3D CHRONOSTRATIGRAPHIC MODEL OF THE PALEOGENE IN THE EASTERNMOST PART OF THE MOESIAN PLATFORM (NORTHEAST BULGARIA)

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Abstract. This study is based on a chronostratigraphic interpretation of biostratigraphic data from 102 boreholes from the easternmost part of the Moesian Platform (Northeast Bulgaria) bordering the Black Sea Basin and including the southernmost part of the South Dobrogea Unit and the easternmost part of the North Bulgarian Dome with its eastern slope. Seven Paleogene chronostratigraphic units were recognised (the Thanetian, Ypresian, Lutetian, Bartonian, Priabonian, Rupelian, and Chattian stages). For the visualisation of their spatial distribution and relationships, a 3D chronostratigraphic model was created.

Keywords: Paleogene, chornostratigraphic units, Moesian Platform, Northeast Bulgaria, 3D modelling.

ТРИИЗМЕРЕН ХРОНОСТРАТИГРАФСКИ МОДЕЛ НА ПАЛЕОГЕНСКАТА СИСТЕМА В НАЙ-ИЗТОЧНАТА ЧАСТ НА МИЗИЙСКАТА ПЛАТФОРМА (СЕВЕРОИЗТОЧНА БЪЛГАРИЯ)

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Резюме. Настоящото изследване е базирано на хроностратиграфската интерпретация на биостратиграфски данни от 102 сондажа от най-източната част на Мизийската платформа (Североизточна България) на границата с Черноморския басейн, включваща най-южните части на южния склон на Добруджанския масив и източния склон на Севернобългарския свод. Установено е присъствието на седем палеогенски хроностратиграфски единици (Танетски, Ипрески, Лютески, Бартонски, Приабонски, Рупелски и Хатски етаж). За визуализирането на тяхното пространствено разположение е създаден триизмерен хроностратиграфски модел.

Ключови думи: Палеоген, хроностратиграфски единици, Мизийска платформа, Североизточна България, триизмерно моделиране.

Introduction

This study is focused on the Paleogene rocks and the geological evolution of the easternmost part of the Moesian Platform (Northeast Bulgaria), bordering the Western Black Sea Basin. Its purpose is (*i*) to recognise the exact chronostratigraphic successions, and (*ii*) to elucidate the spatial distribution and relationships of the chronostratigraphic subdivisions.

In terms of the regional tectonics, the studied area comprises part of the Moesian Platform (Fig. 1), including partly the South Dobrogea Unit (Georgiev, 2012), which is also known as the Dobrogea Massive (Bokov et al., 1987; Dabovski, Zagorchev, 2009), as well as the easternmost part of the North Bulgarian Dome with its eastern slope (Dabovski, Zagorchev, 2009).

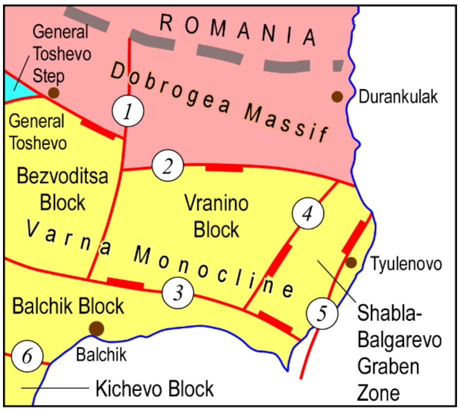

Fig. 1. Tectonic scheme of the studied area (after Bokov et al., 1987; Dabovski, Zagorchev, 2009; modified)
Faults: *1*, Trigortsi; *2*, Silistra-Belgun; *3*, Bezvoditsa-Seltse; *4*, Rakovo-Gorun; *5*, Balgarevo; *6*, Batovo

Material and methods

The investigation is based on integration of lithologic and stratigraphic data from 102 borehole sections, which are unevenly distributed across the studied area (Fig. 2). The primary data were obtained from 32 geological reports (kept at the National Geological Fund, Ministry of Energy of the Republic of Bulgaria) concerning the drilling for oil and gas, as well as the prospecting of the Dobrogea coal basin from the early 1950s to the 1980s (a list of reports, concerning the stratigraphic aspects of the Paleogene investigations were given by Valchev et al., 2018).

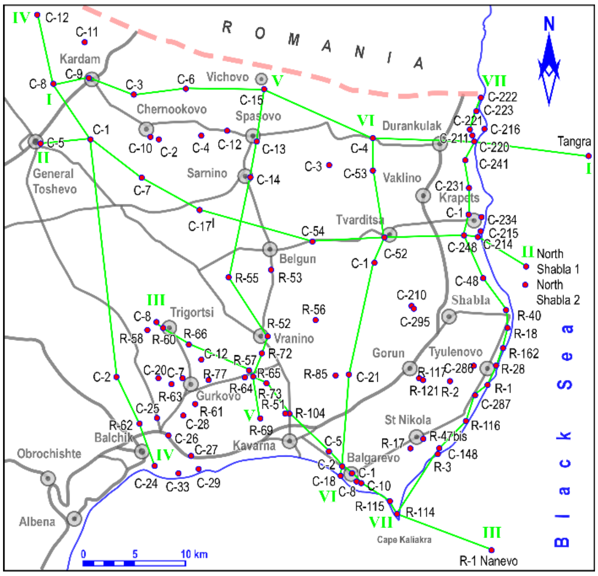

Fig. 2. Distribution of the studied borehole sections with the lines (in green) of the chronostratigraphic charts shown in Figs 4–10

The chronostratigraphic interpretation is based on reinterpreted biostratigraphic data from Shutskaya et al. (1972f[1]). Seven regional chronostratigraphic charts show the temporal distribution of the Paleogene lithostratigraphic units. For further visualisation of the spatial relationships of the chronostratigraphic subdivisions, a 3D model was created.

Stratigraphic background

The geological investigations of the deep structure of the easternmost part of the Moesian Platform started in the early 1950s and by the end of 1980s more than 1000 boreholes were drilled. Until the beginning of the 1970s, the base of the Paleogene had been referred to the Danian belonging then to the Upper Cretaceous (Fig. 3), and the Paleogene was divided into middle and upper Eocene covered with Oligocene deposits.

Stoyanoff (1962) divided and characterised the lower and middle Oligocene, the former with three horizons.

Shutskaya et al. (1972f), summarising the available lithological and paleontological data, proposed the first detailed stratigraphic subdivision. The “Danian” rocks were referred to the upper Paleocene, the Eocene was divided into lower–middle (corresponding to the middle Eocene of the previous investigations) and upper, comprising the Kuberlin-Keresrin, Kumski, and Beloglin horizons. Eight packages were included in the Oligocene which was divided into lower–middle (packages I–III) and upper (packages IV–VIII).

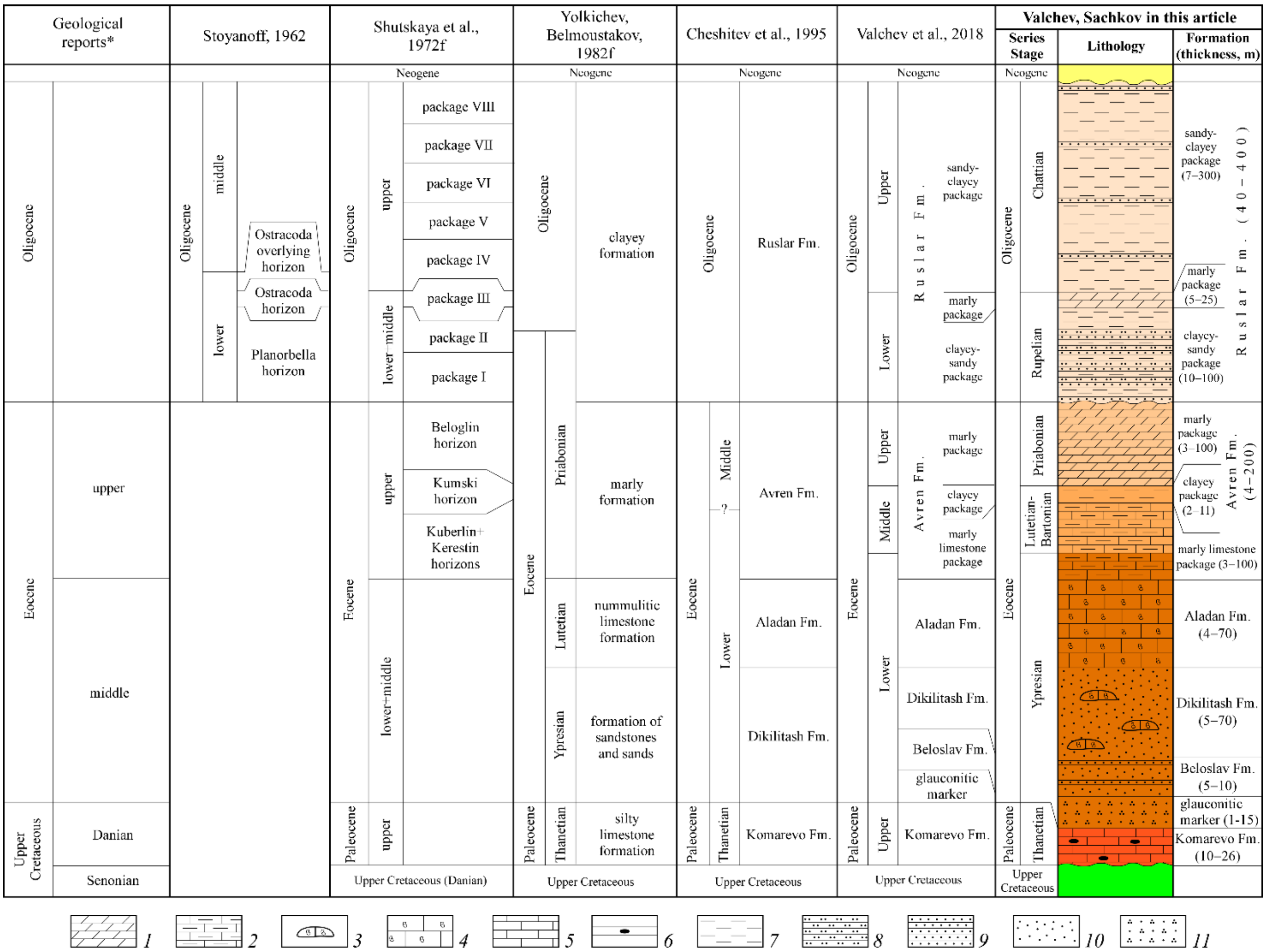

Fig. 3. Stratigraphic background and subdivision of the Paleogene in the Dobrogea area

1, marls; *2*, marly limestones; *3*, bioherms; *4*, organogenic limestones; *5*, limestones; *7*, clays; *8*, siltstones; *8*, sandstones; *10*, sands; *11*, glauconitic sandstones and sands

* This column summarises the lithologic and stratigraphic data obtained from 27 geological reports from the early 1950s to the early 1970s (for reference see Valchev et al., 2018)

Belmoustakov (in: Yolkichev, Belmoustakov, 1982f[2]) studied 16 borehole sections and defined five lithostratigraphic units: a silty limestone formation (Thanetian), a formation of sandstones and sands (Ypresian), a nummulitic limestone formation (Lutetian), a marly formation (Priabonian), and a clayey formation (Priabonian–Oligocene).

On the basis of foraminifera (small and larger) and calcareous nanoplankton, Aladjova-Khrischeva et al. (1983)

[1] Shutskaya, E., Y. Vaptsarova, M. Tanev, B. Goncharenko, D. Dencheva, A. Dianov, K. Jekova, V. Ignatova, M. Kehayova, G. Kulaksazov, T. Nikolov, A. Olferyev, A. Pozemova, I. Sapunov, Ch. Spasov, S. Stefanov, Y. Tenchov, E. Trifonova, D. Tronkov, P. Tsaneva, V. Tsankov, S. Yanev. 1972f. *Report on Topic I. Subdivision and Correlation of Borehole Sections in North Bulgaria.* Ministry of Energy, National Geological Fund, report III-247, 959 p. (in Russian, unpublished).

[2] Yolkichev, N., E. Belmoustakov. 1982f. *Stratigraphy of the Upper Cretaceous and Paleogene in Northeast Bulgaria and the Black Sea shelf.* Ministry of Energy, National Geological Fund, report XV-525, 165 p. (in Bulgarian, unpublished).

proved that the nummulitic limestone formation of Belmoustakov was of lower Eocene age, and that the lower levels of the marly formation belonged to the middle Eocene.

Dzuranov and Darakchieva (1986) formalised the marly formation (introduced as the “Avren marls” by Gočev, 1933) as the Avren Formation and gave planktonic foraminiferal data determining a lower Eocene age for the lowermost levels of the unit.

Filipov (1995) and Cheshitev et al. (1995) referred the silty limestone formation to the Thanetian Komarevo Formation (introduced by Dachev, 1975 in Central North Bulgaria), recognised the lower Eocene Dikilitash and Aladan Formations (both introduced by Gočev, 1933 and formalised by Aladjova-Khrischeva, 1984), confirmed the presence of the Avren Formation (determining its lower–middle Eocene age), and the uppermost levels of the Paleogene were included in the Oligocene Ruslar Formation (introduced by Zlatarski, 1927 and formalized by Aladjova-Chrisčeva, 1991).

Valchev and Juranov (in: Valchev et al., 2018) studied more than 600 borehole sections and refined the lithostratigraphic scheme. They confirmed the presence of the Komarevo Formation. The lower Eocene succession was divided into a glauconitic marker, the Beloslav and Dikilitash Formations, corresponding to the “Dikilitash Formation” of Filipov (1995) and Cheshitev et al. (1995), and the Aladan Formation. The authors subdivided both the Avren (uppermost Lower Eocene–Upper Eocene) and Ruslar (Oligocene) Formations into three distinct packages, reinterpreted the available biostratigraphic data, and gave additional data for the chronostratigraphic range of the lithostratigraphic units. Their spatial distribution was visualised by the generation of a 3D lithostratigraphic model (by Sachkov).

Chronostratigraphic units

We recognised the Thanetian Stage of the Paleocene, the Ypresian, Lutetian–Bartonian, and Priabonian Stages of the Eocene, the Rupelian and Chattian Stages of the Oligocene (the spatial distribution of the units is shown in Figs. 4–10 by compiling seven regional chronostratigraphic charts).

Paleocene

***Danian and Selandian*.** These stages have not been established in the study area. The rocks determined as “Danian” in the geological reports belong to the Upper Cretaceous or more often to the Thanetian.

***Thanetian*.** It comprises the entire Komarevo Formation. The thickness of the unit varies from 5–6 m (in the northern part of the study area), rarely up to 26 m (in the area of Tyulenovo), but it is usually 10–15 m. It gradually increases from the west to the east and southeast. The unit covers different levels of the Upper Cretaceous, as the boundary is an unconformity. The upper boundary is an unconformity with different levels of the Ypresian. In the primary descriptions in the earlier geological reports, these rocks were referred to the “Danian”. Only the summarising work of Shutskaya et al. (1972f) represents these levels as “Upper Paleocene”.

Eocene

***Ypresian*.** The stage comprises the glauconitic marker, the Beloslav, Dikilitash and Aladan Formations, as well as the lower levels of the marly limestone package of the Avren Formation. The thickness varies broadly from 4 m (the Kardam locality) to 139 m (the Tangra borehole), but it is usually 50–80 m. Generally, it increases from the Northwest to the East and Southeast. The lower boundary is an unconformity with different levels of the Upper Cretaceous or the Thanetian. The upper boundary is conformable with the Lutetian, or represents an unconformity with the Priabonian (the Krapets locality) or the Rupelian (the entire northernmost part of the Dobrogea area).

Lutetian. The middle and upper levels of the marly limestone package of the Avren Formation are included in this stage. The lower boundary is conformable with the Ypresian. The upper boundary is also conformable with the Bartonian.

Bartonian. It comprises the uppermost levels of the marly limestonepackage of the Avren Formation and the entire clayey package of the Avren Formation. The lower boundary is conformable with the Lutetian. The upper boundary is conformable with the Priabonian or unconformable with the Rupelian.

As there is no enough biostratigraphic data to define exactly the Lutetian–Bartonian boundary, the two stages are presented as a unified body in the 3D model. Its thickness varies from 5 m (the Gurkovo area) to 94 m (the St Nikola area) and gradually increases to the Southeast.

Priabonian. It is represented by the marly package of the Avren Formation. The thickness varies broadly from 5 m (the Krapets area) to 89 m (the Tyulenovo area). Generally, it increases gradually to the South and Southeast. The lower boundary is conformable with the Bartonian. The upper boundary is an unconformity with the Rupelian.

Oligocene

The Rupelian and Chattian Stages have not been defined in Northeast Bulgaria due to the scarce biostratigraphic data. Here, we accept that they correspond to the “lower Oligocene” and the “upper Oligocene” that were previously divided (see Fig. 3).

Rupelian. It comprises the clayey-sandy and marly packages of the Ruslar Formation. The thickness varies very broadly from 8 m (the Spasovo area) to 202 m (the Vranino area), as it increases to the Southeast. The lower boundary is unconformable with the Priabonian. The upper boundary is a conformity with the Chattian or an unconformity with the Neogene.

Chattian. The sandy-clayey package of the Ruslar Formation is included in this stage. The thickness varies very broadly from 14 m (the Spasovo and Trigortsi areas) to 376 m (the Kavarna-Balgarevo area) and sharply increases to the east-southeast. The lower boundary is conformable with the Rupelian. The upper boundary is an unconformity with the different levels of the Neogene. There are no data concerning the duration of the hiatus.

Regional chronostratigraphic aspects

It can be seen that the thinnest Paleogene succession was recorded in the northwesternmost part of the study area (the Kardam and General Toshevo localities), where only the Ypresian is present (Figs 4, 5, 7). In the Spasovo locality, despite the last, the Thanetian, Rupelian and Chattian occur (Figs 4, 8), while in the Durankulak locality and to the East offshore, the Paleogene section includes the Ypresian, Rupelian and Chattian only (Figs 4, 10). A slow increase of the units' thickness to the East was recorded.

The central localities represent three situations. West of the village of Belgun, the Ypresian and Rupelian comprise the Paleogene succession (Figs 5, 8), while between the villages of Belgun and Tvarditsa, it is composed of the Thanetian, Ypresian, Rupelian and Chattian (Fig. 5). In the Krapets locality (south of the village) and to the East offshore, the Priabonian appears, and thus, despite the last, the section is composed of the Ypresian, Rupelian and Chattian (Figs 5, 10). The thickness of all units is almost constant.

The southwestern part of the study area (the Dobrogea coal basin) reveals a complicated geologic structure and great variations of the stratigraphic record. In a small area near the village of Trigortsi, the Paleogene section, three situations could be seen (Figs 6, 8, 9). The Ypresian, Rupelian and Chattian are present northwest of the village, the Thanetian, Ypresian and Rupelian were established around the village, and to the southeast the Lutetian–Bartonian appear. In the Balchik locality (Fig. 7), the Paleogene succession includes the Thanetian, Ypresian, Lutetian–Bartonian, Rupelian, and Chattian. In the Vranino area (Figs 6, 8), only the Ypresian, Rupelian, and Chattian were recorded, while the Kavarna locality (Figs 6, 8) reveals a complete Paleogene section (from the Thanetian to the Chattian).

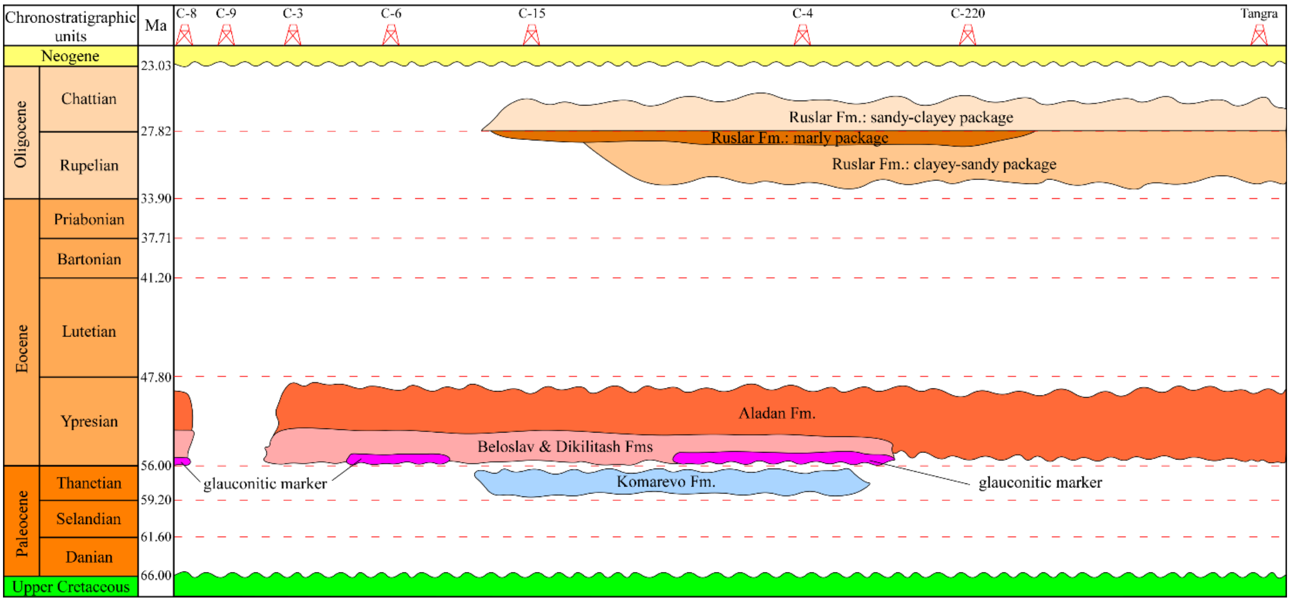

Fig. 4. Regional chronostratigraphic chart I-I

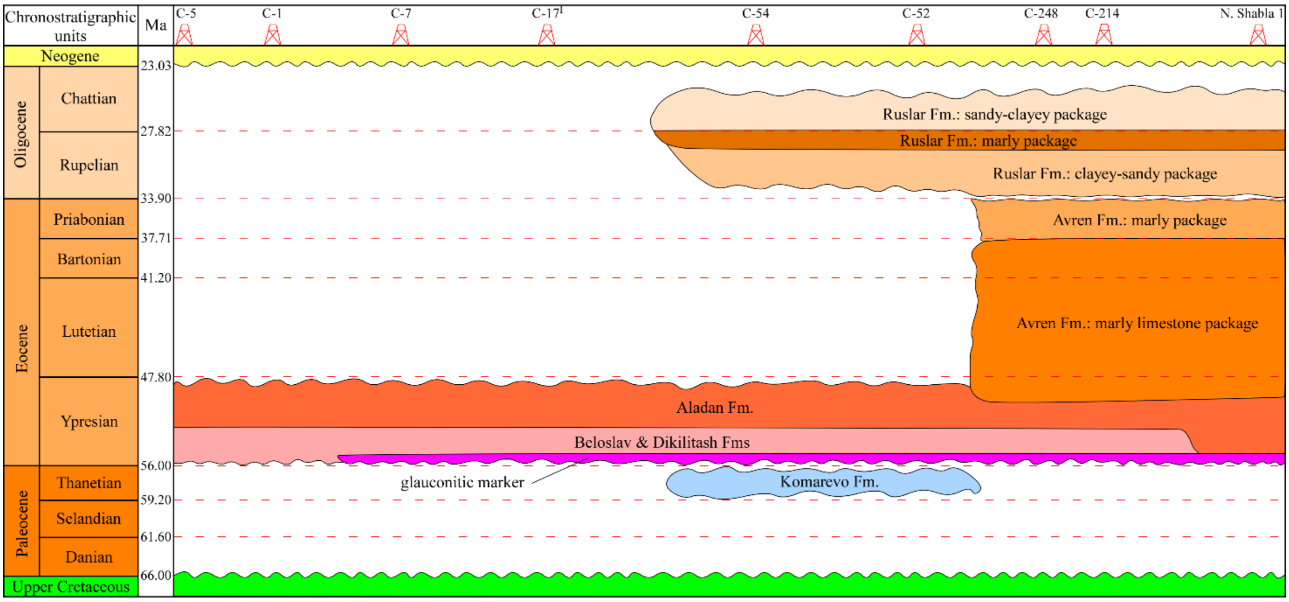

Fig. 5. Regional chronostratigraphic chart II-II

The same chronostratigraphic record was established in the Balgarevo–Cape Kaliakra locality (Figs 6, 9, 10), as thickness variations of the Priabonian and Chattian were observed. To the southwest offshore (R-1 the Nanevo locality), the Thanetian disappears and the thickness of the Priabonian–Chattian interval sharply decreases.

The coastal region between Cape Shabla and Cape Kaliakra reveals a complete Paleogene succession except the

Tyulenovo locality, where the Thanetian is not present (Fig. 10). Variations of the Rupelian and Chattian's thickness were recorded.

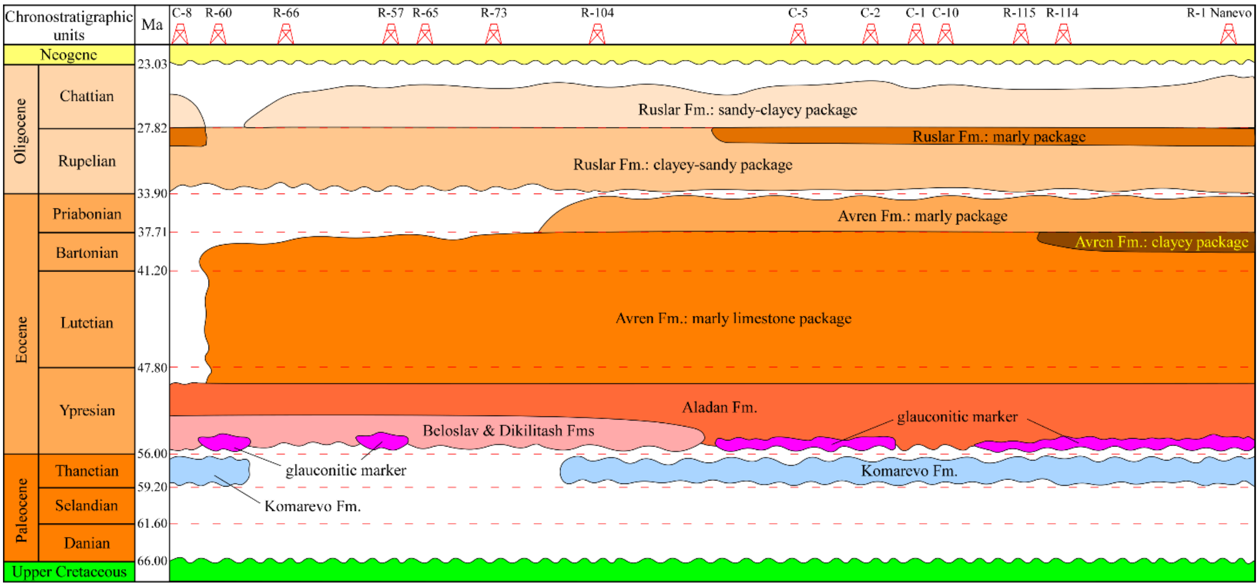

Fig. 6. Regional chronostratigraphic chart III-III

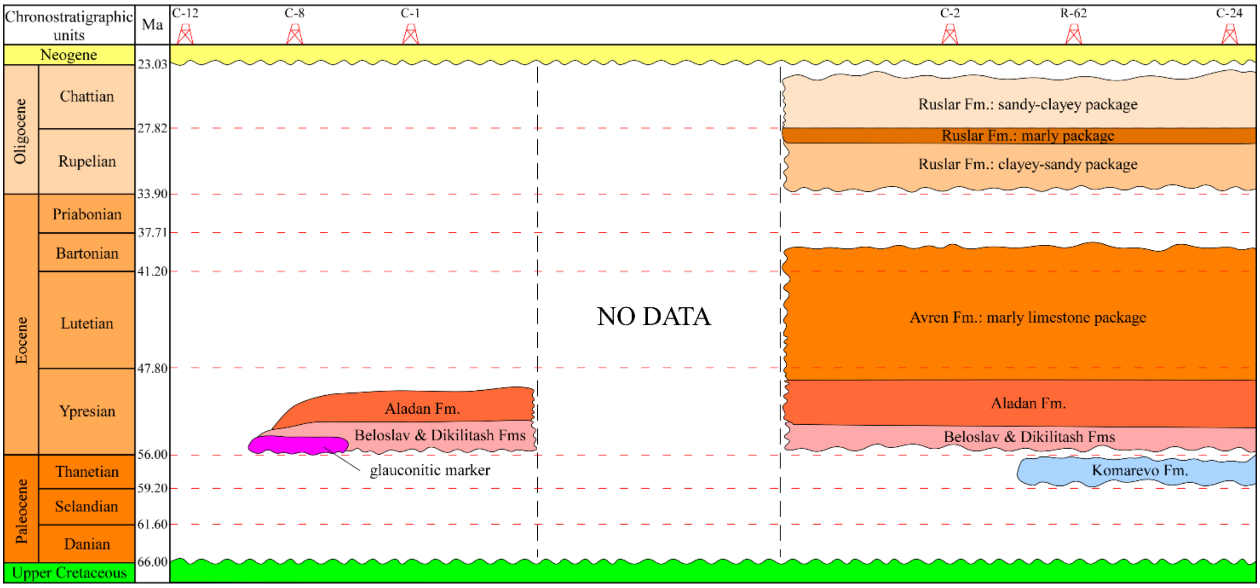

Fig. 7. Regional chronostratigraphic chart IV-IV

3D chronostratigraphic model

For further visualisation of the spatial distribution of the chronostrarigraphic succession, a 3D model was created. For its generation, individual sets of chronostratigraphic bodies were established. They include base, cover, and six bodies concerning the Paleogene chronostratigraphic units (Fig. 11).

The base of the Paleogene succession in the whole study area is the Upper Cretaceous (Fig. 11a).

The distribution of the Thanetian is not ubiquitous (Fig. 11b). This fact could be interpreted as Thanetian non-deposition in broad areas or the presence of partial pre-Eocene local erosion on the carbonate platform.

The Ypresian is distributed over the whole study area (Fig. 11c), but is represented by various rock sequences due to the presence of a dynamic sedimentary environment and a very rapid transformation of basin conditions. The sedimentary environments of the Ypresian are diverse, rapidly changing, and migrating. A hiatus of varying duration is recorded in the upper part of the Ypresian. It is long-lasting in the north-western parts of the onshore part of the study area and in the Black Sea (Figs 5, 7). In the interior of the stage, the occurrence of short-term interruptions is also possible. In some areas, the highest levels of the Ypresian are missing. This patterning of the upper stage boundary is probably related to later events, but it is a fact that the boundary reflects erosional processes affecting the sediments of this stage as well.

In general, the Lutetian and Bartonian rocks have a more restricted distribution compared to those of the Ypresian (Fig. 11d). The sections are lithologically more monothonous. There are no hiatuses in both stages.

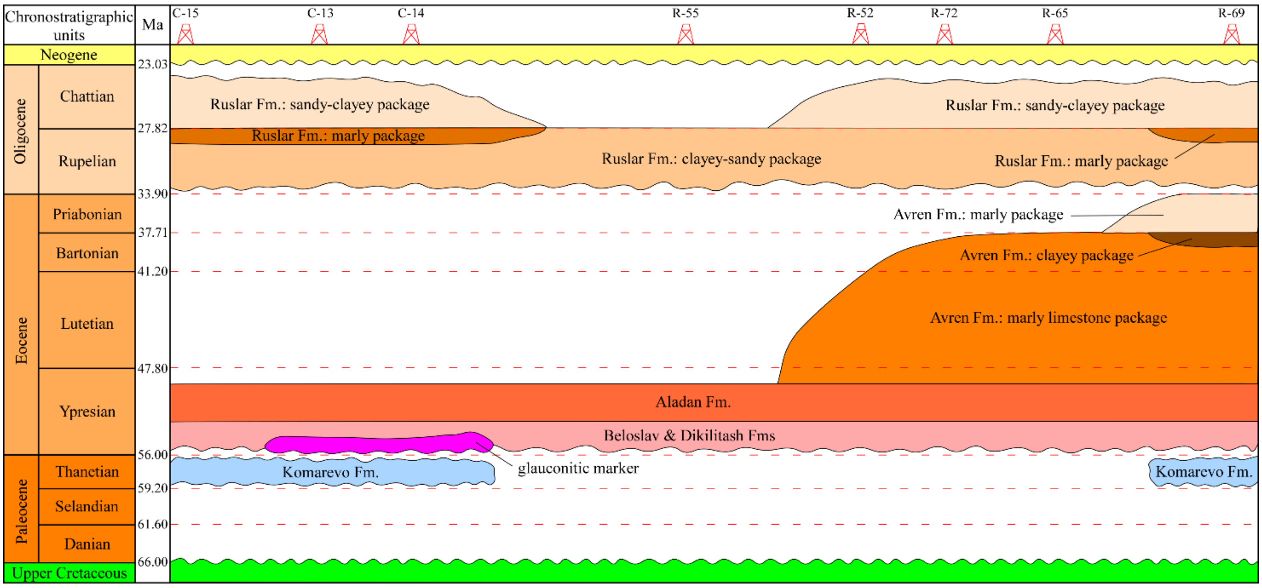

Fig. 8. Regional chronostratigraphic chart V-V

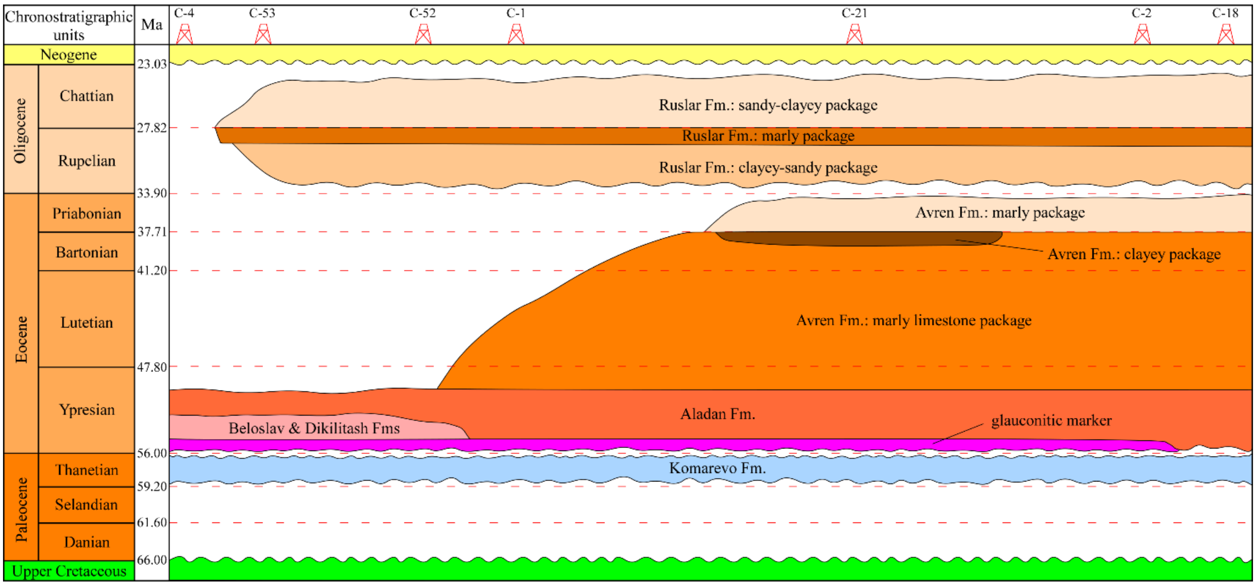

Fig. 9. Regional chronostratigraphic chart VI-VI

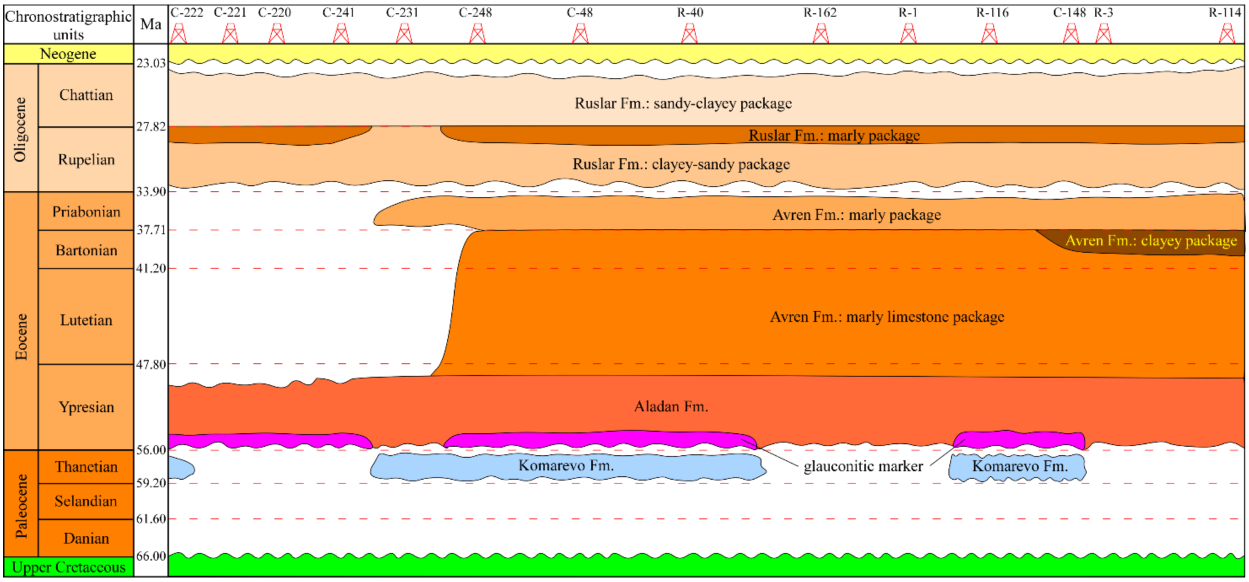

Fig. 10. Regional chronostratigraphic chart VII-VII

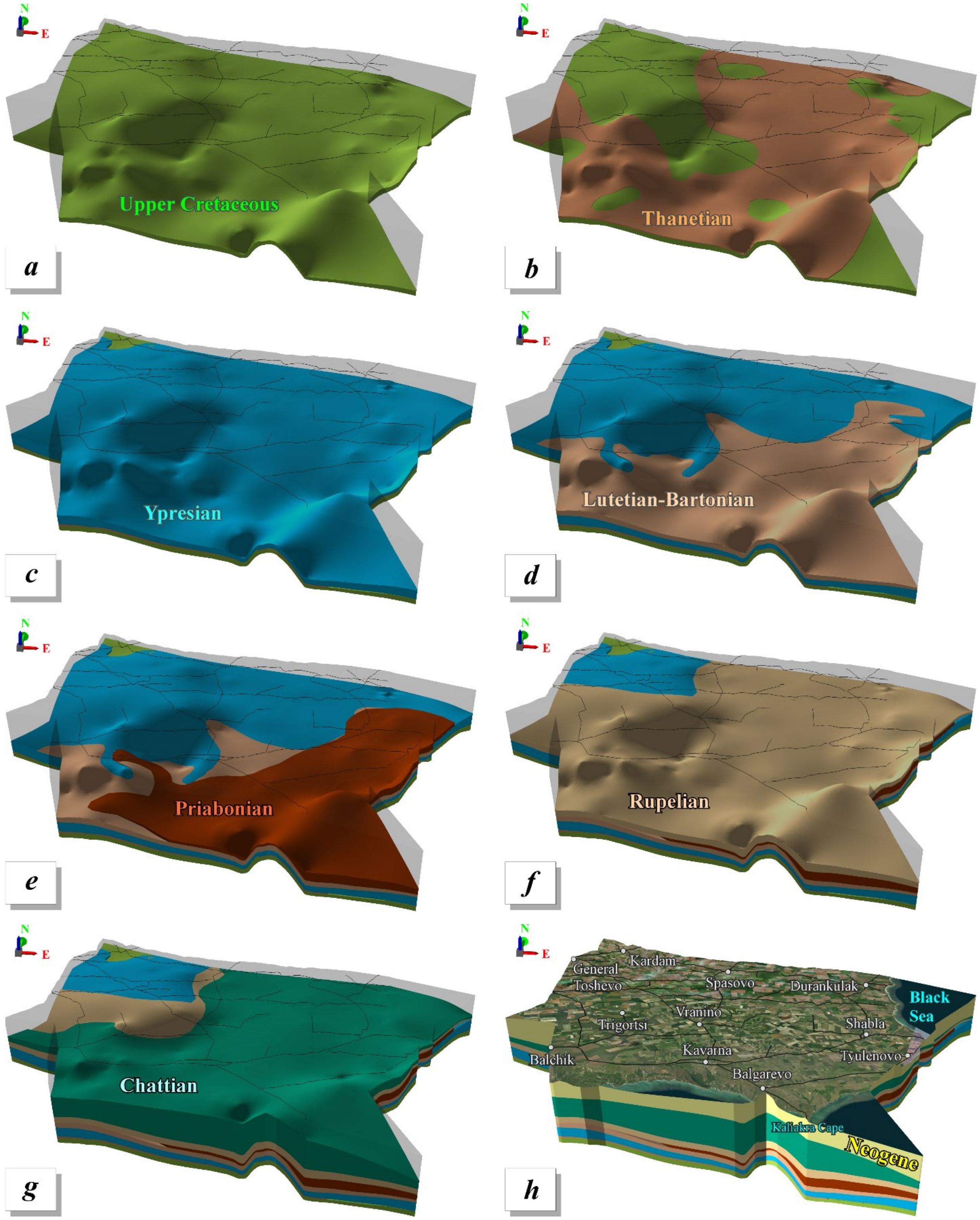

Fig. 11a. 3D model of the Upper Cretaceous base *(a)*, the Paleogene chronostratigraphic units *(b–g)*, and the Neogene cover *(h)*

The distribution of the Priabonian is restricted to the southernmost and easternmost parts of the study area (Fig. 11e). It is unlikely that they were not deposited in its other parts. Rather, this absence is the result of significant pre-Oligocene erosion, which also affects the Lutetian and Bartonian and sometimes even the Ypresian.

The pre-Oligocene erosion is one of the most notable events of the Paleogene at the easternmost part of the Moesian Platform. It is associated with the complete transformation of the basin regime and the complete change of sedimentary settings at the beginning of the Oligocene.

The Rupelian (Fig. 11f) has a relatively wider spatial distribution as compared to the Lutetian–Priabonian rocks. The hiatus along its lower boundary is short-lasting in time, but in certain areas this boundary is associated with continuous erosion affecting all older levels of the Palaeogene. Typically, this situation marks the margin of the Paleogene basin.

Despite the the northwestern part of the study area, only three of the interpreted sections (in Trigortsi area) clearly show the absence of the Chattian sediments (Figs 6, 8, 9, 11g), indicating the presence of local but deep scour affecting the entire stage.

The Neogene covers the entire study area (Fig. 11h).

Conclusions

The chronostratigraphic interpretation of the available biostratigraphic data allowed compiling a reliable database for visualising and analysing the spatial distribution of the Paleogene chronostratigraphic units. Thus, the complicated deep structure of the easternmost part of the Moesian Platform was confirmed and revealed in detail.

The block structure of the basement and the differences in the sedimentary sequences on the individual blocks indicate that the formation of the tectonic boundaries between them occurred at an older time, and their effect on sedimentation is the result of a later reactivation, with different intensities, depending on the geodynamic setting and stress field distribution. To the extent that the block structure of the basement and fault reactivation can influence sedimentation, they determine the different degrees of preservation of sedimentary sequences on the individual blocks, confined between major unconformities, on the formation of local depocentres, and hence, relatively different lithologies within them, areas of unconformity, scouring or condensed sedimentation, possibly the presence of fault-dominated sediments.

Considering that sedimentation occurs mostly in stable epicontinental conditions, the section is dominated by shallow-water sedimentation, suggesting rapid facies migration and a relatively narrow chronostratigraphic range of diachronous boundaries, and the lithological boundaries can be assumed to be synchronous within the range of a century or even an epoch.

The 3D chronostratigraphic model shows the location and duration of the hiatuses in the Paleogene section, as well as the relative rates of sedimentation for individual zones in the basin. Thus, it provides good opportunities for further research and conclusions in the field of basin analysis and sequence stratigraphy.

Acknowledgements. This article is in memory of Dr Sava Juranov, who introduced us to the Paleogene stratigraphy of Northeastern Bulgaria.

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