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Geology of the Čoka structure in northern Banat (Central Paratethys, Serbia)

DEJAN RADIVOJEVIĆ[1], LJUPKO RUNDIĆ[2] and SLOBODAN KNEŽEVIĆ[2]

[1]NIS Naftagas, Narodnog fronta 12, 21000 Novi Sad, Serbia; dejan.radivojevic@nis.rs
[2]Department of Geology, Faculty of Mining and Geology, University of Belgrade, Kamenička 6, P.O. Box 227, 11000 Belgrade, Serbia; rundic@rgf.bg.ac.rs; knezevic.slobodan@gmail.com

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Abstract: The Čoka structure is a fault-bounded anticline in northern Banat, in the southern part of the Neogene Pannonian Basin. The structure and its vicinity were explored by 24 wells. In addition to well logs, paleontological, sedimentological and petrological analyses of cores and 27 seismic sections with different parameters of acquisition and processing were used for geological investigation of the area. The E-SE dipping pre-Neogene basement consists of Lower Triassic clastics and, in the NW part of the study area, Paleozoic greenschists. Thin Middle Miocene (Badenian) sediments unconformably overlie the basement and pinch out towards the elevated NW part of the study area. They are also missing in some wells on the apex of the Čoka structure, probably due to erosion. Badenian sediments were deposited in a shallow marine environment. The late Middle Miocene (Sarmatian) strata are missing and the Badenian is directly overlain by Upper Miocene (Pannonian) sediments. The latter also pinch out towards the NW but in contrast to Badenian sediments, they are present in all boreholes on the Čoka structure. Pannonian deposition took place in a caspibrackish environment of Lake Pannon, with predominance of marls and fine-grained clastics. Pannonian sediments are conformably overlain by latest Miocene (Pontian) and Pleistocene lacustrine, alluvial and terrestrial sediments.

Key words: Miocene, Central Paratethys, Serbia, Northern Banat, tectonics, stratigraphy.

Introduction

For decades, the Neogene Pannonian Basin has been in the centre of interest of stratigraphers, sedimentologists, structural geologists, geophysicists, and paleontologists. Hydrocarbon explorations resulted in an enormous amount of data about the structure, sedimentary fill and evolutionary history of the Pannonian Basin. Most of the important results from the southern, Serbian part of the Pannonian Basin, however, regretfully remained unpublished. The highlight of this paper is to present new data on the stratigraphy and tectonics of the Čoka area, in northern Banat of Serbia (Fig. 1), obtained by subsurface geological methods (reflection seismics, well logs, cores, cuttings, etc.). The Čoka structure represents an anticline, which resulted from the Middle-Late Miocene inversion of an earlier extensional structure (within basin high) covered by Middle Miocene to Quaternary sediments.

Geological setting

The Pannonian Basin was formed due to continental collision and subduction of the European Plate under the African (Apulian) Plate during the late Early to Late Miocene times (Horváth & Royden 1981; Royden 1988; Tari et al. 1992; Horváth 1995; Kováč et al. 1998; Pavelić 2002; Fodor et al. 2005). The Pannonian Basin was bordered by the mountain chains of the Alps, Carpathians and Dinarides (Schmid et al. 2008).

Late Early Miocene subsidence and sedimentation as a consequence of the syn-rift extensional phase resulted in the formation of numerous grabens filled with relatively thin syn-rift marine and brackish deposits (Horváth & Royden 1981; Tari 1994; Tari & Pamić 1998; Lučić et al. 2001; Pavelić 2001). The Late Miocene (pre-Pannonian) unconformity is a result of the first early post-rift phase of basin inversion that occurred during the Sarmatian (the latest Middle Miocene; Horváth & Tari 1999). After that, a quiet and slow thermal subsidence took place, combined with an uplift and erosion of the surrounding mountain belt (Horváth & Royden 1981; Schmid et al. 2008). That post-rift sinking was compensated by intensive sedimentation in the “caspibrackish” Lake Pannon during the Late Miocene (Juhász 1991; Magyar et al. 1999; Rundić 2000; Fodor et al. 2005). As a result, huge amounts of sediment were supplied, via large fluvial to deltaic systems, into Lake Pannon. The final result is successions of several thousand meters of post-rift sediments (Bérczi et al. 1988; Szentgyörgyi & Juhász 1988; Juhász 1991, 1994; Vakarcs G. et al. 1994; Magyar et al. 1999; Fodor et al. 2005; Tóth-Makk 2007).

At about the Miocene-Pliocene boundary, and locally even more intensively in the Quaternary, another compressive phase took place in the Pannonian Basin (Jamičić 1995; Horváth & Cloetingh 1996; Prelogović et al. 1998; Márton et al. 2002). It reactivatied earlier normal faults, into reverse faults, and also resulted in folding of Neogene strata (Saftić et al. 2003; Fodor et al. 2005; Horváth et al. 2006; Marović et al. 2007).

The southern part of the Pannonian Basin is underlain by the Tisza Unit. During the Early and Middle Miocene extension of this unit was synchronous with that of the ALCAPA (Alpine-Carpathian-Pannonian) unit in the north (Saftić et al.

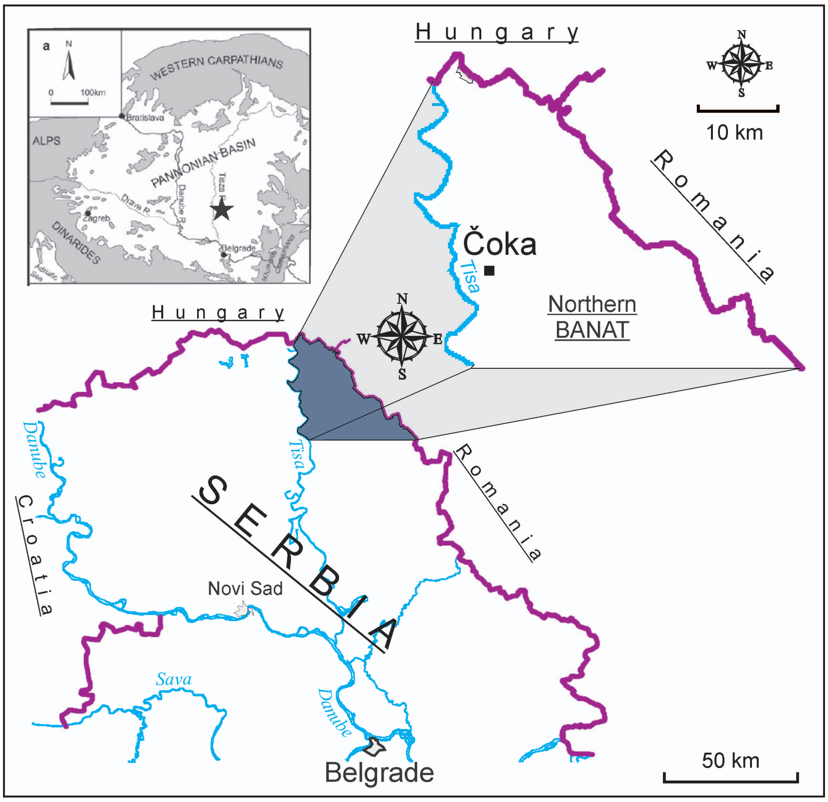

Fig. 1. Location of the study area within the Pannonian Basin System.

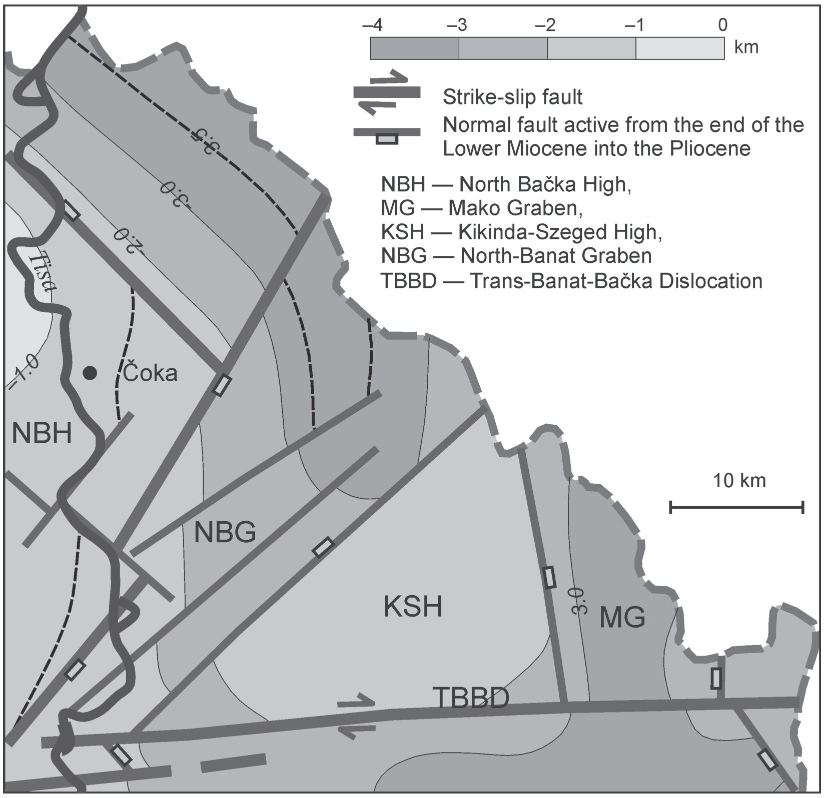

Fig. 2. Top pre-Neogene basement structure contour map of northern Banat (Marović et al. 2007 — modified).

2003; Fodor et al. 2005). From the end of the Karpatian (end of Early Miocene) subsidence of Tisza was coupled with eastward motion and possible clockwise rotation under a transtensive stress field (Csontos et al. 1992, 2002; Csontos 1995; Saftić et al. 2003; Horváth et al. 2006).

The pre-Neogene basement of the northern Banat of Serbia, is tectonically bordered by the Trans-Banat-Bačka Dislocation belt, a complex E-W striking, regional dextral strike-slip fault zone that separates two major tectonic units in the pre-Neogene basement: the Vardar Zone and the Tisza-Dacia block to the south and north, respectively (Fig. 2). West of the Tisa River, the area is bordered by the North Bačka High with pre-Neogene basement at depth between −500 to −1000 m below the surface. It is an isometric plateau formed during younger Miocene tectonic events. The major Neogene tectonic features of the northern Banat are shown in Fig. 2 and include the North Banat and Mako Grabens, which are bounded by NW-SE to N-S striking normal faults. The pre-Neogene basement is downthrown to a depth between 2000 and 3500 meters with a relatively elevated (2000–2500 m) Kikinda-Szeged High which trends NE–SW. The Čoka structure is located on the western flank of the North Banat Graben (Fig. 2).

The Miocene sediments of the northern Banat unconformably overlie strongly deformed Paleozoic-Mesozoic basement of magmatic, metamorphic and sedimentary rocks.

Materials and methods

The geological model of the Čoka area presented here is based on seismic surveys, well logs, and paleontological, petrological, and sedimentological analyses of core samples.

The Čoka structure and its vicinity were explored by 24 wells. The seismic database consisted of 27 profiles with different parameters of acquisition and processing, the most recent made in 2005.

Our geological model was built in three steps: data analysis, interpretation, and synthesis of results. The first step included analyses of all available data and checking of their quality. Data quality was also controlled (well diameters, and well log interpretation).

The second phase included determination of lithology and stratigraphy for each well on the basis of cores, cuttings and well logs, computation of a synthetic seismogram, structural and stratigraphic interpretation of the seismic sections, and construction of structural maps, geological cross-sections and thickness maps. Well logs were calibrated with core data and used for qualitative lithological interpretation where the cores were missing. The main lithology suggested by the mud log was correlated horizontally with gamma ray and spontaneous potential logs, then to other types (resistivity, sonic and neutron), and finally to sidewall cores and cuttings. In cases where the lithological interpretation of logs was ambiguous, we returned to the checking of log quality. Stratigraphic interpretation was based on paleontological analysis of core samples (molluscs, ostracods, foraminifers, and palynomorphs). Lithological-stratigraphic columns were compiled for each well. The nearest well where checkshots were measured was about 11–12 km east of the Čoka locality; therefore a synthetic seismogram based on the sonic and density logs of C-9 was created in order to convert time-structural interpretations into the depth domain. Three structural maps were produced based on interpretation of all seismic sections of the investigated area. Three geological cross-sections, intersecting each other at C-10, were drawn on the basis of the structural maps. Two thickness maps focused on the Čoka structure were constructed according to borehole data; the thickness of Neogene strata in this area was below seismic resolution.

The final step in geological model generation was synthesis of the results obtained in the second phase.

Results

Stratigraphy

In the study area, several boreholes reached the basement of the Neogene deposits (Fig. 3). The basement consisted of breccias, sandstones, clays and dolomitic limestones. Fossils in these sediments are rare, so their age is determined by correlation to other localities in northern Banat and northern Bačka. The occurrence of the foraminifer *Meandrospira pusilla* indicates their Early Triassic age.

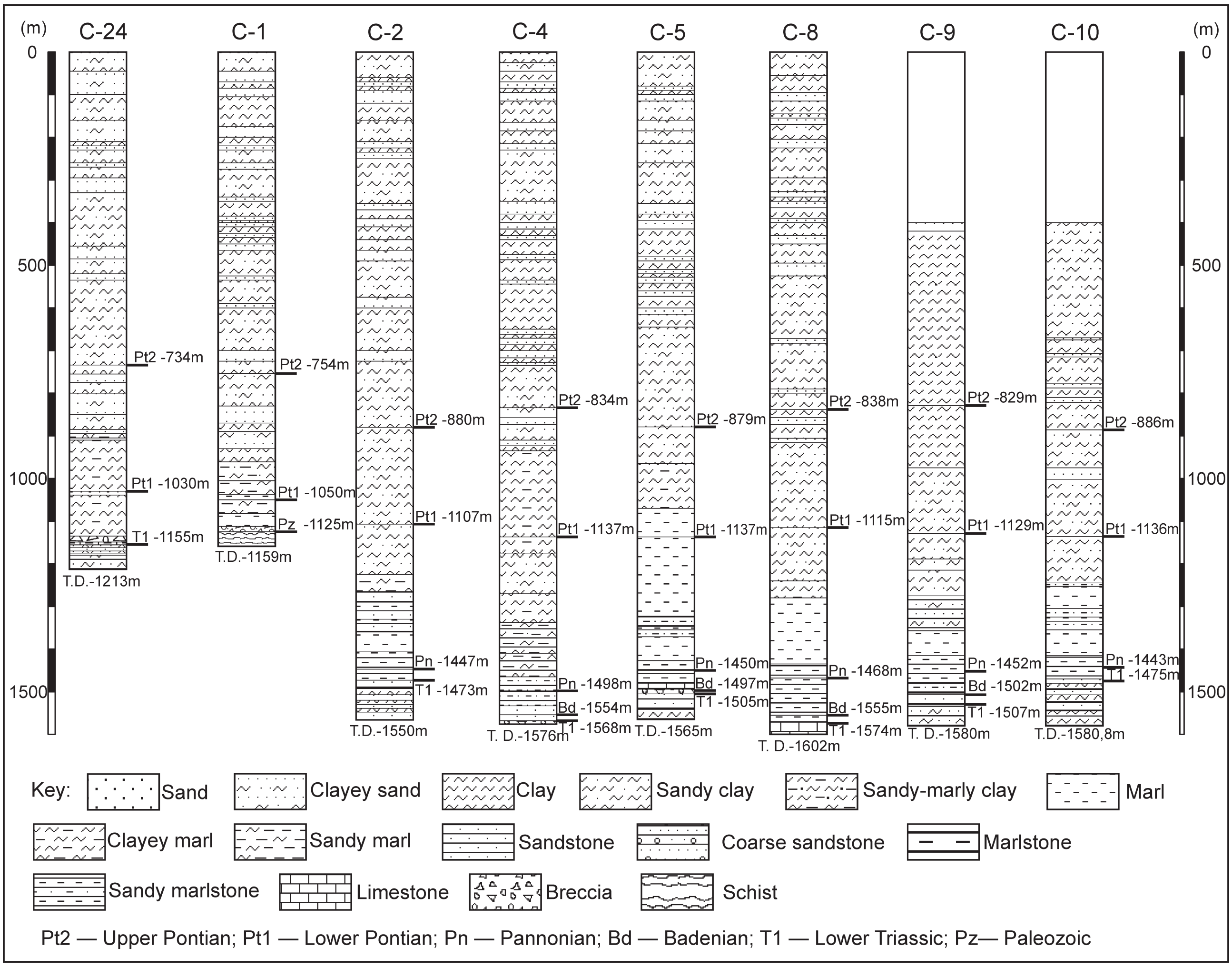

Fig. 3. Lithostratigraphic columns of representative boreholes of the Čoka area. The interpretation is based on well logs and paleontological, sedimentological and petrological analyses of cores and cuttings. Location of the wells is indicated in Figs. 5–7 and 9–13.

In the C-1, the basement was metamorphic (greenschist).

In most of the wells, the Neogene succession starts with biogenic limestones of Badenian age. These include light-grey to white biosparudites and biomicrosparites made up of microsparite matrix and small sparicalcite microfossil shells (detritus made up of molluscs, bryozoans, hydrozoas, corallinacean algae (*Lithothamnion*, *Lithophylum*, etc.), annelids, cidaroids, ostracodes, microgastropods, and various benthic foraminifera, such as *Asterigerinata planorbis*, *Rosalina dubia*, *Elphidium crispum*, *E. fichtelianum*, *E. flexuosum*, *Borelis melo*, *Virgulina schreibersiana*, *Quinqueloculina partschii*, *Q. heidingeri*, *Q. contorta*, *Q. longirostra*, *Q. heidingerii*, *Adelosina longirostra*, *Hansenisca soldanii*, *Cibicidoides ungerianus*, *Ammonia beccarii*, *Globulina gibba*, *Glandulina laevigata* and *Sphaeroidina bulloides*. Palynological investigations revealed the presence of spores and pollen grains of gymnosperms and angiosperms, such as *Sporites* sp., *Polypodiaceoisporites* sp., *Laevigatosporites haardti*, *Cathayapollenites* div. sp., *Pinuspollenites labdacus*, *Cathayapollenites* div. sp., *Monocolpopollenites tranquillus*, *Triatriopollenites coryphaeus*, *Alnipollenites verus*, *Caryapollenites simplex*, *Polyporopollenites stellatus*, *Tricolpopollenites liblarensis* and *T. cingulum*.

In addition to reef limestones, there are light-grey arkoses, carbonate sandstones and siltstones with the forams *Globigerinoides trilobus*, *G. quadrilobatus*, *Elphidium crispum*, *Globigerina bulloides*, *G. concinna*, *Heterolepa dutemplei*, *Cibicidoides pseudoungerianus*, *C. floridanus*, *Pullenia bulloides*, *Uvigerina semiornata*, *U. pygmoides*, *U. aculeata*, *Sphaeroidina bulloides*, *Textularia gramen*, *T. pala*, *Gyroidinoides soldanii*, *Martinottiella communi* and *Glandulina laevigata* present.

The age of these shallow marine and reef sediments is Badenian (early and middle Middle Miocene,

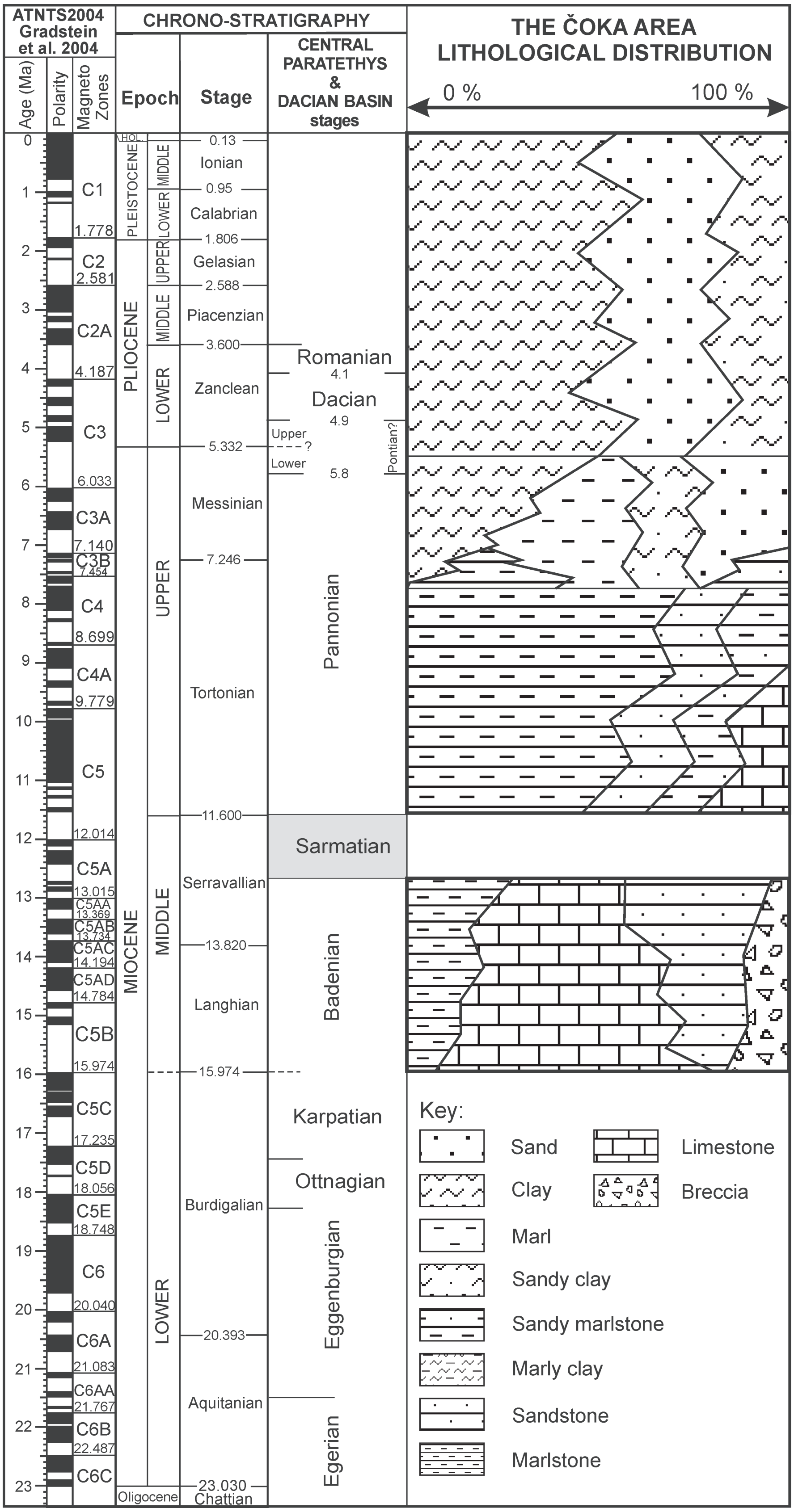

Fig. 4. Chronostratigraphic position of the Neogene to Quaternary succession of the Čoka area (time scale, magnetic polarity zones and chronostratigraphic division of the Neogene after Gradstein et al. 2004; Piller et al. 2007 and Harzhauser & Mandić 2008).

Fig. 4), as indicated by the presence of *Asterigerinata planorbis*, *Elphidium crispum*, *E. aculeatum*, *Borelis melo* etc. The maximum thickness of the Badenian in the selected wells is 19 m (C-8; Fig. 3).

The Badenian is overlain by compact marlstone and marly limestones with fragments of ostracods, such as *Amplocypris* sp., *Hemicytheria* sp., *Candona* (*Lineocypris*) *trapezoidea*, *Candona* (*Caspiolla*) *labiata*, *Loxoconcha schweyeri* and *Leptocythere* sp. In light-grey compact marlstones, there is an association of molluscs including *Gyraulus praeponticus*, *G. dubius*, *Radix croatica*, *Micromelania striata*, *Velutinopsis velutina*, *Limnocardium* sp. and *Orygoceras* sp., as well as associations of spores and microplankton with *Cathayapollenites* div. sp., *Pinuspollenites labdacus* and *Sporites* sp. These ostracods and molluscs were endemic to the brackish Lake Pannon and indicate the Pannonian (Late Miocene) age of these sediments (Fig. 4). In some of the boreholes (C-2 and C-10) the Pannonian layers directly overlie the Triassic basement. The maximum thickness of the Pannonian in the selected wells is 87 m (C-8; Fig. 3).

The Pannonian sediments and the pre-Neogene basement, where they former are missing (e.g. at C-1 and C-24), are overlain by marls with thin intercalations of sandstone and black clays containing rare ostracods such as *Pontoleberis pontica*, *Loxoconcha schweyeri*, *Leptocythere andrusovi*, *Candona* (*Caspiocypris*) *labiata*, *Candona* (*Caspiocypris*) *alta*, *Candona* (*Lineocypris*) *trapezoidea*, *Candona* (*Pontoniella*) *paracuminata*, *Bacunella dorsoarcuata*, *B. abchazica*, *Hemicytheria pejinovicensis* and the camoebians, including *Silicoplacentina majzoni*, *S. hungarica*, and *S. inflata*. This unit is considered to be of Early Pontian age in the sense of Stevanović et al. (1990) and Rundić (1997) (Fig. 4). Its maximum thickness in the selected wells is 361 m (C-4; Fig. 3). The overlying sediments are represented by sand-marly clays with coals, thin sandstone layers and grey-greenish marls with the molluscs *Paradacna* cf. *abichi* and *Lymnocardium* sp., ostracods *Candona (Pontoniella) paracuminata* and *Candona* sp., and the camoebians *Silicoplacentina majzoni*, *S. hungarica* and *S. inflata*. These belong to the Upper Pontian sensu Stevanović et al. (1990), reaching a thickness of 303 m (C-4; Fig. 3).

Further chronostratigraphic boundaries, like the Pliocene–Quaternary, have not been determined, because there is little material for correct stratigraphic correlation. The post-Pontian formations are represented by fluvial, lacustrine, marsh and terrestrial sediments including fine-grained sandstones and gravels, sandy clays with coals, marly-clayey sandstones with the molluscs *Gyraulus* sp., *Lythoglyphus* sp., *Pisidium* sp., and eolian sediments (Figs. 3, 4). Their maximum thickness is 886 m in C-10.

Tectonics

The structure and thickness of individual stratigraphic units are presented in structure contour maps (Figs. 5–7), seismic profiles (Figs. 8, 9), geological cross-sections (Figs. 10–12), and thickness maps (Figs. 13, 14).

Within the study area, the Neogene basement generally dips from northwest to southeast and east in a monoclinal manner (Figs. 5, 8, 10–12). The deepest part of the basement lies at a depth of –1800 m in the eastern part of the research area, whereas the shallowest part is in its northwestern corner at a depth of –1040 m in C-1 (Fig. 5). The inclination of monocline is gentle in the NW and becomes steeper in the SE, where the basement starts to sink steeply into the North Banat Graben (Fig. 2).

The basement of the Neogene is mainly represented by Lower Triassic clastics and, in the northwestern part of the study area, by Paleozoic greenschists (Figs. 5, 8). The metamorphic rocks were hit only by C-1 (Fig. 10). The contact between the two rock types is interpreted to be tectonic in the south, whereas the Lower Triassic depositionally or erosionally pinches out on the elevated Paleozoic basement in the west and east (Fig. 5).

The Čoka structure is a fault-bounded anticline, situated on the basement slope (Fig. 5). This structure is shallowest at the location of C-10 at –1393 m (Figs. 8, 10). The high is accentuated on its west by two clearly recognizable paleodepressions in the southern and central parts of the study area, respectively, at a basement depth of –1500 m (Fig. 5). These depressions are expressed on structure contour map of the top Badenian and top Pannonian horizons (Figs. 6, 7).

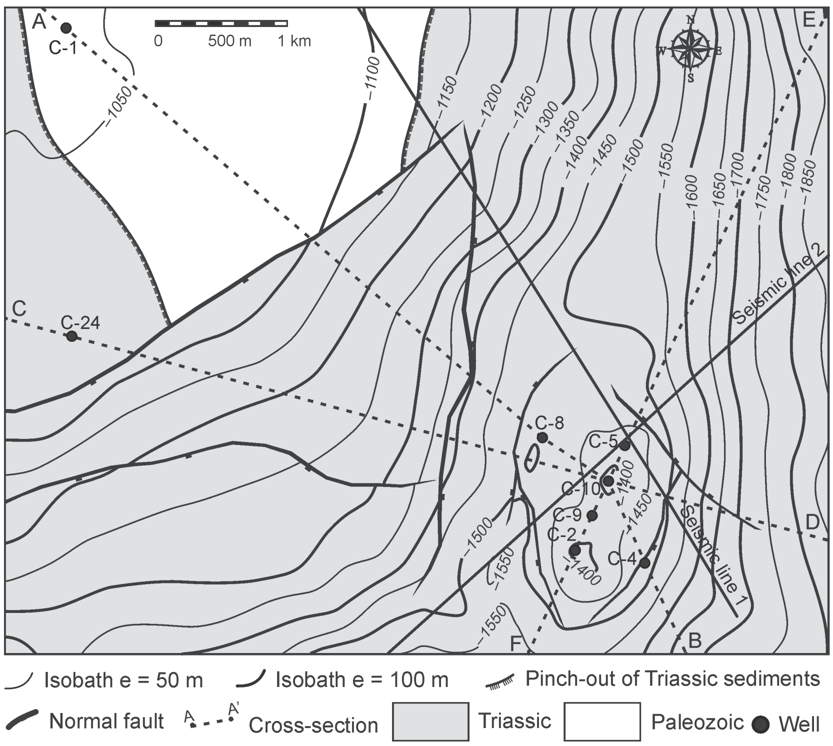

Fig. 5. Structure contour map of the base of the Neogene with location of wells, seismic profiles and geological cross-sections.

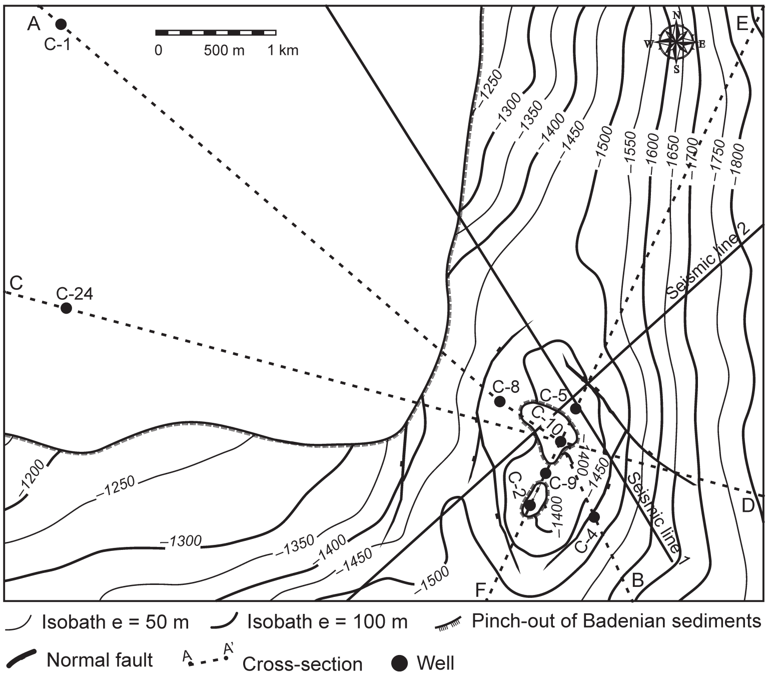

Fig. 6. Structure contour map of the top Badenian with location of wells, seismic profiles and geological cross-sections.

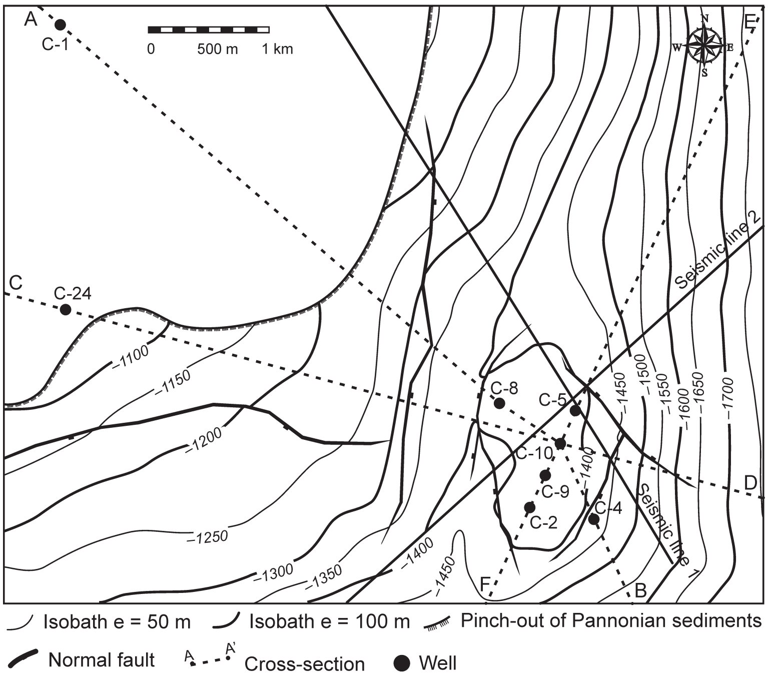

Fig. 7. Structure contour map of the top Pannonian with location of wells, seismic profiles and geological cross-sections.

In the Čoka area, several, N-S and E-W trending normal faults with small movement have been interpreted. All faults present in the Čoka area were probably reactivated during the Pontian as inverted faults which is indicated on seismic and geological cross-sections (Figs. 8–12). Reflectors above the top Pannonian horizon which are also nicely folded and the position of the Pontian sediments on geological cross-sections support this statement.

The Badenian strata pinch out towards the north and west (Figs. 6, 8, 10, 11). They are the shallowest at the pinch-out point (at about −1250 m), while in the eastern part of the research area, they are at a depth of −1800 m. Over the entire Čoka area they are thin and are missing from the top of the Čoka structure (in C-2 and C-10; Fig. 13). Here, their thickness is below the seismic resolution and thus could not be distinguished from the top Triassic reflector (Fig. 9). On the top Badenian structure contour map, normal faults with north-south and north-west-southeast direction can be noted (Fig. 6). All the faults have small throw (few meters to a few tens of meters).

The Pannonian sediments pinch out to the northwest and deepen to the east down to −1750 m (Fig. 7). They are the shallowest near the pinch-out, near C-24 at about −1100 m (Fig. 11). Unlike the Badenian, they are found in all wells above the Čoka structure (Fig. 14). The faults have a small gravitational movement and most of them have a north-south direction. In the western part of the area, there is a large E-W trending normal fault (Fig. 7).

Interpretation and discussion

In the Čoka area, the Badenian represents the oldest Neogene unit; its sediments transgressively overlie the Lower Triassic (Radivojević 2008). The distribution and thickness of the Badenian sediments, including their lack in C-2, C-10, C-22 and C-23, suggest that the Badenian was probably exposed to erosional processes for some time. This interpretation is strongly supported by the complete lack of the subsequent Sarmatian sediments in the studied boreholes.

According to Kemenci (1991), the entire Middle Miocene (Badenian and Sarmatian) can be characterized by significant expansion of the aquatic environments in the southern Pannonian Basin; only restricted areas (the highest parts of the paleorelief) escaped marine flooding. If this interpretation is correct, then the lack of the Sarmatian and eroded nature of the Badenian in the Čoka area is probably due to the tectonic inversion that took place in the Late Sarmatian or Early Pannonian and resulted in a widespread pre-Pannonian unconformity (Horváth & Tari 1999). Tectonic inversion is obvious both, on seismic lines (Figs. 8, 9) and geological cross-sections (Figs. 10–12). All reflectors above the top Pannonian horizon are nicely folded and some inverted earlier normal faults are present. Position of Pontian sediments on geological cross-sections also indicates basin inversion.

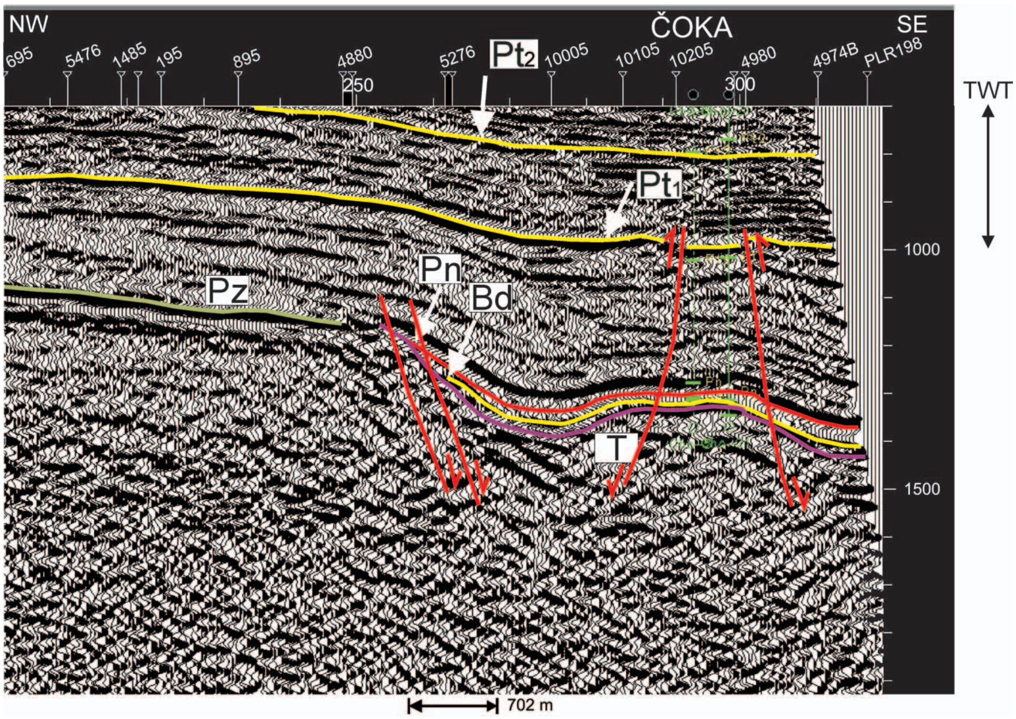

Fig. 8. Seismic profile 1 across the Čoka area. The strong reflector to the left of shot point 250 corresponds to the top of the Paleozoic horizon. The large difference in the velocity between the Pontian sediments (Triassic, Badenian and Pannonian sediments are completely missing) and the schists caused appearance of a multiple under the top Paleozoic. For location of the profile see Figs. 5–7.

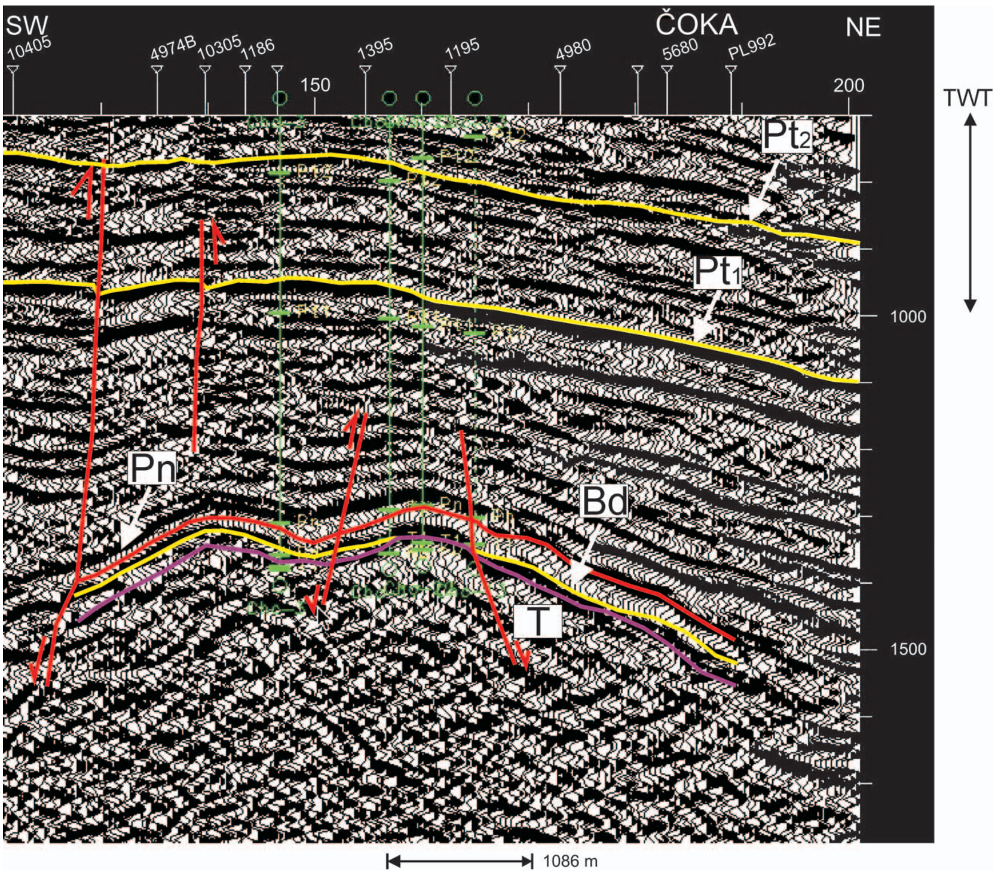

Fig. 9. Seismic profile 2 across the Čoka structure. The Pannonian sediments have a low reflective response over almost the entire study area. The top of the Pannonian on the right side of the profile, however, has a well-defined reflection. This is a typical feature of the top Pannonian in northern Banat. For location of the profile see Figs. 5–7.

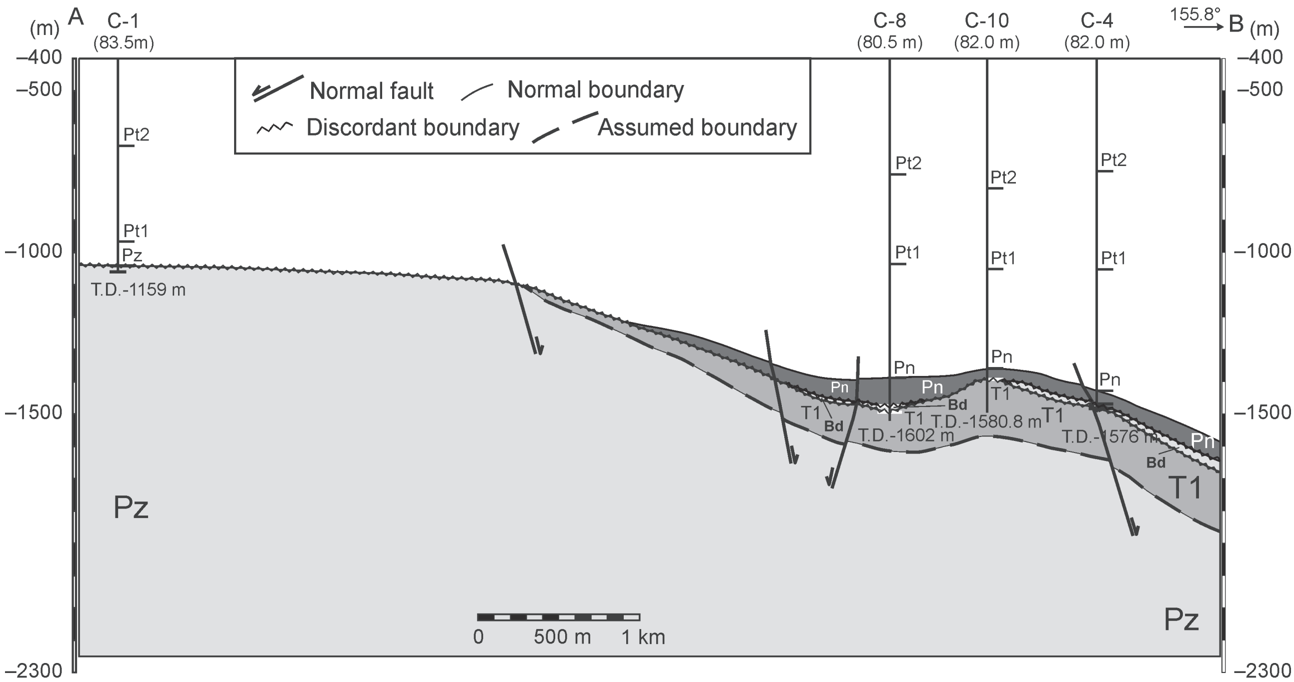

Fig. 10. Geological cross-section A–B (for location see Figs. 5–7). Note the pinch-out trend of the Badenian and Pannonian towards C-1. The Badenian is missing at C-10, probably due to erosion.

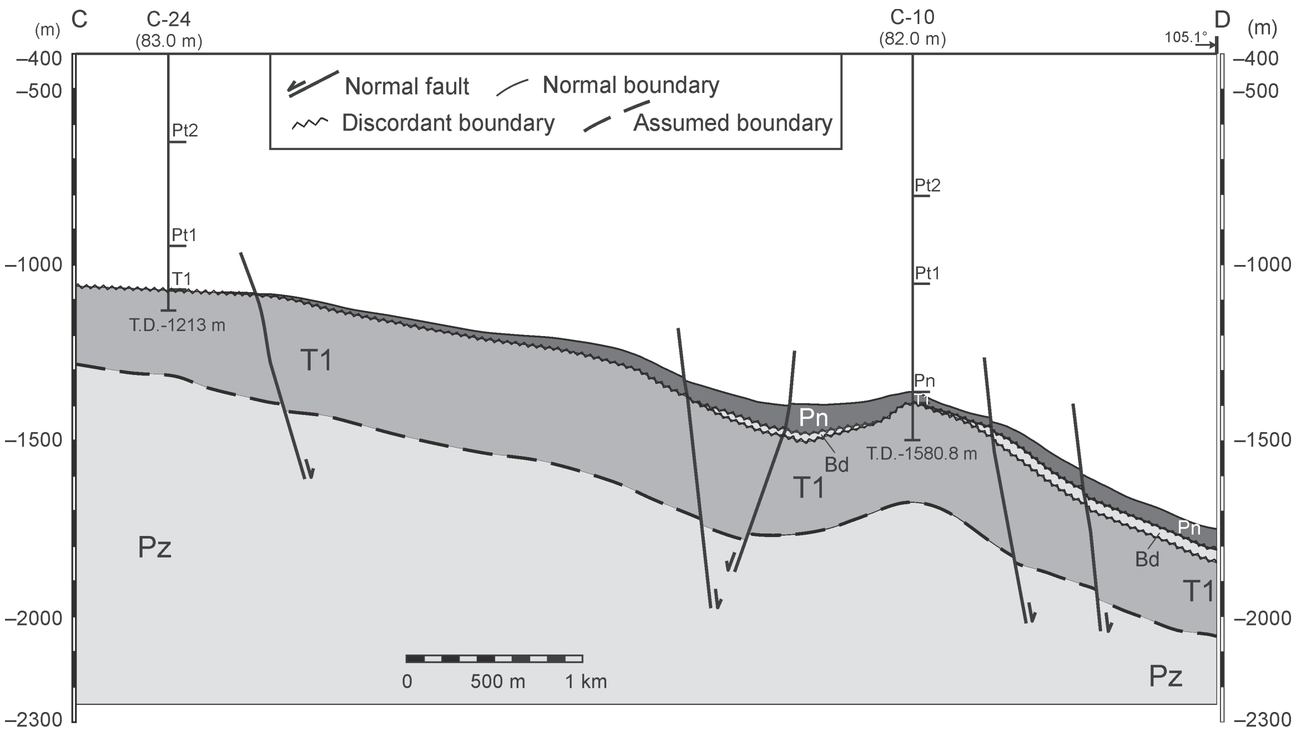

Fig. 11. Geological cross-section C–D (for location see Figs. 5–7). The Badenian and Pannonian pinch out towards C-24.

The Sarmatian-Pannonian boundary, roughly corresponding to the Middle-Late Miocene boundary, was marked by a major regression, which isolated the Central Paratethys from the global sea, and transformed it into the large, long-lived, brackish water body of Lake Pannon (Magyar et al. 1999). The cause of this regression is still highly debated (Săndulescu 1988; Vakarcs et al. 1994; Horváth & Cloething 1996; Harzhauser & Piller 2004).

A lake-level rise during the Pannonian caused flooding of previously emerged regions in northern Banat (Kemenci

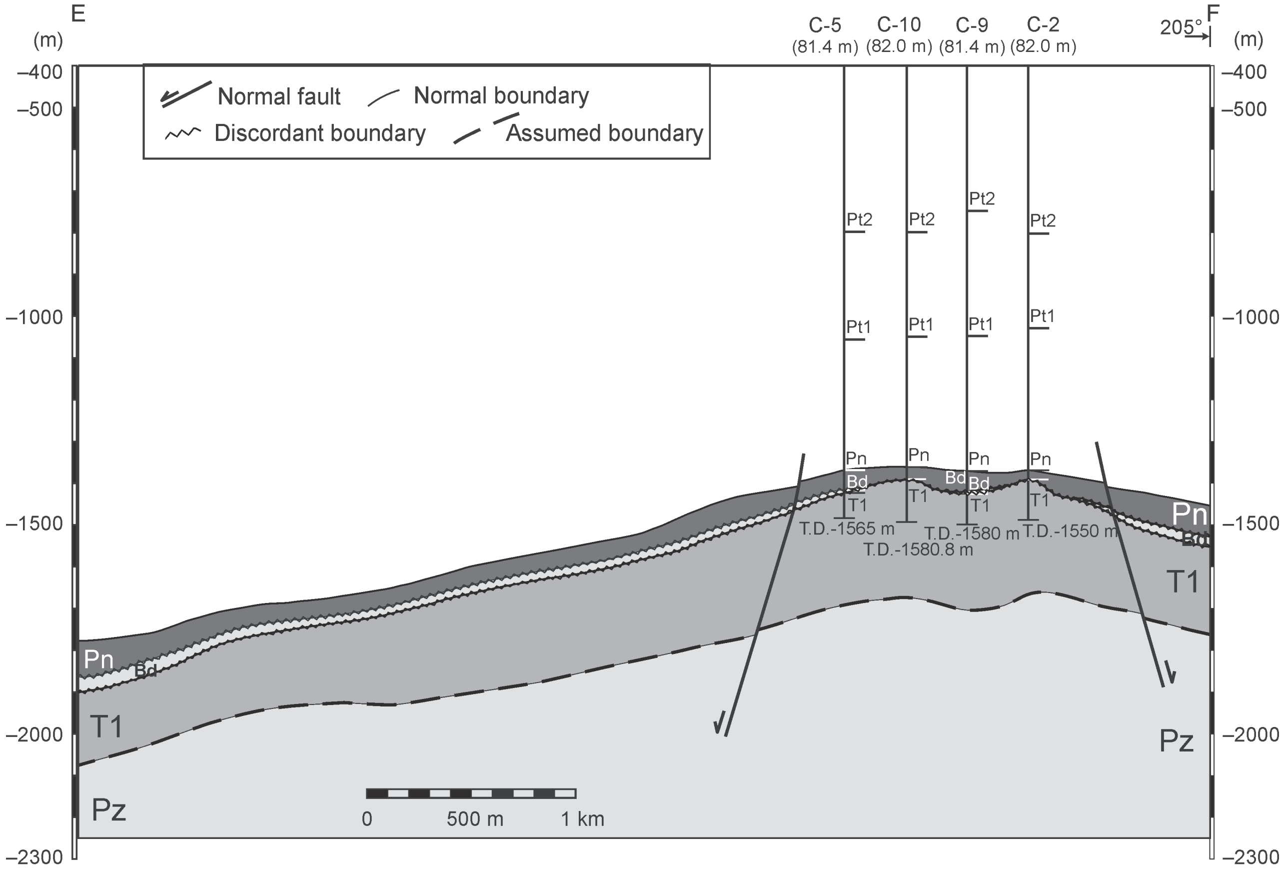

Fig. 12. Geological cross-section E–F (for location see Figs. 5–7).

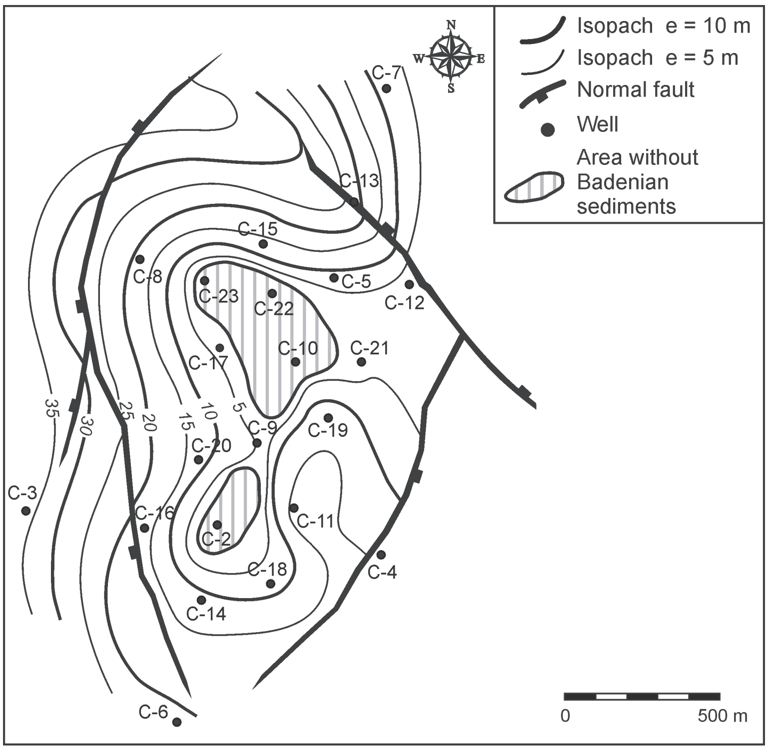

Fig. 13. Thickness map of Badenian sediments above the Čoka structure (based on well data). The Badenian is missing from the most elevated parts of the structure.

1991), thus the Pannonian strata are transgressive at the base and deposited above an unconformity over a greater part of the area. The Pannonian sediments in northern Banat have a wider distribution than the Badenian; they overlie Paleozoic schists and magmatites, Triassic, Badenian, and Sarmatian sediments.

In general, the Pannonian is represented by thin sandstones with carbonate matrix in the littoral facies, by pelites with presence of micrite in the sublittoral facies, and by marls in the deep-basin facies. The lithology as well as the molluscan fauna with *Radix croatica* and *Gyraulus praeponticus* in the Čoka boreholes point to a sublittoral facies that was widespread in the region (Stevanović 1977; Knežević et al. 1994) and represents a transitional zone between the sandy littoral and clayey deep basinal facies. The Pannonian associations of flora and fauna indicate a low-salinity caspibrackish environment characteristic of Lake Pannon (Steininger et al. 1988; Rögl 1996). Data from Čoka area correspond to recent isotope trends studies which indicate that Lake Pannon was a simple system of an alkaline lake with steadily declining salinity (Harzhauser & Piller 2007; Harzhauser et al. 2007).

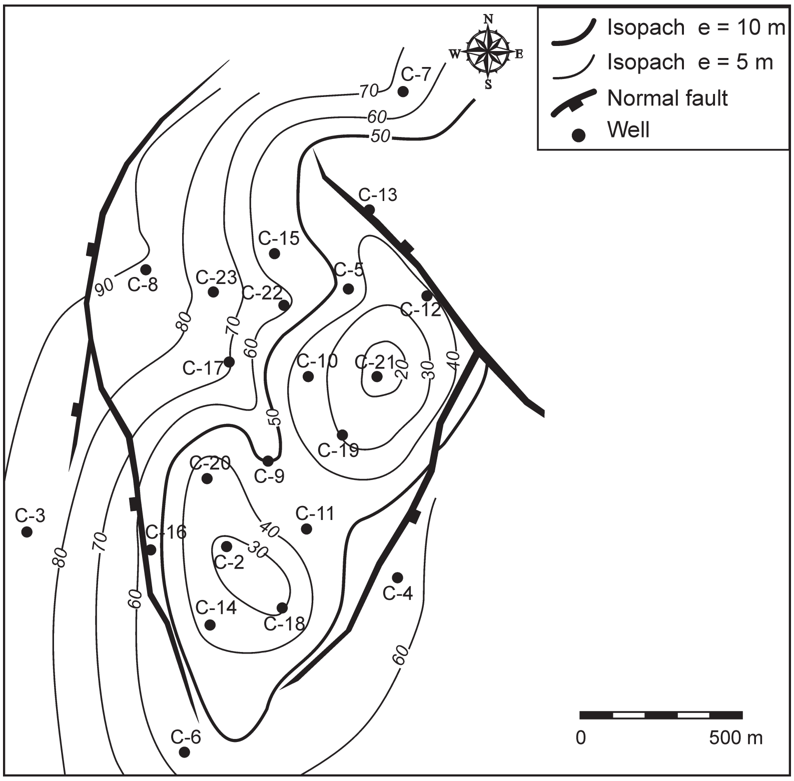

Fig. 14. Thickness map of Pannonian sediments above the Čoka structure (based on well data).

Progradation of deltaic clastic systems, shallowing and finally infilling of the basin during Pontian times was probably caused by deceleration of basin subsidence (Fodor et al. 2005; Horváth et al. 2006). The sedimentary complex deposited during the Pannonian, Pontian and later, in northern and central Banat is very thick, locally it may exceed 4000 m (the Pannonian ranging from several m to several hundred m). In the surrounding areas, such as the southern Banat, Fruška Gora Mts, and most of Bačka, this complex is much thinner (Kemenci 1991; Radivojević 2008).

The stratigraphic position of the oldest post-Pannonian sediments that were treated in this paper is quite questionable. Basic lithostratigraphic and paleontological parameters indicate the presence of the Pontian *s.str.*, which is known in the Eastern Paratethys where they represent a regional stage (Stevanović et al. 1990). From the paleogeographic point of view, it should be emphasized that area of Eastern Serbia corresponds to the Miocene and Pliocene development which exists in Dacian Basin and further to the east, including the Pontian in such development. In earlier references there are data which confirm these correlations, similarities and differences between the Pontian of these basins. However, as in the past 20 years, few results from these areas that are internationally recognized were published, the question of Pontian (none) existence in the Pannonian part of Serbia should be seriously revised, and verified on outcrops. The validity of the model which is applicable for the western part of Central Paratethys can only be tested with direct field observations. In that sense, the adjusted Miocene-Pliocene scheme, which includes both the Pannonian and Dacian Basins is used in this paper as a compromise (Harzhauser & Mandic 2008).

Conclusions

The basement of the Neogene succession in the Čoka area is mainly represented by Triassic sediments, except in the northwestern corner of the study area where it is represented by Paleozoic schists. The paleorelief subsided along normal faults from the North Bačka High in the northwest to the North Banat Graben in the southeast and east. The Čoka structure, which was initiated as a within-basin high and later inverted into the fault-bounded anticline is neighboured by two local paleodepressions in the central and southern parts of the study area.

The shallow marine Badenian sediments were deposited transgressively on the Paleozoic-Triassic basement. They pinch out at the most elevated northwestern part and were eroded from the top of the Čoka structure, as indicated by their small thickness (up to a few tens of meters) and by the lack of Sarmatian deposits.

The sublittoral Pannonian sediments are present in all wells testing the Čoka structure, but they also pinch-out towards the west. They are thicker than the erosionally truncated Badenian sequence (up to 100 m). The overlying Pontian to Quaternary succession, represented by lacustrine to alluvial and terrestrial deposits, is thick (1000–1800 m) and uniform over the entire area.

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