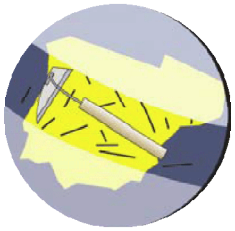

COMPILATION OF PARAMETERIZED SEISMOGENIC SOURCES IN IBERIA FOR THE SHARE EUROPEAN-SCALE SEISMIC SOURCE MODEL

E.S. Nemser (1), J. García-Mayordomo (2), J. Cabral (3), J.F.B.D. Fonseca (4), J.J. Martínez-Díaz (5), S. Vilanova (1), and the 2010 Working Group on Iberian Seismogenic Sources: P. Alfaro García (6), K. Atakan (7), J.M. Azañón Hernández (8), R. Basili (9), G.M. Besana-Ostman (1), M. Bezzeghoud (10), J.F. Borges (1), A. Brum da Silveira (11), F. Carlos Lopes (11), J. Carvalho (12), R.P. Dias (12), P.M. Figueiredo (3), M. García Fernández (13), J. Giner Robles (14), Á. Gonzalez (15), E. Gràcia (16), F. Gutierrez (15), J.M. Insua Arévalo (5), M.J. Jiménez (13), A. Jiménez-Díaz (5), V. Kastelic (9), P. Lafuente Tomás (15), P. Lucha (15), J. Madeira (3), F. Martín-González (17), E. Masana (18), L. Matias (19), X. Moreno (16), M. Ortuño (20), H. Perea (3), R. Pérez López (2), M.A. Rodríguez Pascua (2), P. Ruano (21), P. Santanach (18), P. Silva Barroso (22), S. Silva (23), J.L. Simón (15), P. Terrinha (23), P. Villamor (24), I. Wong (25)

(1) ICIST, Instituto Superior Técnico, Av. Rovisco Pais, 1, 1049-001 Lisboa, Portugal. eliza.nemser@ist.utl.pt; susana.vilanova@ist.utl.pt; glenda.besana-ostman@ist.utl.pt
(2) Instituto Geológico y Minero de España, Madrid, Spain. Julian.Garcia@igme.es; r.perez@igme.es; ma.rodriguez@igme.es
(3) Faculdade de Ciéncias da Universidade de Lisboa, Departamento de Geologia / Instituto D. Luiz, Lisboa, Portugal. jcabral@fc.ul.pt; absilveira@fc.ul.pt; pmfigueiredo@fc.ul.pt; jmadeira@fc.ul.pt; hperea@fc.ul.pt
(4) ICIST & Departamento de Física, Instituto Superior Técnico, Lisboa, Portugal. jfonseca@ist.utl.pt
(5) Dpto. Geodinámica, Facultad de Ciencias Geológicas, Universidad Complutense. c/ José Antonio Novais, 2. 28004-Madrid, Spain. jmdiaz@geo.ucm.es; insuarev@geo.ucm.es; ajimenezdiaz@geo.ucm.es
(6) Universidad de Alicante, Alicante, Spain. pedro.alfaro@ua.es
(7) Universitetet i Bergen, Christiesgate 18, Postboks 7800, 5020 Bergen, Norway. kuvvet.atakan@geo.uib.no
(8) Instituto Andaluz de Ciencias de la Tierra, CSIC- Universidad de Granada, 18002 Granada, Spain. jazanon@ugr.es
(9) Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Sismologia e Tettonofisica, Via di Vigna Murata, 605 - 00143 Roma, Italy. roberto.basili@ingv.it;. vanja.kastelic@ingv.it
(10) Departamento de Física & Centro de Geofísica de Évora, Escola de Ciências e Tecnologia, Universidade de Évora, Évora, Portugal. mourad@uevora.pt; jborges@uevora.pt
(11) Centro de Geofísica, Department of Earth Sciences, University of Coimbra, Coimbra, Portugal. fcarlos@dct.uc.pt
(12) Laboratório Nacional de Energia e Geologia, Lisboa, Portugal. joao.carvalho@ineti.pt; ruben.dias@ineti.pt
(13) Consejo Superior de Investigaciones Científicas (CSIC/MNCN), José Gutierrez Abascal, 2, E-28006- Madrid, Spain. mgarcia@mncn.csic.es mjjimenez@mncn.csic.es
(14) Universidad Autónoma de Madrid, Madrid, Spain. jorge.giner@uam.es
(15) Universidad de Zaragoza, Zaragoza, Spain. Alvaro.Gonzalez@unizar.es; fgutier@unizar.es; palomalt@unizar.es; plucha@unizar.es; jsimon@unizar.es
(16) Unidad de Tecnología Marina - Consejo Superior de Investigaciones Científicas (CSIC/UTM), Spain. egracia@utm.csic.es; xmoreno@utm.csic.es
(17) Universidad Rey Juan Carlos, Spain. fidel.martin@urjc.es
(18) RISKNAT - Universitat de Barcelona, Barcelona, Spain. eulalia.masana@ub.edu; pere.santanach@ub.edu
(19) Centro de Geofísica da Universidade de Lisboa, Lisboa, Portugal. lmatias@fc.ul.pt
(20) Centro de Geociencias, Campus Juriquilla, UNAM, Querétaro, México. maria_ortuno@geociencias.unam.mx
(21) Universidad de Granada, Grandad, Spain. pruano@ugr.es
(22) Universidad de Salamanca, Salamanca, Spain. pgsilva@usal.es
(23) Unidade de Geologia Marinha - Laboratório Nacional de Energia e Geologia, Lisboa, Portugal. soniamanzoni@gmail.com; pedro.terrinha@ineti.pt
(24) GNS Science, New Zealand (GNS). P.Villamor@gns.cri.nz
(25) Seismic Hazards Group, URS Corporation, Oakland, California, USA. Ivan_Wong@URSCorp.com

***Abstract**: SHARE (Seismic Hazard Harmonization in Europe) is an EC-funded project (FP7) that aims to evaluate European seismic hazards using an integrated, standardized approach. In the context of SHARE, we are compiling a fully-parameterized active fault database for Iberia and the nearby offshore region. The principal goal of this initiative is for fault sources in the Iberian region to be represented in SHARE and incorporated into the source model that will be used to produce seismic hazard maps at the European scale. The SHARE project relies heavily on input from many regional experts throughout the Euro-Mediterranean region. At the SHARE regional meeting for Iberia, the 2010 Working Group on Iberian Seismogenic Sources (WGISS) was established; these researchers are contributing to this large effort by providing their data to the Iberian regional integrators in a standardized format. The development of the SHARE Iberian active fault database is occurring in parallel with IBERFAULT, another ongoing effort to compile a database of active faults in the Iberian region.*

The SHARE Iberian active fault database synthesizes a wide range of geological and geophysical observations on active seismogenic sources, and incorporates existing compilations (e.g., Cabral, 1995; Silva et al., 2008), original data contributed directly from researchers, data compiled from the literature, parameters estimated using empirical and analytical relationships, and, where necessary, parameters derived using expert judgment. The Iberian seismogenic source model derived for SHARE will be the first regional-scale source model for Iberia that includes fault data and follows an internationally standardized approach (Basili et al., 2008; 2009). This model can be used in both seismic hazard and risk analyses and will be appropriate for use in Iberian- and European-scale assessments.

***Key words**: fault, database, SHARE, seismogenic*

Active fault databases provide essential input data for robust probabilistic seismic hazard analyses (PSHA) that integrate both seismicity and active fault data into the hazard calculations. SHARE is a regional program of the Global Earthquake Model (GEM) initiative, and represents a large collaborative effort to compile a seismic hazard model for the Euro-Mediterranean region to be used for PSHA. The SHARE seismic source model will rely on a logic tree that incorporates seismicity data, a seismic source zonation model, and data on active faults (herein termed "seismogenic sources" following SHARE terminology). One of the major tasks within project SHARE is the compilation of a European database of seismogenic sources to be used in the source model. Specifically, within SHARE, an important task is devoted to expanding the Italian Database of Individual Seismogenic Sources (DISS) (Basili et al., 2008, 2009) to include the larger Euro-Mediterranean area. This ambitious goal requires the integration of a vast amount of knowledge and data into a uniform European framework, and necessitates the adoption of common methodologies and uniform standards for the definition and characterization of active seismogenic sources.

Project SHARE was designed to follow the SSHAC (Senior Seismic Hazard Analysis Committee) Level-3 strategy, wherein regional experts come together in a workshop setting to present the results of relevant research to integrators and external experts (SSHAC, 1997). The integrators and experts are responsible for evaluating the data and determining how to synthesize the various contributions using a logic tree approach. SSHAC recommendations detail a strict protocol for incorporating expert opinions and capturing uncertainties in PSHA (SSHAC, 1997). SSHAC Level-3 guidelines have been recently updated and revised based on lessons learned from a decade of implementing the original guidelines (Hanks et al., 2009). SSHAC explicitly recognizes that whereas true consensus is not a realistic goal, a PSHA source model should aim "to represent the center, body, and range of technical interpretations" of the larger informed technical community (SSHAC, 1997).

In keeping with the SSHAC methodology, a SHARE Iberian regional workshop was held in January 2010 in Olhão, Portugal. This productive meeting brought together researchers from throughout Portugal and Spain to present their research on active faulting in Iberia. At the Iberian regional meeting, the SHARE Iberian fault database was established as a broad, community effort, and researchers (the 2010 Working Group on Iberian Seismogenic Sources) were invited to submit their active fault data to the regional integrator for incorporation into the SHARE Iberian fault database. Following this meeting, to facilitate progress of the database, a distinction was made between two separate but related goals of project SHARE: the short-term, immediate goal of developing a parameterized European seismogenic source model, and the longer-term goal of expanding the DISS database into a comprehensive European database of seismogenic sources.

For the source model, only basic seismogenic parameters are required, whereas for the European database, substantially more detailed information is needed for each source. Accordingly, two levels of data completeness were designated, termed "Level-1" and "Level-2" data. Level-1 data is defined as the basic, essential parameterization for the seismogenic source model, including published references but excluding summaries and supporting material. Mandatory Level-1 parameters considered to be integral for a fault to be used in the source model include: source name, fault location (described as two or more pairs of geographic coordinates), fault segmentation data, preferred values for fault strike, fault dip, and fault rake; estimates of slip rate and maximum magnitude; references, and an indication of the type of evidence that a certain fault exists, according to a specified "quality factor" scheme. For details on the definitions of all seismogenic parameters, see Basili et al. (2009).

For these purposes, Level-2 data completeness is defined as complete and comprehensive fault characterizations that include summaries and supporting material. In addition to the aforementioned "Level-1 mandatory parameters", the remaining fields for parameters that describe each seismogenic source in the SHARE Iberian fault database include: compiler name and affiliation, minimum, maximum and preferred values for fault length, fault width, minimum and maximum rupture depth, strike, dip, rake, slip rate, and maximum magnitude; preferred values for recurrence interval, single event displacement, style of faulting, most recent earthquake, elapsed time since most recent earthquake, and penultimate earthquake; summaries, notes, and links to relevant files. The specification of minimum, maximum and preferred values for many of these parameters ensures that the database contains the appropriate epistemic uncertainty ranges to encompass these critical parameters. For consistency with the DISS database, each parameter has an associated code that indicates whether the value is based on 1) literature data, 2) original data, 3) empirical relationships, 4) analytical relationships, or 5) expert judgment (Basili et al., 2009).

In keeping with conventions established within the existing DISS database, seismogenic sources in the SHARE Iberian database are characterized in terms of "composite seismogenic sources". Composite seismogenic sources (termed "seismogenic areas" in Basili et al., 2008; later renamed within the DISS database) are modeled with a complex geometry to capture both geological and geophysical data from large-scale tectonic features and localized geomorphic, geological, or geophysical evidence for active deformation (Basili et al., 2008). The composite seismogenic source framework for describing active fault zones was developed specifically for use in regional-scale PSHA applications (Basili et al., 2008).

The definition of an "active fault" can vary widely, for example, the Quaternary Fault and Fold Database of the United States includes faults that are considered to have been active during the Quaternary (the past 1,600,000 years) (USGS, 2006), whereas the Active Faults Database of New Zealand only includes faults that are known to be active in the Late Quaternary and younger (GNS website). For practical purposes in PSHA applications, the appropriate definition of an active fault may be different for different tectonic regimes. Due to the slow slip rates in Iberia and the limited (but rapidly expanding) body of paleoseismic data, it was established at the SHARE Iberian regional meeting that all faults with a reasonable likelihood of being active and seismogenic within the current stress regime meet the criteria for inclusion in the SHARE Iberian seismogenic source database.

Whereas a protocol has not yet been established within project SHARE for handling the epistemic uncertainty that pertains to whether or not a specific fault source is active and capable of generating earthquakes, it has been recommended that the active fault database should include a quantification of the likelihood of activity of each source. "Probability of Activity" [P(a)] is a variable that has been used in PSHA studies to capture the epistemic uncertainty inherent in the judgment about whether or not a fault is active and seismogenic (e.g., SSHAC, 1997). In the implementation of this system, P(a) occupies the fault database as an independent field and provides a quantification of whether or not a fault is active; this uncertainty is then treated in a probabilitistic manner within the PSHA. Because of the slow slip rates in Iberia, there is a substantial amount of uncertainty regarding the Quaternary activity of many faults, and the implementation of a P(a) classification within the database allows for the inclusion of fault sources for which there is some, but no definitive data to indicate that they are active. The approach within the existing DISS database to these controversial sources is to label them as "debated seismogenic sources". However, a shortcoming of that approach is that the debated seismogenic sources are ultimately subject to a binary decision about whether or not they should be included in the source model. In order to accommodate a more robust representation of the potentially active faults in Iberia, the concept of debated seismogenic sources has been replaced with the P(a) scheme within the SHARE Iberian database; all faults with a P(a) <1 can be considered as debated sources, and the database can be filtered according to P(a) for use in the source model, as deemed appropriate.

To develop the SHARE Iberian database, all regional experts in the 2010 Working Group on Iberian Seismogenic Sources were invited to act as (and be credited as) compilers of the seismogenic source parameters. However, in order for the fault sources to be included in the SHARE hazard model, it was necessary for the integrators to make informed assumptions to complete the parameter table. These assumptions are preliminary and will be updated on a case-by-case basis, as appropriate, with the introduction of additional credible data.

To date there are 96 composite seismogenic sources and 187 individual fault segments in the preliminary SHARE Iberia fault database, which currently only includes sources on the mainland (Figure 1).

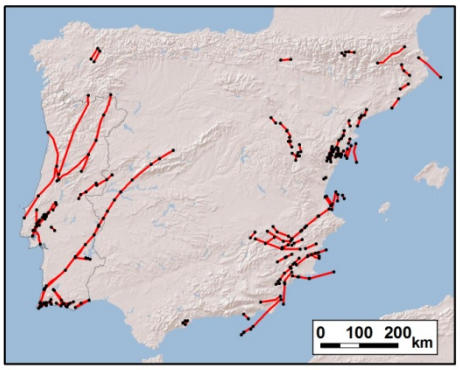

Figure 1. Map of mainland Iberia, showing the surface traces of the composite seismogenic sources included in the preliminary version of the SHARE Iberia fault database. Segment boundaries are indicated with black dots.

Approximately 74% of the fault segments in the database at the time of writing have associated slip rate estimates (139 of the 187 segments). The sources with the highest slip rates (≥0.4mm/yr) include the Carrascoy fault (e.g., Silva et al., 2003; Garcia-Mayordomo et al., 2007; Garcia-Mayordomo and Álvarez-Gómez, 2006; Sanz de Galdeano et al., 1998), the Carboneras fault zone (e.g., Gràcia et al., 2006; Moreno et al., 2008; Bell et al., 1997; Negredo et al, 2002), and the Alhama de Murcia fault (e.g., Martínez-Díaz, 1999; Masana et al., 2004; Garcia-Mayordomo et al., 2007; Silva et al., 2003) in southeastern Spain, and the Manteigas-Vilariça-Bragança fault in northeastern Portugal (Rockwell et al., 2009; Cabral, 1989; Vilanova and Fonseca, 2007). The majority of the individual fault segments in the database have substantially lower slip rates and are only expected to contribute to the seismic hazard at long return periods: 113 fault segments (81% of the segments with slip rate estimates) have preferred slip rate values between 0.01mm/yr and 0.1mm/yr.

In June 2010 at the first annual meeting of SHARE, a preliminary fault model was presented and initial steps were taken towards the integration of the Iberian source data with other SHARE regional centers. The expectation is that in conjunction with the IBERFAULT meeting in October 2010, this preliminary database will undergo a round of revision by regional experts and external experts, in accordance with SSHAC methodology. At this point, and in parallel with the IBERFAULT database, the SHARE Iberian source model will be improved with a greater level of detail, including the introduction of Level-2 data, where possible. This revised database with more detailed data on Iberian seismogenic sources will be incorporated into the updated SHARE European fault database.

Acknowledgements: Funding was provided by Project SHARE (FP7-226967) and Project RETURN (FCT-PTDC/CTE-GIN/67367/2006). The SHARE project is financed by the European Commission under the 7th Framework Programme for Research and Technological Development, Area "Environment", Activity 6.1 "Climate Change, Pollution and Risks". This abstract reflects the

author's views. The European Commission is not liable for any use that may be made of the information contained therein.

References

Basili, R., Kastelic, V., Valensise, G., and DISS Working Group 2009 (2009). DISS3 tutorial series: Guidelines for compiling records of the Database of Individual Seismogenic Sources, version 3. Rapporti Tecnici INGV, 108, 20 p., http://portale.ingv.it/produzione-scientifica/rapporti-tecnici-ingv/archivio/rapporti-tecnici-2009/.

Basili R., Valensise G., Vannoli P., Burrato P., Fracassi U., Mariano S., Tiberti M.M., & Boschi E. (2008). The Database of Individual Seismogenic Sources (DISS), version 3: summarizing 20 years of research on Italy's earthquake geology. Tectonophysics, doi:10.1016/j.tecto.2007.04.014.

Bell, J.W., Amelung, F., & King, G.C.P. (1997). Preliminary late Quaternary slip history of the Carboneras Fault, southeastern Spain. J. Geodyn, 24, 51-66.

Cabral, J. (1989). An example of interplate Neotectonic activity, Vilariça Basin, Northeast Portugal. Tectonics, 8 (2), 285-303.

Cabral, J. (1995). Neotectónica em Portugal Continental, Memórias do Instituto Geológico e Mineiro, Memória 31, Lisbon, 265 p.

García-Mayordomo, J. & Álvarez-Gómez, J.A. (2006). Estimación del terremoto máximo posible y su intervalo de recurrencia en la Falla de Carrascoy (Murcia) para su implementación en el cálculo de la peligrosidad sísmica de la región. Geogaceta, 39, 51-54.

García-Mayordomo, J. , Gaspar-Escribano, J.M., & Benito, B. (2007). Seismic hazard assessment of the Province of Múrcia (SE Spain): analysis of source contribution to hazard. Journal of Seismology, 11, 453-417.

Gràcia, E., Pallas, R., Soto, J. I., Comas, M., Moreno, X., Masana, E., Santanach, P., Diez, S., García, M., & Dañobeitia, J. (2006). Active faulting offshore SE Spain (Alboran Sea): Implications for earthquake hazard assessment in the Southern Iberian Margin. Earth and Planetary Science Letters 241, 734-749.

GNS http://data.gns.cri.nz/af/.

Hanks, T.C., Abrahamson, N.A., Boore, D.M., Coppersmith, K.J. & Knepprath, N.E. (2009). Implementation of the SSHAC Guidelines for Level 3 and 4 PSHAs—Experience Gained from Actual Applications. USGS Open-File Report 2009-1093, U.S. Geological Survey, Reston, Virginia, 72 p.

Martinez-Díaz, J.J. (1999). Neotectónica y tectónica activa del sector centro-occidental de la región de Murcia y sur de Almería (Cordillera Bética, España). PhD Thesis. Universidad Complutense Madrid, 477 pp.

Masana, E., Martinez-Díaz, J.J., Santanach, P. Y Hernandez-Enrile J.L.(2004). The Alhama de Murcia Fault (SE Spain), a seismotectonic fault in a diffuse plate boundary. Seismotectonic implications for the Iberomagrebian region. Journal of Geophysical Research, 109, B01301, doi: 10.1029/2002JB002359.

Moreno, X., Masana, E., Gràcia, E., Bartolomé, R., & Piqué-Serra, O. (2008). Estudio paleosismológico de la Falla de Carboneras: Evidencias tierra-mar de actividad tectónica reciente. GeoTemas, 10, 1035-1038.

Negredo, A.M., Bird, P., Sanz de Galdeano, C. & Buforn, E. (2002). Neotectonic modeling of the Ibero–Maghrebian region. J. Geophys. Res., 107 (B11), 2292-2307.

Rockwell, T., Fonseca, J., Madden, C., Dawson, T., Owen, L.A., Vilanova, S., & Figueiredo, P. (2009). Paleoseismology of the Vilariça segment of the Manteigas-Bragança Fault in northeastern Portugal. In: Palaeoseismology: Historical and Prehistorical Records of Earthquake Ground Effects for Seismic Hazard Assessment (Reicherter, K., Michetti, A.M. & Silva, P. G., eds.). The Geological Society, London, Special Publications, 316, 237-258.

Sanz de Galdeano, C., López-Garrido, A.C. & García-Tortosa, F.J. (1998). Nuevos datos para la estimación de los valores de levantamiento desde el Tortoniense Superior a la actualidad en la parte centro-occidental de la Sierra de Carrascoy (provincia de Murcia). Geogaceta, 23, 139-142.

Silva, Í., Cruz, I., Gomes, J., Costa, A., Almeida, P., Cabral, J., Taborda, R., Caranova, R., Laiginhas, C., Angelucci, D., Carrilho, F., & Matias, L. (2008). GIS Seismotectonic database for mainland Portugal. ESIG 2008 - 10º Encontro de Utilizadores de Informação Geográfica, 14 - 16 de Maio, Taguspark, Oeiras, Portugal. 10p.

Silva, P.G., Goy, J.L., Zazo, C. & Bardají T. (2003). Fault-generated mountain fronts in southeast Spain: geomorphologic assessment of tectonic and seismic activity. Geomorphology, 50, 203-225.

SSHAC [Senior Seismic Hazard Analysis Committee, Budnitz, R.J., Chairman, G., Apostolakis, D.M., Boore, L.S., Cluff, K.J., Coppersmith, C.A., Cornell, & P.A. Morris] (1997). Recommendations for probabilistic seismic hazard analysis: Guidance on uncertainty and use of experts: Washington, D.C., U.S. Nuclear Regulatory Commission Report, NUREG/CR-6372.

U.S. Geological Survey (2006). Quaternary fault and fold database for the United States, accessed 06/23/2010, from USGS web site: http//earthquakes.usgs.gov/regional/qfaults/.

Vilanova, S. & Fonseca, J. F. B. D. (2007). Probabilistic seismic-hazard assessment for Portugal. Bulletin of the Seismological Society of America, 97, 1702-1717.