Scientific Annals, School of Geology, Aristotle University of Thessaloniki Proceedings of the XIX CBGA Congress, Thessaloniki, Greece	Special volume 100	191-196	Thessaloniki 2010

SEISMOTECTONIC MODEL ON GEOLOGICAL DATA FOR 1892 DULOVO EARTHQUAKE, LOWER DANUBE VALLEY

Shanov S. and Radulov A.

Laboratory of Seismotectonics, Geological Institute, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria, s_shanov@geology.bas.bg, radulov@geology.bas.bg

Abstract: The potentially active faults in the area of Lower Danube Valley between the arcs of Carpathian and Balkan mountain chains are not properly recognized. The epicentre of the only historically known "strange" earthquake on the territory of Bulgaria with a magnitude evaluated at M_s = 7, known as the "1892 Dulovo Earthquake" is situated in this area. The first step for creating a seismotectonic model for this earthquake is the identification of the nearby active fault. The analysis has shown that it is realistic to accept that the earthquake occurred in the frames of the Tutrakan Graben. A fault segment of the Dulovo Fault, the most probably activated during the 1892 Dulovo Earthquake, is recognised. Its length is 42±5 km, and the width is 15±2 km. The offset of the normal faulting from the last seismic events is evaluated at 2 m. Three approaches are used for determination of the maximum magnitude of the earthquake that can be generated. They give M_s in the range between 6.8 and 7.5. The most probable value is 7.0.

Keywords: Lower Danube Valley, active fault, Dulovo Earthquake, seismotectonic model

1. Introduction

The Lower Danube Valley dominates over the territory of the Moesian Platform. The potentially active faults in this area between the arcs of Carpathian and Balkan mountain chains are not properly recognized. The only pretended major active structure passing trough the territory of Bulgaria along the border between Bulgaria and Romania (Cadet and Funiciello, 2004) is the Intramoesian Fault, crossing Danube River from NW to SE. The fault is of a length several times greater than the known active faults generating strong earthquakes of magnitude around 7.0 (Fig. 1). The known strong historical earthquake in the area that could be related (or not) to this structure is 1892 Dulovo Earthquake of magnitude evaluated approximately at 7.0 (Fig.1). The identification of the geological active structure that might generate the 1892 Dulovo Earthquake is the aim of the study. The error of the location of the Dulovo Earthquake by Bulgarian, Romanian and Russian authors is 200 km (Glavcheva and Radu, 1994). Thus, the identification of the active fault structure able to produce such an earthquake is of significant importance for understanding the geodynamics of the area and for the seismic hazard assessment for both countries Bulgaria and Romania.

2. 1892 Dulovo Earthquake

The earthquake occurred the 14th of October 1892. In this time regular seismological observations on the Balkan Peninsula just had been started, and this earthquake has been more than once a matter of study. Handling the entire quantity of reports Glavcheva and Radu (1994) have made new assessments of the isoseismal map according to the MSK-64 scale and relocation of the epicentre. They argued that the contradictory conclusions of previous studies on the 1892 Earthquake are due to the fragmentary use of original descriptions, the incomplete use of reports, the heritage of wrong suggestions and application of different intensity scales. As a result of the analysis of the distribution of the intensity data it was possible to assess the earthquake parameters as presented in table 1.

3. Geology and tectonics of the epicentral area of 1892 Dulovo Earthquake

The epicentral area of 1892 Dulovo Earthquake is situated in the relatively elevated eastern part of the Moesian Platform. This platform**,** dominated by the large plane region of the Low Danube River, was named the Moesian Platform in 1946 (Bonchev, 1971). Its geological and tectonic characteristics, as well as its deep structure**,** have been studied and discussed by a number of authors (Bonchev, 1946; Muratov, 1949; Popescu et al., 1965; Atanasiu and Chirac, 1965; Dobrev, 1966; Bonchev 1971 and many others). Newly published geophysical and geological data have recently completed the knowledge for the inner structure of the platform and for its geodynamic evolution (Tari et al., 1997; Hausser et al., 2001). For the area of the SE Moesian Platform**,** the difference is that the most important faults inside the platform were recognised only by industrial geophysical works and drilling. Most of them had not been active since the Triassic time (Bokov and Chemberski, 1987). Only a few of the faults, later activated during different tectonic phases and situated near the southern and the eastern periphery of the studied area**,** can be recognised geologically on the surface. Thus, the study of the recent kinematics of the faults is difficult, if possible at all.

Fig. 1. Regional sketch of Lower Danube Valley with the active faults and fault segments, and the probable epicenter of 1892 Dulovo Earthquake.

The present knowledge about the recognized main faults and the principal regional structures was summarized by Tari et al. (1997). The geotectonic evolution of the Moesian Platform is mainly characterized by four main sedimentary cycles: Middle Cambrian-Upper Carboniferous, Permian-Triassic, Jurassic- Cretaceous, and Neozoic, being defined in connection with the tectonic activity. From seismotectonic point of view the Quaternary stage of development of the Moesian Platform is the most important.

The tectonic heritage from the most recent processes for the area of interest is represented by the North Bulgarian Uplift (or Arch) bordered to NE by the Tutrakan Subbasin (or the Tutrakan Depression), to the north – by the Alexandria Subbasin on the territory of Romania, to the south – by the structures of the Fore-Balkan, and to the west – by the Iantra-Iskar Step (Fig. 2). During the Plio-Quaternary stage the North Bulgarian Uplift was submitted to continuous but not very intensive elevation. According to Yaranov (1960) the elevation during the Quaternary was about 80 m for the central part of the Uplift, and of about 50 m towards the periphery.

Table 1. Seismological evaluation for the 1892 Dulovo Earthquake.

Time	1892, October 14, 04 h. 54 min. GMT
Coordinates of the epicenter:	43°45' N, 26°55' E (±10 km)
Hypocentral depth:	35-50 km
Intensity:	Io = 8 [MSK]
Magnitude	Ms = 7 (uncertain)

The differential movements that had superposed North Bulgarian Uplift and the Lom Depression to the west ended at 2,59 Ma BP. The Neotectonic stage is characterized by continuous elevation of the principal tectonic blocks. After the regression of the Dacian Basin (0,82 Ma BP) and till now, the upper level of the alluvium is raised 130,10 m in Yantra-Iaskar Step and at 121,00 m in NE Bulgaria (including the North Bulgarian Uplift).

4. Methodology

The first step for creating of the seismotectonic model is the identification of the active faults. The identification of faults that pose earthquake hazards requires application of a fault-activity criterion to filter out ancient faults that are unlikely to rupture during future earthquakes.

The magnitude of the earthquake can be evaluated using the relationships proposed by Wells and Coppersmith (1994):

$$M_s = 6.04 \pm 0.22 - 0.71(\pm 0.12)\ SRL \qquad [1]$$

where S*LR* is the length of the fault rupture from the earthquake.

Another possibility for normal faults is to use the evaluated geologically offset (average slip on the fault) *D* and the fault area *A.* The fault area *A* is:

$$A = LW \qquad [2]$$

where *L* is the length of the activated fault segment and *W* is its wide in depth. The expected maximum magnitude is:

$$M_s = 6.78(\pm 0.34) - 1.32(\pm 0.26)\ AD \qquad [3]$$

The third approach used for characterizing of an active fault is based on the relationship between the moment magnitude and the seismic moment. The milestone in this approach is the converting the magnitude M_s onto the moment magnitude scale M_w. The suggestion of Bayliss and Burton (2007) for this part of the Balkan Peninsula was adopted – northern of 43^0 N the most appropriated relationship is:

$$M_w = M_s \qquad [4]$$

The definition of the moment magnitude M_w is:

$$M_w = (2/3)\log_{10}(M_0) - 10.73 \qquad [5]$$

where M_0 is the seismic moment [dyne-cm].

By definition:

$$M_0 = \mu AD \qquad [6]$$

where μ - shear modulus (often G in engineering), A - fault area, D - average slip on the fault. For the conditions of the hypocenters in the Earth's crust it is widely accepted to use the value $\mu = 3.3 \times 10^{11}$ dyne/cm^2.

geologically active structure capable to generate this seismic event is discussed bellow.

5.1. Regional fault structures

A number of sub-parallel faults striking NW-SE have been mapped on the level of the Precambrian - Paleozoic fundament in NE Bulgaria. These faults define the main block structures having the same orientation (Fig. 3). The most important for the geological models are the Intramoesian Fault and Dulovo Fault (named also Balchik – Tervel Fault) framing the Tutrakan Depression (Bokov and Chemberski, 1987). The faults cut also the Mesozoic sedimentary cover (epicontinental sediments of Late Jurassic – Early Cretaceous age).

5.2. Indications for Neotectonic activity

In the frames of Tutrakan Depression, only an important area of Neogene limestones and terrigenous sediments can be found (Fig. 3). On the adjacent and elevated Dobrogea and Vetrino blocks, the Neogene sediments are of insignificant thickness or missing (Geological Map of Bulgaria in a scale 1:100 000, Sheets Dulovo, Tutrakan, Razgrad, Dobritch, Isperih, Russe, Gen.Toshevo, Biala, Popovo, Griaka, Vetovo, Silistra). The spread of the Neogene deposits defines the Tutrakan Depression as an area of sin-sedimentary subsidence. A normal faulting along the bounding Intramoesian and Dulovo faults may be the reason for the recorded sin-sedimentary subsidence.

The enlargement of the Upper Romanian – Lower Pleistocene Basin, north-eastward the Dulovo Fault is a fact demonstrating the continuous tendency of subsidence inside the graben during the

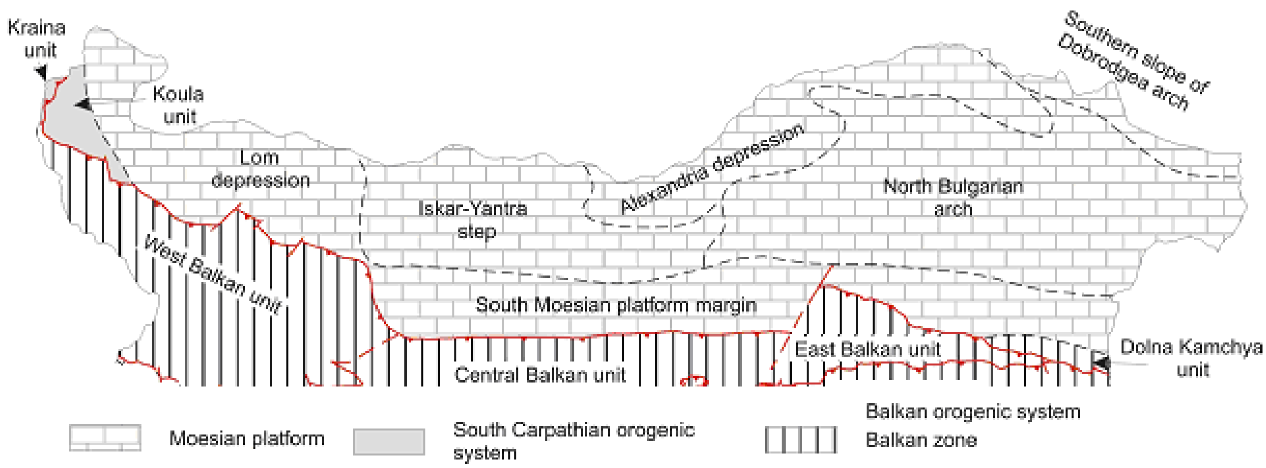

Fig. 2. Tectonic scheme of Northern Bulgaria (according to Dabovski et al. 2002).

The slip rate cannot be determined from the slip and time of only the most recent earthquake, since only an incomplete cycle has taken place. If the magnitude of historical earthquake is known the geometric characteristics of the activated fault segment can be deduced, and vice-versa.

5. Results and Discussion

According to the geophysical data, the inner part of the Moesian Platform has a block structure. Earthquakes with magnitudes of less than 4.5 were recorded (Bonchev, 1979; Visarion et al., 1988**;** Tzvetanov, 1990) in different parts inside the platform. The only historically known "strange" earthquake with a magnitude evaluated at M_s = 7 is the 1892 Dulovo Earthquake. The identification of the

Early Pleistocene. The basin existed till the beginning of Marine Isotopic Stage (MIS) 21 (Evlogiev, 2000).

The differential vertical displacement along the faults during the formation of Danube River terraces after the MIS 21 is confirmed by the lateral distribution of the terraces. All terraces from T6 to T1 are elevated along the Bulgarian Danube riverside between the towns of Tutrakan and Russe. They are not presented eastwards in the Tutrakan Depression (Evlogiev, 2000). The highest river terrace along the Romanian riverside is limited only westward the Arges River outflow (the town of Oltenita). The line Tutrakan – Oltenita separates two blocks with different vertical velocities during the Pleistocene. The western uplifted block contains the all range of terraces, while the eastern block experiences subsidence at the same time. The zone of the differential vertical movements can be identified as a fault segment belonging to the Dulovo Fault (Fig. 3).

The presence of Holocene alluvial fans along the NE block of the Intramoesian Fault and the absence of these sediments in its SW block is an indication for a relative uplifting of the NE block. The different width of the floodplain and terraces from the two sides of the Intramoesian fault also indicates its activity during Pleistocene and Holocene time.

An elevation profile parallel to the Danube River on the surface of the Upper Romanian – Lower Pleistocene Basin shows that the Tutrakan Depression is 26 m lower than Vetrino Block and 19 m lower than Dobrogea Block (Fig. 4). The rate of subsidence of Tutrakan Depression during the Pleistocene reflects the cumulative effect of the displacements along the bordering faults. It is not possible to evaluate the rates of offsets separately for each of the bordering faults.

Another elevation profile along the Danube floodplain shows Holocene deformations, too. The displacement at the Dulovo Fault is evaluated to about 2 m (Fig. 4). Eastward the Intramoesian Fault, the Danube floodplain is also elevated, and even slightly inclined opposite to the flow.

On the base of the elevation profiles and the distribution of the sediments we can conclude that the subsidence in the Tutrakan Depression occurs during the entire Quaternary, even in Holocene time. Hence, the faults bounding the graben should be active at that time.

The first reported data for the Dulovo earthquake (Hepites, 1894) locates the epicentral area near the

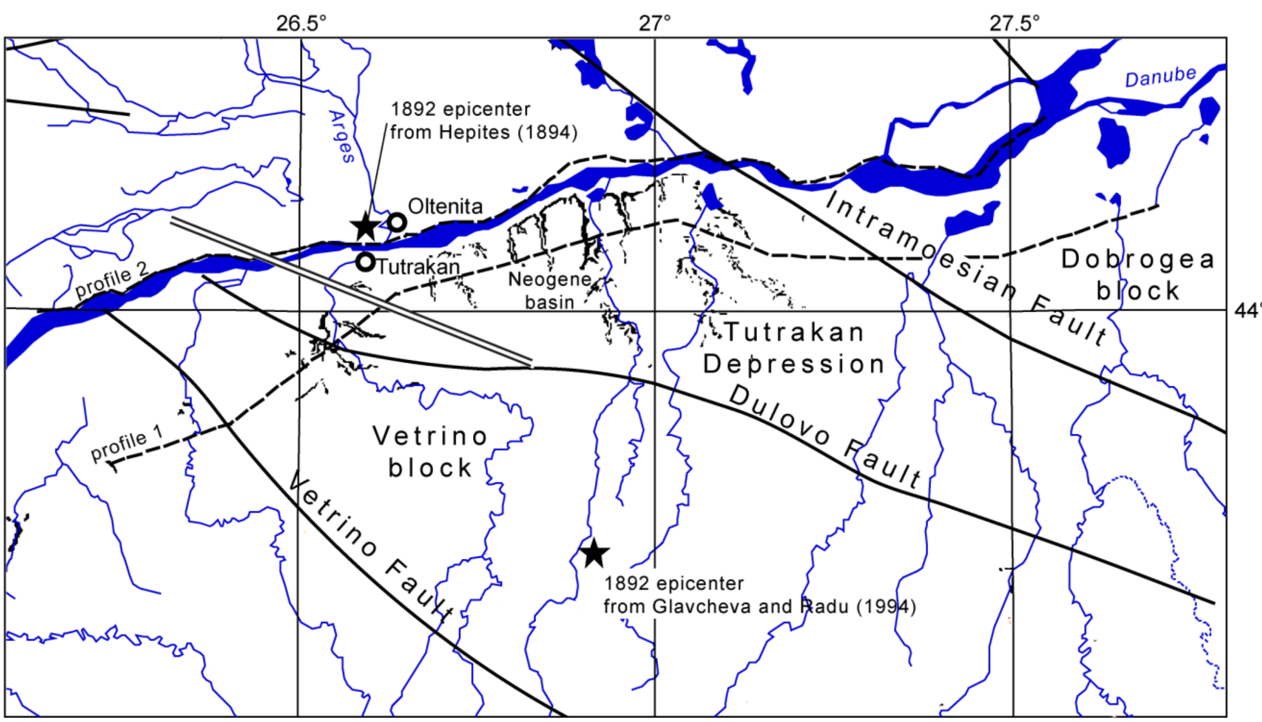

Fig. 3. Structural sketch of the Tutrakan Depression. Main faults in the basement (from Bokov and Chemberski 1987) bound also the Neogene basin (black pattern). Epicenter locations of the 1892 Dulovo earthquake from different authors are shown by stars. Double line shows the segment of the Dulovo Fault controlling relief and Pleistocene-Holocene deposition. Dashed line shows elevation profiles from Fig. 4.

town of Oltenita, situated in the central most subsided part of Tutrakan Depression (Fig. 3). It is realistic to accept that the earthquake occurred in the frames of the graben. The tectonic control on the relief of the segment from the Dulovo Fault crossing the Danube floodplain at the position of the recorded 2 m offset could be traced between the Romanian riverside and an overstep in Bulgaria. This segment may be a seismic source. Its length is 42±5 km. Taking into account the Holocene age of the terrace, the slip rate of Dulovo Fault during the Holocene time is evaluated at 0.28 mm/year.

5.3. Seismotectonic model

The presented above geological consideration give the reason the accept the following characteristics of the activated fault segment during the 1892 Dulovo Earthquake: Fault length (L) - 42±5 km; Width (W) from M_0 – 15±2 km; Depth (H) at dip 60°±10° (normal faults in upper crust) – 13±3 km; Displacement assuming a single event displaced the Danube River floodplain – 2 m.

The maximum possible magnitude of the earthquake that can be generated by the activated segment is evaluated by using the presented relationships [1], [3] and [5]. The results are plotted on table 2. These values are comparable with the Dulovo Earthquake characteristics from table 1 (Glavcheva and Radu, 1994). Following the hypothesis of strict periodicity of the strong seismic events, and using the nomogram of Slemmons and dePolo (1986) the recurrence interval of the strong events is evaluated at 3 000 years, the displacement (vertical offset) is 2 m.

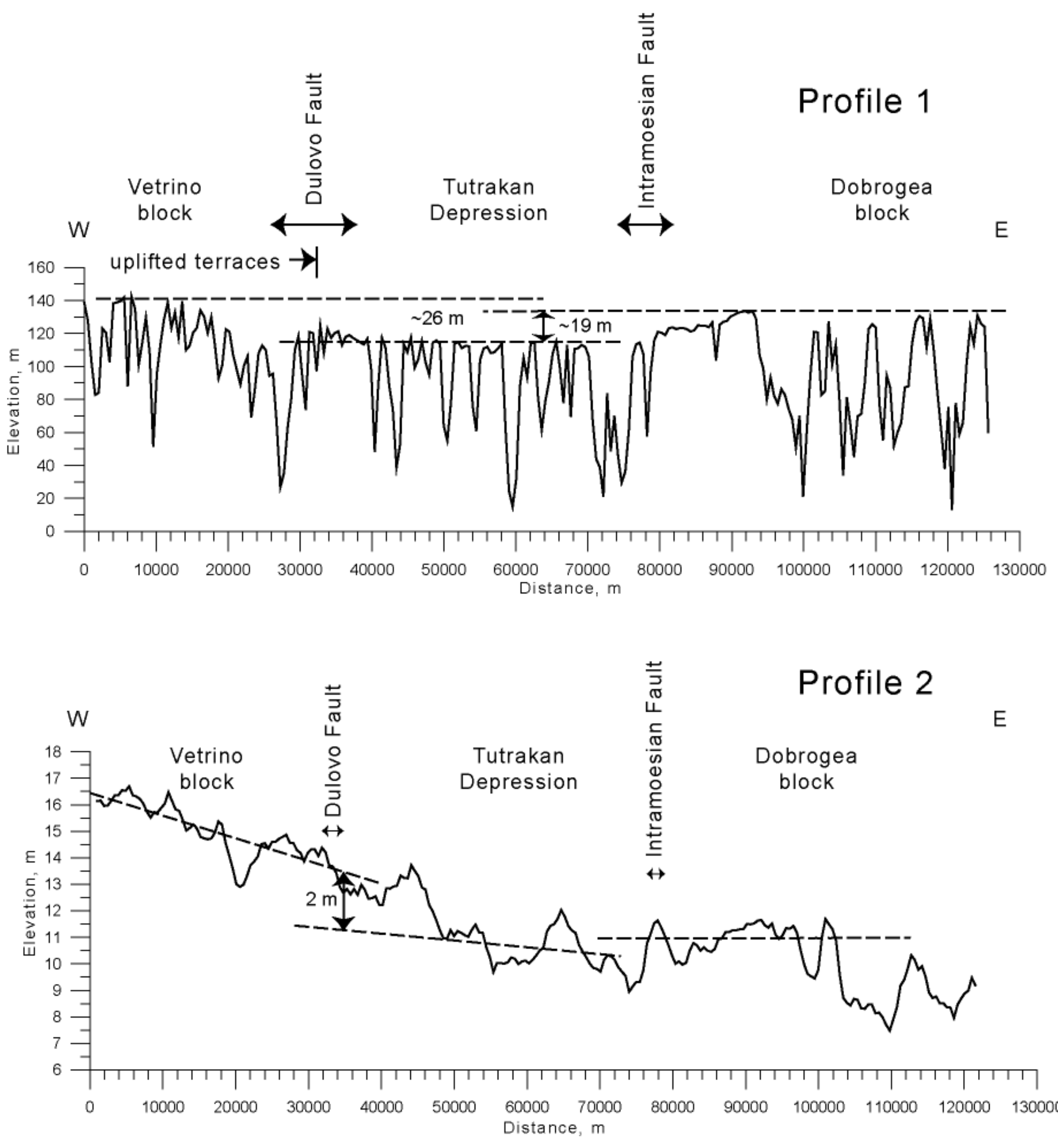

Fig. 4. Elevation profiles across the Tutrakan Depression along the surface of the Upper Romanian – Lower Pleistocene Basin (profile 1) and along the Danube floodplain (profile 2).

Table 2. Dulovo Fault – Seismotectonic model.

Constants and fault characteristics	Magnitude Ms		
	Relationship [1]	Relationship [3]	Relationship [5]
$\mu = 3.3 \times 10^{11}$ dyne/cm^2 Mo = 3.935×10^{26} dyne-cm Vertical offset D = 2 m Fault length = 42±5 km Fault width = 15±2 km	7.2 ± 0.3	7.0 ± 0.1	7,02

6. Conclusions

The study presents a new solution for the epicentre location of 1892 Dulovo Earthquake by recognising the fault structure able to produce an earthquake of magnitude 7. The segment of Dulovo Fault (NE border fault of Tutrakan Graben) is described as the most probable geological structure, activated during the earthquake.

The available data enhanced the creation of an acceptable seismotectonic model. It reflects the latest displacement along the fault. The normal displacement of 2 m created by earthquake of magnitude M_s = 7 seems to be reasonable. The model is based also on the assessment that the Holocene slip rate along the Dulovo Fault (vertical component – the most lower possible) is 0.28 mm/y. The recurrence interval of the strong events is evaluated at 3 000 years.

References

Atanasiu L. and Chiriac I., 1965. Considération géologique sur les plates-formes du territoire de la République Populaire Roumanie. 7th Congr. of the Carpatho-Balkan Geol. Assoc., Sofia, Vol. I, 251-255.

Bayliss T.J. and Burton P.W., 2007. A new earthquake catalogue for Bulgaria and the conterminous Balkan high hazard region. Natural Hazards and Earth System Sciences, EGU, 7, 345-359.

Bokov P. and Chemberski, H. (Eds), 1987. Geological conditions for the oil and gas accumulation in North-Eastern Bulgaria. Technika Publ. House, Sofia, 332 p. (in Bulgarian)

Bonchev E., 1946. Bases of the tectonics of Bulgaria. Ann. of the Direction for Geol. and Mining Exploration, part A, v.IV, 336-379. (in Bulgarian)

Bonchev E. 1971. Problems of the Bulgarian geotectonics. Sofia, Tehnika Publ. House, 204 p. (in Bulgarian)

Bonchev E., 1979. The Moesian platform and its role in the Phanerozoic evolution of the Balkan Peninsula. Zavod za Geol. i Geof. Istrazivanja, Beograd, kn. XXXVII, ser. A, 49-58.

Cadet J.P. and R. Funiciello, 2004. Geodynamic map of the Mediterranean. – Commission of the Geological map of the World, 2 sheets.

Dabovski C., Boianov I., Khrischev Kh., Nikolov T., Sapunov I., Yanev Y. snd Zagorchev I., 2002. Structure and Alpine evolution of Bulgaria. Geologica Balcanica, 32, 2-4, 9-15.

Dobrev T., 1966. Structure of the foundation of the Moesian platform in the territory of Bulgaria. Soviet Geology, 11, 44-45. (in Russian)

Evlogiev J., 2000. Quaternary in Northeast Bulgaria. - J. of the Bulg. Geol. Soc., 61, 1-3, 3-25 (in Bulgarian).

Glavcheva R. and Radu C., 1994. On the strong 1892 earthquake in South Dobrudzha. Bulgarian Geophysical Journal, v.XX, No 3, pp. 88-94

Hausser F., Raileanu V., Fielitz W., Bala A., Prodehl C., Polonic G. and Schulze A., 2001. VRANCEA99 – the crustal structure beneath the southeastern Carpathians and the Moesian Platform from a seismic refraction profile in Romania. Tectonophysics, 340, 233-256.

Hepites S., 1894. Le tremblement de terre du 14 octobre 1892. – Analele Inst. Meteor. Rom., 7, 20.

Muratov M.V., 1949. Tectonics and history of the development of the Alpean geosyncline region of the European part of URSS and the adjacent countries. In: - Tectonics of USSR, Moscow, v.II, 204-265 (in Russian)

Popescu M., Patrut, I., Paraschiv, D. and Molnar, M., 1965. Present stage of geolgical knowledge of the Moesic Platform, Romania. Proc. of 7th Congr. of the Carpatho-Balkan Geol. Assoc., Sofia, Vol. I, 333-337.

Slemmons, D.B. and dePolo, C.M., 1986 Evaluation of active faulting and associated hazards. Studies in geophysics — active tectonics: National Academy Press, Washington, DC, 45-62.

Tari G., Dicea O., Faulkerson J., Georgiev G., Popov S., Stefanescu M. and G. Weir. 1997. Cimmerian and Alpine Stratigraphy and Structural Evolution of the Moesian Platform (Romania/Bulgaria). In: - Robinson A. G. (Ed.) Regional and Petrolium geology of the Black Sea and surrounded region: AAPG Memoir 68, 63-90.

Tzvetanov P. (Ed.), 1990. Belene NPP – Investigations and attitudes of the Bulgarian Academy of Sciences, Sofia, BAS Publ. House, 412 p. (in Bulgarian)

Visarion M., Sandulescu M., Stanica D. and Veliciu S., 1988. Contribution à la connaissance de la structure profonde de plate-forme Moesienne en Roumanie. Studii Tehnice si Economice, Seria D, Geofizica, Bucuresti, 15, 211-222.

Wells, D.L. and Coppersmith K.J. 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. Bulletin-Seismological Society of America 84, no. 4: 974-1002.

Yaranov D., 1960. Tectonics of Bulgaria, Tehnika Publ. House, 282 p. (in Bulgarian).