3.4. NEW LOOK ON THE SEISMOTECTONIC PROBLEMS OF THE CENTRAL BALKAN PENINSULA

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3.4.1. Introduction

The processes marking the tectonic development of a particular region, and especially the Balkan Peninsula, are controlled by more global impacts, which could not be always registered through the standard seismotectonic approaches at local level. In depths, in the Earth mantle, imposing processes are acting, which made long term traces in the Earth lithosphere. The behaviour of the uppermost parts of Earth's crust is only an adaptation of the structures to the most sustainable energetic equilibrium in the space, with a tendency for compensation of the tectonic stress. The compensation goes in different ways – from slow movements and plastic type deformations to the faulting and fracturing with sharp "discharges" of the energy accumulated, as earthquakes. The identifications of the information about these processes could be realised only at joint analysing of all data from different sources with critical evaluation of their quality.

The purpose of the present study is to present the regional seismotectonics in the light of the new geophysical, geodetic and geological data. This data gives some possibility to approach at different way the unresolved seismotectonic problems of the Balkan Peninsula, as well as to give some ideas about the most important future works for improving the geodynamical model of the area.

Three principal problems could be recognised and proposed as critical ones for the better understanding of the contemporary geodynamics of the Central Balkan Peninsula:

1. The causes for the extensional regime in Northern Aegean area;
2. The intraplate seismicity and the problems of the active faults on Bulgarian territory;
3. Intramoesian Fault: Its unknown role as an active fault.

3.4.2. Causes for the extensional regime in Northern Aegean area

Aegean Region is one of the most geodynamically active areas of the Mediterranean. It demonstrates a number of traits of active plate edge (example: Mc Kenzie, 1972). The data published recently permits to see the processes in the Northern Aegean from new point of view.

3.4.2.1 Satellite laser ranging and GPS data

The Satellite Laser Ranging (SLR) geodetic solution for the plate motion of the Balkan Region and the surrounding areas is based on the analysis of observations of the geodynamic satellites Lageos 1 (Laser GEOdynamic Satellite) covering the period April 1984 – December 2000, and Lageos 2 for the period January 1993 - December 2000 (Georgiev et al., 2001, Tzankov et al., 2001, Georgiev, Shanov, 2002). According to these results, the West and Central Europe – the "stable" part of the Eurasian plate, is

moving north-eastward with an average velocity of 20-25 mm/y and no intra-plate motion is detected (Fig. 3.4.1 a, b). The north – north-westward motion of the Arabian plate and its impact on the Anatolian plate is expressed with rotation of the velocity vectors towards west along the North Anatolian Fault System. This well expressed motion is represented and discussed by a number of publication with the results of the GPS records (Reilinger et al., 1997, McClusky et al., 2000).

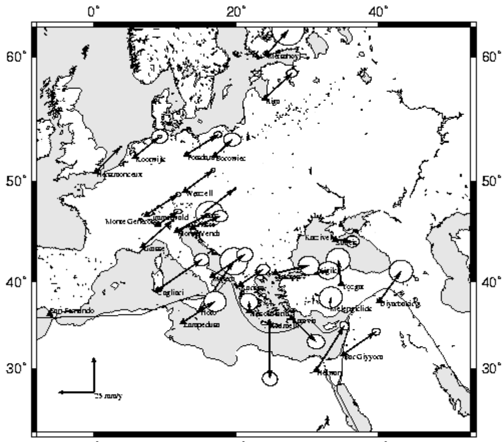

Fig. 3.4.1a. Absolute motions of Europe, African and Anatolian plates according to SLR geodetic solution (Georgiev, Shanov, 2002)

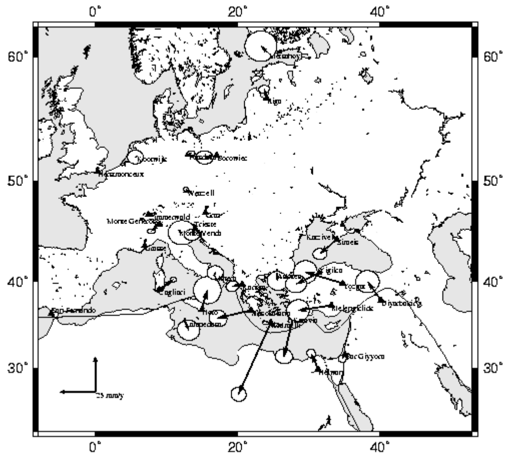

Fig. 3.4.1b. Motions relative to Eurasia for the SLR stations around and in the Carpathian-Balkan Region (Georgiev, Shanov, 2002)

According to all available data from LRS and GPS analyses the southern part of the Aegean plate is moving towards south - south-west. The relative motion of the Carpathian-Balkan Region relative to Eurasia is practically zero. Well expressed are the movements of Anatolian plate relatively westwards to Eurasia along the North Anatolian Fault System. The high strain capacity of the Anatolian plate on the structures of Eurasia is clearly underlined by its relative motion. This relative motion towards west and its transformation to well expressed southwards displacement with velocities higher than 30 mm/y in the Aegean denotes the complicated crustal and mantle processes of this part of Eurasia.

3.4.2.2 Models

Speaking in general terms, because of the approaching between Africa and Eurasia, the related compression leads to creation of conditions for subduction along the southern and the western parts of the Aegean Region. The different authors are not significantly differing in their principal conclusions, and one of the contributions using at the best way the information from different sources is published by Mattauer, Mercier (1980). The analysis of Pavlides, Caputo (1994) came to the conclusion that the North Aegean Region represents a "tectonic paradox". At the end area of the North Anatolean Fault, at the northern part of the Aegean Sea, a compression should be expected, because of the right-lateral displacement along the fault. Practically, the known data speaks about regional extension with dominating North-South direction, and all authors agree with the extensional regime in the Earth's crust of the Northern Balkan Peninsula.

The geodynamic peculiarities of the Rhodopes are closely connected to the evolution of the structures of the upper mantle beneath the Balkan Peninsula. The published works,

based on different methods for interpretation of the P-wave residuals from earthquakes (Babushka et al., 1986, Spakman, 1986, Botev 1987, Botev et al., 1987, Spasov, Botev, 1987) have given reason to look at the deep structures beneath the Rhodopes from a new point of view (Shanov, 1998). Spakman (1986) interpreted high-velocity structures dipping to the north as remnants of paleosubduction zones beneath the Balkans. Botev (1987) reported about the existence of "a high-velocity body" beneath the West Rhodopes and supposed that the roots of the high velocity mantle go deeper than 250 km. Spassov and Botev (1987) drew attention to the fact that under some conditions the existence of a subducted mass can be supposed even at depth more than 250 km. The analyses of Shanov et al. (1987) showed the Rhodope Region as a zone over a high-velocity body in the mantle, its upper surface probably lying at a depth of about 140 km. One attempt for spatial designing of this heavy body was carried out, using the isoline of 1% relatively higher velocity. The upper surface of the body is shallowest beneath the island of Thassos (see Fig. 3.4.3.) where the depth is evaluated of about 100 km. It deepens towards the North-East and reaches a depth of 210 km under the Srednogorie tectonic zone (northern borders of the Rhodopes) where surface heat flow anomalies marked its boundaries. The areas with raised levels of seismicity (earthquakes of magnitudes more than 6.0) define in the brittle crust around this structure the places of the most active recent deformations and confirm the possibility of current movement of the detected heavy body in the upper mantle (Riazkov, Shanov, 1989).

Independently, Spakman et al. (1988) and Spakman (1990) used tomographic images of the upper mantle bellow the Balkan Peninsula to develop of anomaly patterns in the upper mantle from the North-West to the South-East along the Dinarides-Helenides boundary of the Eurasian Plate, which they interpreted as being an image of slab detachment. The deep part of the slab anomaly consists of two parts, not clearly separated in the tomographic inversion. Beneath the Northern Aegean and the Moesian Platform high velocities are mapped in the lithosphere, separated by an approximately 200 km wide "channel" of low velocities below the Rhodopes. Exactly beneath this zone, at a depth of about 200 km, is a high velocity anomaly pattern, interpreted as a slab detachment, which presumably migrated in time from Northern Adriatic towards the Southern Aegean (Spakman, 1990).

3.4.2.3. Possible causes for the extensional regime

At the area of the "tectonic paradox" of Pavlides & Caputo (1994), the velocity of the Anatolian Plate towards west accelerates from 10-12 mm/y even to 30 mm/y with clear tendency of southwest-southward "deviation" (Reilinger et al, 1998). According to the results obtained for the velocities of the laser sites for the European and Mediterranean area West and Central Europe – the "stable" part of the Eurasian plate, is moving northeastwards with an average velocity of 20-25 mm/y (Georgiev et al., 2001). The north – north-westwards motion of the Arabian plate and its impact on the Anatolian plate is expressed with rotation of the velocity vectors towards west along the North Anatolian Fault System.

Fig. 3.4.2. Model of the process of deviation of the Anatolean Plate, because the slab detachment in the Earth's mantle beneath the Rhodopes, and the consecutive creation of general north-south extension in North Aegean.
1 – zone of subduction; 2 – normal faults; 3 – general trend of movement of the plates; 4 – isodepths of the upper surface of the slab detachment [km]; 5 – direction of extension.

It seems that the slab detachment from the paleosubduction zone beneath the Rhodopes, with its deep roots is the obstacle making the Anatolean Plate to turn towards south – southwest. The area northwards from the North Anatolean Fault shows a displacement with velocity of about 2-3 mm/y in south-southeast to eastern direction relative to stable Europe. Thus, this displacement is in a good agreement to the dextral movement along the North-Anatolian Fault. But, taking into account the fact, that the motion of the Anatolian Plate is several times faster than the recorded for the area of the Central Balkan Peninsula, accepted as the southern edge of Eurasia, it is evident that the counter-clock rotation of the Anatolian Plate is accompanied by its southwards detaching from stable Europe. This is expressed exactly by the described north-south

tectonic extension in the structures of the Northern Aegean Sea area, and this could be also one possible explanation of the "tectonic paradox". On Fig. 3.4.2 is represented the model of this process, using the main results of the mentioned above number of publications.

3.4.3. Intraplate seismicity and the problems of the active faults on Bulgarian territory

The earthquakes epicentral map for the Central Balkan Peninsula (Fig. 3.4.3) shows that the seismic process is concentrated not only along the plates' edges. Inside the plate of the Balkan Peninsula the contemporary seismicity (taking into account also a number of historical earthquakes of magnitude more than 7) denote the existence of active faults having or supposed to have significant seismic potential.

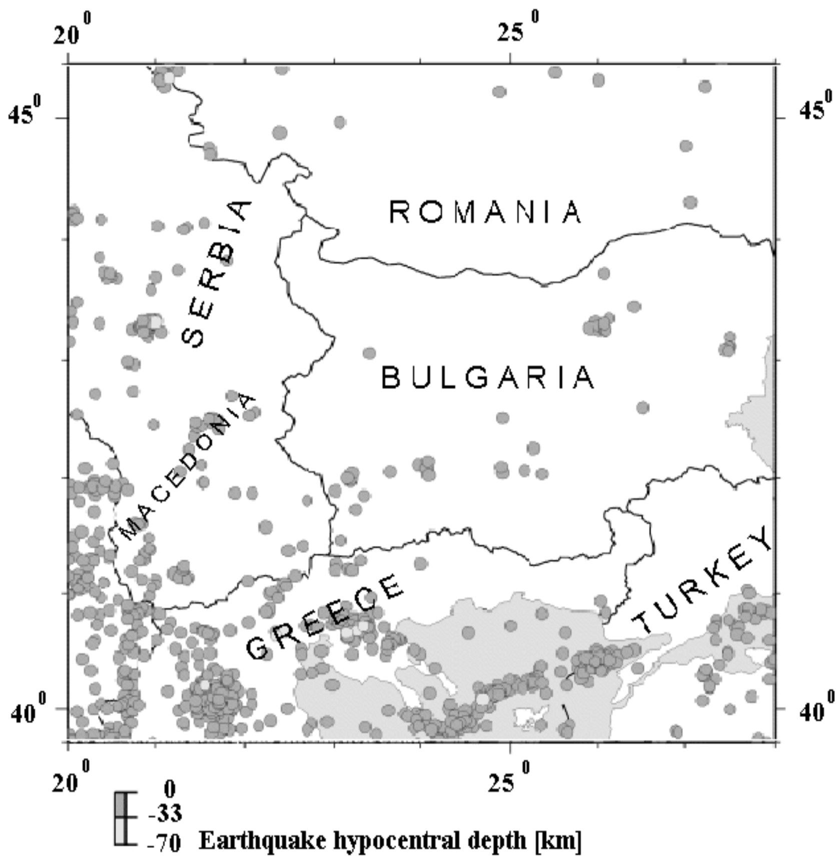

Fig. 3.4.3. Epicenters of crustal earthquakes (hypocentral depth less than 35 km) with magnitudes greater than 4.0 in the Central Balkan Peninsula for the period 1973-2005 (data from NEIS)

The map of the active faults (Fig. 3.4.4) for the territory of Bulgaria and the surrounding areas is based on all available geological and geophysical data. But only 10% of these faults were studied according to the most modern understanding how to describe the active fault. In many cases the offshore active faults are not well recognised. The unknown real geometry, segmentation and dynamics of the active faults may lead to overestimation or underestimation of the seismic and tsunami hazards. This fact is an obstacle for creating a more adequate picture of the faults systems and an improved seismotectonic model of the area.

Fig. 3.4.4. Map of the active faults for the territory of Bulgaria and the surrounding areas (created by A.Radulov, G.Nikolov and St.Shanov from the Laboratory of Seismotectonics, Geological Institute – BAS). The framed area includes Chirpan (1) and Popovitsa (2) Faults activated in April 1928 (M=6.8 and 7.1, respectively)

The recently published Geodynamic Map of the Mediterranean (Cadet, Funiciello, 2004), especially for the set of the active faults in Central Balkans is not acceptable because a number of errors. Only on the territories of Greece, Bulgaria and Turkey paleoseismological studies have been performed for evaluation of the seismic potential of active faults and the cycles of catastrophic earthquakes.

The performed studies on the territory of Bulgaria have shown some new peculiarities, maybe not well understood by the specialist on earthquake hazard and risk evaluation. The precise mapping of fault ruptures has been made for a part of the activated fault segment of Chirpan Fault and Popovitsa Fault during the two earthquakes of April 1928 (magnitudes 6.8 and 7.1). The faulting history is reconstructed for these two studied segments using the methods of Paleoseimology during the work from 2000 to 2005. The main conclusions of the studies are:

- **The type of the movement along the Chirpan Fault is with predominant normal component. Along Popovitsa Fault the movement is with predominant right strike-slip component (1.5 times exceeding the normal component). In the paleoseismological trenches we can compare only the normal components of the displacements from the earthquakes along the faults. For the moment we have not answer on the question if the triggering effect existed in the past.**
- **For Chirpan Fault they were established (Vanneste et al., 2006):**

- **4 events including 1928 earthquake and indirect evidence for one more event;**
- **Displacement 0.30 - >0.70 m (normal faulting);**
- **Paleoevents are of similar size or larger than 1928 earthquake;**

- **Mean recurrence interval 2900-2200 years;**
- **Slip rate 0.15-0.25 mm/year;**

- **For Popovitsa Fault they were established (Yaneva et al., 2004):**

- **4 events, including 1928 one;**
- **The sizes of previous events are similar to 1928 event;**
- **Recurrence interval: 1000-3000 years;**
- **Strike-slip component in fault kinematics.**

These results put a big question mark on the approaches for evaluation of the seismic hazard and, as a consequence, these ones for evaluation of the seismic risk. If the recurrence interval of the strong intraplate earthquakes is of similar rate, the probability for strong seismic events from the known fault segments for the nearest future is very low. So, most attention have to be directed to the faults of clear neotectonic or more recent activity according to geological considerations, but without expressed historical seismicity. This type of faults could be most important for the evaluation of the seismic hazard, because the highest probability to realise their sesmic potential at the nearest future.

3.4.4. Intramoesian fault: its unknown role as an active fault

The territory named Dobrudja is the northeastern part of the Moesian Platform. The potentially active Intramoesian Fault crosses Dobrudja from NW to SE, and it is of a length several times greater than the known active faults in Southern Bulgaria generating strong earthquakes of magnitude around 7.0 during the last century. This tectonic structure is known in Bulgaria as Silistra-Belgun Fault (Bokov, Chemberski, 1985), and in Romania as Intramoesian Fault. Romanian geologists prolonged Intramoesian Fault in Bulgaria, across the Danube River and along the continental border between the two countries (Fig. 3.4.5), exactly following the trace of Silistra-Belgun Fault. The same trace of the fault was recently plotted on the Geodynamic Map of the Mediterranean (Cadet, Funiciello, 2004), without any real arguments for its activity. In any case, it can be postulated that the Intramoesian Fault is an important key structure for solving the problems of the seismic hazard of the area. The known strong earthquakes that could be related to this structure is 1892 Dulovo Earthquake of magnitude evaluated at approximately 7.0 and the 1901 Shabla Earthquake evaluated at 7.1. The error of the location of the Dulovo earthquake by Bulgarian, Romanian and Russian authors is 200 km (Glavcheva, Radu, 1994). According to number of publications (as example: Vissarion et al., 1988, Hippolyte, 2002, Diaconescu et al., 2004, and many others) the Intramoesian Fault is an active tectonic structure in Romanian territory, representing SW bordering fault of the plate subducting below the Eastern Carpathians in the area of Vrancea. In other publications (Hippolyte, Sandulescu, 1996) the contemporary activity of the fault is under question. Thus, the identification of the geophysical and geological evidences supporting or rejecting the contemporary activity of the Intramoesian Fault is of significant importance for understanding the geodynamics of the area and for the seismic hazard assessment for both countries.

The unknown real geometry, segmentation and dynamics of the Intramoesian Fault may lead to overestimation or underestimation of the seismic hazard. Till now differences exist between Bulgarian and Romanian scientists for the fault networking design in this area. This fact is an obstacle for creating a more adequate picture of the faults systems and an improved seismotectonic model.

The location of geological active structure of 1892 Dulovo Earthquake and its magnitude is one of the important challenges of the future studies. For this part of the territories of Bulgaria and Romania we need a new and conform to the contemporary knowledge and conceptions Map of the Active Faults.

The segmentation of the fault is unknown, the length of the segments is of critical importance for evaluation of the maximum expected earthquake magnitudes. Theoretically it is not possible to represent more than 100 km long fault as active one. That is why special attention should be given to the identification of active fault segments and their branching and to their peculiarities.

Fig. 3.4.5. Regional sketch of the active faults and fault segments with the position of the Intramoesian Fault and the probable epicenter of 1892 Dulovo Earthquake

Till now Dulovo Earthquake fault structure was never identified (Fig. 3.4.5.), nor the time interval of the possible seismic cycle. Taking into account the low precision of determination of the probable epicentral area of this earthquake, it can be supposed the role of the Intramoesian Fault or related to it satellite fault structures.

3.4.5. Conclusions

The overview of some of the problems of the Seismotectonics of the Balkan Peninsula shows that the new geophysical and geodetic data have to be introduced in the seismotectonic models. The evolution of the ideas based on the new knowledge could be not acceptable for a number of scientists, but this is the only way for approaching and to solving the problems of the seismic hazard.

Till now, and maybe in the future, every new strong earthquake was and will be "unexpected event". The prediction of the time of occurrence and the magnitude is in fact unresolved problem. But we are able to propose better and better models for determining the zones of probable occurrence of strong earthquakes.

We need to revise the conception about the seismic hazard evaluation. The paleoseismological studies give a reason for different type of thinking about the faults that can be considered as capable to produce strong earthquakes in the nearest future.
The big challenge in the nearest future for the scientists working on Seismotectonics of the Balkan Peninsula will be the need to resolve some critical trans-border problems and step-by-step to approach the creation of unified and working models of the seismic hazard of the Balkan Peninsula.

It is necessary to create and promote as soon as possible projects directed towards resolving one important cross-border problems. The final aim of these projects has to be the seismic hazard assessment of large territories. As an example is the necessity of correct evaluation of the activity of Intramoesian Fault for identifying the risk to the safety of civil and industrial facilities on Bulgarian and Romanian territories. The importance for all Balkan countries is the harmonisation of legislation, guidelines, and methodologies with these of the European Union. This need is reflected in the requirements of EC8 (Euro Code 8) for civil building in seismically active areas. This is one very important step towards the correct forecast of the possible ground displacement, velocity and acceleration from strong and damaging earthquakes generated by active faults.

3.4.6. References

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