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Abstract

The 23 April 1909 earthquake, with epicentre near Benavente (Portugal), was the largest crustal earthquake in the Iberian Peninsula during the 20th century (M_w = 6.0). Due to its importance, several studies were developed soon after its occurrence, in Portugal and in Spain. A perusal of the different studies on the macroseismic field of this earthquake showed some discrepancies, in particular on the abnormal patterns of the isoseismal curves in Spain. Besides, a complete list of Intensity Data Points for the event is unavailable at present. Seismic moment, focal mechanism and other earthquake parameters obtained from the instrumental records have been recently reviewed and recalculated. Revision of the macroseismic field of this earthquake poses a unique opportunity to study macroseismic propagation and local effects in central Iberian Peninsula. For this reasons, a search to collect new macroseismic data for this earthquake has been carried out and a re-evaluation of the whole set has been performed and it is presented here. Special attention is paid to the observed low attenuation of the macroseismic effects, heterogeneous propagation and the distortion introduced by local amplifications. Results of this study indicate, in general, an overestimation of the intensity degrees previously assigned to this earthquake in Spain, also it illustrates how difficult it is to assign an intensity degree to a large town, where local effects play an important role, and confirms the low attenuation of seismic propagation inside the Iberian Peninsula from west and southwest to east and northeast.

Keywords: Benavente earthquake; Macroseismic field; Intensity data points

Introduction

The Lower Tagus Valley is located in the central part of Portugal mainland. It is oriented in a NE direction and it reaches, in its southern part, the city of Lisbon, occupying an area of approximately 3,200 km^2. The seismicity pattern of this region is characterised by several small and medium earthquakes, and some strong earthquakes that occurred in historical times, Figure 1. The last large earthquake that occurred in this region was the 23 April 1909 earthquake (M_w = 6.0), which destroyed several small towns located in the valley. In particular, the village of Benavente, located at about 30 km NE from Lisbon on the eastern bank of the Tagus River, was destroyed during this violent shock (it is why many authors refer to it as the "1909 Benavente earthquake"). Since then, the seismic activity in the Lower Tagus Valley has been very low: during the last 30 years of the XX century, 39 earthquakes were felt, three of which with magnitude greater or equal to 4.0, and sixteen with magnitudes between 3.0 and 3.9 (Carrilho *et al.*, 2004).

Comment [PTC1]: Figure1

Among previous earthquakes, the first described in detail occurred on January 26th, 1531. Its epicentre was located between Vila Franca de Xira and Azambuja (see Figure 1) and the maximum felt intensity was IX-X (Modified Mercalli intensity scale of 1931). Intensities of VIII and IX were reported in Lisbon: about 25% of the houses were damaged, 10% suffered total collapse and 2% of the population was killed (Henriques *et al.*, 1988). Magnitudes Mb 7.1 (Martins and Mendes-Victor, 1990) or Mw 6.9 (Vilanova and Fonseca, 2007) are assigned to it. The main seismogenic structure within this region able to produce large earthquakes is the Lower Tagus Valley Fault which is, in fact, a system of faults (Cabral *et al.*, 2000; 2004). However, the thick sedimentary cover of this valley, in particular in the eastern bank of the Tagus River, does not allow a clear identification of all the potential active faults (see Figure 1).

The 1909 Benavente earthquake was the largest crustal earthquake occurred in the Iberian Peninsula during the XX century and it importance was recognized from the very beginning as it is demonstrated by several contemporary studies devoted to it (Calderón, 1909; Comas Solà, 1909; Cabral, 1909; Messerschmitt, 1909; Bensaude, 1910; Navarro Neumann, 1910; Diniz, 1910; Choffat and Bensaude, 1912). These studies dealt mainly with the macroseismic field but, even at such early times of instrumental seismology, some studies using seismographic records were already undertaken (Comas Solá, 1909; Messerschmitt, 1909; Inglada, 1909; Navarro Neumann, 1910).

The magnitude assigned to this earthquake was 6.6 (Ms) (Kárník, 1969). However, more recent analysis, based on the seismic moment estimation using the spectral analysis of digitized seismic records, suggest a lower magnitude M_W between 6.0 and 6.2, and M_S close to 6.3 (Teves-Costa *et al.*, 1999; Dineva *et al.*, 2002; Stich *et al.*, 2005; Teves-Costa *et al.*, 2005). Stich *et al.* (2005), using inversion of recorded body waves, determined its tensor moment and focal mechanism: a reverse faulting originating at 10 km depth. This is in agreement with other focal mechanisms obtained for this region (Borges *et al.*, 2001), as well as with the tectonic behaviour of the main structures present in this area (Cabral *et al.*, 2004).

Judging from the available macroseismic information, the epicentre was estimated at 38.9°N, 8.8°W (Kárník, 1969). In accordance with an attenuation law derived for Portugal mainland (Teves-Costa *et al.*, 2002), the observed macroseismic far-field shows an abnormal intensity pattern as compared with synthetic isoseismal curves generated by such an earthquake (see Figure 2). This could indicate the occurrence of local site effects or regional geology dependent effects. Also, the huge area where it was felt (about 215,000 km^2) was quite large for an earthquake with its magnitude, indicating complex seismic propagation and low attenuation processes. For instance, in the Messina earthquake of 1908, with magnitude close to 7.2, the area of perceptibility was much smaller (less than one third!). However, that behaviour seems to be common in earthquakes that affect the whole Iberian Peninsula (Choffat and Bensaude, 1912; Martínez Solares and Mezcua, 2002).

Several authors presented isoseismal maps for this earthquake: the most up-to-date, covering the whole Iberian Peninsula, was published in Mezcua (1982); Moreira (1991) and Senos *et al.*, (1994), for instance, published partial maps; Oliveira and Sousa (1991) presented synthetic isoseismals for the epicentral area (Figure 2 presents two of these maps). In fact, Mezcua (1982) presents a simplified copy of the original map drawn by Choffat and Bensaude (1912) with slight modifications. The intensity distribution in the near-field is well constrained due to the large amount of intensity data points contained in the exhaustive work performed by Choffat and Bensaude (1912). However, in the macroseismic far-field the isoseismal curves present a strange pattern, probably due to the small amount of assigned intensities in Spain. Moreover, up to present a complete list of sites, their geographical coordinates and their assigned intensities is unavailable. This is, the macroseismic maps are preserved but the data used to draw them are not. This poses a serious drawback for any detailed study to be undertaken.

Comment [PTC2]: Figure2

This paper is devoted to review the macroseismic field in order to understand the strange pattern in Spain, which seems to be heavily conditioned by the intensity assigned to larger towns such as Madrid and Ciudad Real. Also, questions related with the assignation of an intensity level to larger towns (which probably exhibit site effects) and their implications on the global isoseismal map estimation will be also addressed.

Macroseismic data assembly

The report published in 1912 by Choffat and Bensaude (C&B from now) is the primary source of macroseismic data for the 1909 Benavente earthquake. It is a very exhaustive report, compiling a large amount of information about its effects, in particular for Portugal, and it includes maps and photographs. The work describes the damage and effects caused by the earthquake in the entire country. These descriptions are more detailed for the zones near the epicentre and become more generic (usually only the attribution of an intensity degree) for the less affected zones. The report is presented taking into account the major geological units, specifying the surface geology, and grouping zones with the same intensity; C&B also took into account the limits of the administrative regions. The authors visited the most affected zones several times, where they observed the damage and collected information directly from the residents; for the other zones they collected information from newspapers, personal reports, official reports issued by the Civil Works, as well as from the answers to 1131 questionnaires sent-out to persons with different professions in 17 districts of Portugal. From Spain, they took the works of Calderón (1909) and Navarro Neumann (1910) as reference, and they also consulted two Spanish newspapers and the bulletin of the Cartuja seismic station (in Granada). Unfortunately, the report does not include geographical coordinates for the described places.

For each village or site, C&B assigned an intensity degree based on the Mercalli Cancani (MC) intensity scale (Cancani, 1904; Davison, 1933), with 12 degrees, but with a small personal adaptation to take into consideration the specific characteristics of the Portuguese building constructions (Bensaude, 1910). This scale is equivalent to the Modified Mercali (MM) intensity scale of 1931 (Wood and Neumann, 1931), which present a more detailed description of each degree and includes effects on nature (Musson *et al.*, 2009)

The paper published in 1910 by Navarro Neumann (N-N, from now), director of Cartuja seismic station, assigned macroseismic intensities based on the review performed by Calderón (1909), on the analysis of information published in Portuguese and Spanish newspapers, on descriptions sent by individual persons, as well as on the information sent by M. A. Sieberg from Strasbourg seismic station. N-N assigned to each village or site an intensity based on the Forel Mercalli (FM) intensity scale (Mercalli, 1902; Davison, 1921) but, in its report he did not describe the observed effects or damage. So, there is no information on which basis he assigned a specific intensity degree to a given site. As in C&B, geographical coordinates (and even maps) of cited places are unavailable.

The FM intensity scale has only 10 degrees. The main difference between this scale and the MC intensity scale used by C&B, is that this last one includes two more degrees to take into account the catastrophic effects produced by very strong earthquakes (Cancani, 1904). Besides, in the FM scale, degrees equal or higher than IV usually correspond to lower intensity levels in a 12 degree intensity scale (Guidoboni and Ebel, 2009; Musson *et al.*, 2009). So, our first concern was to re-evaluate all the intensities in Spain based on a 12 degree intensity scale.

According to Musson *et al.* (2009) all 12 degree intensity scales are equivalent. The differences (usually up to 0.5 degree) are more due to the persons that assigned the intensities than to the scales. This can often be seen when comparing evaluations of the same earthquake data performed by two different persons; these differences are larger than the differences on the intensities assessed by the same person using two different 12 degree intensity scales.

We decided to re-evaluate the intensities in Spain in the MM intensity scale in order to avoid many changes on the intensities assigned for Portugal by C&B (as stated before, the MM intensity scale is equivalent to the MC intensity scale used by C&B). It can be shown that the intensities assessed by C&B exhibit great coherency, by observing the regular distribution of the intensities with distance (Figure 3), which gives confidence to their results. Also, the C&B report gives enough information about s occurred in sites on the epicentral area to allow an independent evaluation, as we did. The result is that our evaluations do not differ from those of C&B. Finally, the MM intensity scale description seems to be more adequate to evaluate the intensity degree at the time of the earthquake occurrence. Besides, the re-evaluation of the intensities in the more recent EMS98 scale (Grünthal, 1998), requires reviewing the primary original information (the macroseismic questionnaires) which, unfortunately, is missing. For these reasons, MM scale was adopted in this study.

Comment [PTC3]: Figure3

We started on reviewing and completing the primary available information for Spain, with analysing a set of newspaper articles, and performing a critical review of the Calderón report, which described effects but did not assign intensity degrees. We have been able to assign independently intensities to 46 sites, 21 of them new; also we identified 7 sites where it was reported that the earthquake was not felt (interested readers may find a transcription of all the analyzed newspapers, as well as indexes of the cited places, in the electronic supplement material - ESM).

After careful analysis of all data, we performed a critical review of all assigned intensities, and gave to each site, whenever possible, a unique intensity degree value. To assign the final intensity value we used mainly the original intensities given by C&B. When they were contradictory with those of N-N or with our evaluation, we checked the available reports to make the final decision. In general, original intensities given by N-N, for the localities inside Portugal, tend to be one degree higher that those attributed by C&B. For some sites we accepted incertitude between two degrees (for instance, V-VI) and, for larger towns, we accepted an intensity range (e.g., III to V in Vila Nova de Gaia).

Maps of intensity data points (IDP) and isoseismal curves

As referred, the available reports did not include the geographical coordinates for the described places. So, it was necessary to geographical locate all the sites, before plotting the intensity data points (IDP) or drawing the isoseismal curves. This task posed some difficulties because, in Portugal and Spain, there are several small locations with the same name (or very similar), frequently at very short distances from one another. We used an available website (http://www.heavens-above.com) to assign the coordinates, but in several cases the identification was not clear. As an example, there are 145 locations named "Santiago" in Spain, many of which in the same administrative region (Galicia). So we were forced to check many locations visually, using old and recent atlases, and taking advantage of free access to Google Earth. Also, small villages have been absorbed, or their names changed, since 1909, making their identification very difficult. At the end we ignored a few places from the original C&B report that we were unable to locate confidently. Finally, we recovered coordinates and intensities for a total of 504 locations in Portugal and Spain (all these sites, with coordinates and assigned MM scale intensities, are presented in the ESM).

Figures 4 and 5 present the IDP for Portugal and Spain (up to longitude of 1ºE) and a zoom for the epicentral area, respectively, together with tentative isoseismal curves performed manually. The sites with information "not felt" give an idea of the area of perceptibility of the earthquake. In spite of an intensity II assigned to Barcelona, it seems reasonable to define the area of perceptibility of the earthquake in southern Spain up to longitude of 1º E. From Figure 4 it can be seen, as expected, that the intensity decreases with distance increasing. However, as it is also normal, we can find some sites with "anomalous" higher intensity outside the respective isoseismal curve. Some of these sites, located in the north-western part of Portugal, correspond to larger villages

Comment [PTC4]: Figure4

(usually surrounded by small localities) which have a considerable number of structures and, due to the absolute amount of damaged buildings, the intensity assigned to them was higher than the intensity assigned to the surrounding smaller localities. This problem, already pointed out by C&B, is usually found in the estimation of intensities for historical earthquakes.

In spite of the now larger amount of points with information on the earthquake effects in Spain, there can be great incertitude over the assigned intensity value. Sometimes, our estimation is based on a short phrase or a paragraph found in a newspaper (see ESM). However, for most of the sites, the incertitude is concealed between two intensity degrees. Besides, larger towns in Spain may present higher intensities, for the same reasons as explained for Portugal, or due to the existence of site effects, for instance. Due to these facts, the area in Spain with intensity V, in Figure 4, can be understood as a zone with intensity IV-V.

It can also be observed that the isoseismal limit of the area with intensity IV is mainly conditioned by the high intensities felt in several towns in Spain, in particular Segovia, Madrid, Villamanrique and Granada. These high intensities conditioned the general isoseismal map. So, it is very important (and critical) to define a criterion to attribute intensities to larger villages or towns.

Especially in dealing with historical seismicity, most of the authors assigned to each village the intensity associated to the maximum observable effects. These effects can be related with the existence of local effects or to poor seismic resistance of very vulnerable structures. This induces an overestimation of the intensity, as it is well known for many historical earthquakes. We think that the best criterion is to assign the intensity felt in most part of the city. However this information is rarely available, which can bias the general intensity map. Sometimes an intensity interval is available but, more often, only the maximum felt intensity was provided. The problem with the attribution of a single intensity value to a large town will be discussed further.

From the analysis of Figure 5 it can be seen that macroseismic information is sparser in the eastern margin of the Tagus River, due to the fact that it was less populated than the western part at the time of the earthquake. Intensities greater or equal to VIII are grouped close to the epicentral area (up to 25 km, approximately) but intensities equal to VII can be found up to distances close to 100 km. This could be due to local effects. Intensity VI area extends to the Portugal-Spain border, up to a distance close to 130 km, and the intensity V area extends in Spain to a distance larger than 230 km (see Figure 4). The distance between the epicentral area and the farther site exhibiting intensity IV is larger than 500 km (Madrid is at 460 km, approximately). As can be observed in Figure 4, the seismic attenuation is higher in the north-south direction than in the west-east direction. However, as already pointed-out, the area where the earthquake was felt was "anomalously" large, compared to other earthquakes with the same or larger magnitude. Using our

Comment [PTC5]: Figure 5

values as radii of circular areas and the formulas given by Johnston (1996) to relate intensity areas with moment magnitude in stable continental regions values of 6.3 ± 0.4 are obtained, indicating that the macroseismic affected area is larger than expected for and earthquake of magnitude Mw 6.1. This is a strong proof of the low seismic attenuation in central and south-southwest Iberian Peninsula (as pointed by Casado *et al*., 2000).

The isoseismal curves presented in Figures 4 and 5 were manually drawn, in order to compare our map with those formerly published. The large difference between the density of points in Portugal and in Spain does not allow a good definition of the isoseismal curves in Spain. However the map presented in Figure 4 accurately reproduces the two main features of the earthquake: the large affected area and the weak W-E attenuation. This can also be seen in the isoseismal map presented by Mezcua (1982) (Figure 2a), but in which the intensity values in the far-field are overestimated. Due to the large amount of confident data in the near field the different maps are very similar (Figures 2 and 5) and the differences arise only from the interpretation of the authors (very often, there is no unique way to draw the isoseismals).

Discussion

As mentioned before, to plot the IDP and the isoseismal maps it is necessary to attribute a single value to the intensity felt in each site. This is, very often, a difficult problem to be solved for the largest towns. For instance, the report presented by N-N assigned intensity VI FM to Madrid; after the conversion for the MM scale we could attribute an intensity V. However, it is well known how difficult it is to assign an intensity degree to a large town where topographical and/or geological local effects may play an important role, as also the existence of heterogeneity in the building stock. Many examples, mainly directed at the study of vulnerability in large towns, can be found in literature (Guidoboni *et al*., 2003; Cifelli *et al*., 2000; Giammarinaro *et al*., 2005, for instance). For the Benavente earthquake, this is the case of Lisbon, Madrid and other towns.

Particularly Madrid is a noteworthy case-study, because it is located far away from the epicentre (more than 450 km). A thorough search in newspapers, periodicals and other contemporary literature sources allowed us to assemble a large collection of references about the effects of this earthquake at many different places of Madrid. Main sources of information have been, besides the report of Calderón (1909), the contemporary Spanish newspapers *ABC*, *El Heraldo*, *El Liberal* and *El Siglo Futuro*, from Madrid; *Diario de Barcelona* and *La Vanguardia*, from Barcelona; and *El Mercantil Valenciano* and *Las Provincias*, from Valencia (original transcriptions of all consulted newspapers are in the ESM). From the collected reports it is possible to infer that the intensities felt in Madrid showed large variations. For instance, at the "Cortes" (the Spanish Parliament) the earthquake was not even felt during an on-going session; nevertheless, at least a clock stopped in that building. On the other hand, the earthquake was strongly felt inside other buildings: "people ran outside and some cracking in the plaster and other small s occurred". All these effects point to intensities ranging from degree II to V, of the MM scale.

We did not find evidence for the VI degree assigned by N-N. It is possible that degree VI had been assigned mainly relying on the descriptions of "general fear". However it should be noticed that, at that time, special sensitivity to earthquakes was due to the recent Messina 1908 earthquake, which caused about 86,000 casualties and produced large damage, and occurred only four months prior to the Benavente event. The contemporary press commented on the impressive images of the Messina earthquake shown in the cinemas (probably the first cinematographic reports of this type ever shown in Madrid and many other towns in Europe). People were afraid that a similar event occurred in Portugal or Spain, and panic easily (as also noticed by Toppozada and Parke, 1982). Another fact, not easy to account for, is how different individual reactions to the earthquake shaking can be (Dengler and Dewey, 1998).

Also, we are aware that, in general, macroseismic descriptions in the newspapers mainly informed about the most important felt effects and, they had a tendency to exaggerate or romanticize the response of the population. The same facts were chronicled in the almost contemporary reports of the San Francisco 1906 earthquake (Toppozada and Parke, 1982; Meltzner and Wald, 2002). Evidently, newspapers inform about the most remarkable or conspicuous news. In this sense, they tend to overestimate the damage by reporting only the most severe effects. Careful reading of some other comments in the news lead us to understand that general effects of the earthquake were smaller to those described depicting mainly the extreme cases. For this reason, it can be assumed that the most likely felt intensity for the largest part of Madrid should be IV-V or, even IV.

The same analysis and procedure was performed for other largest towns, when enough information was available. When an intensity interval was assigned, we took its mean value to plot in the IDP and the isoseismal maps

It is also interesting to mention that the unusually high intensities assigned to a large number of towns, mainly district and province capitals, may be "correlated" with the surface geology. We can notice that most towns were burgeoned near a river or in an alluvial plain, due to water supply, communications and proper agricultural terrains. For instance, Zamora, Salamanca, Valladolid, Badajoz, Sevilla and Cordoba, in Spain, are settled over river sediments. This kind of geological cover may result in an increase of felt seismic intensity.

On the other hand, this earthquake was felt over a large area in the Iberian Peninsula. This is not usual for a European earthquake, but is not unusual for an Iberian earthquake (C&B). Besides the 1755.11.01 earthquake (with a larger magnitude) felt in the whole Iberian Peninsula, Justo and Salwa (1998) mentioned also that the effects of the 1531 Lisbon earthquake in Spain (also with epicentre inland), point to a weak attenuation mechanism in Iberia. In fact, looking at the historical earthquakes occurred in the Iberian Peninsula and presented in the Spanish Catalogues (Mezcua, 1982; Martínez Solares and Mezcua, 2002), it can be seen that those occurred in the western and the south-western regions of the Iberian Peninsula are felt in large areas. Casado *et al*. (2000) also refer that the intensity attenuation is low when the earthquake occurs in the W-SW part of the Peninsula, and is high when the epicentre lies in the south or east parts. They explain this behaviour due to diverse seismotectonic environment and to the different construction techniques in each region. Also, the results obtained using Jonhston (1996) formulas for earthquakes in stable continental regions show that even under this assumption the earthquake shows low attenuation. In what concerns Portugal mainland, an attenuation law that fits small and large soil movements was derived (Baptista *et al.*, 2005). However, the authors were not able to fit this law with the near and the far-field data of the Benavente earthquake, due to the fact that the attenuation phenomena involved in the near-field (with a more rapid dissipation of the energy by friction and other processes) are very different from the physical attenuation processes involved in the far-field, where the waves travel deeper through a rock medium with very low attenuation coefficient. It is also known that Rayleigh waves show low attenuation in the western part of the Iberian Peninsula (Caselles *et al*., 1993; Lana *et al*., 1999) but a more detailed regionalization and correlation with the seismotectonic setting is still necessary (Martínez *et al*., 2005).

Conclusions

A review of the intensity field of the 23 April 1909 Benavente earthquake, as well as the elaboration of a comprehensive intensity dataset for more than 500 sites, has been done (see ESM for the complete dataset). It is based on the analysis of previous available reports and includes revised “old points” and new points collected mainly from Spanish newspapers. The Modified Mercalli intensity scale of 1931 was used to maintain the homogeneity of the data interpretation and due to the fact that the primary original information (the macroseismic questionnaires) is missing.

The collected dataset has been used to redraw the isoseismal map for the whole Iberia. Special attention was paid to the far field interpretation. It should be stated that, even with the new points added, the point density is much more reduced in Spain than in Portugal. The resulting map shows similarity with the one published in Mezcua (1982), but with lower intensity values that seem more realistic. This pattern, resulting from a low attenuation of the seismic propagation along the Iberian massif in the west-east direction, has also been noticed by several authors (C&B; Justo and Salwa, 1998; Casado *et al*., 2000). Possibly, soil motion amplification in the Guadalquivir Basin plays an important role, as occurred in the 1755 earthquake (Martínez Solares and Mezcua, 2002).

The problem of assign an intensity degree to the largest towns was also addressed. As it is well known, intensities for historical earthquakes are often overestimated and, for this particular earthquake, the recent Messina 1908 earthquake, occurred just four months before, generated special sensitivity towards earthquake effects. We can say that: (1) intensity assignment in large towns becomes very difficult due to differences in the geological cover, to irregularities in the topography and to the diversity of building construction types and conservation states; (2) it would be suitable to perform microzonation studies for the largest towns in order to identify potential site effects.

The authors expect that this study on the intensity distribution for the 1909 Benavente earthquake, the largest surface earthquake occurred inland in the Iberian Peninsula during the last century, could contribute to the evaluation of more accurate seismic attenuation laws for western Europe.

Data and resources

No unpublished data were used in this paper. Some plots were made using the Generic Mapping Tools (GMT) version 3.4.3 and the Surface Mapping System (Golden Software Inc., Surfer Version 8.01). Some sites were localized with the help of Google Earth.

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Figure 1 – Seismicity of the Lower Tagus Valley, from 1910 to 2007, presented over the Geological map of the region. The size of the symbols is proportional to the magnitudes which lie between 2.0 and 5.3. The 1531 Lisbon earthquake (triangle) and the 1909 Benavente earthquake (square) are also presented (sources: Martins and Mendes-Victor, 1990; Carrilho et al., 2004). Geological map of the Lower Tagus Valley region, adapted from Oliveira et al. (1992). 1: Paleozoic basement; 2 and 3: Jurassic and Cretaceous sediments of the Lusitanian Basin, respectively; 4: Sintra Late-Cretaceous intrusive massif; 5, 6 and 7: Paleogene, Miocene and Pliocene sediments of the Lower Tagus Basin, respectively; 8 and 9: Pleistocene and Holocene fluvial sediments of the Tagus river, respectively; 10: mapped faults; 11: mapped reverse faults (adapted from Cabral *et al.*, 2004).

Figure 2 – Isoseismal curves for the 1909 Benavente earthquake. (a) from Mezcua (1982); (b) from Senos et al. (1994).

Figure 3 – Distribution of C&B assigned intensities with distance. Crosses represent individual points, black triangles the arithmetic mean and open diamonds the median of the distance for each assigned intensity value. Approximately exponential decay of the means with distance is observed which indicates a good coherent distribution of the assigned intensity degrees.

Figure 4 – Intensity data points and tentative isoseismal curves for the 1909 Benavente event, using intensity information collected for 504 points. When the assigned intensity present incertitude between two degrees (for instance IV-V), the inner colour is the lower degree and the outside circle presents the colour of the higher degree.

Figure 5 – Zoom of figure 4 for the epicentral area (the intensity scale is presented in figure 4).

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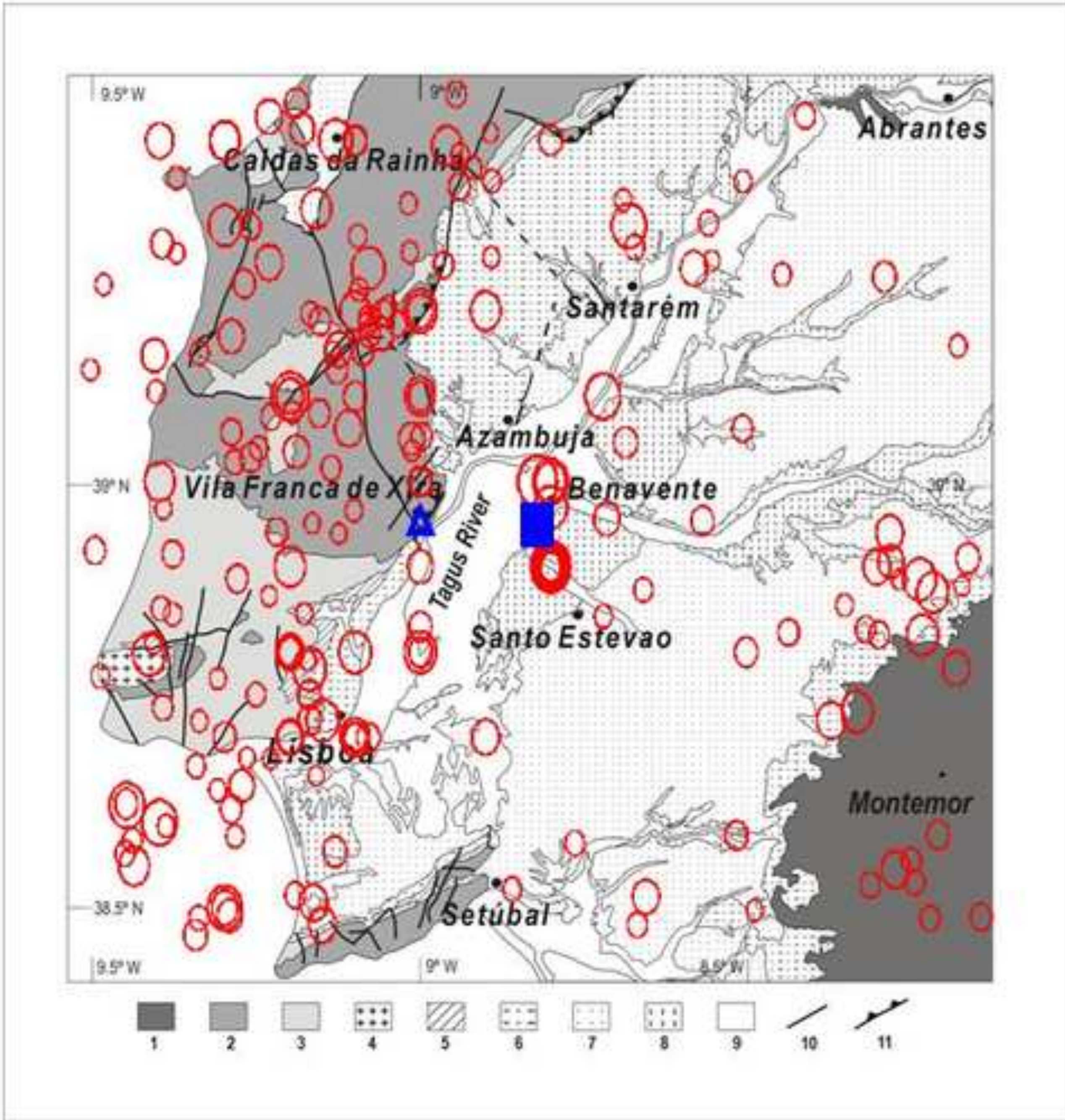

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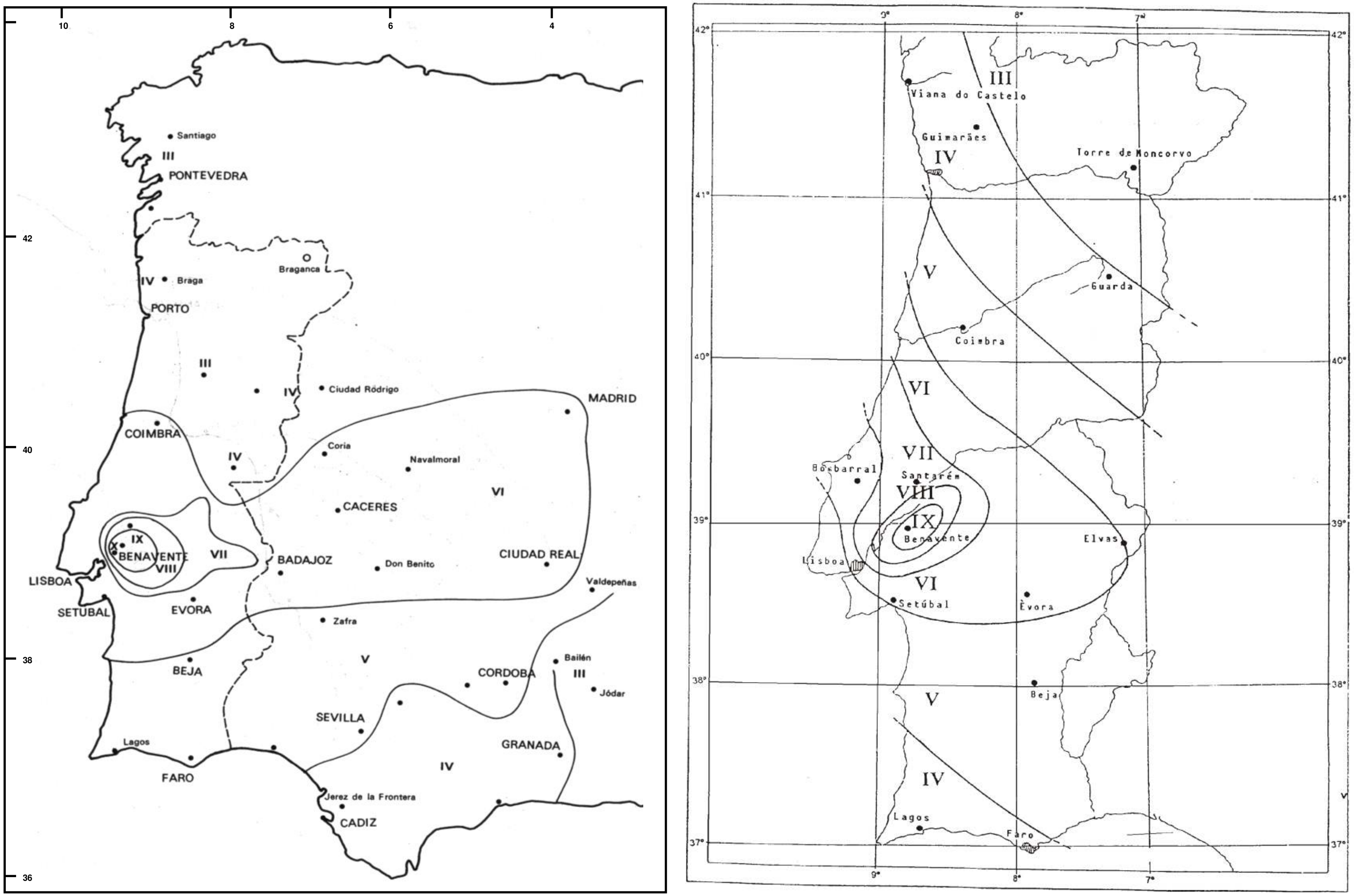

(a) (b)

Figure 2

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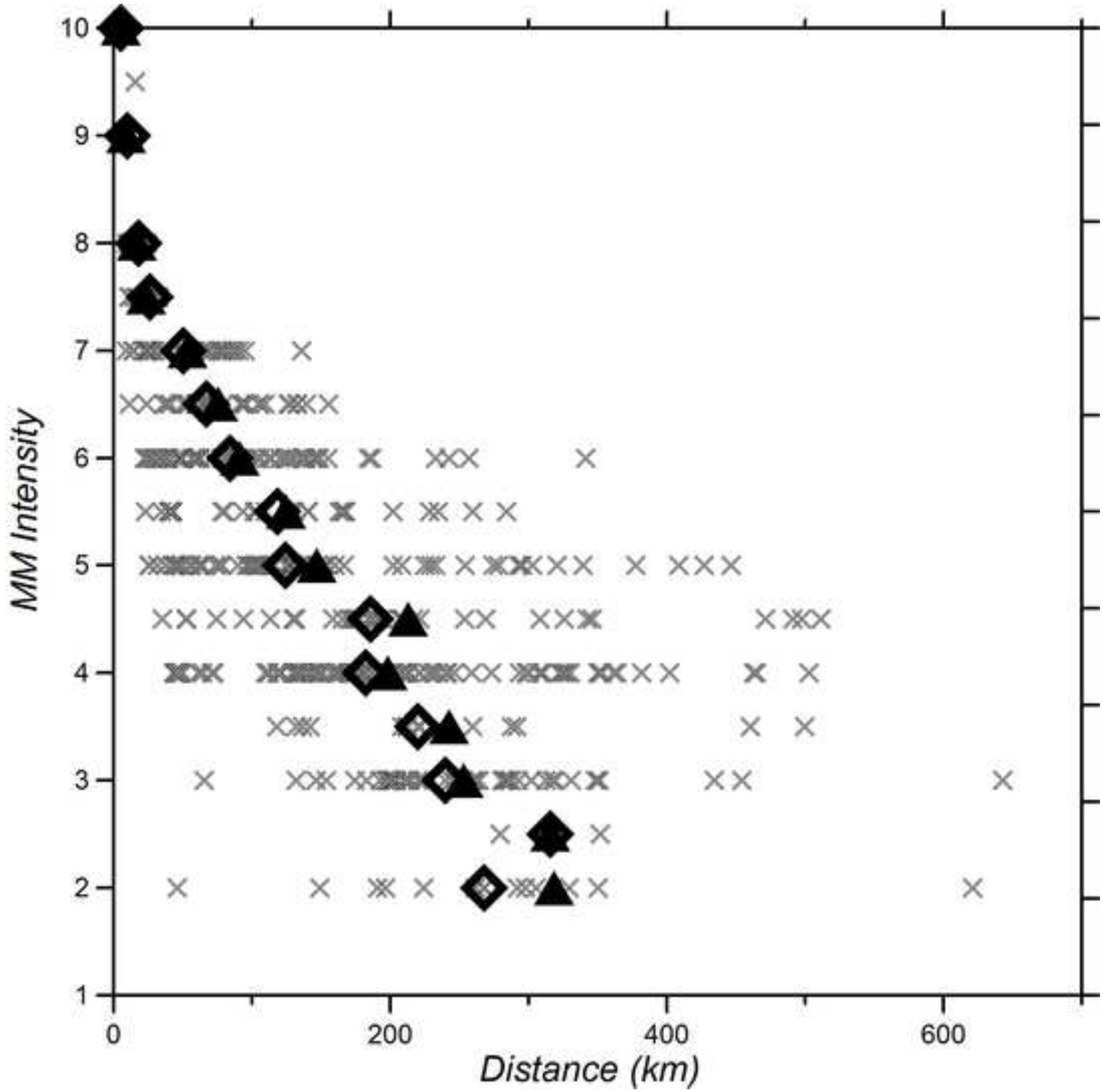

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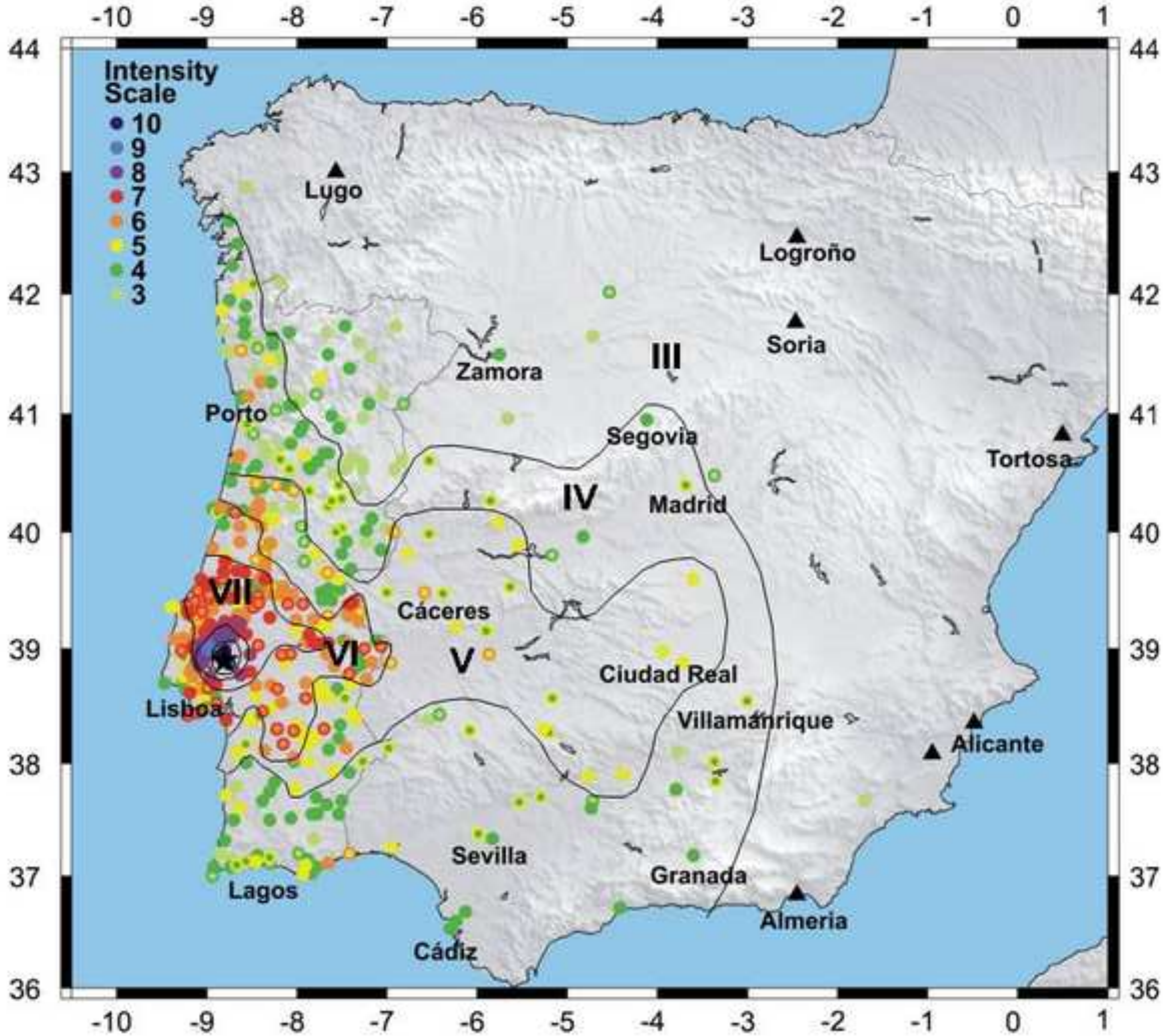

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