Paleoseismological investigation of the fault rupture associated with the M 6.8 earthquake of April 14, 1928 near Chirpan, Southern Bulgaria

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Introduction

In 1928, three strong earthquakes struck Southern Bulgaria in a short span of time and space (Fig. 1): a M 6.8 earthquake with epicentre near Chirpan on April 14, a M 7.1 earthquake with epicentre near Popovitsa on April 18, and a smaller M 5.7 event near Gulubovo on April 25 (Christoskov, 2000). The first and third events activated the south-dipping Chirpan fault north of the Maritsa river, the second and largest earthquake occurred on a north-dipping fault south of the Maritsa river. Together, these faults define a 10-15 km wide graben, situated in the centre of the larger E-W oriented Upper Thracian Depression, bordered by the Sredna Gora Mountains in the north and the Rhodope Mountains in the south. Contemporary sources describe extensive surface faulting for these events, with vertical displacements of 0.3-0.4 m for the April 14 earthquake, and of 1.5 m up to in one place 3.5 m for the April 18 earthquake. Since a few years, we are reinvestigating the surface ruptures associated with the 1928 earthquakes, to determine the return period of such events.

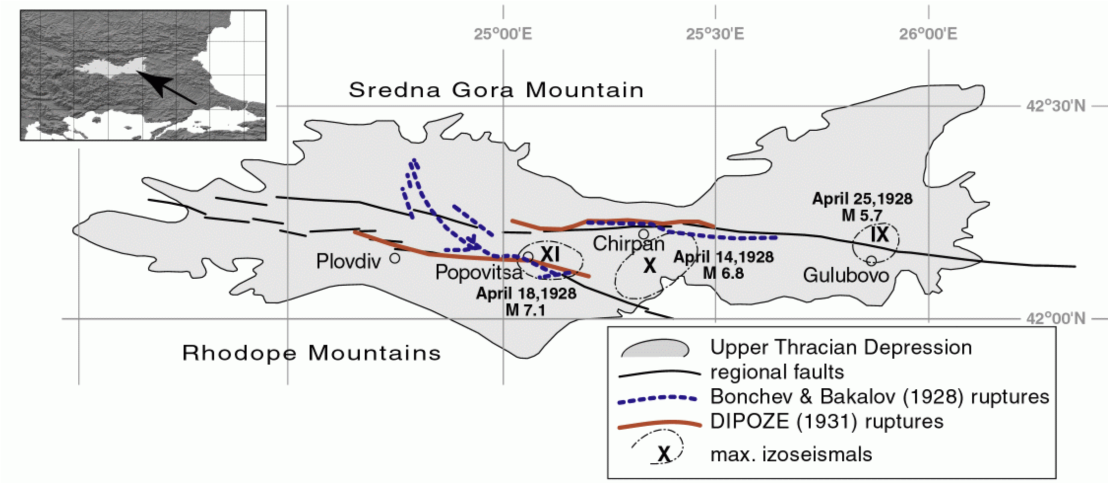

Figure 1. Map of the 1928 surface ruptures in the Upper Thracian Depression.

Geomorphological and geophysical survey of Chirpan fault

A first reconnaissance of the 1928 ruptures showed that, even though vertical offsets were much larger on the southern fault, this fault is actually more difficult to recognize in the field, mainly due to dramatic anthropogenic modification of the landscape. We therefore focused on Chirpan fault in a first phase of the investigation. The Chirpan fault is a normal fault striking E-W and dipping to the south in the central part of the Upper Thracian Depression. Three sources described and/or mapped the ruptures associated with the April 14 earthquake on this fault, but unfortunately significant divergence exists between them (Fig. 1): Bakalov (1928) described a rupture north of Chirpan, extending 15 km westward towards Orizovo. Later, S. Bonchev & Bakalov (1928) extended the rupture 20 km to the east, whereas G. Bonchev & Bakalov (in DIPOZE, 1931) added 5 km to the east and 20 km more to the west. However, no vertical displacements observed in 1928 can be related with certainty to these later extensions. In addition, all sources report a second rupture farther south, parallel and antithetic to the main rupture. Data from levelling surveys before and after the 1928 earthquakes (Mirkov, 1933) do not show any permanent surface deformation along this line, however. Most likely, this second “rupture”, which runs along the Maritsa river, represents only secondary deformation. Using aerial photographs, 1:5000-scale topographic maps, a DEM of the same scale, and field observations, we have identified the 1928 fault scarp in the field, and mapped it more precisely. The Chirpan fault is expressed in the morphology as a ± 30-m-high linear range extending over a distance of 12 km between Rupkite (north of Chirpan) in the east and Cherna Gora in the west, more or less corresponding to the rupture length originally described by Bakalov (1928). The fault scarp is not well preserved: the area is intensely cultivated, and in some places roads have been constructed in front of it. The scarp is only visible where topographic offset is in the order of 1 m. We investigated several sites using electric sounding and tomography, detailed levelling and boreholes. This confirmed the presence of a normal fault beneath the scarp, and provided information about the nature of the deposits affected by faulting. In a large part of the area, the fault juxtaposes the Plio-Pleistocene fluvial Ahmatovo Fm. (characterized by intermediate resistivity) in the footwall, against younger Quaternary deposits (low resistivity) in the hanging wall (Fig. 2). The base of the intermediate-resistivity layer is displaced 10-15 m, but the exact age of this horizon is unknown, however. In addition, we found evidence for a second fault more to the north, which in general juxtaposes Paleogene marl and limestone in the footwall against the Ahmatovo Formation in the hanging wall. Although this fault in some places shows up as a lineament on aerial photographs, it does not appear to be associated with a topographic scarp.

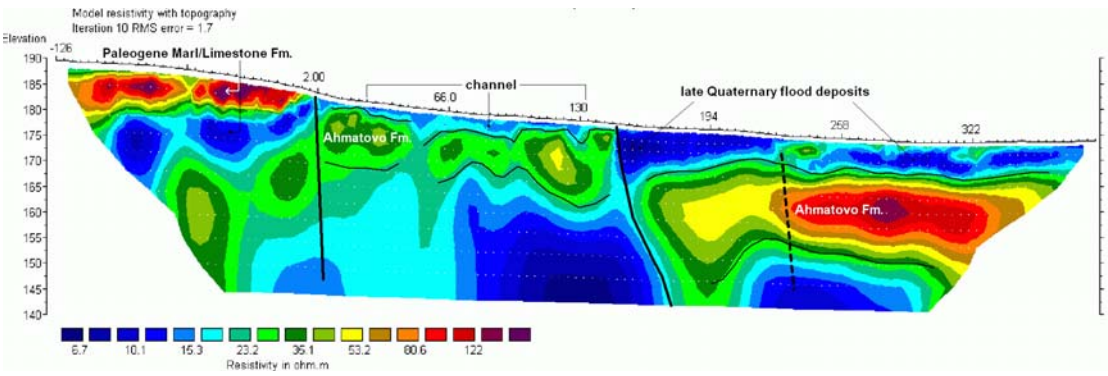

Figure 2. Interpreted 2-D-resistivity profile across Chirpan fault at Kopanite (V.E. = 2.5).

Results from a first trench in Cherna Gora

In 2002, we excavated a first trench across Chirpan fault to obtain a record of fault activity. The trench was located 1 km north of Cherna Gora, and ± 1 km east of where the main fault scarp disappears, probably due to an important step. The main criteria for selecting this site were the clear geomorphic expression and the large thickness of late Quaternary sediments in the hanging wall. Geomorphically, the trench is situated on the interfluvium between a small dry valley to the west and a small active creek (associated with a spring) to the east. The fault scarp is fairly straight, with strike varying between N 85° E (where the trench was excavated) and N 95° E. Levelling profiles indicate a topographic offset of about 1 m, which is larger than the displacement observed in 1928.

The trench was 54 m long, 4 m wide, 4 m deep and perpendicular to the fault strike. The trench walls exposed a very narrow fault zone, separating very different sediments on either side: in the footwall mainly compact clayey-silty sand of the Plio-Pleistocene Ahmatovo Fm., and sandy-clayey silt of alluvial origin in the hanging wall. The sediments in the hanging wall were deposited by temporary flooding of the nearby Suata creek and of the Omourovo river, the main drainage in the area, intersecting the scarp ± 3 km east of the trench site. A log of the eastern trench wall is shown in Fig.3. Units U, V, W and X are layers of the Ahmatovo Fm., each with a thin bed of gravel at the base. An extensive calcic network is developed in unit X. The overlying unit Z consists of Ahmatovo parent material, but with 20% of calcite in the matrix; this unit is interpreted as a Bk horizon forming a continuous soil profile with the calcic network below. The hanging wall sediments were subdivided into units F, E2, E1, D, C2, C1, B and A, but they show only vague stratification. Units F (black colour) and unit E (reddish-brown colour) contain large calcite nodules, whereas unit D (pale brown colour) contains 20% of calcite in the matrix rather than in nodules. Unit D can thus be interpreted as a Bk horizon similar to unit Z in the footwall, but developed in different parent material. Units C1, B and A are black-coloured layers of alluvium rich in organic material, partly extending onto the footwall. They are interpreted as stacked A soil horizons, with unit A mostly corresponding to the current plough layer. These are the only sediments that can be correlated across the fault. Mineralogy and pollen content show that only unit F was deposited in a cold climate, probably during the Late Glacial. The pollen in the overlying alluvial layers reflect warmer climate, and thus indicate a Holocene age. *Cerealia* pollen appearing near the top of unit E2 indicate human settlement, which was first established in the region around 5000 BC, based on archaeological remains. The base of unit C more or less coincides with intensified agricultural activity.

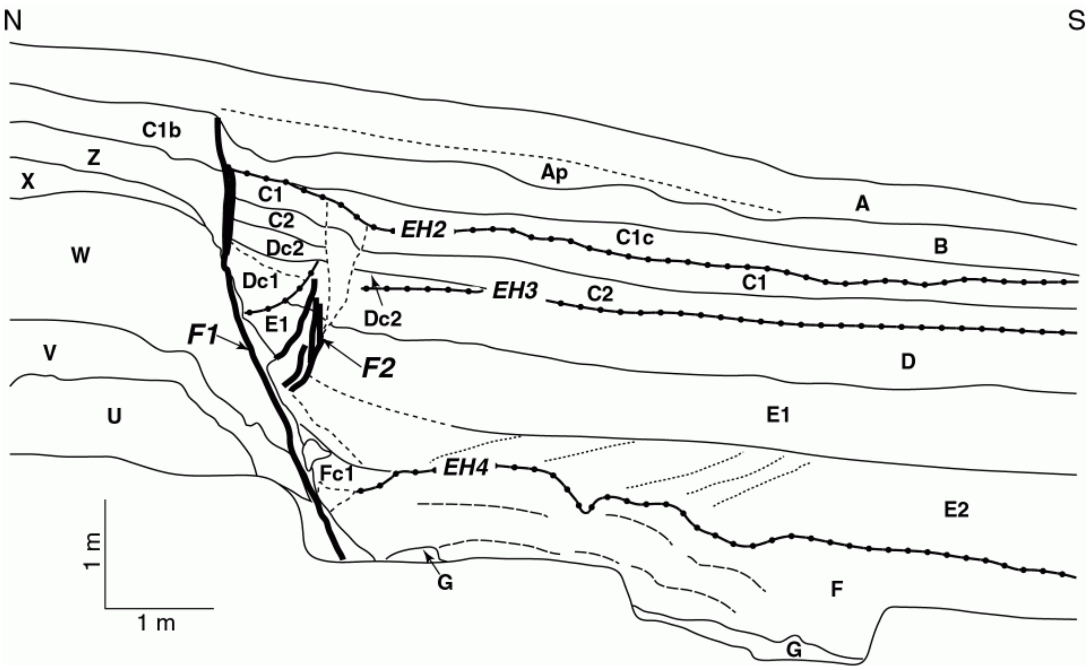

Figure 3. Fault zone on east wall of Cherna Gora trench.

The fault zone is very narrow and complex, consisting of several splays which merge into a single shear zone dipping 70° at the base of the trench. Through a detailed analysis of the fault zone, we could identify several deposits of colluvial origin in the hanging-wall sediments, which we interpret as colluvial wedges derived from the fault scarp. We thus found evidence for at least four paleoearthquakes, including the 1928 event, since the Late Glacial to Holocene transition. Due to the absence of datable organic material, age control for these events is limited, however. The 1928 earthquake is marked by abrupt thickening of unit A next to fault F1. Due to intense cultivation at the site, the colluvium related to this event is masked by a 40-cm-deep plough layer. The part of unit A lying below the plough layer (Ap in Fig. 3) probably represents the A horizon that was at surface before 1928. Using the thickness of this preserved part as a minimum estimate for the offset yields 30 cm; if we measure the offset over a larger distance between the top of unit B and its analogue in the footwall (unit C1b), we obtain 45 cm. These values are in good agreement with the reported displacements of 30-40 cm. The penultimate earthquake (event 2) occurred on fault F2, and displaced C2 and the base of unit C1. Unit C1c, which can be discerned from C1 by a more chaotic stratification, represents the colluvial wedge associated to this event. The offset estimated on the fault is 15-30 cm, while the thickness of the colluvial wedge is 25-30 cm, which must be considered as a minimum estimate. The age for event 2 is bracketed between c. 3 ka BP (base of unit C corresponds to transition Sub-Boreal to Atlantic according to pollen) and 1928. The wedge-shaped unit Dc1 next to F1 is evidence for a third event near the top of unit D. This unit consists of unsorted debris derived from both the footwall (unit Z) and the hanging wall (unit D). We interpret unit Dc1 as chaotic colluvium deposited in an open fault-related graben, and the overlying unit Dc2 as a more stratified colluvial wedge, deposited over and beyond the graben. This is supported by significant back-erosion (paleo-scarp) in the footwall of the top of unit Z, which formed a continuous (arid) soil horizon with unit D before the event, as discussed above. Evaluating the displacement of the top of this paleosol, subtracting the cumulative displacement of the two later events, we find a maximum offset of 65 cm for this event. The event horizon is situated in the upper part of unit D, which contains pollen of Sub-Boreal age. We can therefore loosely constrain the age of event 3 between c. 5 ka BP and c. 3 ka BP. The evidence for the fourth event is very similar to that of event 3: a wedge-shaped unit Ec1 is lying on top of unit F next to fault F1, consisting of debris derived from both footwall and hanging wall (unit F). The shape of this wedge was partially destroyed by later faulting. Its position is consistent with indications that the top of unit F may represent an event horizon: internal stratification and perpendicular cracks inside unit F are warped, whereas the overlying unit E2 shows mostly horizontal stratification. Due to the absence of units F and E2 in the footwall, it is difficult to estimate the offset for event 4, but the thickness of the colluvial wedge is 50-70 cm. The pollen record indicates that event 4 likely occurred around the Late Glacial to Holocene transition. There is some indirect evidence (thickness of units E1 + E2, tilted aligned concretions within E2 which could be interpreted as fissures) for an additional paleoearthquake between events 3 and 4, but this needs to be confirmed.

Conclusions

For the first time, the large 1928 earthquakes in Southern Bulgaria have been studied using paleoseismology. We have mapped the Chirpan fault over a minimal length of 12 km. In a first trench near Cherna Gora we could identify 30-45 cm of offset associated with the M 6.8 April 14 earthquake. The trench record provided evidence for at least three similar-sized paleoearthquakes since probably the Late Glacial to Holocene transition. Though age control is limited, we infer a recurrence period between 1400 and 2400 years for large earthquakes on this fault segment. We calculate a fault slip rate of 0.19 – 0.32 mm/yr for the last two cycles preceding the 1928 event. More trenches will be needed, however, to refine these values, to determine the total segment length, and to understand the activity of other faults in the Upper Thracian Depression, in order to properly assess seismic hazard of this rapidly developing region, which contains the second largest city of the country.

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