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Seismic Hazard in Asia

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Identification of earthquake prone areas with morphostructural zoning and pattern recognition

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Identification of earthquake prone areas with morphostructural zoning and pattern recognition

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Contents of the presentation

- Methodology:

Stage 1: morphostructural zoning method

Stage 2: pattern recognition of seismogenic nodes

- Worldwide applications and validity of the methodology
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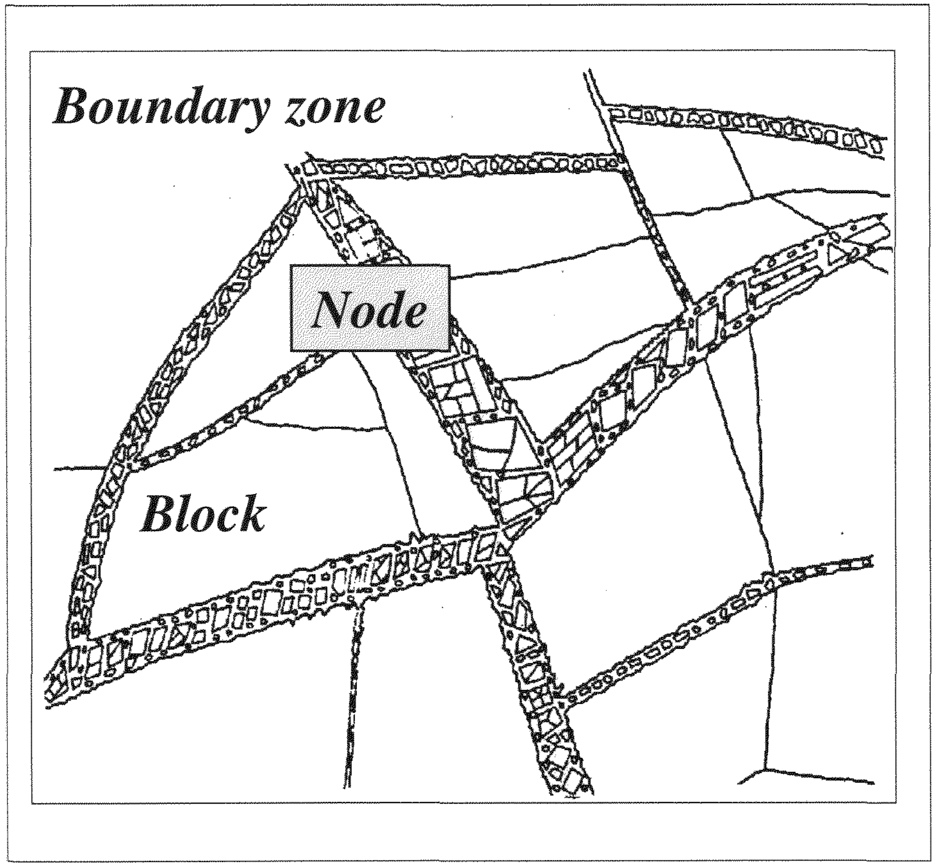
Unraveling Earthquake-Prone Areas

A zero approximation in forecasting large earthquakes is resolving a question of ***where*** such events can occur. The question is highly important for knowledgeable hazard and risk assessment.

Methodology combines geomorphic and mathematical approaches and includes two research *stages*.

Morphostructural zoning is based on the concept that the lithosphere is a complex hierarchical system

The supporting medium of earthquakes is a hierarchical dynamic system of lithospheric blocks and their boundaries. The driving forces arising from thermal and gravitational convection in the mantle of Earth govern movements in this medium that cause seismic activity.



Formation of nodes

The phenomenon was first described by McKenzie and Morgan [1969] for a triple junction. They found a condition under which a single junction "can retain its geometry as the plates move," so that stress will not accumulate. G. King [1983, 1986] suggests that in the general case the ensuing fracturing would not dissolve the stress accumulation but only redistribute it among newly formed corners, thus triggering a chain:

corners of blocks at the fault junction collide □

□ **stress accumulates** □

□ **smaller faults appear and form new intersections** □

□ **corners of the blocks at the new intersections collide**
□ etc.

As a result, a hierarchy of progressively smaller and smaller faults is formed about an initial intersection; this is a node, recognizable by its densely mosaic structure

Stage 1

Delineation of earthquake-controlling structures with the ***morphostructural zoning method***

Compilation of a morphostructural map at the scale of 1: 1,000,000 requires the following data sets:

- **topographic maps**
- **tectonic maps**
- **geological maps**
- **satellite photos**
- **relevant publications**

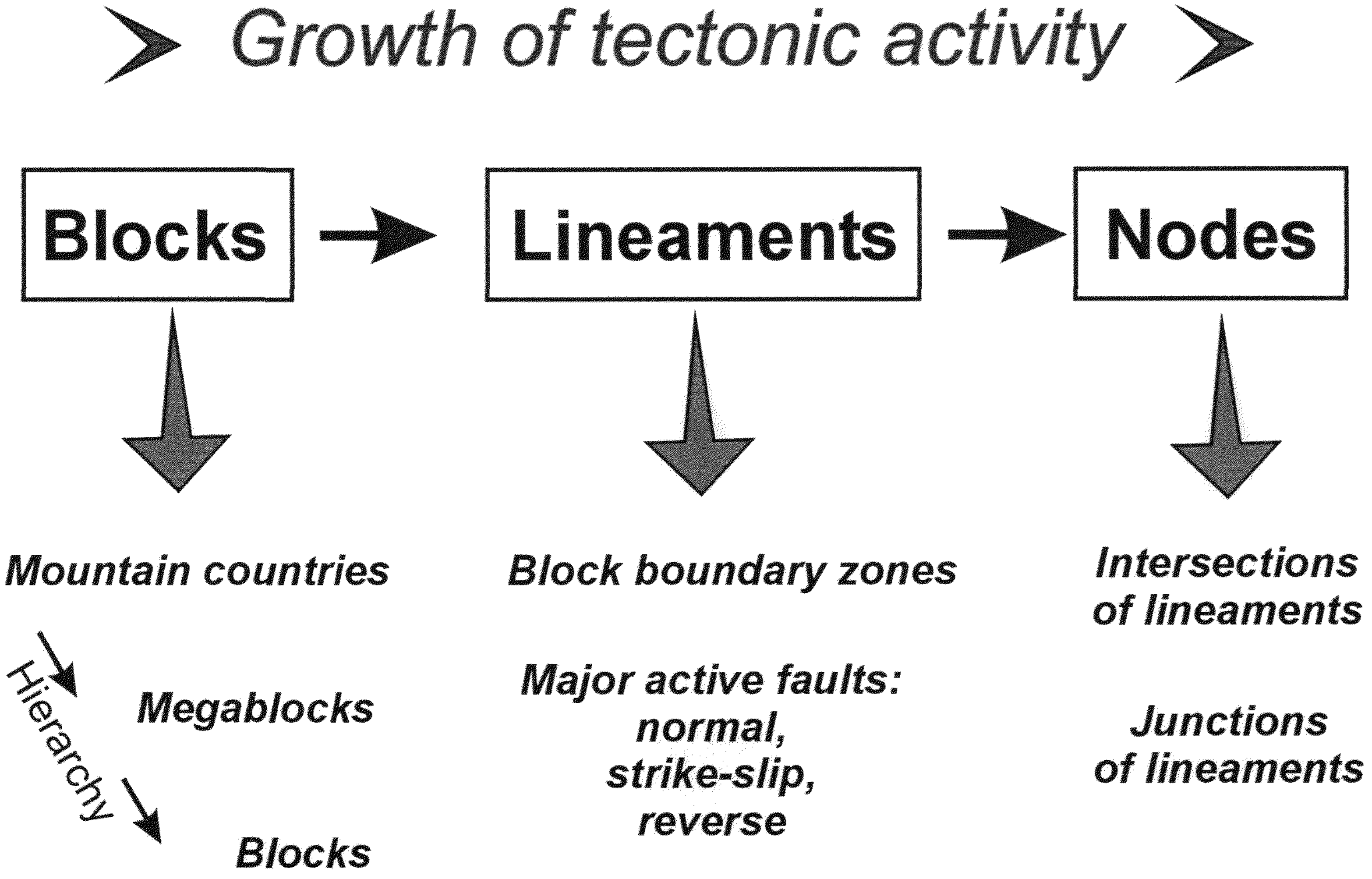
Stage 2

Identification of earthquake-prone areas by ***pattern recognition methods***

Places already marked by large seismic events might have a similar portrayal that can be used to identify sites, which did not yet explicitly show up as earthquake-prone.

No any information on seismicity is used at Stage 1

Stage 1: Morphostructural Zoning



Growth of tectonic activity

Blocks → **Lineaments** → **Nodes**

Mountain countries

Hierarchy

Megablocks

Blocks

Block boundary zones

Major active faults:
normal,
strike-slip,
reverse

Intersections of lineaments

Junctions of lineaments

Blocks

A single **mountain country** is a territory of the same orogenesis and certain appearance of the relief. The same orogenesis can result in territories with a different appearance of relief (physiography). The territories belong to different mountain countries:
(1) if their levels of maximum altitude Hmax differ roughly by 2000 meters;
(2) if their combination of large topographic forms are different;
(3) if the dominating strikes of large topographic forms are nearly perpendicular.

An abrupt change of any of the following quantitative index distinguishes **megablocks**:
(1) gradual increasing altitude of ranges;
(2) gradual decreasing width of near-parallel basins or a chain of basins;
(3) successive changes in orientation of ranges;
(4) concordant changes in the altitude of near-parallel ranges.

A sharp and considerable change of at least one index distinguishes morphostructural **blocks** from each other. Among the index are
(1) the difference in altitude of neighboring summits above one-tenth of the main range's altitude;
(2) the bend of a range or of a footline above 20^0;
(3) the age of rocks belongs to different geologic periods (Pre-Mesozoic, Mesozoic-Eocene, Oligocene-Neogene, and Quaternary).

Lineaments

With respect to the regional trend of the tectonic structure and topography, two types of boundary zones are distinguished: *longitudinal* and *transverse* lineaments.

Longitudinal lineaments are approximately parallel to the regional strike of the tectonic structure and of the topography and, as a rule, include the prominent faults. In general, they are more evident than transverse lineaments.

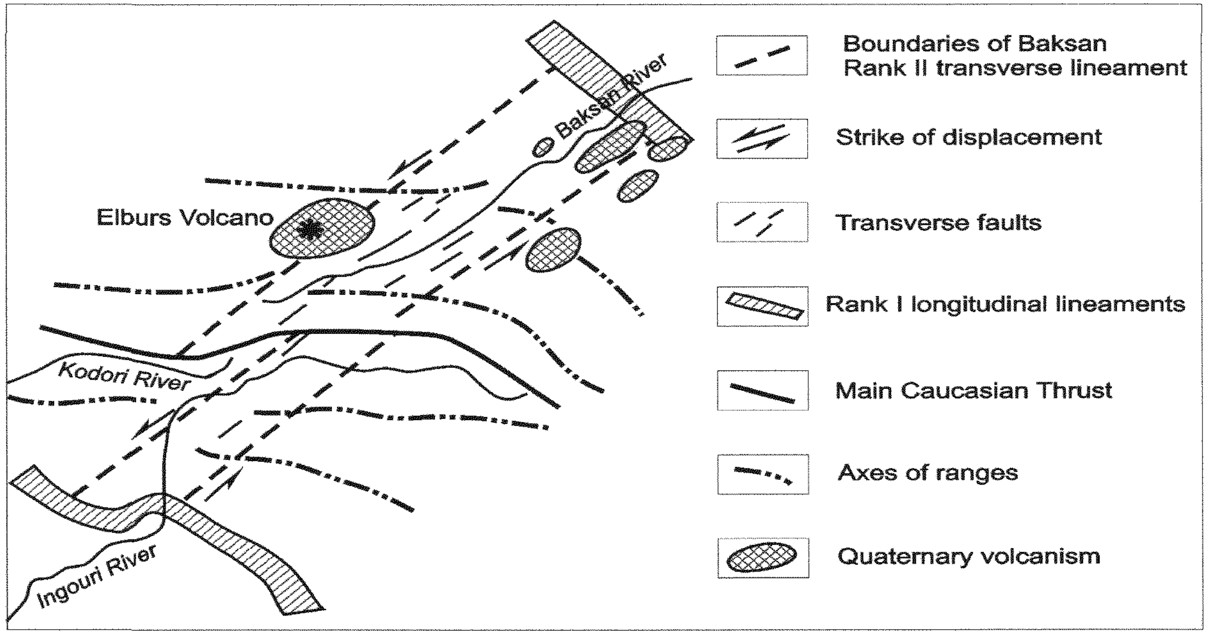
Transverse lineaments go across the regional trend of the tectonic structure and of the topography. Normally, they appear on the Earth's surface discontinuously and are represented by escarpments, by rectilinear parts of river valleys, and partly by faults.

Higher rank lineaments include the wider zone of deep-seated deformation. For instance,in the Caucasus Western Alps first and second rank lineaments associate with considerable changes in the thickness and in the configuration of Moho discontinuity, while third rank lineaments correspond to the escarpments in the crystalline basement.

A real size of the lineament zone can be mapped from fieldwork; according to our experience, the width of the first rank lineaments, for example, varies from 5 – 8 km to 25 – 30 km. Additionally, the width of this complex zone may vary along a given lineament.

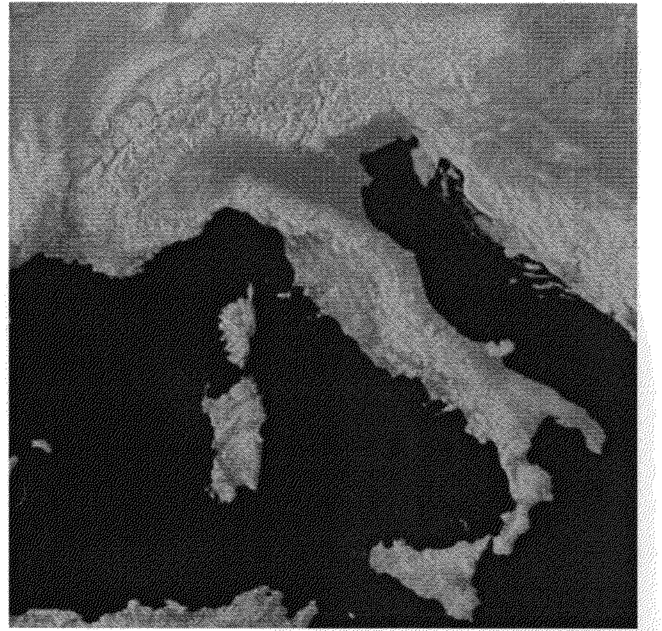
An example of transverse lineament

The Baksan transverse lineament in the Greater Caucasus

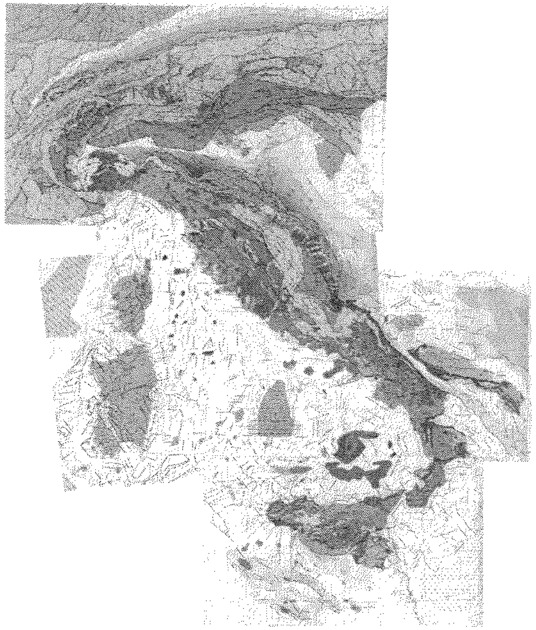


Initial data for morphostructural zoning

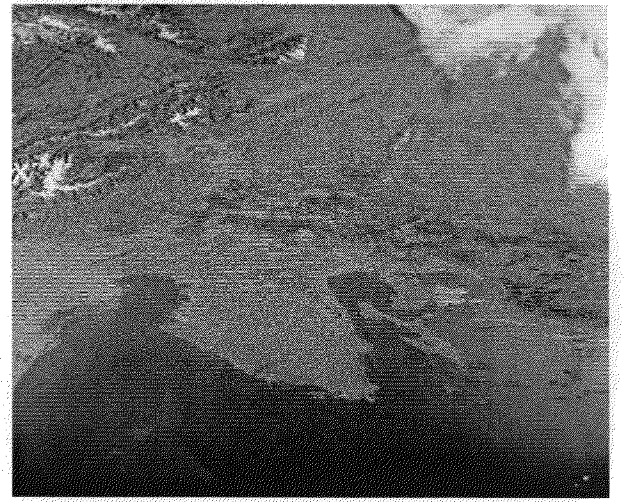
Topography



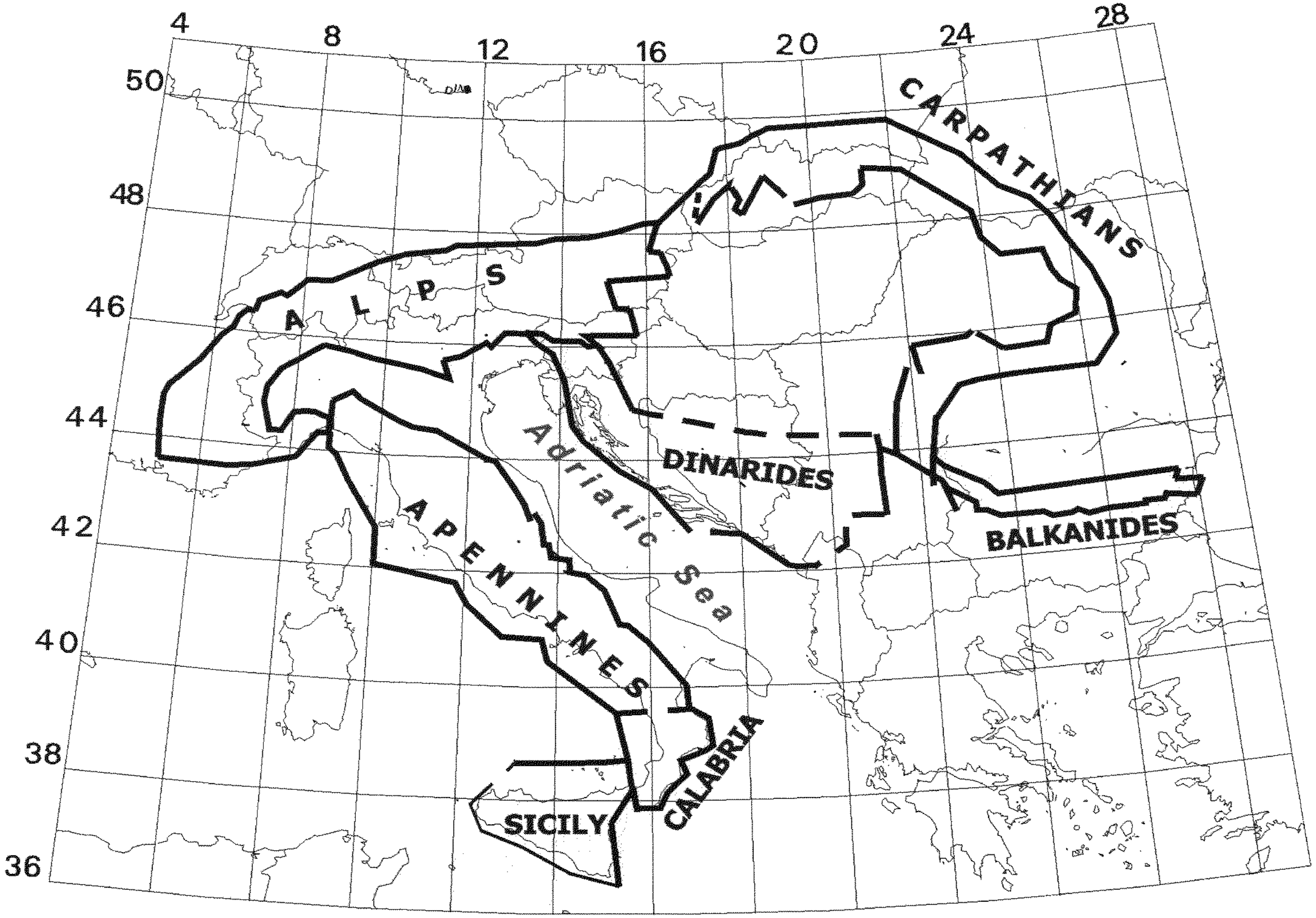
Tectonic structure



Satellite photos

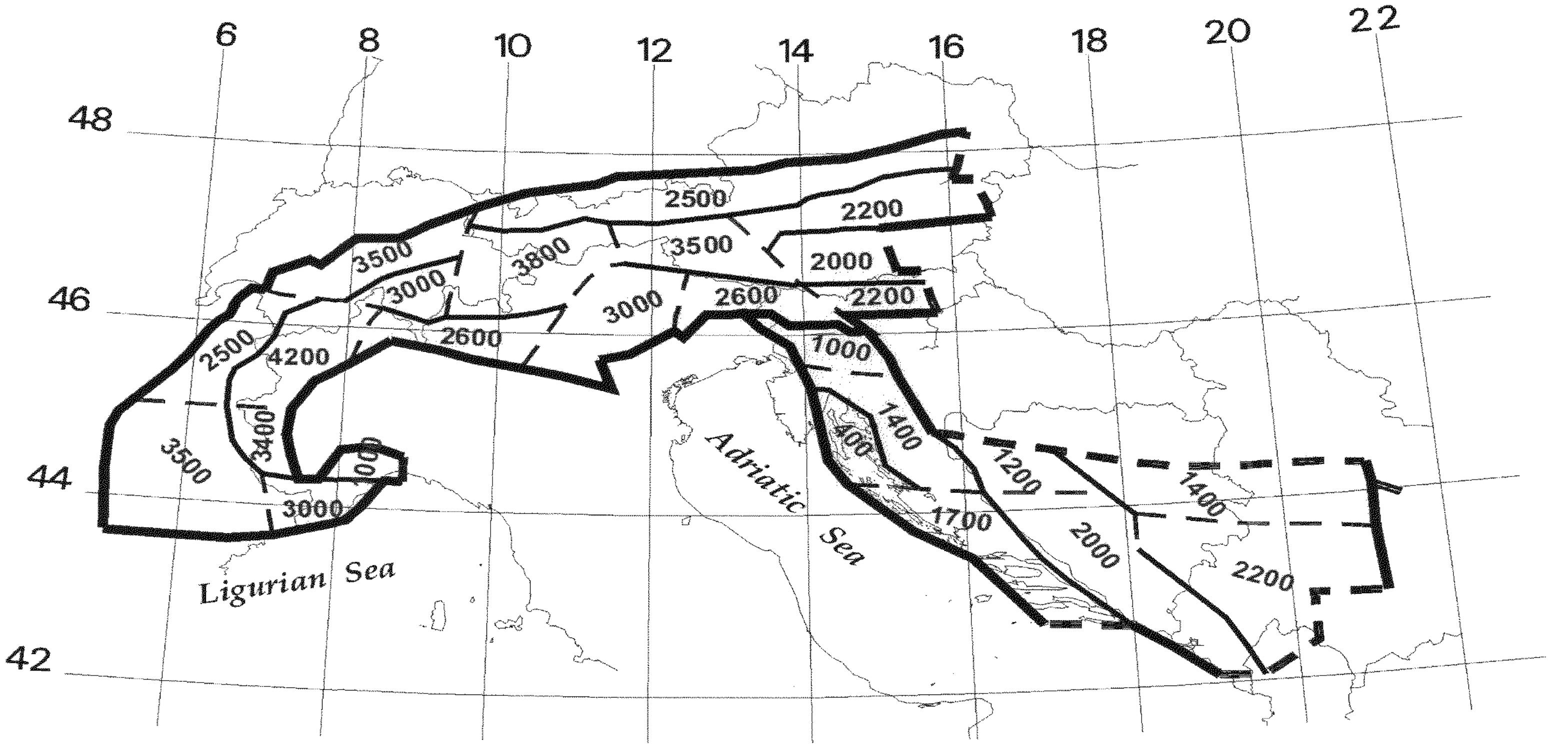


An example of morphostructural zoning:
Mediterranean region



mountain countries and first rank lineaments

An example of morphostructural zoning:
second rank morphostructural units in the Alps and Dinarides



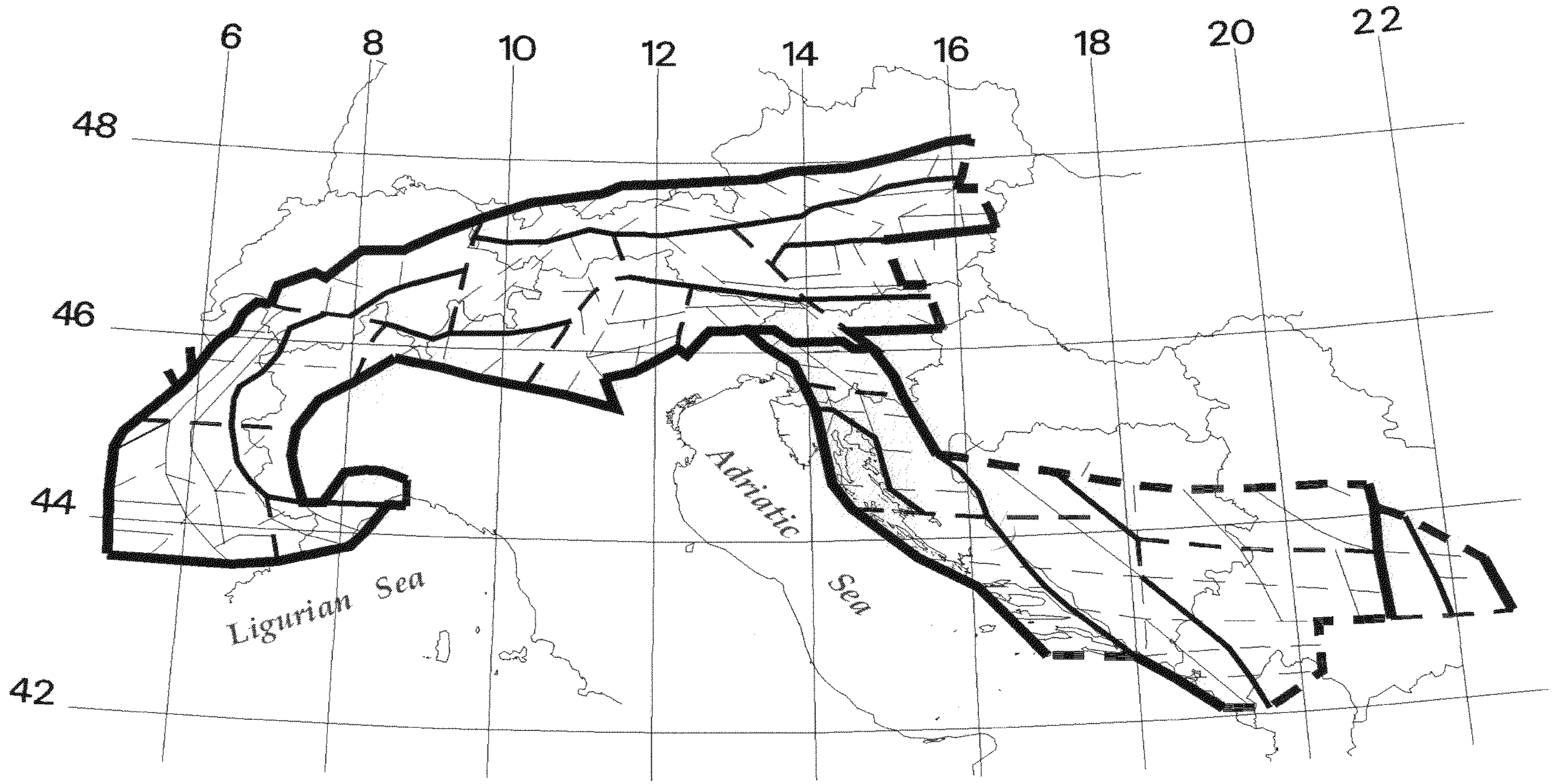
Pink numerals mark mean peak elevation and major strike of topography within each megablock.

Longitudinal lineaments follow the boundaries of large topographic forms; they usually include zones of the prominent faults and, in general, are more evident than transverse lineaments.

Transverse lineaments cross the predominant trend of topography and tectonic structures. Normally, they appear discontinuously on the surface. Zones of transverse lineaments are traced rectilinear segments of river valleys, tectonic scarps, faults, flexures and narrow intrusive bodies, and linear contacts in rocks.

Alps and Dinarides:third rank morphostructural units

blocks and third rank lineaments



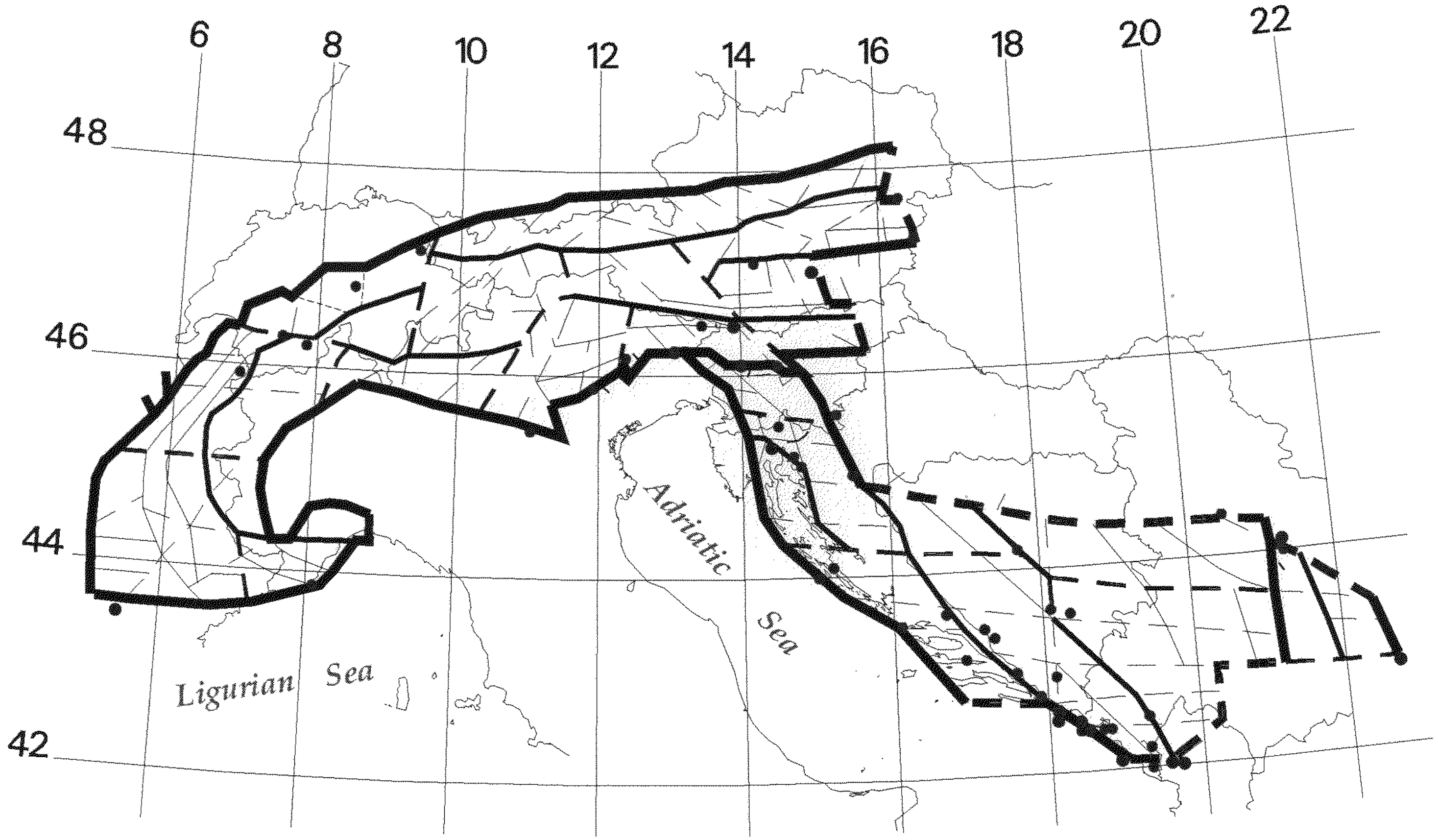
we outline a block if :

✓the difference in altitude of neighboring blocks above one-tenth of the mean peak mountains elevation

✓the bend of a range above 30^0

✓the age of rocks in neighboring areas belongs to different geologic periods (Pre-Mesozoic, Mesozoic- Eocene, Oligocene-Neogene, and Quaternary)

Alps and Dinarides: the correlation of large earthquakes with nodes



Red dots depict epicenters of earthquakes with $M \geq 6.0$

Gorshkov A.I., Panza G.F., Soloviev A.A., Aoudia A. (2004). Identification of seismogenic nodes in the Alps and Dinarides. ***Bollettino della Societa Geologica Italiana*****. Vol.123, 3-18**.

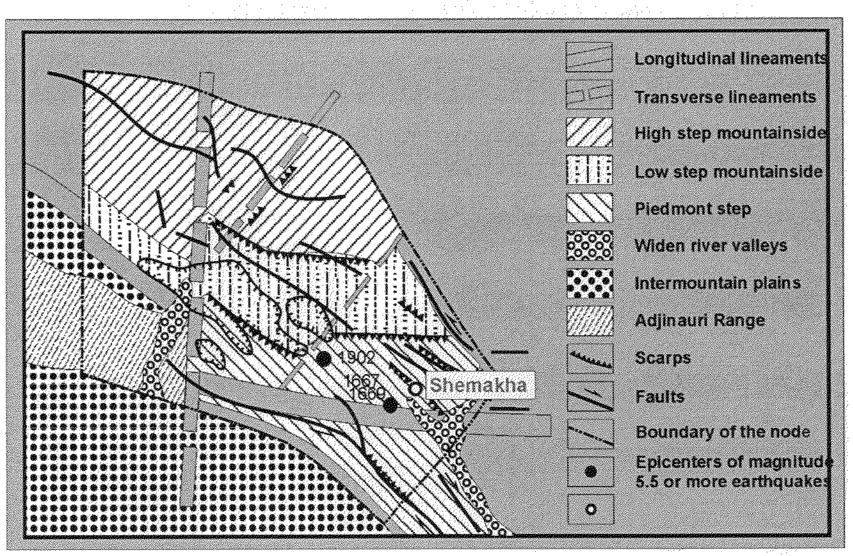
Stage 2. Recognition of earthquake-prone areas

A seismic region is considered. The problem is to determine in the region the areas where strong (with magnitude $M \geq M_0$ where M_0 is a threshold specified) earthquakes are possible. The objects are the selected earthquake-controlling structures (e.g. nodes) defined in the region. The possibility for a strong earthquake to occur near the object is the feature under consideration. The problem as the pattern recognition one is to divide the selected structures into two classes:

- structures where earthquakes with $M \geq M_0$ may occur;
- structures where only earthquakes with $M < M_0$ may occur

Objects of recognition

The Shemakha node in the Greater Caucasus



The size of the node can be defined during field investigations. If no field work have been carried we define the node as a circle of 25 km of radius, centered at the point of intersection of the lineaments. Using this formal node definition, each point of lineament intersection is a node but, in reality, two or three closely situated intersections may belong to the same node. Such node dimensions are in agreement with the size of earthquake source for the magnitude range 6.0 – 6.5. According to Riznichenko (1976) and Wells & Coppersmith (1994), the source size of an earthquake with *M*=6.0 is about 20 km in length and about 10 km in width.

The CORA-3 algorithm

The algorithm CORA-3 is logical algorithm of recognition. As a rule logical algorithms are applied to vectors with binary components. The detailed description of this algorithm can be found in *Gelfand et al.* (1976).

Therefore, if the set of recognition objects initially consists of vectors with real components (functions) then prior to an algorithm application, the coding of objects in the form of vectors with binary components has to be carried out. For this purpose, the parameters of recognition oblects are discretized, i.e. ranges of their values are represented as the union of disjoint parts. Then each of these parts is given accordingly by the value of a component of a binary vector or by the combination of values of its several components.

Stage 2. Recognition of nodes prone to large earthquakes with the CORA-3 algorithm

Recognition steps:

- **parametrization of the nodes**
- **selecting sample nodes to form the training set**

  sample nodes form a training sets of nodes that belong to *a priori* known classes:

  - the training set $\mathbf{D_0}$ includes the nodes most closely situated to the recorded events with $M \geq 6.0$
  - the training set $\mathbf{N_0}$ includes the nodes that are most distant from the recorded epicenters
  - the set $\mathbf{X}$ consists of the nodes hosting earthquakes with $M = 5.0 \div 5.9$
- **learning stage**

  selection of the *distinctive features* of each class on the basis of the training set composed by $\mathbf{D_0}$ and $\mathbf{N_0}$
- **classification stage**

  determination of which class each node belongs to.
- **evaluation of the reliability of classification from control tests**

Input for the pattern recognition algorithm CORA-3: *parameters of the nodes*

- ***Topographic parameters***

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

- ***Geological parameters***

The portion of soft (quaternary) sediments,

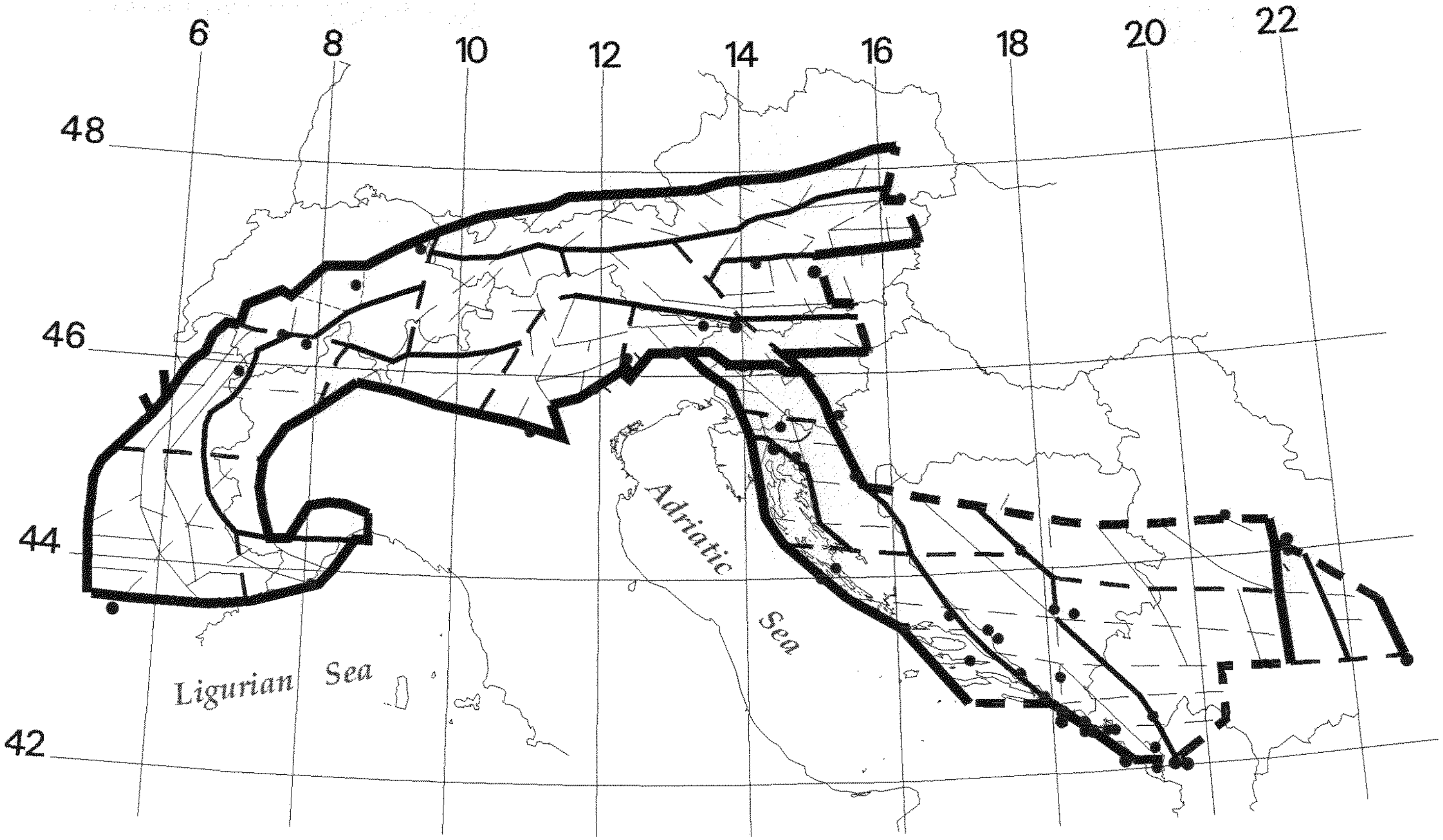
Parameters of lineament-and-block geometry ?

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 parameters 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

Earthquakes with $M \geq 6.0$ used to select D_0



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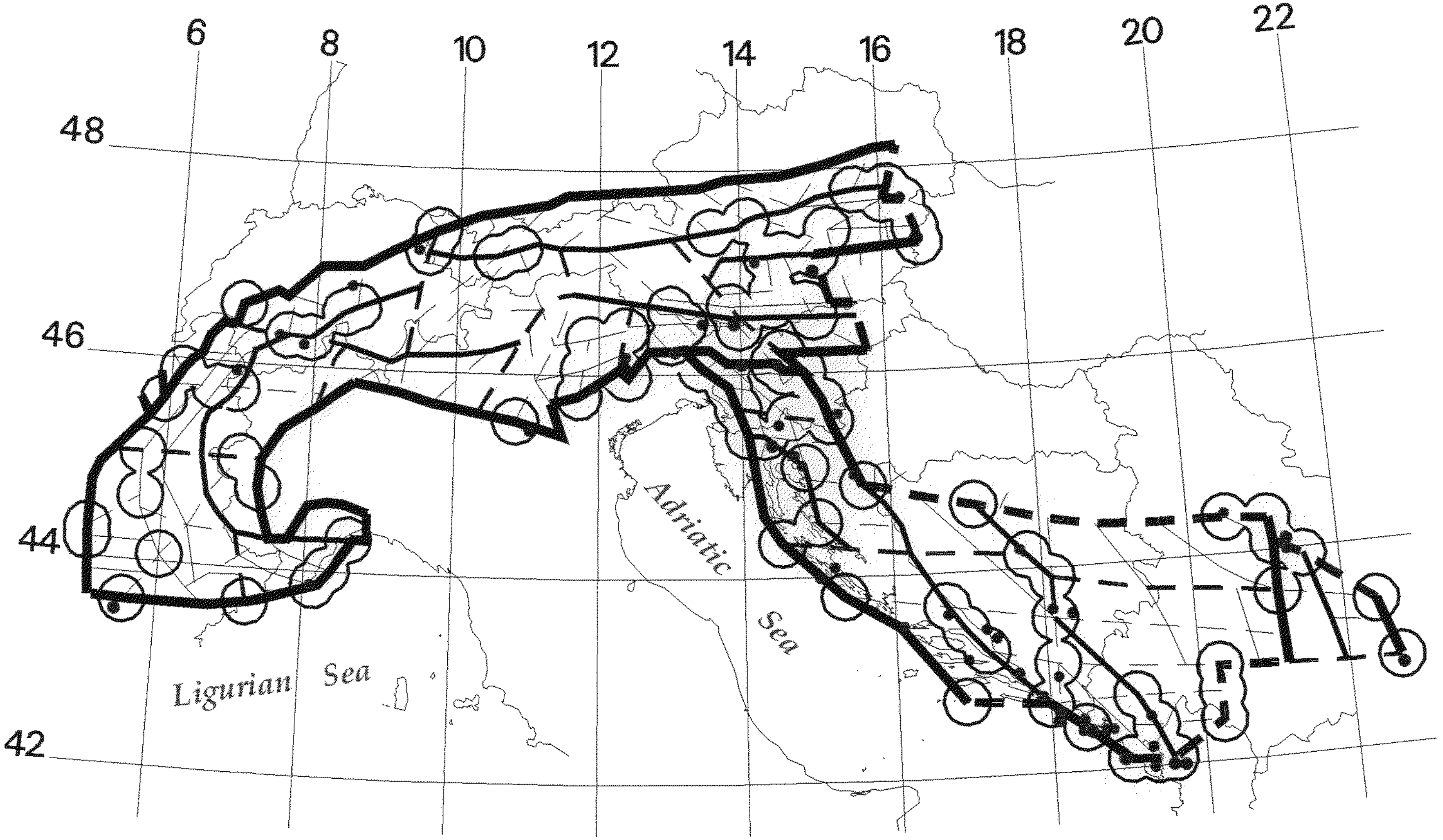
Distinctive features discriminating D and N nodes in the Dinarides

#	**Parameters**				
	Hmax, m	**NL**	**L, km**	**Dn, km**	**Q, %**
Characteristic traits of class D					
1			> 34		> 20
2	> 1479		> 26		> 20
3		> 2	> 34	≤ 34	
4	> 1795		> 34	≤ 34	
5	> 1479	> 2	> 34		
6	≤ 1795	> 2	≤ 26		
Characteristic traits of class N					
1		2		> 25	≤ 20
2		2	≤ 34		≤ 20
3	≤ 1795	2			≤ 20
4	≤ 1795		≤ 34	> 34	
5		2	≤ 34	> 25	

Alps and Dinarides: recognized seismogenic nodes prone to earthquakes with $M \geq 6.0$



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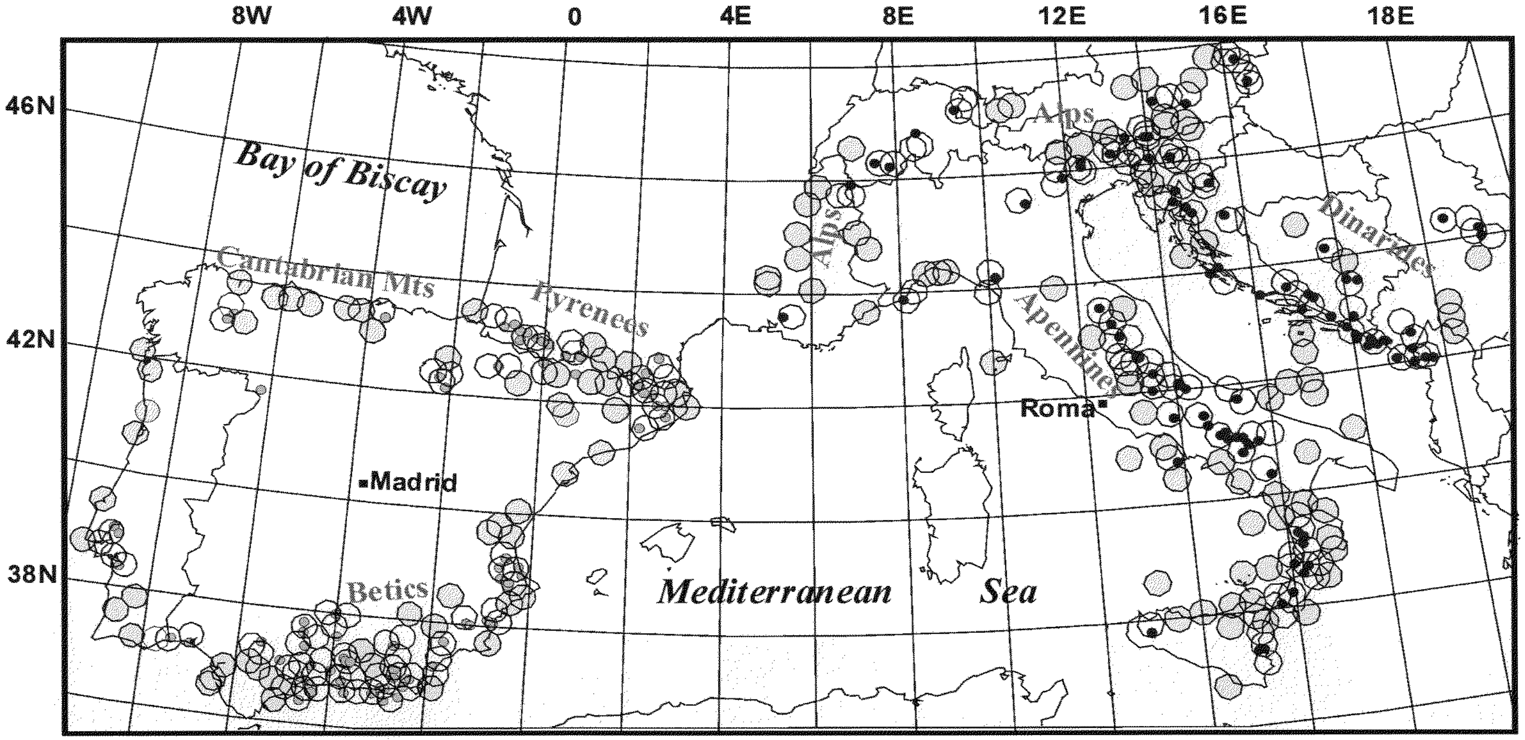
Unraveling earthquake-prone areas in the Mediterranean

Target magnitudes:
M >= 6.0 - Alps, Apennines and Dinarides
M >= 5.0 - Iberia

circles show the nodes
dots mark target earthquakes
yellow marks the nodes where such earthquakes are still unknown



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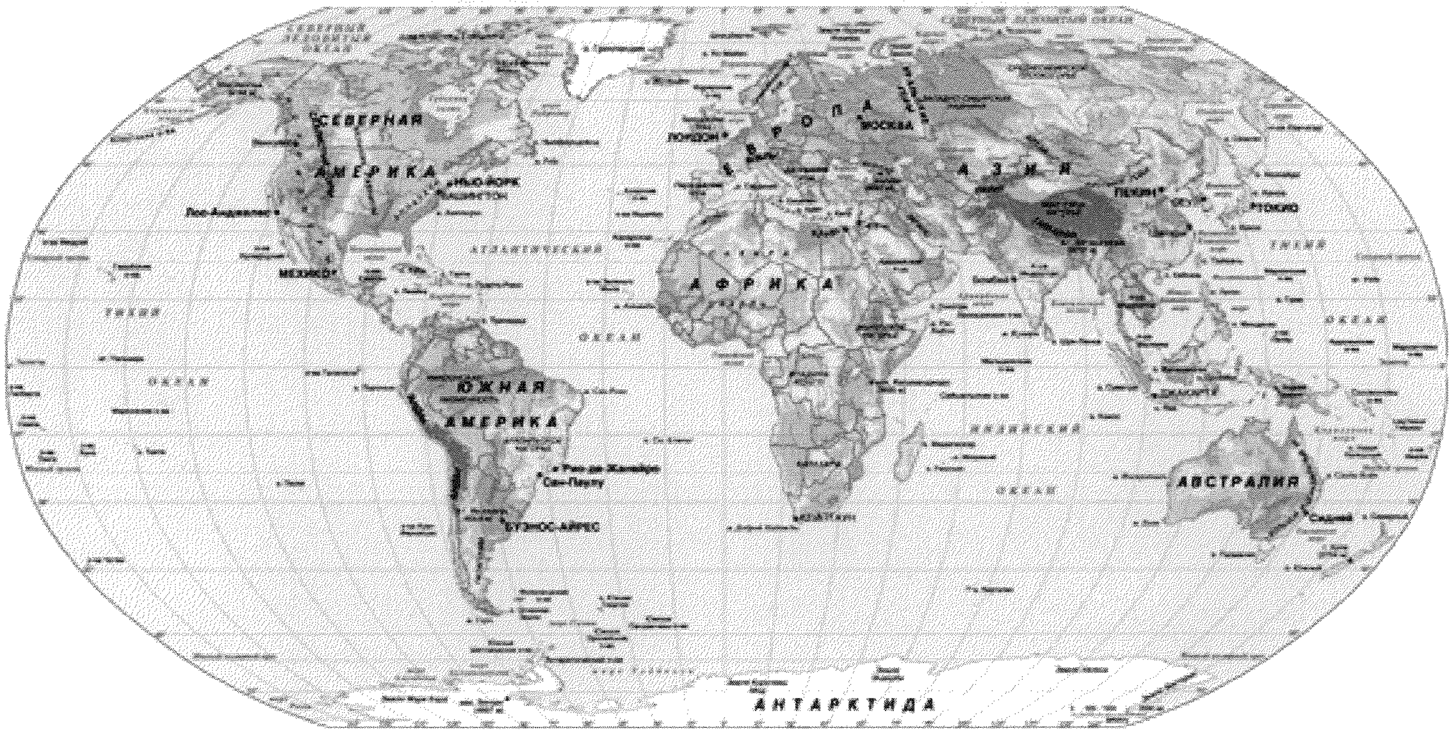
Worldwide applications and validity of the methodology

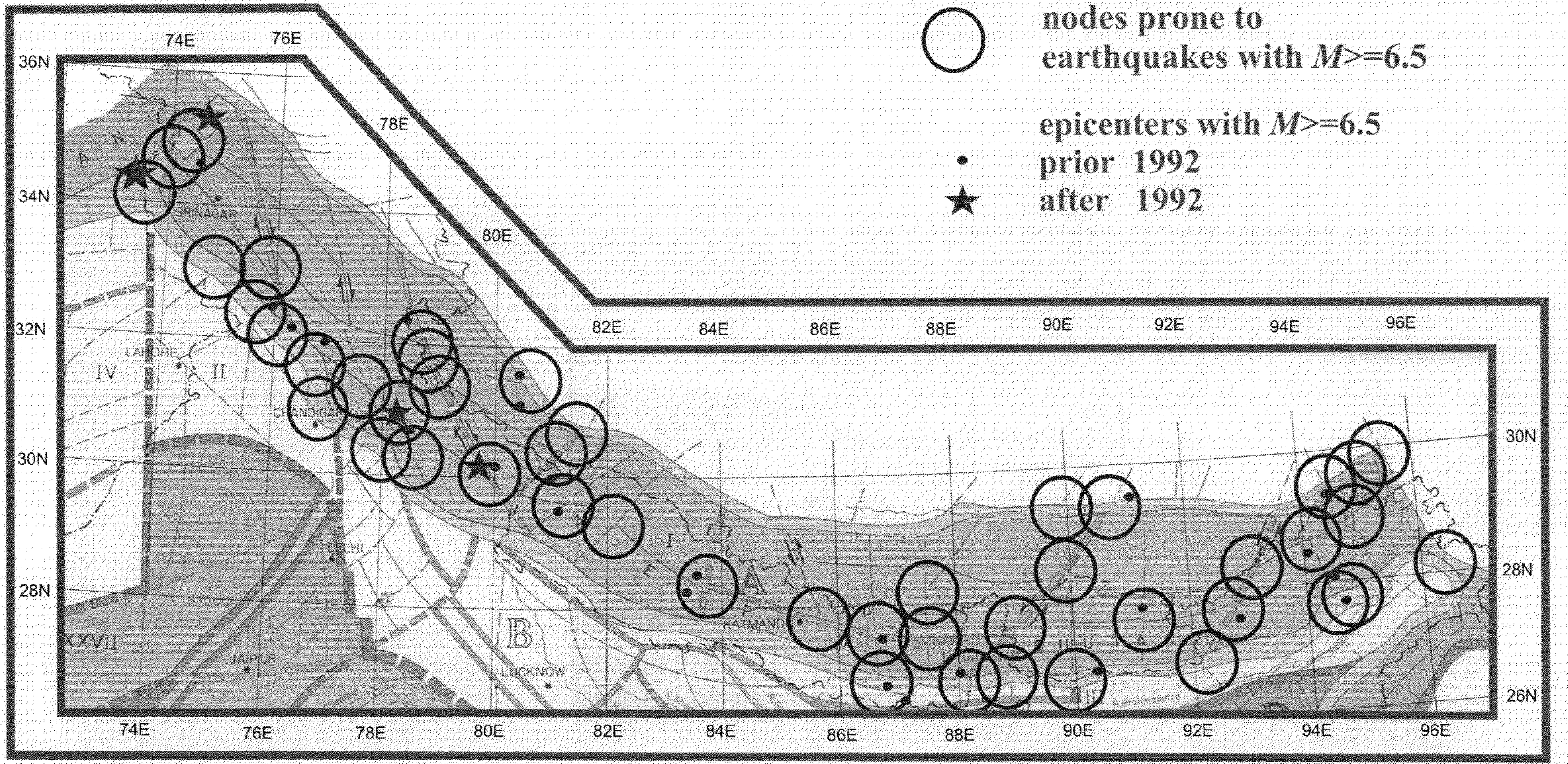
Worldwide applications



Pamirs and Tien Shan (1972) Balkans – Asia Minor (1794) California and Nevada (1976)
Italy (1980) South America Andes (1984) Western Alps (1985)
Greater Caucasus (1986) Kamchatka (1986) Pyrenees (1987)
Lesser Caucasus (1991) Himalaya (1992) Indian Peninsula (1996)
Carpathians (2000) Kopet Dagh (2002) Peninsular Italy and Sicily (2002)
Alps and Dinarides (2004) Iberian Peninsula (2005) Alborz (2006)

Recognition of earthquake-prone areas in the Himalaya (1992)

Bhatia S.C., Chetty T.R.K., Filimonov M., Gorshkov A., Rantsman E., Rao M.N. (1992)
Identification of potential areas for the occurrence of strong earthquakes
in Himalayan arc region. Proc.Indian Acad.Sci. (Earth Planet.Sci), 101, n4, 369-385



○ **nodes prone to earthquakes with $M>=6.5$**

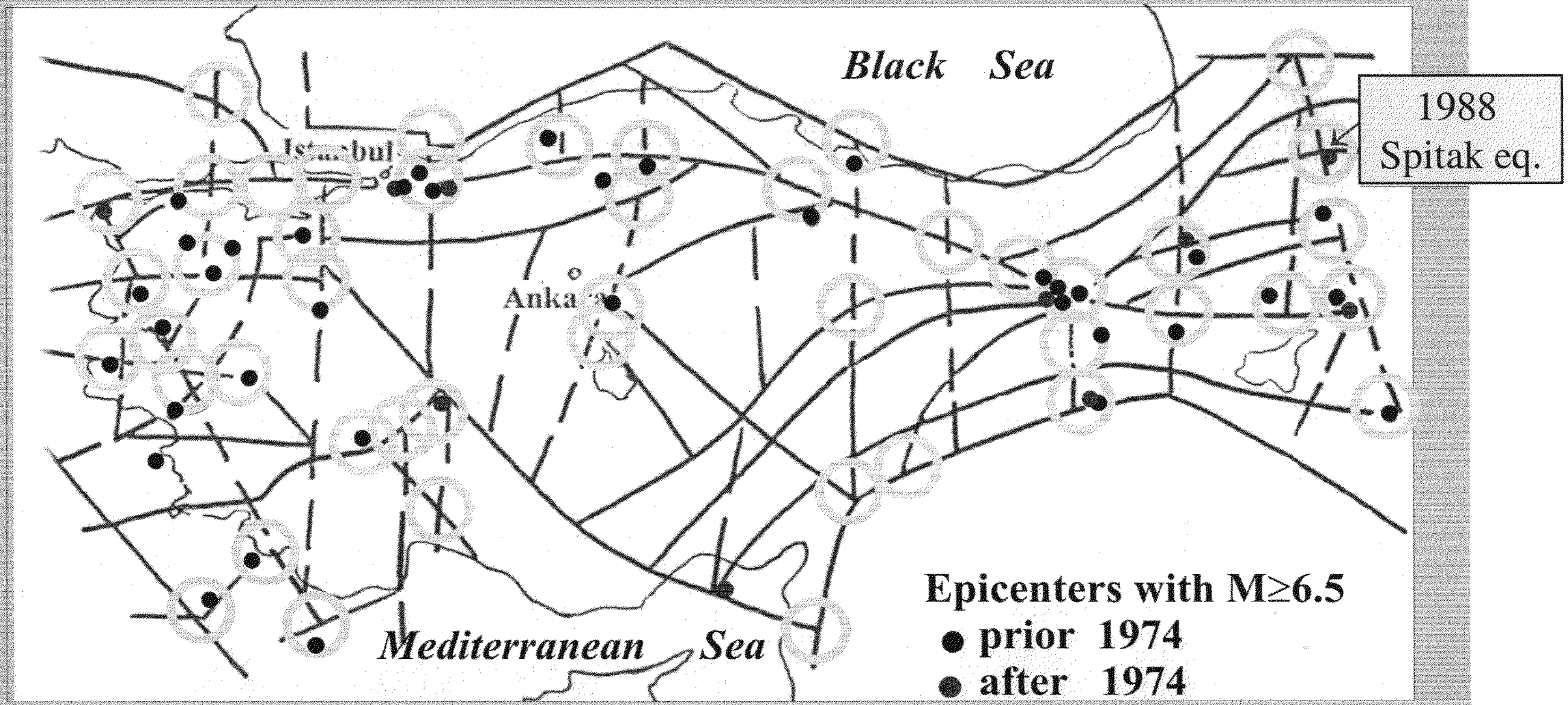
epicenters with $M>=6.5$
- • **prior 1992**
- ★ **after 1992**

Post-publication earthquakes

Asia Minor (1972)

Nodes prone to earthquakes with $M \geq 6.5$

Gelfand I., Guberman Sh., Izvekova M., Keilis-Borok V., Rantsman E. 1972.
Criteria of high seismicity determined by pattern recognition. *Tectonophysics*, 13 415-422

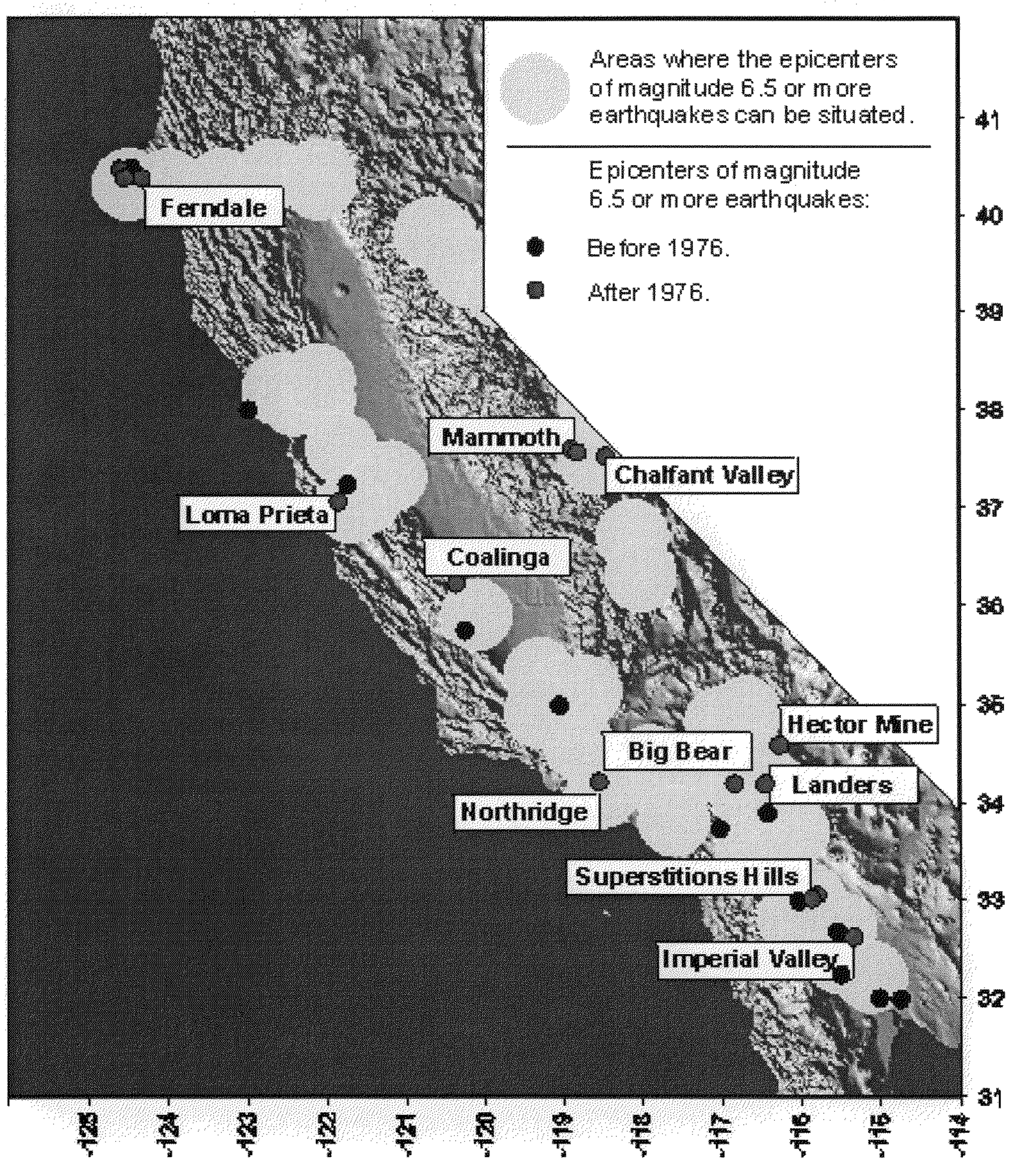


1988 Spitak eq.

Epicenters with M≥6.5
- ● prior 1974
- ● after 1974

Yellow circles show the nodes recognized prone to M ≥ 6.5
Dots mark target earthquakes

Post-publication earthquakes California



The 73 intersections of morphostructural lineaments in California and Nevada determined by *Gelfand et al.* (1976) as earthquake-prone for magnitude 6.5+ events.

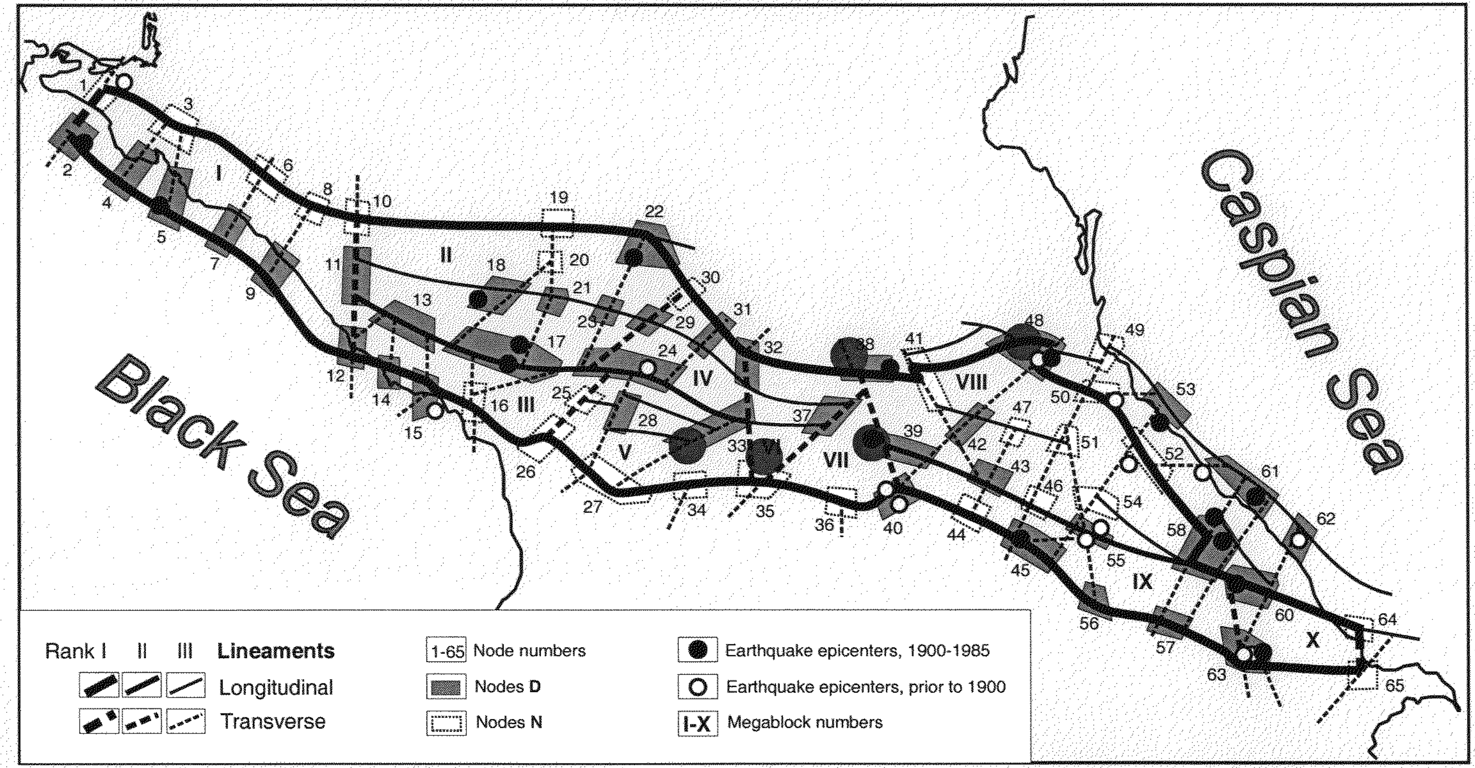
Since 1976 fourteen magnitude 6.5+ earthquakes occurred, all in a narrow vicinity of the D-intersections

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

Post-publication earthquakes

Greater Caucasus(1987)

Nodes prone to earthquakes with M>=5.5



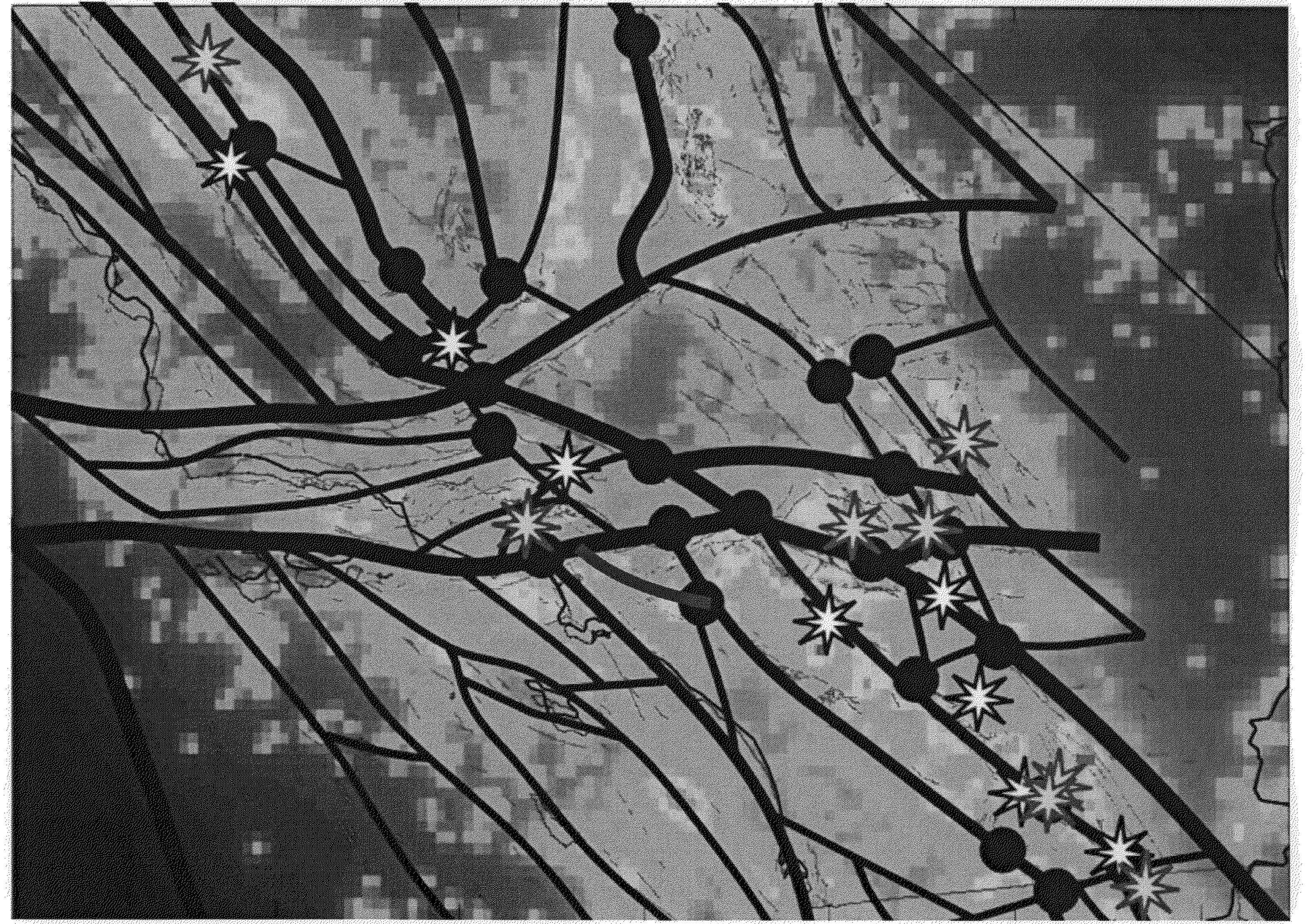
● Earthquakes with M>=5.5 after 1987

Methodology Validity

- **81** post-publication strong earthquakes took place in the studied regions.
- **77** post-publication strong earthquakes did occur at mapped nodes. This fact confirms the initial hypothesis of nucleating strong earthquakes within nodes.
- **71** events occurred at **D** nodes;

  21 of **71** events took place at the unraveling nodes**,** *i.e.* at nodes where no large earthquakes had been reported prior to pattern recognition.
- **6** events occurred at **N** nodes;
- **4** events are not associated with the mapped nodes.

At least one of the newly discovered faults, i.e., the Puente Hills thrust fault **(Shaw, J.H., and Shearer, P.M. 1999, An elusive blind-thrust fault beneath metropolitan Los Angeles. *Science*,** 238, **1516-1518),** coincides exactly with the lineament drawn in 1976.



Conclusions

The methodology enables to recognize still unknown areas, where epicenters of large earthquakes may be situated. These are densely fragmented structures, nodes, formed about fault intersections. Maps of such areas have been published since the early 1970s for numerous regions of the world. Subsequent seismic history confirmed these maps: 71 out of 81 post-publication earthquakes occurred within predicted areas; in 21 of these areas, such earthquakes had been previously unknown.

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 the methodology provides a necessary input for seismic hazard evaluation both for an entire region and for specific objects including high-risk facilities. In some studied the recognised seismogenic nodes expose high seismic hazard to NPPs.

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

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Bhatia S.C., Chetty T.R.K., Filimonov M., Gorshkov A., Rantsman E., and Rao M.N. Identification of potential areas for the occurrence of strong earthquakes in Himalayan arc region. Proc.Indian Acad. Sci. (Earth Planet Sci.), 1992. 101 (4), 369-385.

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Thank you very much