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Seismological database - Identification of high potential seismogenic sources

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"Seismological database - Identification of high potential seismogenic sources "

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METHODOLOGY

Two principal steps compose the methodology:

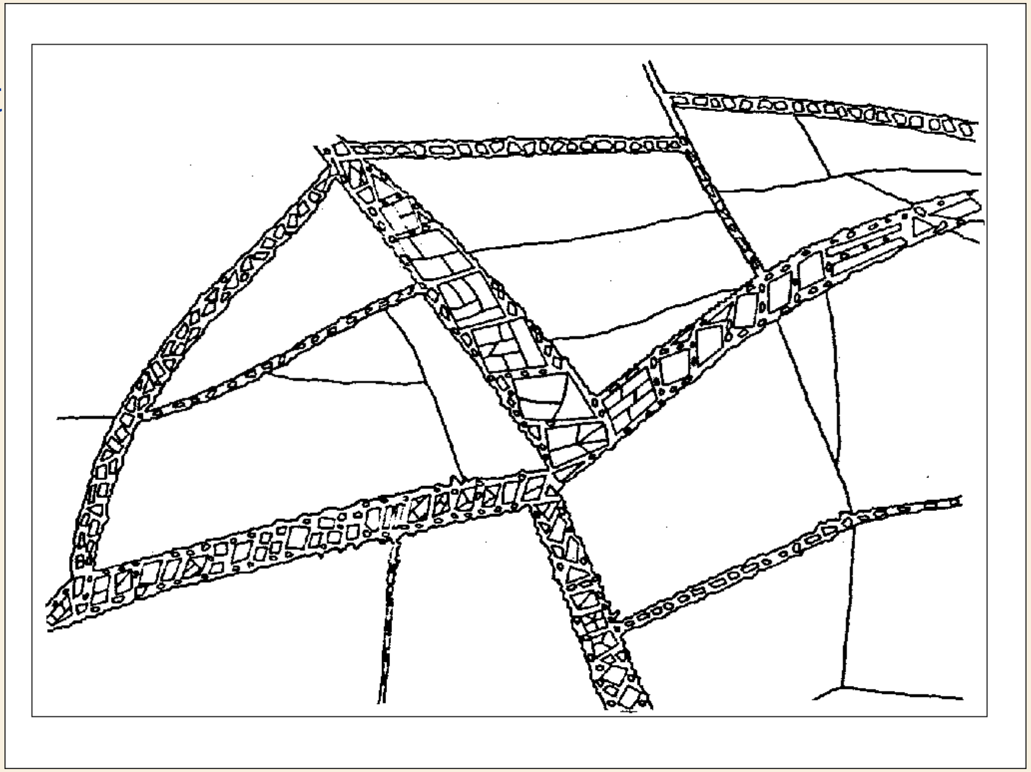
The first step is the delineation of the objects of the analysis – the morphostructural nodes – by the morphostructural zoning (MZ) method.

The second one is classification of all mapped nodes by the pattern recognition algorithm CORA-3 into nodes where earthquakes with magnitude exceeding a certain threshold are possible and nodes where only earthquakes with smaller magnitude may happen.

Lithosphere: a hierarchy of blocks

The approach presented here is based on a widely accepted concept that the lithosphere consists of different-scale blocks separated by mobile boundaries.

The division of a territory into a system of hierarchically ordered blocks is rather evident in a present-day topography, which clearly expresses recent tectonics.



Initial data for Morphostructural Zoning at the scale of 1: 1,000,000

- **topographic maps** (1 : 500,000 - 1:1,000,00)
- **tectonic maps** (1 : 500,000 - 1:1,000,00)
- **geological maps** (1 : 500,000 - 1:1,000,00)
- **satellite photos**
- **relevant publications**

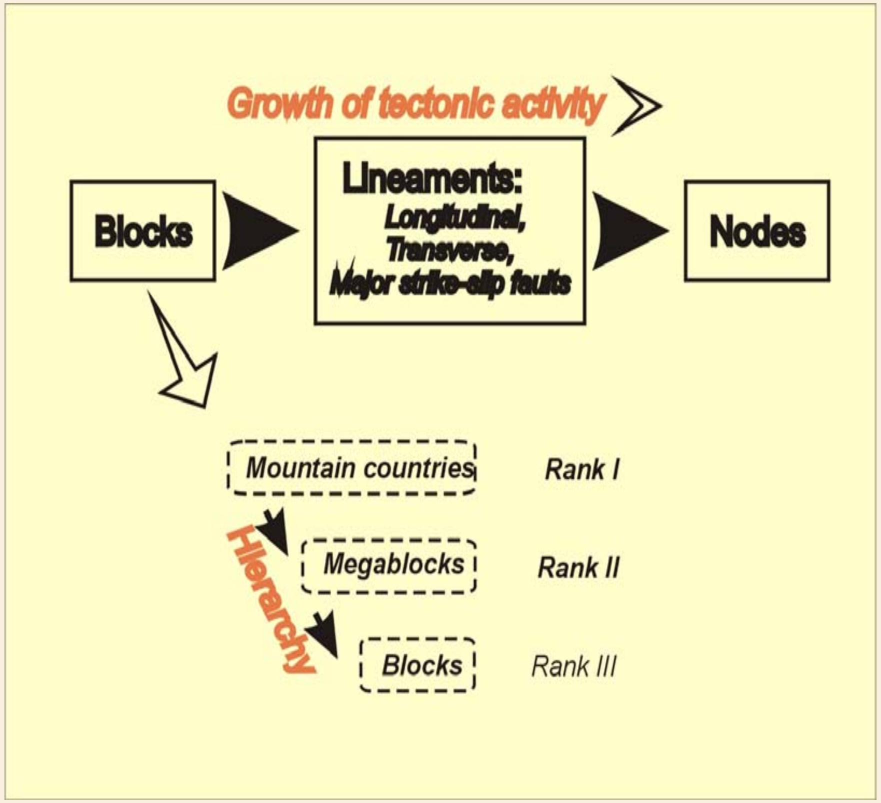
Basic definitions

By the MZ a studied region is divided into a system of hierarchically ordered areas (blocks) characterized by homogeneous present-day topography and tectonic structure. MZ distinguishes *(1)* ***blocks*** of different rank; *(2)* their boundary zones, ***morphostructural lineaments***; and *(3)* sites where lineaments intersect, ***nodes***.

Large-scale geostructures (*e.g.,* the Alps) developed by a common orogenesis and characterized by uniform orographic appearance 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.

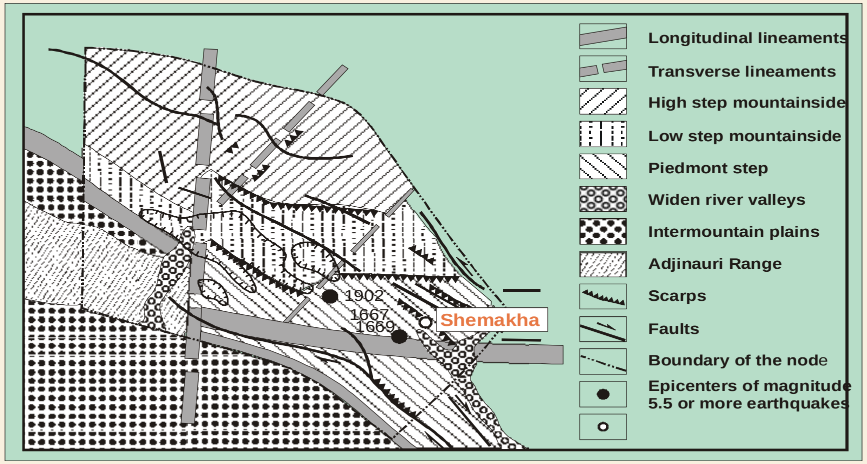
Morphostructural nodes are formed around the intersections or junctions of two or more lineaments. A node may include more than one intersection or junction.



What is a node?

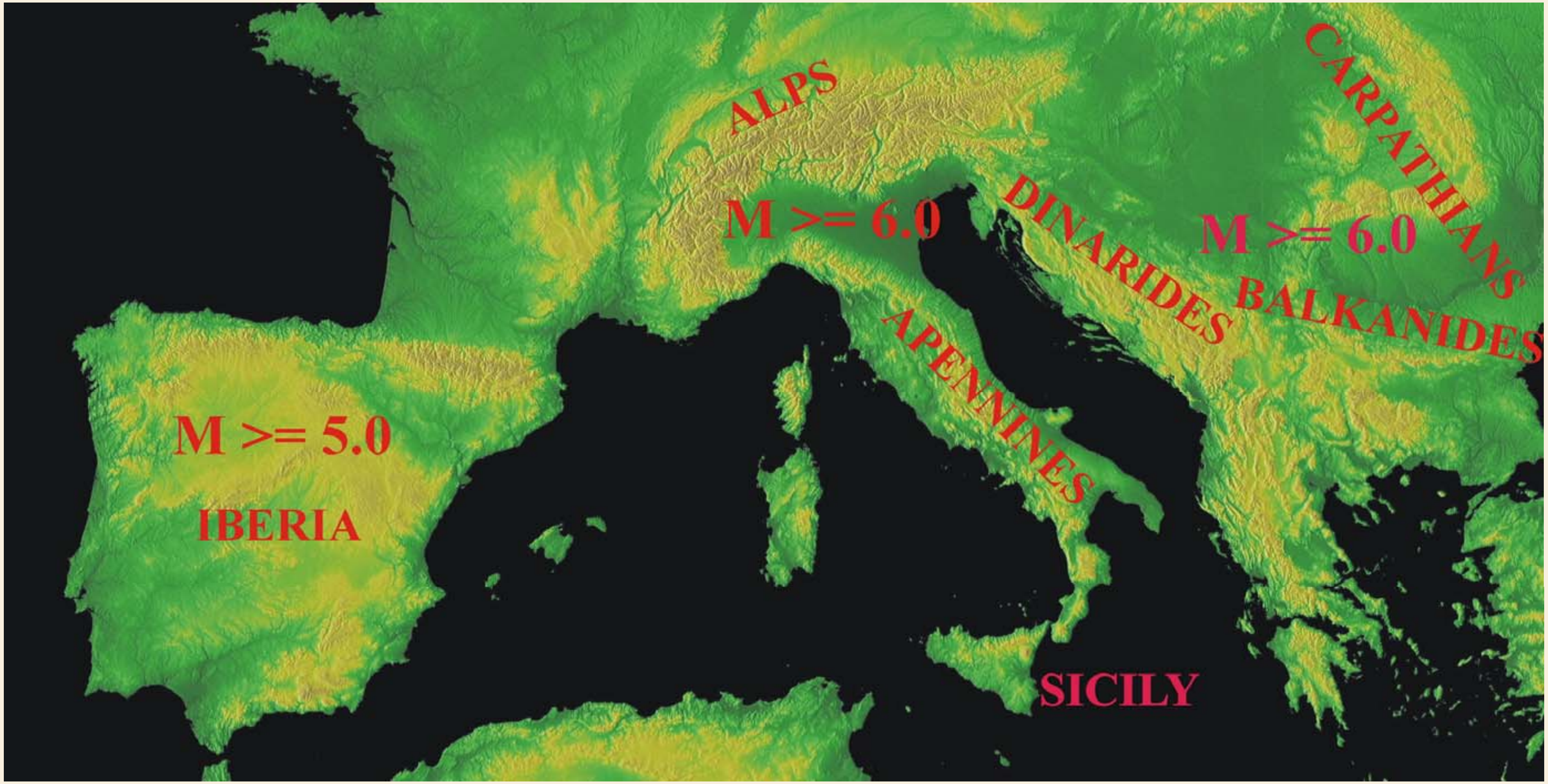
Lineament zones become wider at nodes. Nodes are characterized by a mosaic combination of various topographic forms and by an increased number of linear topographic forms of various strikes that reveal the instability of the area. River valleys within the nodes are represented by a sequence of rectilinear segments that are often shifted with respect to each other. Knee-like bends are characteristic of the river courses at a node. In the vicinity of nodes, tectonic faults branch and /or become bent; sometimes a fault system with one orientation merges into a fault system with another orientation.

The Shemakha node in the Greater Caucasus

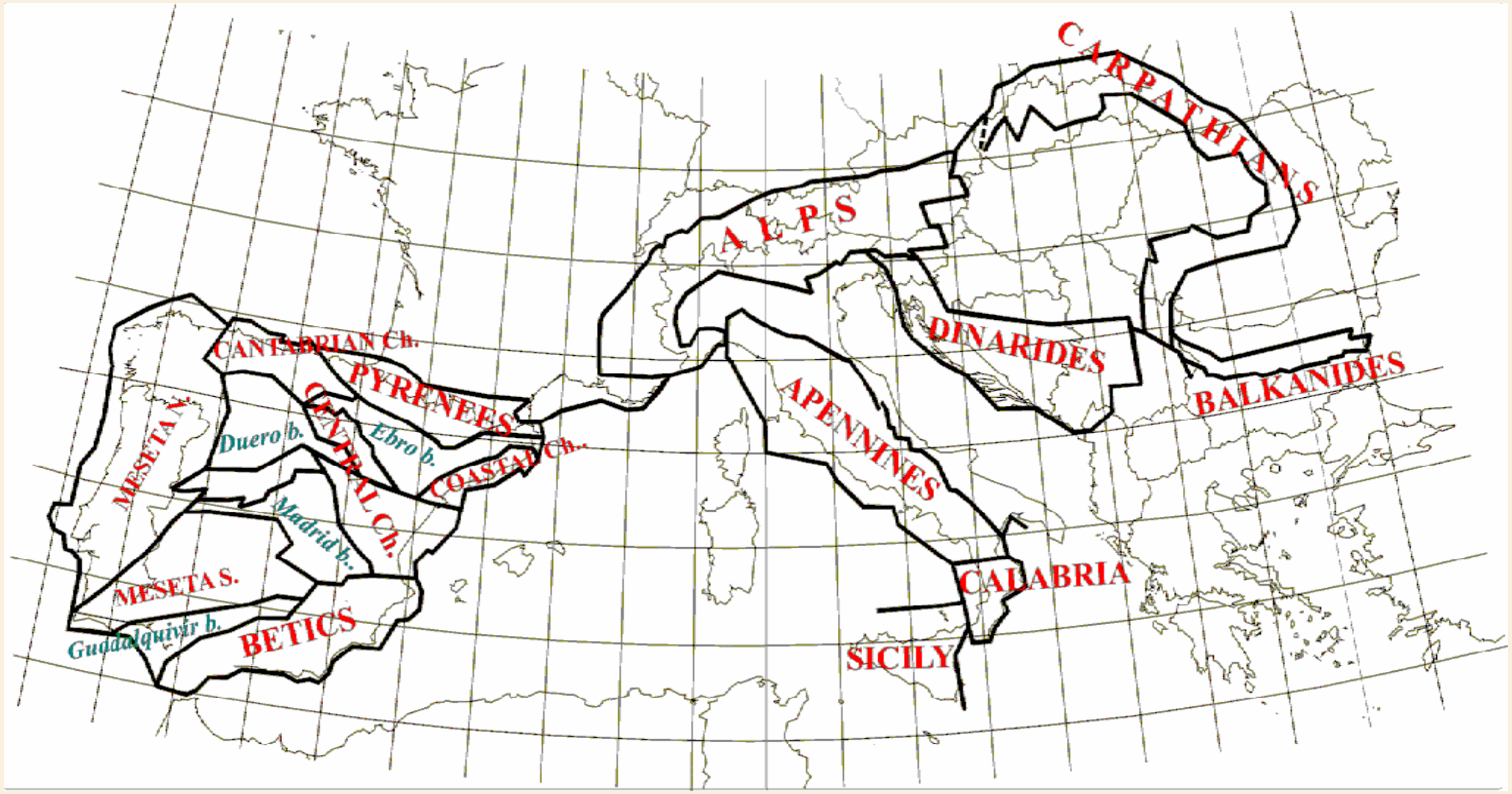


Special fieldwork is needed to outline them reliably. If no field investigations were made, a certain circle could be used as a substitute for a node (for instance, a 25-km radius for seismic regions of moderate activity and M_0 = 5-6). Field investigations in the Tien Shan and Caucasus show that nodes are usually asymmetrical with regard to intersections and lineament axes. The sizes of nodes range drastically and depend on the number of intersections or junctions that form a node.

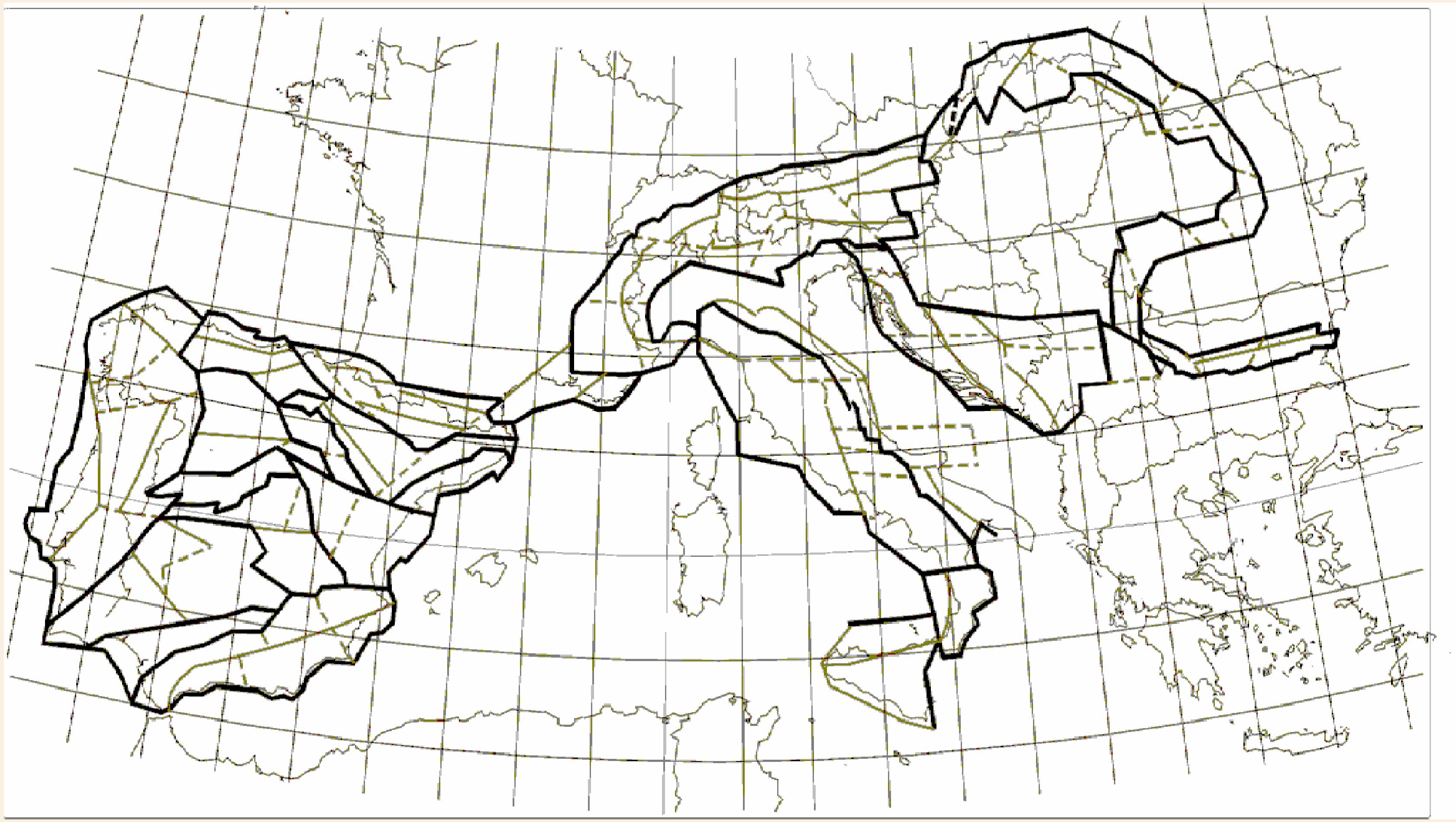
The study regions in Central and Southern Europe



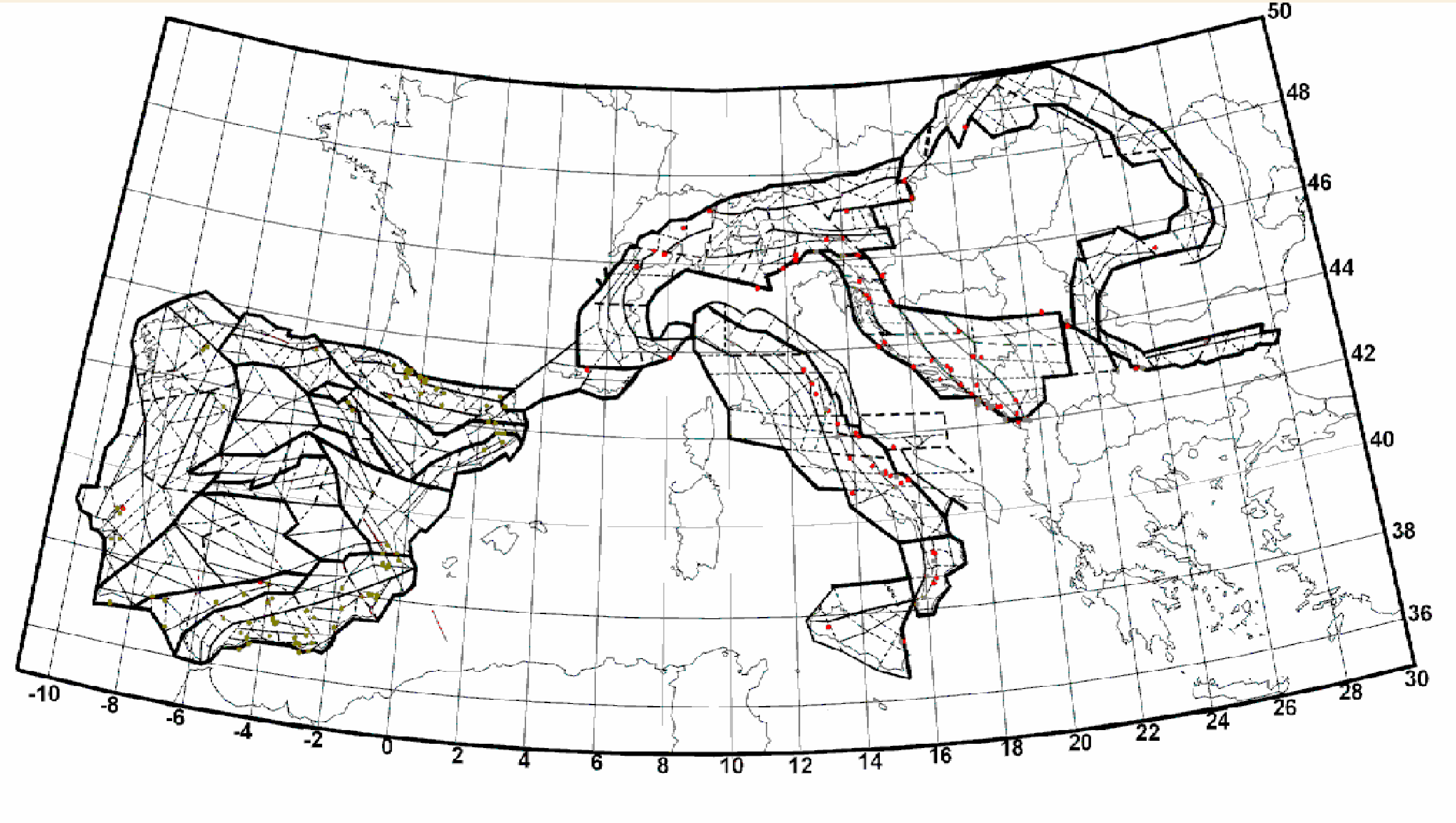
First rank morphostructural units



Second rank morphostructural units



MZ map and earthquakes used to select training sets for the CORA-3 algorithm



Pattern recognition applied to seismogenic nodes identification

The goal of the recognition is to classify all the nodes delineated within a region into the two classes:

- **class D containing the seismogenic nodes where earthquakes with magnitude $M \geq M_0$ may occur;**
- **class N containing the nodes where only earthquakes with $M < M_0$ may occur.**

Application of the CORA-3 algorithm consists of the two stages:

- **(1) *learning stage* - selection of the distinctive features of each class on the basis of the training set composed by D_0 and N_0 subsets, which are constituted by all the sample nodes representative of the classes D and N, respectively;**
- **(2*) classification stage* – determination of which class each node belongs to.**

At the learning stage all the nodes are *a priori* divided into three sets:

- the training set D_0 includes the nodes most closely situated to the recorded epicenters;

- the training set N_0 includes the nodes that are most distant from the recorded epicenters;

- the set X consists of the nodes hosting earthquakes with $M < M_0$

Input for the CORA-3 algorithm

- ***Topographic parameters***

Maximum topographic altitude, (Hmax)
Minimum topographic altitude, (Hmin)
Relief energy, (DH) (Hmax - Hmin)
Distance between the points Hmax and Hmin, (L)
Slope, (DH/L)

- ***Geological parameters***

The portion of soft (quaternary) sediments,

- ***Gravity parameters***

Maximum value of Bouguer anomaly,
Minimum value of Bouguer anomaly,
Difference between Bmax and Bmin,

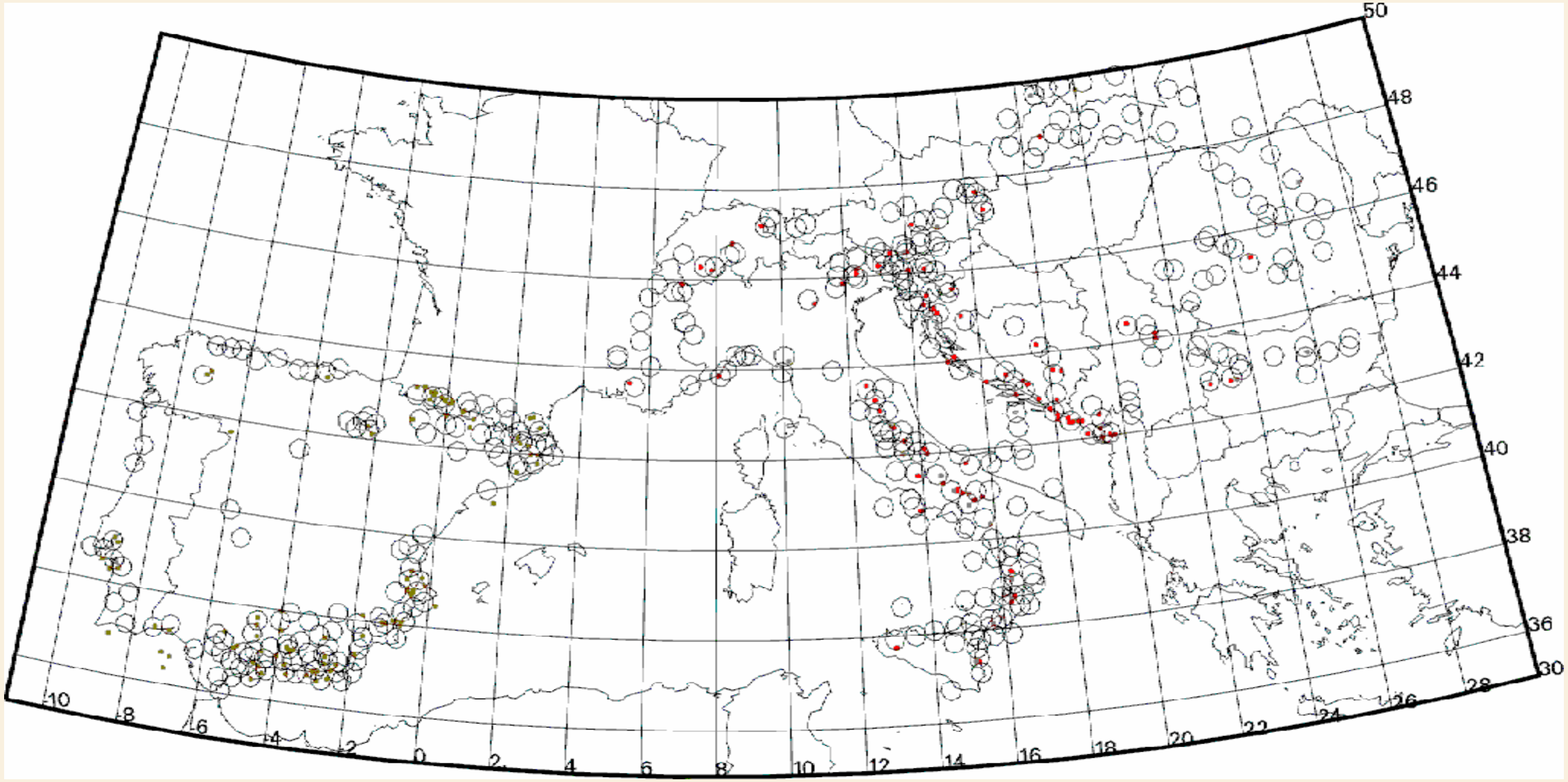
- ***Parameters from the morphostructural map***

The highest rank of lineament in a node
Number of lineaments forming a node,
Distance to the nearest 1st rank Lineament
Distance to the nearest 2nd rank lineament
Distance to the nearest node

- ***Morphological parameters***

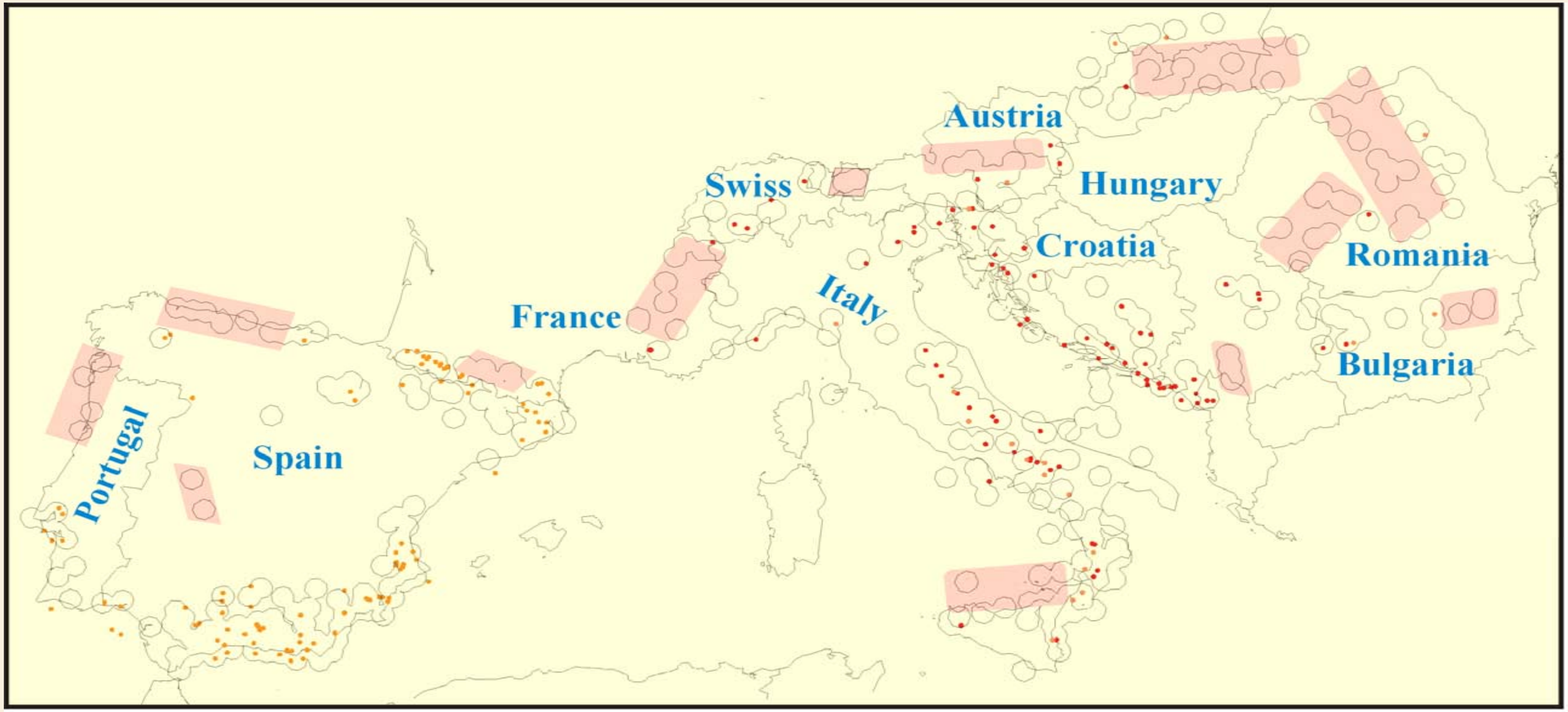
Topographic altitudes and the area of soft sediments characterize indirectly the contrast and intensity of the present-day tectonic movements, while those describing the density of lineaments and gravity anomalies can be related to the degree of crust fragmentation and heterogeneity.
The values of the parameters have been measured for each node from the relevant maps.

Recognized seismogenic nodes



Recognized seismogenic nodes

pink areas mark “silent” nodes



Central and Southern Europe: distinctive features of the seismogenic nodes

- **Most seismogenic nodes are associated with the first and second rank lineaments, *i.e.* with the boundaries of larger blocks.**

Characteristic traits defined by the CORA-3 algorithm for seismogenic nodes suggest :

- **the contrast in neotectonic movements**
- **an increased fragmentation of the crust at depth**
- **subsidence for some seismogenic nodes in the Dinarides**

Validity of the results

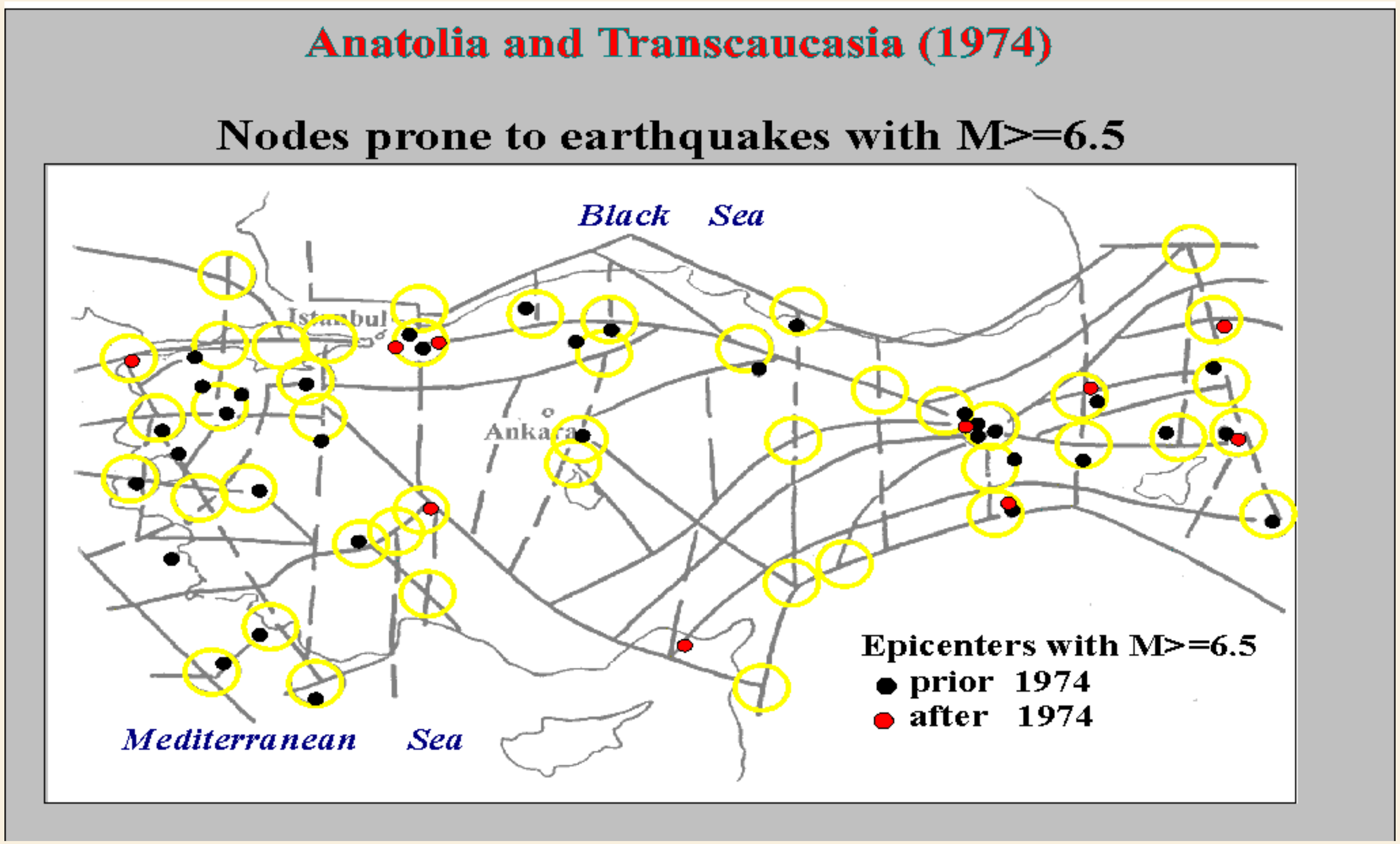
In the past three decades, pattern recognition of seismogenic nodes based on MZ was performed in many regions of the world.

All MZ maps were developed through the same methodology, although on different scales. Seismic potential of the nodes was defined with pattern recognition algorithms for different magnitudes of strong earthquakes.

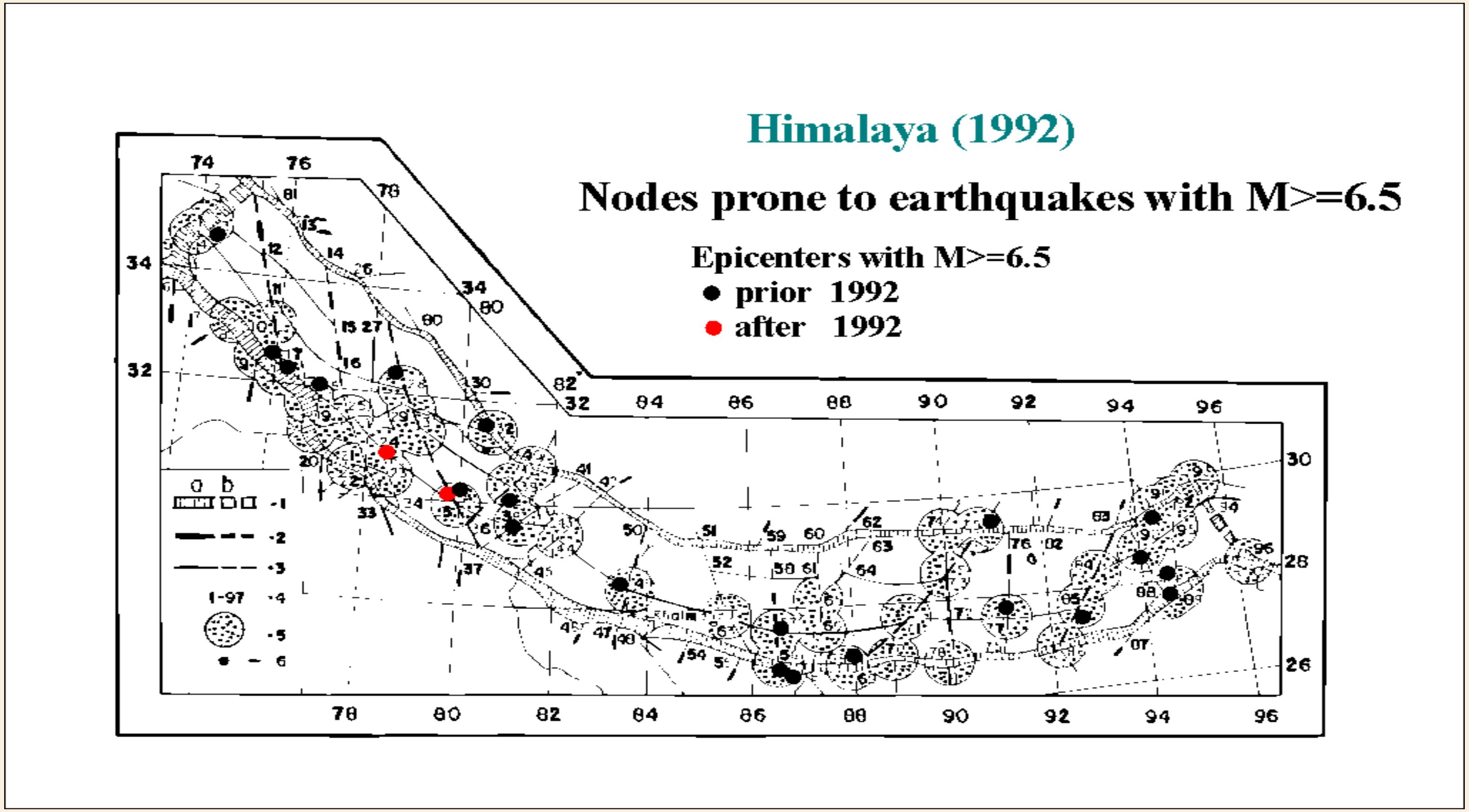
The test consists of comparing locations of seismogenic nodes with post-publication earthquakes of relevant magnitudes. The starting date of the test differs from region to region; the ending date is 1 July , 2000.

The global NEIS earthquake catalog has been used as the source of uniform data on earthquakes. The earthquake was selected for the test if any of the four magnitudes reported by the NEIS catalog was equal to or larger than M_0 defined in the region previously.

Post-publication earthquakes



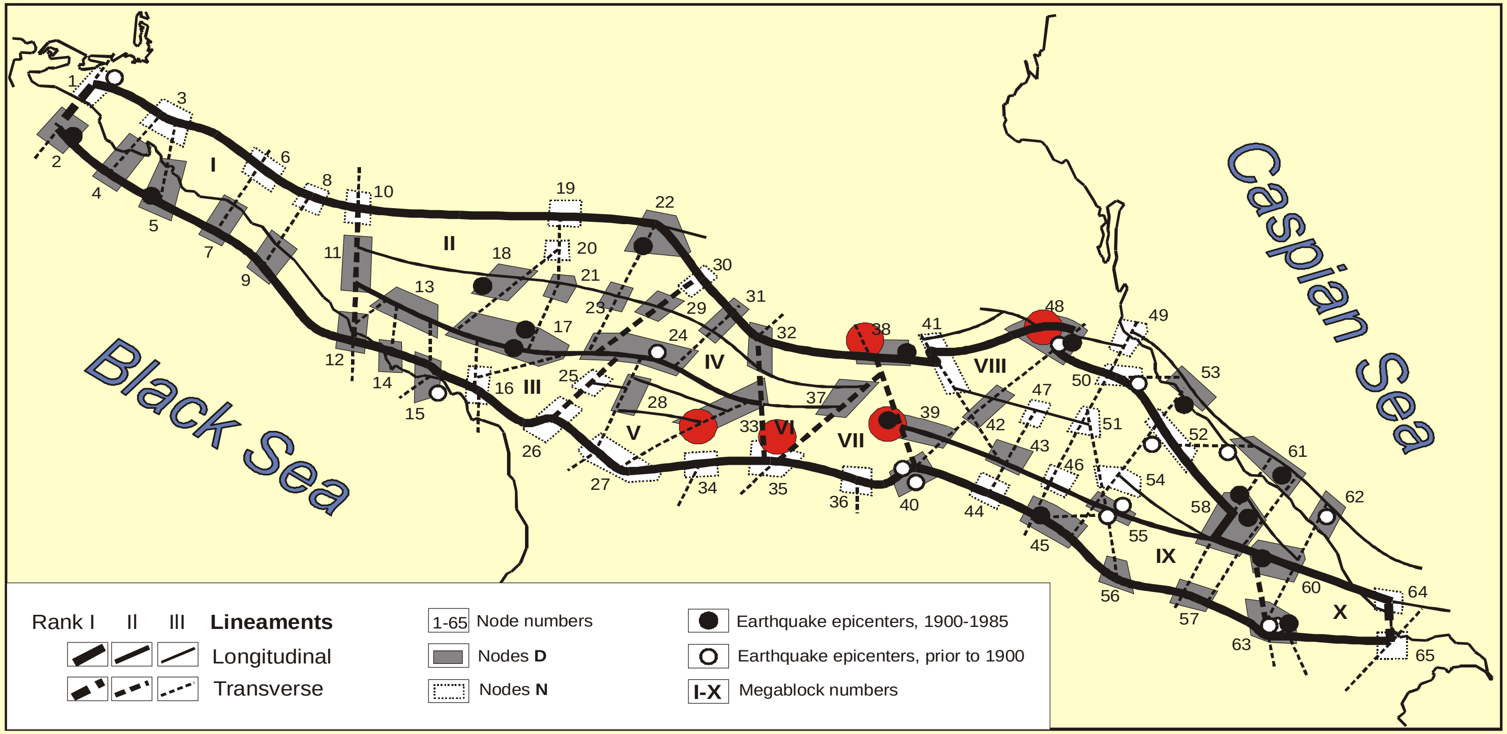
Post-publication earthquakes



Post-publication earthquakes

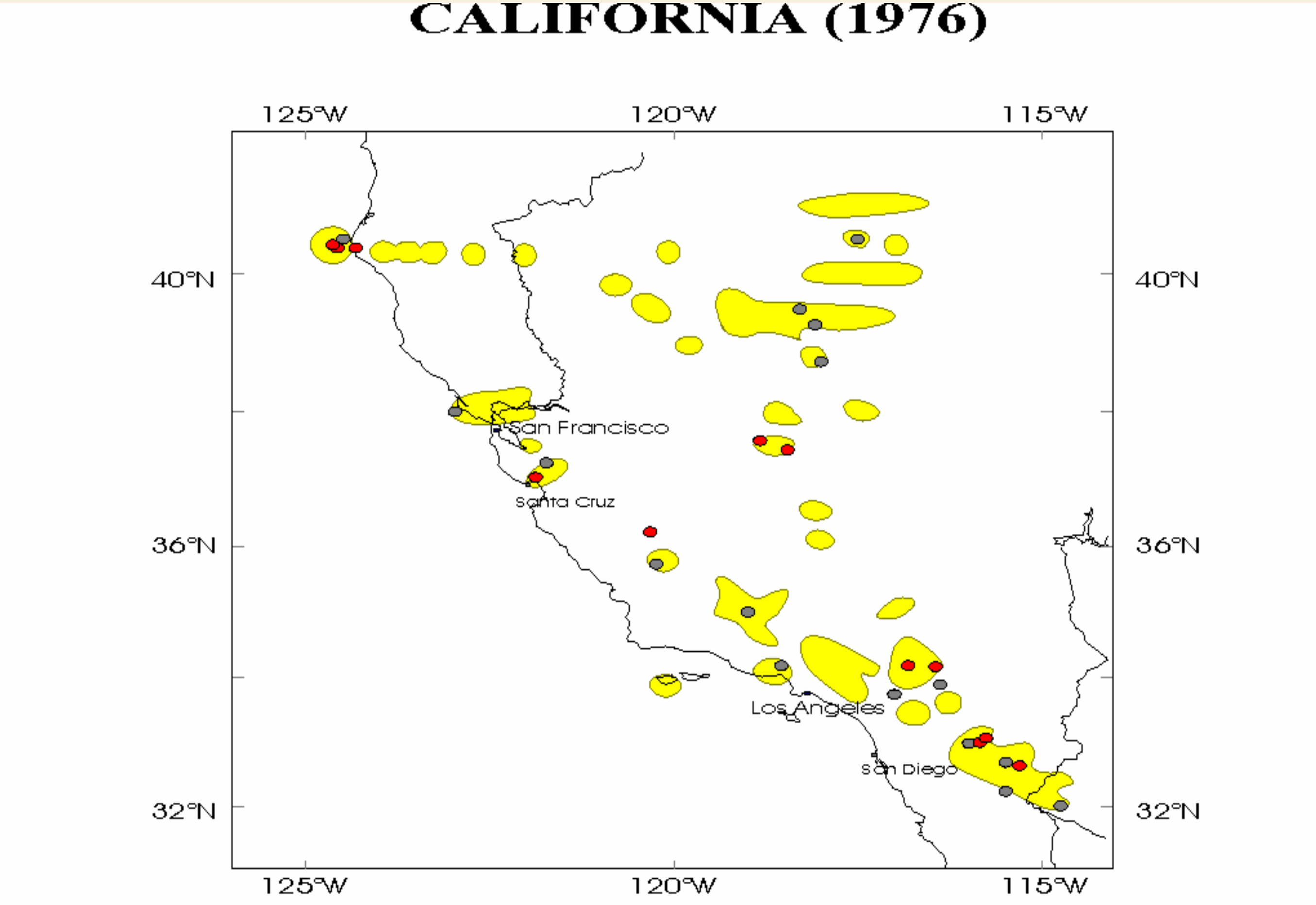
Greater Caucasus(1987)

Nodes prone to earthquakes with M>=5.5



● Earthquakes with M>=5.5 after 1987

Post-publication earthquakes



Areas where the epicenters of the earthquakes of magnitude 6.5 or more can be situated

Epicenters of earthquakes with magnitude 6.5 or more

prior 1976

after 1976

Post-publication earthquakes

Region	M_0	Publication year	Number of post-publication earthquakes: total in region	at seismogenic nodes D (D*)	at non-seismogenic nodes N
Tien Shan-Pamirs	6.5	1973	6	4 (1)	
Balkans-Asia Minor-Transcaucasia	6.5	1974	20	19 (5)	1
California	6.5	1976	15	13 (5)	
Italy	6.0	1979	5	3 (1)	
Andes of South America	7.75	1982	2	2 (1)	
Kamchatka	7.75	1984	1	1 (1)	
Western Alps	5.0	1985	5	4 (1)	1
Greater Caucasus	6.5	1986	3	2 (1)	1
	5.5	1987	5	4 (1)	1
	5.0	1988	14	11 (3)	1
Pyrenees	5.0	1987	2	1	1
Himalaya	6.5	1992	2	2 (1)	
TOTAL			**72**	**60 (16)**	**6**

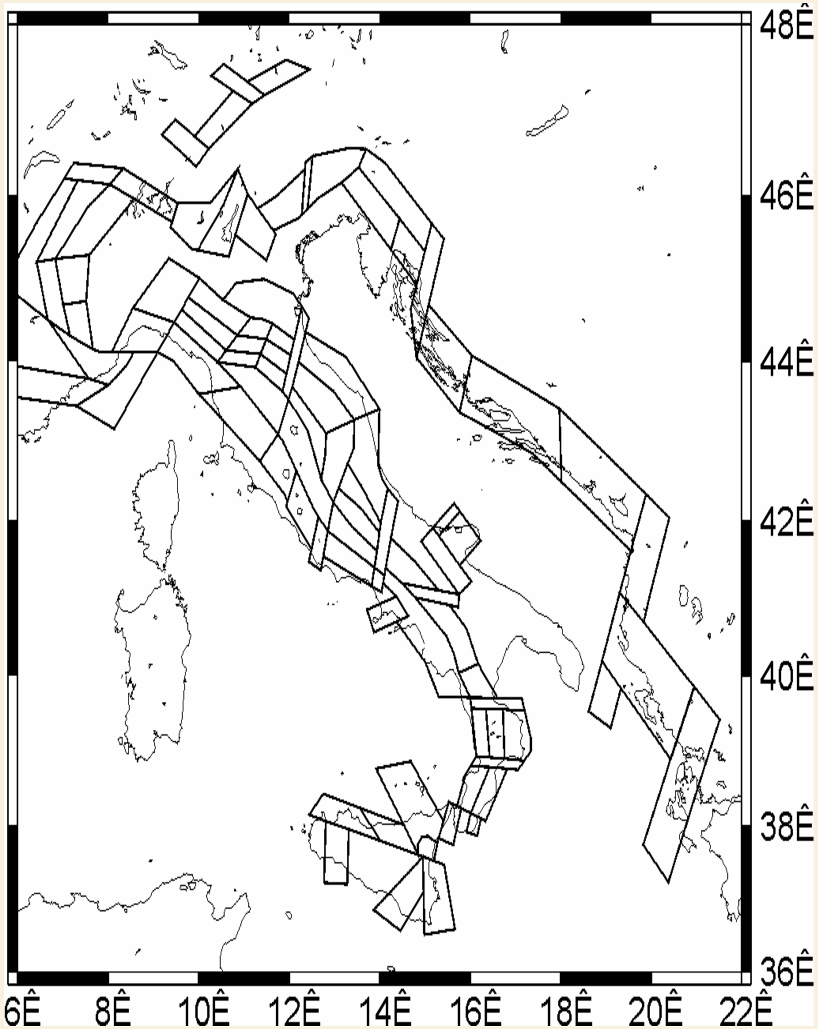
Methodology: Reliability and Uncertainties

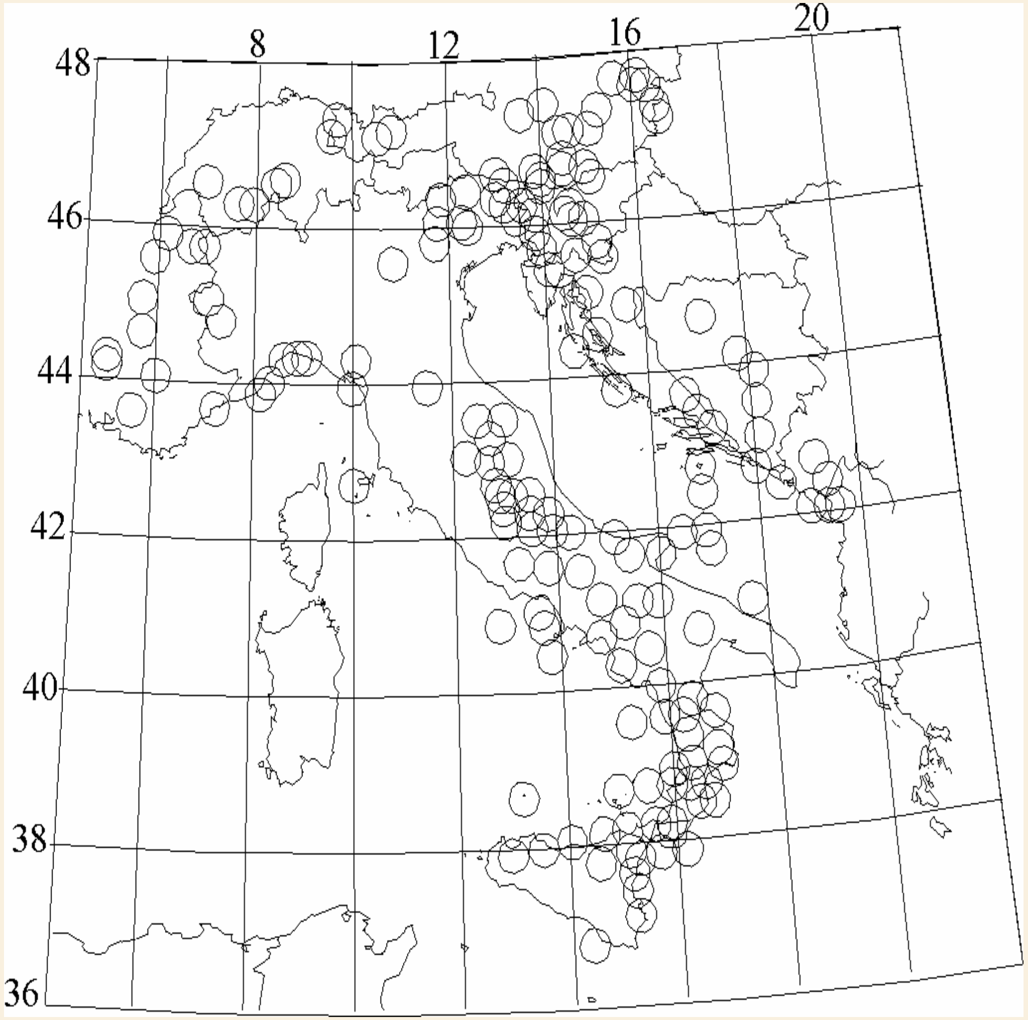
72 post-publication strong earthquakes took place in the studied regions.
•64 nodes did occur at mapped nodes. This fact confirms the initial hypothesis of nucleating strong earthquakes within nodes.
•60 events (83%) occurred at **D** nodes; 19 (32%) out of 60 events took place at the "silent" nodes, *i.e.* at nodes where no large earthquakes had been reported prior to pattern recognition. This highlight the necessity of using pattern recognition results in estimating seismic risk, *e.g.*, in seismic zoning. The other 41 strong earthquakes occurred at the nodes where such events were already reported. This, perhaps, evidences the existence of long-term clustering of large earthquakes.
•4 events (6%) occurred at N nodes;
•8 events 11%) are not associated with the mapped nodes.

The probability of classification error can be estimated by the ratio of the number of strong earthquakes at **N** to the total number of strong earthquakes associated with nodes. This ratio equals 4/64 = 6.25%, confirming the high reliability of classifications that define seismogenic nodes.

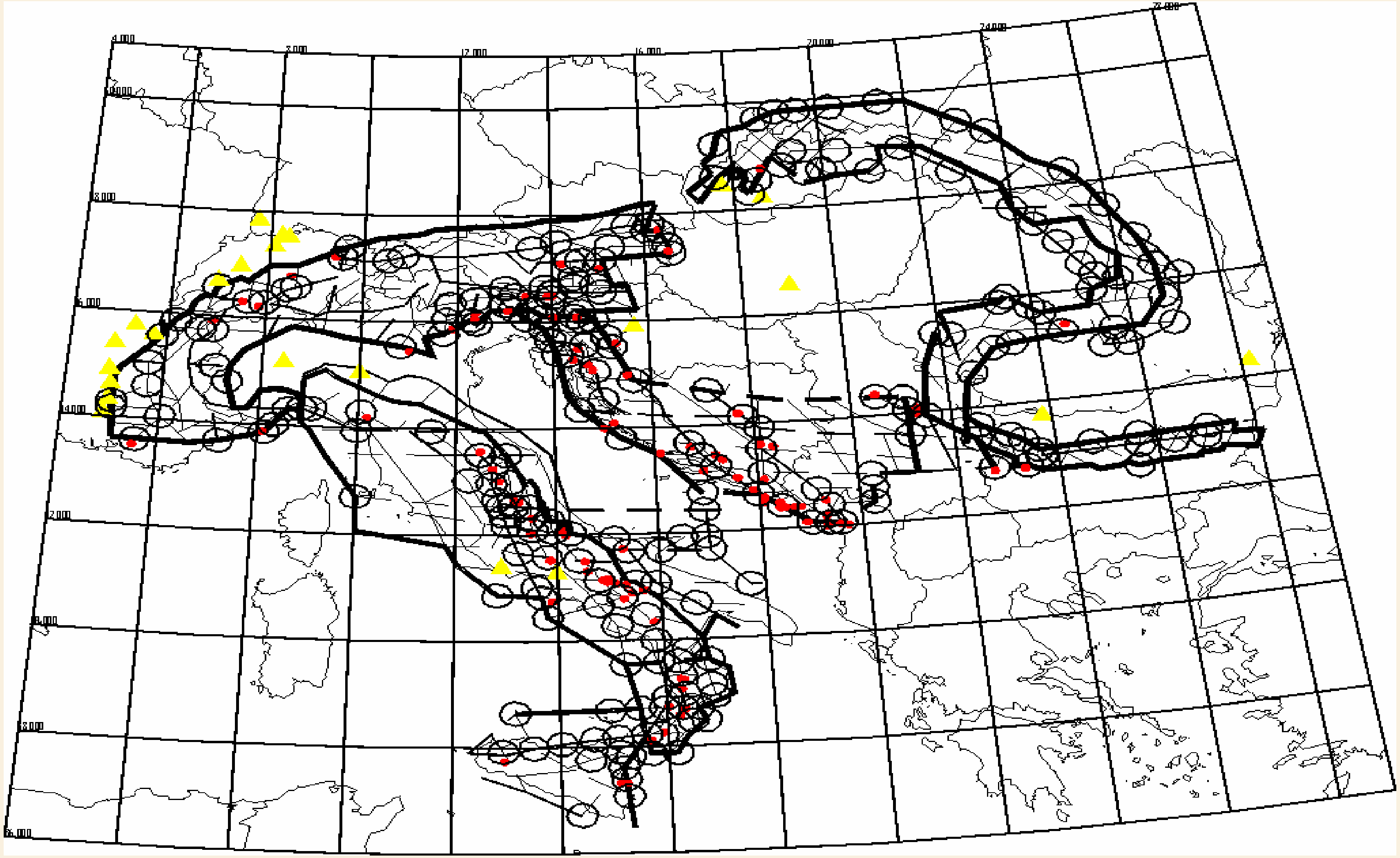
The test confirms that the pattern recognition approach to the determination of seismogenic nodes is most sensitive to the following factors:
•the completeness of the MZ maps;
•an adequate characterization of nodes by parameters naturally related to seismogenic processes;
•sufficient size of the training set $\mathbf{D_0}$.

Seismogenic zones by Meletti et al.(2000) and seismogenic nodes

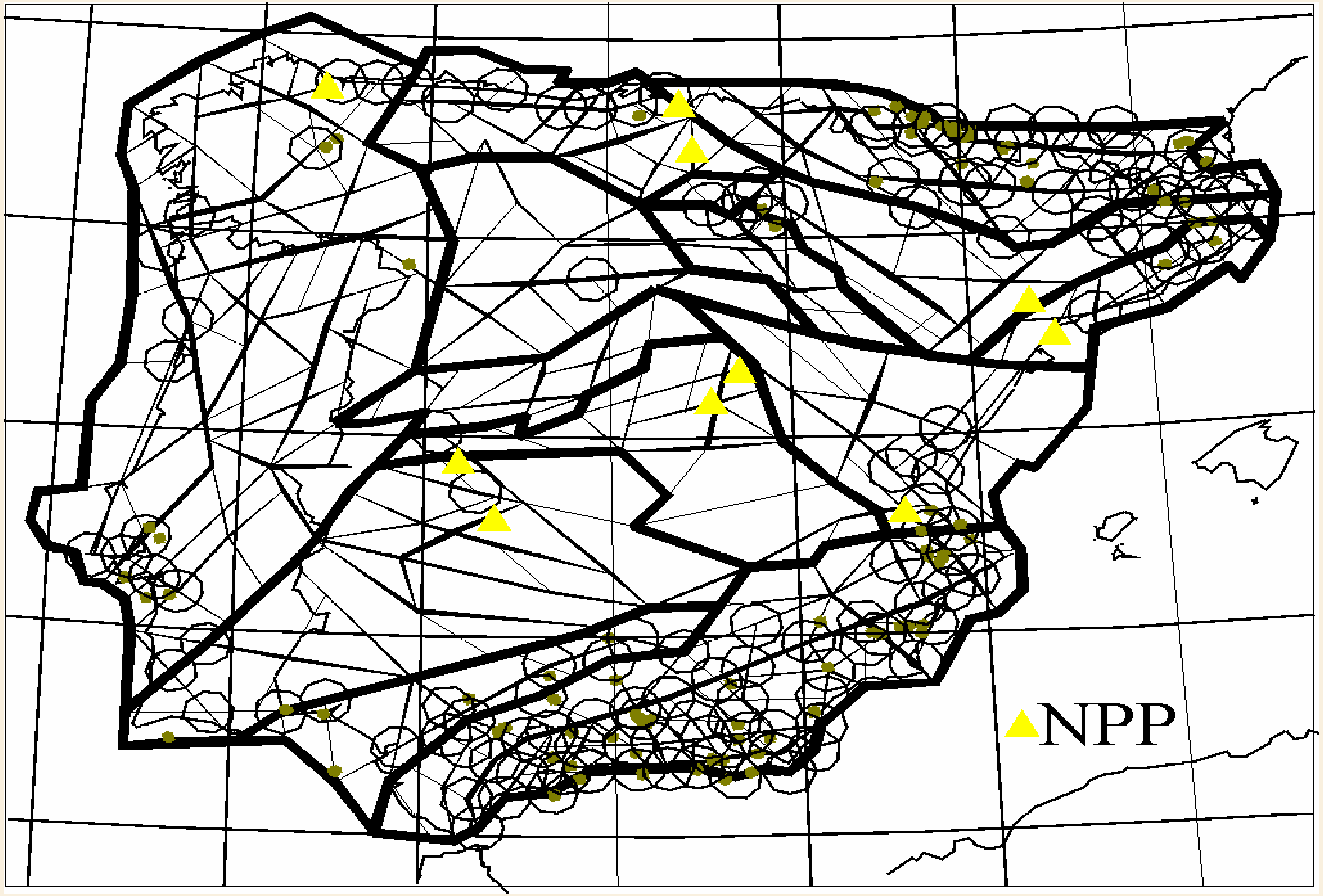




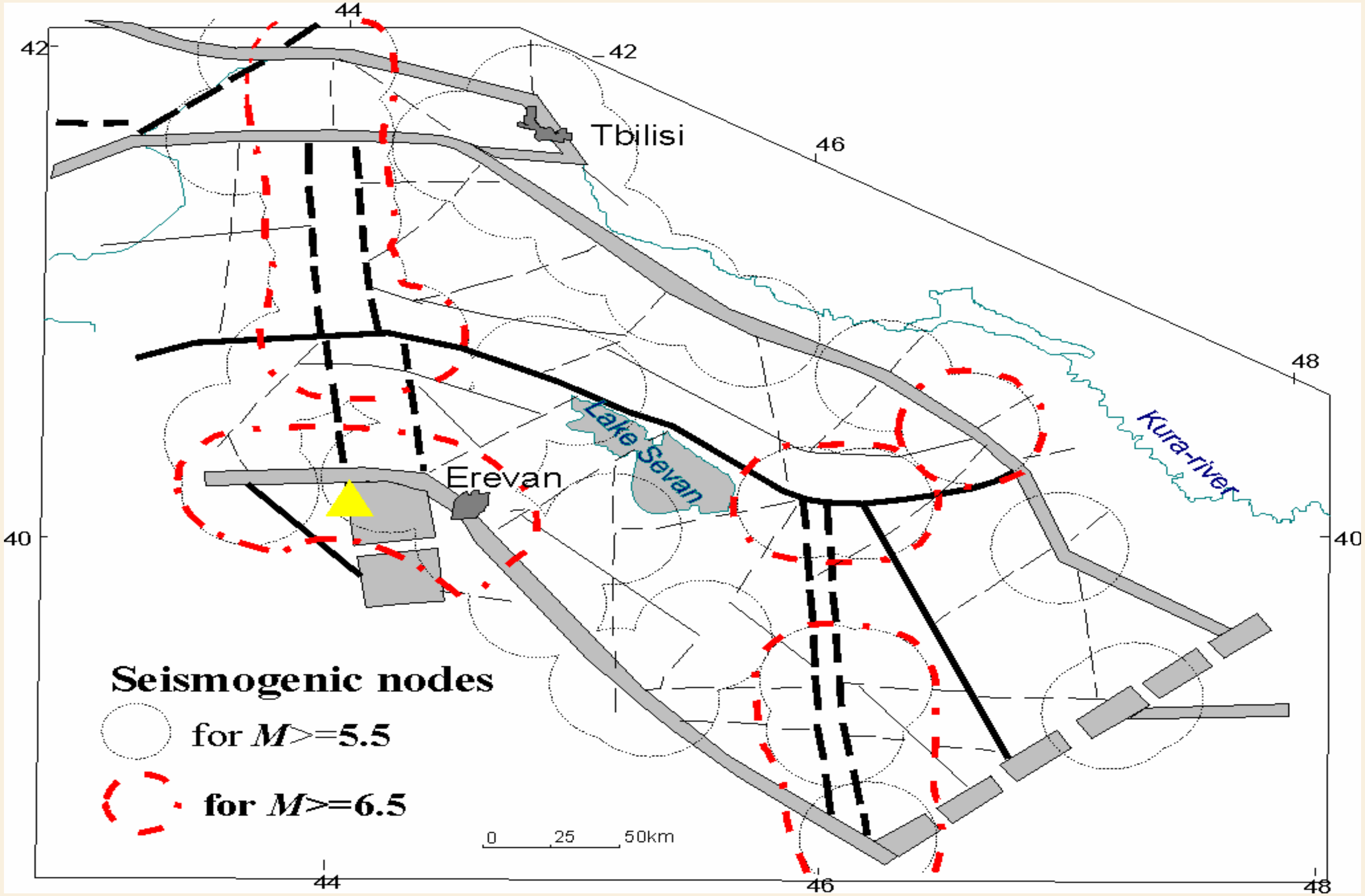
Seismogenic nodes for $M \geq$ 6.0 and NPP in Central Europe



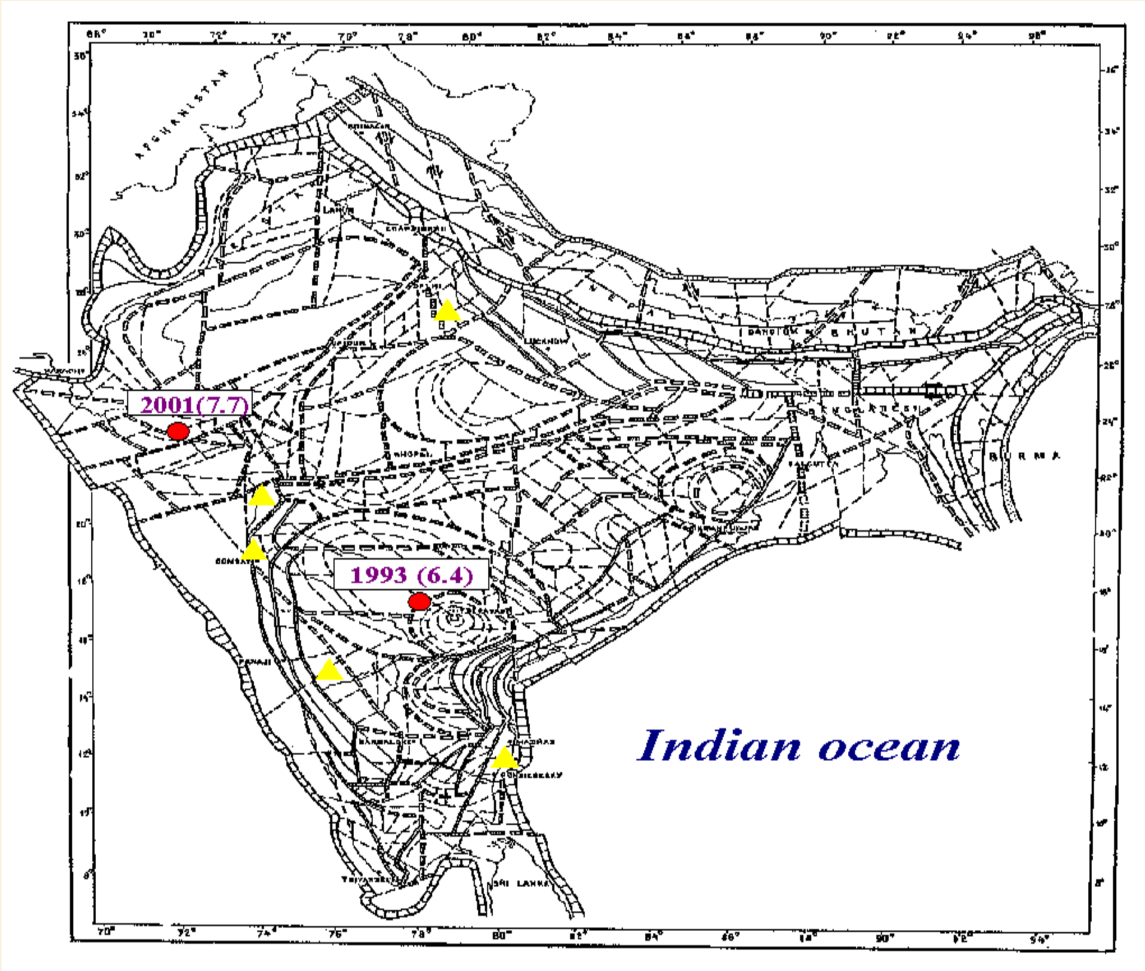
Iberia: seismogenic nodes for *M* ≥ 5.0 and NPP



Armenian NPP and seismogenic nodes for $M \geq 6.5$



Indian Shield: MZ, NPP and strong earthquakes



Lessons Learned and Conclusions

The introduced methodology

- identifies high potential sources, including the “silent” ones;
- provides information for seismic hazard evaluation for high-risk facilities, including NPP;
- reduces spatial uncertainties in the delineation of seismogenic provinces.

Uniformly defined seismogenic nodes within a vast seismic regions contribute to the challenging problem of the uniformity of seismic hazard research.

Summary of the presentation

The presentation introduces the methodology for the identification of seismogenic nodes. The nodes are delineated by the morphostructural zoning (MZ) method and their seismic potential is evaluated by the pattern-recognition method. The methodology has been tested in many seismic regions of the world to identify the nodes of high seismic potential. Recent earthquakes in the previously studied regions have proved the reliability of the results obtained. About 90% of the post-publication events with relevant magnitudes occurred at the mapped nodes and 83% of the post-publication events took place at the nodes recognized as prone to strong earthquakes.

The methodology permits to associate earthquake sources with nodes, local morphostructures of relatively small size (first tens kilometres), while other seismotectonic methods as a rule delineate seismogenic zones of larger size.

Sufficiently accurate localisation of earthquake sources defined with this methodology provides the necessary input for seismic hazard evaluation both for an entire region and for particular objects, *e.g.* for high-risk facilities. It is shown that in some studied regions NPP are situated at recognised seismogenic nodes or in their nearest vicinities.

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Glossary

morphostructural zoning (MZ). The subdivision of a studied region into a system of hierarchically ordered areas characterized by homogeneous present-day topography and tectonic structure. MZ distinguishes *(1) blocks* of different rank; *(2)* their boundary zones, *morphostructural lineaments*; and *(3)* sites where lineaments intersect, *nodes*.

a node. Specific morphostructure formed about the intersections or junctions of two or more lineaments. A node may include more than one intersection or junction.

pattern recognition. Mathematical method used here to classify all the nodes delineated within a region into the seismogenic and non-seismogenic ones with respect to the selected magnitude range.

seismogenic node. A node defined with pattern recognition algorithm as prone to strong earthquakes.