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ALPINE THRUST AND FAULT TECTONICS IN SOUTH BULGARIA

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ABSTRACT

Alpine normal faulting and thrusting occurred in South Bulgaria in different times. Events of normal faulting were accompanied by deposition of fault-bound sedimentary formations in Late Triassic, Early Jurassic, Aalenian - Bathonian, Callovian - Oxfordian, Early Turonian, Senonian, Palaeocene - Middle Eocene, Late Eocene, Middle Oligocene - Early Miocene, and Late Miocene - Pliocene times. The most important thrusting events occurred in the latest Triassic, after the Berriasian, in Mid Cretaceous time, in the Campanian and the Maastrichtian, at the end of the Middle Eocene, after the Early Oligocene, and in the beginning of the Miocene. Vergences changed throughout the thrusting phases, and the thrust sheets often formed complex thrust systems. Some normal faulting, or thrusting, events have been most probably diachronous in different parts of the region.

INTRODUCTION

The first time chart of the Alpine sedimentation, folding and thrusting in West Bulgaria (BONCEV, 1936) was based on limited evidence and was greatly influenced by the geological experience in the classical areas of the Alps. The Late Oligocene - Early Miocene ("Savian") thrusting at the boards of the Bobovdol graben served as critical evidence for to ascertain the dominating role of this thrusting phase. Another important event at the Middle Eocene - Late Eocene boundary was later (BONCEV, 1988) described as "Illyrian turning point" in the evolution of the Balkanides. Laramide (Late Cretaceous) and "Austrian" s.l. (Mid Cretaceous) events have been recognised also by Boncev, Kostadinov and other authors (references in DINKOVA et al., 1987).

The aim of the present paper is to summarise the existing evidence about the main thrusting and faulting events in South Bulgaria (mainly in its western part, Fig. 1), south of the Srednogorie zone (a volcanic island arc of Late Cretaceous age). The epochs of intense normal faulting and extension were marked by the deposition of thick terrigeneous formations compensating the fast erosion in adjacent uplifting horsts. The dating of the events (Fig. 2) is based on sealing of the fault structures (thrusts or normal faults) by younger fossil-proven sediments. In some cases, the upper age limit of thrusting or normal faulting is based on observations on cross-cutting igneous rocks or younger faults.

The comparatively precise dating of some of the events in South Bulgaria may be important for recognition of similar events in the southern parts of

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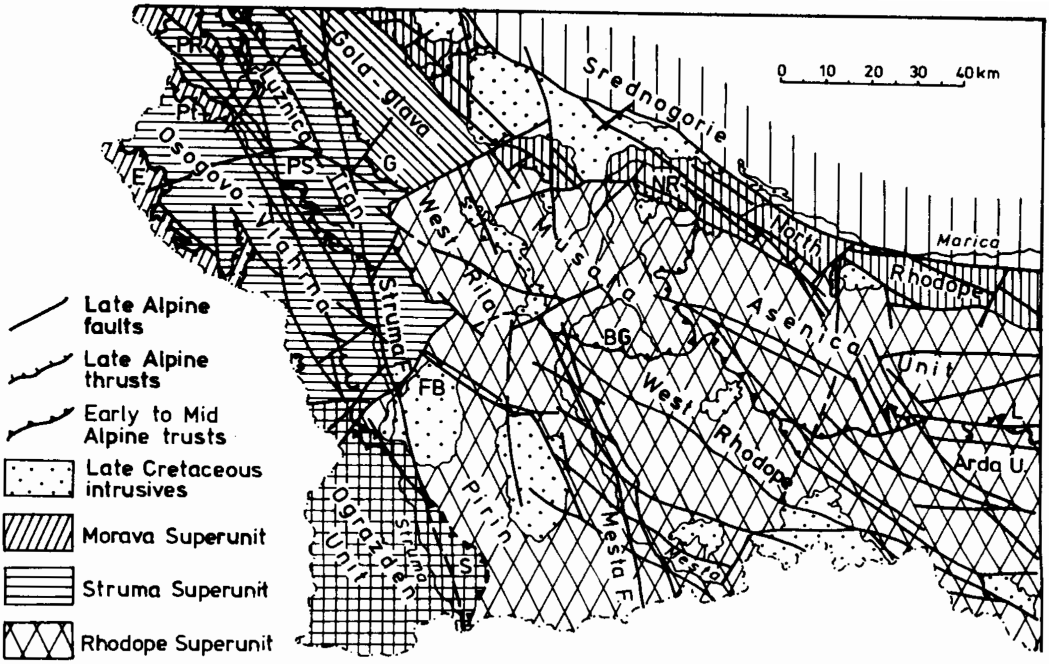

Fig. 1: Tectonic sketch map of the main tectonic units and superunits in the western part of South Bulgaria. Complex thrust zones: PS - Poletinci-Skrino. Mid Cretaceous thrusts: Pk - Penkyovci; Pt - Poletinci; E - Elesnica; S - Strimon. Mid Cretaceous or/and Late Cretaceous thrusts: BG - Babyak-Grasovo; L - Lakavica Middle Rhodope). Late Oligocene to Early Miocene thrusts: G - Golaglava; NR - North-Rhodope.

the Rhodope region (Greece) where the lack of corresponding marker events makes the dating less reliable.

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NORMAL FAULTING

Normal faulting occurred often over long time intervals (Fig. 1). Fault-bound coarse terrigeneous sediments (thick breccia or conglomerate) are thinning gradually out away from the syn-sedimentary faults into the finer-grained formations. Such examples are known mainly from the Struma Zone (fig. 1).

Late Permian basins were limited to the west by a NNW-SSE striking fault east of the Osogovo horst (ZAGORCEV, 1981): west of this boundary, Lower Triassic transgressive conglomerate covers directly the pre-Permian basement. Differences in the thickness of the basal mature Lower Triassic conglomerate and oligomictic sandstone point at possible small graben depressions at the background of the subsiding late Hercynian peneplain.

Late Triassic graben formation is marked by the presence of coarse breccia and conglomerate built up exclusively of pebbles from Anisian - Carnian limestone or dolomite (BUDUROV et al., 1993). These breccia and conglomerate interfinger with red Upper Triassic siltstone and sandstone within the Golo-bardo Unit. The latter represented at that time a small

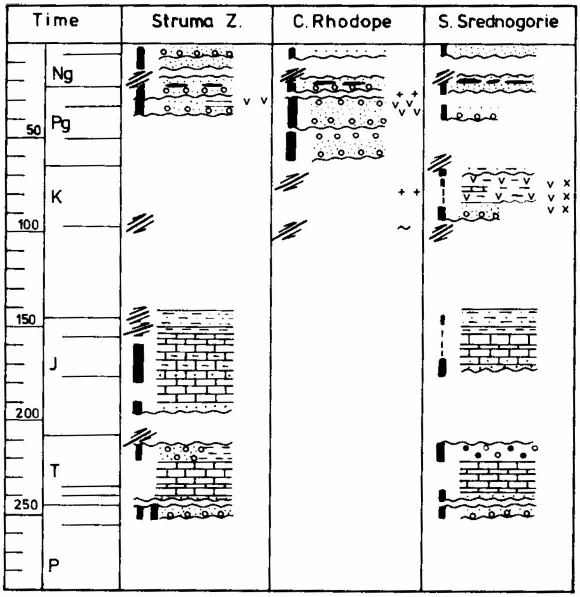

Fig. 2: Time chart for the normal faulting (black vertical lines) and thrusting events in South Bulgaria. Coeval rock lithologies are designated with conventional signs. Unconformities (wavy lines), high-grade metamorphism (tilde), volcanism, acid (crosses) and intermediate intrusive igneous activities are also shown.

palaeograben filled in by coarse material coming from the adjacent palaeohorsts. In the palaeohorsts (e.g., the Lyubas Unit), the deeply eroded and washed-out surface of the Spathian to Lower Anisian formations is covered trangressively by Pliensbachian to Bajocian terrigeneous and carbonate formations (DINKOVA et al., 1987).

Active normal faulting has been proven also during the marine sedimentation in Early and Middle Jurassic times (DODEKOVA et al., 1984), with formation of submarine grabens and horsts. The Callovian - Oxfordian Lobos Formation (breccia and conglomerate) is composed of limestone pebbles (from Middle Triassic to Bathonian in age), and has been also deposited into a submarine graben (SAPUNOV et al., 1985).

Active Senonian normal faulting can be supposed at the boundary with the adjacent Srednogorie Zone, and at its southern margin with the Struma Zone (e.g., Golo-bardo and Melovete Units), shallow-water coarse sediments have been deposited in Early Turonian time, followed by non-volcanic marine sedimentation in the Senonian.

Striking examples of active normal faults with adjacent coarse lacustrine fault-bound sediments have been recorded for the Late Eocene (ZAGORCEV et al., 1989), Middle - Late Oligocene, and Late Miocene and Pliocene (ZAGORCEV, 1992) events.

The Rhodope region (Rhodope Superunit - Fig. 1) has been probably uplifted (low horst area) during most of this time. The Late Cretaceous thrusting was followed by normal faulting with fast differential uplift and exhumation of Upper Cretaceous granitoid and monzonitic bodies, and deposition of thick coarse mostly lacustrine sediments of Palaeocene - Middle Eocene age (GORANOV & ATANASOV, 1992). After a short planation event, the differential uplift continued with formation of fault-bound depressions (grabens) filled in with thick lacustrine coarse sedimentary and volcano-sedimentary formations with Late Eocene - Early Oligocene age, mostly controlled by faults belonging to the WNW-ESE and NNW-SSE fault sets. The same fault sets controlled also the formation of Late Miocene and Pliocene depressions (e.g., BOYANOV et al., 1984).

Movements along some of the normal faults have been renewed several times (e.g., DINKOVA et al., 1987) with changing kinematics (a first normal faulting could be followed by wrench movement with normal or reverse fault component). Bounding normal faults have been sometimes transformed (BONCEV, 1936, 1961) during the next event into reverse faults (upthrusts).

Most of the normal faults dip at angles of 60 - 70. This corresponds to the conventional kinematics of normal faulting (e.g., RAMSAY & HUBER, 1987), and to extension in the direction of the maximum principal extension stress (horizontal or subhorizontal) not exceeding the vertical displacement. However, some Palaeogene (ZAGORCEV et al., 1989) and Late Miocene to Pliocene (ZAGORCEV, 1992) normal fault zones comprise also low-angle normal faults (Fig. 3) dipping at angles between 20 and 45. Some of these faults have been recently interpreted as Late Oligocene - Neogene detachments with enormous extension (DINTER & ROYDEN, 1993; SOKOUTIS et al., 1993). An extensive discussion on these problems is published elsewhere (ZAGORCEV, 1994).

Steep to vertical (80 - 90) fault surfaces are frequent, especially in the Rhodope Region (KOZHOUKHAROV, 1965). Some of the older vertical or steep faults could derive from normal faults dipping at 60 - 70, and further rotating to vertical due to differential uplift in compressional regime, or restricted extension possibilities. Other steep faults could be initially formed as wrench faults that further took over differential vertical movements.

Some of the normal faults are concentrated into long fault belts (lineaments), as, e.g., the Struma (Krasitid) and the Marica lineaments (review in ZAGORCEV, 1992). However, most of the second-order normal faults belong to several principal strike sets, and form a peculiar graben-and-horst pattern, which is almost isometric in some parts of the Rhodope Region but becomes clearly oriented near the huge lineaments (Fig. 1).

THRUSTING EVENTS

Thrusting events were not so numerous in the tectonic history of South Bulgaria (Fig. 2) as the normal faulting events. They were usually closely related to, and/or slightly pre-dating or post-dating, major folding events, i.e. corresponded to major compressional phases.

The oldest possible (but not yet definitely proven) thrusting event is attributed (ZAGORCEV, 1981) to the latest Triassic and earliest Jurassic time ("Early Cimmerian" phase). Southwest-verging thrusting with numerous imbrications within the Permian and Triassic formations in the Poletinci-Skrino fold-thrust zone (Fig. 4) was followed by a northeast-verging folding and thrusting along new thrust surfaces. The whole SW-verging isoclinal fold-and-thrust pattern was deformed and displaced by the post-Triassic and pre-Palaeogene (thrusts and folds sealed by Upper Eocene and Oligocene formations) NE-verging thrusting. As far as the southwestern block (hanging-wall block for the late thrust) was not covered by Jurassic formations, and the NE-verging thrusts are typical for the Mid-Cretaceous

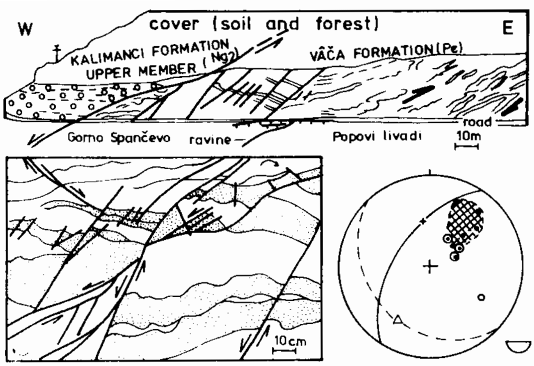

Fig. 3: Low-angle normal fault (last movement - late Pliocene) from the West-Pirin fault zone (on the road from the village of Gorno-Spancevo to Popovi livadi and Goce Delcev). Drawings from photographs, and diagram on equal-area net. Earlier folds related to Mid-Cretaceous thrusting are cross-cut by normal faults. Pegmatitic leucosome is stippled.

("Austrian" phase) folding and thrusting events, the older SW-verging thrusting is believed to be of Late Triassic to earliest Jurassic age.

The most important thrusting occurred after the Berriasian and before the Turonian (ZAGORCEV, 1984, 1990b) but the exact timing is often impossible due to the lack of suitable markers. The youngest sediments involved in the big thrusts in the northern part of the Struma Zone are of Middle Berriasian to Aptian age. The first thrusting events could be coeval to the formation of the Nis-Troyan flysch trough (Kimmeridgian - Berriasian) as far as olistostroms with matrix of Middle Tithonian and Early Berriasian age contain huge olistoliths (up to few hundred meters) from Devonian limestone (TRIFONOVA et al., 1989) typical of the allochthonous Moravide

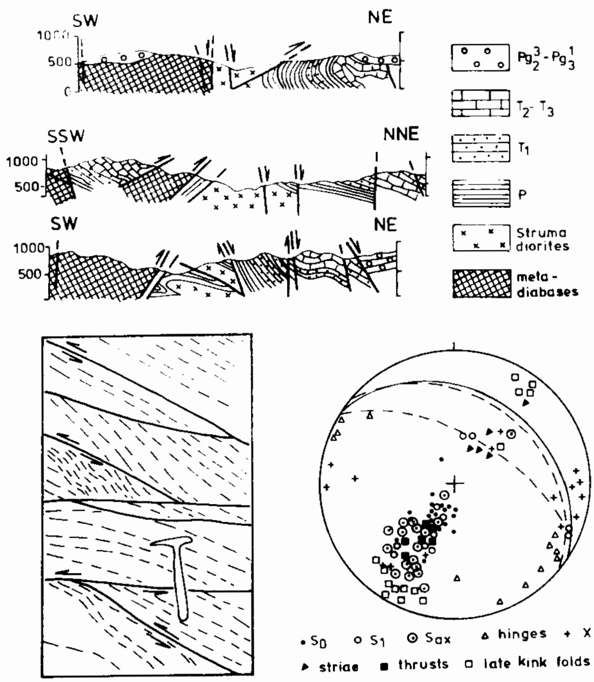

Fig. 4: Folding and thrusting along the Poletinci-Skrino fold-thrust zone, Skrino Gorge of the river Struma. Cross sections (from ZAGORCEV, 1981), drawings of duplexes in Permian red beds (from field photograph), and diagram (equal-area net, lower hemisphere)

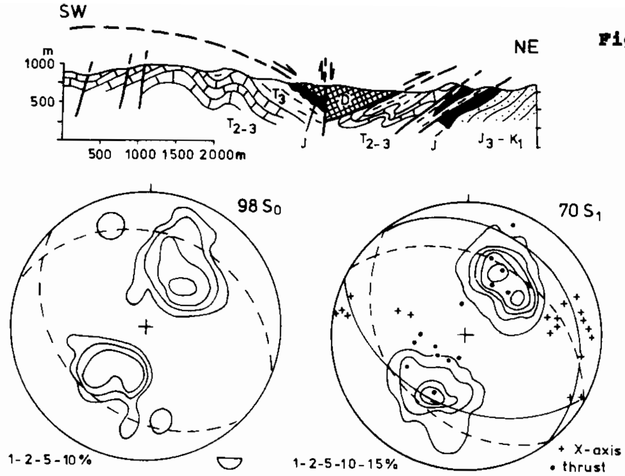

Fig. 5. Cross section through the Treklyano Klippe (Penkyovci thrust) with diagrams (equal-area net, lower hemisphere) for bedding (S_0), cleavage (S_1), maximum elongation (X-axis) and thrust structures.

terrane (Morava Zone). However, the principal thrusting (Penkyovci, Poletinci and Elesnica thrusts) post-dated the Mid-Cretaceous (post-Aptian) folding and denudation, as far as the allochthonous thrust sheets of the Morava Zone covered the folded and deeply eroded structure of the Struma Zone.

In the western part of the Struma Zone, the allochthonous thrust sheets of the Morava Zone cover directly (with some thin Triassic imbrication horses in between) the pre-Permian amphibolite-facies basement (Fig. 5). After the principal thrusting, the thrust surface, the allochthonous sheets,

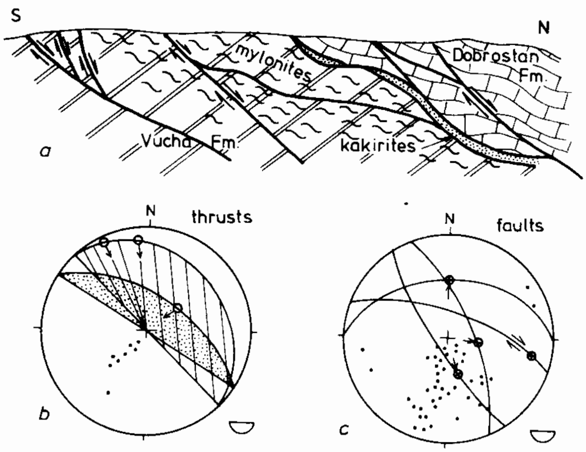

Fig. 6. Cross section (a) through the late Cretaceous Central-Rhodope (Lakavica) thrust (b) with related mylonites and kakirites, intersected by numerous later (Palaeocene - Oligocene) normal faults (c).

and the autochthon have been folded together during a younger, Late Cretaceous event, and this complex structure of folded nappe stack has been sealed by Palaeogene sedimentary formations. The upper age limit for the "Austrian" thrusting of the Ograzden Unit over the Pirin Unit of the Rhodope Superunit (Fig. 1) along the NW prolongations of the Strimon overthrust (KOCKEL & WALTHER, 1965) is defined by its cross-cutting by the North-Pirin granitoid pluton that is of Late Cretaceous age (about 90 Ma).

Late Cretaceous thrusting events are referred to the latest Turonian and Santonian - Campanian times ("Subhercynian phase"), and to the end of the Maastrichtian (early "Laramide" phase). They are proven mainly in the southern periphery of the Srednogorie Zone (GOCEV, 1983), where a Permian

- Turonian section is thrusted over the Upper Turonian formations. The thrusting was directed towards south, thus corresponding to the south-verging Late Cretaceous (KOZHOUKHAROV et al., 1991) Central-Rhodope (Lakavica) thrust sealed by Palaeocene - Middle Eocene lacustrine sediments (Fig. 6). In the Rhodope Region (Superunit), the thrusting occurred at comparatively shallow depths (very low-grade facies mylonites) but the thrust kinematics corresponds to the south-verging movements in amphibolite-facies conditions (proven by "top-to-south" movements inferred from shear-sense indicators - BURG et al., 1990) probably related to the Mid Cretaceous event.

Local thrusting occurred probably also at the end of the Early Oligocene (late "Pyrenean" phase) when a weak folding pre-dated the regression of the sea gulfs and the formation of coal-bearing lacustrine basins. However, in most cases the corresponding thrusts are dated only as post-Early Oligocene and pre-Late Miocene, and could belong to the Early Miocene event ("late Savian" or "early Styrian" phase) first proven by BONCEV (1936). The Early Miocene thrusts are a manifestation of the last compressional phase in South Bulgaria. They displaced all older rocks, the coal-bearing Middle Oligocene - lowermost Miocene deposits included (ZAGORCEV, 1992), and were followed by the Early - Middle Miocene planation, and sealed by Uppermost Badenian - Sarmatian and Maeotian - Pontian to Upper Pliocene sediments. As observed already by BONCEV (1936), the Early Miocene thrusts and upthrusts represented usually rotated normal faults at the boundaries of the grabens, and the thrusting direction (verging) varied in function of the strike and position of the thrusts at the graben boundaries: towards NE or ENE at the SW or WSW boundaries, and towards SW or WSW, at the NE or ENE boundaries.

SOME GENETIC PROBLEMS

The morphological features of the thrust structures were controlled by different origin and kinematics. Synkinematic thrust structures often form thrust systems (complexes) (BOYER & ELLIOTT, 1982; RAMSAY & HUBER, 1987; ZAGORCEV, 1990a).

The Morava Zone (Moravides) is an allozonal (entirely allochthonous terrane) thrust system that consists of several principal internal thrusts with imbrications (leading imbricate fans) within the thrust sheets. Second-order faults have been sometimes related to the major thrusts too. Beneath the Morava thrusts, the parautochthonous Struma Zone contains "rabotage thrusts" (footwall horses) formed as trailing imbricate fans and further reworked by continuous translation; their thrust sheets have been scrubbed from the thrust sole (the Struma Zone itself). They can also represent reworked huge olistoliths from the olistostrom flysch Tithonian - Berriasian sequence but most frequently come from the elevated hill areas shaped by the pre-thrusting erosion. In the Struma Zone, the autozonal thrust systems have been formed as: (i) duplexes (often using the anisotropies of bedding, bedding-parallel lamination, and cleavage) between two or more subparallel major thrust surfaces (formed as detachment surfaces in most incompetent layers), (ii) in the inverted limbs of tight to isoclinal verging folds, or (iii) as trailing imbricate fans. The complex Mid Cretaceous thrust system of the Morava Zone (Penkyovci - Elesnica system) consists of related allozonal, intermediate horses ("rabotage") and autozonal thrusts, which have been further deformed by gentle normal folds in Late Cretaceous time, and by normal faults and reverse faults and thrusts, in Palaeogene and Neogene times. The presumed older (Late Triassic) south-verging thrust system in the Poletinci-Skrino fold-thrust zone consists of thrusts, fold thrusts and duplexes (Fig. 4).

Palaeogene and Early Miocene thrusts are usually related to compression of graben structures, with transformation of the bounding normal faults into reverse faults and thrusts (BONCEV, 1936, 1961). They are often antivergent, and in some cases are related to strike-slip movements along big faults of major lineaments (ZAGORCEV, 1992). Imbrication systems (usually trailing imbricate fans - ZAGORCEV, 1992, Fig. 5) can be formed too. Gravitational thrusts due to gravity-induced downslope gliding of Triassic or Jurassic limestones or Precambrian (Rhodopian Supergroup) marbles are another type of thrusts, usually of a Palaeogene age.

Besides the transformation of the normal graben-bounding faults into reverse faults and thrusts, the opposite sequence of events can also happen as a result of changes in the orientation of the stress field. Thus, the major thrusting of Late Cretaceous (pre-Palaeogene) age in the Central Rhodope (Lakavica thrust) has been followed (Fig. 6) by normal faulting with considerable extension (often along low-angle normal faults partially coinciding with previous thrust surfaces) which probably occurred during the Late Eocene - Early Oligocene orogen collapse and extension with formation of large graben depressions filled in by thick sedimentary and volcanic formations.

CONCLUSIONS

Normal faulting and thrusting events occurred in South Bulgaria in several principal deformation phases throughout its Alpine evolution. The exact dating of a given fault structure or related movement is often impossible due to the long time span between the age of the displaced formations and the age of the sealing deposits. Verging often changes, and thrusts of the same age may be antivergent while thrusts of different ages can possess similar kinematic features, verging included. Some normal faulting events or thrusting events can be diachronous in different parts of the region studied.

In northern Greece, the dating is even more difficult. Most commonly, the formations displaced by Alpine thrusts or faults are of pre-Alpine age, and the sealing deposits belong to the Pliocene. Typical thrust surfaces can be confused with low-angle normal faults, and vice versa. Dating of the movements is particularly difficult in the cases of repeated movements of different kinematics. The history of tectonic research in South Bulgaria shows how often wrong dating of thrusting or normal faulting events has been the consequence of incorrect dating of sealing or displaced formations, or to wrong determination of kinematics and/or dubious correlations using vergences or other morphologic or kinematic features.

REFERENCES

BONCEV, E. (1936). Versuch einer tektonischen Synthese Westbulgariens. - *Geologica Balcanica, 2,* 1, 5-48 (in Bulgarian, with German summary).

BONCEV, E. (1961). Notes on the principal fault structures in Bulgaria. - *Travaux sur la géologie de la Bulgarie, ser. Stratigraphie et tectonique, 2,* 5-29 (in Bulgarian, with French summary).

BONCEV, E.(1988). Notes sur la tectonique alpine des Balkans.- *Bulletin de la Société géologique de France, 8,* 2, 241-249.
BOYANOV, I., YOSIFOV, D. and BONCEV, E. (1984). The Thracian Median and the Rhodope Massif. Geotectonic position and disintegration processes. - in: Block Structure and Faults in Geosynclinal Regions. Bulgarian Academy of Sciences, Sofia, 112-141 (in Russian, with English abstract).
BOYER, S.E. and ELLIOTT, D.(1982). Thrust systems. - American Association of Petroleum Geologists Bulletin, 66, 1196-1230.
BUDUROV, K., ZAGORCEV, I. and TRIFONOVA, E.(1993). The Triassic in Southwest Bulgaria. Upper Triassic red beds (Moesian Group) in the Golo-bardo Unit. - Geologica Balcanica, 23, 5, 35-45.
BURG, J.-P., IVANOV, Z., RICOU, L.-E., DIMOV, D. and KLAIN, L. (1990). Implications of shear-sense criteria for the tectonic evolution of the Central Rhodope massif, southern Bulgaria. - Geology, 18, 451-454.
DINKOVA, J., ZAGORCEV, I. and TZANKOV, TZ. (1987). Relationships between Early Alpine deformations in the Tran anticlinorium. - Geotektonika, tektonofizika i geodinamika, 20, 33-48 (in Bulgarian, with English summary).
DINTER, D. and ROYDEN, L. (1993). Late Cenozoic extension in northeastern Greece: Strymon valley detachment system and Rhodope metamorphic core complex. - Geology, 21, 45-48.
DODEKOVA, L., SAPUNOV, I. and TCHOUMATCHENCO, P. (1984). Stratigraphy of the Aalenian, Bajocian and Bathonian deposits in a part of Southwest Bulgaria. - Geologica Balcanica, 14, 2, 3-55 (in Russian, with English abstract).
GOCEV, P. (1983). Subhercynian allochthon in the Western Srednogorie. - Geotektonika, tektonofizika i geodinamika, 15, 3-16 (in Bulgarian, with English summary).
GORANOV, A. and ATANASOV, G. (1992). Lithostratigraphy and formation conditions of Maastrichtian - Palaeocene deposits, Krumovgrad District. - Geologica Balcanica, 22, 3, 71-82.
KOCKEL, F. and WALTHER, H.-J.(1965). Die Strimonlinie als Grenze zwischen Serbo-Mazedonischen und Rila-Rhodope Massiv in Ost Mazedonien. - Geologisches Jahrbuch, 83, 575-602.
KOZHOUKHAROV, D. (1965). Structure of the crystalline in the Central Rhodopes. - Izvestija NIGI, Sofia, 2, 131-167 (in Bulgarian, with English summary).
KOZHOUKHAROV, D., KATZKOV, N., DIMITROVA, R., and MARINOVA, R. (1991). Lithostratigraphy of the pre-Priabonian Palaeogene sediments in the area south of Laki, Plovdiv District. - Geologica Balcanica, 21, 2, 39-49 (in Russian, with English abstract).
RAMSAY, J.G. & HUBER, M.I. (1987). The Techniques of Modern Structural Geology. Vol. 2: Folds and Fractures. Academic Press, London, 700 pp.
SAPUNOV, I., TCHOUMATCHENCO, P., DODEKOVA, L. and BAKALOVA, D. (1985). Stratigraphy of the Callovian and Upper Jurassic deposits in Southwest Bulgaria. - Geologica Balcanica, 15, 2, 3-61 (in Russian, with English abstract).
SOKOUTIS, D., BRUN, J.P., VAN DEN DRIESSCHE, J. and PAVLIDES, S. (1993).A major Oligo-Miocene detachment in southern Rhodope controlling north Aegean extension. - Journal of the Geological Society, London, 150, 224-243.

ZAGORCEV, I, (1981). Early Alpine deformations in the red beds of the Poletinci-Skrino fault zone. 2. Structure and deformations in the northern part of the Vlahina block. - Geologica Balcanica, 11, 1, 101-126 (in Russian, with English abstract).

ZAGORCEV, I. (1984). The importance of overthrusts in the Alpine structure of Kraistids. - Geologica Balcanica, 14, 4, 37-64 (in Russian, with English abstract).

ZAGORCEV, I. (1990a). Principal genetic types of Early Alpine thrusts and klippes in southwest Bulgaria and east Serbia. - Comptes-rendus de l'Académie bulgare des Sciences, 43, 4, 47-49 (in Russian).

ZAGORCEV, I. (1990b). Correlation between the tectonic units and zones in the border areas of southwest Bulgaria and Yugoslavia. - Comptes-rendus de l'Académie bulgare des Sciences, 43, 7, 53-56 (in Russian).

ZAGORCEV, I. (1992). Neotectonics in the central parts of the Balkan Peninsula: basic features and concepts. - Geologische Rundschau, 81, 635-654.

ZAGORCEV, I. (1994). Discussion on a major Oligo-Miocene detachment in southern Rhodope controlling north Aegean extension. - Journal of the Geological Society, London, 151, 413-414.

ZAGORCEV, I., POPOV, N. and RUSEVA, M. (1989). Stratigraphy of the Palaeogene in a part of southwest Bulgaria. - Geologica Balcanica, 19, 6, 41-69 (in Russian, with English abstract).