Macroseismic and instrumental data comprehensive analysis: Earthquake of June 2, 1930 in Catalonia (Spain)

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[1] Modern concept of seismic hazard assessment is based on the assumption that what was observed in the past could likely be expected in the future. It could be easily recognized by comparison of spatial distribution of maximum intensity of shaking ($I_{\max}$) from past earthquakes and actual seismic hazard maps. This makes crucially important the re-evaluation of parameters of earthquakes close to the maximum observed ones in a certain area: even a small change of the parameters can affect considerably the final hazard assessment. A case study of the earthquake on 2 June, 1930 in southern Catalonia, Spain, is presented. A comprehensive analysis of macroseismic and instrumental data leads to a good agreement in magnitude re-evaluation. The earthquake magnitude M_S is within the interval 4.5–4.8, which is significantly larger than that reported earlier (3.9). Relatively accurate magnitude evaluation allows us also to assess the hypocenter depth to be at 20–30 km, deeper than it is commonly assumed for this region. Occurrence of large earthquakes in southern Catalonia at various depths (from 10 km to 30 km) reflects the presence of seismogenic structures which are able to produce earthquakes with magnitudes at least as large as 4.5–4.8. Orientation of isoseismals lets us also to suggest that these seismogenic structures are oriented almost perpendicular to strike of topographic elevations, which follow along the seashore. Modern topography does not inherit deep (mid and low crust) structures. *INDEX TERMS:* 0935 Exploration Geophysics: Seismic methods; 7223 Seismology: Earthquake interaction, forecasting, and prediction; 7230 Seismology: Seismicity and tectonics; *KEYWORDS:* Earthquake intensity, Iberian Peninsula, Macroseismic analysis, Old seismograms, Seismic hazard assessment.

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Introduction

[2] The modern concept of seismic hazard assessment is based on the assumption that what was observed in the past could likely be expected in the future. Usually this principle is stated explicitly but even if not so, it is followed implicitly. It could be easily recognized by comparison of the spatial distribution of maximum intensity of shaking ($I_{\max}$) from past earthquakes with seismic hazard maps. *Tatevossian et al.* [2006] showed recently that the spatial distribution of $I_{\max}$ (the observed ones supplemented by calculated values based on the epicentral intensities) over the Spanish territory is well correlated with the peak ground acceleration (PGA) contours obtained within the frames of the Global Seismic Hazard Assessment Program [*Jiménez and García-Fernández,* 1999]. This fact makes crucially important to

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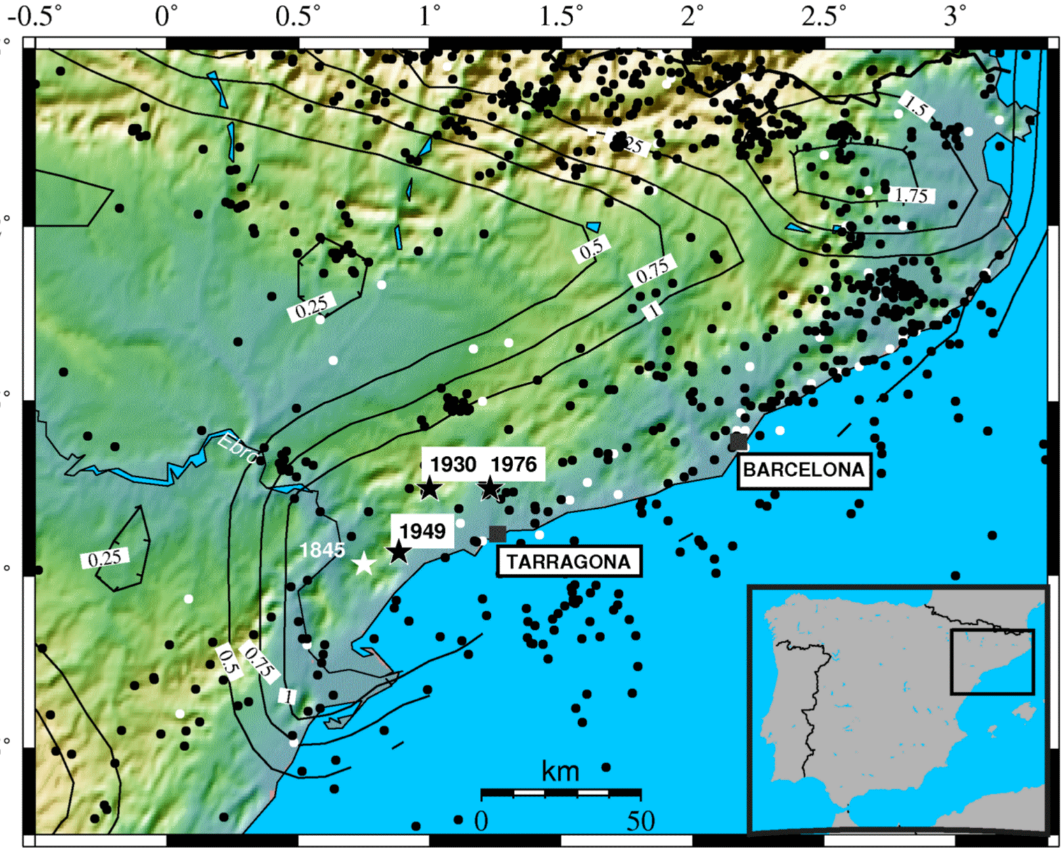

Figure 1. Spatial distribution of seismicity in Catalonia and seismic hazard map. Earthquakes in southern Catalonia with magnitude higher than 3.5, are shown in black stars. White star is for a preinstrumental time period earthquake with epicentral intensity $I_0 = 6.5$. Dots are earthquake epicenters (white dots are for historical earthquakes, black ones are for seismic events since 1901). Contours are isolines of PGA (in m sec^{-2}) taken from GSHAP map [*Jiménez and García-Fernández,* 1999].

re-evaluate the parameters of earthquakes close to the maximum observed ones in a certain area: even a small change of them can affect considerably the final hazard assessment. In this paper comprehensive analysis of macroseismic and instrumental data for accurate re-evaluation of earthquake parameters is presented. The most promising time period for this objective is the so-called early instrumental period. Before that time period we simply do not have instrumental data, and for the time period after the 1960's, when the World Wide Standardized Seismograph Network (WWSSN) was set in operation, the instrumental observations ensure relatively high data quality, which is enough to get reliable earthquake parameter determinations.

[3] In this work we will address to the seismicity of southern Catalonia, Spain. Though Catalonia is not large, the spatial distribution of seismicity over its territory is rather inhomogeneous (Figure 1). The highest activity both in historical and modern times is concentrated in its northern part along the Pyrenean Range, approximately up to Barcelona. On the other hand, the part from Tarragona to Ebro valley in the south presents moderate seismic activity. According to the seismic catalogue of the Spanish National Geographic Institute (IGN) [*Martínez-Solares and Mézcua,* 2002; *Mézcua and Martínez-Solares,* 1983], (IGN Database, 2004, http://www.mfom.es/ign/), earthquakes with magnitudes greater than 4 are not known in this part of Catalonia. The spatial distribution of seismicity is also reflected in the hazard map (Figure 1). PGA values along the Pyrenees are greater than or equal to 1.25 m s^{-2}, whereas to the north of Barcelona it exceeds 1.75 m s^{-2}. On the other hand, the isoline of 1.0 m s^{-2} contours southern Catalonia.

[4] The importance of every earthquake for hazard assessment becomes higher in areas of low and moderate seismicity. At the same time, the parameters of small earthquakes ($M \leq 4$) are usually defined with greater uncertainty, especially before the operation of the WWSSN started, because only few stations could record them. In a certain sense, the level of seismic activity justifies our choice of the study region.

[5] Stars in Figure 1 show the relatively large earthquakes occurred in southern Catalonia. Black stars correspond to seismic events with $M = 3.5$–4 (larger magnitudes are not known in this region). The epicentral intensity (I_0) of the 1845 earthquake (white star) is the highest reported ever.

Table 1. Parameters of the earthquakes of 2 June, 1930, and 13 February, 1949 from the IGN catalogue [*Mézcua and Martínez-Solares,* 1983].

Date (yyyy/mm/dd)	Time (hhmm)	Latitude, °N	Longitude, °E	H, km	m_bLg	N	I_0	Map	Epicentral area
1930/06/02	0152	41.250	1.000	–	3.9	5	5	yes	Cornudella
1949/02/13	0506	41.067	0.883	–	4.0	1	5	yes	Colldejou

Its magnitude (in fact there were 3 shocks on October 1, 3 and 7) is not defined in the IGN catalogue. The epicentral intensity of the first shock is 4, whereas for next two shocks it is 6.5. These are the highest reported I_0 in the area. But probably I_0 is somewhat exaggerated because of superposition of macroseismic effects from the sequence of shocks.

[6] We will focus our study on the earthquake of 1930. It clearly can be considered as a seismic event of the early instrumental period. Its magnitude in the IGN catalogue is 3.9 whereas I_0 is 5 and hypocenter depth is not assigned. It has to be noted that the source depth is neither reported for 1949, nor for 1976 earthquakes with magnitudes 4.0 and 3.6; both with epicentral intensity 5. The absence of hypocenter depth determination could be interpreted as an evidence for low accurate solution for this earthquake. This is again a reason to look more carefully at the seismicity of the region, which was not well monitored instrumentally probably up to mid of 1970's. The importance of source depth for seismic hazard analysis is evident from the macroseismic field equation [*Shebalin,* 1971]:

$$I_{\mathrm{i}} = bM - \nu \log(R^2 + H^2)^{1/2} + c \ , \tag{1}$$

which in the epicentral area becomes:

$$I_0 = bM - \nu \log H + c \ , \tag{2}$$

where I_{i} is the intensity at a distance R km from the epicenter, I_0 is the epicentral intensity, M is the magnitude, H is the hypocenter depth in km, and b, ν, c are coefficients which are equal to 1.5, 3.5 and 3.0 respectively for earthquake sources within the Earth crust. These values of coefficients were proved in most of the world seismic active regions [*Kondorskaya and Shebalin,* 1982; *Shebalin et al.,* 1974] and they suggest a strong dependence of intensity with depth. It has to be emphasized that the absence of depth for largest earthquakes is an essential drawback not only for hazard assessment but also for the understanding of seismotectonic features governing the seismicity of the region.

[7] Further we will present the record lines for the 1930 earthquake from the parametric catalogue, then we will examine the macroseismic data referenced in the catalogue and finally we will revise the macroseismic and instrumental data to get mutually consistent interpretation.

Reported Parameters for the 1930 Earthquake

[8] We accept as the reference source of information the IGN earthquake catalogue (IGN Database, 2004, http://www.mfom.es/ign/), [*Martínez-Solares and Mézcua,* 2002; *Mézcua and Martínez-Solares,* 1983], which is the official catalogue of earthquakes in Spain. The parametric lines for the 2 June, 1930 and 13 February, 1949 earthquakes in the IGN catalogue are shown in Table 1. There are two versions of the isoseismal map for the 1930 earthquake in *Mézcua* [1982], each referring to different sources of information. Both versions are reproduced in Figure 2. The 1949 earthquake map is reproduced in Figure 3 [*Mézcua,* 1982]. All maps have been re-sized to be approximately in the same scale.

[9] Even a brief examination of the isoseismal maps reveals some incoherencies. Though magnitudes of the 1930 and 1949 earthquakes are almost the same (3.9 and 4.0), the felt area of the first one is larger. It is also much larger (more than 2 times) the area contoured by the intensity IV isoline (regardless to which version of the isoseismal map of the 1930 earthquake we compare with the 1949 map). This could hardly be attributed to different attenuations of seismic waves radiated by both earthquakes, because the distance between their epicenters is about 20 km, so the source-locality travel paths are almost the same for both earthquakes. An explanation could be the assumption of a deeper source for the 1930 earthquake. But a deeper source of the 1930 earthquake will become in contradiction with equal magnitudes and epicentral intensities ($I_0 = 5$) for both earthquakes. According to equation (1) and (2), the epicentral intensity, magnitude and felt area of the 1949 earthquake are coherent with the assumption of a relatively shallow source (10–15 km), so the discrepancy between these parameters for the 1930 event has to be solved. For this purpose we have to verify both macroseismic and instrumental data.

Analysis of Macroseismic Data

[10] The intensity data were read from the maps in Figure 2 (a and b, named Source 2 and Source 3, respectively) and they were supplemented with data from two other sources: the archive of the Cartographic Institute of Catalonia [*Susagna and Goula,* 1999, named Source 1] and *Fontseré* [1940] (named Source 4). All these data are summarized in Table 2.

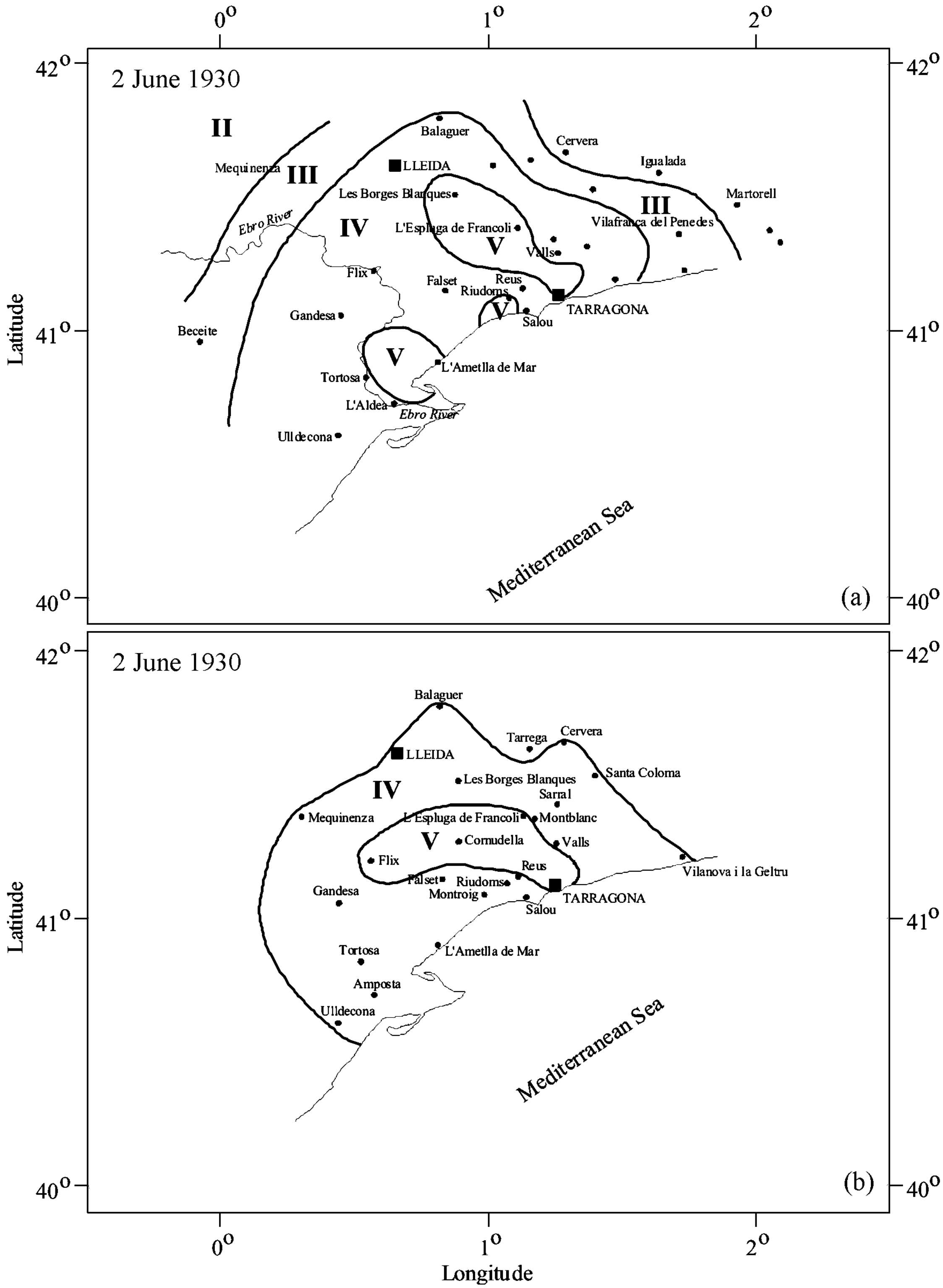

Figure 2. Two versions of the isoseismal maps for the 2 June, 1930 earthquake [*Mézcua,* 1982], (a) source SSIS and (b) source *Fontseré* [1940].

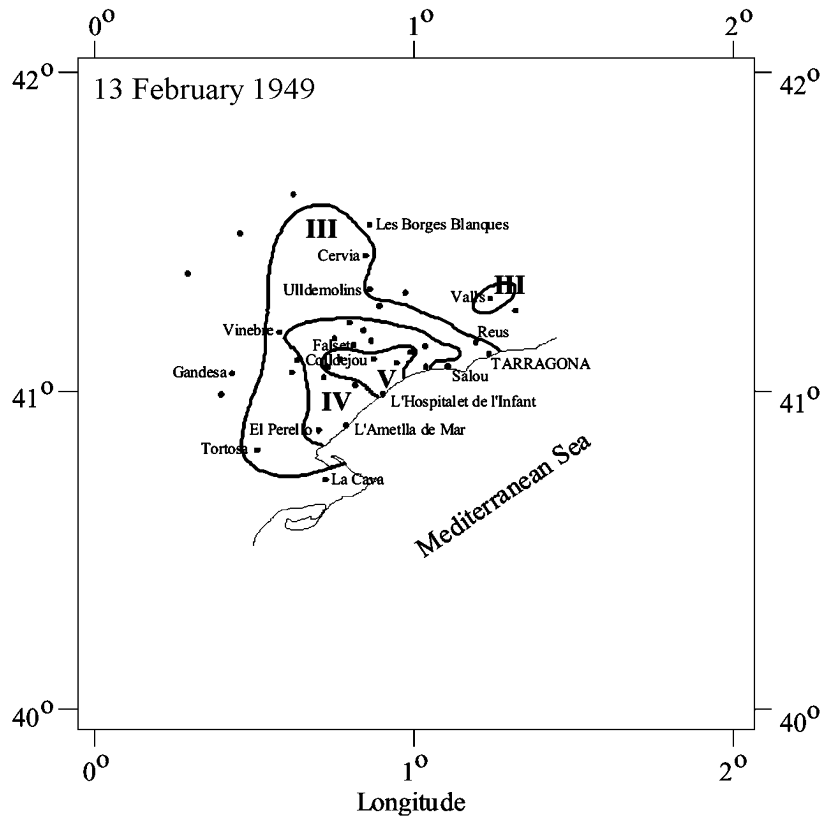

Figure 3. Isoseismal map for the 13 February, 1949 earthquake [*Mézcua,* 1982]; source *Fontseré* [1951].

The localities for which the intensity values from 2 or more data sources coincide are highlighted in bold. There are only 9 such cases from a total number of 74 localities. On one hand, this fact demonstrates the lack of detailed and accurate data, which make possible unique intensity assessments and, on the other hand, it proves that different data sources present independent researches. However, in most of the cases the intensity discrepancy does not exceed 1 degree, which could be accepted as a reasonable accuracy of assessment for the majority of reported intensities. Of course in some cases the error could be greater. The last column of the table compiles the intensity degrees considered in this paper. In agreement with European Macroseismic Scale [*Granthat,* 1998] we follow the convention that sign "–" means uncertainty and not the precision, i.e. I=4–5 means that we are not able to distinguish between 4 or 5 and not that the intensity is 4.5 (which would imply an accuracy of 0.5 degree). The epicenter locations from different sources do not differ significantly because all of them are within a 7 km radii circle. It also has to be mentioned that though none of the sources report observed intensities greater than 5, the Source 1 assesses an epicentral intensity 5–6.

[11] The map of intensity data points considered in this work is presented in Figure 4. Question marks denote doubtful cases, such as when the intensity in a locality differs significantly from the ones for cluster of nearby localities. For example, intensity 4 is assigned to locality Sant Feliu de Llobregat by Source 1, but there are other four close localities with intensity 2. Other type of doubtful case is when the reported locality is in obvious contradiction with any reasonable attenuation, like in Solsona for which the only source is Source 1. This source assigns intensity 4 to this locality, which is at about 100 km from the epicenter of an earthquake with epicentral intensity 5. The same source assigns an intensity degree 4 to Riumors (42.229°N; 3.044°E), which even falls out of the presented map boundaries, with an epicentral distance of about 180 km. Nevertheless, such strong incoherencies are rare (6 points from a set of 74 localities). This also confirms our assumption that the accuracy for most of the intensity assessments is not worse than 1 degree. It is important to emphasize that the fact of adding the information from two new sources does not change the main features observed when comparing the isoseismal maps of Figures 2 and 3: the felt area and the $I_{\mathrm{i}} = 4$ area for the 1930 earthquake are larger than those for the 1949 seismic event. Moreover, this difference becomes sharper.

[12] The isolines drawn in Figure 4 are calculated using equations (1) and (2). The epicenter location is taken from the IGN catalogue. Because all the earthquake locations from different sources are close to each other, the arbitrariness of this choice does not affect the result. Then we plot 8 isoline sets for different depth values (from 5 km to 40 km with a 5 km step). In the macroseismic field equations a mean radius of isoline is assumed. For the elliptical iso-

Table 2. Intensity data points from different sources and assessed in this paper.

Locality	Source 1	Source 2	Source 3	Source 4	Final	Locality	Source 1	Source 2	Source 3	Source 4	Final
Aiguamúrcia	Y				Y	Molins de Rei		2			2
Alcanar				2–3	2–3	Montblanc			4		4
Alcaniz				4–5	4–5	Mont-Roig del Camp			4		4
Aldea. L’		4		3–4	3–4	Móra d’Ebre	IV			3	3–4
Aldover				4	4	Móra la Nova	IV				4
Alfarrás				3	3	Nulles	IV			4–5	4–5
Alió	Y				Y	Peñarroya de Tastavins				2–3	2–3
Ametlla de Mar. L’		5	4	5	4–5	Pobla de Montornés. La	III	4			3–4
Amposta			4	3–4	3–4	Pont d’Armentera. El	Y				Y
Arnes				2–3	2–3	Prat de Llobregat. El	N				2
Balaguer	**IV**	**4**	**4**		**4**	Reus	Y	4	4		4
Barcelona	Y				Y	Riba. La	Y				Y
Batea				2–3	2–3	Riudoms		5	4		4
Beceite	**III**	**3**			**3**	Riumors	IV				4
Bellpuig	**IV**	**4**			**4**	Sant Feliu de Llobregat	IV				4
Borges Blanques. Les		5	4		4–5	Santa Coloma de Queralt	IV	3	4		3–4
Capellades				4–5	4–5	Sarral			4	3	3–4
Cervera	IV	2	4		3	Salou	IV	4	4	3–4	4
Cornudella de Montsant			5		5	Solivella				3–4	3–4
Cretas				2–3	2–3	Solsona	IV				4
Espluga de Francoli. L’	**V**	**5**	**5**		**5**	Tarragona	IV	5	5		4–5
Falset	IV	4	4	3	4	**Tàrrega**	**III**	**3**	**3**		**3**
Flix	IV	4	5		4–5	Tivissa	IV			4	4
Gandesa	IV	4	4	3	3–4	Torre de l’Espanyol. La	IV				4
Garcia				2–3	2–3	Tortosa	V	4	4	3–4	3–4
Godall	Y				Y	**Ulldecona**	**IV**	**4**	**4**	**4**	**4**
Horta de Sant Joan				4	4	Valderrobres				3	3
Hospitalet de Llobregat		2			2	Valls	IV	4	4		4
Igualada	**N**	**2**			**2**	Vendrell. El				3	3
Lilla		4			4	Verdú	III–IV				3–4
Lleida	**IV**	**4**	**4**		**4**	Vilafranca del Penedés	III–IV	3			3–4
Maella				3–4	3–4	Vilanova i la Geltrú	IV	3	4		3–4
Martorell	**N**	**2**			**2**	Vila-Rodona	IV	4			4
Masó. La				3–4	3–4	Vila-Seca	IV				4
Mazaleón				3	3	Vilella Alta. La				3	3
Mequinenza			4	2	3	Vinaròs				3	3
Miravet				4–5	4–5	Xerta				4	4

Note: Source 1 corresponds to the archive of the Cartographic Institute of Catalonia [*Susagna and Goula,* 1999]; Sources 2 and 3 are the values reported by *Mézcua* [1982] in Figures 2a and 2b, respectively. Source 4 is *Fontseré* [1940]. Column Final of the Table is the intensity degrees assessed in this paper. “N” means, “not felt” and “Y” means “felt”.

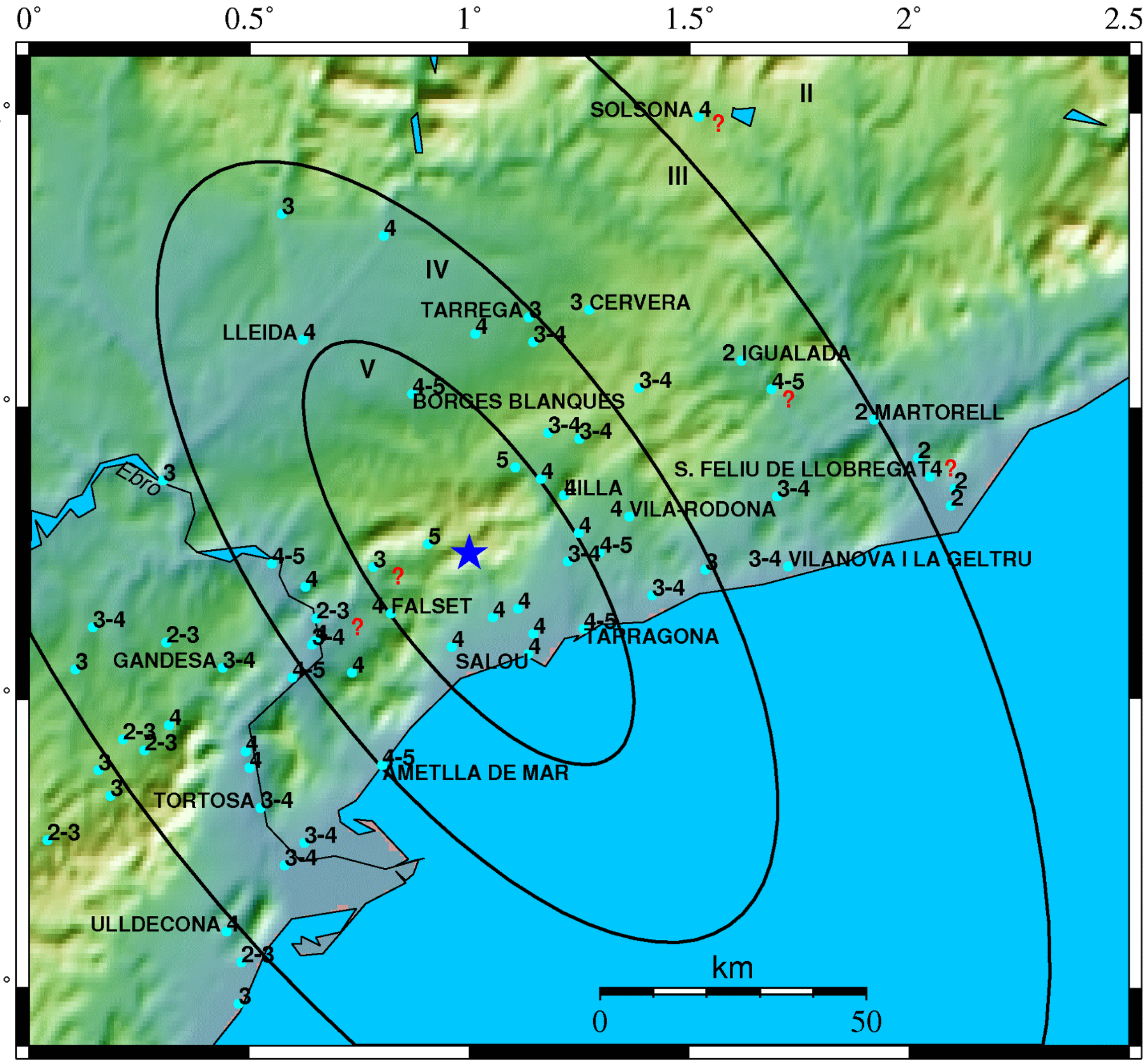

Figure 4. Intensity data points and theoretical isoseismals ($H = 30$ km, elliptical model) for the 2 June, 1930 earthquake.

lines we assumed that $R_{\mathrm{mean}} = (ab)^{1/2}$, where a and b are the ellipse semiaxis. The ratio a/b depends on the number of isoline from the epicenter. The ratio is larger for those, which are close to the epicenter. We also vary the orientation of isolines. The isoline set shown in Figure 4 gives the best separation of plotted data (it should be remembered that the symbol "–" is interpreted as uncertainty). The set corresponds to the following parameters: $H = 30$ km; $(a/b)_{\mathrm{V}} = 2.5$; $(a/b)_{\mathrm{IV}} = 2.25$; $(a/b)_{\mathrm{III}} = 2.2$.

[13] To fit the epicentral intensity $I_0 = 5$ and the isoseismal radii in Figure 4 the earthquake magnitude has to be set to $M_S = 4.8$. Taking into account the accuracy of intensity assessments in the localities together with the number of model variables used for the calculation of each set of isoseismals, one has to be cautious with the obtained magnitude value. However, we have strong reasons to conclude that a larger earthquake magnitude than that reported in the IGN catalogue is expected. To be more confident we have to verify instrumental data.

Analysis of Instrumental Data

[14] According to *Hughes and Bellamy* [1935] the 1930 earthquake was recorded on 13 stations at epicentral distances ranging from 0.6° to 11.2°. The fact that the earthquake was recorded up to 1200 km distance already supports a relatively large magnitude value. The reported magnitude by the International Seismological Summary (ISS) *Kárník* [1969] is $M_S = 4.6$ (based on data of 2 stations) whereas in the column of remarks a magnitude $M = 5.0$ calculated by *Munuera* [1963] with a local magnitude scale is given. Our assessment ($M_S = 4.8$) based on macroseis-

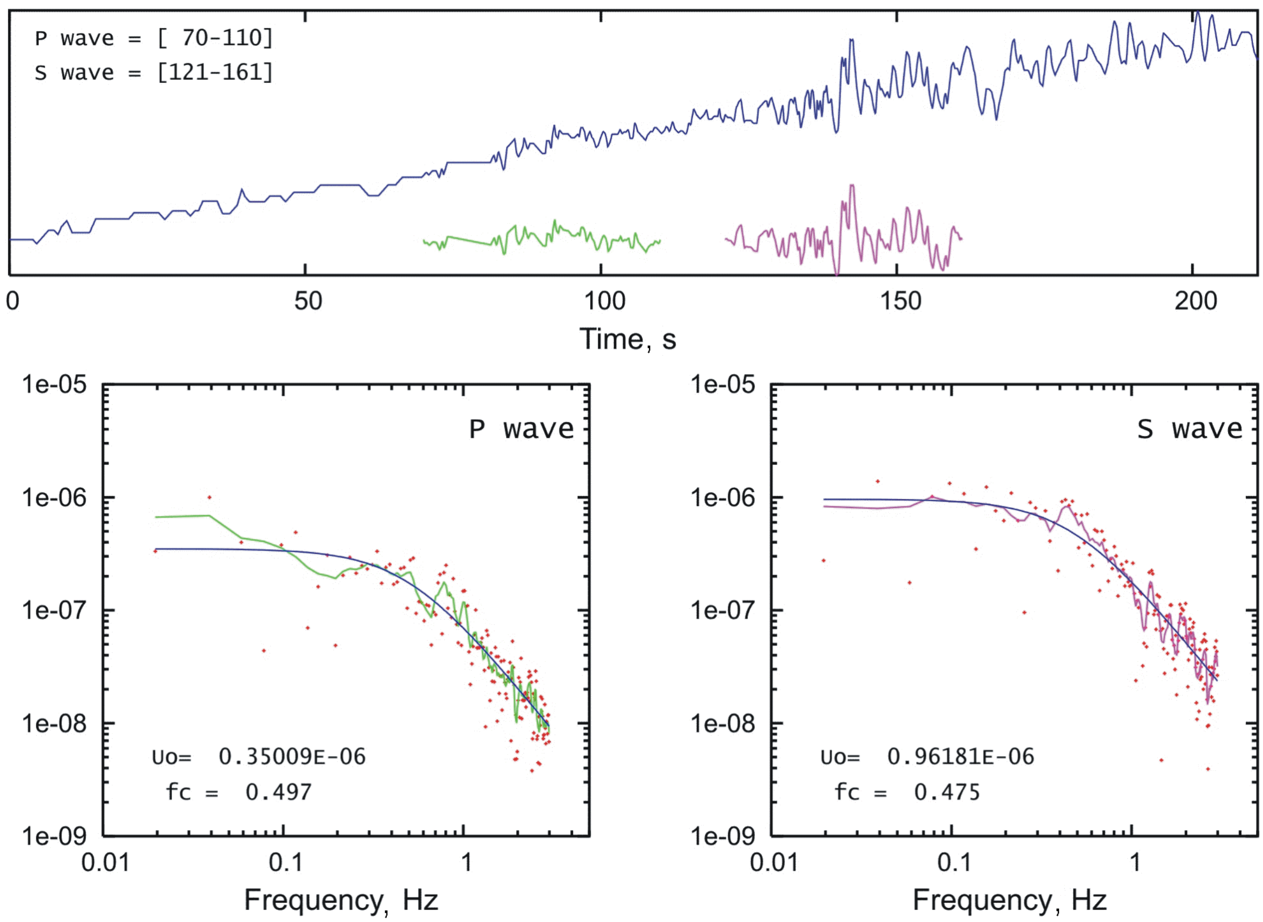

Figure 5. Example of one digitized signal recorded by the NE-SW component Wiechert seismograph at Toledo Observatory. The best fits for the seismic moment calculation for P and S waves are also shown.

mic data analysis is in a very good agreement with these values. The source depth is not defined in *Kárník* [1969]; it is only marked as "normal". On the other hand, the 1949 earthquake is not consigned by the ISS. *Kárník* [1969] gives a magnitude (4.2) (brackets in the original) taken from *Munuera* [1963]. However, as it has been shown recently [*López and Muñoz,* 2003] the methodology used by *Munuera* [1963] presents some shadows really difficult to elucidate now. In an unpublished research, *Sánchez-Contador* [1988] calculated a local magnitude ($M_{\rm L}$) equation for the Mainka's seismographs and a duration magnitude (M_t) equation for the Vicentini seismograph of the Fabra Observatory (FBR) in Barcelona, situated approximately at one degree of distance from the epicentral zone. The application of these equations gives $M_{\rm L} = 5.0$ and $M_t = 4.9$ for the 1930 earthquake and $M_{\rm L} = M_t = 4.5$ for the 1949 event. *Samardjieva et al.* [1998] also calculated the M_t and M_S magnitudes for the Horizontal Wiechert seismograph at Toledo Observatory (TOL) and obtained 4.5 and 4.1 values, respectively, for the 1930 earthquake. The 1949 event was not recorded at that observatory.

[15] Although all presented data sustain the assumption that the 1949 earthquake had a lower magnitude than the 1930 event, in order to shed light on these discrepancies the instrumental magnitudes for both events were re-calculated using the original seismographic recordings summarized in Table 3. All the recordings have been previously scanned, digitized and processed as described in *Dineva et al.* [2002]. However, some problems with the stylus inscription, time marks and not damped instruments make most of the records not valid for the seismic moment calculation. The only useful records are those from Toledo Observatory. Thus, the moment magnitude (M_w) has been calculated for the 1930 event. The obtained ground displacement spectra (U) of the digitized recordings have been modelled following *Brune* [1970, 1971] by fitting:

$$U(\omega) = U_0/(1 + (\omega/\omega_c)^\gamma) \tag{3}$$

using the non-linear χ^2 criteria where U_0 is the low-frequency level and $f_c(\omega_c = 2\pi f_c)$ the corner frequency.

[16] Then, the seismic moment was estimated using the formulation of *Keilis-Borok* [1960] from the low-frequency

Table 3. List of the original seismograms and recording constants for the 1930 and 1949 events.

Earthquake of 2 June, 1930					
Station	Type of instrument	Component	Magnification	$T_0(s)$	Damping
TOL	Wiechert	NE-SW; NW-SE	480; 420	11.6; 12.1	0.46; 0.47
	Wiechert	Z	110	4.3	0.38
EBR	Mainka	N-S	230	14.8	0.29
	Mainka	E-W	123	7.8	0.33
	Vicentini	Z	62	0.8	–
	Vertical Pendulum	N-S	110	2.6	–
FBR	Mainka	N-S	50	9.8	0.37
	Mainka	E-W	80	9.9	0.45
Earthquake of 13 February, 1949					
Station	Type of instrument	Component	Magnification	$T_0(s)$	Damping
EBR	Mainka	N-S	187	15.4	0.25
	Mainka	E-W	220	10.8	0.25
	Vertical Pendulum	N-S	230	2.5	–
FBR	Mainka	N-S	64	9.0	0.30
	Mainka	E-W	73	9.0	0.34
	Vicentini	Z	125	0.9	–

level of the spectra of body-waves:

$$M_0 = (4\pi\rho v^3 U_0)/(G(r)R_{\theta\varphi}C) \ , \tag{4}$$

where $\rho = 2.7$ g cm^{-3} is the density in the source region; v the wave velocity; U_0 the low-frequency level of spectrum in m·s; $G(r)$ the geometrical spreading factor which depends on the distance r; $R_{\theta\varphi}$ is the correction for the radiation pattern, which takes an average value of 0.4 for P waves [*Wyss and Brune,* 1968] and 0.63 for S waves [*Boore and Boatwright,* 1984]; and $C = 2.0$ is the correction for the free surface [*Moskvina,* 1987].

[17] The moment magnitude, M_w, is calculated using the empirical relation [*Hanks and Kanamori,* 1979]:

$$M_w = \frac{2}{3}\log M_0 - 6 \tag{5}$$

with M_0 given in N·m. Figure 5 shows one example of the digitized records and the ground displacement spectra fits (3) for P and S waves. From the obtained U_0 values and after applying (4) and (5) results give a value of $M_w = 4.4$ for P waves and $M_w = 4.2$ for S waves. Results are also larger than the value previously reported in the IGN catalogue ($M_S = 3.9$). However, the relationship between both magnitude scales show that M_S values are larger than M_w, for M_w less than about 6 [*Utsu,* 2002].

[18] On the other hand, although a moment magnitude calculation for the 1949 earthquake has been impossible, the original records give us information about the different size of both events. The Mainka instruments of EBR and FBR stations recorded both events with unchanged working characteristics. Figure 6 shows, in the same scale, the records on the Mainka N-S component of EBR. The Ebro observatory seismic bulletin states an epicentral distance of 56 km for the 1930 event and 32 km for the 1949 one. A rough visual comparison of maximum amplitudes supports a difference on magnitude between the two events of almost half unit.

Conclusions

[19] There are different concepts of macroseismic intensity. Some seismologists suppose, that there are so many uncontrollable factors influencing the intensity of shaking in a given locality, that it makes no sense to look for any regularity in spatial distribution of intensities. In other words, it doesn't matter how big is discrepancy between intensities expected from equation (1) and reported in a locality. Especially, if the reported intensity referrers to original questionnaires, which, supposed, automatically ensures high accuracy of intensity assessments. Others assume that, though intensity is a complex phenomenon indeed, anyway, it is not a kind of miracle: mostly source magnitude, depth, and source-locality distance govern spatial distribution of intensities. Local ground effects are very important, too, but they cannot completely alter in general regular character of intensity distribution. The second concept being physically reasonable seems more preferable.

[20] An obvious inconsistency between the reported parameters for the 2 June, 1930 earthquake in southern Catalonia in the IGN catalogue and the already published isoseismal maps for this seismic event provoked revision of the

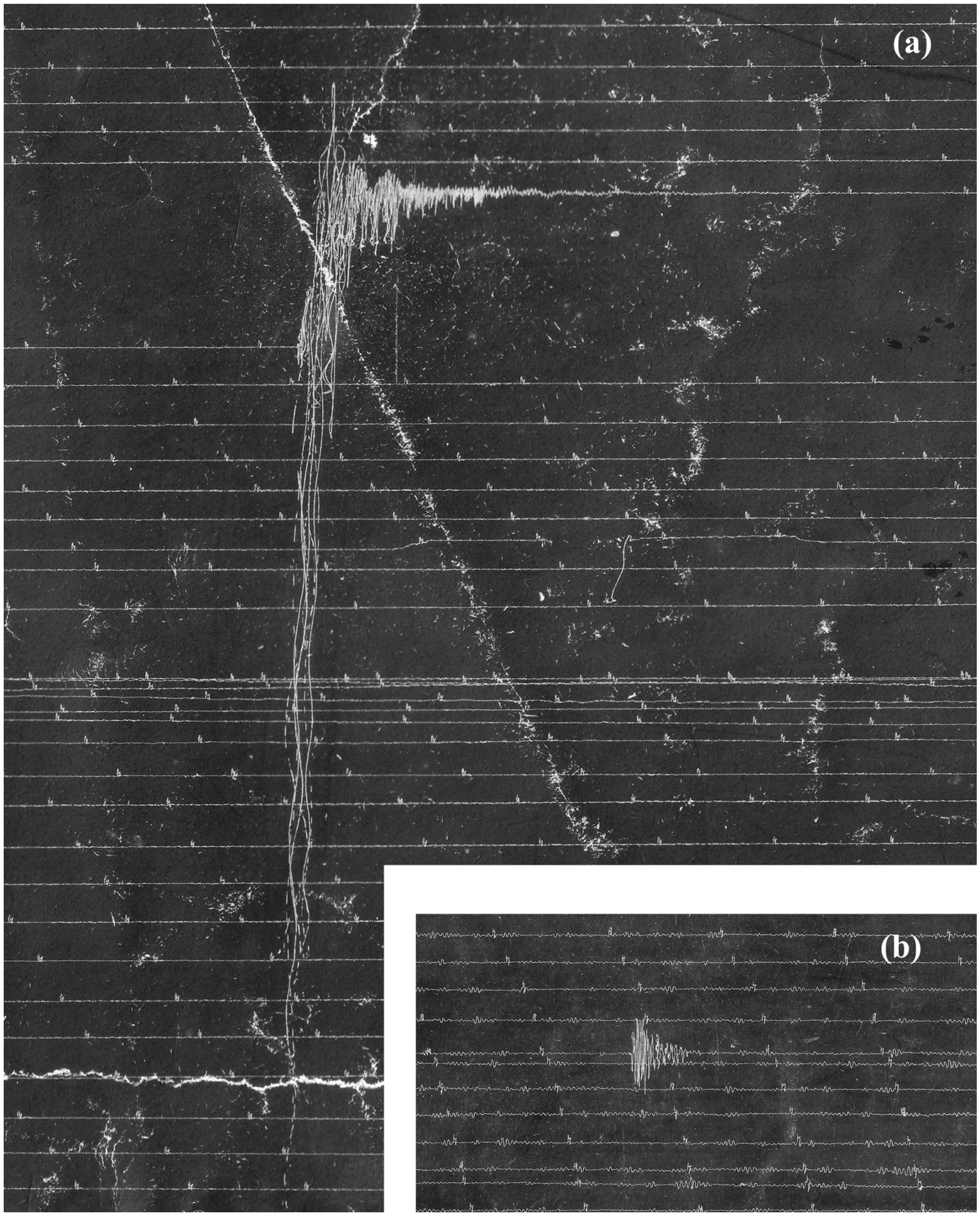

Figure 6. Example of the (a) 2 June, 1930 and (b) 13 February, 1949 earthquake records at EBR Observatory (N-S component of the Mainka Seismograph). Both seismograms are plotted at the same scale.

available data. The fact, that instrumental records, being absolutely independent from macroseismic ones, also prove a larger magnitude, than previously evaluated one, support the assumption that intensity of shaking is controlled (at least in general) by regular physical laws.

[21] Comprehensive analysis of macroseismic and instrumental data leads to a remarkably good agreement in magnitude re-evaluation. Results show that the earthquake magnitude M_S is within interval 4.5–4.8, which is significantly larger than the value previously reported in the IGN catalogue ($M_S = 3.9$). The relatively accurate magnitude evaluation allows us also to assess the hypocenter depth to be at 20–30 km. On the other hand, the instrumental data analysis gives values of moment magnitudes $M_w = 4.4$ for P waves and $M_w = 4.2$ for S waves, also larger than the M_S value previously reported. However, M_S values should be larger than M_w, for M_w less than about 6 [*Utsu,* 2002]. Finally, results of the isoseismal map analysis of the 13 February, 1949

earthquake are in agreement with the previously reported magnitude and relatively shallow depth (10–15 km). Thus, it can be concluded that the occurrence of large earthquakes in southern Catalonia at various depths (from 10 km to 30 km) reflects presence of seismogenic structures there that are able to produce earthquakes with magnitudes at least as large as 4.5–4.8. The orientation of isoseismals lets us also to suggest that these seismogenic structures are oriented almost perpendicular to strike of elevations, which follow along the seashore. The modern topography does not inherit deep (low crust) structures. The same situation was observed near the western termination of the Caucasus near the Black Sea shore, as revealed by the Lower Kuban, November 9th, 2002 earthquake [*Tatevossian et al.,* 2003]. In the latter case this conclusion was also supported by the fault plane solution: its strike was in remarkable agreement with the elongation of isoseismals.

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