

Catalogue of instrumentally recorded seismicity of Portugal (1900-1960)

DETAILED REPORT

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Introduction

This database, Catalogue of instrumentally recorded seismicity of Portugal (1900-1960), is an output of project INSPIRE (Instrumental Study of Portuguese Earthquakes 1900-1960; ref. PTDC/CTE-GIX/122262/2010), funded by the Portuguese Fundação para a Ciência e a Tecnologia (<https://www.fct.pt/>) and developed in the period 2011-2014.

1.-INSPIRE project – Objectives/rationale

This project aims at studying the earthquakes in Portugal for the period 1900-1960. It focuses on improving the knowledge of the epicentral parameters for events occurred in this period. It relies on the valuable heritage of instrumental records existent in Portugal and Spain. Bulletins, historical seismograms and other documents have been collected and analyzed with state-of-the art techniques. The results have specific impact in the understanding of the Portuguese seismicity and tectonics and, from there, an immediate impact in seismic risk mitigation.

The main idea for this project is that the assessment of source parameters based on instrumental data has suffered dramatic improvements in parallel with the evolution of earthquake theories. Magnitude determination was first introduced in 1935 and, in Portugal, the regular assignment of magnitudes dates back to the 1950's. Only in the 1970's did epicentres become located through numerical computation. For these reasons, the epicentral parameters contained in diverse catalogues have different reliability, not properly stated up to now. Thus, homogenization of the determination of earthquake epicentral parameters and of the quality/error of the obtained values is a key point and objective of the present project.

The period from 1961 to present has been already revised and homogenized (Senos *et al.*, 2004; Pena *et al.*, 2014). Thus, our objective focus on the period 1900-1960. The homogeneous assessment of instrumental epicentral parameters and their quality, one of the main objectives of this project, has been attained in two steps: (1) location and recovery of seismic bulletins, seismograms and complementary information; (2) relocation of events.

2.-Project development. Tasks

The development of the project was organized in four tasks. Here we summarize the development of the different tasks.

2.1.- Bulletin, seismograms and other document compilation

Original information about earthquakes occurred in the period 1900-1960 is not preserved in a unique repository. It exists dispersed on different observatories and archives in Portugal as well as in other countries. Thus, this task involved (a) locating, copying and classifying all available materials and (b) to transcript them into digital format for further use in the project (and for other researchers).

To fulfill these objectives several archivist searches, of different types, were undertaken.

I.-Searches on the web:

Several webs around the world contain materials of seismological interest for Portugal. The more interesting for our purposes are:

- <http://sismos.rm.ingv.it/>
- http://storing.ingv.it/es_web/
- <http://ds.iris.edu/seismo-archives/>
- https://www.ign.es/web/ign/portal/sis-publicaciones-sismicas?p_p_id=IGNSISSPublicaciones_Bulletines_WAR IGNISIPublicaciones_Boletinesportlet&p_p_lifecycle=1&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_count=1&IGNSISSPublicaciones_Bulletines_WAR IGNISIPublicaciones_Boletinesportlet_javax.portlet.action=setTabBoletin (Spanish Bulletins)
- <http://www.seismology.harvard.edu/HRV/archive.html>
- <https://am.uc.pt/journal/87463> (Bulletins of Coimbra Observatory)
- <https://www.icgc.cat/en/Public-Administration-and-Enterprises/Services/Recorded-earthquakes-and-seismic-information/Seismic-information-and-maps-collections/Fabra-Observatory>.
- <https://www.icgc.cat/en/Public-Administration-and-Enterprises/Services/Recorded-earthquakes-and-seismic-information/Seismic-information-and-maps-collections/Ebre-Observatory>.
- <http://isc.ac.uk/printedStnBulletins/>.

All of them were searched.

II.- "In person" searches at different observatories and seismological data centers.

Not all needed documents are in electronic/digital format. Many of them (specifically the seismograms) are unique copies stored at different places. As starting point, the wonderful collection of seismograms of Coimbra (COI) has been at our disposal, as well as those smaller of Lisbon (LIS), Ponta Delgada (PDA) and Angra do Heroísmo (ADH).

From the beginning, a search to recover as much material as possible from the Coimbra observatory was started. Coimbra observatory preserves the larger collection of old Portuguese seismograms and a large number of worldwide bulletins (Custodio et al., 2012). The same search was developed at the offices of the old seismic station LIS, in the Escola Politecnica, Lisbon. The number of materials found in Lisbon it not so big as those of Coimbra because a fire in 1978 destroyed a part of the originals. The location and electronic copy (mainly scanning) of selected documents at these places and others was performed by us.

The USGS Center at Golden, CO, USA, was visited in search of seismograms of Portuguese earthquakes available on the microfilm collections. A mission to the IPG at Strasbourg allowed collecting seismograms from the STR station and from the microfilm collections. Also bulletins from the old IAG collection were collected.

Toledo Geophysical observatory, in Spain, was visited in three occasions and bulletins and seismograms collected.

III.-Specific demands to selected observatories, allowed to assemble a large number of bulletins, seismograms and other documents useful for the exhaustive analysis of the Portuguese earthquakes. The most important contributions come from KNMI at De Bilt (DBN station seismograms), Weston College at Boston (WES seismograms), and the Council for Geosciences, South Africa (HER seismograms).

At the end of this task almost 900 seismograms were collected. The recovered material has been classified and organized. A complete index of the collected seismograms has been constructed.

2.2.- Earthquake location

Analysis of seismic bulletins and seismograms collected under task 1 allowed to prepare a new database with available phase readings for earthquakes occurred in Portugal and instrumentally recorded on the period under study. The main bulletins used were:

- Shide Circular: 1900-1912.
- Bulletin of the British Association for the Advancement of Science: 1913-1917.
- ISS (International Seismological Summary): 1918-1960.
- Seismological Bulletin USCGS: 1943-1960.
- Boletim sísmico do Obs. Meteorológico do Infante D. Luis (Lisboa): 1920-1925, 1940-1960.
- Boletim sísmico do Instituto Geofísico da Universidade do Porto: 1958-1960.
- Boletim sísmico do Serviço Meteorológico dos Açores: 1927-1930, 1951-1960.
- Boletim sísmico do Observatório Geofísico de Coimbra: 1909-1923, 1941, 1945-1960.
- Boletim sísmico del Instituto Geográfico y Catastral (Spain): 1924-1936, 1951-1960.
- Galbis (Spanish seismic catalogue): 1900-1933 (Galbis, 1932, 1940).
- Boletín del Observatorio del Ebro: 1910-1936, 1942-1951.

For the large earthquakes of this period some other bulletins of contemporary stations were also accessed. This supplementary information has been consigned in the event files described below.

For each earthquake a file, containing all readings as presented in original bulletins and the references where they were extracted from, was compiled (see an example in figure 1). This procedure has been used to keep the track of the sources for each earthquake. This is really important when trying to elucidate possible mismatch/errors on the original sources. From these files, new equivalent files in "Nordic format" (using the common procedures of earthquake location at IPMA) to be used for the relocation of the studied events were obtained. The earthquakes have been relocated using Hypocenter program included in the SEISAN software package and using the IASPEI91 velocity model. When necessary, errors on the original phases (misidentification, printing errors, etc.) have been corrected.

As a result, all earthquakes for which available information allowed a relocalization have been processed. They have been located with repeatable and homogeneous methods using the same procedures used presently at IPMA and the result is an event database for these old earthquakes fully compatible with those already available from 1961 to present. (Senos *et al.*, 2004; Pena *et al.*, 2014).

As a result, now Portugal has a catalogue of instrumentally recorded events fully homogeneous. From 1900 to 2014 all events occurred on Continental Portugal and the Atlantic Ocean up to the Azores Islands have been located using the same procedures. Even more important than homogeneity, now the epicentral location reliability is known for each event. As the corresponding phase readings database sustaining the locations is also homogeneous, it will be really easy to relocate the whole set of events with future improved procedures. Thus, objectives of this task were fully accomplished.

Significant differences with previous locations have been found mainly for earthquakes occurred in the Atlantic. Also, now we know that the reliability of some of the available locations is really poor (epicentral errors larger than 100km can be expected). A map with the new event locations can be found in figure 2. Figure 3 of this report shows the differences from old to new locations (some really large). Figure 4 shows the 90% confidence ellipses as obtained with hypocenter.

Some statistics about the work done: Now, for the period 1900-1960 the Portuguese catalogue contains 1052 events; but only 348 have some kind of instrumental record. For the remaining ones we have just macroseismic information. From 348 instrumentally recorded events just 192

can be located instrumentally (5 of them for the first time). For the remaining ones there are not enough data to locate them. On this last group, 71 have macroseismic location and 85 have been recorded (mainly at Lisbon or Coimbra) but there has not been felt, thus, they are not located and considered as local earthquakes occurred near the recording place.

About some specific events worth to mention: an earthquake occurred in the Atlantic on 1910-11-25 and up to now ignored was discovered. Several events occurred on 1919-09-10 and following days, located in the NW Portugal by the ISS were discarded (they really occurred in the SE Spain) and a duplicated Atlantic event on the ISS catalogue on 1960-06-04 was discovered.

3.- Presentations of results at Scientific Meetings

The preliminary (and others more definitive) results obtained during the development of this project have been presented, for discussion, at several national and international meetings.

- a - Carvalho, S.; Custódio, S.; Batlló, J.; Martins, D. R.; Antunes, F.; Narciso, J.; Lima, V.; Lopes, F. C.; Ribeiro, P.; Gomes, C. (2012). Evolução instrumental da estação sísmica COI (Portugal) (poster), I Congresso Internacional "GeoCiências na CPLP", Coimbra, Portugal, 16/19 May.
- b - Carvalho, S.; Custódio, S.; Batlló, J.; Martins, D.; Antunes, F.; Narciso, J.; Lima, V.; Lopes, F. C.; Ribeiro, P.; Gomes, C. R.; Sleeman. R. and Alves. E. I. (2012). Instrumental Evolution of the Seismic Station COI, 38 Workshop of the International School of Geophysics – Global challenges for seismological data analysis, Erice, Italy, 25/30 May.
- c - Batlló, J. (2012). Localização instrumental de terramoto pre-WWSSN no Atlântico. VII Asamblea Hispano-Portuguesa de Geodesia y Geofísica, San Sebastián, Spain, 23/28 June.
- d - Carvalho, S.; Custódio, S.; Batlló, J.; Martins, D. R.; Antunes, F.; Narciso, J.; Lima, V.; Lopes, F. C.; Ribeiro, P.; Gomes, C. (2012). A herança histórica da estação sísmica COI (poster), VII Asamblea Hispano-Portuguesa de Geodesia y Geofísica, San Sebastián, Spain, 23/28 June.
- e - Batlló, J.; Custódio, S.; Macià, R.; Teves Costa, P. (2012). Study of the 11th July, 1915, Portuguese offshore earthquake, in the Atlantic from contemporary seismograms and bulletins (poster), AGU Fall Meeting, San Francisco (USA), 3/7 December.
- f - Rodrigues, I.; Batlló, J.; Custódio, S. (2013). Localização instrumental de terramoto Portugueses 1900-1960, 8º Simpósio de Meteorologia e Geofísica da APMG, Ericeira, Portugal, 18/20 March.
- g - Baptista, M. A.; Omira, R.; Miranda, J. M.; Batlló, J.; Lourenço, N. (2013). Tsunami Scenarios from Large Earthquakes in the NE Atlantic: the Gloria Fault and the Southwest Iberia Margin case studies. Geophysical Research Abstracts, Vol. 15, EGU General Assembly 2012, Viena, Austria, 7/12 April.
- h - Batlló, J.; Martinez Solares, J. M.; Macià, R.; Stich, D.; Morales, J. (2013). The autumn 1919 Jacarilla/Torremendo (SE Spain) earthquake series. Macroseismic vs. instrumental studies (poster), Knowledge for the Future: Joint Assembly IAHS - IAPSO - IASPEI, Gothenburg, Sweden, 22/26 July.
- i - Torres, R.; Batlló, J.; Rodrigues, I. (2014). Relocalização instrumental de terramoto Portugueses 1900-1960 (poster), 8ª Assembleia Luso-Espanhola de Geodesia e Geofísica, Évora, Portugal, 29/31 January.

j - Ribeiro, P.; Batlló, J., Martins, D. (2014). Os 150 Anos do Instituto Geofísico da Universidade de Coimbra: Itinerários para a História da Meteorologia, Geomagnetismo e Sismologia em Portugal, 4o Encontro Nacional de História das Ciências e da Tecnologia, Aveiro (Portugal), 12/14 September.

k - Torres, R.; Batlló, J.; Custódio, S. (2014). Relocation of instrumental earthquakes in Portugal (1900-1960) (poster), School for the Study of "Earthquakes: nucleation, triggering, and relationships with aseismic processes", Cargèse, Corsica, 3/10 November.

l - Torres, R.; Cruz, J.; Batlló, J.; Custódio, S.; Carrilho, F. (2015). Homogenized focal parameters for Portuguese earthquakes between 1900 and 1960 (poster), EGU General Assembly 2015, Vienna, Austria, 12/17 April.

4- Related Publications

The list at present of papers, books, Grade these and other publications related to this project is as follows:

- Custódio S., Batlló J., Martins D., Antunes F., Narciso J., Carvalho S., Lima V., Lopes F. C., Ribeiro P., Gomes C. R., Sleeman R., Alves E. I. (2012). Station COI: Undusting an Old Seismic Station, *Seismological Research Letters*, vol. 83, num. 5, 863-869. Doi: 10.1785/0220120014
- Domingues, S. (2012). Relocalização de sismos antigos Portugueses de 1940 a 1960, Trabalho de investigação de lic. MOG (supervisão: Batlló, J.),
- Cabral, J.; C. Moniz, J. Batlló, P. Figueiredo, J. Carvalho, L. Matias, P. Teves-Costa, R. Dias and N. Simão (2013). The 1909 Benavente (Portugal) earthquake: search for the source, *Natural Hazards*, vol. 69, num. 2, 1211-1227, Doi: 10.1007/s11069-011-0062-8.
- Silva, S. (2014). "Re-Localização de Sismos: Portugal 1920-1940", Trabalho de investigação de lic. MOG (supervisão: Batlló, J.).
- Batlló, J., Martínez Solares J. M., Macià R., Stich D., Morales J., Garrido, L. (2015). The autumn 1919 Torremendo (Jacarilla) earthquake series (SE Spain), *Annals of Geophysics*, vol. 58, n. 3, 16 p. Doi: 10.4401/ag-6686.
- Baptista M. A., Miranda J. M., Batlló J., Lisboa F., Luis J., Macià R. (2016). New Study of the 1941 Gloria Fault Earthquake and Tsunami, *Natural Hazards and Earth System Sciences*, vol. 16, 1967-1977. Doi: 10.5194/nhess-16-1967-2016.

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Batlló, J. (2004). *Catálogo - Inventario de Sismógrafos Antiguos Españoles*. Instituto Geográfico Nacional, Madrid. ISBN 84-96363-54-6, 414 pp. (in Spanish).

<https://www.ign.es/web/resources/sismologia/publicaciones//Catalogosismografo.pdf>.

Batlló, J.; Stich, D.; Macià, R. (2008). Quantitative Analysis of Early Seismograph Recordings, in Fréchet, J.; Meghraoui, M.; Stucchi, M. (Eds.): *Historical Seismology: Interdisciplinary Studies of Past and Recent Earthquakes*, Springer Verlag, Berlin, ISBN: 978-1-4020-8221-4, pp. 379-396.

Batlló, J.; Stich, D.; Macià, R. and Morales, J. (2010). The 5th July 1930 earthquake at Montilla (S Spain). Seismic Moment Tensor, *Seismological Research Letters*, vol. 81, num. 5, 724-731. Doi: 10.1785/gssrl.81.5.724.

Galbis, J. (1932). *Catálogo sísmico de la zona comprendida entre los meridianos 5ºE y 20ºW de Greenwich y los paralelos 45ºN y 25ºN*, Dirección General del Instituto Geográfico, Catastral y de Estadística, Madrid), Tomo I, pp. 807.

<https://www.ign.es/web/resources/sismologia/publicaciones//GalbisTomo1.pdf>.

Galbis, J. (1940). *Catálogo sísmico de la zona comprendida entre los meridianos 5ºE y 20ºW de Greenwich y los paralelos 45ºN y 25ºN*, Instituto Geográfico y Catastral, Madrid), Tomo II, pp. 277.

<https://www.ign.es/web/resources/sismologia/publicaciones//GalbisTomo2.pdf>.

Kárník V (1969). *Seismicity of the European area*, part 1. Reidel, Dordrecht, 364 pp.

Martins, I. and L. A. Mendes-Victor (2001). *Catálogo Sísmico de Portugal*, Monografía, Instituto Geofísico Infante D. Luis, Universidade de Lisboa, 66 pp.

Mezcua, J. and J. M. Martínez Solares (1983). *Sismicidad en el área Ibero-Mogrebí*. Madrid, Instituto Geográfico Nacional. Publicación Técnica Nº 203, 299 pp.

<https://www.ign.es/web/resources/sismologia/publicaciones//SismicidaddelAreaIberoMogrebi.pdf>.

Oliveira, C. S. (1986). *A Sismicidade Histórica e a Revisão do Catálogo Sísmico*. Lisboa, Laboratorio Nacional de Engenharia Civil, LNEC, 192 + 11 pp.

Pena, J. O.; Costa Nunes, J. and Carrilho, F. (2014). *Catálogo Sísmico de Portugal Continental e Região Adjacente para o Período 1960-1069*, I.M., Lisboa, 73 p.

<https://www.ipma.pt/export/sites/ipma/bin/docs/relatorios/geofisica/catalogo-sismico-co-61-69.pdf>.

Senos, M. L.; Carrilho, F.; Costa Nunes, J. and Pena, J. (2004). *Catálogo Sísmico de Portugal Continental e Região Adjacente para o Período 1970-2000*, I.M., Lisboa, ISBN: 972-9083-12-6. <https://www.ipma.pt/export/sites/ipma/bin/docs/relatorios/geofisica/catalogo-sismico-co-70-00.pdf>.

Stich, D.; Batlló, J.; Macià, R.; Teves-Costa, P; Morales, J. (2005). Moment tensor inversion with single-component historical seismograms: The 1909 Benavente (Portugal) and Lambesc (France) earthquakes, *Geophysical Journal International*, vol. 162, 850-858. Doi: 10.1111/j.1365-246X.2005.02680.x

Teves Costa, P., I. Rio, C. Marreiros, R. Ribeiro and J. F. Borges (1999). Source parameters of old earthquakes: semi-automatic digitization of analog records and seismic moment assessment, *Natural Hazards*, vol. 19, 205-220. Doi:10.1023/A:1008140908258.

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Localização SEISAN
1913 5 4 0953 2.0 D 36.118 -8.711 0.0 TES 4 3.3
GAP=273           6.53      150.5     67.2 42.3 -0.5022E+04 0.1655E+03
0.1588E+04E

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Informação nos boletins
Coimbra - Serra de Ossa

Boletim Sismico Coimbra

COI	P	3	0955	00.0
COI	M	4	0955	36.0
COI	F	4	0959	00.0

Boletim Meteorológico IGIDL

LIS	P	3	0953	42.0
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Galbis tomo 1 p.248-250

CRT	ENE	P	3	0954	12.0
CRT	ENE	S	3	0954	58.0
CRT	ENE	L	3	0955	12.0
CRT	ENE	M	4	0955	47.0
ALM	NNWiP		3	0954	15.0
ALM	NNWiS		3	0955	23.0
ALM	NNW	M	4	0955	53.0
ALM	NNW	M	4	0956	13.0
ALM	NNW	F	4	1000	03.0
TOL	e	4	0955	37.0	
TOL	F	4	1020	12.0	
EZR	N	P	3	0955	12.0
EZR	E	P	4	0955	13.0
EZR	Z	P	4	0955	16.0
EZR	N	S	3	0956	52.0
EZR	Z	S	4	0956	55.0
EZR	E	S	4	0956	56.0
EZR	NE	M	4	0957	55.0
EZR	N	M	4	0957	56.0
EZR	E	M	4	0957	56.0
EZR	Z	M	4	0958	06.0
EZR	NW	M	4	0958	18.0
EZR	NW	L	4	0959	18.0
EZR	Z	F	4	1005	00.0
EZR	N	F	4	1007	00.0
EZR	E	F	4	1010	00.0
EZR	NW	F	4	1015	00.0
EZR	NE	F	4	1020	12.0

Table 1: Input file for the 1913-05-04 event. The original phase reading and their origin are preserved. Location have been introduced later (it helps to know the characteristics of the event).

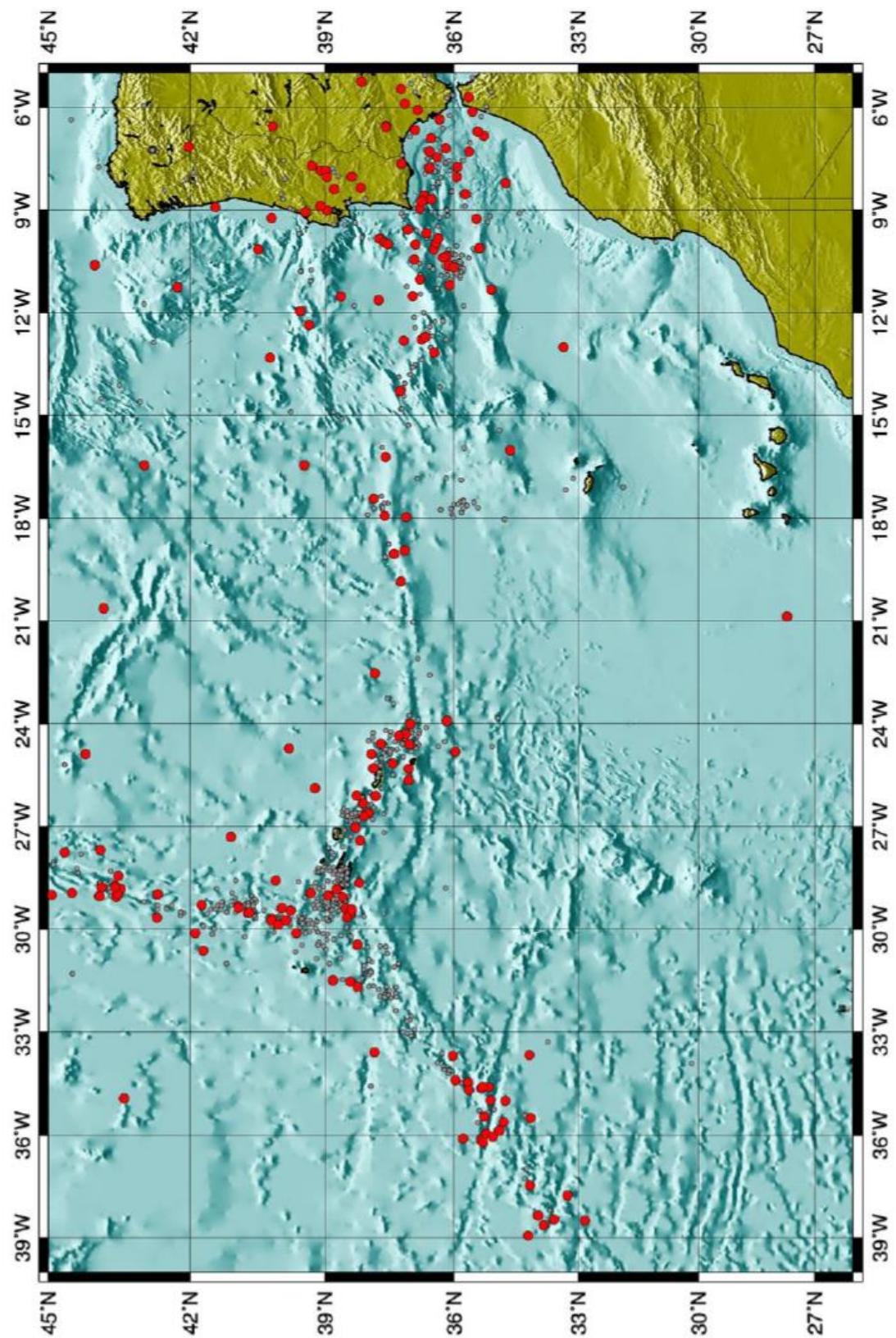


Figure 2.- Location of the earthquakes instrumentally relocated for the period 1900-1960. Events with magnitude $M > 4$ for period 1961-2000 are plotted as small green points.

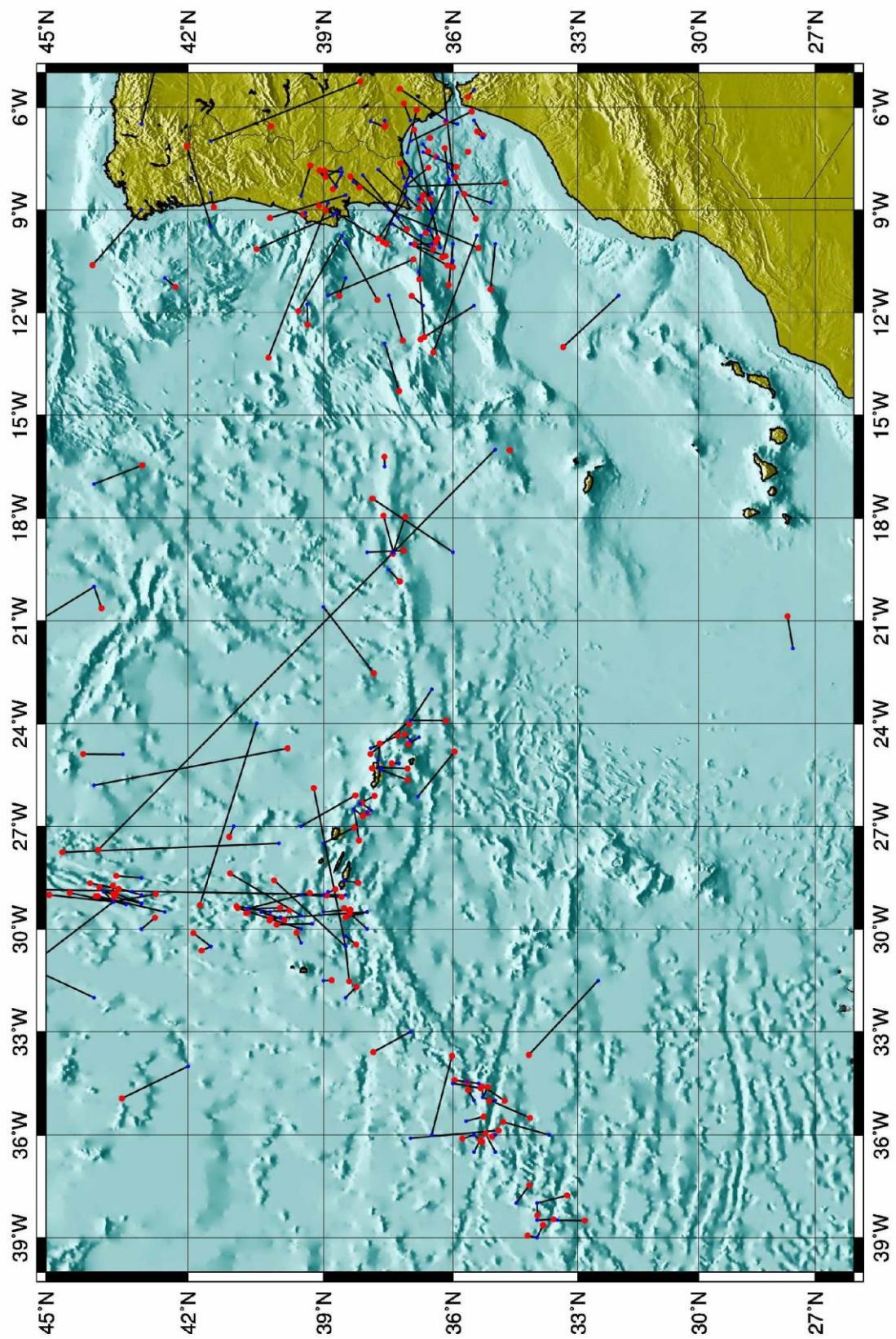


Figure 3.- Relocation of the studied earthquakes blue point – old locations; red circles – new locations.

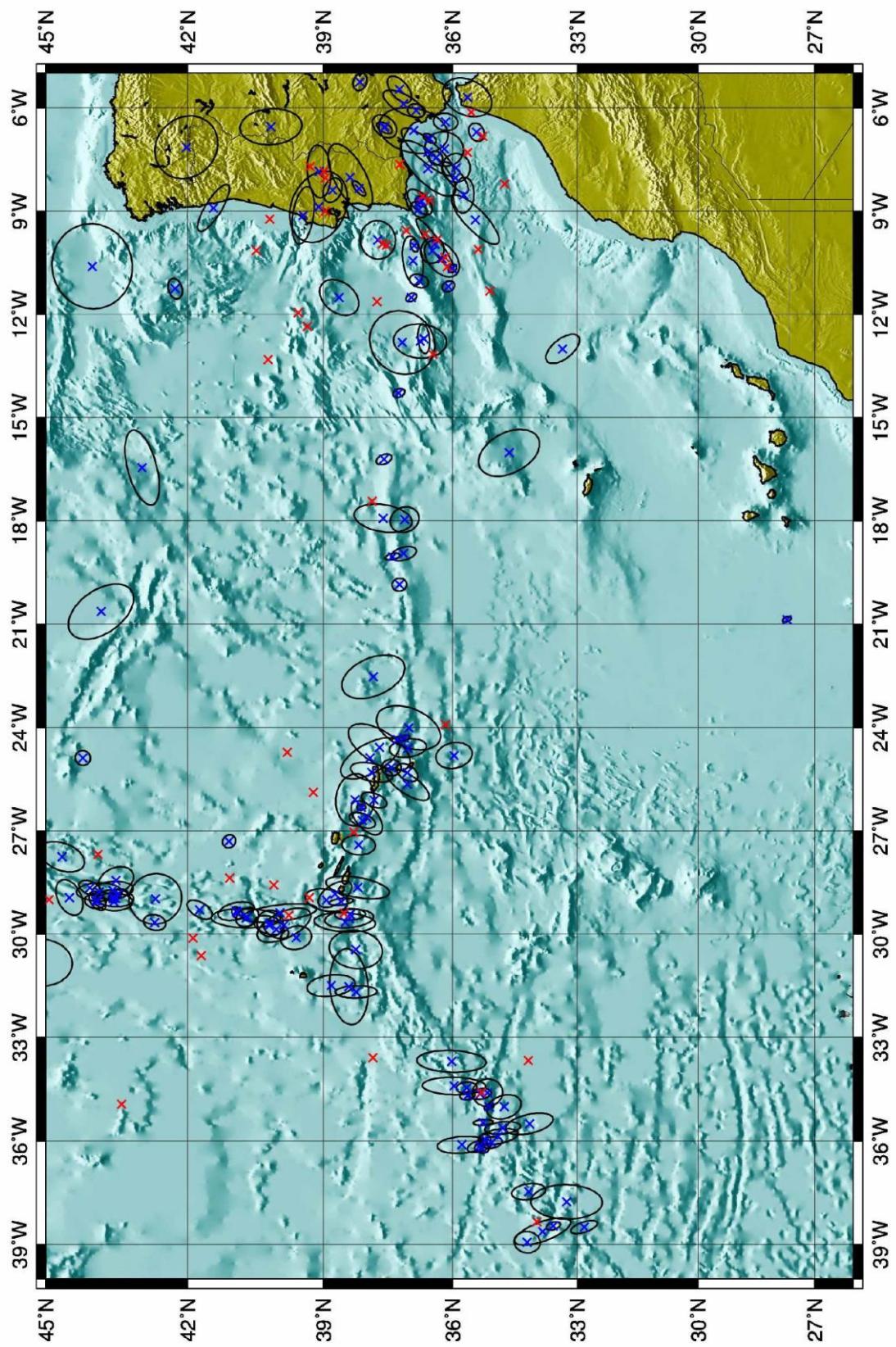


Figure 4.- New locations with the error ellipses (90% confidence). Ellipses for some events have not been plotted because their major axis exceed the 200 km.