EVIDENCE OF GEODYNAMIC TORSION IN THE VRANCEA ZONE (EASTERN CARPATHIANS)

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La torsion géodynamique dans la zone de Vrancea (les Carpates Orientales). L'article met en évidence les mécanismes de déclenchement des principaux tremblements de terre à profondeur moyenne qui ont lieu dans la zone active de Vrancea. Les tremblements affectent la plaque lithosphérique relicte qui est considérée comme la plus importante en ce qui concerne le volume sismogénique de cette zone. Les particularités structurales et les propriétés géométriques de la plaque relicte ont été établies surtout à l'aide de l'analyse de l'image tomographique magnétotellurique 3D et les diagrammes d'impédence polaire. Les informations démontrent que la plaque relicte est affectée par une torsion en sens antihoraire, générée par les courants asténosphériques environnants. Les résultats suggèrent que le comportement sismique de la zone active de Vrancea peut être associé au processus de déformation cassante, déterminé par la torsion géodynamique de la plaque relicte.

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

INTRODUCTION

The seismically active Vrancea zone is located within the arcuate portion of the 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 180 km. 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.

Rev. roum. GÉOPHYSIQUE, **48**, p. 15–19, 2004, Bucureşti

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 the continental crust, is sinking gravitationally. Oncescu (1984) and Oncescu *et 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 the 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 the continental collision and the 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 the oceanic lithosphere; the authors also reconstruct a migration path of the retreating slab between the Moesian and the 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, a comprehensive and appropriate model is not yet available 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), were performed in a time interval of about eight years. 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 (Fălciu) towards southwest (Vrancea zone). By using the phase gradients it was also possible to draw the two main crustal faults (Peceneaga–Camena and Trotuş) 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 6 km.

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).

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 Figs. 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. Furthermore the 3-D tomographic results shown in Fig. 7 image the relic slab as a coherent body characterized by relatively high resistivities (6–10 ohm.m); this body is clearly distinguished from the asthenospheric material (having resistivities lesser 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.

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).

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 map of magnetotelluric impedance polar diagrams. This map was 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 been possibly activated and sustained by asthenospheric currents developed around the slab. 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 mentioning that the results of the 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.

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.

In conclusion, the inferred torsion that may result from the effects due to descending asthenospheric currents, on the 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 the Eastern Carpathians, and the surrounding asthenosphere.

REFERENCES

CONSTANTINESCU, L., ENESCU, D. (1984), *A tentative approach to possibly explaining the occurrence of the Vrancea earthquakes.* Rev. Roum. Géol., Géophys., Géogr., **28**, 19–23.

FAN, G., WALLACE, T.C., DAPENG, Z. (1998), *Tomographic imaging of deep velocity structure beneath the Eastern and Southern Carpathians, Romania: implication for continental collision.* J. Geophys. Res., **103**, 2705–2724.

FUCHS, K., BONJER, K.-P., BOCK, G., CORNEA, I., RADU, C., ENESCU, D., JIANU, D., NOURESCU, A., MERKLER, G., MOLDOVEANU, T., TUDORACHE, G. (1979), *The Romanian earthquake of March 4, 1977. Aftershocks and migration of seismic activity.* Tectonophysics, **53**, 225–247.

KHAIN, V.E., LOBKOSKY, L.I. (1994), *Conditions of existence of the Residual Mantle seismicity of the Alpine Belt in Eurasia.* Geotectonics, **2**, 54–60.

LINZER, H.-G. (1996), *Kinematics of retreating subduction along the Carpathian arc, Romania.* Geology, **24** (2), 167–170.

ONCESCU, M.C. (1984), *Deep structure of the Vrancea region, Romania, inferred from simultaneous inversion for hypocenters and 3-D velocity structure.* Ann. Geophys., **2**, 23–28.

ONCESCU, M.C., BURLACU, V., ANGHEL, M., SMALBERGHER, V. (1984), *Three-dimensional P-wave velocity image under the Carpathian Arc.* Tectonophysics, **106**, 305–319.

PINNA, E., SOARE, A., STĂNICĂ, D., STĂNICĂ, M. (1992), *Carpathian conductivity anomaly and its relation to deep substratum structure.* Acta Geodaet. Geophys. Mont. Hung., **27**, 35–45.

SĂNDULESCU, M., VISARION, M. (2000), *Crustal structure and evolution of the Carpathian-western Black Sea area.* EAEG, First Break, **18**, 3, 103–108.

STĂNICĂ, D., STĂNICĂ, M., ZUGRĂVESCU, D. (1999), *Geodynamic evolution of the Vrancea seismogenic volume revealed by magnetotelluric tomography.* St. cerc. GEOFIZICĂ, **37**, 61–69, Bucureşti.

STĂNICĂ, M., STĂNICĂ, D., MARIN-FURNICĂ, C. (1999), *The placement of the Trans-European Suture Zone on the Romanian territory.* Earth, Planets and Space, **51**, 10, 1073–1078.

STĂNICĂ, D., STANICA, M. (2002), *Geodynamic twist process of the seismogenic slab – a new attempt to explain the earthquakes' mechanism of the Vrancea zone*. Abstract accepted on the 16th Workshop on EMI in the Earth, Santa Fe, New Mexico, USA, June 16–2.

STĂNICĂ, D., STĂNICĂ, M. (2003), *The Trans-European Suture Zone (TESZ) and its geodynamic interrelation with the Vrancea seismogenic slab, Romania.* Abstract Volume, IUGG, 30 June – 11 July, 2003, Sapporo, Japan, B.186.

TRIFU, C.-I., RADULIAN, M. (1989), *Asperity distribution and percolation as fundamentals of earthquakes cycles*. Phys. Earth Planet. Inter., **58**, 277–288.

*** (1999), The Collaborative Research Center "Strong earthquakes (CRC) 461: A Challenge for Geosciences and Civil Engineering", German and Romanian Group for Strong Vrancea Earthquakes (RGVE), Vrancea earthquakes, Tectonics, Hazard and Risk Mitigation, 2–15.

Received February, 2004
Accepted June 8, 2004