INDICATIONS FOR THE ACTIVITY OF THE TUNDZHA FAULT IN THE MARBLE EXPOSURES AT THE KONEVETS GORGE OF RIVER TUNDZHA, SOUTHEASTERN BULGARIA

Dian Strahilov, Ivan Dimitrov

University of Mining and Geology "St. Ivan Rilski", 1700 Sofia; idim68@abv.bg

ABSTRACT. It is believed that the Tundzha fault (or fault swarm) is a significant in depth and lateral distribution structure, buried under the Quaternary alluvial sediments of the Tundzha valley, between the towns of Yambol and Elhovo. So far, this fault has been mentioned in a significant number of publications but no field geological data for its existence have been offered. The Tundzha valley is divided in two parts, the Yambol part and the Elhovo part, by the Konevets sill (gorge). In this area the river valley changes its direction from northwest to northeast, and is tens of meters wide. There are numerous kinematic arguments, that in this area, composed of metamorphosed Triassic carbonates, the evidence of fault shear, along the Tundzha fault, must be well visible. Indeed, the thin bedded marbles carry the traces of intense deformations. In this work, results of structural analyses are shown, including superimposed folding and kinematic analysis of faults and conjugate joints. They suggest for a significant fault tectonics and superposition of various stress fields, indicative not only for the Tundza fault, which is striking north-south, but also for the west-east striking structural trend along the Northern border of the Sakar-Strandzha dome, known as the Boznia zone. Thus, the Tundzha fault remains elusive but the evolution of the Konevets sill is clarified as a rock strip, protruding along the west-east strike-slip zone.

Keywords: Tundzha valley, joints, faults, folds, directions of principal stresses

ИНИДИКАЦИИ ЗА АКТИВНОСТТА НА ТУНДЖАНСКИЯ РАЗЛОМ В МРАМОРНИТЕ РАЗКРИТИЯ ОТ ДЕФИЛЕТО НА РЕКА ТУНДЖА ПРИ СЕЛО КОНЕВЕЦ, ЮГОИЗТОЧНА БЪЛГАРИЯ

Диян Страхилов, Иван Димитров

Минно-геоложки университет "Св. Иван Рилски", 1700 София

РЕЗЮМЕ. Предполага се, че Тунджанският разлом или разломен сноп, е значителна по дълбочина и латерално разпространение структура, погребана под кватернерните седименти на долината на р. Тунджа, между градовете Ямбол и Елхово. Досега за този разлом се споменава в голям брой публикации, но към момента не са представени теренни геоложки данни за неговото съществуване. Долината на р. Тунджа е разделена на две части: Ямболска и Елховска, като между тях се разполага Коневецкият праг (дефиле). В този участък долината сменя посоката си от северозападна на североизточна и е широка едва няколко десетки метра. Поради редица кинематични съображения, в този участък, изграден от триаски мраморизирани карбонати, е най-целесъобразно да се търсят следи от приразломно срязване, свързано с Тунджанския разлом. В действителност тънкопластовите доломитни мрамори от Коневецкия праг са много интензивно деформирани. В тази работа се представят резултатите от структурни изследвания, включващи анализ на многофазна нагънатост и кинематичен анализ на пукнатини и разломи. Данните действително указват за проява на значима разломна тектоника и налагане на различни стресови полета, не само характерни за Тунджанския разлом, който е с посока север-юг, но също и за запад-източните деформации, характерни за северната граница на Сакар-Странджанската зона, известна като Босненска дислокация. Така че към момента кинематиката на Тунджанския разлом остава неясна, но за сметка на това се изяснява еволюцията на Коневецкия праг, като скална пластина, претърпяла отседни движения в запад-източна посока.

Ключови думи: долина на Тунджа, пукнатини, разломи, гънки, посоки на главни напрежения

Introduction

The Konevets gorge, known in the Bulgarian geomorphologic literature as the Konevets sill, separates the middle Tundzha valley into two hydrologically separate parts, known as the Yambol trough and the Elhovo trough. When and how it appeared is not clear yet, but it has obviously existed at least since the late Neogene, because it splits into two separate depositional environments the Elhovo Neogene (Pontian-Dacian) coal basin (Fig. 1). Savov (1983) named it Yambol and Elhovo syncline. The Yambol syncline contains discontinues and thin coal layers, but the Elhovo syncline has 3 well defined and several meters thick coal layers. To the north of the gorge the Yambol syncline, or more appropriately the Yambol structural depression, is 12 km long and 8 km wide, while to the south of the gorge the Elhovo depression is 18 km long and approximately 12 km wide (Savov, 1983).

The gorge itself is carved into Triassic low-grade metamorphic calcitic and dolomitic marbles, which pinch the valley into tens of meters narrow space. The marbles form a well-defined strip, which is running in the east-west direction for tens of kilometres along the northern border of the Strandzha Zone of Southeast Bulgaria (Čatalov, 1990). The marble exposures are located on both sides of the river, but better exposed rocks are found only on the west side (Fig. 2).

The Tundza fault was first proposed by Čatalov (1965) without serious field or theoretical evidence. The first geophysical data were provided by Sockerova et al. (1966) using seismic data from the earthquake that happened on 15 of March 1964, with a shallow epicentre (h=5 +/-3km), located to the west of Yambol, below the village of Skobelevo. Reading this paper the reader will be left with mixed feelings. It is because the writhers do not specifically attribute this earthquake and many other tremors from the Yambol seismic zone, to the N-S trending fault along the valley of Tundzha, namely the Tundzha fault, but to other NW-SE trending faults. The only possible argument in favour of the Tundza fault in this paper is the slight elongation of the macro-seismic effects, shown on the isoseist map of the earthquake, to the south along the Tundza River valley. Nevertheless, drawn on the map in this paper by P. Gochev as a N-S trending reverse or normal fault (Fig. 11 in Sokerova et al., 1966) this structure began its life in the Bulgarian literature.

Bonchev et al. (1969) used the fault to develop their model of blocky macro-fabric of the Stranzha Zone.

The most exhaustive attempt to define this fault was made by Savov and Petkov (1972). They attempted to interpret regional magnetic and gravimetric data as well as any usable information that was available at the time. As a result, they offered not a single structure but an array of three faults namely the Yambol fault, the Konevets fault and the Lesovo fault (Fig. 1).

The exposures studied in this paper (Fig. 2) are located in the area between the tips of the Konevets fault and the Lesovo fault. However, the locations, scope of the deformation zones, and the kinematic nature of these faults are not specified in detail. The main argument used by the authors was the existence of gravity and magnetic maximums and steep gravity transitions, which may be aligned to indicate elongated faulted blocks. However, the map of gravity and magnetic signature provided by the authors emphasised the ambiguity of such speculations.

In the later works, the Tundza fault was assumed as existing and was usually shown as a single line (e.g. Vrablianski, 1975) following loosely the Tundza River valley. It is worth mentioning that on the geological map of Bulgaria in scale 1:100000, Elhovo map sheet (Dabovski et al., 1993; 1994) the existence of such fault is not indicated by any means.

Review of the tectonic activity in the Tundzha structural depression was provided by Aleksiev and Georgiev (1996). They published new data about significant earthquakes in the Yambol seismic zone and a map of the vertical crustal movements. Direct evidence about the existence of the Tundza fault or fault zone are not offered but the Yambol seismic zone, elongated in west-east direction, is better characterised. The grouping of the epicentres suggests a fault control by the west-east striking structures.

Preliminary data from structural analysis of surface exposure in the Konevets sill are provided in this paper. The purpose is not to prove or refute the existence of the Tundzha fault, but to bring into consideration additional data and to provide much needed geological consideration into this discussion, which so far relied only on indirect arguments.

The main usefulness of the study area comes from the fact that the studied exposures are the only rocks exposures in the Tundza River valley between Yambol and Elhovo, and the river valley changes direction exactly at the studied point (Fig. 1). So if shearing along the valley occurred, it would be expressed in some way in the marbles of the Konevets gorge.

The preliminary character of the study stems from the finding that there is evidence of superimposed stress fields, so additional efforts are needed to discern these stress fields, which may happen in another publication specifically focused on fault striation analysis not only for these exposures but for the entire region.

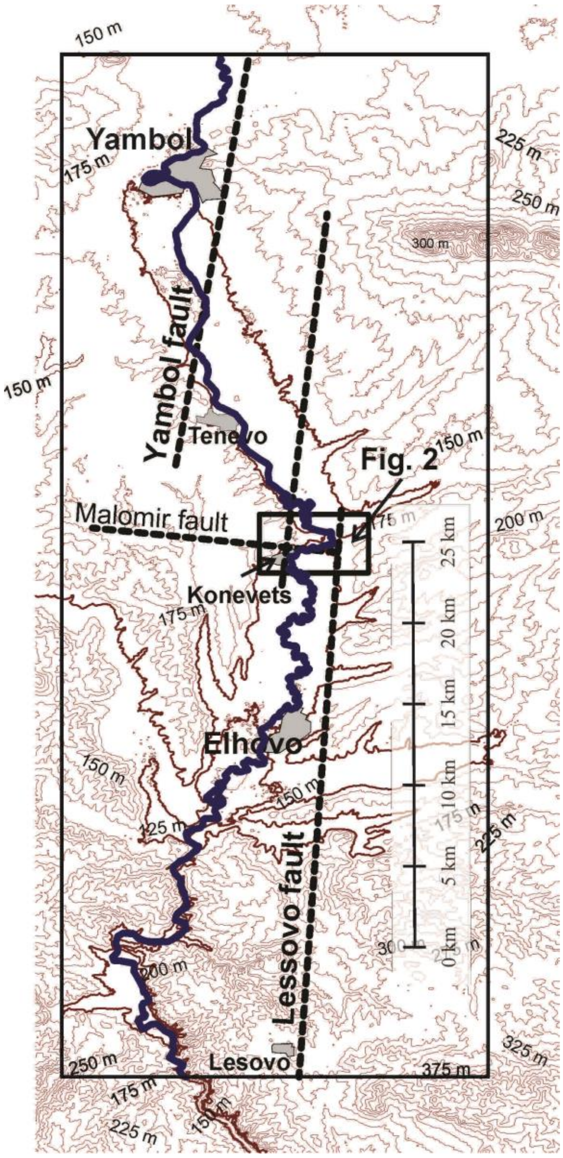

Fig. 1. Location of the Konevets sill in the middle of the Tundzha valley: three interpreted faults, believed to represent the Tundzha north-south striking fault swarm (Savov, Petkov, 1972), are shown in their approximate position with dashed lines; the position of another inferred fault, running in west-east direction and named as the Malomir fault (Savov, Petkov, 1972) is also indicated

Study area

The study area (Fig. 2) is naturally unexposed but numerous small pits have been made by local miners, extracting marble for quicklime production in the past. In these pits bedding can be measured as well as hinges of numerous small folds, joints and small faults. Evidence for existence of a single large fault is not available but the small scale folding and faulting are very prominent.

The overall strike of the beds in these exposures is NW-SE, which is emphasised by a large fold with a hinge in the same direction. All the observed small scale structures are either reworked in parallelism with this trend or superimposed on it.

The marble beds are exposed in two packages: a thin-bedded one, originally comprising clay rich limestone with some marls, and a thick-betted package, which was thoroughly dolomitised and at present is mined in a larger quarry, known as the Konevets quarry. The younging is to the north, so the thick-bedded or massive dolomites consistently overlay the thin-bedded marbles along a strike in normal superposition.

Fold superposition

In the course of this study 134 bedding planes have been measured throughout the area to the west of the river. Plotted on a stereographic net, they demonstrate the girdle of the predominant NW-SE trending fold, shown with beta (β) axes f1 in Figure 3.

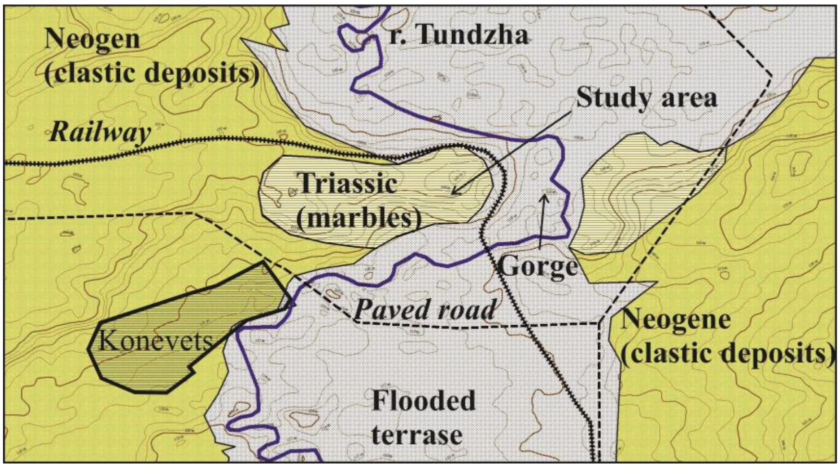

Fig. 2. Sketch map of the Konevets sill, showing the area where the structural geological measurements were made; the studded exposures are in the marble to the west of the Tundzha River; topographic contours are superimposed on the sketch to emphasise the geomorphology of the gorge

In addition, three other fold girdles can be recognized shown with circles around the β axes and numbered f2, f3 and f4 in Figure 3. From these, f2 and f3 are relatively easy to discern but f4 is indicated by only several measurements. This picture corresponds to a complex interference pattern. The girdles can be seen also on the β intersection plot shown in Figure 4.

The first, and easy, conclusion from this geometry is that the main fold (f1) has a curved hinge plunging between 20° and 50° to NW. The curvature of the hinge is emphasised by the size of the circle of Figure 3. This curvature is common for a "whale back" or a "turtle back" shaped folds that are usually formed by two stages of deformation.

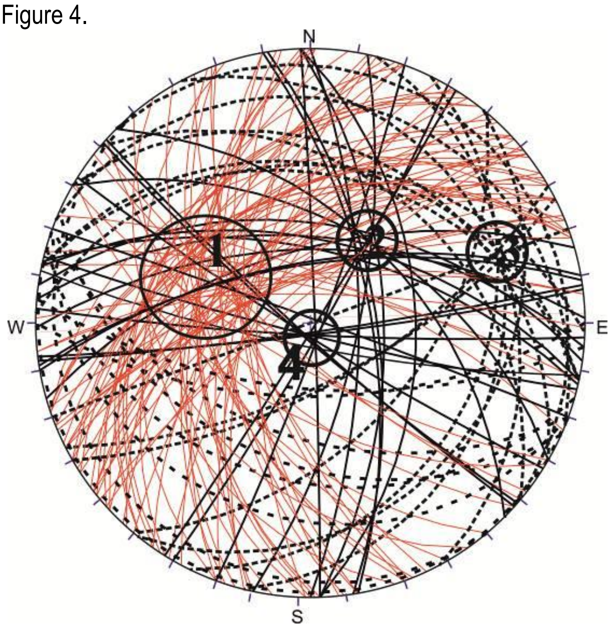

Fig. 3. Great circles of 134 bedding planes from exposures shown in Fig. 2: the beds show one well defined gird represented by an area of bed intersections numbered f1, but also 3 other not so well defined girdles, represented by intersection f2, f3 and f4

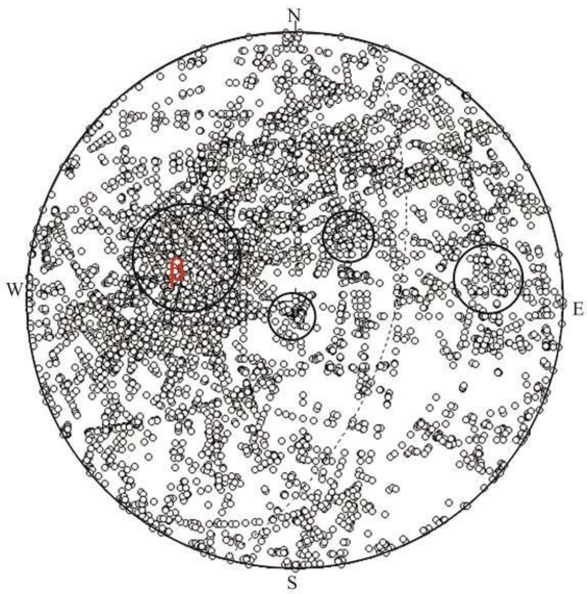

Fig. 4. The same data as in Fig. 3, processed to show the beta (β) intersections of the beds: the intersection are found using the software package Geoorient made by Rod Halcomber

The origin of girdle 4 is relatively clear. These folds were found to be kinks (Fig. 5) on a very steep to vertical beds. The kinks reflect bedding – parallel strike-slip shear, which resulted in nearly vertical plunges of the kink folds. Small faults, striking in the same direction, have also been found. Because this shear happened in a plane close to the axial surface of f1, it is likely to be cinematically related to the main folding.

Fig. 5. Small folds formed by bedding parallel shear. The folded beds and the hinge lines are emphasised by dark lines. The scale is a GPS receiver shown on the left.

Not all small folds have been formed this way. There is a variety of small fold geometry (Figs 6, 7), which reflect different mechanisms and possible different timing of these deformations. F*2* and f*3* are ambiguous and at this stage of the study they cannot be properly explained.

Fig. 6. Fault related fold with axial surface tangential to the tectonic mirror of the fault visible at the left side of the picture: for a scale the tree visible in the upper right corner can be used

The complexity of the deformation is reflected in the texture of the rocks. More than in any other location in the region, extensional vain textures are visible here (Fig. 8). In some exposures the two dimensional areal expansion measured by the area of the veins on bed surfaces reaches 20%. The nature of this volume enlargement is not clear. It is possible that fault related brecciating on a wider scale is also present but it is not observed, because of the limited exposure.

There is a possibility that a major fault zone still exists but it is covered by the alluvial sediments of Tundzha River, so only its vicinity is recorded in these exposures. The so-called Lesovo fault of Savov and Petkov (1972) was shown on their map to tip in the area of the Konevets gorge, however it is rather interpretation and speculation than a proven fact.

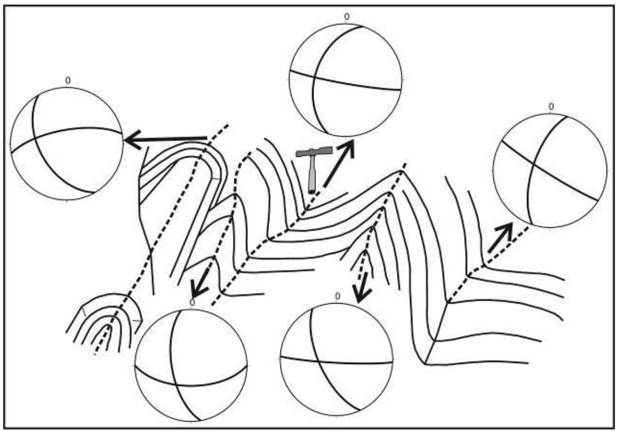

Fig. 7. Small folds redrawn from a photograph: the orientation of the beds is shown on the stereograms (scale is a silhouette of a geological hammer)

Fig. 8. Typical texture of a bed surface, exposing "chocolate tablet" extensional vein pattern: all the veins on the picture are calcitic with fibres grown perpendicular to the vain walls; to the right of the coin two hydraulic extensional gaps are visible, which were also filled with calcite

Analysis of the small folds

The abundance of small folds is the most conspicuous feature of these exposures. The orientation of small fold hinges was measured directly or was assembled by stereographic intersection of fold limbs. Most of the measured hinges plunge westward but some are horizontal or plunge shallowly to NE. In order to clarify their origin some geometric analyses were made.

When tested for a conical best fit (Fig. 9) it appears that the fold hinges arrange in a cone, the axis of which corresponds to the hinge of the prominent regional fold numbered f1 in this paper.

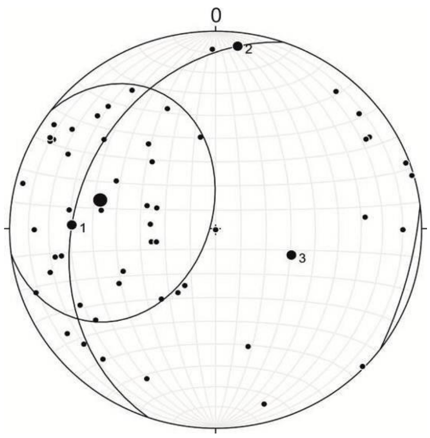

Fig. 9. Cylindrical and conical best fit, found by Bingham approximation of 52 fold's small axes, from exposures shown on Fig. 2: for the Bingham analysis the package Stereonet was used, which is made by Rick Allmendinger and distributed for free; the results of the analysis are as follows:

Axis	*Eigenvalue*	*Trend*	*Plunge*	*±min*	*±max*
1	**0.5655**	**272.0**	**30.8**	**14.3**	**20.9**
2	**0.2595**	**006.6**	**07.7**		
3	**0.1749**	**109.1**	**58.1**	**14.2**	**45.8**

Best fit great circle (strike, dip RHR) = 199.1, 31.9, Conical best, Data set name: Konevets small folds, axis trend & plunge = 285.0, 41.6; half apical angle = 46.1

The cylindrical best fit arranges them around a plane that might represent the prominent direction of bedding, unfolded around the hinge of f1. These observations suggest the possibility that the majority of the small folds are contained in the limbs of the f1 fold and thus can even predate the f1 formation. However, not all small folds comply with this geometry.

It is reasonable to find where the fold axes fall, when the plot is rotated around the hinge of f1. For this purpose, the geometry is simplified to only the hinges and two limbs for each fold found in this exposures (Fig. 10).

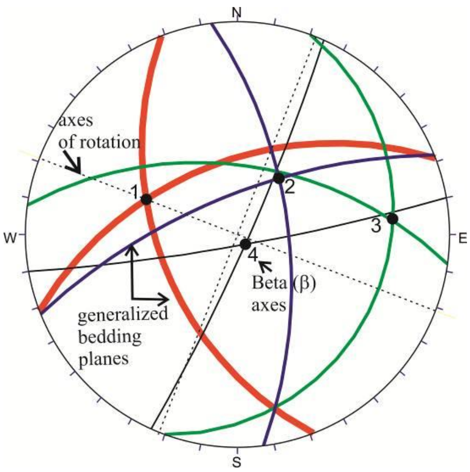

Fig. 10. Simplified representation of the bed intersections shown on the previous figures. The axes of rotation used to unfold the data about the hinge of the main fold f1 are shown with dotted lines

If the hinge of f1 is rotated to horizontal (Fig. 11) it is obvious that f2 and f4 hinges are relatively far from the limbs of f1, so they are obviously not contained in the general stratification folded by f1, hence, further rotations will prove no connection between them.

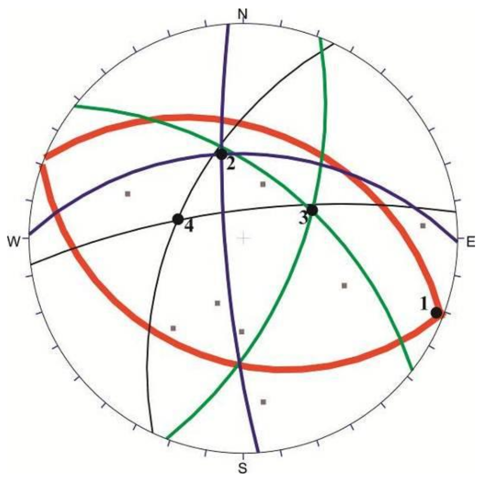

Fig. 11. All beds rotated, so that the hinge of the main fold (1) is horizontal

The hinges of f4 are far from the limbs of f1, so most likely they are fault related folds. F3 also appear not to be related to the f1 geometry. This analysis shows that the fold pattern needs further field work and possibly on a larger region.

Analysis of the joints

In most regions of the world the joints group statistically in three or four statistical maximums as two of them represent a conjugate shear couple and one of them represent the extensional joints (Hancock, 1985). This, however, is indicative of a simple stress field, which did not rotate with the time and do not carry the signature of the simultaneous or superimposed action of different stress fields.

In the studied domain, the joint pattern is complex. The joints disperse on a larger area of the stereographic net, forming more than four maximums. It was possible, by isolating conjugate shear joints from the nearby exposures, to construct the stereogram in Figure 12. On this figure, three couples of shear joints are shown. All couples were measured directly on a rock surface, where the polished walls of the joints are visible and the line of intersection can be observed.

As it is seen, the joints (Fig. 12) intersect at very different places on the net. If the line of intersection is interpreted as the direction of the intermediate principle stress, than it can be seen that each couple of shear joints represents a different stress field.

Analysis of small faults

In order to derive the orientation of the instantaneous stress axes, fault slip analysis (e.g. Allmendinger et al., 1989) was made using fault striations on fault planes. Only faults with simultaneous exposure of striation and steep steps perpendicular to it were used, so the direction and the sign of the movement could be found unambiguously on these surfaces. Principal stress directions from 6 faults from exposures in the most eastern part on the west board of the valley are shown in Figure 13. This plot indicate for a NW plunging principal stress, which is compliant with a normal fault striking in the NW or NE quadrant as suggested by Savov and Petkov (1972).

However, the above shown analysis is not conclusive. It is because the joints indicate for a more complex stress field and the small folds from f4 indicate for a consistent W-E directed bedding-parallel shear. Because of the uneven exposure it is likely that not all significant small faults were measured or they were not split into groups representing contemporaneous stress fields.

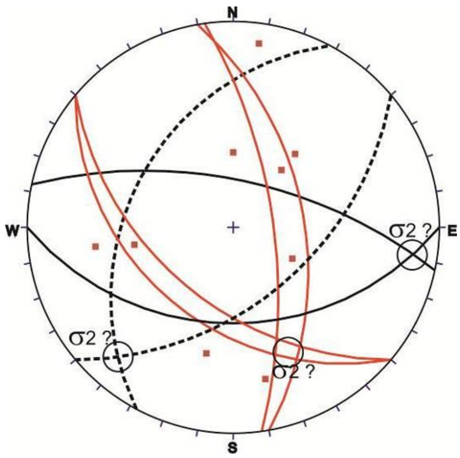

Fig. 12. Three sets of conjugate joints, measured in exposures on the western slope of the gorge (Fig. 2): the position of the intermediate stress (σ2) at the intersection of the joints is indicated

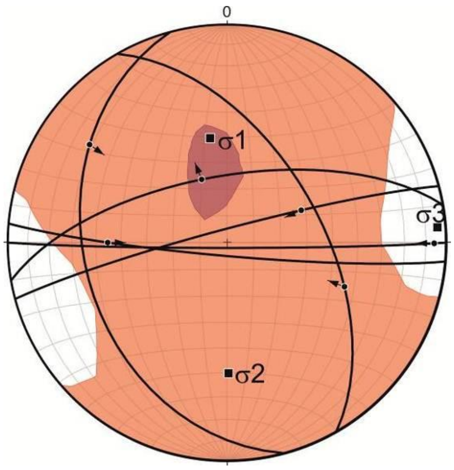

Fig. 13. Orientation of principal stresses found by 6 faults with striation, using the FaultKin software, made by Richard W. Allmendinger: the great circles of the faults, the directions of striations and the direction of the principal axes of stress are shown on the plot

Conclusions

The structural analysis of the Konevets gorge shows that the small, decimetre to metre scale structures, were formed by different deformation mechanisms at different geological times. Most of the small folds are contained in the stratification that was folded by the main NW trending alpine folds of the region, roughly coeval with the late Cretaceous magmatic activity. So, these small folds may predate the pick of folding and some of them may be even sin-sedimentary slump folds or formed by early tectonic folding in Jurassic or Early Cretaceous time, which is very difficult to be discerned at present.

The small folds, which are not contained in the stratification and are with steeply plunging hinges (f4) correspond to a bedding parallel strike-slip shear. These can be contemporaneous to the main folding or connected to a later strike-slip shear like the one related to the Malomir Fault of Savov and Petkov (1972).

The joints suggest multiple brittle deformations and obviously different stress fields. The fault slip analyses confirmed the conclusions about a north-south striking normal fault but the data are insufficient to draw concrete conclusions.

Acknowledgements. This study was supported by the Research project N224/11.03.2019 (Science Fund of the University of Mining and Geology "St. Ivan Rilski", Sofia).

References

Aleksiev, G., Ts. Georgiev. 1996. Geodinamic problems of the Tundzha structural decline. – *J. Bulg. Acad. Sci.*, *1*, 27–33 (in Bulgarian with English abstract).

Allmendinger, R. W., J. W. R. Gephart, A. Marrett. 1989. *Notes on Fault Slip Analysis. Prepared for the Geological Society of America Short Course on "Quantitative Interpretation of Joints and Faults", November 4–5, 1989*. Department of Geological Sciences, Cornell University, Ithaca, New York, 1–59.

Bončev, E., S. Savov, G. Čhatalov. 1969. Über die Schollengliederung des Strandža-Antiklinoriums. – *Bull. Geol. Inst., Ser. Geotectonics*, *18*, 143–157 (in Bulgarian with German abstract).

Čatalov, G. 1965. New tectonic structures in the area between Sakar Mountain and Strandzha Mountain. – *Proc. Bulg. Acad. Sci.*, *18*, 9, 861–864 ((in Russian).

Čatalov, G. 1990. *Geology of Strandzha Zone in Bulgaria*. BAS, Sofia, 271 p. (in Bulgarian with English abstract)

Dabovski, C., S. Savov, G. Chatalov, G. Shiliafov. 1993. *Explanatory Note to the Geological Map of Bulgaria in Scale 1:100000. Elhovo Map sheet*. Committee of Geology and Mineral Resources, Geology and Geophysics, Bolid, Sofia, 75 p. (in Bulgarian with English abstract)

Dabovski, C., S. Savov, G. Chatalov, G. Shiliafov. 1994. *Geological Map of Bulgaria in Scale 1:100000. Elhovo Map sheet*. Committee of Geology and and Mineral Resources, Geology and Geophysics, Sofia.

Hancock, P. L. 1985. Brittle microtectonics: Principles and practice. – *J. Struct. Geol.*, *7*, 437–457.

Savov, S. 1983. Structure of Elhovo structural depression. – *Rev. Bulg. Geol. Soc.*, *44*, 3, 326–331 (in Bulgarian with English abstract).

Savov, S., I. Petkov. 1972. About the deep structure of the Tundza fault swarm. – *Bull. Geol. Inst., Ser. Applied Geophys.*, *21*, 123–133 (in Bulgarian with Russian abstract).

Sokerova, D., E. Grigorova., P. Gochev. 1966. Study of the elements of the seismotectonic characteristics of the earthquake of 15 March 1964 in the Yambol district. – *Bull. Geophys. Inst., Bulg. Acad. Sci.*, *9*, 101–118 (in Bulgarian).

Vrablianski, B. 1975. On the neotectonic activity of the fault structures in Bulgaria. – *Geotecton., Tectonophys., Geodynam.*, *2*, 15–27 (in Bulgarian with English abstract).