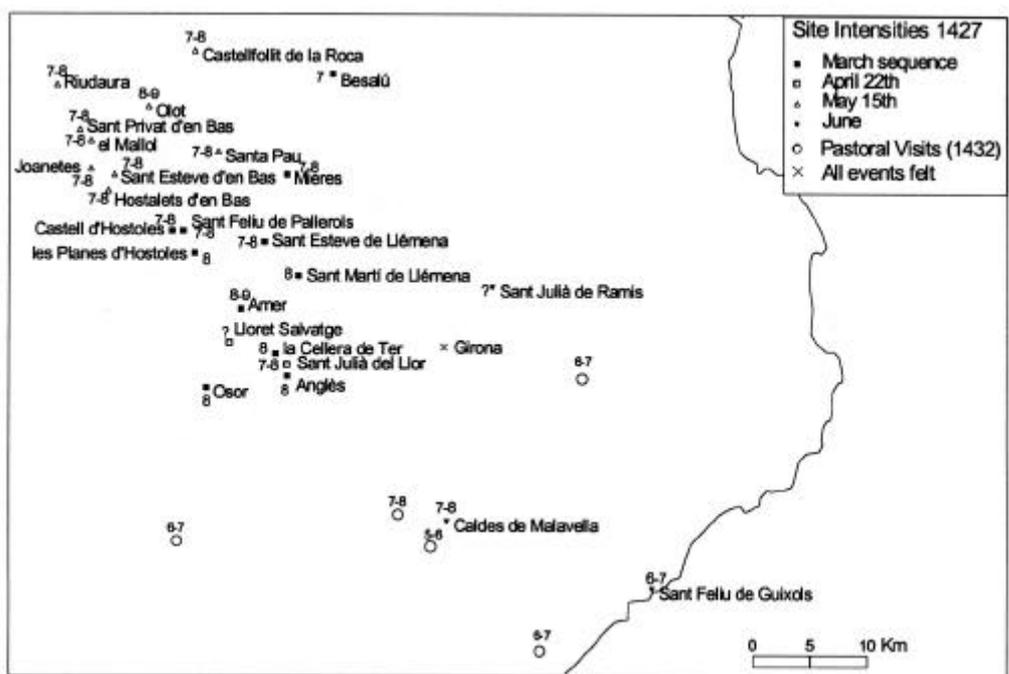
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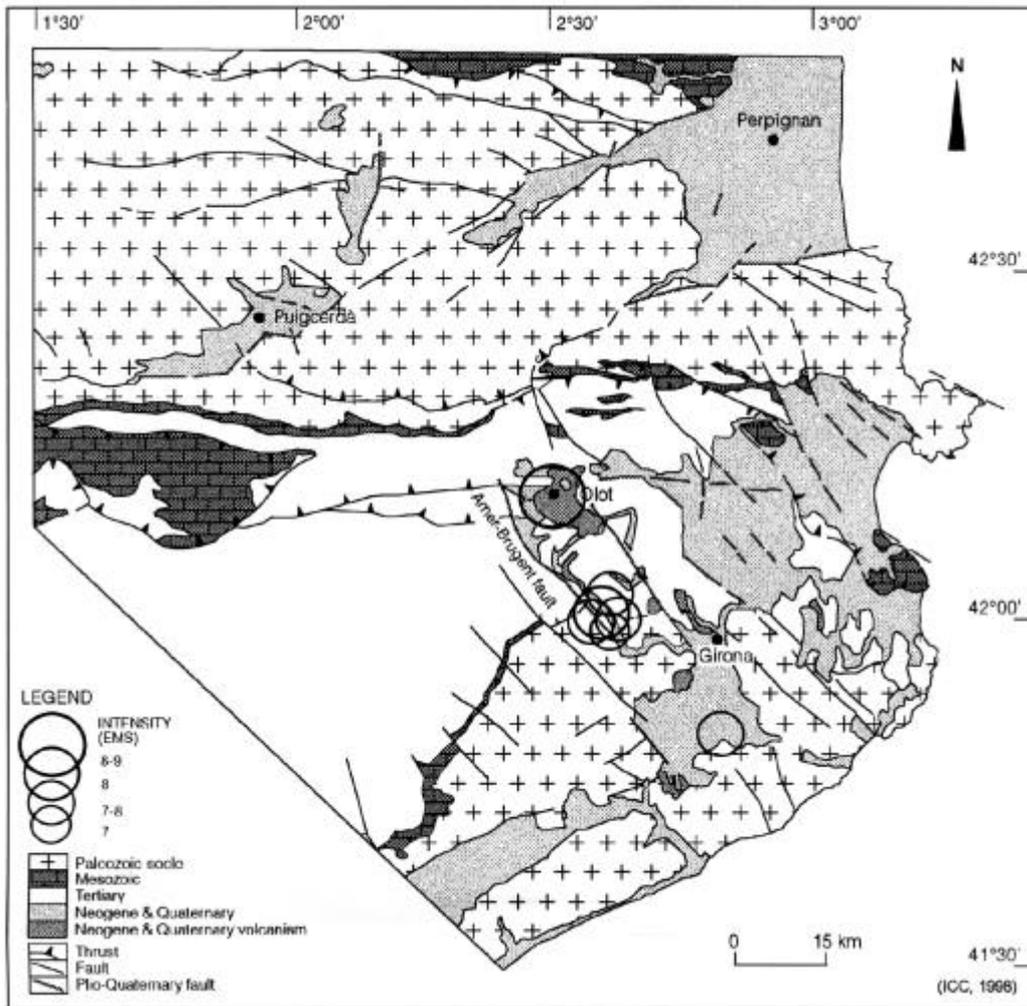
FIGURAS



**Figura 1.** Localities for which information on effects from the 1427 earthquakes is available.  
 Damage takes place within the squared zone.



**Figura 2.** Site intensities EMS-92 (see text).



**Figura 3.** Epicentres of 1427 with assigned intensity are plotted on a structural geological scheme.