Seismogenic nodes within mountain belts of Southern Europe

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Seismogenic nodes have been recognized in mountain environments of Southern Europe, including the Alps, Carpathians, Balkanides, Dinarides, and Peninsular Italy with Sicily. We regard the output of our work — uniformly defined seismogenic nodes within a vast seismic region — as a contribution to the challenging problem of the uniformity of seismic hazard research. For a recent attempt towards such standardization see Panza et al., (2000).

Methodology

The methodology used includes two principal steps. The first step is the delineation of the objects of the recognition — the morphostructural nodes. The second one is the classification of all delineated nodes with the pattern recognition technique into nodes where earthquakes with magnitude exceeding a certain threshold are possible and nodes where only smaller earthquakes may happen.

The nodes were defined by the *Morphostructural Zoning* method (MZ) that is based on the concept that the lithosphere is built up by different-scale blocks separated by mobile boundaries. By the MZ a studied region is divided into a system of hierarchically ordered areas characterized by homogeneous present-day topography and tectonic structure. MZ distinguishes *(1)* areas (blocks) of different rank; *(2)* their boundary zones, *morphostructural lineaments*; and *(3)* sites where lineaments intersect, *nodes*.

Large-scale geostructures, developed by a common orogenesis and characterized by uniform orography are considered the highest first rank units, *mountain countries*. They are divided into second rank areas, *megablocks*, which are further subdivided into third rank areas, *blocks*. The rank of the lineament depends on the rank of the area limited by the lineament. MZ distinguishes two types of boundary zones: longitudinal lineaments that are approximately parallel to the regional trend of the tectonic structure and of the topography and transverse lineaments that cross them. Morphostructural nodes are formed around the intersections or junctions of two or more lineaments, *i.e.* a node may include more than one intersection or junction. In topography nodes are represented by a mosaic combination of various topographic forms and by an increased number of linear topographic forms of various strikes that reveal the instability of the area.

Figure 1 displays the morphostructural map of the study region that shows the hierarchical block-structure of the region, the network of lineaments, and the loci of the nodes. The map has been compiled at the scale of 1:1 000 000 on the basis of the joint analysis of topographic and tectonic maps as well as satellite photos. A node is defined in a formal way as a circle of 25 km of radius, centered at the point of intersection of the lineaments.

The goal of pattern recognition is to divide all nodes in the studied region in class **D** composed by nodes capable of large earthquakes and class **N** constituted by the nodes incapable of earthquakes with magnitude considered. The well-tested CORA-3 pattern recognition algorithm has been used in this work (Gelfand et al., 1976; Gorshkov et al., 2003). At the learning stage the algorithm selects the distinctive features of each class on the basis of *a priori* defined training sets, which are constituted by all the sample nodes representative of the classes **D** and **N**. The training set for **D** class includes the nodes situated most closely to the epicenters of earthquakes with considered magnitude. The training set for class **N** includes the nodes that are most distant from large earthquakes recorded in the study region. At the classification stage the algorithm assigns each node to one of two classes using distinctive features for classes **D** and **N** defined at the learning stage.

Recognition of seismogenic nodes within mountain belts of Southern Europe

The recognition has been conducted separately for peninsular Italy and Sicily (Gorshkov et al., 2002), for the Alps (Gorshkov et al., 2004), and for the Di-

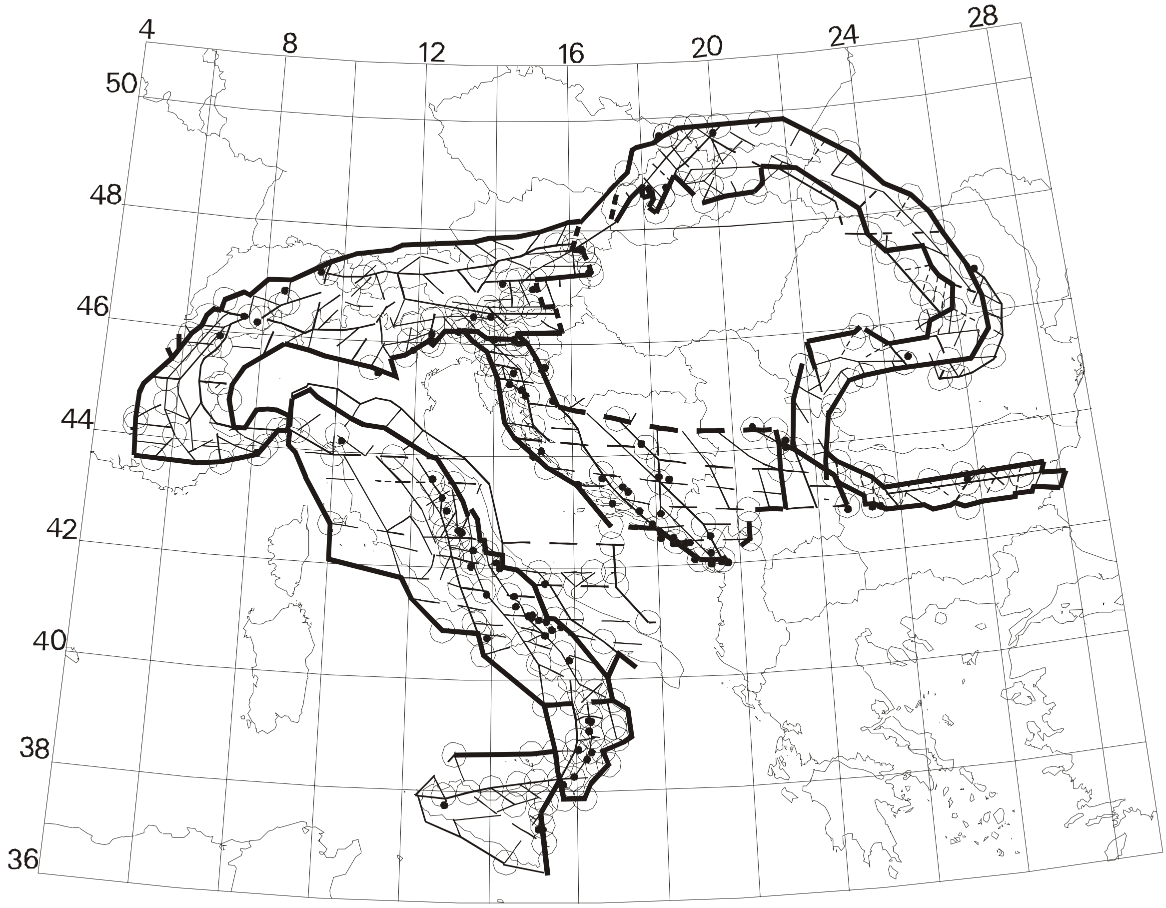

Fig. 1. Southern Europe: morphostructural map and seismogenic nodes prone to earthquakes with $M \geq 6.0$.
Lines indicate lineaments of different rank.
Black dots show epicenters of earthquakes with $M \geq 6.0$.
Circles depict nodes capable of earthquakes with $M \geq 6.0$.

narides including the northern part of the Serbo-Macedonian Massif (Gorshkov et al., 2004). In the Carpathians and Balkanides, the number of known relevant earthquakes is too small to allow a satisfactory learning stage of the pattern recognition. Therefore, in these regions we defined the nodes capable of earthquakes with $M \geq 6.0$ exploiting the characteristic traits defined by CORA-3 for **D** nodes in the Dinarides.

At the learning stage of the recognition of the recognition we selected the sample nodes for each region using the information on shallow events with $M \geq 6.0$ reported by the earthquake catalogues. The selected earthquakes with $M \geq 6.0$, both historical and instrumental ones, are plotted in fig.1. The epicenters of these earthquakes are located near the intersection of lineaments, *i.e.* at the nodes. With only a few exceptions, related to very ancient events in the Dinarides, the distance between the epicenters and the points of intersection does not exceed 25 km.

At the learning stage all the nodes have been *a priori* divided into three sets. In the sets $\mathbf{D_0}$ we included the nodes most closely situated to the epicenters shown in fig.1. On the contrary, to the sets $\mathbf{N_0}$, we assigned the nodes that are most distant from the epicenters in fig.1 and, to be conservative, from events with smaller magnitudes ($5.5 \leq M < 6.0$). The nodes, which are neither not close enough to the relevant epicenters nor sufficiently distant from them, were not included in the training set. They were not employed for the selection of the characteristic traits but they have been classified at the recognition stage.

A uniform characterization of the nodes in the form of a common questionnaire is needed to apply the pattern recognition technique. We used morphometric and gravity parameters as well as parameters of lineament-and-block geometry defined with MZ. The values of the parameters have been measured within each node, *i.e.* inside a circle with 25-km of radius, from available topographic, geological, and gravity maps as well as from the compiled MZ map (fig. 1).

Results

Recognized **D** nodes are plotted in fig. 1 the as the scaled circles with the radius of 25 km. Each non-circled intersection of lineaments in fig. 1 is **N** node.

As seen in fig. 1, **D** nodes are spatially distributed in different ways across each mountain country that compose the study mountain belt. In peninsular Italy, **D** nodes almost continuously cover internal areas of the peninsula from the Central Apennines, in the north, up to northeastern Sicily, in the south. In the Carpathians and Balkanides, **D** nodes are mostly concentrated on first rank lineaments that limit these mountain countries. The scattered distribution of **D** nodes is characteristic to the western part of the Alpine Orogen, while in the Eastern Alps **D** nodes form the prominent clusters in its southern and easternmost areas. In the Dinarides, large clusters of **D** nodes are situated in the north and in the southwest. Figure 1 exhibits the large agglomeration of **D** nodes in the junction zone between the Eastern Alps and the Dinarides that indicates the high seismic potential for this area. The overwhelming majority of the recognized **D** nodes sit on first and second rank lineaments, *i.e.* on the boundaries of larger blocks.

The sufficiently large amount of **D** nodes has been recognized in the areas where strong earthquakes have not happened so far. Most of such nodes have been identified in the Alps, specifically, in the Western Alps, in the Carpathians, and in the Balkanides.

The characteristic traits defined with CORA-3 indicate the contrast in neotectonic movements in **D** nodes vicinities and suggest an increased fragmentation of the crust around **D** nodes at depth.

The results obtained indicate a high seismic potential for large areas within mountain belt of Central Europe: a number of nodes where strong events have not occurred so far, have been recognized prone to large earthquakes. This generates the need for interdisciplinary efforts and attempts to explain how the structure and the dynamics of the lithosphere in the region brings into existence the seismogenic nodes at the sites represented in this work.

References

Gelfand, I., S. Guberman, V. Keilis-Borok, L. Knopoff, F. Press, E. Rantsman, I. Rotwain, A. Sadovsky. 1976. Pattern recognition applied to earthquake epicentres in California. — *Phys. Earth Planet. Inter.*, *11*, 227—283.

Gorshkov, A., V. Kossbokov, A. Soloviev. 2003. Recognition of earthquake prone areas. — In: Keilis-Borok, V., A. Soloviev (Eds.). *Nonlinear Dynamics of the Lithosphere and Earthquake Prediction*. Heidelberg, Springer, 235—320.

Gorshkov, A. I., G. F. Panza, A. A. Soloviev, A. Aoudia. 2002. Morphostructural zoning and preliminary recognition of seismogenic nodes around the Adria margin in peninsular Italy and Sicily. — *JSEE: Spring*, *4*, No 1, 1—24.

Gorshkov, A. I., G. F. Panza, A. A. Soloviev, A. Aoudia. 2004. Identification of seismogenic nodes in the Alps and Dinarides. — *Boll. Soc. Geol. Ital.*, *123*, 3—18.

Panza, G., M. Radulian, C. Trifu (Eds.). 2000. *Seismic hazard of the Circum-Pannonian region. Special Issue, Pure Appl. Geophys.*, *157*, 1/2, 1—279.