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STUDY OF PLATE TECTONIC TRANSITION BOUNDARIES IN BULGARIA FROM GPS

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Key words: *GPS, velocity, Euler pole, tectonic plate*

Abstract: *Three microplates in Bulgaria are inferred on the base of estimation of relative Euler rotation vectors and Euler poles with respect to the Eurasia stable plate and they fit very well with the tectonic setting of the territory of the country. GPS data from 26 GNSS permanent stations on the territory of Bulgaria and nearby have been processed with the Bernese software, version 5.0 and station coordinates and velocities have been estimated in ITRF2005, afterwards transformed into ETRF2000. Several groups of relative Euler pole parameters have been estimated in least squares adjustment process on the base of obtained ETRF2000 coordinates and velocities of several sets of GNSS permanent stations. Analysis of the estimated parameters of Euler pole confirm the suggestion given from other researchers that the Moesia platform belongs to the Eurasia plate. Two other microplates have been inferred in this study – Maritsa region and region belonging to the Aegean extensional zone, which boundaries match well with the tectonic boundaries. GNSS stations involved in this study cover evenly the whole territory of Bulgaria but denser network of stations will contribute to more precise verification of the transition zones.*

ИЗСЛЕДВАНЕ НА ГРАНИЦИТЕ НА ПРЕХОД НА ТЕКТОНСКИ ПЛОЧИ В БЪЛГАРИЯ ОТ GPS

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Ключови думи: *GPS, скорост, Ойлеров полюс, тектонска плоча*

Резюме: *На базата на оценки на Ойлеровите относителни ротационни вектори и Ойлеровият полюс по отношение на Евроазиатската стабилна плоча са изведени три микроплочи за територията на България, които съответстват много добре на тектонската обстановка на територията на страната. GPS данните от 26 GNSS перманентни станции на територията на България и от съседни страни са обработени с Бернския софтуер, версия 5.0. Координатите и скоростите на станциите са оценени в система ITRF2005 и са трансформирани в ETRF2000. Няколко групи относителни ротационни параметри и Ойлерови полюси са оценени чрез изравнение по метода на най-малките квадрати на базата на получените ETRF2000 координати и скорости за съответни конфигурации от GNSS перманентните станции. Анализът на оценените Ойлерови параметри потвърждават предположението, дадено и от други изследователи, че Мизийската платформа принадлежи към Евроазиатската плоча. В това изследване са изведени две други микроплочи: първата обхващаща Маришкия басейн, а втората – областта, принадлежаща към Егейската екстензионна зона, като получените граници за последната съответстват много добре с тектоничните граници. GNSS станциите включени в това изследване са равномерно разпределени по цялата територия на България, но една по-гъста мрежа от точки би допринесла за по-точно установяване и потвърждаване на преходните зони.*

Introduction

The region of Balkan Peninsula and in particular the territory of Bulgaria characterizes with active tectonics and seismotectonics. A number of geological, geophysical and geodetic investigations demonstrate the recent activity of the region and tried to give a reasonable and adequate

interpretation of the obtained results [2], [4], [5], [6], [7], [9], [11], based on the analysis of estimated stations velocities from GPS data processing.
This work is an attempt to contribute to clarify the boundaries of the Eurasian plate in the country with applying another approach for boundary determination, i.e. by applying the theory of Euler rotation pole to the estimated coordinates and velocities of freely accessible GNSS permanent stations operating in Bulgaria and nearby.

GPS data processing

For purposes of the study data from 26 GNSS permanent stations are used as 19 of them are on the territory of Bulgaria, 2 permanent stations in Romania, 4 permanent stations in northern Greece and 1 permanent station in north-east Turkey (*Figure 1*).

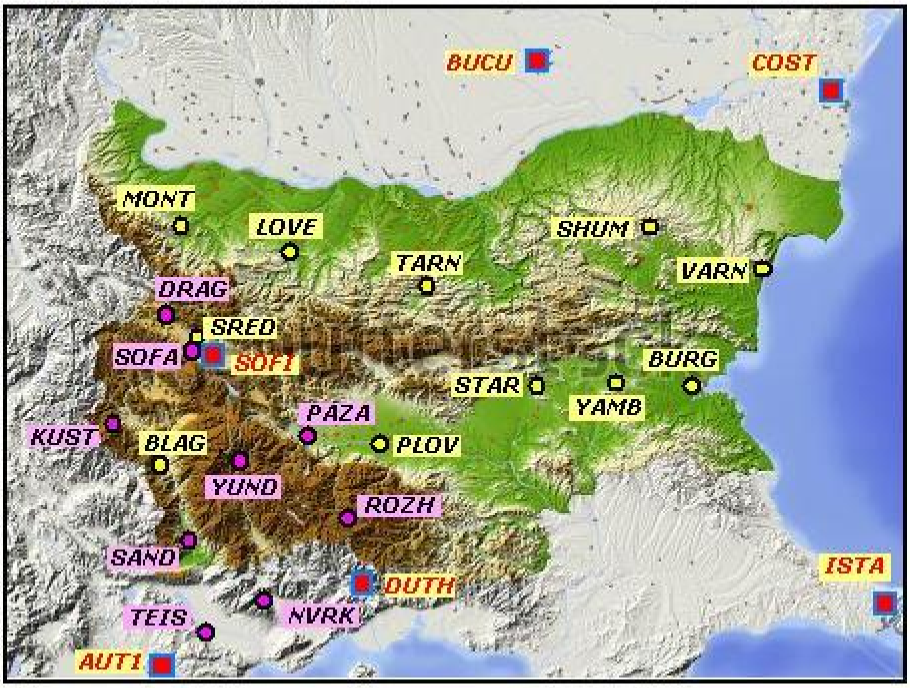

Fig. 1. GNSS permanent stations involved in this study

Velocity vectors used in this study were obtained earlier in two time frames [12], [13]. Station velocity vectors were estimated in [12], for the investigation of geodynamics of the territory of the Balkan Peninsula. For their estimation, one week GPS data in every year from 2006 up to 2010 were processed with the Bernese software, version 5.0 in ITRF2005. Obtained results for the Bulgarian stations - DRAG, SOFA, KUST, PAZA, YUND, SAND, VARN, ROZH, and SOFI are used for this study. The other part of the stations was involved in a later investigation [13] of GNSS BULiPOS permanent network [10]. One week GPS data of BULiPOS stations were processed with the same software, in the same coordinate system, in every year from 2009 up to 2011. To be consistent and comparable results for the station velocities in both works, all GPS data of BULiPOS network are reprocessed with the same IGS stations for datum definition as they are used in Vassileva, 2013a. New estimations of station coordinates and station velocity components (V_X, V_Y, V_Z) are obtained from their combined solutions in ITRF2005, referred to epoch 2000.0. For the local movements of the stations, which are more important for their behaviour, the ETRF horizontal station velocity vectors (*Figure 2*) have been obtained by applying ETRF components of the Eurasia plate rotation pole [1] to the obtained ITRF2005 velocity vectors. Then they have been transformed into ETRF2000.

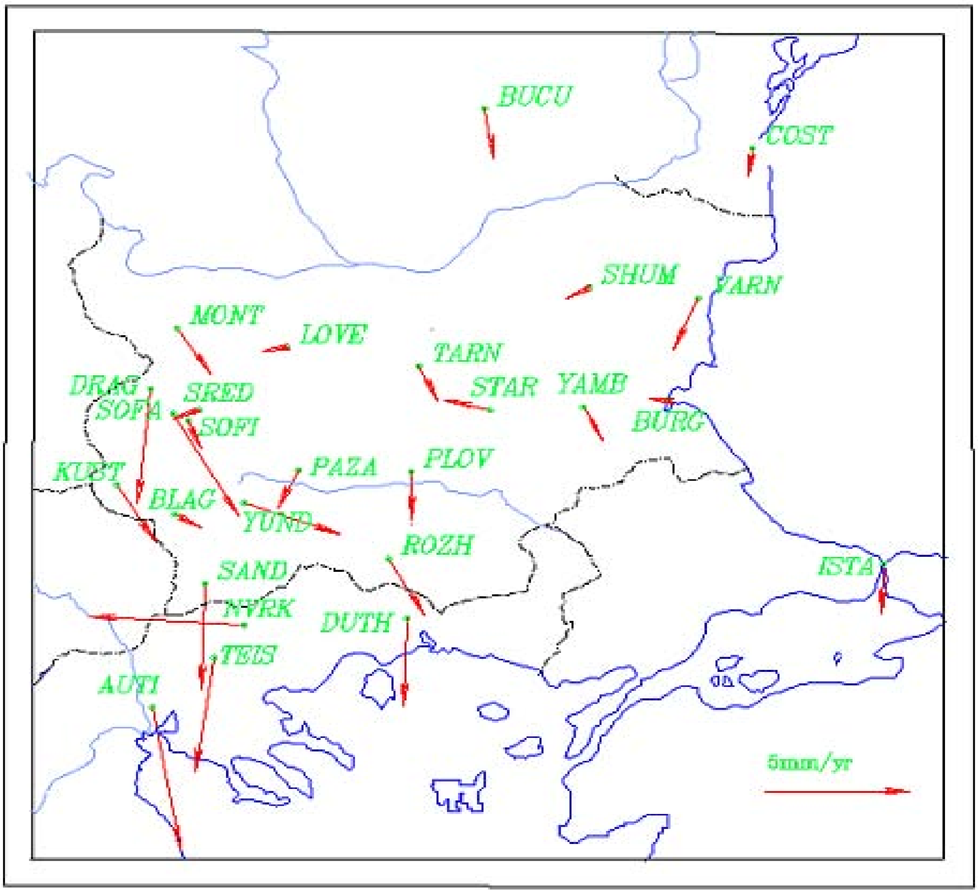

Fig. 2. Obtained ETRF2000 horizontal velocity vectors of participated GNSS permanent stations

The magnitude of the obtained horizontal station velocities varies from 0,2mm/yr up to 3,8mm/yr for the Bulgarian stations and up to 10mm/yr for stations in northern Greece. Such small magnitudes of movements of points over the territory of the country have been also obtained by other researchers [2], [4], [6].

Estimation of relative Euler rotation pole parameters

Different relative Euler rotation vectors and Euler poles are computed using resulting relative velocity vectors in previous section to obtain information about the motion of supposed microplates on the territory of the country.

The kinematic plate model of each tectonic plate can be presented by altogether six parameters: Euler rotation vector Ω (Ω_X, Ω_Y, Ω_Z) and Euler pole (φ, λ, Ω). Relation between estimated parameters of a single station – Cartesian geocentric coordinates (X, Y, Z) and station velocity components (V_X, V_Y, V_Z), and unknown values of the Euler rotation vector - Ω (Ω_X, Ω_Y, Ω_Z) gives the linearized observation equation for the station. Plate kinematic models are estimated by applying the least squares method using reduced to the Eurasia stable plate coordinates and velocities of GNSS stations. GPS relative velocity vectors are modelled as [10]:

(1) $$\vec{V} = \vec{\Omega} \times \vec{P}$$

or

(2) $$\begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} = \begin{bmatrix} 0 & -\Omega_Z & \Omega_Y \\ \Omega_Z & 0 & -\Omega_X \\ -\Omega_Y & \Omega_X & 0 \end{bmatrix} . \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

where P (X, Y, Z) is the vector defining the position of the GPS station, V (V_X, V_Y, V_Z) is the relative velocity vector at that station, and Ω (Ω_X, Ω_Y, Ω_Z) is the rotation vector defining the motion of the plate carrying the station.

Estimating Euler rotation vector Ω (Ω_X, Ω_Y, Ω_Z) it is possible to calculate the Euler pole (φ, λ, Ω).

(3) $$\varphi = arctan\left(\frac{\Omega_Z}{\sqrt{\Omega_X^2+\Omega_Y^2}}\right)$$

(4) $$\lambda = arctan\left(\frac{\Omega_Y}{\Omega_X}\right)$$

(5) $$\Omega = \sqrt{\Omega_X^2+\Omega_Y^2+\Omega_Z^2}\,.$$

Nine sets of stations with their estimated ETRF2000 coordinates and velocities have been configured considering the tectonic setting of the territory of the country (*Figure 3*, after Dabovski, Zagorchev, 2009) and respective parameters of the Euler rotation pole have been estimated.

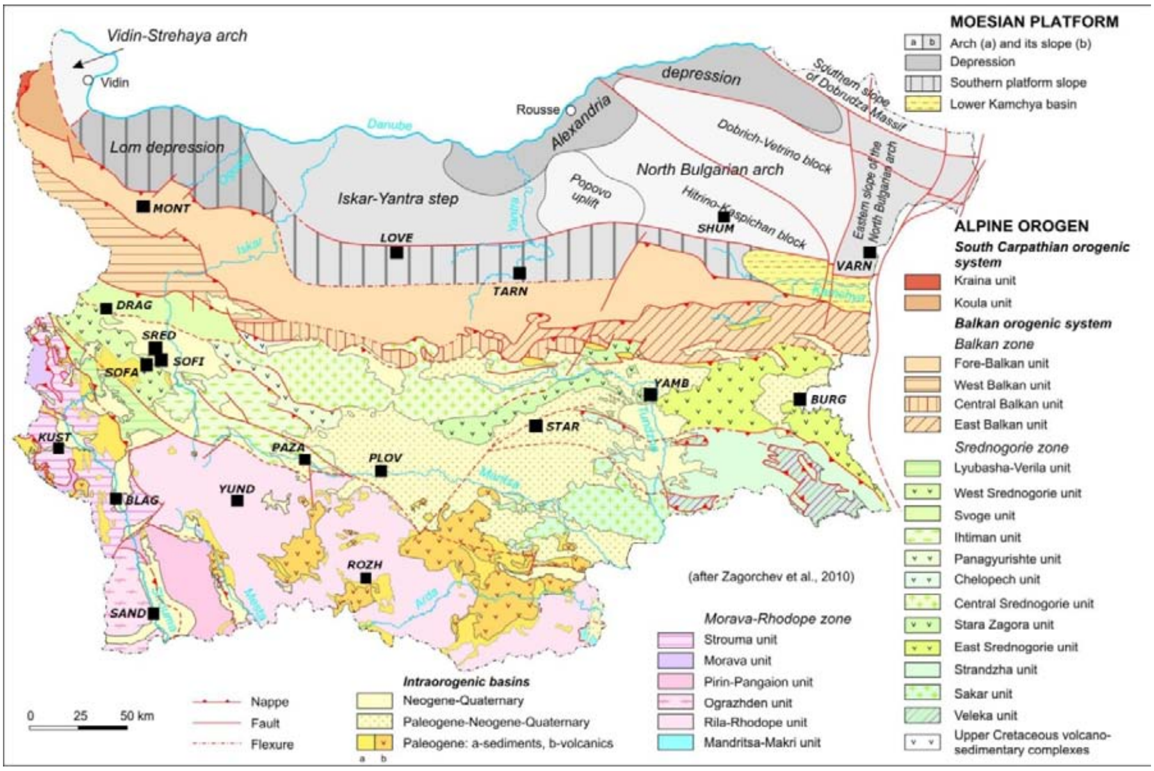

Fig. 3. Tectonic setting of Bulgaria, after Dabovski, Zagorchev, 2009 and location of GNSS stations

Burchfiel et al., 2006 and Kotzev et al., 2008 suggest that the northern boundary of the Aegean extensional region passes through the Central Bulgaria. Other researchers [4], [5], [8] also suggest that the boundary of the Eurasian plate follows the Balkan mountain chain. By this reason two main sets are configured from all stations in northern Bulgaria and two stations in Romania (*Table 1*- sets 1and 2) and respectively from all stations in southern Bulgaria, northern Greece and northern Turkey. The sets in south Bulgaria (*Table 1*- sets from 3 up to 9) are configured in such a way that stations gradually are added considering the principle tectonic extensional areas of Bulgaria (Figure 4, [14]) and to be followed the changes of the estimated Euler parameters.

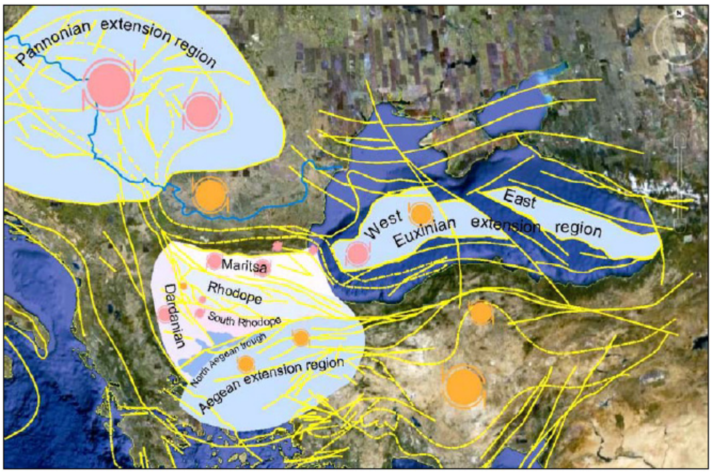

Fig. 4. Principle extensional areas and regional rotation patterns, after Zagorchev, 2011

Principal extensional areas – light blue, Principal faults – yellow,
Zone boundaries – dashed yellow lines, Block rotations – clockwise rotation in pink,
counterclockwise rotation in orange.

The obtained results for Euler pole (*φ, λ, Ω*) of all sets are given in *Table 1*.

Table 1. Inferred Bulgarian microplates relative to Eurasia plate

Microplate	***Set***	Ω_X [*mas/yr*]	Ω_Y [*mas/yr*]	Ω_Z [*mas/yr*]	λ [°]	ϕ [°]	Ω [*mas/yr*]	***Site Name***
Moesia plate	1	0.0702	0.0642	0.0918	42.4718	43.9861	0.1322	*MONT, LOVE, TARN, SHUM, BUCU, COST*
	2	-0.0491	0.0096	-0.0372	-11.086	-36.626	0.0624	*MONT, LOVE, TARN, SHUM, BUCU, COST, VARN*
Maritsa Basin	3	0.8402	0.4254	0.8594	26.8683	42.4020	1.2750	*SOFA, SOFI, SRED, DRAG, STAR, YAMB, BURG, PLOV,PAZA*
	4	0.7095	0.3724	0.7367	27.7107	42.6184	1.0885	*SOFA, SOFI, SRED, DRAG, YAMB, BURG, PLOV, PAZA*
	5	0.3911	0.2075	0.4104	27.9675	42.8497	0.6037	*SOFA, SOFI, SRED, STAR, YAMB, BURG, PLOV,PAZA,*
	6	0.4605	0.2393	0.4615	27.4751	41.6683	0.6945	*STAR, YAMB, BURG, PLOV,PAZA*
	7	0.4744	0.2585	0.4882	28.5990	42.1192	0.7282	*YAMB, BURG, PLOV,PAZA*
Aegean extensional region	8	-0.6380	-0.1793	-0.5515	15.7031	-39.7863	0.8622	*BLAG, KUST, YUND, SAND, AUT1, TEIS*
	9	-0.6147	-0.1600	-0.5374	14.5974	-40.2550	0.8321	*BLAG, KUST, SAND, AUT1, TEIS*

Discussion and conclusion

The obtained results of Euler pole for two sets of the Moesia microplate show quite different values and different rotation with adding the station VARN - set 2 (*Table 1*). We suggest that the reason for this result could be the local geology of the station VARN, which is located very close to the Black Sea coast.

The Euler pole parameters of the sets suggested for the Maritsa basin could be divided in two groups. First group consists of sets 3 and 4 and the second group consists of sets 4, 5, 6 and 7. The main difference between these two groups is that the station DRAG participates only in the first group. That could be interpreted as the station DRAG does not belong to the Moesia microplate. The results for two sets of the Aegean extensional region are very similar and they confirm the belonging of all these stations to this microplate. According to the results obtained in this study three major microplates, shown in figure 5 can be inferred for the territory of Bulgaria, which confirm the suggested principal areas by Zagorchev, 2011.

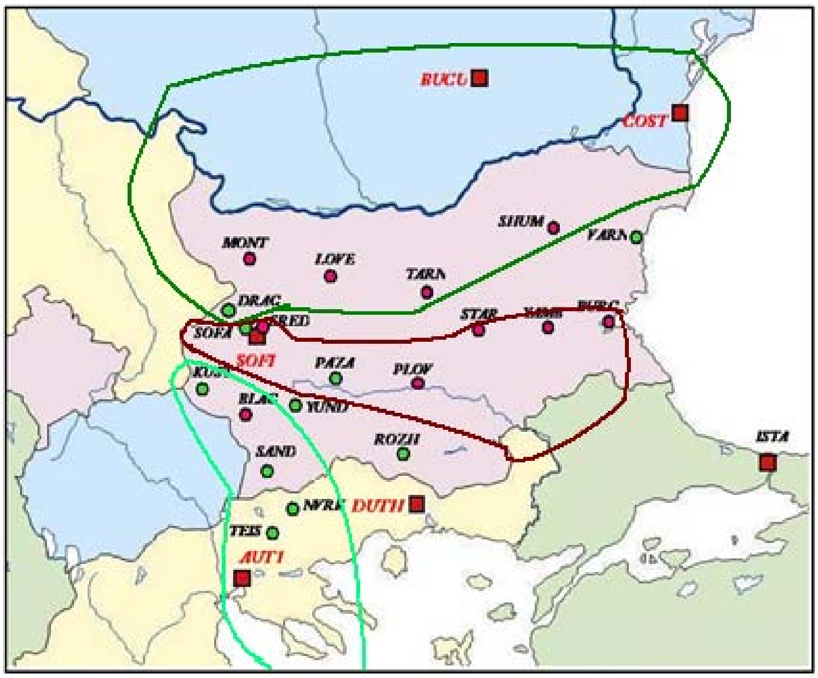

Fig. 5. Suggested microplates from this study – Moesia (in green), Maritsa (in dark red) and Aegean (in light green) zones

We tried to find the boundaries of the Rhodope region as proposed by Zagorchev, 2011, but the results are not optimistic due to the low number of GNSS permanent stations in this region.

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