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SURFACE SEISMIC DEFORMATIONS IN THE PLOVDIV REGION (BULGARIA) BY SPACE GEODESY AND SEISMOLOGY DATA

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***Abstract:** The two major April'1928 shocks in the Plovdiv region (Central Bulgaria) are very well documented by description of the observed 105 km long surface breaks. The leveling data evaluated the classical seismic vertical changes with maximum uplift 0.53 m and maximum subsidence 1.05 m. Nowadays modern GPS data with classical triangulation observations are used to determine the seismic horizontal deformations in the region. GPS measurements are carried out in 1993 by the Central Laboratory of Geodesy and the Institute du Globe de Paris, using the well preserved original monuments of the first and second order pillar of the triangulation network. A second GPS campaign is carried out over the same network in 2003 in collaboration with the Royal Observatory of Belgium. The results of the GPS measurements analysis are correlated with seismological data.*

1. Regional tectonics and active faulting

The earthquakes of April, 14 and April, 18 1928 occurred North of Aegean Sea in Upper Thrace Lowland in Bulgaria (High Maritza Valley) between the Rhodope massif at South and the crystalline Balkan mountain at North (Fig.1). The structural trend is approximately N-S in Dinarides and Hellenides at East; then turns NW-SE in Rhodope montains to E-W in the Balkan, as shown by the topography and the courses of large rivers. These mountain belts have been formed mainly in late Mesosoic and early Neogene as a crustal shortening was taking place between the converging Africa and Eurasia plates. In post-Oligocene the region appears mostly under N-S crustal extension and is considered to be the far of northen part of the Aegean stretched domain [1]. Other hypothesis emphasized on a two-stage evolution resulting from the recent propagation of North Anatolian fault to the already slowly extending Aegean domain [2].

In Bulgaria, the normal faults strike mostly E-W to E-SE and are slightly oblique to the fabric in the Rhodope and the Balkan belts. They are less developed than the normal faults in Central Greece and Western Turkey (Fig. 1) some of which have ruptured with clear surface breaks: Thesaloniki, Ms=6.4 in 1978; Grevena Ms=6.6 in 1995 [3].

Ten destructive earthquakes (I>VIII) in High Maritza valley, between Rhodope and the Balkans mountain belts have been mentioned during the last millennium [4]. There occurred also the April'1928 sequence. Their epicentral area corespond to a large E-W asymmetric graben filled with Neogene continental sediments and Quaternary alluvials.

The Maritza fault system could be considered as N-W extension of North Anatolian fault system [5].

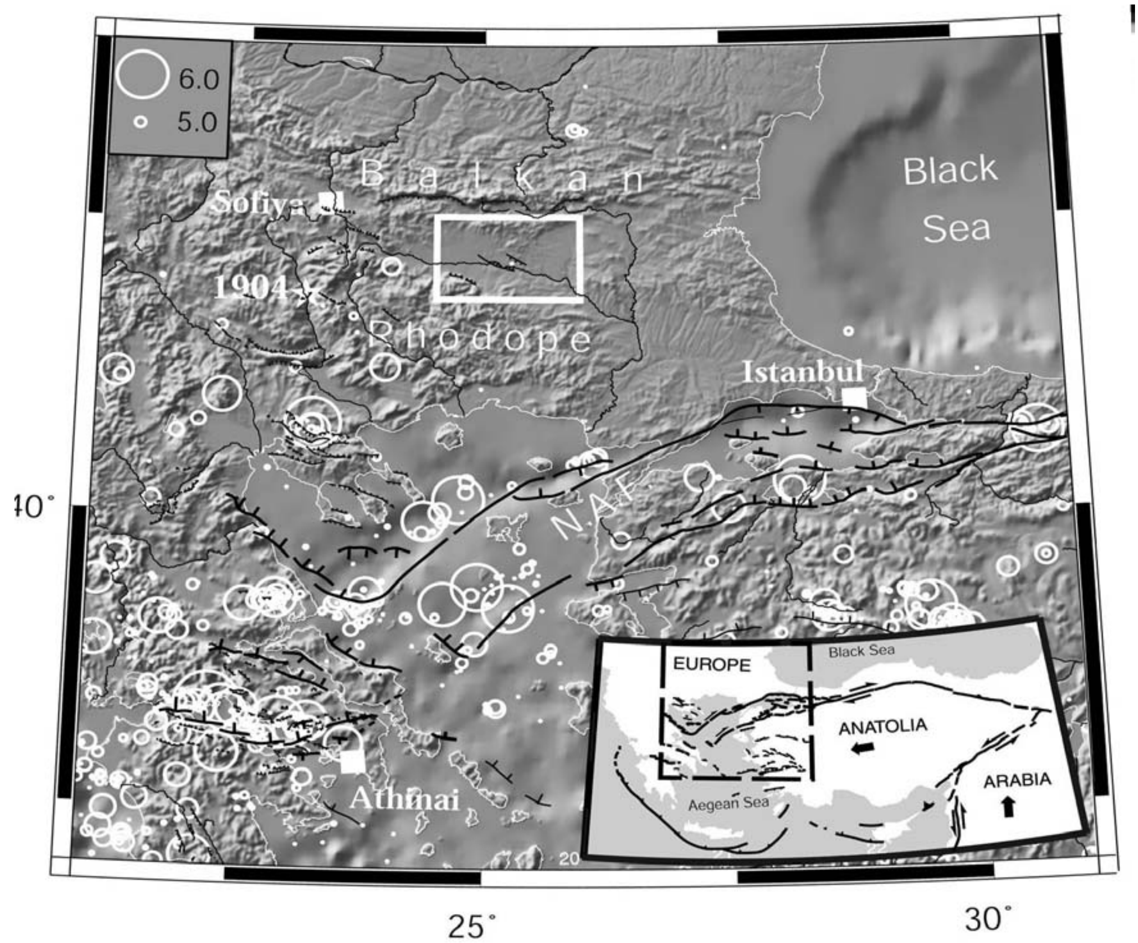

Figure 1. Seismo-tectonics of the Noth-East of the Mediterranean area. Seismicity (1964-1999) from the ISC catalogue and DEM from GTOPO 30. White star indicates location of the 1904 Struma earthquake. N.A.F. relate to the North Anatolian Fault system termination in the Aegean. Active faults compiled from bathymetry, geological studies and satellite imagery by Armijo et al. (1999); Meyer et al., 2002). Box outlines the Plovdiv area enlarged in the next figures.

2. Geodetic data

The two major earthquakes (M=6.8 and M=7.0, [6]) occurred on April 14, and April 18, 1928 and affected a large area of about 3000 km^2 causing the destruction of 5 towns, more than 240 villages and many other important damages. Many reports with detailed descriptions of the very important tectonic deformations have been published. The National Cartographic Institute of Bulgaria (NCI) performed levelling surveys of the area before and soon after the earthquake [7] providing a very important set of co-seismic elevation changes [8].

2.1. Angular observations 1926 and GPS measurements 1993

In 1926 the NCI performed measurements on 1-st and 2-nd order triangulation network in Plovdiv area. The same net was partially re-measured in 1928 soon after April, 14 and 18 earthquakes. The random error for the angular observations 1926 was estimated at ≤1.0" (arc-sec) [7]. In 1958 only 5 triangulation points were re-observed in the zone showing angular change of 11.13" at distance of 11.5 km. These observations confirm evident co-seismic deformation of the network. The original monuments and benchmarks of this network being very well preserve are now used to carry out GPS survey in order to estimate horizontal deformations associated with co-seismic *(and post-seismic ?*) stages of seismic cycle.

The first GPS campaign was realized in October 1993 by the Central Geodetic Laboratory of the Bulgarian Academy of Science (BAS) in cooperation with the Institute de Physique du Globe de Paris (IPG) and the Cartographic Military Institute of Bulgaria. The coordinates of eleven points of the 1926 triangulation network were re-determined by using Ashtech GPS receivers. Twenty-two GPS bases were measured. The data set has been adjusted by 3D-adjustment program in order to obtain relative coordinates for 1993. The resulting RMS residual [O-C (Observation-Calculation)] is ± 11 mm. The fixed points are located on Balkan Mountain, far from the affected zone. Despite the low accuracy of the former triangulation measurements, the displacement vectors are consistent with NS to NNE-SSW extension of the zone with maximal displacement of 83 cm ± 13 cm between Popovitza and Parvomai (Fig. 2).

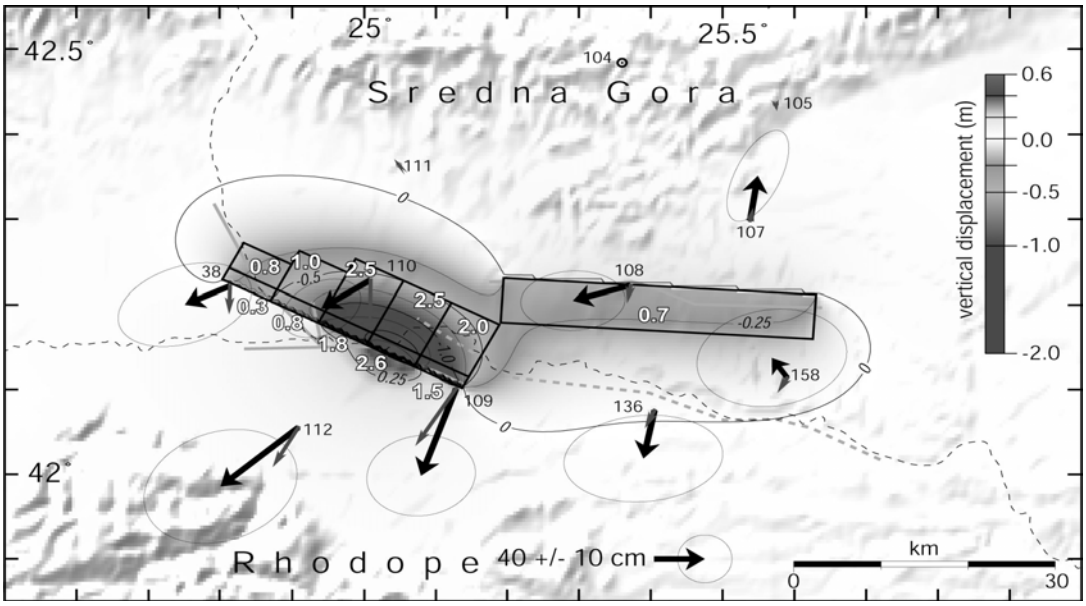

Figure 2. Dislocations (black rectangles) with the corresponding slip (in meters) that produce the vertical field displacement presented with thin contour lines (every 0.25 m). The horizontal relative to point 104 “co-seismic” vector observations are plotted in black thick arrows and vectors predicted by the model in fine arrows.

2.2. GPS measurements 2003 and comparison with GPS measurements 1993

In 2003 a second GPS campaign was realized by CLG in collaboration with Observatoire Royal de Belgique (ORB). The network of 1993 was re-measured in order to determine recent (post/inter-seismic) displacement vectors. Data acquisition was made at minimum 2 days x 8h with 15 seconds rate. Both 1993 and 2003 GPS surveys have been processed with same method and software. The horizontal velocities 1993-2003 relative to same point in Sredna Gora montain are reported in Fig. 3. The analysis of geodetic data from two GPS campaigns shows recent tectonic deformations in the region. The evaluated inter-seismic horizontal deformation velocities 1993 - 2003 is ≤ 1mm/y and shows succeeded (continuous) tectonic activity, associated with the main faults of April, 1928 earthquakes.

3. Fault geometry of April'1928 EQ by modelling of geodetic co-seismic data

The revised fault geometry of April' 1928 Bulgarian earthquakes by analysis of levelling and GPS data compiled by Okada's models of co-seismic displacements in homogeneous half-space [9] indicates - in agreement with surface breaks and other field data- that the observed surface breaks could be satisfactory explained by 2 main faults:

- one normal fault striking N 94.5^o E associated with April,14 earthquake: 36 km long and 10 km wide, dipping 60^o South, with a normal slip of 0.7 m; Total moment Mo = 0.96x10^{19} [N.m] corresponding to Mw = 6.7. The Southern rupture of April, 14 shock following very closely the bed of Maritza River is interpreted as a secondary fissure;
- one listric fault associated with April,18 main shock, composed by 10 sub-faults striking N 118.6^o E, dipping 75^o NE near the surface and 45^o NE in depth; 31 km. length, width varying from 14 km to 10 km at the NW extremity. The normal slip varies from 0.3 to 2.6 m near the surface and up to 2.5 m in depth, its dextral strike-slip component is in conformity with the focal mechanism. The total moment Mo = 2.8 x 10 ^{19} [N.m], corresponds to Mw = 7.0.

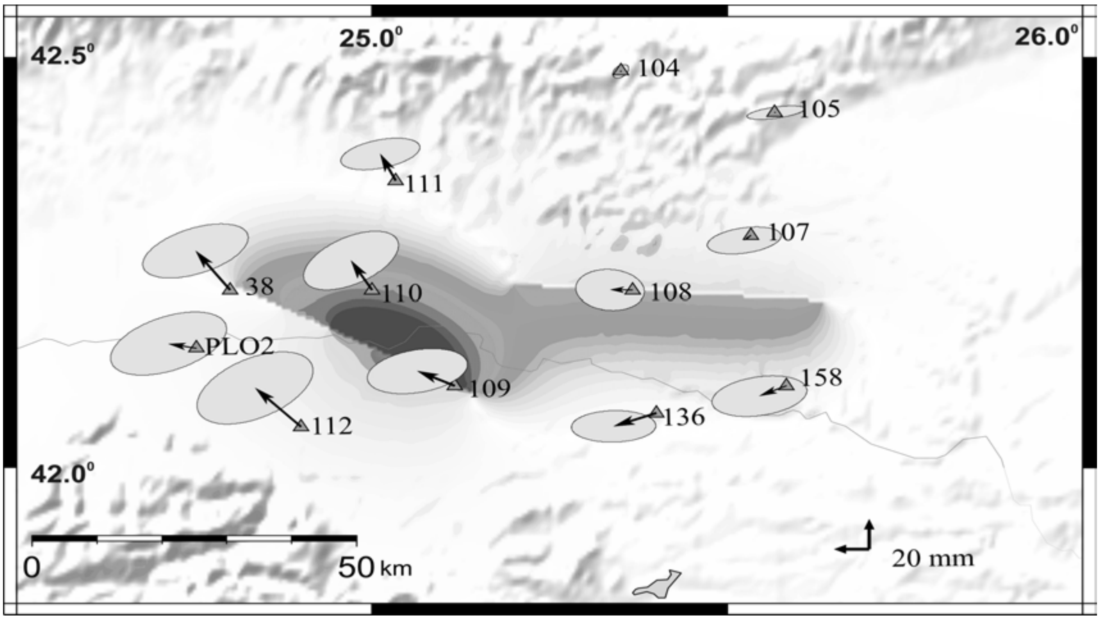

Figure 3. "Inter-seismic" vectors (relative to same point 104) of horizontal displacements derived from 1993– 2003 GPS campaigns are plotted with 95% confidence ellipses.

4. Discussion and conclusion

The analysis of triangulation data 1926 and GPS data 1993 revealed the co-seismic displacement vectors of 11 stations - a NNE-SSW extension with maximum displacement of 83 cm ± 13 cm in the zone of major co-seismic vertical displacement. The analysis of both GPS geodetic data 1993 and 2003 revealed the recent tectonic deformations in the region. The evaluated inter-seismic horizontal deformation velocities 1993 - 2003 is rather than 1mm/y, and shows succeeded tectonic activity associated with the main faults of April, 1928 earthquake.

The co-seismic and succeeded inter-seismic deformation in the Plovdiv 1928 Earthquakes is related on the main faults of Maritza fault system associated with NE -SW tectonic extension North of Aegean system.

The analysis of the instrumental seismicity of Maritza Valley during the period 1980 – 2004 is based on the results of the National Seismological Network monitoring [10, 11]. The epicentral and depth distribution of the major part of the earthquakes (with M> 2.5) in the zone are located around the main April, 1928 earthquakes faults (Fig.4a,b). Surface deformations in the region of Plovdiv by space geodesy are compatible with seismological data and also are in agreement with recent study for seismic cycle [12].

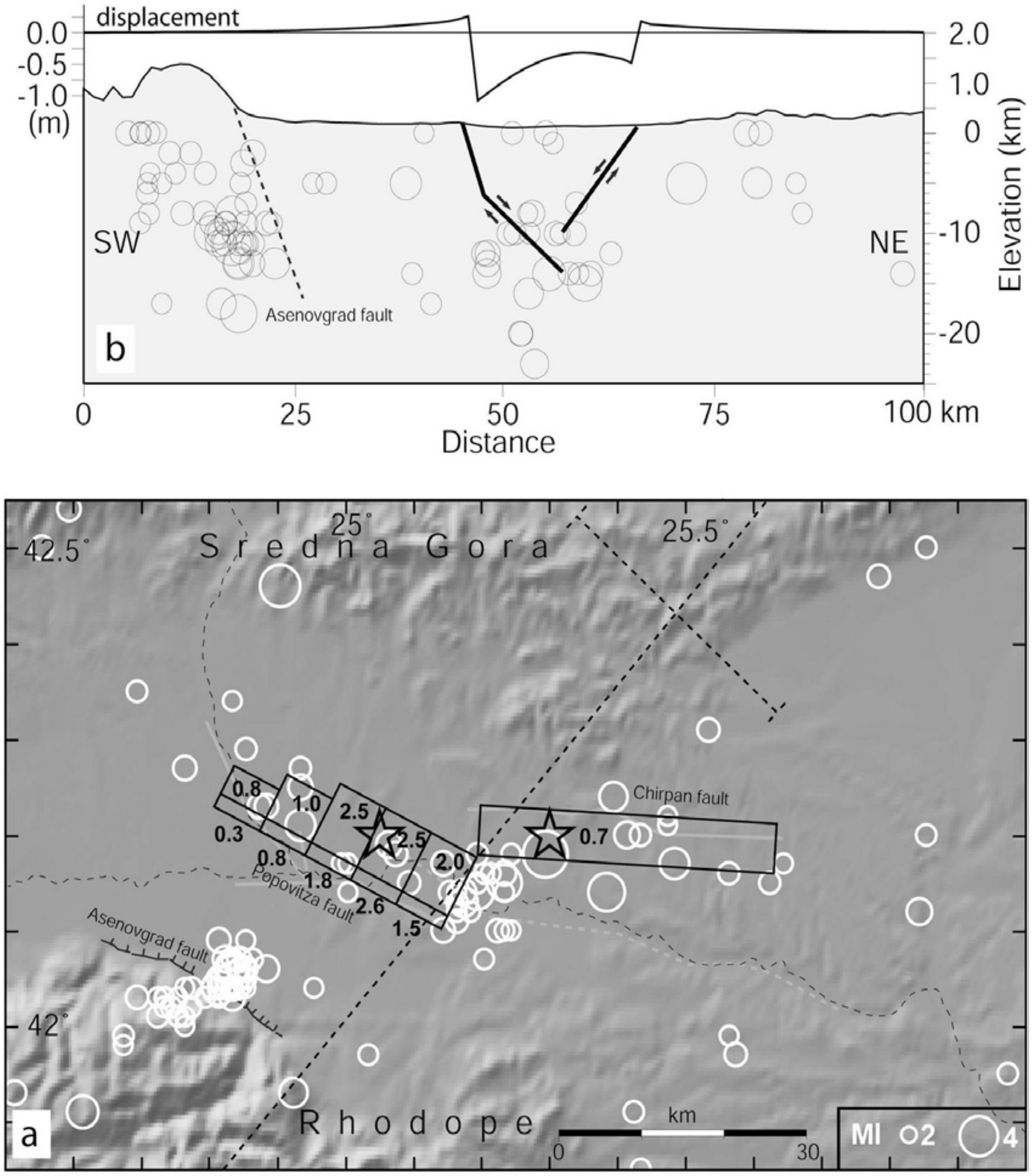

Figure 4. (a) Fault model with slip amount (in meters) and instrumental seismicity 1980-2004 (Ml>2.5) determined by the Bulgarian National Telemetric Seismic Network show an activity recorded on the main April, 1928 earthquakes faults. Dashed line refers to cross-section presented in Fig. 4b. (b) Cross-section of the seismicity, fault model and topography projected from SW to NE. Note scale exaggeration for topography (x5 to the right). Top - surface vertical displacement predicted by model presented in Fig.3 (scale to the left).

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