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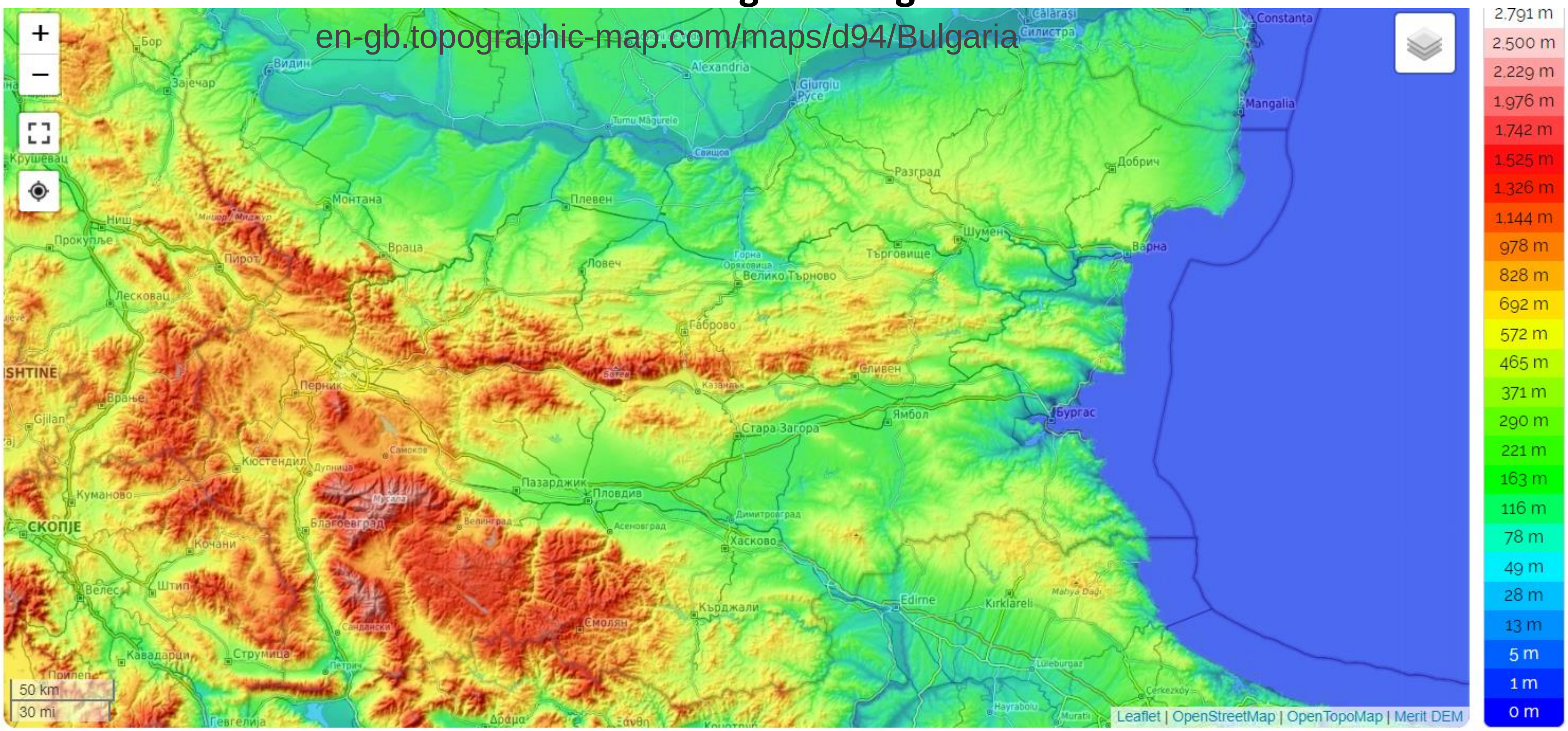
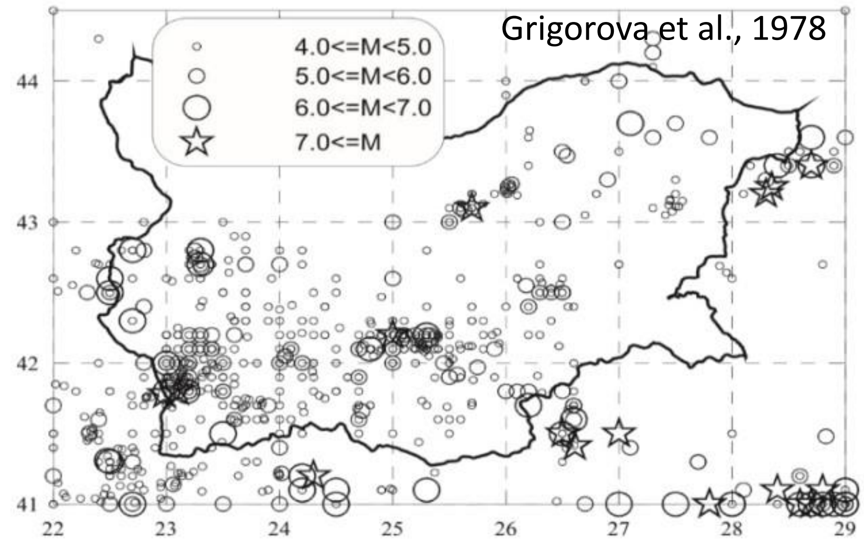
Seismogenic nodes in the Bulgarian territory, defined by pattern recognition

The Bulgarian region over the centuries has been exposed to a high seismic danger (Grigorova et al., 1978; Solakov et al., 2020). An accurate definition of earthquake sources plays the main role in the development of seismic hazard assessment regardless of the applied methodology, either probabilistic or deterministic.

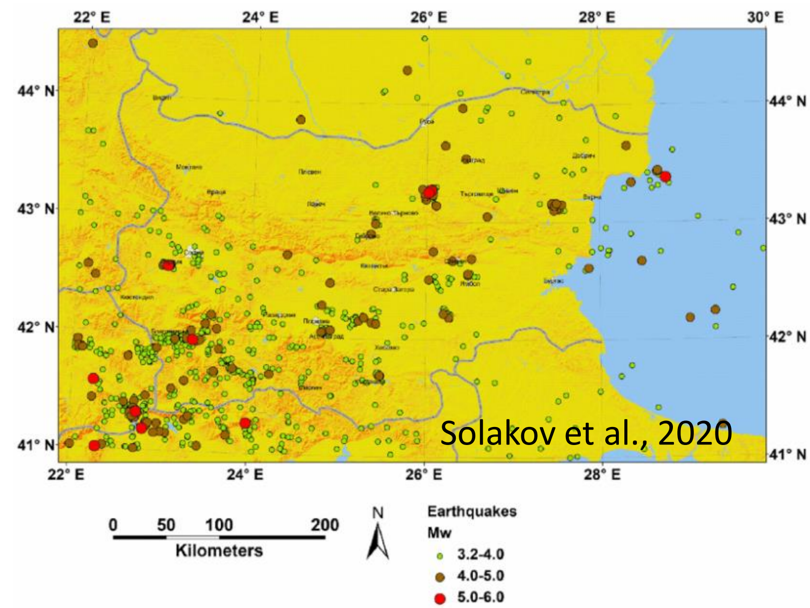
The goal of this work is to identify the potential locations of earthquakes M6+ in the Bulgarian region.



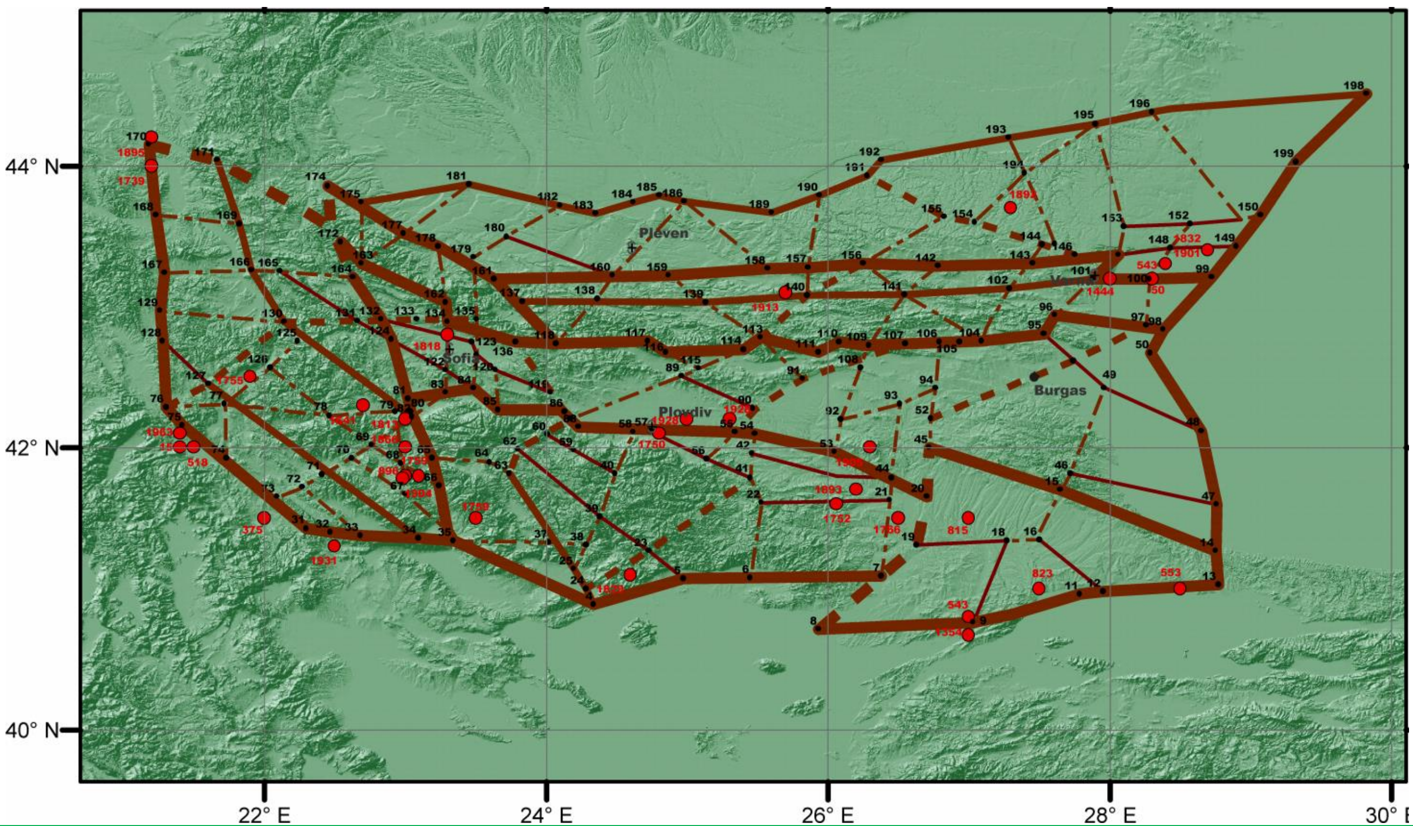
The **methodology** is based on the hypothesis about the nucleation of the epicenters of strong earthquakes at **morphostructural nodes**, which are formed at the intersection of morphostructural lineaments bounding morphologically homogeneous blocks of the earth's crust (Gelfand et al., 1972, Rantsman, 1979; Gorshkov et al., 2003). Seismogenic nodes are defined by the **pattern recognition**.



Long-term studies of seismically active regions of the world have shown a sufficiently high reliability of the methodology for identifying **seismogenic nodes**. Estimations of the validity of the worldwide recognition results of earthquake-prone areas demonstrate that **86% of post-publication earthquakes** fall in the recognized seismogenic nodes (Soloviev et al., 2014; Gorshkov and Novikova, 2018).

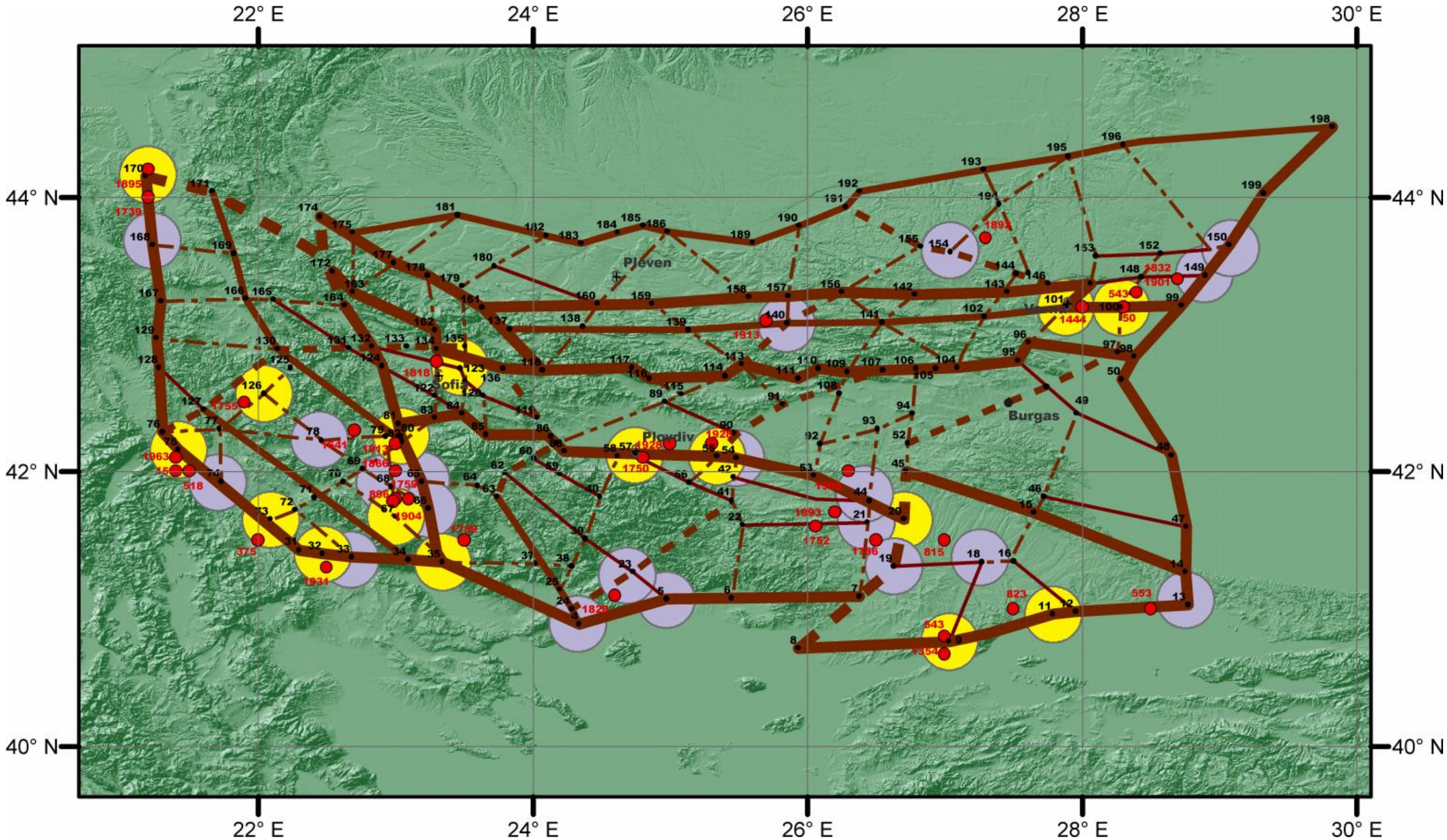


Two principal steps compose the methodology. The first step is the delineation of the objects of the analysis – the morphostructural nodes – by **morphostructural zonation** method. The MSZ map was compiled on the basis of joint analysis of **topographic, tectonic, geological maps, and satellite photos**. The map shows the hierarchical block-structure, the network of the lineaments bounding blocks, and the loci of nodes forming at sites where lineaments intersect.



Thick lines are the **lineaments** of the first rank, medium lines are the lineaments of the second rank, thin lines are the lineaments of the third rank; continuous lines note longitudinal lineaments, dashed ones - transverse lineaments. Red dots are epicenters of earth-quakes with M ≥ 6.0.

30 earthquakes M6 + are documented In the study region for the period from the 1st century to present (Grigorova et al., 1978; Solakov et al., 2020).



16 nodes (yellow circles) – associated with recent instrumentally recorded earthquakes;

142 nodes (non-circled nodes) – no seismicity in the 25-km-radius;

20 nodes (violet circles) – associated with historical seismicity.

The second is the 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.

Parameters of nodes, defined in radius of 25 km around the intersection point:

Group I

1. Maximum altitude , Hmax
2. Minimum altitude, Hmin
3. Minimum distance between the points with Hmax - Hmin.
4. Relief contrast, ΔH= Hmax - Hmin .
5. Measure of slope, ΔH/l.
6. Large topographic forms combination:
   - a) Mauntain (m)
   - b) Mountain range separated by a longitudinal valley and mountain (m/m)
   - c) Mountain range and a piedmont plain (m/p)
   - d) Mountain range and piedmont hills (m/pd)
   - e) Mountain range, piedmont hills, and a piedmont plain (m/pd/p)
   - f) Piedmont plains (p)
   - g) Piedmont hills and a p. plain (pd/p)
7. The percentage of Quaternary deposits, Q.

Group II

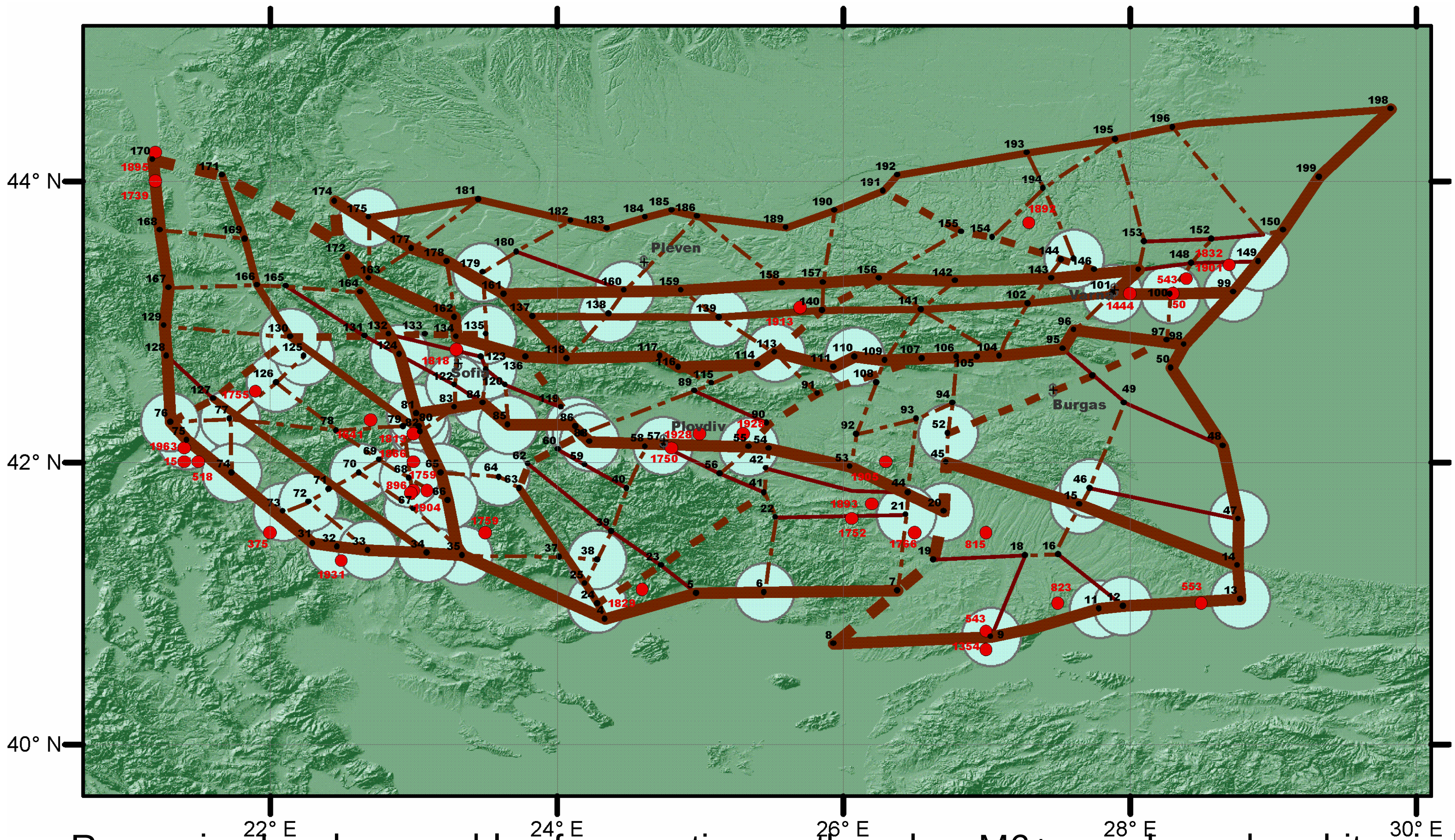
8. The highest rank of lineament in the node, RL
9. The number of lineaments in the node, nL
10. The distance from the node to the nearest intersection, rint
11. The distance from the node to the nearest I rank lineament, r1.
12. The distance from the node to the nearest II rank lineament, r2.
13. The number of faults in the node, NF.

Group III

14. Maximum Bouguer anomaly, Bmax. .
15. Minimum Bouguer anomaly, Bmin
16. Gravity "relief energy", ΔB= Bmax – Bmin
17. Maximum geomagnetic anomaly, MAmax. .
18. Minimum geomagnetic anomaly, MAmin
19. Geomagnetic "relief energy", ΔB= Bmax - Bmin

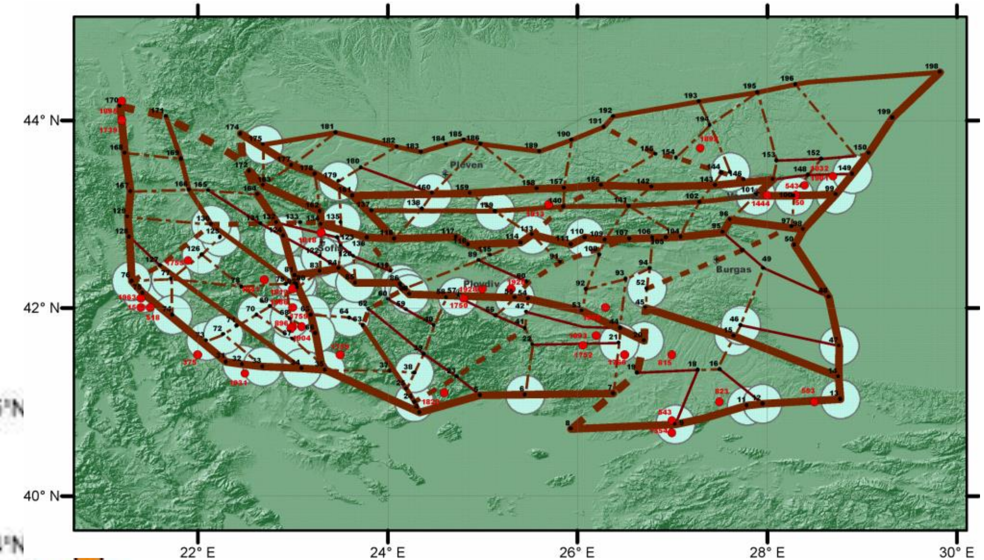
Parameters	Thresholds of discretization
A) Morphometric parameters	
Minimum topographic altitude, *m* (**Hmin**)	91; 238
Relief energy, *m* (□**H**) (Hmax - Hmin)	896
Distance between the points Hmax and Hmin, *km* (**L**)	23
Slope, (□**H/L**)	24; 55
B) Lineaments-and-blocks geometry	
The highest rank of lineament in a node, (**HR**)	1
Distance to the nearest 1st rank lineament, *km*, (**R1**)	0
Distance to the nearest 2nd rank lineament, *km*, (**R2**)	23
Distance to the nearest node, *km*, (**Rint**)	18
C) Gravity parameters	
Maximum value of Bouguer anomaly, mGal ,(**Bmax**)	35; 50
Difference between Bmax and Bmin, mGal ,(**ΔB**)	20
D) Magnetic field parameters	
Maximum value of the magnetic field in the vicinity of the node(**Moma**)	23.3
Minimum value of the magnetic field in the vicinity of the node(**Momi**)	-42.4 ; -8.0
Difference between the maximum and minimum of the magnetic field in the vicinity of the node(**Modif**)	48.8

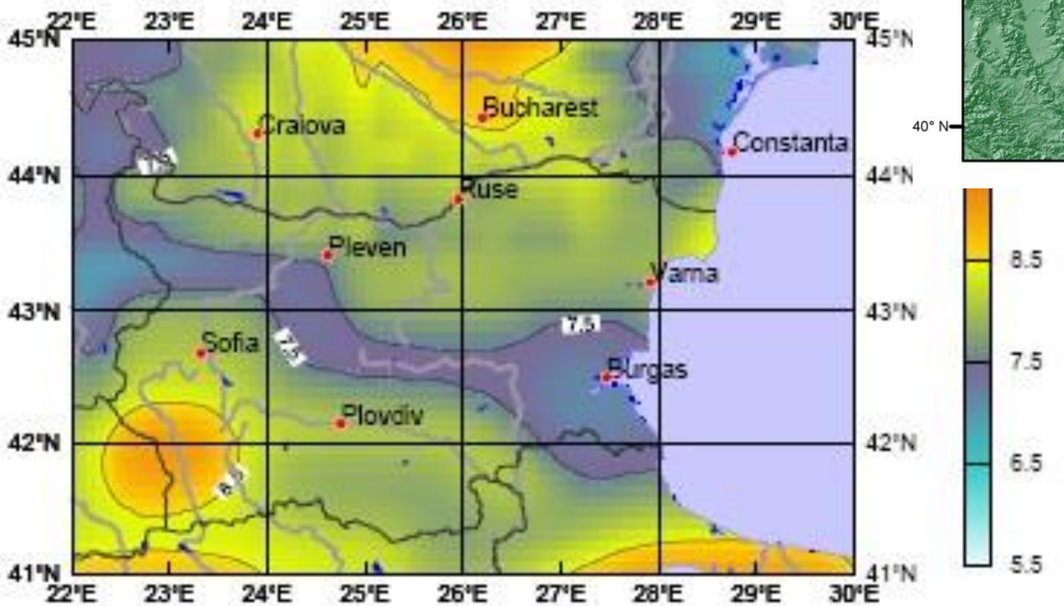
Recognized seismogenic nodes for M6+



Recognized nodes capable of generating earthquakes M6+ are shown by white circles.
Out of defined 178 nodes, 59 (33%) ones were assigned by Cora-3 to seismogenic class D.

Recognized D nodes





Simeonova et al. (2006). Probabilistic seismic hazard map for Bulgaria as a basis for a new building code

Fig. 4. Seismic hazard from all source zones for a recurrence period of 475 years; colours represent intensities in MSK-1964 scale.

Conclusions

The most of the identified earthquake-prone nodes are located on the lineaments of the highest (first and second) ranks, which divide the largest blocks of the earth's crust in Bulgarian region. The majority of D nodes are located in the mountainous areas: in the Rila, Pirin and Rhodope massifs, as well as in the Stara Planina mountain range.

According to characteristic features defined by Cora-3, D nodes are characterized by “large” values of the relief energy and relief gradient in combination with “large” values of gradients of gravitational and magnetic anomalies. The set of characteristic features of seismogenic nodes established by recognition indicates the high contrast of neotectonic movements and the presence of deep inhomogeneities in the earth's crust (Yosifov et al., 2020) in the vicinity of such nodes.

The results obtained provide information for long-term seismic hazard assessment on the potential earthquake sources in the Bulgarian region. The recognition performed, pinpoints a number of D nodes where events M6+ have not been documented to date that could provide additional information to improve seismogenic source models.

The information on the possible locations of strong earthquakes provided by this work can be directly incorporated in the neo-deterministic procedure for seismic hazard assessment, thus, filling in possible gaps in known seismicity in Bulgarian territory.

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