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Crustal movements in Bulgaria from GPS solutions

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Outline

- **Introduction**
- **Effect of datum definition on estimated station velocities from GPS solutions**
  - ***Datum definition with minimum constraint conditions in GPS data processing***
  - ***GPS data processing of BULiPOS reference network***
- **Search of plate transition boundaries in Bulgaria with GPS**
  - ***Station horizontal velocities analysis***
  - ***GPS Data Processing***
  - ***Estimation of the parameters of the Euler rotation pole***
- **Discussion and conclusion**

Introduction

- The advanced GNSS (Global Navigation Satellite Systems) techniques have been recently used for geodetic observations and determination of the earth crust movements in millimeter level.
- Velocity vectors of located GNSS stations can be estimated in global and in local geodetic coordinate systems and their behaviour can be studied.
- However different datum definitions are used in data processing of different studies.
- As a consequence more or less different values of estimated station velocity vectors are obtained for identical stations and for geodynamic study their direct comparison is not reliable for validation of the results obtained.
- The effect of datum definition changes on the estimated station horizontal velocity vectors by using Bernese software have been studied for the case of a Bulgarian GNSS station network.

Introduction

- **Another important issue for the territory of the country, which characterizes with active tectonics are transition zones.**
- **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, based on the analysis of estimated stations velocities from GPS data processing.**
- **It is an attempt to contribute to clarify the transition boundaries 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 GNSS permanent stations operating in Bulgaria and nearby.**

Effect of datum definition on estimated station velocities from GPS solutions

Datum definition with minimum constraint conditions in GPS data processing

▪**GNSS data processing with Bernese software is based on the least squares method . Station coordinates and velocities are the most sought parameters of GNSS analysis.**

▪**Datum definition of coordinates and velocities can be defined with minimum constraints or by constraining coordinates and velocities of reference sites to a priori values.**

▪**Minimum constraint network conditions are based on the assumption that there are two reference frames:**

1) an a priori reference frame,

2) reference frame of the estimated coordinates (and velocities).

Both reference frames are related to each other by the 7-parameter transformation:

$$\begin{pmatrix} \tilde{X}_i \\ \tilde{Y}_i \\ \tilde{Z}_i \end{pmatrix} = \begin{pmatrix} X_i \\ Y_i \\ Z_i \end{pmatrix} + \begin{pmatrix} 1 & 0 & 0 & 0 & -Z_i & Y_i & X_i \\ 0 & 1 & 0 & Z_i & 0 & -X_i & Y_i \\ 0 & 0 & 1 & -Y_i & X_i & 0 & Z_i \end{pmatrix} = \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \\ \alpha \\ \beta \\ \gamma \\ \mu \end{pmatrix} \quad \textbf{or} \quad \tilde{X}_i = X_i + G_i \delta$$

Effect of datum definition on estimated station velocities from GPS solutions

GPS data processing of BULiPOS reference network

GNSS *BULiPOS* station network is the Bulgarian segment of the *EUPOS* (*European Determination Positioning System*) system and service.

Location of BULiPOS network stations (in red) and IGS reference stations introduced (in black)

Effect of datum definition on estimated station velocities from GPS solutions

One week GPS data from three years (2009, 2010 and 2011) of *BULiPOS* station network have been processed with Bernese software in ITRF2005. Estimated coordinates and velocities of the network stations have been obtained by applying the least squares method with minimum constraint conditions for coordinates and velocities of selected reference IGS stations.

10 IGS reference stations with their coordinates and velocities in ITRS realization ITRF2005, referred to the epoch 2000.0 have been used in the combined solution.

For representation the local movements of the stations which are more important for their behaviour study, the ETRF horizontal station velocity vectors have been obtained in ETRF2000.

The magnitude of the obtained *BULiPOS* horizontal station velocities varies from 0,2mm/yr up to 3,8mm/yr.

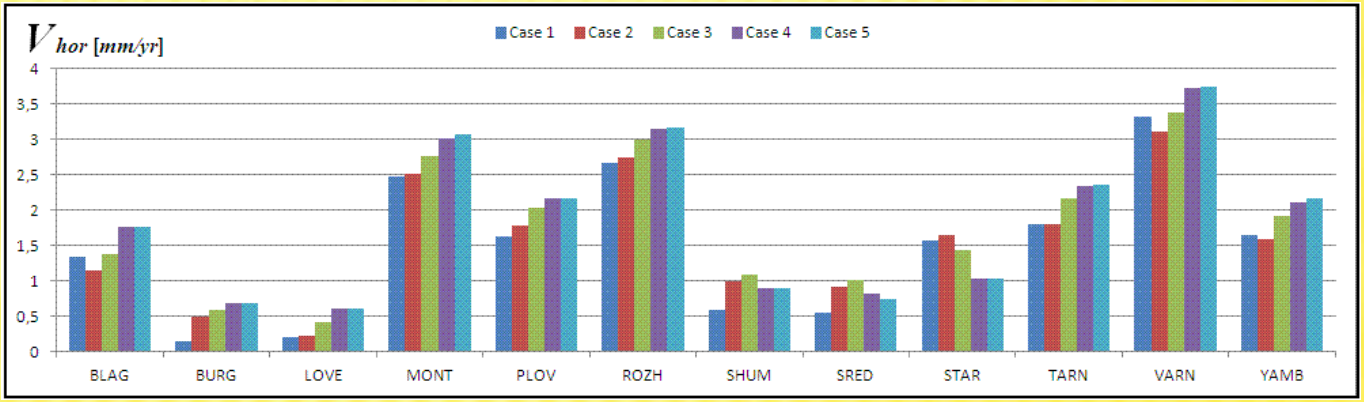
Five slightly more or less different datums defined by different number of the involved IGS reference stations have been applied in the combined solutions of three year's one week solutions of the network as follows.

Effect of datum definition on estimated station velocities from GPS solutions

Station horizontal velocities analysis

Obtained horizontal velocities from all 5 cases have been compared for the identical stations, shown in the figure below.

Differences between all 5 cases are almost with the same magnitude of 0,4÷0,6mm/yr for the majority of the stations. For some stations (BURG, LOVE, SHUM, SRED) the differences are comparable to the magnitude of the station velocities themselves

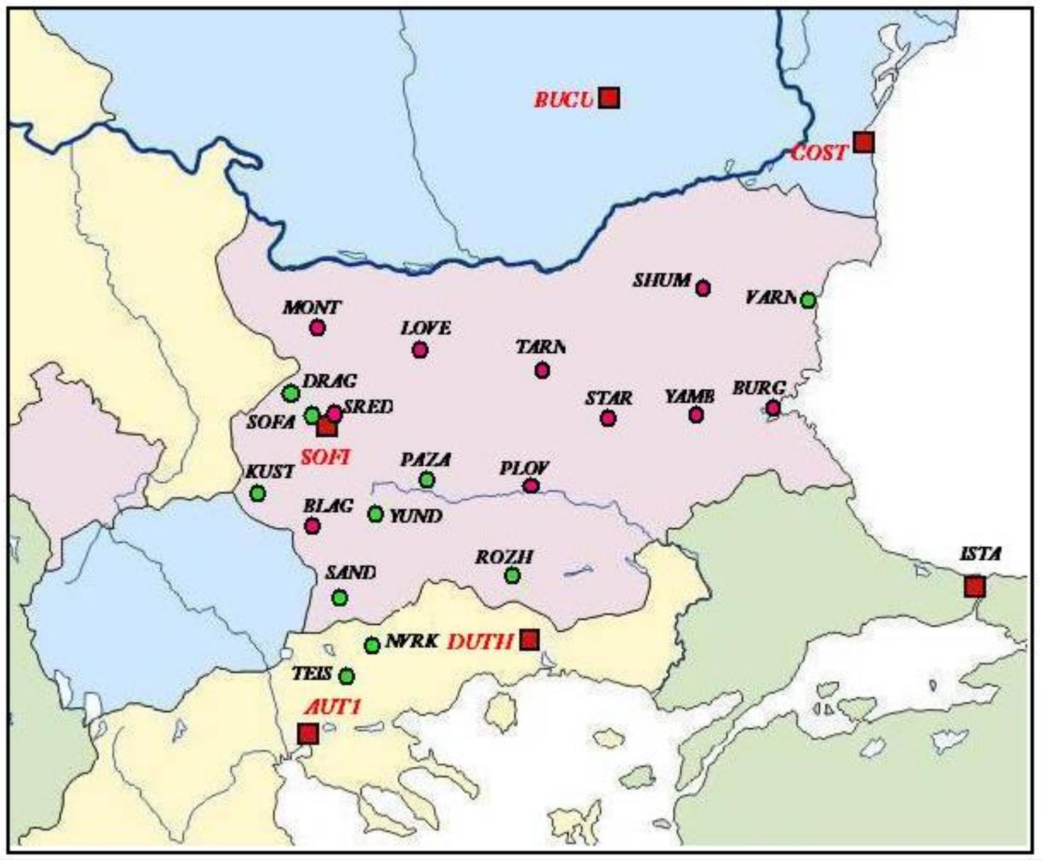


The obtained differences the horizontal velocities of stations with slow movements (0,2÷0,6mm/yr) show that the effect of the datum definition changes is significant. The problem arises due to the similarity of the magnitudes of differences and velocities themselves.

Search of plate transition boundaries in Bulgaria with GPS

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 .



Search of plate transition boundaries in Bulgaria with GPS

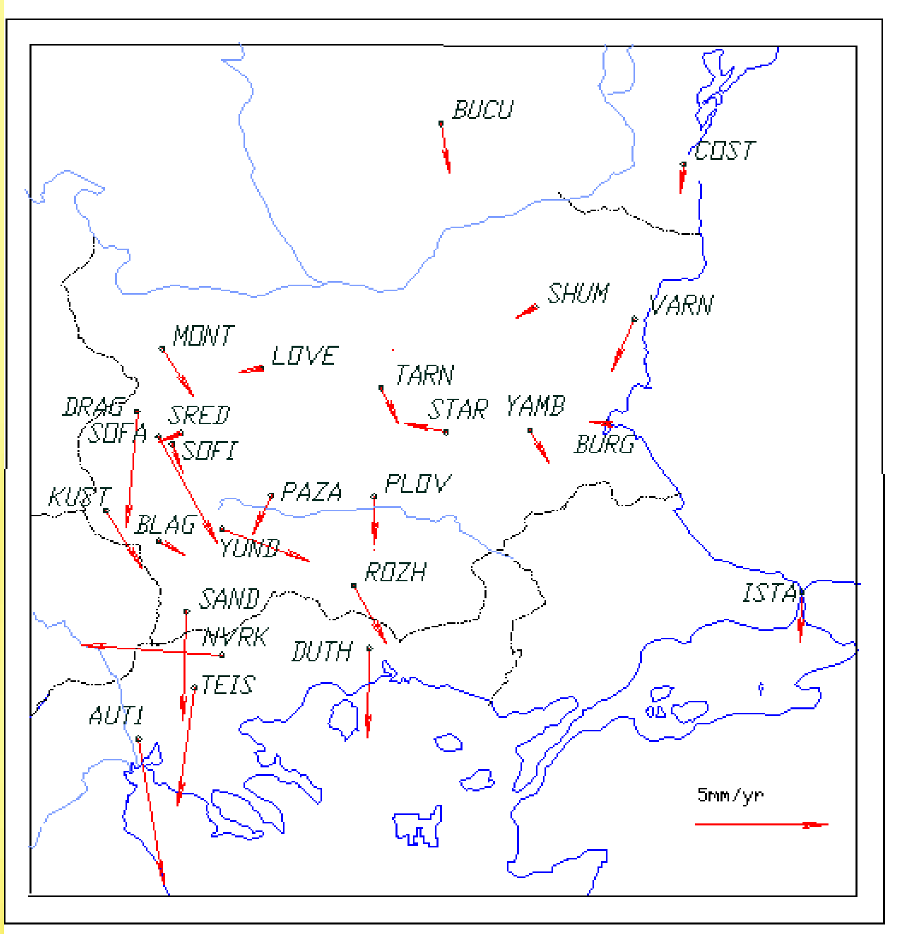
Velocity vectors used were obtained earlier in two time frames.

•From the investigation of geodynamics of the territory of the Balkan Peninsula.

•The other part of the stations was involved in the investigation of GNSS BULiPOS permanent network.

To be consistent and comparable station velocity results from both works, all GPS data of BULiPOS network are reprocessed with the same IGS stations for datum definition.

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 and transformed into ETRF2000.



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.

Search of plate transition boundaries in Bulgaria with GPS

Estimation of the parameters of the Euler rotation pole

Each tectonic plate included in some kinematic plate model has 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.

Using the estimated coordinates and velocities of GPS stations it is possible to estimate the plate kinematic model.

GPS velocities in a Cartesian geocentric frame can be modelled as:

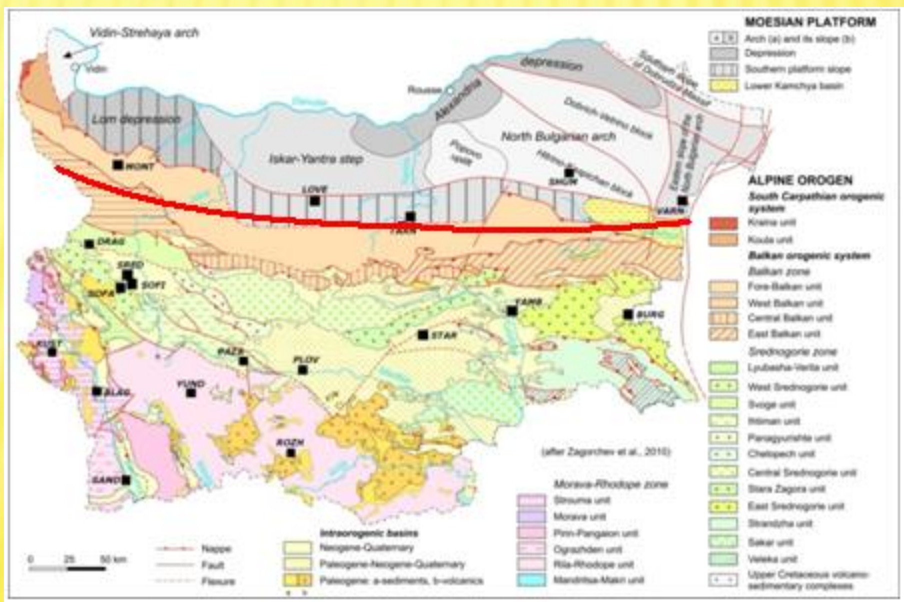
$$\vec{V} = \vec{\Omega} \times \vec{P} \quad \textbf{or} \quad \begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} = \begin{bmatrix} 0 & -\Omega_Z & \Omega_Y \\ \Omega_Z & 0 & -\Omega_X \\ -\Omega_Y & \Omega_X & 0 \end{bmatrix} . \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$\varphi = arctan\left(\frac{\Omega_Z}{\sqrt{\Omega_X^2 + \Omega_Y^2}}\right) \qquad \lambda = arctan\left(\frac{\Omega_Y}{\Omega_X}\right) \qquad \Omega = \sqrt{\Omega_X^2 + \Omega_Y^2 + \Omega_Z^2}\,.$$

Search of plate transition boundaries in Bulgaria with GPS

Burchfiel et al., 2006 and Kotzev et al., 2008 and other researchers suggest that the northern boundary of the Aegean extensional region passes through the Central Bulgaria, the boundary of the Eurasian plate follows the Balkan mountain chain.

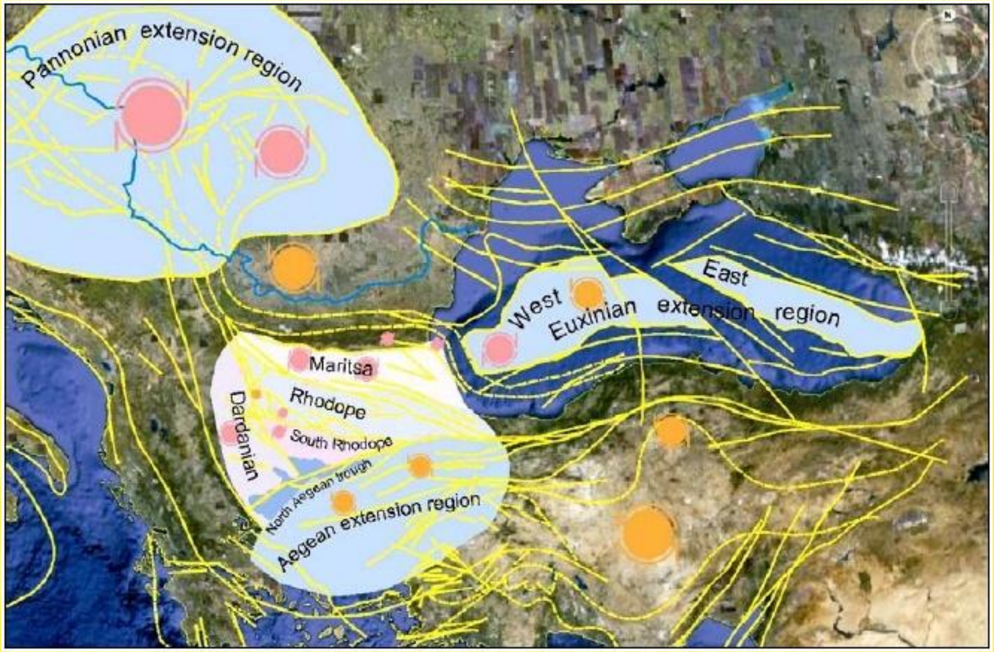
By this reason and considering the tectonic setting of the territory of the country 9 sets of stations with their estimated ETRF2000 coordinates and velocities have been configured and respective parameters of the Euler rotation pole have been estimated.



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

Search of plate transition boundaries in Bulgaria with GPS

The sets in south Bulgaria are configured in such a way that stations gradually are added considering the principle tectonic extensional areas of Bulgaria (figure below) and to be followed the changes of the estimated Euler parameters.



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.

Search of plate transition boundaries in Bulgaria with GPS

Inferred Bulgarian microplates relative to Eurasia plate

Micro plate	*Set*	Ω_X	Ω_Y	Ω_Z	λ	ϕ	Ω	*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***

Search of plate transition boundaries in Bulgaria with GPS

Micro plate	*Set*	Ω_X	Ω_Y	Ω_Z	λ	ϕ	Ω	*Site Name*
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***

Search of plate transition boundaries in Bulgaria with GPS

Micro plate	*Set*	Ω_X	Ω_Y	Ω_Z	λ	ϕ	Ω	*Site Name*
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

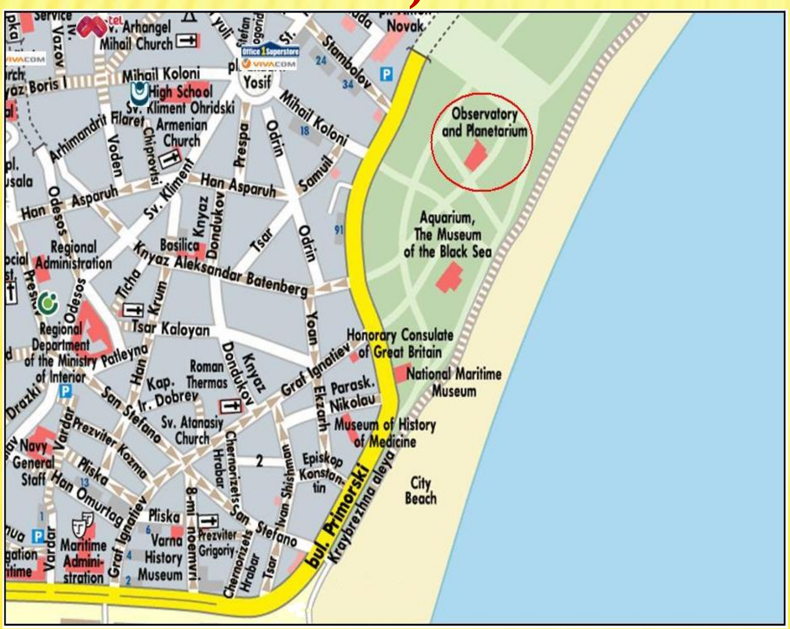
- **This study shows that changes in datum definition result different estimations of the station velocities and the effect is very important and significant in combined use of velocities taken from different sources as input data in geotectonic and/or in geophysical investigations and interpretations.**

- **For reliable comparison and validation of horizontal velocity estimations from different studies it is necessary to be taken into account datum definitions.**

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.

- The suggested reason for this result could be the local geology of the station VARN, which is located very close to the Black Sea coast (on the building roof of the National Astronomical Observatory (NAO) in the Sea Garden).



Location of Varna Permanent Station

NAO – at the edge of the Galata formation:

- Sands with layers of clays,
- Sandstones and
- Rarely conglomerates.

Towards the sea are revealed contemporary marine formations (beach sands) – Quaternary; Holocene

Discussion and conclusion

The Euler pole parameters of the 5 sets suggested for the Maritsa basin could be divided in 2 groups.

The main difference between these two groups is that the station DRAG participates only in the first group and the Euler pole parameters are different.

- **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.**

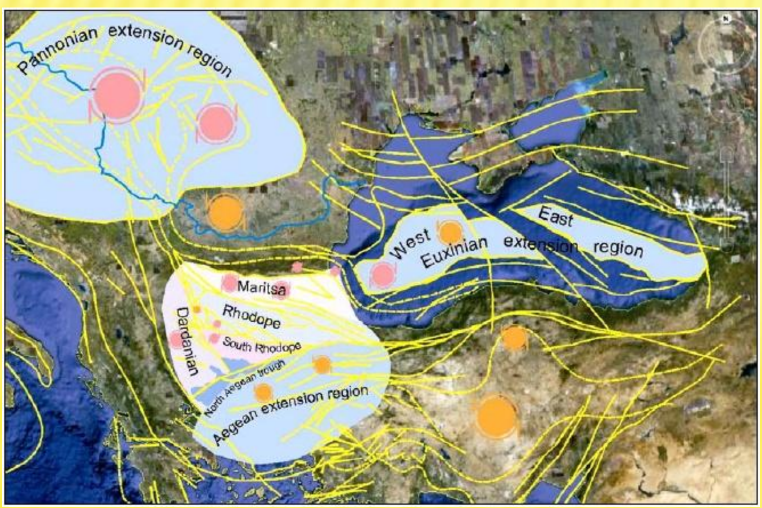
Discussion and conclusion

- **According to the results obtained in this study <u>three major microplates</u> can be inferred for the territory of Bulgaria, which correspond the suggested principal areas by Zagorchev, 2011.**

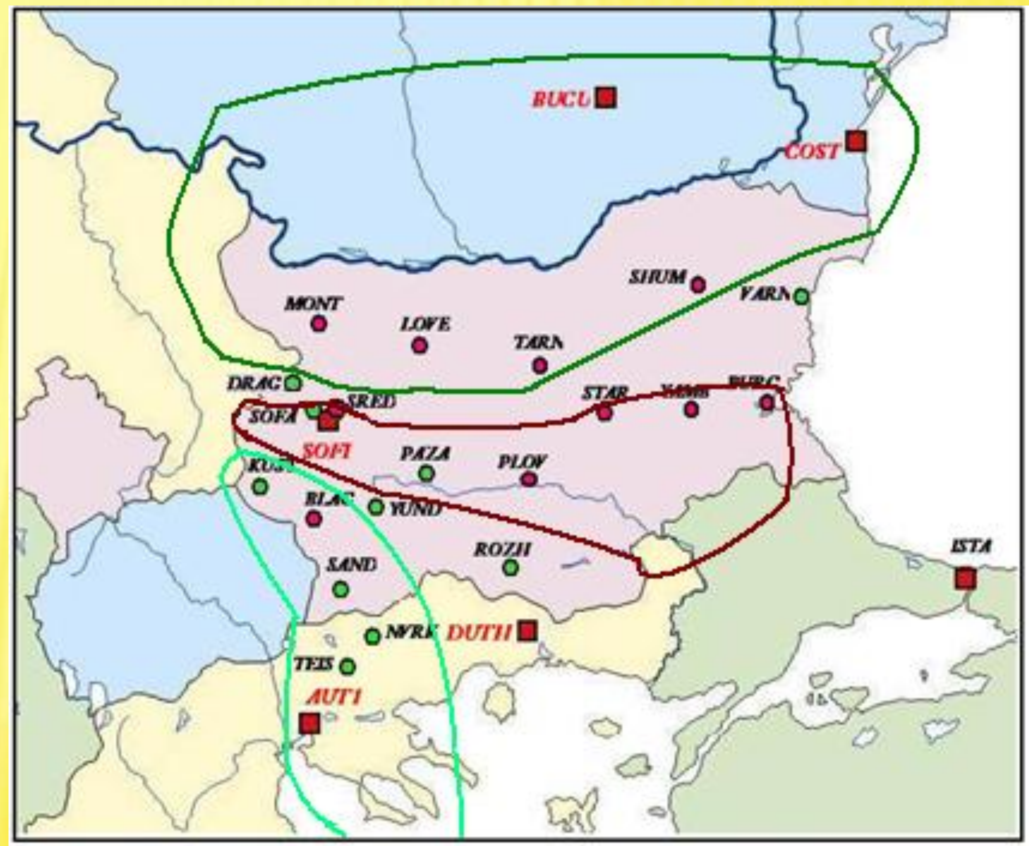
Moesia zone

Maritsa zone

Aegean zone



Principle extensional areas, after Zagorchev, 2011



Suggested microplates from this study

THANK YOU FOR YOUR KIND ATTENTION

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