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Zone (Eastern Carpatians-Romania); Evidence of the
Geodynamic Torsion Process**

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MODELING OF BLOCK AND FAULT SYSTEMS OF THE ACTIVE VRANCEA ZONE (EASTERN CARPATIANS - ROMANIA); EVIDENCE OF THE GEODYNAMIC TORSION PROCESS

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ABSTRACT

This paper is focused on geophysical evidence of the triggering mechanisms for the main intermediate-depth earthquakes located in the active Vrancea zone. The earthquakes affect a relic lithospheric slab that is considered to be the main seismogenic volume in the area. The structural peculiarities and the geometric properties of the relic slab were assessed mainly through the analysis of 3-D magnetotelluric tomographic imaging and impedance polar diagrams. This information also reveals that the relic slab is experiencing a counterclockwise torsion that might be generated by surrounding asthenospheric currents. The results of our work suggest therefore that the seismic behavior of the active Vrancea zone may be related to brittle deformation processes induced by geodynamic torsion of the relic lithospheric slab.

Key words: Eastern Carpathians, seismicity, 3D magnetotelluric tomography, impedance polar diagrams.

INTRODUCTION

The seismically active Vrancea zone is located within the arcuate portion of Eastern Carpathians (Săndulescu, Visarion, 2000; Fig. 1); it is bounded to the north and northeast by the Scythian and East European platforms, to the south by the Moesian Platform, and westwards by the Transylvanian Basin.

The hypocenters of the intermediate-depth seismic events recorded in the area are concentrated within a seismogenic body having approximately a parallelepiped form, which is about 80 km long and 40 km wide and extends to a depth of about 180km. According to the seismic historical catalog (Table 1), 18 earthquakes with magnitude higher than 6.5, occurred in the area with a periodicity of three to seven times per century.

Table 1

Strong intermediate-depth earthquakes in the Vrancea zone, since 1600

No	Date: m/d/y	Magnitude
1	9/01/1637	6.6
2	9/09/1679	6.8
3	8/18/1681	6.7
4	6/12/1701	6.9
5	10/11/1711	6.7
6	6/11/1738	7.0
7	4/06/1790	6.9
8	10/26/1802	7.4
9	11/17/1821	6.7

10	11/26/1829	6.9
11	1/23/1838	6.9
12	10/06/1908	6.8
13	11/01/1929	6.6
14	3/29/1934	6.9
15	11/10/1940	7.4
16	3/04/1977	7.2
17	8/30/1986	6.9
18	5/31/1990	6.7

Several models have already been proposed for the Vrancea zone (Fuchs et al., 1979; Constantinescu and Enescu, 1984; Oncescu, 1984; Oncescu et al., 1984; Trifu and Radulian, 1989; Khain and Lobkosky, 1994; Linzer, 1996; CRC 461, 1999; Stănică et al.; 1999; etc.). In particular, Fuchs et al.(1979) considered the Vrancea zone as a place where an oceanic slab, detached from continental crust, is sinking gravitationally. Oncescu (1984) and Oncescu at al. (1984) proposed a double subduction model on the basis of 3-D seismic tomographic images: in their interpretation, the intermediate-depth earthquakes are generated within a vertical surface separating the sinking slab from stable lithosphere. Constantinescu and Enescu (1984) emphasize that the breaking off of the oceanic lithosphere took place after the beginning of the collision, and that the resulting slab is almost sub-vertical. Trifu and Radulian (1989), analyzing the seismic behavior of the Vrancea zone, proposed a model based on the existence of two active zones located at depths of 80-110 km and 120-170 km. Both zones are characterized by local stress inhomogeneities capable of generating large earthquakes. Khain and Lobkosky (1994) suggest that the Vrancea zone results from delamination processes occurred during continental collision and lithosphere sinking into the mantle. Linzer (1996) shows that the vertical position of the Vrancea slab may be due to the final rollback stage of a small fragment of oceanic lithosphere; the authors also reconstructs a migration path of the retreating slab between the Moesian and East European platforms. The CRC Group 461 (1999), taking into consideration that the geometry of the subduction zone was not unequivocally defined, proposed four possible configurations for the Vrancea zone. The subduction process was modeled as: a subduction beneath the suture zone; a subduction beneath the foredeep area; two interacting subduction zones, and a subduction beneath the suture, followed by delamination. In two papers, Stănică et al. (1999) and Stănică, and Stănică (2002) show the results of magnetotelluric tomographies and propose: (i) a continental origin for the seismogenic body, and (ii) that the changing orientation of the slab strike with depth is the result of a geodynamic torsion.

In conclusion, at present, there is not yet available a comprehensive and appropriate model for explaining the intermediate-depth earthquakes triggered in the Vrancea zone, and their lack of occurrence in the depth-interval of 40-70 km. In this paper we focus on a possible mechanism that, in our opinion, may be responsible for triggering the main earthquakes which occur in the Vrancea zone, with the aim of improving our knowledge of the phenomenon and to address our results to gain social and economic advantages. Our model, which is based mainly on our improved knowledge of the deep structure of

the Vrancea zone, emphasizes the possibility that seismicity in the area results from a geodynamic torsion of a relic continental slab.

THE DEEP STRUCTURE OF THE VRANCEA ZONE

Over 100 magnetotelluric (MT) soundings, mainly located along four profiles crossing the Vrancea zone and the surroundings areas (Fig.1), have been performed in a time interval of about eight years.

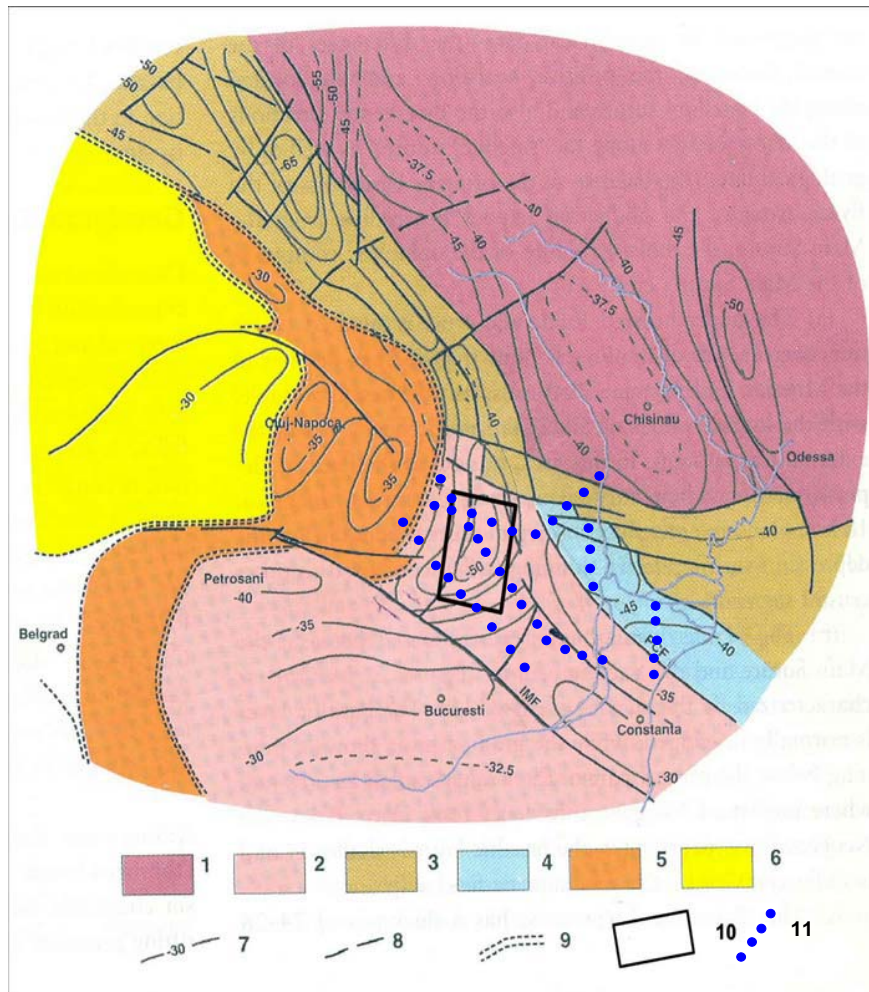


Fig.1. Seismic active Vrancea zone and magnetotelluric profiles on the crustal map (elaborated by Săndulescu and Visarion, 2000). (1) Precambrian East European Platform crust; (2) Precambrian Moesian crust; (3) Paleozoic Scythian crust; (4) Cimmerian North Dobrogea crust; (5) Transylvanian type crust; (6) Pannonian type crust; (7) depth to Moho; (8) main deep faults; (9) position of the suture zones at the Moho level; (10) the intermediate-depth seismic active Vrancea zone; (11) magnetotelluric profiles.

The results acquired during these years allowed us to better depict the deep structure of the area, and to construct the phase sections shown in Fig.2 (in B and E-polarized modes). The phase plots clearly highlight the sloping interface between the crystalline basement and the sedimentary cover of the East European Platform, which plunges from northeast (Falciu) towards southwest (Vrancea zone). By using the phase gradients it was also possible to draw the two main crustal faults (Peceneaga-Camena and Trotus) occurring in the area, and the top of the inferred seismogenic body. Our results show that, at this depth level, the Peceneaga-Camena fault displays a vertical displacement of about 6km.

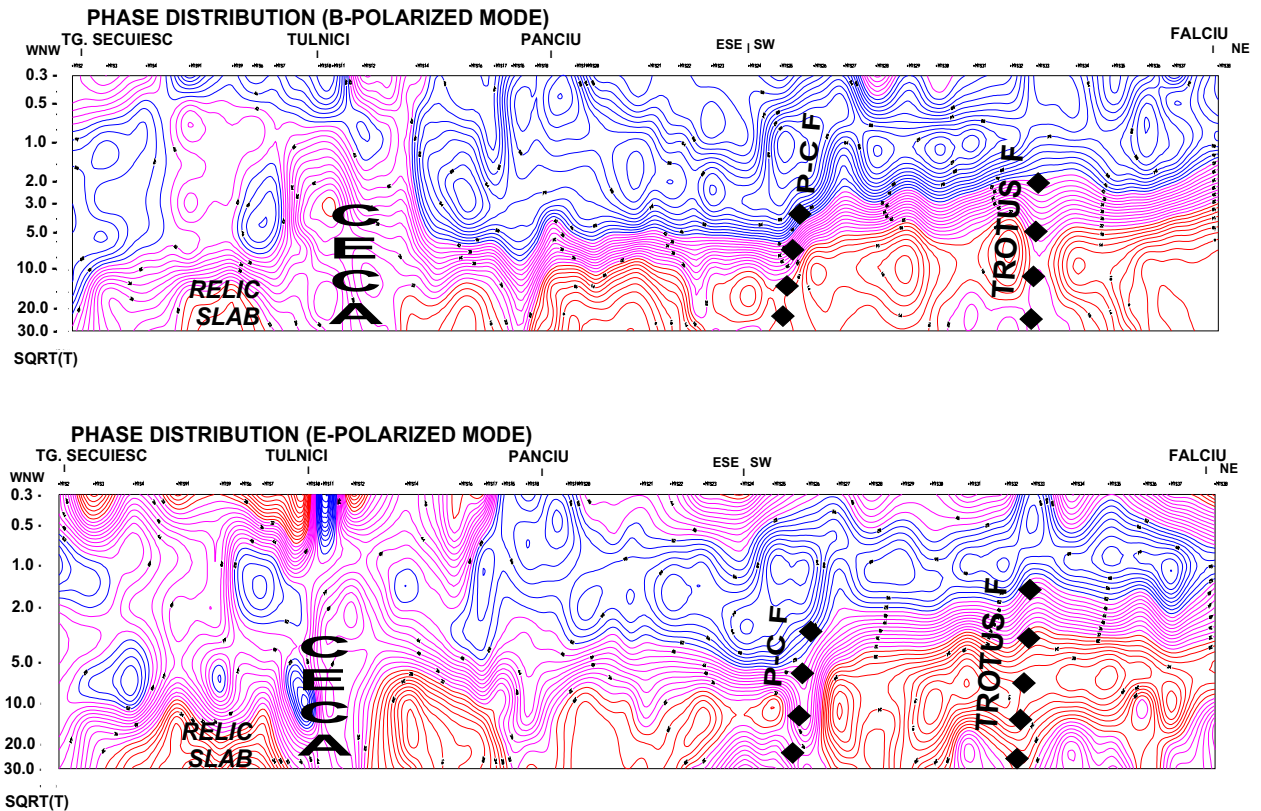


Fig.2. Magnetotelluric phase pseudo-sections along the profile Tg.Secuiesc-Tulnici-Panciu-Fălcui. (P-C F) Peceneaga - Camena fault.

This kind of information was integrated with available geological and geophysical data such as: the induction arrows map (Pinna et al., 1992) showing the Carpathian electrical conductivity anomaly (CECA - Fig.3), and the map of the brittle-ductile transition zone within the lower crust (Fig.4), where the Trans-European Suture Zone (TESZ), with a width of about 40 km, is also clearly delineated (Stănică et al., 1999).

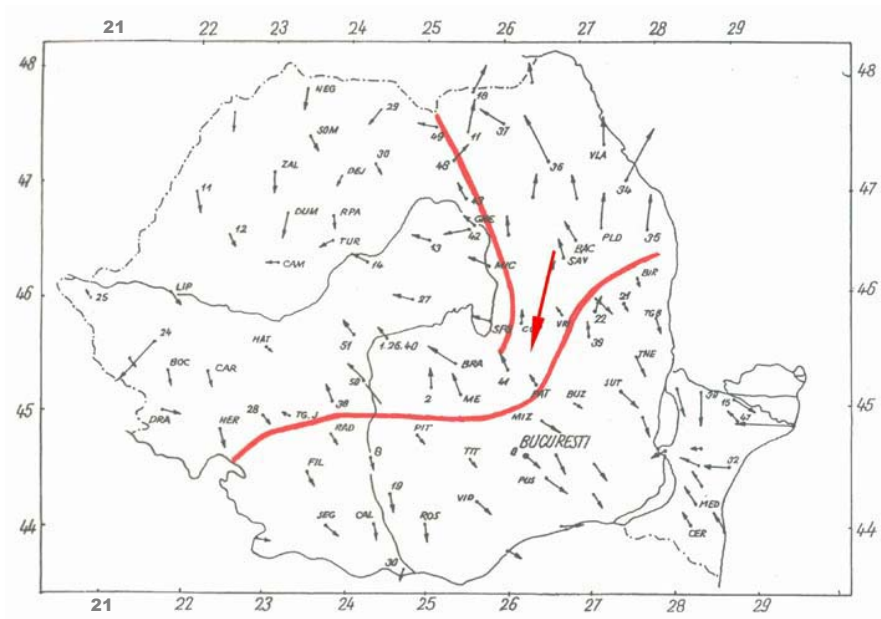


Fig.3. Induction arrows map (after Pinna et al, 1999). Red line is Carpathian electrical conductivity anomaly (CECA); the arrow shows the extension direction of the East European Platform.

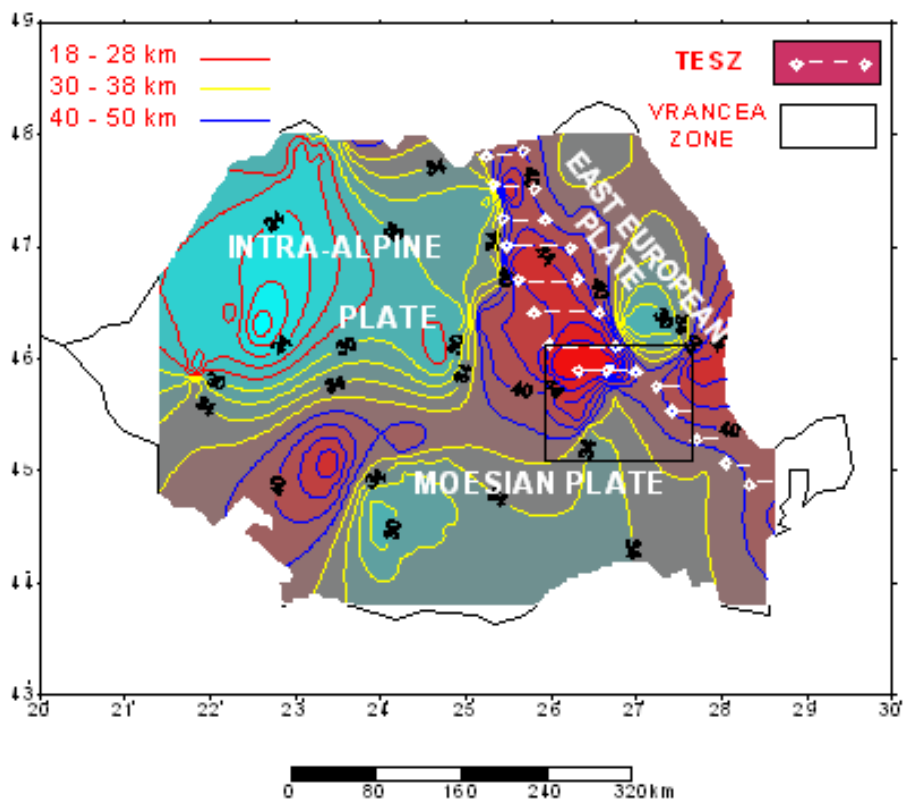


Fig.4. Map at the brittle-ductile transition zone in lower crust (Stănică et al.,1999). (TESZ) is Trans-European Suture Zone.

In the following section, we present a model of the Vrancea zone which is mainly based on MT tomography analysis performed at different depth intervals. The results of the analysis are shown in figures 5 and 6, where the images at two depth levels (100 km and 150 km) are given. Our data emphasize a southwestward extension of the East-European Platform, to a depth where most of the earthquakes foci are concentrated.

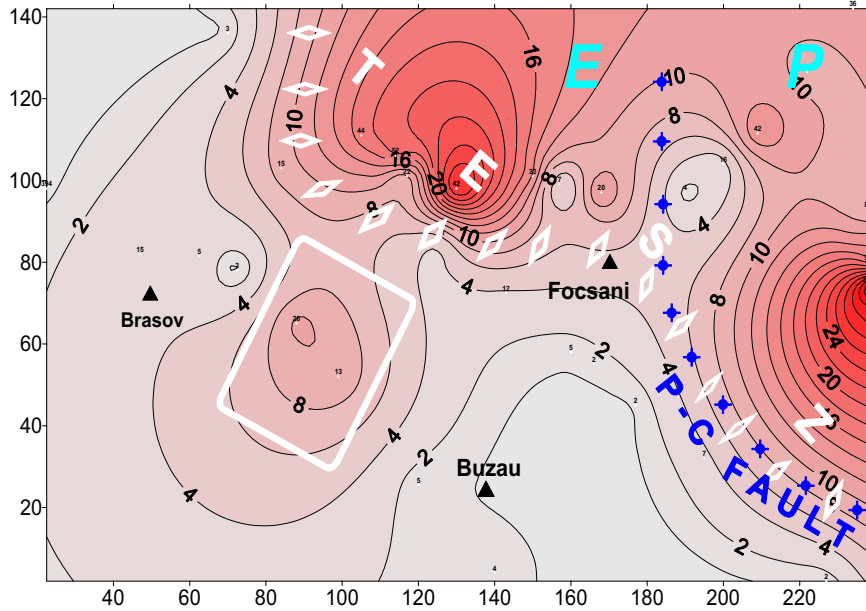


Fig.5. Magnetotelluric tomography (resistivity distribution) at 100 km depth. (EP)-European Platform; the diamonds delineate Trans-European Suture Zone; the cross-wisps delineate the Peceneaga-Camena fault; the white rectangle is horizontal cross-section through relic slab.

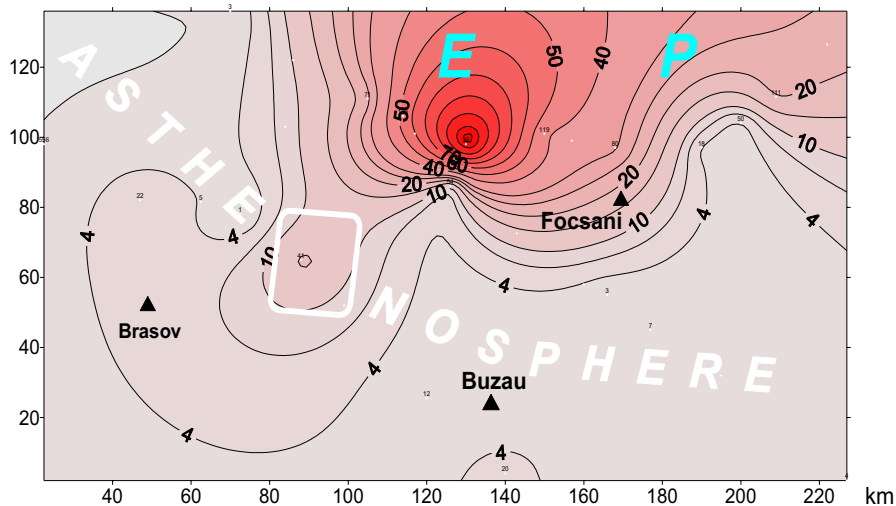


Fig.6. Magnetotelluric tomography (resistivity distribution) at 150 km depth. (EP)-European Platform; the white rectangle is a horizontal cross-section through the relic slab.

Furthermore the 3-D tomographic results shown in Fig.7 image the relic slab as a coherent body characterized by relatively high resistivities (6-10ohm.m); this body is clearly distinguished from the asthenospheric material (having resistivities less than 4 ohm.m) extending towards west and southwest, and from the European Platform (with resistivities higher than 70 ohm.m) located to the northeast.

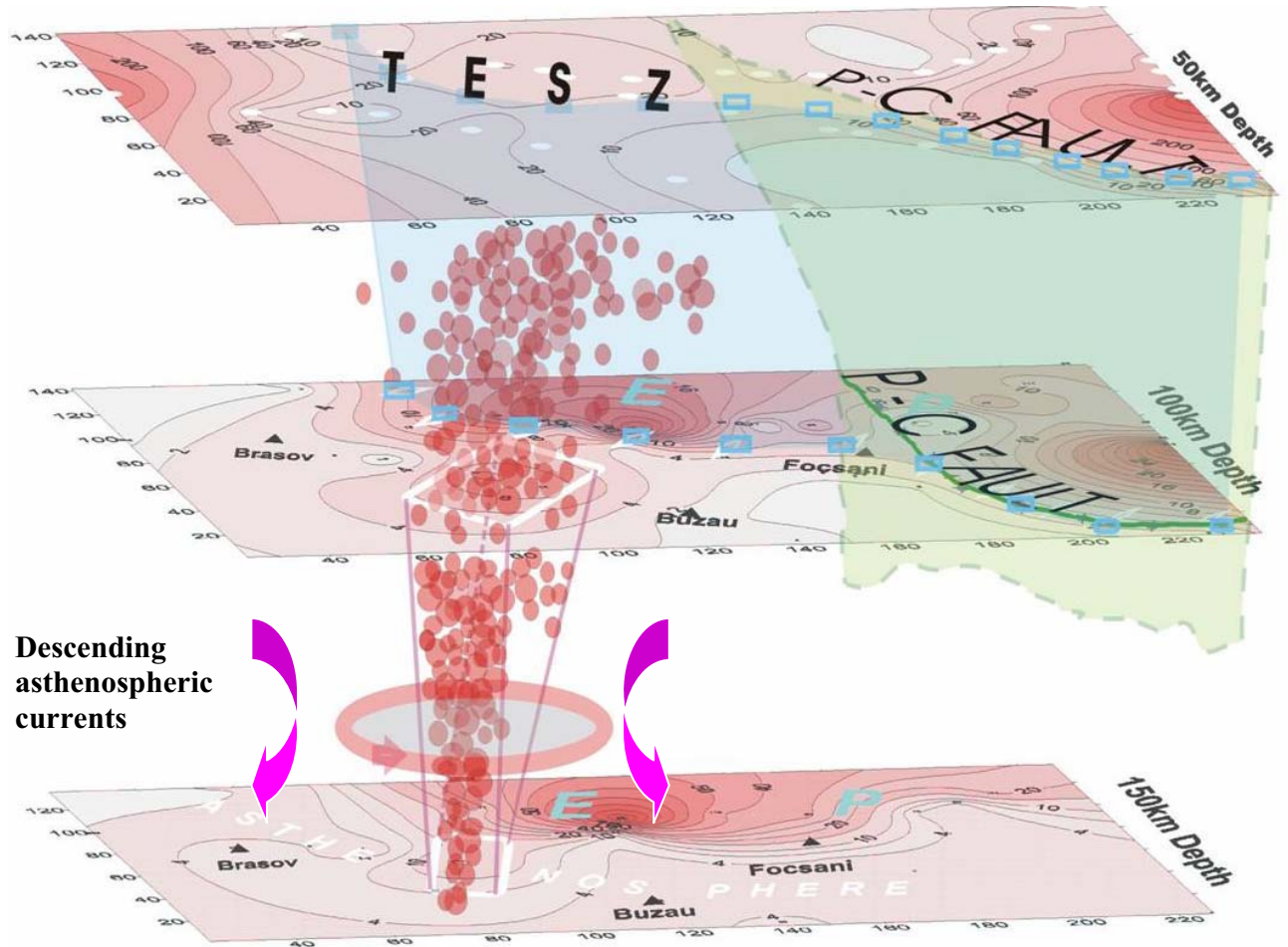


Fig.7. 3-D magnetotelluric tomographic imaging (Vrancea zone). The circles are intermediate-depth foci

The relatively high resistivities which characterize the seismogenic body suggest a continental origin of the slab (Stănică and Stănică, 2003), and a possible geometric model of the deep structure of the Vrancea zone (Fig. 8).

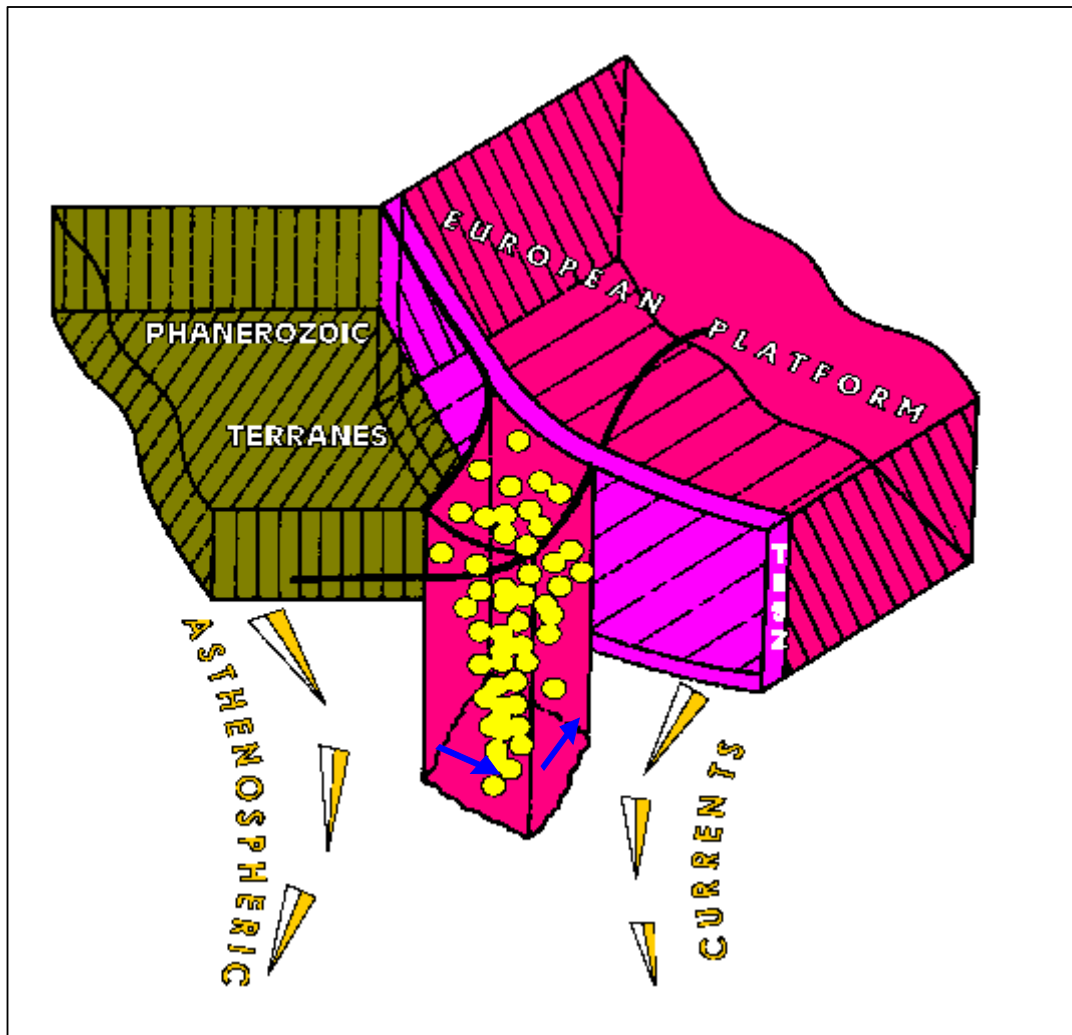


Fig.8. Geodynamic model elaborated beneath the crustal level. The thick black lines represent CECA; the circles are intermediate depth earthquakes; the arrows indicate the torsion direction of the relic slab.

A GEODYNAMIC MODEL OF THE VRANCEA ZONE: PROPOSAL, DISCUSSION AND CONCLUSION

In this paper we propose a possible model for the deformation processes acting in the Vrancea zone, in order to relate the observed main features characterizing its deep structure and the seismicity of the area. In Fig. 9 we show a distribution of magnetotelluric impedance polar diagrams constructed for a large scale of frequencies corresponding to intermediate-depth intervals (70-150 Km). As shown in Fig. 9, the orientation of the major axes of the diagrams records a counterclockwise rotation with depth, hence suggesting that the slab underwent some torsion. This process may have

possibly been activated and sustained by asthenospheric currents developed around the slab (Fig. 7). Consequently, the strike of the slab is about NE-SW, at 70 km depth, and roughly N-S at a depth of 150 km. It is also worth mention that the results of seismic tomography by Fan et al. (1998) depict a similar situation, with a body of high velocity material (i.e. the seismogenic volume) striking roughly NE-SW within the depth interval of 112-152 km and about N-S at depths higher than 152 km. Based on these data, the authors conclude that the directional change of collision in the Eastern Carpathians is preserved in the tomographic image, as the N-S oriented high-velocity body might represent older westward subducted material detached from the foreland lithosphere, but still attached to the upper NE-SW trending portion of the Vrancea slab.

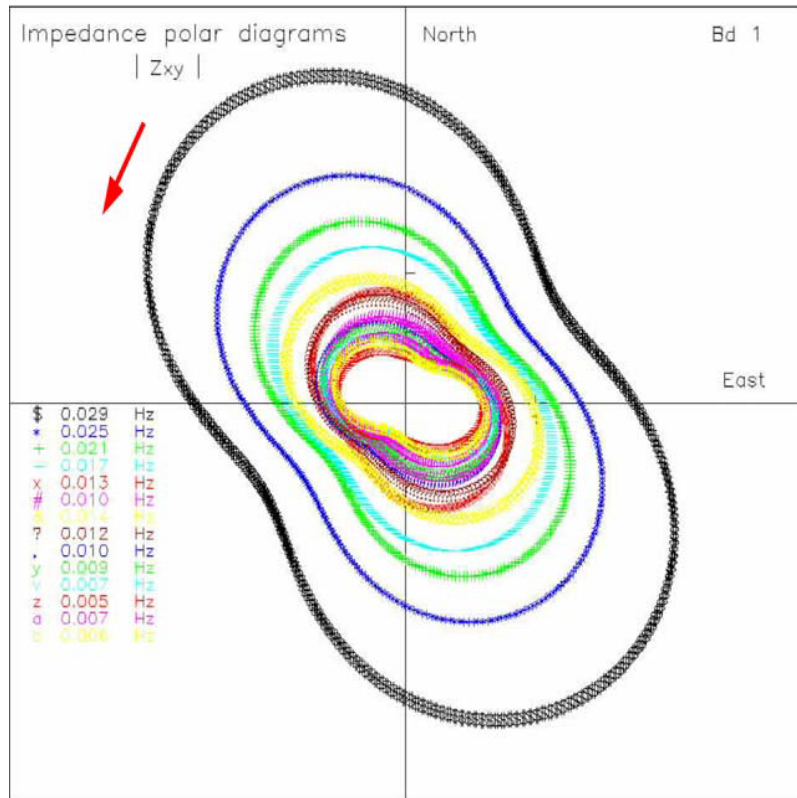


Fig.9. Magnetotelluric impedance polar diagrams. The arrow indicates the torsion direction of the relic slab.

To further investigate this hypothesis, we analyzed ten earthquakes which occurred in the Vrancea zone in the time interval August 2002- June 2003. In Fig. 10, we show their spatial distribution both at depth (Fig. 10a) and at the surface (Fig. 10b). Our results seem to support the idea that the whole sequence may be interpreted as the result of a torsion process affecting the relic slab.

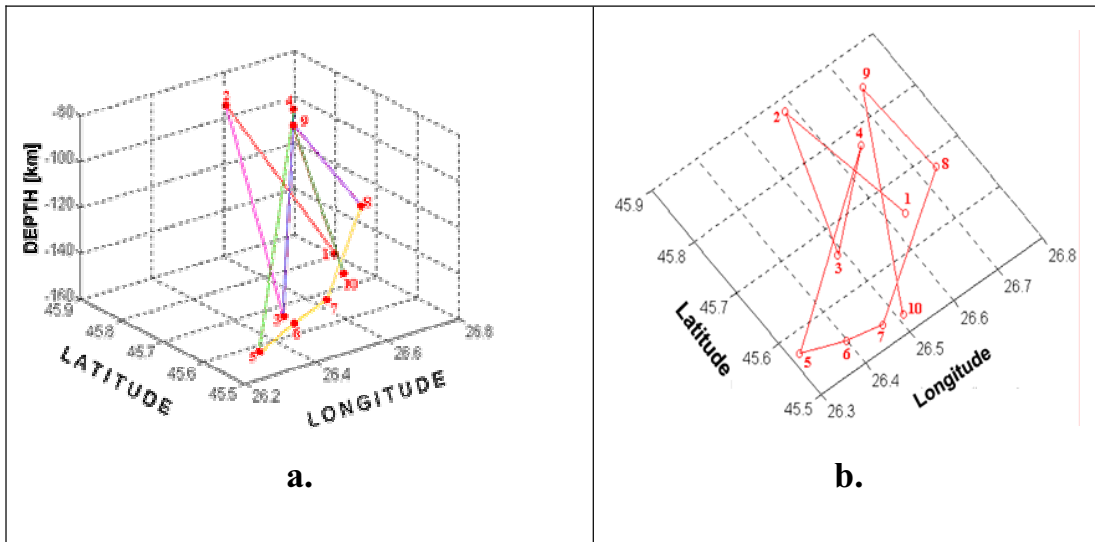


Fig.10. Distribution of 10 consecutive earthquakes occurred in the Vrancea zone.
 (a) hypocenters; (b) epicenters.

In conclusion, the inferred torsion that may result from the effects due to descending asthenospheric currents, on one hand, and to the irregular shape of the relic slab on the other, is capable, in our opinion, of generating a torque that may increase shear stress and drive faulting and re-shear within the rigid slab. If this is the case, then the triggering of the intermediate-depth earthquakes, in the Vrancea zone, may be interpreted as the rock response to active torsional processes sustained by a counterclockwise rotation of the slab which is induced by the complex interplay among the threefold structure of the lithosphere, in this sector of Eastern Carpathians, and the surrounding asthenosphere.

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