

## SEISMOGENIC ZONATION AS A BRANCH OF THE LOGIC-TREE FOR THE NEW ITALIAN SEISMIC HAZARD MAP - MPS16: A PRELIMINARY OUTLINE

A. Rebez<sup>1</sup>, M. Santulin<sup>5,1</sup>, A. Tamaro<sup>1,6</sup>, D. Slejko<sup>1</sup>, F. Sani<sup>2</sup>, L. Martelli<sup>3</sup>, M. Bonini<sup>4</sup>, G. Corti<sup>4</sup>, M.E. Poli<sup>7</sup>, A. Zanferrari<sup>7</sup>, A. Marchesini<sup>7</sup>, M. Busetti<sup>1</sup>, M. Dal Cin<sup>1,10</sup>, D. Spallarossa<sup>8</sup>, S. Barani<sup>8</sup>, D. Scafidi<sup>8</sup>, G. Barreca<sup>9</sup>, C. Monaco<sup>9</sup>

<sup>1</sup> Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste, Italy

<sup>2</sup> Dipartimento di Scienze della Terra, Università degli Studi di Firenze, Italy

<sup>3</sup> Servizio Geologico, Sismico e dei Suoli, Regione Emilia-Romagna, Bologna, Italy

<sup>4</sup> Istituto di Geoscienze e Georisorse, Consiglio Nazionale delle Ricerche, Firenze, Italy

<sup>5</sup> Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Milano, Italy

<sup>6</sup> Dip. Politecnico di Ingegneria e Architettura, Università degli Studi di Udine, Italy

<sup>7</sup> Dipartimento di Scienze AgroAlimentari, Ambientali e Animali, Università degli Studi di Udine, Italy

<sup>8</sup> DISTAV, Università degli Studi di Genova, Italy

<sup>9</sup> Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università degli Studi di Catania, Italy

<sup>10</sup> Dipartimento di Matematica e Geoscienze, Università degli Studi di Trieste, Italy

The importance of the seismogenic zonation definition has been focused in some sensitivity analysis (Rebez and Slejko, 2000; Barani *et al.*, 2007) as the most influent parameters in a seismic hazard study according to the seismotectonic probabilism approach. The definition of the seismogenic sources is generally based on evidence coming from geology and seismicity. Usually, it is hard to find a direct relation between the two pieces of information since, in practice, it is anything but simple to identify tectonic structures with documented seismic activity. Frequently, geology identifies tectonic structures that were, and maybe still are, active. Seismicity depicts earthquakes scattered in broad areas, where many faults exist. In addition, the geometry of the faults at depth is unknown and cannot be inferred from surface geology. For these reasons, a different way to establish a link between geology and seismicity is needed: the definition of a general kinematic framework. Seismotectonic regions with homogeneous behaviour are identified based on this kinematic framework. The definition of these regions leads to mapping seismogenic zones (SZs) that collect one fault, or alternatively, a homogeneous fault population with their associated earthquakes.

The zonation presented in this study was developed with the aim to be applied as a branch of the logic tree that will be used for the new Italian seismic hazard analysis (MPS16) according to the probabilistic approach originally proposed by Cornell (1968), using the Openquake software (Pagani *et al.*, 2014).

The Cornell's approach (1968) is based on two hypotheses:

- 1) earthquake occurrence intervals follow an exponential distribution (i.e., occurrences follow a Poisson process);
- 2) magnitude is distributed exponentially according to the Gutenberg – Richter (GR) relation.

A third hypothesis is that the seismicity is considered to be uniformly distributed inside seismic sources.

The Cornell (1968) method needs the following input data: seismic source geometry, earthquake potential (which is defined in terms of average number of earthquakes per magnitude class, and maximum magnitude), and one or more ground motion prediction equations (GMPEs). Uncertainty quantification (McGuire, 1977) represents a crucial point in probabilistic seismic hazard analysis (PSHA). In fact, PSHA results are characterized by two kinds of uncertainties: aleatory variability and epistemic uncertainty (McGuire and Shedlock, 1981; Toro *et al.*, 1997). The aleatory variability is related to the randomness of natural phenomena. The epistemic uncertainty is related to limited knowledge about the earthquake process. In practice, it is reflected in the choice of alternative mathematical models and parameter values used in the computations. The logic tree approach (Kulkarni *et al.*, 1984; Coppersmith and Young, 1986) was proposed to treat the epistemic uncertainties affecting the various assumptions of a PSHA. It consists of a series of nodes and branches that collect all alternative assumptions, each of which is assigned a weighting factor that is representative of the relative likelihood of that assumption being correct. The models considered in the logic tree must be exhaustive (representing the scientific community opinions) and mutually exclusive. The sum of the probabilities (weights) associated with each path in the logic tree must be 1. The final weight of the final results of every path is equivalent to the product of the weights associated with each branch along the same path.

The new SZs have been defined taking into account the available information on:

- epicentral distribution of earthquakes from the new historical catalogue CPTI15 (Rovida *et al.*, 2016) and regional instrumental bulletins (Scafidi *et al.*, 2015);
- observed and/or estimated maximum magnitude;
- focal mechanisms [from European-Mediterranean RCMT catalogue by Pondrelli *et al.* (2011)];
- hypocentral depth;
- geometry, type and kinematics of potentially active or recent (Quaternary) structures identified on the basis of morphological and structural data and integrated with the sources from the database of the Italian seismogenic sources DISS 3.2.0 (DISS Working Group, 2015) and the available literature.

In defining the zone boundaries, particular attention was paid to regional seismotectonic settings and seismic history in order to avoid excessive extrapolation of local features, which could lead to an underestimation of the hazard produced by more active local structures, and to an overestimation of the hazard related to less active sources. The seismotectonic conditions are considered homogeneous within each area.

For each zone, it was proposed a failure mechanism defined by:

- geometry of the failure plane (strike and dip),
- fault kinematics (normal, reverse, strike-slip, or mixed),
- hypothesized hypocentral depth (range).

This new zonation is generally more detailed if compared to the current national one [ZS9: Meletti *et al.* (2008)]. When the difference between the new SZs and those of the ZS9 were

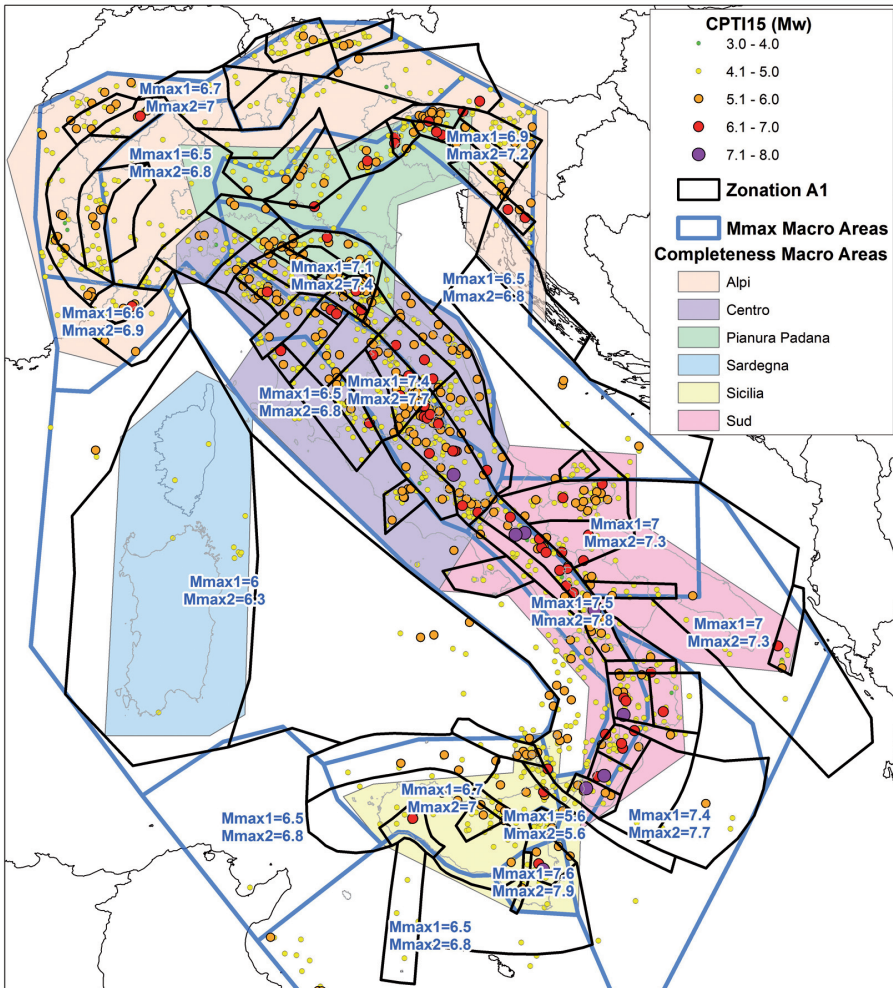


Fig. 1 – In black the A1 zonation; in blue the Mmax macroareas; in pastel colour fill the completeness macroareas and the CPTI15 areal distribution.

found negligible, in terms of geographical boundaries and seismotectonic characteristics, the ZS9 zones were retained.

For some zones, more failure mechanisms were considered possible; in such cases, various estimates of the percentage of occurrence have been assigned (depending on the information available). To cover the whole national territory the SHARE zonation (Giardini *et al.*, 2013) was also adopted with its rates and Mmax values.

The main novelties of the proposed zonation are:

- a division of some very large ZS9 zones which, in the opinion of the authors, include seismogenic structures with different geometry and failure mechanisms;
- the introduction of new SZs including areas not considered seismogenic until now.

The new version of the Italian Parametric Catalogue CPTI15 (Catalogo Parametrico dei Terremoti Italiani) was used for the hazard computation (Fig. 1). It represents a significant innovation with respect to the previous ones:

- the time coverage, extended from 2006 to the end of 2014;
- the associated macroseismic database [DBMI15: Locati *et al.* (2016)], completely updated;

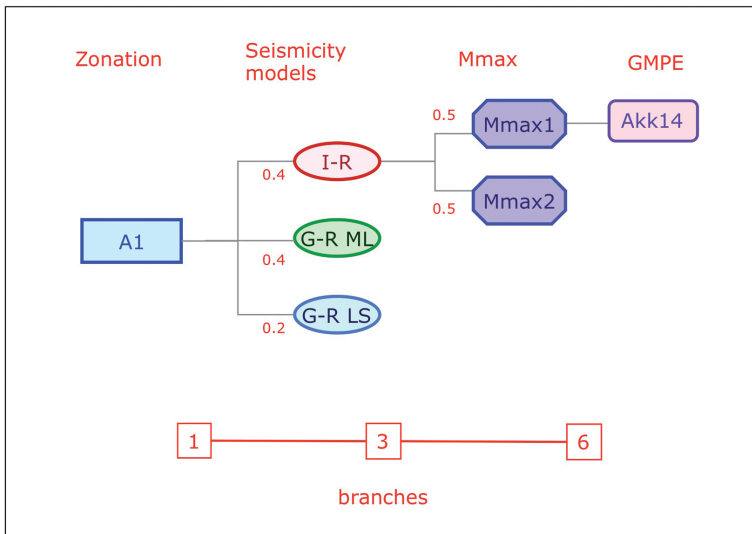


Fig. 2 – A1 zonation model: logic tree.

- the considered instrumental data, new and/or updated;
- the energy thresholds, lowered to intensity 5 or magnitude 4.0 (instead of 5-6 and 4.5, respectively);
- the determination of parameters from macroseismic data, based on a new calibration of the Boxer method (Gasperini *et al.*, 1999);
- the instrumental magnitudes, resulting from new sets of data and new conversion relationships.

The catalogue covers almost the entire Italian territory together with some neighboring areas and seas. It collects 4584 earthquakes in the time period 1000-2014.

Earthquake magnitude is expressed in terms of moment magnitude (Mw). For all earthquakes in the catalogue, the related uncertainty is provided.

Originally, the CPTI15 catalogue includes foreshocks and aftershocks. Therefore, it should be deprived of dependent events in order to reflect the Poisson assumption underlying the seismicity process. This was achieved by using a table/map for the completeness/declustering of the catalogue provided by the CPTI15 working group (Fig. 2).

For the zonation presented here (A1: Rebez *et al.*, 2016), a logic tree of six branches is considered (Fig. 2): three branches are considered to account for the epistemic uncertainty in the seismicity model and two branches are related to alternative Mmax values. Concerning the node relative to the seismicity model, one branch accounts for individual rates (I-R) while the remaining two use different approaches to compute the values of the GR coefficients (*a* and *b*-values): one uses the least mean square approach (GR-LS) and one adopts the Maximum Likelihood method of Weicher (1980) (GR-ML). Although the least-squares method is often used, it is not formally suitable since magnitude is not error free, cumulative event counts are not independent, and the error distribution of the number of earthquake occurrences does not follow a Gaussian distribution. The maximum likelihood method has been widely applied: Weichert (1980) proposed a general routine suitable also for different completeness periods of the earthquake catalogue. For these reasons a weight of 0.4 is applied to the ML branch and only 0.2 to the LS one (Fig. 2). The maximum magnitude was evaluated for macro areas representing portions of the Italian territory and surroundings for which it is expected a homogeneous tectonic behaviour. It represents the magnitude value for which the rate of occurrence is considered negligible for 30-5000 year mean return periods. The data used for the maximum magnitude assessments are the historical seismic catalogue (CPTI15) and the composite seismogenic database (DISS 3.2.0). Mmax1 is equal to the highest magnitude observed or computed (from



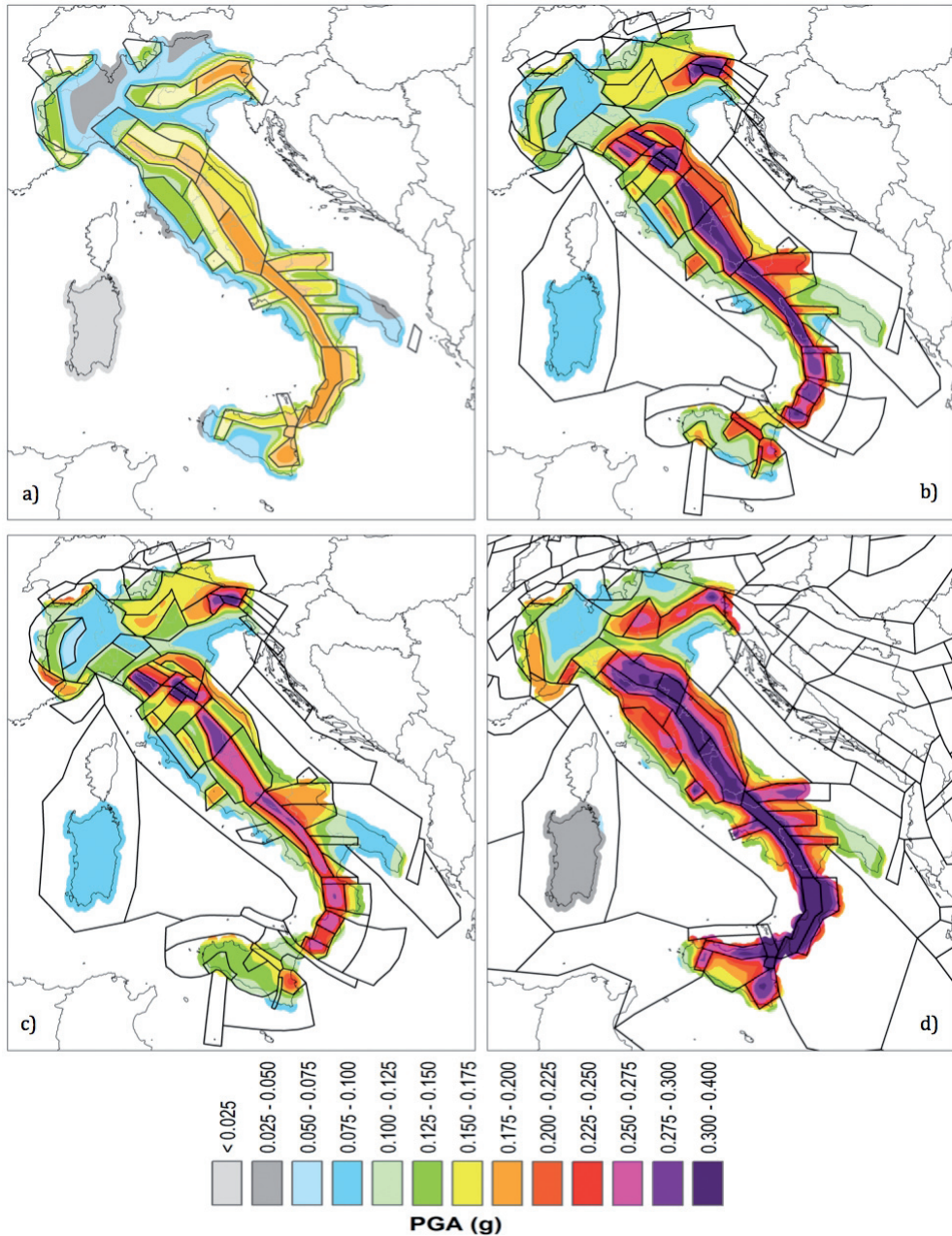


Fig. 3 – PGA with a 475-year return period: a) original MPS04; b) A1 zonation (J&B distance, Akkar *et al.*, 2014) ; c) A1 zonation (hypocentral distance, Akkar *et al.*, 2014); d) original SHARE.

the dimensions of the faults) for the zone, increased of its standard deviation.  $M_{max2}$  is assumed conservatively equal to  $M_{max1} + 0.3$ . A weight of 0.5 is applied to each branch.

To compute the preliminary hazard results, the Akkar *et al.* (2014) GMPE was applied, both using the Joyner-Boore and hypocentral distance versions.

A strict comparison with the values of the previous Italian seismic hazard map [MPS04: Gruppo di Lavoro MPS04 (2004); Stucchi *et al.* (2011)], which is assumed as reference by the Italian building code, is not possible because the two maps use different earthquake catalogues

and GMPEs as inputs. A comparison is possible in terms of areal distribution of the PGA values. The expected ground motion computed with this seismogenic zonation is much more articulated than that of MPS04 because of the more detailed zonation with narrower SZs, which sometimes concentrate the shaking. Conversely to MPS04 (Fig. 3a), where the largest hazard refers to the central-southern Apennines, the new maps show the largest hazard in the northern Apennines and in Friuli. An additional comparison has been established with the European seismic hazard map developed within the framework of the SHARE project (Giardini *et al.*, 2013), where an articulated logic tree was considered for several parameters, among which zonation and GMPE (see Slejko *et al.*, 2014). Differences between the two maps (compare Figs. 3b and 3d) can be observed in several sectors of the study region (e.g. the Friuli area in the north-eastern Italy). Also the areas with the largest PGA values differ slightly.

## References

- Akkar S., Sandikkaya M. A., Bommer J. J.; 2014: *Empirical Ground-Motion Models for Point- and Extended- Source Crustal Earthquake Scenarios in Europe and the Middle East*, Bulletin of Earthquake Engineering, **12**(1), 359-387.
- Barani S., Spallarossa D., Bazzurro P., Eva C.; 2007: *Sensitivity analysis of seismic hazard for Western Liguria (North Western Italy): A first attempt towards the understanding and quantification of hazard uncertainty*. Tectonophysics, Volume **435**, 1-4, 13-35. ISSN 0040-1951, <http://dx.doi.org/10.1016/j.tecto.2007.02.008>.
- Coppersmith K. J. and Young R. R.; 1986: *Capturing uncertainty in probabilistic seismic hazard assessments within intraplate environments*. In: Proceedings of the Third U.S. National Conference on Earthquake Engineering, August 24-28, 1986, Charleston, SC, Earthquake Engineering Research Institute, El Cerrito CA U.S.A., vol. 1:301-312.
- Cornell C. A.; 1968: *Engineering seismic risk analysis*. Bull. Seism. Soc. Am., **58**, 1583-1606.
- DISS Working Group; 2015: *Database of Individual Seismogenic Sources (DISS), Version 3.2.0: A compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas*. <http://diss.rm.ingv.it/diss/>, © INGV 2015 - Istituto Nazionale di Geofisica e Vulcanologia. DOI:10.6092/INGV.IT-DISS3.2.0.
- Gasparini P., Bernardini F., Valensise G., Boschi E.; 1999: *Defining seismogenic sources from historical earthquake felt reports*. Bull. Seism. Soc. Am., **89**, 94-110.
- Giardini D., Woessner J., Danciu L., Crowley H., Cotton F., Grunthal G., Pinho R., Valensise G., Akkar S., Arvidsson R., Basili R., Cameelbeeck T., Campos-Costa A., Douglas J., Demircioglu M.B., Erdik M., Fonseca J., Glavatovic B., Lindholm C., Makropoulos K., Meletti C., Musson R., Pitalakis K., Sesetyan K., Stromeyer D., Stucchi M., Rovida A.; 2013: *Seismic hazard harmonization in Europe (SHARE): Online Data Resource*. doi:10.12686/SED-00000001-SHARE.
- Gruppo di Lavoro; 2004: *Redazione della mappa di pericolosità sismica prevista dall'Ordinanza PCM 3274 del 20 marzo 2003*. Rapporto conclusivo per il Dipartimento della Protezione Civile, INGV, Milano - Roma, 65 pp + 5 App.
- Kulkarni R.B., Youngs R. R. and Coppersmith K. J.; 1984: *Assessment of confidence intervals for results of seismic hazard analysis*. In: Proceedings of the Eighth World Conference on Earthquake Engineering, July 21-28, 1984, San Francisco CA U.S.A., Prentice-Hall Inc., Englewood Cliffs NJ U.S.A., vol. 1, pp. 263-270.
- Locati M., Camassi R., Rovida A., Ercolani E., Bernardini F., Castelli V., Caracciolo C.H., Tertulliani A., Rossi A., Azzaro R., D'Amico S., Conte S., Rocchetti E.; 2016: *DBMI15, the 2015 version of the Italian Macroseismic Database*. Istituto Nazionale di Geofisica e Vulcanologia. doi:<http://doi.org/10.6092/INGV.IT-DBMI15>.
- McGuire R. K.; 1977: *Seismic design spectra and mapping procedures using hazard analysis based directly on oscillator response*. Earthq. Engin. Struct. Dyn., **5**, 211-234.
- McGuire R. K. and Shedlock K.M.; 1981: *Statistical uncertainties in seismic hazard evaluations in the United States*. Bull. Seism. Soc. Am., **71**, 1287-1308.
- Meletti C., Galadini F., Valensise G., Stucchi M., Basili R., Barba S., Vannucci G. and Boschi E.; 2008: *A seismic source zone model for the seismic hazard assessment of the Italian territory*. Tectonophysics, **450**, 85-108.
- Pagani M., Monelli D., Weatherill G., Danciu L., Crowley H., Silva V., Henshaw P., Butler L., Nastasi M., Panzeri L., Simionato M., Vigano D.; 2014: *OpenQuake-engine: an open hazard (and risk) software for the global earthquake model*. Seismol. Res. Lett., **85** (3), 692-702.
- Pondrelli S., Salimbeni S., Morelli A., Ekström G., Postpischl L., Vannucci G. and Boschi E.; 2011: *European-Mediterranean Regional Centroid Moment Tensor Catalog: solutions for 2005-2008*. Phys Earth Planet Int **185**. doi: 10.1016/j.pepi.2011.01.007.
- Rebez A. and Slejko D.; 2000: *Sensitivity analysis on the input parameters in probabilistic seismic hazard assessment*. Soil Dynamics and Earthquake Engineering, **20**(5-8):341-351
- Rebez A., Santulin M., Sani F., Poli M.E., Barani S., Barreca G., Corti G., Bonini M., Martelli L., Slejko D., Busetti M., Zanferrari A., Spallarossa D., Monaco C., Tamaro A., Marchesini A., Scafidi D., Dal Cin M.; 2016: MPS16 Project - Model A1 descriptive report. Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste, Relazione OGS n. 2016/78 CRS16. 52 pp.

- Rovida A., Locati M., Camassi R., Lolli B., Gasperini P.; 2016: *CPTI15, the 2015 version of the Parametric Catalogue of Italian Earthquakes*. Istituto Nazionale di Geofisica e Vulcanologia. doi:<http://doi.org/10.6092/INGV.IT-CPTI15>.
- Scafidi D., Barani S., De Ferrari R., Ferretti G., Pasta M., Pavan M., Spallarossa D. and Turino C.; 2015: *Seismicity of northwestern Italy during the last thirty years*. *Journal of Seismology*, **19**, 201-218.
- Slejko D., Santulin M. and Garcia J.; 2014: *Seismic hazard estimates for the area of Pylos and surrounding region (SW Peloponnese) for seismic and tsunami risk assessment*. *Boll. Geof. Teor. Appl.*, **55**, 433-468. doi:10.4430/bgta0090.
- Stucchi M., Meletti C., Montaldo V., Crowley H., Calvi G.M. and Boschi E.; 2011: *Seismic hazard assessment (2003–2009) for the Italian building code*. *Bull. Seism. Soc. Am.*, **101**, 1885–1911. doi: 10.1785/0120100130.
- Toro G. R., Abrahamson N. A. and Schneider J. F.; 1997: *Model of strong motions from earthquakes in central and eastern North America: best estimates and uncertainties*. *Seism. Res. Lett.*, **68**, 41-57.
- Weichert D. H.; 1980: *Estimation of the earthquake recurrence parameters for unequal observation periods for different magnitudes*. *Bull. Seismol. Soc. Am.*, **70**, 1337-1346.