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Geodetic monitoring of the recent crustal movements in Southwestern Bulgaria

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Introduction

South-western (SW) Bulgaria is the most active tectonic area with high seismicity in Bulgaria. The area (fig. 1.) belongs to the southern marginal parts of the Central-Balkan Neotectonic Region — a zone of recent extension of the Earth's crust with complex interference of horizontal and vertical movements of the geological structures (Zagorchev, 1992, 2001). The area is in the north of the North Aegean Neotectonic region, and is greatly influenced by its tectonics and high seismicity. The strongest earthquake for the last two centuries in Europe occurred in SW Bulgaria in the Krupnik-Kresna region with magnitude M ~ 7.8 (Botev, 2000). Recent crustal movements in SW Bulgaria are resulted from the long time extensional movements in the inner part of the Aegean region although the kinematic model of the North Aegean and Central Balkan regions is still under debate. The region has a key position in the regional neotectonics and recent tectonics being situated at the crossing points between several important fault belts (lineaments): the NNW-SSE striking Struma (Kraishtid) lineament, the WNW-ESE striking Maritsa Lineament, and the northernmost western feathering faults of the North Anatolian Fault (NAF) zone (Zagorchev, 1992).

GPS network, data analysis and velocity solution

A GPS network for monitoring the present-day kinematics in SW Bulgaria and West Rhodope has been established in early 2001. The network consists of 38 points chosen to cover the main tectonic structures and to provide spatial coverage throughout this region (fig. 1 and fig. 3). The points are monumented into solid bedrock with bronze and stainless steel bolts. The network includes three EUREF points and two triangulation first-order points: the highest peaks on the Balkans — Musala (2925 m) and Vihren (2918 m). One point of the regional network is a point from a local geodynamic network in Krupnik — concrete pillar with enforced centring device.

GPS sites are measured in campaign mode, every year in the period from 2001 to 2004. Expected velocities in the region are up to 2-3 mm/yr (McClusky et al., 2000). Simultaneous GPS observations are performed with Trimble 4000SSE, Trimble 4400 and Trimble 5700 receivers equipped with L1/L2 ground plane antennas. All observations are made with sampling rate of 30 seconds and 10^0 elevation masks. Data from previous GPS campaigns (1996, 1997 and 1998) were used for some points — three EUREF points (SATO, PETR and SAPA), and FROL, PADA, MALA and BELM (Милев и др., 1999). The typical occupation time for each site in 1996, 1997 and 1998 is 48 hours and for 2001—2004 campaigns — over 36 hours.

All SW Bulgaria GPS campaigns are processed in the International Terrestrial Reference Frame 2000 (ITRF2000). The processing of the data was performed with the Bernese Software 4.2. Data from 10 IGS stations are integrated in the analysis to constrain the network into a global reference frame. Ionosphere models for Europe are used to help the ambiguity resolution and troposphere parameters for each station (for details see Georgiev and Dimitrov, 2006). For East Mediterranean region the Eurasia plate is assumed to be stable and velocities are given relative to the rigid Eurasia. All GPS results are relative to the Eurasian plate after the rigid rotation of the plate is removed (fig. 3).

Vertical movements from repeated levelling measurements

The study of the recent vertical movements of the Earth's crust is carried out using the existing first and second order levelling lines in the region of SW

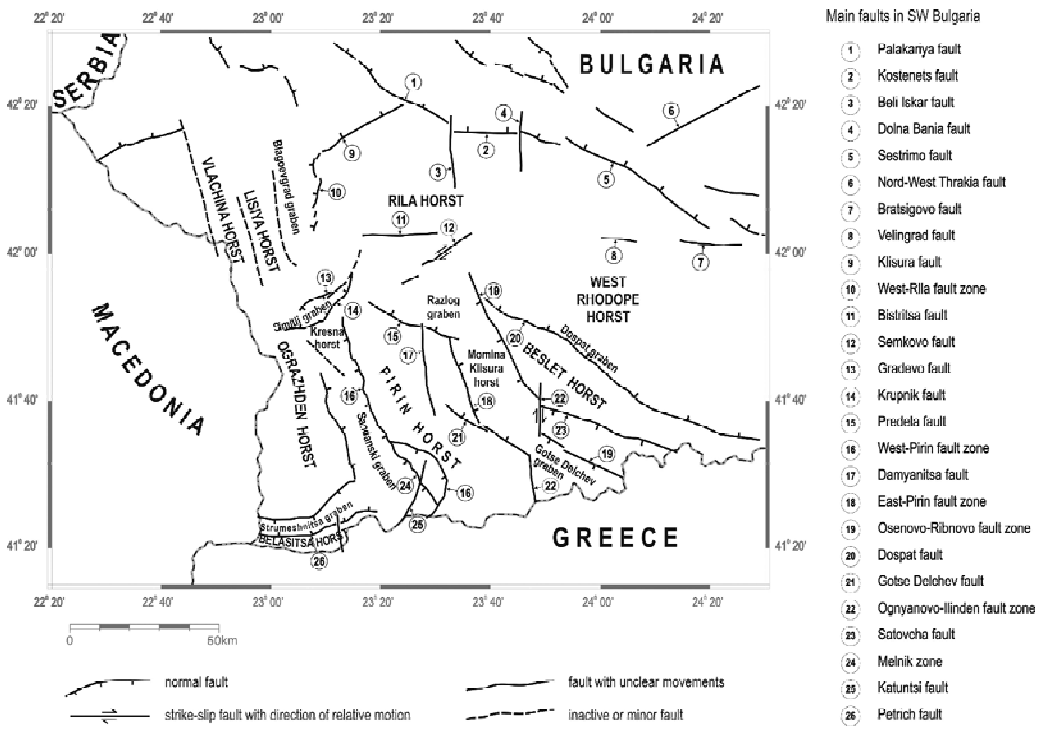

Fig. 1. Scheme of main tectonic structures in SW Bulgaria

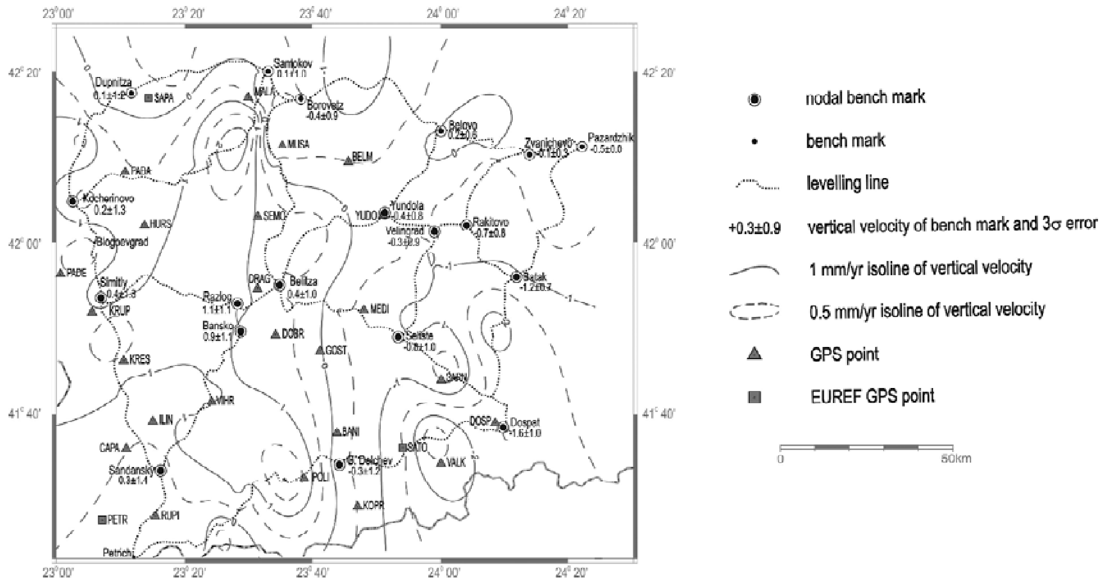

Fig. 2. Map of the recent vertical movements of the SW Bulgaria region

Bulgaria. The measurements along the 16 levelling lines, which formed 10 loops, are performed in three cycles. The number of nodal benchmarks is 19, as 12 of them are located on the first order lines. The sections of the first order lines between nodal benchmarks are considered as single lines. The vertical velocities are calculated assuming linear vertical movement in time.

The nodal benchmark in Pazardzhik is chosen as the initial for the levelling network adjustment for the whole SW Bulgaria region. The rms of the adjusted relative velocities is ± 0.14 mm/yr per km and the rms for the whole network calculated from the loop's misclosures is ± 0.13 mm/yr. The absolute vertical velocities are within the range of -3.0 to +1.2 mm/yr and -1.6 to +2.4 mm/yr for the first and sec-

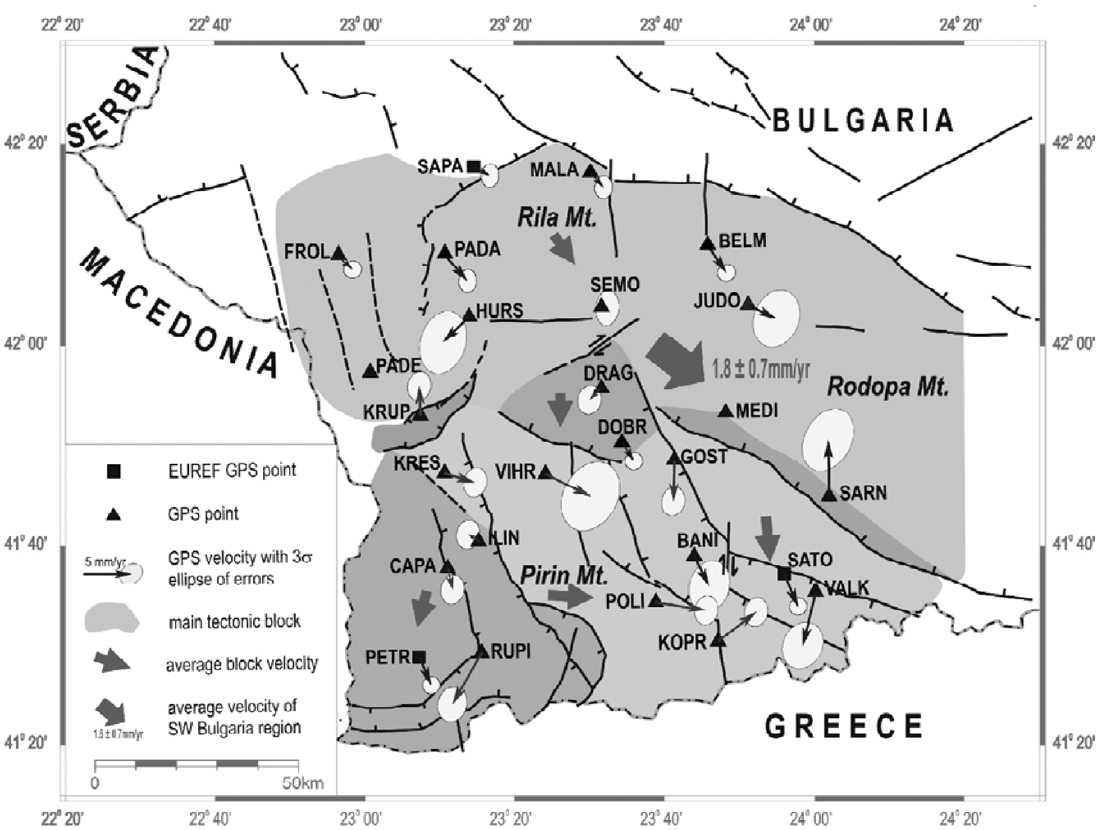

Fig. 3. GPS-derived velocities with 95% confidence ellipses relative to Eurasia for sites in SW Bulgaria and blocks with homogeneous movements

ond order levelling lines, respectively. The absolute values of vertical velocities for all benchmarks are plotted on a map and the isolines are drawn up by interpolation (fig. 2).

Geodetic constrains in SW Bulgaria

The horizontal velocities of 38 GPS points in the region of SW Bulgaria indicate movement in the south-southeast direction with respect to the stable Eurasia. The average velocity is of about 1.8 ± 0.7 mm/yr (fig. 3). This movement is in good agreement to the dextral movement along the NAF zone.

On the map of the vertical movements the zero velocity isoline divides the SW Bulgaria region to an eastern part with predominant negative, and a western part with predominant positive values. There is a clearly expressed uplifting of the west part of the Rila horst, which is separated from the horst itself by the Beli Iskar fault. Local uplifts are found out south from Blagoevgrad and from Krupnik, respectively. According to the geological data they coincide with the Momina-Klisura horst and Kresna horst, which have been uplifting during the Neogene. Negative velocities are predominant for the whole West Rhodope region with the minimum value of — 3 mm/yr in the region of Satovcha. Based on the tectonic structures, the obtained horizontal and vertical crustal movements, we separate the SW Bulgaria at five zones with homogeneous movements (fig. 3). The average movements of each block range from 1.3 to 3.4 mm/yr.

Conclusions

A GPS geodynamic network of 38 sites is established in SW Bulgaria in order to monitor the present day deformation associated with recent tectonic processes. Based on analysis of geodetic data we conclude that: the SW Bulgaria region has displacement with velocity of about 1.8 ± 0.7 mm/yr in southeast direction N154^0 relative to stable Eurasia; SW Bulgaria could be divided on five homogeneous according to its movements blocks; vertical movements show that the Rila and Pirin Mountains are uplifting as confirmed by geological data, as the West Rodhope is subsiding.

The general tendency of the area of SW Bulgaria is the southeast movement relatively to Eurasia with increasing velocities from north to south. Based on the obtained results from GPS measurements movements, we can speculate, that there is tectonic activity along the West Pirin fault, which marks the eastern margin of the Sandanski graben, the Melnik fault and probably also the Katuntsi fault. The Krupnik fault is undoubtedly recently active. The Predela and Dospat faults are marked as active normal faults. Activity is indicated along the northeast border of the Gotse Delchev graben — the Satovcha normal fault.

The obtained results constrained the complicated tectonic model of the SW Bulgaria and contribute to understand the dominant regional extension N-S regime. The movement of the SW Bulgaria is in agreement with this of Northern Greece and clarifies the regional geodynamic settings and is in a good agreement also to the dextral movement along the NAF (McClusky et al., 2000). Considering that the movement of the Aegean plate is several times faster than this in the SW Bulgaria region, it is evident that the counter-clock rotation of the Anatolian and Aegean plates is accompanied by its southwards detaching from stable Europe. This is expressed exactly by the north-south tectonic extension in the structures of the Northern Aegean Sea area — west North Anatolian fault and North Anatolian trough strike-slip and extensional zone (Shanov et al., 2001; Zagorchev, 2001).

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Геодезически мониторинг на съвременните движения на земната кора в Югозападна България

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Резюме. Районът на Югозападна България попада в южната част на Централно-Балканския неотектонски район и граничи със северната част на Северно-Егейската сеизмична зона. Съвременните движения на земната кора и сеизмичността се определят предимно от субдукцията в Йонийско и Адриатическо море и процесите, свързани с движенията по Северно-Анадолския разлом. През 2001 г. в Югозападна България бе изградена GPS мрежа от 38 точки за изследване на тектонските деформации. От анализа на GPS измерванията за периода 1996—2004 г. е получено векторно поле на хоризонталните скорости. Скоростите са определени спрямо стабилната част на Евроазиатската тектонска плоча. Изработена е карта на съвременните вертикални движения на земната кора, като са използвани прецизни нивелачни измервания за периода 1929—1991 г. Въз основа на съвместния анализ на геоложките и геодезическите данни, Югозападна България е разделена на пет хомогенни по отношение на движенията си блока. Средната хоризонтална скорост на целия район е 1.8 ± 0.7 mm/yr с посока N154^0. Получените резултати допълват сложния тектонски модел на Югозападна България и допринасят за изясняване на геодинамичната обстановка в Северно-Егейския регион.