

Post-Illirian major-fold subdivision of the transitional area between the Middle and Eastern Balkan Mountains

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Ц. Цанков, М. Паскалев, Р. Наков — Постиллирийское расчленение в области сочленения Средней и Восточной Старой планины на основании мегаскладчатого строения. В верхнемеловой эпохе рассматриваемая область являлась частью обширной территории с монотонной тектофацальной эволюцией. Здесь осуществлялись пространственно-устойчивое ритмическое (главным образом флишевое), карбонатно-терригенное и вулканно-терригенное (под влиянием активного вулканизма на соседних территориях) осадконакопления, локально проявленные в пространстве и во времени конседиментационными блоковыми движениями. С севера к югу установлены части иллирийского Лудокамчийского синклинория и обрамляющие его с юга тоже иллирийские структуры — Качулская антиклиналь и Врылецкий антиклинорий. На его западный периклинорий с юга взброшена или надвинута сильно полифазово деформированная и интенсивно блоково расчлененная северо-восточная окраина восточного окончания лярмидского Средногорского антиклинория. Не подвергается существованию т. наз. „Козуйненской синклинали“ к западу от г. Сливена. Установлены существенные структурные различия между Средногорским антиклинорием и соседними иллирийскими мегаскладчатыми структурами. Самое большое скопление разломов с верхнемеловой тектонической активностью и Твърдицким простирианием указывает, что здесь в верхнемеловое время проходила осевая часть Твърдицкого сдвигового пучка.

Abstract. During the Upper Cretaceous, the land concerned in this study was part of an extensive area of monotonous tectofacies evolution involving a spatially uniform, rhythmic (mostly flysch), carbonate-terrigenous and volcanic-terrigenous (there was active volcanism in adjacent areas) sedimentation, the general monotony being broken by events of olistostrome deposition and consedimentation block movements restricted both in space and in time. From the north to the south, the post-Illirian structural pattern has been found to involve parts of the Illirian Luda-Kamčija synclinorium and the contemporaneous Kačulka anticline and Vrålec anticlinorium surrounding it from the south. By either thrust faulting or recumbent folding, the latter's western periclinorium was overlaid by the northeastern margin of the eastern end of the Laramide Srednogorie anticlinorium, the margin manifesting intense polyphase deformation and block fragmenting. The existence of the so-called Kozuina syncline, named after a mountain peak west of the town of Sliven, has not been confirmed in this study. Essential structural differences have been found between the Srednogorie anticlinorium and the adjacent major Illirian folds. In the area studied, there is the largest areal concentration of faults of Tvårdica orientation and Upper Cretaceous tectonic activity indicating that the Tvårdica strike-slip fault set axis active during the Upper Cretaceous geochron to the south of the Balkan Range should be sought there.

Introduction

This study concerns the areal extension, the differences and the relations between the Laramide and Illirian major fold structures in the southeastern extremity of the Elena-Tvårdica Balkan Mt. (the Peak Kuzoina massif) and in the westernmost part of the Sliven Balkan Mt. (Fig. 1). The regional analysis of major structures is based on the lithostratigra-

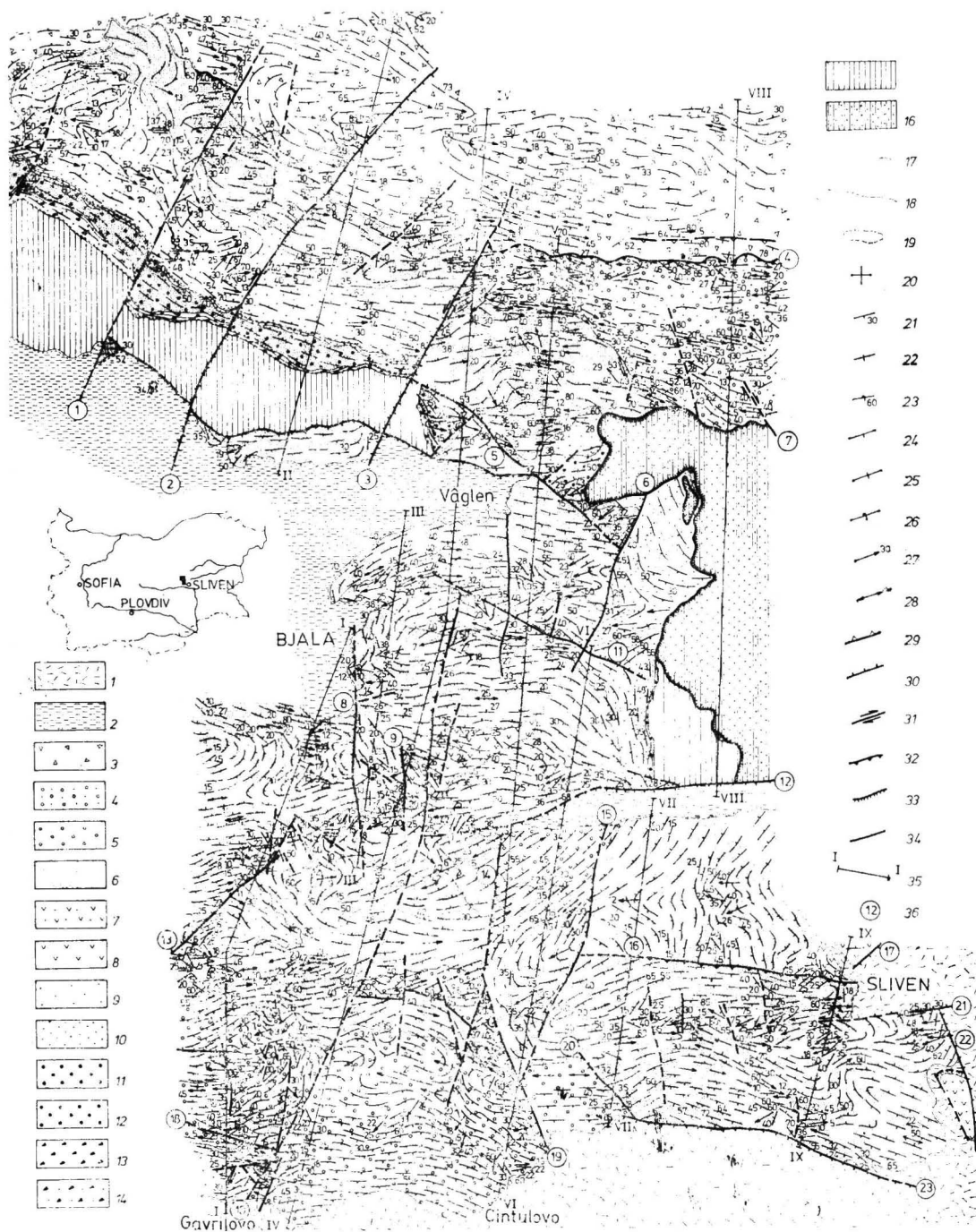


Fig. 1. Geological-structural map of parts of the Elena-Tvrdica and Sliven Balkan Mt.
 1—Quaternary deposits; 2—mixed sandy-clayey formation (Priabonian); 3—marl-sandstone formation (Lutetian); 4—Emine Formation (Campanian-Maastrichtian); 5—flysch calcareous-sandy formation (Upper Campanian?-Maastrichtian); 6—Vetrila Formation (Campanian); 7—sandstone-marl-volcanic formation (Lower Senonian); 8—volcanic-sedimentary formation (Upper Turonian—Lower Senonian); 9—flysch formation (Lower Turonian—Lower Senonian); 10—marl formation (Lower Turonian); 11—Rusalka Formation (Upper Cenomanian); 12—coal-superjacent marl formation (Upper Cenomanian); 13—coal forma-

phic work done by Paskalev (1983, 1985 and 1986) to the northeast of the towns of Bjala and Sliven and still being done by R. Nakov to the southwest of Peak Kuzoi-na. Interpretations use the original structural evidence collected by the authors and published only in parts (Паскалев, 1985, 1986). Both the text and the figures have been prepared jointly by the authors under the general supervision of Tz. Tzankov.

Historical review

Fragmentary and unsystematic account of the structural situation in the area studied may be found in the works of Тоула (1896), Ст. Бончев (1900, 1910, 1927, 1929), Коскел (1927), С. Вончев (1936), Муратов (1949), Йорданов (in: Бошев & Зафиров, 1956, 1960), Ек. Бончев (1957, 1958, 1964, 1971, 1986), Бончев & Карагюлева (1961), Ек. Бончев et al. (1975), Кънчев (1962), Каменов et al. (1964), Попов (1969, 1970), Чешитев (in: Чунев & Дабовски, 1971), Вълчанов (1974), Начев (1977), Николов (1979), Попов et al. (1980), Гочев (1981), Паскалев (1983, 1983a, 1983b, 1985, 1986) and in several unpublished survey reports. Concerning the interpretation of regional tectonic features and the geotectonic affiliation of these lands, the earlier contributions may be summarized as follows:

Ст. Бончев (1900, p. 6) was the first to point out the major-fold structure of the area.

Defining "the Srednogie anticline-nappe reclining to the north", that author (Ст. Бончев, 1910, p. 13) has argued that eastwards it extends into the Eastern Sredna Gora Mt. dipping gradually down until at Binkos (west of Sliven) its Archean core plunges under the Mesozoic sequence forming the massif of Čatal-Balkan. This viewpoint has been shared by Бончев & Карагюлева (1961, pp. 31-41) who defined and nominated the Srednogie Anticlinorium as a structural unit.

Later on, Муратов (1949, p. 90) has regarded the region against the background of "the Balkan Range megaanticline" as the area where "the Svoge-Sliven and the Aitos Anticlinorium" are linked together, referring to the latter all terrains of mappable Upper Cretaceous series. Йорданов (in: Бошев & Зафиров, 1956) has generally shared this opinion. Ек. Бончев (1957, p. 221) has referred the area to "the autochthon of the Central Balkan Mt." which is "a vast anticlinal structure of complicated folding pattern".

Каменов et al. (1964) have referred the Kačulka anticline, defined by V. Tzankov and described by Кънчев (1962), and the Predela anticline to the Central Balkan Anticlinorium (p. 382). Николов (1979, p. 41) has adopted the same viewpoint. Ек. Бончев et al. (1975) have pointed out the role of the Divina flexure in the formation of the Kačulka anticline described in that paper and elsewhere (Ек. Бончев, 1971) as a

tion (Lower Cenomanian); 14 — basal terrigenous formation (Lower Cenomanian); 15 — Permian and Triassic rocks of the basement of the Upper Cretaceous sequence; 16 — Permian and Triassic rocks of the Sliven nappe allochthon; 17 — transgressive lithostratigraphic boundary; 18 — normal lithostratigraphic boundary; 19 — olistostromes; 20—23 — measured positions of bedding surfaces (20 — horizontal, 21 — inclined, 22 — vertical, 23 — overturned); 24—26 — generalized pattern of bedding surfaces (24 — inclined, 25 — vertical, 26 — overturned); 27-28 — fold axis (27 — inclined, 28 — horizontal); 29 — flexural fold; 30 — fault; 31 — strike-slip fault; 32 — thrust fault; 33 — nappe; 34 — fault of undefined displacements of its sides; 35 — profile line; 36 — fault structure names (numbers in circles) (1 — Kačulka strike-slip fault, 2 — Arnaut Dol normal-slip fault, 3 — Beglik Dol normal-slip fault, 4 — Arabadži Burun thrust fault, 5 — Väglen normal fault, 6 — Dragoikino fault, 7 — Davidova Reka strike-slip fault, 8 — Bârdare fault, 9 — Šumen Dol fault, 10 — Gavrailovo fault, 11 — Asenovska Reka fault, 12 — Ablanovo fault, 13 — Gradište fault, 14 — Maslenik fault, 15 — Dobrev Rat fault, 16 — Urum Tarla thrust fault, 17 — Baramuk fault, 18 — Goljam Vrah fault, 19 — Lozen Dol fault, 20 — Goliš fault, 21 — Klucovor fault, 22 — Sliven fault, 23 — Rečica fault, 24 — Čolak fault)

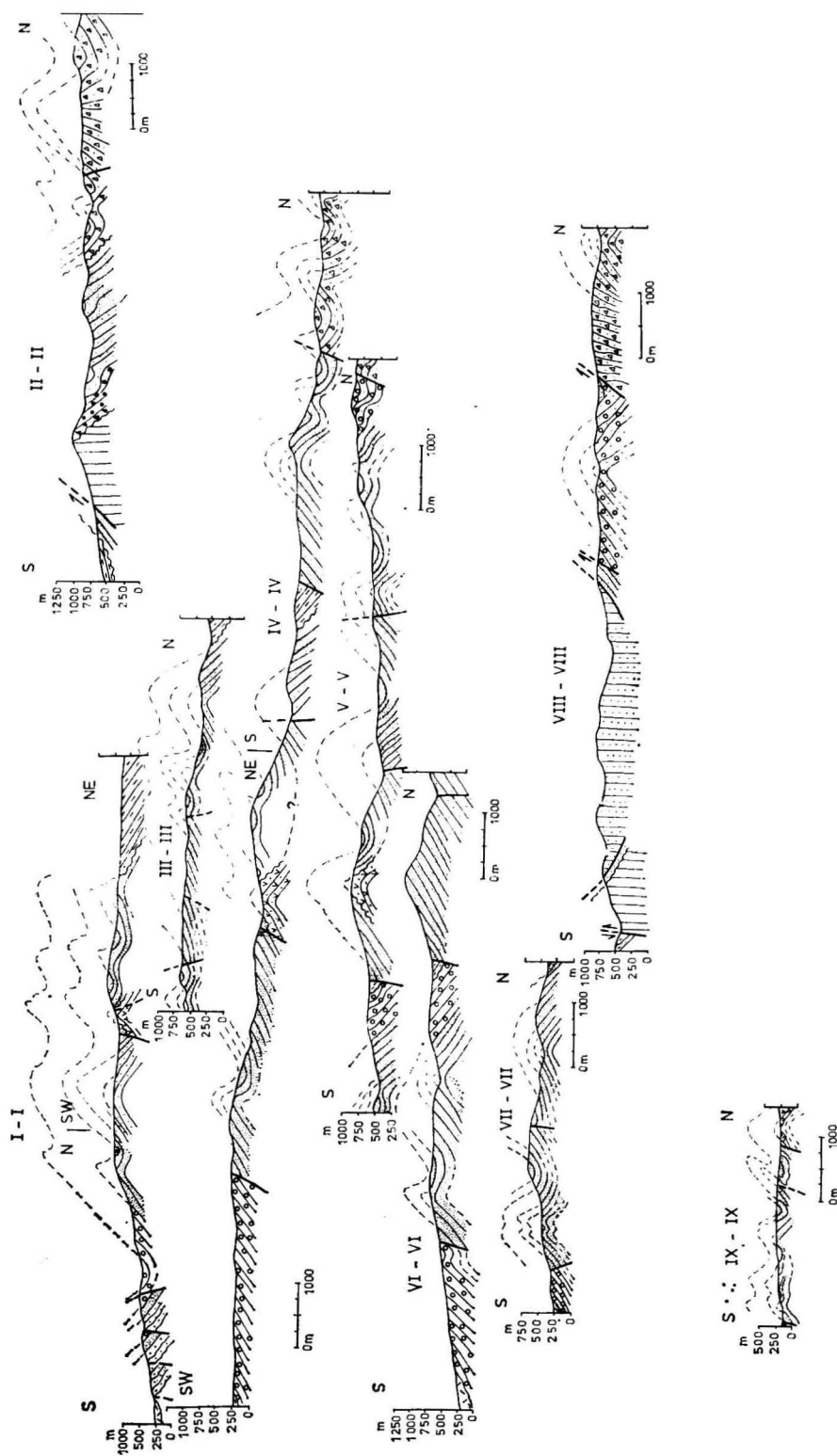


Fig. 2. Geological-structural profiles across parts of the Elena-Tivdica and Sliven Balkan Mt. (symbols as in Fig. 1.)

monocline (p. 39). Recently, Е. К. Бончев (1986) has argued that it is unrelated to the Tvârdica anticline although the two show similar structures (p. 76, 79, etc.).

At the end of the twenties and during the thirties, the idea of a thrust sheet-nappe structure of that land was introduced and established (С. Т. Бончев, 1927, p. 161; 1929; Коккел, 1927; С. Т. Бончев, 1936). Вълчанов (1974) has reported drill-core evidence for the allochthonous structure of large parts of the Sliven Balkan Mt. (p. 97) concluding that "the eastern pericline of the Srednogorie Anticlinorium (?), the Kuzoina syncline, the Predela and Kačulka anticlines and the Botev Peak allochthon form parts of an integral structure thrust over the Burgas Anticlinorium, the Western Balkan Anticlinorium and the Fore-Balkan" (p. 101). The "structure" has been called "Srednogorie allochthon" by that author (p. 101). Николов (1979) has particularly noted that "...the thrust surface is very well seen along the road from the village of Bjala to the Kačulka Mine" (p. 40) where it dips at an angle of about 25°. Besides, the Belene Tertiary basin is treated as "a fragment of the integral Trans-Balkan Paleogene graben..." displaced to the north as the result of the thrusting process (Николов, 1979, p. 40).

Начев (1977) has treated all mappable Triassic and Permian rocks in the Sliven Balkan Mt. as parts of "the Karandila extra-olistostrome" ("olistoplate") referred to the Turonian—Senonian—Lower-Paleocene Flysch Formation (p. 46, Fig. 1).

Попов et al. (1980) have regarded the lands to the south of the Neikovči syncline as part of the large "Laramide" Sliven nappe. The now allochthonous Karakjutjuk and Predela anticlines, formed against that background, "probably were higher-order folds of a large positive structure which may be regarded as an easternward extension of the Tvârdica anticline. The nappe formation may be interpreted as part of the evolution of the anticline structure, its northern limb being torn off during the final stage of folding" (pp. 95-96).

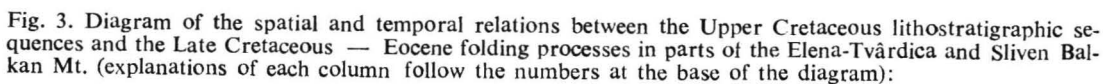
Гочев (1981, p. 52, Fig. 22) has defined the area under consideration as "blocks (an allochthon) with a 'basement' belonging to the Inner Balkanides" on the basis of ERTS satellite photographs made in 1972.

Паскалев (1983) has confirmed the existence and has defined more precisely the areal extent both of the Sliven nappe, built up of Permian quartzporphyries and Triassic deposits, and of the overridden Upper Cretaceous series to the northeast of the Sliven-Bjala road. Later on, Паскалев (1985) has published a systematic study of the regional morphostructural characteristics of deformations in the Turonian, Senonian and Paleogene sedimentary series in the area.

For the purposes of this study we have used (with some corrections and additions concerning the area southwest of the Sliven-Bjala road) the lithostratigraphic subdivision of the Upper Cretaceous sequence in the area made by Паскалев (1983, 1985) (see Appendix I).

Features of the Late Cretaceous — Eocene geotectonic evolution

The Late Cretaceous sedimentation processes in the area started over a mixed basement (aftermath of the Austrian folding) at the beginning of the Cenomanian Age continuing with short, mostly local intermissions until the Late Maestrichtian Subage, i. e. a span of slightly more than 30 Ma in the absolute age interval of 97 to 64 Ma B. P. (Fig. 3). They are readily divided into a Lower Cenomanian Stage of continental sedimentation (about 3.5 Ma) and an Upper Cenomanian — Maestrichtian Stage of marine sedimentation (about 25 Ma). The latter consists of the following well defined substages: initial Upper Cenomanian — Lower Turonian substage of terrigenous-carbonate sedimentation (about 3 Ma), early Lower Turonian — Santonian substage of flysch terrigenous and volcanic-terrigenous sedimentation (about 7.5 Ma), Campanian substage of rhythmic carbonate sedimentation (about 8 Ma), and late Upper Campanian — Maestrichtian substage of flysch and flyschoid terrigenous-carbonate and volcanic-terrigenous sedimentation (of the order of 8 to 9 Ma).



During the Late Cretaceous, the area to the north of the Sliven-Bjala line suffered various manifestations of consedimentation block tectonics (Паскалев, 1983a). It may well be that they echoed some of the Subhercynian orogenic processes (the Mediterranean, Illseder, Wernigerode and Ressen phases after Tollman, 1966). The Late Cretaceous sedimentation in the area ceased before the Laramide orogeny (first Laramide phase after Tollman, 1966) in the Srednogie. The Upper Cretaceous lithostratigraphic sequence formed includes about 100 meters of continental deposits and a series of marine ones, locally exceeding 1300 meters, which, with few exceptions, show laterally uniform lithofacies features and generally persistent tectofacies characteristics of cross-sections. That is why outlining any major paleogeographic boundaries in the area studied seems unjustified as far as the Late Cretaceous epoch is concerned. Furthermore, the fact that most sedimentary series are of rhythmic, flyschoid or flysch character is largely responsible for their similar regional response to the later deformations.

The Lutetian sedimentation, which started after a long (about 22 Ma) period of emergence, was probably restricted to the northern part of the area. The Middle Eocene deposits preserved there overlie transgressively but concordantly the Senonian series. They are very thick (over 500 m) and of marked and laterally persistent flysch character. Therefore they readily yielded to deformations of similar type as those in the Upper Cretaceous rocks. The Lutetian sedimentation ceased before the beginning of the powerful Illirian orogeny during which fold and nappe structures were successively formed. This resulted in a comparatively short (about 2 or 3 Ma) period of emergence.

The Priabonian mixed, markedly terrigenous deposits of varying thickness differ appreciably from the Upper Cretaceous and Lutetian sequences in the area. These youngest brackish lake formations are of local occurrence in intermontane depressions controlled in part by the faulting pattern.

A common feature of all terrigenous rock complexes described is the presence of variable amounts of olistostromes (for details see Hachev, 1977).

This review shows that during the Upper Cretaceous the area studied formed part of a much more extensive region of prolonged and laterally persistent rhythmic, largely flysch carbonate-terrigenous and volcanic-terrigenous (caused by active volcanoes in adja-

J — folding phases after Tollman (1966) (A — Austrian or Late Austrian, Md — Mediterranean, Id — Illseder, VG — Wernigerode, Rs — Ressen, L-1 — first Laramide, L-2 — second Laramide, L-3 — third Laramide, Il — Illirian, Pr — Pyrenean); 2 — deformation intensity (expressed by the arrow length according to the fivegrade scale in the top left corner of the diagram); 3 — absolute geological age (in Ma); 4 — names of geochronological units; 5 — time span of geochronological units (in Ma); 6 — time elapsed from the beginning of the Upper Cretaceous (in Ma); 7 — Luda Kamčija Synclinerium (LS); 8 — Kačulka anticline (KA); 9 — eastern part of the Vråilets Anticlinorium inside the area studied (VA-W); 10 — western part of Vråilets anticlinorium in investigated area (VA-W); 11 — northeastern margin of the Srednogie Anticlinorium (SA-N); 12 — Srednogie Anticlinorium west of the Gavrilovo fault (SA).

Lithostratigraphic units (numbers in circles): 1 — basal terrigenous formation; 2 — coal formation; 3 — coal-superjacent marl formation; 4 — Rusalka Formation; 5 — marl formation; 6 — flysch formation; 7 — volcanic-sedimentary formation; 8 — Vetrila Formation; 9 — flysch calcareous-sandy formation; 10 — Emine Formation; 11 — marl-sandstone formation; 12 — mixed sandy-clayey formation; 13 — periods of olistostrome formation; 14-16 — Upper Cretaceous — Paleogene sedimentation proceeded: (14 — substages during the Upper Cretaceous marine sedimentation stage: M-L — initial (of terrigenous-carbonate sedimentation), M-2 — early (of flysch, terrigenous and volcanic-terrigenous sedimentation), M-3 — substage of rhythmic carbonate sedimentation, M-4 — late (of flysch and flyschoid terrigenous-carbonate and volcanic-terrigenous sedimentation); 15 — stages of the Upper Cretaceous sedimentation cycle: Kr' — C — continental, Kr' — M — marine; 16 — sedimentation cycles: Kr' — SED — Upper Cretaceous, Ec' — SED — Lutetian, Ec' — SED — Upper Eocene; I-IV — regional manifestations of Upper Cretaceous and Paleogene folding and faulting processes (Roman numbers in triangles):

I — Upper Cretaceous sedimentation block movements north of the Srednogie Anticlinorium; II — Early Laramide folding within the Srednogie Anticlinorium, IIIa — Illirian folding north of the Srednogie Anticlinorium, IIIb — intense tectonic reworking of Laramide structures within the Srednogie Anticlinorium, IV — thrust faulting or recumbent folding of the Sliven nappe allochthon. In the columns of rock sequences, normal lithostratigraphic boundaries are given with straight lines, and transgressive boundaries with undulating lines

cent areas) sedimentation characterized also by olistostrome formation and local as well as intermittent consedimentation block movements. This "monotony" of the Upper Cretaceous tectofacies (in the sense of Mahel) characteristics of the area studied determines the importance of subsequent deformations for the post-Illirian tectonic zonation there.

Main features of the regional structural setting

About 2000 structural measurements (including over 1600 measurements of bedding surfaces and over 360 measured or reconstructed fold axes) were made in order to determine the structural characteristics of terrains occupied by Upper Cretaceous — Eocene series (covering a total area of about 160 sq. km.). Applying morphostructural analysis to systematize these data (remote sensing methods have not been used), we compiled the map shown in Fig. 1 and the profiles in Fig. 2. Allowing for the scale used, the following first-rank features of the regional post-Illirian major-fold pattern may be derived from the field information represented in this way.

1. The northeastern part of the area (Fig. 1) is dominated by structures involving mostly Lutetian series and belonging to the explored section of the southern flank of the Luda Kamčija Synclinorium (=Neikovci syncline, Toulal, 1896; Kockel, 1927; =Luda Kamčija Synclinorium, Муратов, 1949, Fig. 90; Йорданов et al., 1956; Кънчев, 1962, p. 357; Каменов et al., 1964, p. 382; Попов 1969, p. 14; Кънчев, 1971, p. 401; Ек. Бончев, 1971, p. 77; Николов, 1979, p. 43; Попов et al., 1980; Паскалев, 1983, p. 53, 1985, p. 226; Ек. Бончев, 1986, p. 60). These are well defined, as a rule echelon-like trains of parallel to subparallel brachyfolids oriented at about 100° and of more or less pronounced northern vergence. Such are the essential characteristics and spatial relations of the superimposed pattern of minor, higher-order folds (Паскалев, 1985).

2. South of the Luda Kamčija Synclinorium and, correspondingly, north of the Belene Tertiary Basin and west of the Vâglen meridian (Fig. 1), the folding pattern is dominated by the eastern section of a major anticline found by V. Tzančov and coauthors unpublished survey report, 1954) who called it Kačulka anticline (Йорданов in: Бошев & Зафиров, 1960; Кънчев, 1962, pp. 368-369; Каменов et al., 1964, pp. 39, 41; Ек. Бончев, 1971, p. 74; Ек. Бончев et al., 1975, p. 39 — "Kačulka monocline"; Николов, 1979, p. 39, Fig. 3, IV, p. 41; Попов et al., 1980, pp. 95-96; Ек. Бончев, 1986, pp. 76, 79). Its northern limb is distinctly outlined throughout the local Upper Cretaceous lithostratigraphic sequence (Fig. 1). The southern limb is covered to a large extent by Priabonian deposits and is broken by longitudinal faulting (Fig. 1). On the whole, this is a linear-brachyform conical to paraboloidal fold of fairly distinct eastern pericline to be followed north of the village of Vâglen (Fig. 1). Its core consists of Triassic sedimentary series showing different tectonic behaviour as compared to the Upper Cretaceous cover (Паскалев, 1985). The anticlinal hinge is oriented at about $100-115^\circ$. Borehole evidence (Кънчев, 1962) has shown that downwards the northern limb straightens up and overturns which illustrates explicitly the northern vergence of this structure.

3. At the Vråilets Peak, in the area between the Ablanovo half-graben in the south, the Belene Tertiary Basin in the west and northwest and the Sliven Nappe allochthon in the east (Fig. 1), we have traced the central part of a westward-dipping periclinorium belonging to a fold called by us the Vråilec Anticlinorium. Its constituent structures, both the major (elementary) folds and the minor, higher-order ones, show a markedly uniform, nearly W-E orientation of their hinges which dip mostly to the west or are horizontal (Fig. 1). This is the area where Каменов et al. (1964), Попов (1969, 1970), Николов (1979) and Попов et al. (1980) have traced the western periclinal folds of the Predela and Karakjutjuk anticlines. The structures in the Upper Cretaceous outcrops east

of the Beglik Dol fault in the Paletto locality south of the Arabadži Burun overthrust (Fig. 1) should be regarded as relics of the northern flank of the Vråilets Anticlinorium. A fragment of the southern part of the anticlinorium is the section south of the Ablanovo half-graben between the Dobrev Rât fault and the Asenovo overthrust (Fig. 1).

4. The territory surveyed south of the line running through Bjala, the Ablanovo half-graben western end, the Dobrev Rât fault and the Asenovo overthrust (Fig. 1) represents the preserved northeastern margin of the Srednogorie Anticlinorium eastern extremity that survived intense polyphase deformation and block fragmentation (in agreement with the ideas of С.Т. Бончев, 1910, p. 13; Бончев & Карагюлева, 1961, p. 33; Ек. Бончев, 1964, p. 227; Каменов et al., 1964, p. 385; Чешитев in: Чунев & Дабовски, 1971, p. 357). This part of the megastructure is characterized by folds, well defined on a regional scale, whose hinge run in one of the following three intervals: $55-70^\circ$, about 90° , and $100-125^\circ$ (Fig. 1). In the area, the Srednogorie Anticlinorium has been pushed from the south over the Vråilets Anticlinorium along the Asenovo overthrust (Fig. 1) which suggests that the Kačulka anticline underlying the Priabonian series of the Belene Tertiary Basin may have been also involved in the process. Furthermore, the structural pattern to the southeast of Bjala (Fig. 1) clearly shows that the hinges of folds belonging to the western periclinorium of the Vråilec Anticlinorium, on the one hand, and those of the Srednogorie Anticlinorium eastern parts, on the other, plunge steeply against each other at the common tangent.

In the part of the Srednogorie Anticlinorium studied here, we did not find evidence confirming the existence of the so-called Kuzoina syncline inferred by V. Tzankov by general geological reasoning (see Кънчев, 1962, p. 357), most later authors adopting the idea (Кънчев, 1962; Каменов et al., 1964; Ек. Бончев, 1971 — "Kuzoina Synclinorium"; Чешитев in Чунев & Дабовски, 1971; etc.). This problem will find its final solution after a structural study of the western section of the Peak Kuzoina massif.

The parts of the Luda Kamčija Synclinorium, the Kačulka anticline, the western periclinorium of the Vråilets Anticlinorium and the Srednogorie Anticlinorium in the area studied show significant similarities as well as differences with respect to essential morpho-structural features (Figs. 4, 5 and 6). First of all, the orientation of bedding surfaces and hinges of folds of various order in the first three of them and in the transitional zone between the Vråilets Anticlinorium northern flank and the Kačulka anticline (Fig. 4, D-1, D-2, D-3 and D-4; Fig. 5, D-7, D-8, D-9 and D-10; Fig. 6, D-13, D-14, D-15 and D-16) shows that all these are conical, or more precisely paraboloidal (bedding surfaces plot on more than one concentric small circles in stereographic projection) major folds of generally very similar structures, almost vertical axial planes and mostly inclined hinge surfaces (to the east in the Luda Kamčija Synclinorium and the Kačulka anticline, and to the west in the Vråilets Anticlinorium). It is also typical that the bedding plane normals are always grouped in two distinct, more or less strong and almost perfectly symmetrical maxima the angle between which is fairly invariable. The geometry and location of small circles on the density stereoplots show similar characteristics. The relations in the Srednogorie Anticlinorium are drastically different (Fig. 4, D-5, D-6; Fig. 5, D-11, D-12; Fig. 6, D-17, D-18). The density stereoplots of bedding surfaces in that structure show a girdle with two maxima which, though symmetrical, are of different intensity. In addition, normals are generally scattered forming vague secondary submaxima in the directions NW-SE and SW (to the east of the Gavrailovo fault, D-6). The density stereoplots of fold crest surfaces also show appreciable differences in the Srednogorie Anticlinorium as compared to the other major structures. The latter invariably show a distinct maximum at $90-100^\circ$ whereas in the Srednogorie Anticlinorium there is a very extended maximum (passing into a girdle) in the interval E-NE — E-SE (Fig. 5, D-11, D-12).

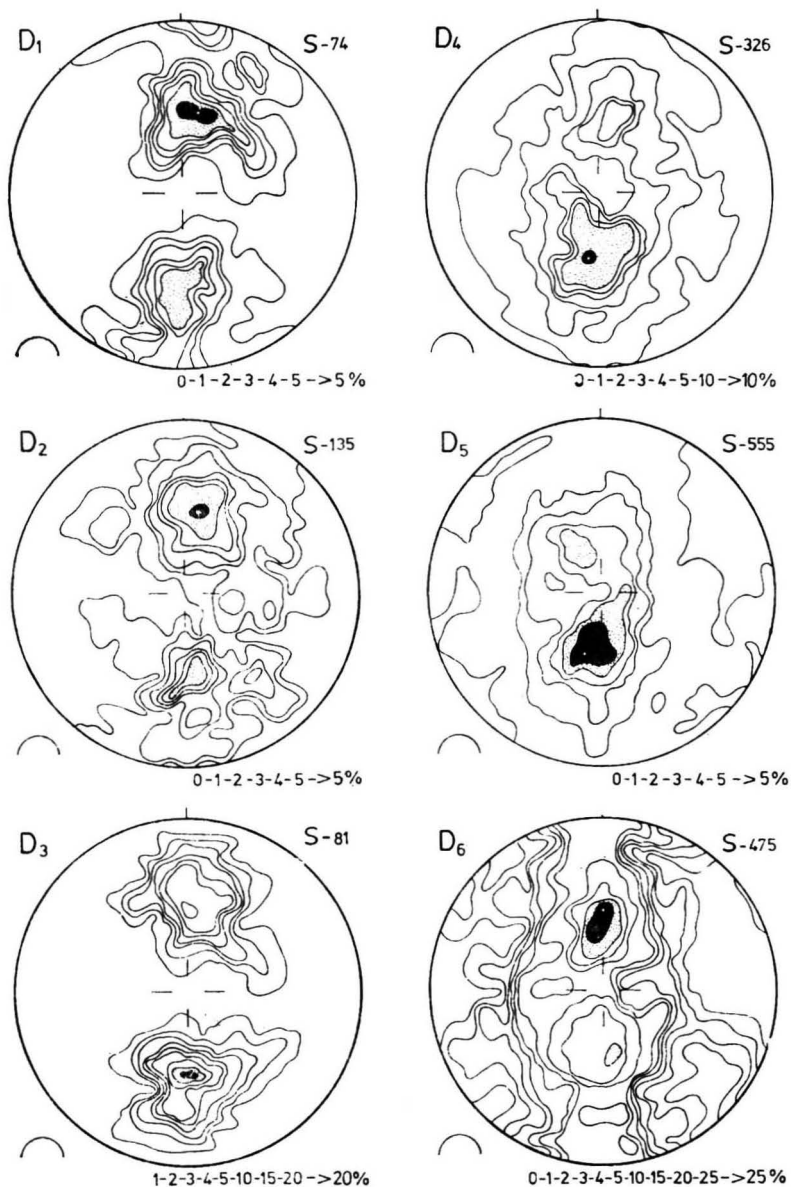


Fig. 4. Density stereoplots of bedding surfaces (projection on the upper hemisphere):

D-1 — Luda Kamcija Synclinorium, D-2 — Kačulka anticline, D-3 — zone of the interlocking between the Kačulka anticline and the Vråilets Anticlinorium northern flank, D-4 — Vråilets Anticlinorium, D-5 — D-6 — Srednogorie Anticlinorium, to the east (D-5) and west (D-6) of the Gavrailovo fault, respectively

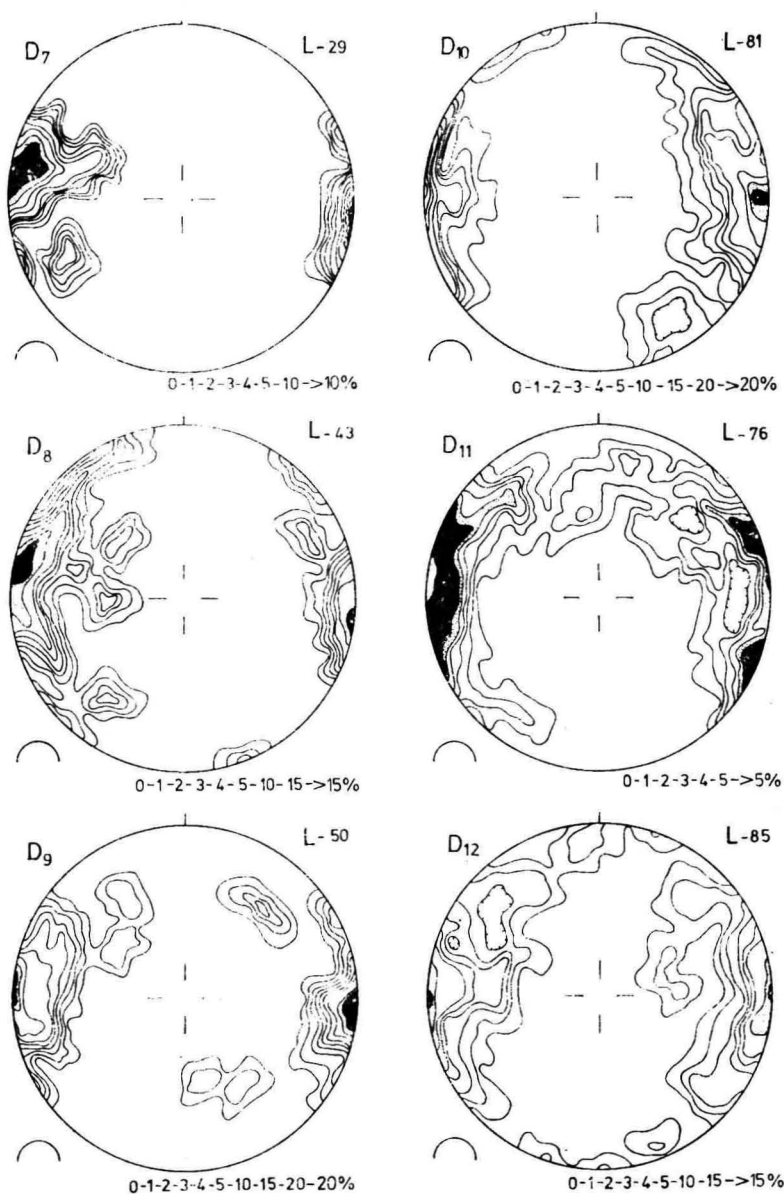


Fig. 5. Densiplot stereoplots of fold hinges (projection on the upper hemisphere): D-7 — Luda Kamčija Synclinorium; D-8 — Kačulka anticline; D-9 — zone of the interlocking between the Kačulka anticline and the Vráilets Anticlinorium northern flank; D-10 — Vráilets Anticlinorium; D-11 — D-12 — Srednogorie Anticlinorium, to the east (D-11) and west (D-12) of the Gavrilovo fault, respectively

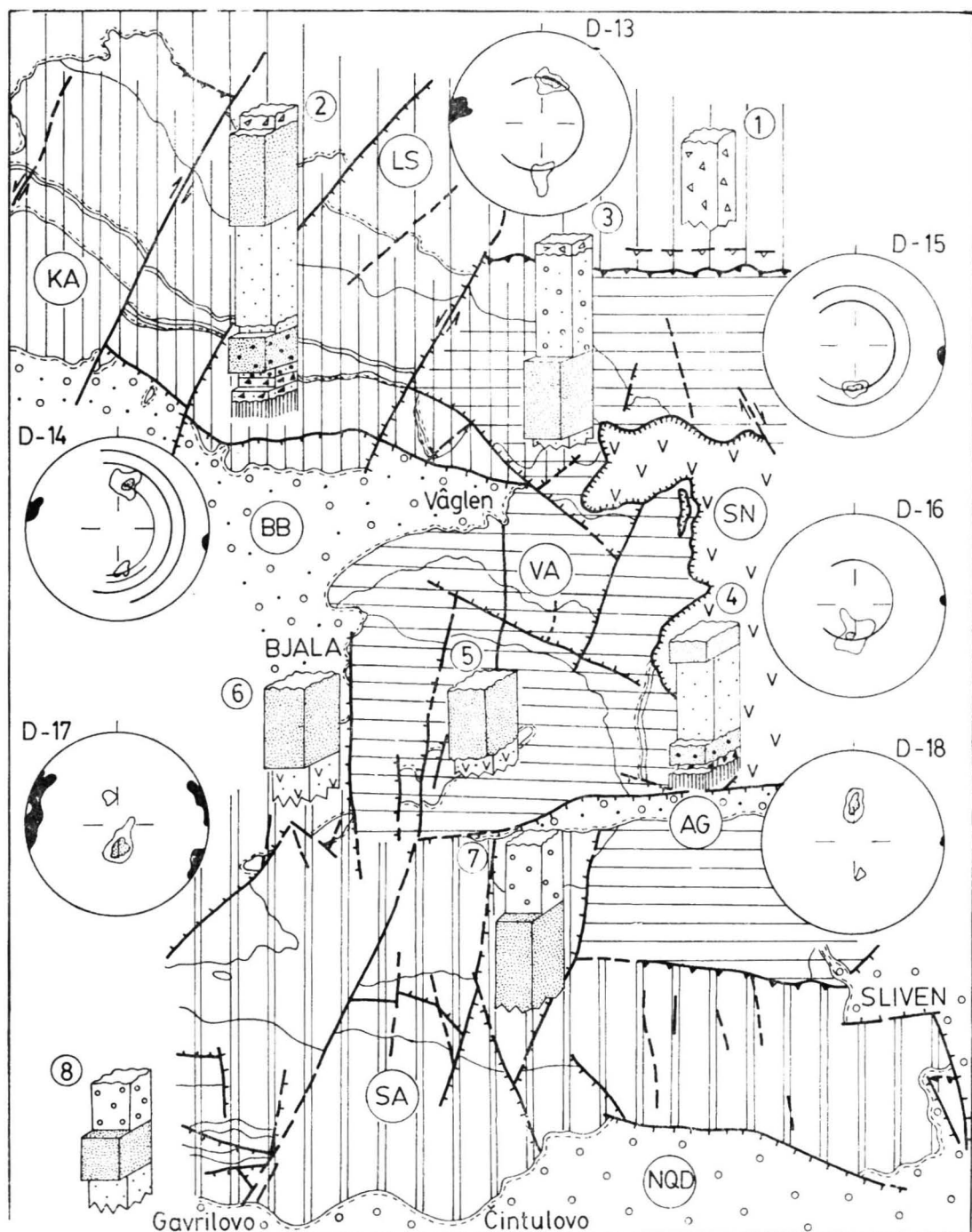


Fig. 6. Tectonic scheme of the main structural elements during the Upper Cretaceous — Paleogene evolutionⁿ of parts of the Elena-Tvrdica and Sliven Balkan Mt.:

LS — Luda Kamčija Synclinorium, KA — Kačulka anticline, VA — Vrâilets Anticlinorium, SA — Srednogie Anticlinorium, BB — Belene Tertiary basin, AG — Ablanovo graben, NQD — Back-Balkan Neogene — Quaternary Depression, SN — Sliven nappe.

Local Upper Cretaceous—Eocene lithostratigraphic sequences (numbers in circles): 1 — Rakovo, 2 — Kačul-

Conclusion

The above morphostructural similarity between the explored parts of the Luda Kamčija Synclinorium, the Kačulka Anticline and the Vrålets Anticlinorium is the logical consequence of the fact that these major structures are products of the Illirian folding alone (Fig. 3). In turn, the relics of the Srednogorie Anticlinorium studied here show fairly complex, interferential structural characteristics. Their present-day state reflects the superposed effects of the Laramide structure formation (which produced the anticlinorium, Fig. 3), the Illirian folding and the subsequent thrust faulting and probably also recumbent folding of the Upper Cretaceous rock complexes from the cover northwards over the Vrålets Anticlinorium (Fig. 1).

As part of the Balkanide segment of the Tvårdica fault set (treated by Ек. Бончев (1986a) as a transcurrent lineament set), the area studied (Fig. 4) is characterized by: 1) the largest areal concentration found so far of faults of a general "Tvårdica" orientation, a considerable number of which manifest cosedimentation tectonic activity during various intervals (Паскалев, 1983) of the Upper Cretaceous; 2) precisely in those places echelons of major Illirian folds run against each other ending with opposite dips at the junction; 3) the remarkable transverse structural depression formed in the area during the Laramide and Illirian orogenies. As shown by the analysis of the Ptičevo line (in the sense of Бончев, 1958) made by Stojanov & Tzanov (1968), these characteristics indicate that during the Upper Cretaceous — Eocene period of Balkanide evolution the "axial" segment of the Tvårdica set ran across that very area (Fig. 4).

Appendix

Brief lithostratigraphic notes

Basal terrigenous formation (Ек. Бончев et al., 1975; Попов et al., 1980; Паскалев, 1983; =basal conglomerate after Цанков, 1947; Цанков & Кехайова, 1963; =basal horizon after Манолов, 1959; Кънчев, 1962, 1964; Кънчев & Чешитев, 1962). Lower boundary: the base of the formation rests transgressively and discordantly over various Triassic deposits. Rock composition: quartz conglomerates with clayey-sandy matrix, less common sandstones. Upper boundary: conglomerates disappear to be replaced by argillites and marls. Thickness: ranging from 0 to 40-45 m. Age: Lower Cenomanian (Кънчев, 1962). Occurrence: discontinuous.

Coal formation (Паскалев, 1983; =coal-bearing series after Цанков, 1947; Манолов, 1959; =coal-bearing horizon after Кънчев, 1962, 1964; Кънчев & Чешитев, 1962; Цанков & Кехайов, 1963; Цанков, 1968; Каменов et al., 1964 =lower coal series after Ек. Бончев et al., 1975; Попов et al., 1980). Lower boundary: rapid gradual transition. Rock composition: argillites, bituminous argillites, coal, dark marls, sandstones. Section usually starts with argillites or directly with coal. Upper boundary: transition from the sandstones or the other rock varieties involved to grey-greenish marls. Thickness: 40-50 m. Age: Lower Cenomanian (Кънчев, 1962). Occurrence: discontinuous.

Coal-superjacent marl formation (Ек. Бончев et al., 1975; Попов et al., 1980; Паскалев, 1983; =coal-superjacent marl after Цанков, 1947; =coal-superjacent horizon after Кънчев, 1962, 1964; =marls after Начев, 1977). Lower boundary: gradual transition. Rock composition: fine-layered to fine-banded, locally poorly stratified grey-greenish clayey marls. Small (2-3 cm in diameter) rounded rusty-coloured clay concretions are fairly common. Upper boundary: appearance of quartzitized sandstones. Thickness: 15 m. Age: Upper Cenomanian (Кънчев, 1962). Occurrence: discontinuous.

Rusalka Formation (the name has been first introduced as Rusalka sandstone) (Ст. Бончев in: В. Цанков, 1947, p. 156). Under Article 37 of the Stratigraphic Code, the name is applicable and is the valid

ka, 3 — Beglik Dol, 4 — Asenovska Reka, 5 — Šumen Dol, 6 — Gradište, 7 — Maslenik, 8 — Gavrailovo. Stereoplots (upper hemisphere projections) show the spatial relations between fold hinge density maxima (black) and bedding surfaces density maxima (dotted). Small circles (in D-13, D-14, D-15 and D-16) are constructed to follow the bedding surfaces density distribution. D-13 — Luda Kamčija Synclinorium, D-14 — Kačulka Anticline, D-15 — zone of the interlocking between the Kačulka anticline and the Vrålets Anticlinorium northern flank, D-16 — Vrålets Anticlinorium, D-17 — D-18 — Srednogorie Anticlinorium, to the east (D-17) and west (D-18) of the Gavrailovo fault, respectively

one being the oldest. Although erroneously crediting himself with the authorship of that unit, the earliest revising author E. Bončev in Ек. Бончев et al. (1975) was the first to define its rank as a Formation and to characterize it explicitly giving detailed information about its age, relationships and occurrence. Other names used so far: Rusalka quartzite horizon, Цанков (1947); Rusalka horizon, Кънчев (1962, 1964); Кънчев & Чешитев (1962); Цанков & Кехайова (1963); Каменов et al. (1964); sandstones, Начев (1977). Lower boundary: gradual transition. Rock composition: thick-bedded, very hard, grey, locally whitish or pale pink, medium- to coarse grained silicified sandstones. The upper part of the section contains thin (4-5 cm) interlayers of sandy marls. At the Kaculka mine, the formation ends up with a thick (7-8 m) packet of quartz conglomerates of clayey-sandy matrix containing rudists. Upper boundary: appearance of marls. Thickness: 90 m (the Kaculka mine), 110 m (the Sasa Dol locality). Age: Upper Cenomanian (Кънчев, 1962). Occurrence: ubiquitous.

Marl formation (Ек. Бончев et al., 1975; Паскалев, 1983; =flysch type of Turonian after Берегов, 1942; Цанков, 1947; =marl horizon after Кънчев, 1961, 1962; =lower flysch series after Начев, 1977). Lower boundary: gradual transition. Rock composition: grey-green marls showing yellowish-brown weathered surfaces. Upper boundary: change to argillites and sandstones. Thickness: 20 m. Age: Lower Turonian (Кънчев, 1962). Occurrence: discontinuous.

Flysch formation (Ек. Бончев et al., 1975; Попов et al., 1980; Паскалев, 1983; =Rado-va zone after Ст. Бончев see Кънчев, 1962; Маринов, 1928; =dark flysch after Берегов, 1942; Коен, 1946; Ек. Бончев, 1955; Манолов, 1959; =Turonian flysch after Цанков, 1947; =flysch horizon after Кънчев, 1962; Кънчев & Чешитев, 1962; Цанков & Кехайова, 1963; Цанков, 1968; =flysch subhorizon after Каменов et al., 1964; =third Turonian horizon and Lower Senonian after Кънчев, 1964). Lower boundary: transgressive overlap of the marl series. Rock composition: multiple rhythmic flysch to flyschoid alternation involving thinly bedded (about 10 cm on the average, rarely up to 1 m bed thicknesses), dark grey to black, fissile argillites splitting into thin (1-3 mm) plates and micaceous sandstones (of centimeter or decimeter, rarely up to one meter bed thickness) with clayey-silty cement. These two end varieties bracket a range of intermediate ones. Upwards the sandstones become less abundant and carbonate constituents appear the top of the section. Small weathered ellipsoidal clay and siderite concretions are common at the base of the series. There are thin (1-2 cm), laterally discontinuous intercalations of dark-grey to dark-green silicites. In the cross-sections north of the Kačulka mine, downstream along the Magareška River and especially at the upper reaches of the Sasa Dol valley, there are intraolistostromes containing clasts of dolomites, olistostromes and olistoplates (Ек. Бончев et al., 1975; Начев, 1977, 1980; Николов, 1979). Upper boundary: comparatively slow (within an interval of 50-60 m) gradual transition to the Vetrila Formation mostly argillaceous limestones. Thickness: about 330-350 m. Age: Lower Turonian — Lower Senonian (Кънчев, 1962). Occurrence: ubiquitous. Discussion: In their report on the structure of the Kuzoina syncline (unpublished, report of Geological Survey, Sofia, 1954), В. Цанков et al. have noted the occurrence of flyschoid Senonian deposits north of the villages Goljam Čočoven, Čintulovo, Seliminovo and Gavrailovo. They start with a transition from a "Turonian flysch" grading upwards into the "Vetrila marls proper". These rocks we refer to the uppermost part of the flysch series.

Volcanic-sedimentary formation (Карагюлева & Костадинов, 1977; Паскалев, 1983; =andesite formation after Гоцев, 1970; =volcanic-sedimentary formation after Кънчев, 1971; =sedimentary volcanic flysch after Aiello et al., 1977; =clayey-carbonate series after Карагюлева & Костадинов, 1977; =tephroid flysch after Начев, 1977). Lower boundary: not exposed. Rock composition: flysch to flyschoid rhythms involving light-brown thin-, medium- and thick-bedded (up to 2.5 m) layers and packets of andesite tuff, intercalations of tephroid sandstones (mean thickness of 7-8 cm), medium-thick (up to 10 cm) siltstones and separate layers (10-15 cm thick) of grey clayey limestones. The lower levels of outcrops are dominated by andesitic tephroturbidites. Higher up the sequence consists of thin rhythmic layers of tephroidal deposits, sandstones, marls and individual intercalations of clayey limestones. Upwards the portion of sandstones becomes gradually greater until balancing the tephroturbidites. Along the Sliven-Bjala road, the series ends up with breccia-conglomerate 1-2 m thick, probably indicative of slight local denudation. Upper boundary: end of tephroturbidites and tephroid sandstones. Thickness: apparently 100-110 m. Age: Upper Turonian — Lower Senonian (?). Occurrence: discontinuous; the series apparently thins rapidly out to the southwest, west and north. The series may represent: 1) some constituent element (member?, wedge?) of the uppermost part of the flysch series, 2) a "lense" trapped in the Vetrila Formation, or 3) an independent lithostratigraphic unit underlying parts of the Vetrila Formation and laterally interlocked with the topmost parts of the flysch series.

Vetrila Formation (the name has been introduced as Vetrila marls) (Ст. Бончев, 1927, p. 160). Under Article 37 of the Stratigraphic Code, the name is applicable and is the valid one being the oldest. Although erroneously crediting himself with the authorship of that unit, the first revising author Паскалев (1983, p. 33) has defined its rank as a Formation, has characterized it explicitly and has given detailed information about its age, relations and occurrence. Other names used so far: clayey-carbonate formation, Карагюлева & Костадинов (1977); upper flysch formation Начев (1977); clayey-limestone formation Попов et al. (1980). Lower boundary: gradual transition from the volcanic-sedimentary formation in the latter case there are indications (occurrence of a conglomerate packet at the top of the volcanic-sedimentary sequence) of a local interformational break in sedimentation. Rock composition: grey well-bedded (bed thickness up to 10 cm) clayey limestones containing thin (2-3 cm) and long (7-8 cm) platy flint nodules parallel to the bedding. North of the Kačulka mine at the middle of the sequence there are thin (1-3 cm) interlayers of dark-grey to black argillites. To the southeast of Bjala, in the places where the for-

mation overlies the volcanic-sedimentary formation the limestones are tinted reddish by iron hydroxides and the middle of the sequence contains individual interbeds of grey-green coarse-grained sandstone (bed thickness 10-15 cm). Upper boundary: the appearance of the coarse-grained mica-bearing quartz sandstones typical of the Emine Formation. Thickness: 350-400 m north of the Kaculka mine and 22-250 m east and south-east of Bjala. Age: Campanian (Паскалев, 1983, 1985). Occurrence: ubiquitous.

Emine Formation (the name has been introduced as Emine beds) (Гочев, 1932, p. 204) (see Паскалев, 1983a; Джуранов & Пимпирев, 1989). Other names used so far: Emine Formation, Ек. Бончев (1955); Emine flysch formation, Атанасов & Кънчев (1965); Emine formation Карагюлева & Костадинов, (1977); upper part of a flysch formation, Начев (1977); flysch formation, Попов et al. (1980). Lower boundary: gradual transition from the rocks of the Vetrila Formation. Rock composition: flysch or flyschoid rhythms of clayey limestones with or without chert, grey-yellow to rusty marls, grey medium- to coarse-grained mica-bearing quartz sandstones, some sandy limestones and scarce fine-detrital quartz conglomerates of sandy or calcareous-sandy matrix. The sandstone and conglomerate beds reach up to 1 m in thickness. A notable feature of the Emine Formation is the common presence of extraolistostromes with a variety of clasts at various levels across the sequence. Generally, these are elongated sheets up to 5 km long, 0.5 km wide and 1-2 to 70 m thick. The clast composition is dominated by clayey and sandy limestones, limestones and abundant quartzites; sandstones, chert nodules and argillites are less common. Well-preserved intraolistoliths up to 2.5 m in diameter are also to be observed. Fragments of quartz-porphyrates and Triassic dolomites from the Sliven nappe are completely absent. The matrix is largely sandy-clayey, less commonly sandy-calcareous. Upper boundary: erosional, transgressive. Thickness: 380-400 m north of the Tâtenite resort and 100-120 m in the west near the Paletto locality. Age: Upper Campanian — Maastrichtian (Карагюлева & Костадинов, 1977). Occurrence: proven in the northeastern part of the area.

Flysch calcareous-sandy formation (=the uppermost part of the complete Senonian column north of the villages Seliminovo and Gavrailovo as given by Каменов et al., 1964). Lower boundary: distinct, through gradual transition from the rocks of the Vetrila Formation; the boundary is placed at the first massive sandstone bed and the following carbonate-terrigenous flysch rhythms. Rock composition: flysch to flyschoid rhythms of invariably present largely medium- to coarse-grained (passing locally into small-fragment breccia-conglomerates) grey-brown muscovite-bearing quartz sandstones (bed thickness 10-12 cm, rarely up to 80-100 cm) probably containing tephroidal (tuffaceous) constituents, with sandy to calcareous-sandy matrix and rusty-brown weathered surfaces (giving a characteristic brown colour to soil), and usually white-grey to dark-grey highly sandy, sandy-clayey or clayey limestones (bed thickness from 2-3 to 10-15 cm) occasionally containing chert; the less common varieties in the cross-section include siltstones and even scarcer gravelites or small-fragment breccia-conglomerates. A notable feature of this formation are the rapid lateral and vertical changes in the ratio between sandstone and limestone bed thicknesses. That is why in bad exposures dominated by one of these rock types the sequence may be wrongly referred to some other unit, e.g. the Vetrila Formation. Typical cross-sections: north of the villages of Gavrailovo, Seliminovo, Goljam Čočoven, Čintulovo and near the Maslenik Peak. Upper boundary: erosional, transgressive; north of the Maslenik Peak the formation is overlain with an angular unconformity by Priabonian deposits. Thickness: varying from several tens to several hundred meters. Age: presumably Upper Campanian — Maastrichtian. Occurrence: in the southwestern-most corner of the area studied. Discussion. According to В. Цанков et al. (unpublished, Georecords Library at the Geological Survey, Sofia, 1954), "marls at the top of the Senonian sequence alternate also with andesite tuffs and tuffaceous sandstones". Кънчев (1962) has outlined "a southern type of Senonian" in the area on his geological map without giving any textual characteristics of the deposits. Каменов et al. (1964) wrote: "A full Senonian section may be observed at... the Kuzoina massif north of the villages of Seliminovo and Gavrailovo. The base of the Senonian sequence is of flyschoid character. Upwards this flyschoid horizon is followed by grey-greenish marls, grey-bluish thinly bedded limestones crosscut by a network of calcite veinlets, cherty limestones and conglomerates occurring as separate interlayers up to two or three meters thick. The Senonian sequence ends up with green thin-layered marls and dove-coloured limestones" (p. 380) and further: "Andesite tuffs and tuffites are abundant in the Senonian sequence of the Kuzoina massif and especially in its eastern part near the town of Sliven" (p. 381). Цанков (1968) has pointed out that "Lower Senonian has not been reported so far... from the Sliven district" (p. 277) specifying further: "The Maastrichtian in the Srednogorie from Čirpan... to Sliven occurs in fairly numerous facies varieties. Generally, they may be reduced to the following lithological horizons: 1. Basal marl horizon... 2. Pyroclastic horizon... 3. Flysch horizon... In the Kuzoina syncline between the Čumerna railroad station and the town of Sliven, only two Maastrichtian horizons are to be observed (the flysch one is absent there)" (pp. 279-280). In all geological maps of the area (Цанков et al., 1954, unpublished; Каменов et al., 1964; Ек. Бончев et al., 1975, appendix II; Попов et al., 1980; *Geological Map of Bulgaria* on a scale 1:200000), the outcrops of the series described around the Peak of Maslenik are given as "Turonian flysch". We have found during this study that these rocks overlie normally the Campanian limestone of the Vetrila Formation with no apparent signs of overturning in the sequence. The same clear, doubtlessly normal primary relationships between the two units are to be found in the outcrops north of the villages of Goljam Čočoven, Seliminovo, Gavrailovo and Čintulovo. This fact, as well as the close lithological similarity between the sections of this newly defined lithostratigraphic unit and of the Emine Formation in the area, show that we have a case of either 1) some portion of the Emine Formation, or 2) a part of the Upper Cretaceous lithostratigraphic sequence in the Stara Zagora strip east of the village of Korten, or 3) an independent lithostratigraphic unit belonging to the transitional zone between the Kuzoina massif and Stara Zagora strip

Upper Cretaceous sequences. A study of the lands south of the explored area to resolve that problem is forthcoming.

Marl-sandstone formation (Паскалев, 1985; =flysch horizon of the Lutetian after Кънчев, 1962; =marine subformation of the Lower-Molasse Formation after Начев, 1969; =rhythmic molasse after Гочев, 1981). Lower boundary: the formation is geographically unconformable with and overlies progressively a mixed substrate of the Emine Formation, Vetrila Formation and the flysch formation. Rock composition: irregular alternation of thinly bedded grey to yellowish-grey marls with grey medium- to coarse-grained, locally gravel-size sandstones of distinct graded bedding. The latter occasionally form thick (up to 70-80 m) packets. Extraolistostromes consisting of angular fragments of sandstone, clayey limestone, argillite and some quartz are widespread at various levels of the formation. There are also chert nodules, granodiorite fragments and occasionally larger (up to 1.5-2 m³) olistoliths of the same lithological composition as the formation. Upper boundary: erosional. Thickness: 400-650 m. Age: Lutetian (Кънчев, 1962). Occurrence: in the northeastern part of the area studied.

Sandstone-marl-volcanic formation (=the Lower Senonian section in the southern outskirts of Sliven, after Aiello et al., 1977). Lower boundary: not exposed. Rock composition: at the base, alternating silicified marls, marls with chert nodules, marls, siltstones and fine-grained sandstones. Higher up, flysch rhythms of silty marls, fine-grained volcanic sandstones and conglomerates showing structures of primary consolidation flow running almost along the parallel of latitude. At the top, volcanics and pyroclastics with silty marls. Bed thicknesses vary from 5-20 to 2-5 cm. The section is described in detail by Aiello et al. (1977, p. 4, Fig. 2; p. 7, Fig. 4b; p. 11). Upper boundary: erosional. Thickness: about 100 m observable thickness. Age: Lower Senonian (Aiello et al., 1977). Occurrence: in the area studied, the only outcrops of this series are along the railroad cut in the southern outskirts of Sliven and to the north of it, west of the Sliven — Nova Zagora road. Discussion: for the present, the spatial relationships of this formation at its exposure near Sliven with Upper Cretaceous rocks remain undefined. Its detachment, the degree of tectonic reworking of rocks and the age (as defined by Aiello et al., 1977) suggest that the unit may represent either a fragment of the sedimentary-volcanic formation or a southward extension of the latter. The question may be conclusively answered after an exhaustive characterization of the Upper Cretaceous sequence around the Sliven Spa and the village of Zlati Voivoda.

In addition to the lithostratigraphic units described, a mixed *sandyclayey formation* of Priabonian age (Цанков et al., 1954) occurs locally in the Belene Tertiary basin overlying transgressively and discordantly a mixed Upper Cretaceous sequence. At the base it consists of coal-bearing breccia deposits passing upwards into marine sandy siltstones, calcareous sandstones and sandy limestones (Попов et al., 1980).

Translated by I. Veselinov

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