GEOSCIENCES 2006

The 14 and 18 April 1928 Chirpan-Plovdiv Earthquakes – fault model from geodetic and seismic data

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Key words: geodetic data, earthquakes, active faults

Regional tectonics and active faulting

The earthquakes of April, 14 and April, 18 1928 occured 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. 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 (Jackson, Mc Kenzie, 1988). Other hypothesis emphasized on a two-stage evolution resulting from the recent propagation of North Anatolian fault to the already slowly extending Aegean domain (Armijo et al., 1999).

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 some of which have ruptured with clear surface breaks: Thesaloniki, Ms=6.4 in 1978; Grevena Ms=6.6 in 1995 (Meyer et al., 2002).

Ten destructive earthquakes (I>VIII) in High Maritza valley, between Rhodope and the Balkans mountain belts have been mentioned during the last millennium (UNESCO, 1974). There occurred also the April'1928 sequence. Their epicentral area correspond to a large E-W asymmetric graben filled with Neogene continental sediments and Quaternary alluvials.

Geodetic data

The two major earthquakes (M=6.8 and M=7.0, Karnik, 1969) 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 (Mirkov, 1932) providing a very important set of co-seismic elevation changes (Jankov, 1938 — cited by Richter, 1958).

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) (Mirkov, 1932). 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.

Fault geometry of April'1928 EQ by modelisation from geodetic and 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 indicates- in agreement with seismic data, surface breaks and other field data — that the observed surface breaks could be satisfactory explained by 2 main faults (fig. 1):

— one normal fault striking N 94.5° E associated with April,14 earthquake: 36 km long and 10 km wide, dipping 60° South, with a normal slip of 0.7 m; Total moment Mo = 0.96x1019 [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°E, dipping 75° NE near the surface and 45° 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.

Discussion and conclusion

The proposed final model is consistent with the available seismologic and tectonic data. Taking a shear modulus of 33 GPa, the model yields a moment of 1.0×10^{19} Nm (Mw = 6.7) for the April, 14 earthquake and 2.8×10^{19} Nm (Mw = 7.0) for the April, 18 con-

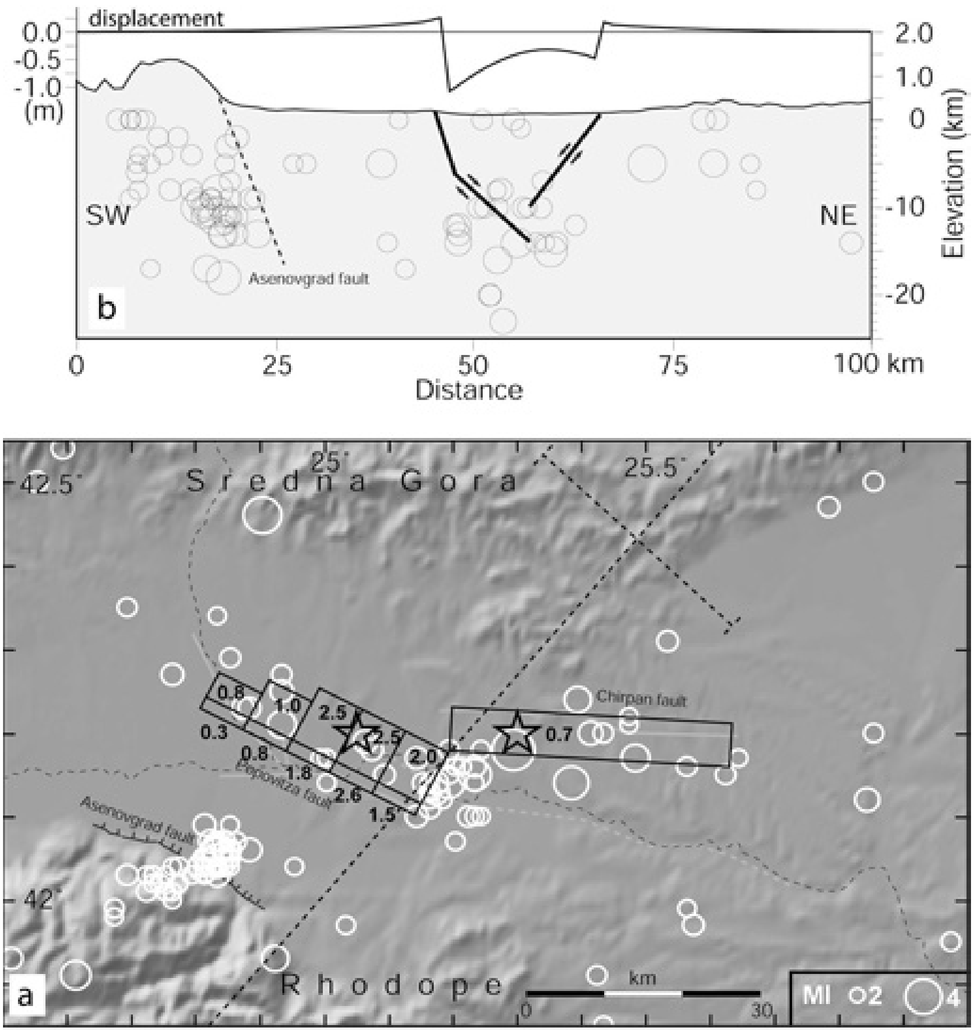

Fig. 1. (a) Fault model with slip amount (in meters) and instrumental seismicity 1980-2004 (Ml>2.5) determined by the Bulgarian National Telemetric Seismic Network show an activity recorded on the main April, 1928 earthquakes faults. Dashed line refers to cross-section presented in fig. 1b. (b) Cross-section 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 scale to the left.

sistent with the seismologic and macro-seismologic estimations (respectively M = 6.8 and M = 7.0).

For the April, 14 first shock the geodetic data do not resolve the eastern extension of the slip. Taking a 10 km shorter dislocation to the east leads to a moment of 0.7 $x10^{19}$ Nm (Mw = 6.6) slightly smaller than the estimations.

During the second April, 18 shock 73% of the total moment is released by the more active Popovitza fault.

The antithetic Chirpan fault accommodates only 27% of the total moment value that corresponding to a slip of 70 cm. It could be interpreted as a consequence of the flexure of the hanging wall due to the major faulting observed along the southern system. The dominance of the southern system being observed during the 1928 sequence (Popovitza fault) and also in the topography (Asenovgrad fault).

The instrumental seismicity of Maritza Valley during the period 1980—2004 (by The National Seismological Network monitoring), shows that the major part of the earthquakes with M>2.5 in the zone are located around the main April, 1928 earthquakes faults.

Paleoseismologic investigation of the fault that ruptured in the April 14, 1928 (Vanneste et all., 2006) confirmed location of Chirpan fault by model from geodetic and seismic data.

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Земетресенията в Чирпан — Пловдив на 14 и 18 април 1928 г. — модел на разломите по геодезични и сеизмични данни

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Резюме. Двете разрушителни земетресения (M = 6.8 и M =7.0) станали на 14 и 18 април 1928 г. близо до град Пловдив, Южна България, са едни от най-значителните, случили се в Европа и в Източната Средиземноморска област през 20 век. Подробният анализ на съществуващите в литературата тектонски наблюдения ни позволява да установим, че поредицата от събитията през 1928 г. е реактивирала последователно два противоположни второстепенни разседни разломи с дължина съответно 38 и 53 km, което е в съгласие с наличните сеизмоложки данни. Използван е необикновен набор от геодезични данни, образуван от нивелачни линии с дължина 500 km и повторни GPS измервания на Държавната триангулачна мрежа, за да се характеризира полето на косеизмичните деформации. Деформацията е асиметрична, с основно разломяване при втория трус, по протежение на залягащия към север разлом с максимално вертикално преместване от 2 m. Това поле на преместванията и повърхностните разкъсвания са възпроизведени чрез дислокации в едно хомогенно еластично полупространство. Това изисква за първия трус един разлом, залягащ към юг с равномерно хлъзгане от 0.7 m. Вторият трус поема около 75% от сеизмичния момент на поредицата в залягащия към север разлом с по-стръмно спадане на повърхността, отколкото в дълбочина, и максимално хлъзгане от 2.6 m. Учудващо е, че тези две главни земетресения са реактивирили второстепенни разломи, а не са хлъзнали по-големия разлом в тази област. Това поставя тектонски и механични проблеми относно режима на деформиране в Северния Егейски район.