CRETACEOUS-CENOZOIC PALEOBIOGEOGRAPHY OF THE SOUTHERN ROMANIAN BLACK SEA ONSHORE AND OFFSHORE AREAS

Mihaela Carmen MELINTE

National Institute of Marine Geology and Geoecology (GeoEcoMar Bucharest),
23-25 Dimitrie Onciul St, 024053, Bucharest, Romania
Corresponding author: melinte@geoecomar.ro

Abstract. Investigations carried out on 22 drillings on the Southern onshore area of the Romanian Black Sea and on one drilling from the Southern offshore area of the Romanian Black Sea are presented here. The lithological/sedimentological investigations and the micropalaeontological (calcareous nannoplankton) quantitative and qualitative analyses revealed several depositional sequences. The oldest identified sedimentary cycle is latest Jurassic (Tithonian) - Early Cretaceous (Berriasian - Valanginian) in age and composed of marine shallow water carbonates. The next cycle, in stratigraphic order, is Barremian - Early Aptian in age, composed of marine shallow water carbonates. A fluvial-lacustrine formation, Middle - Late Aptian in age, was observed only in the drillings from onshore area. The youngest Cretaceous cycle (Santonian – Maastrichtian) is mainly composed of chalks, with intercalations of glauconitic sands towards the base. In the chalk offshore deposits of the Black Sea, a continuous sedimentation took place within the Cretaceous/Tertiary boundary interval. The Paleogene deposits (Middle – Late Eocene) are characterized by the presence of marlstones and claystones. These are overlain by Oligocene black shales, rich in organic matter and fish remains. Miocene, Pliocene and Pleistocene deposits were sedimented in a brackish environment, but several marine influxes probably occured (based on the nannofloras encountered) within the Middle Miocene, latest Miocene-earliest Pliocene and Late Pleistocene. The Cretaceous-Eocene nannofloras are dominated by warm water taxa (Tethyan nannofloras). The occurrence of the Cretaceous calcareous nannoplankton confined to high latitudes (Boreal taxa) within the Late Valanginian, the Barremian - Aptian boundary interval and the latest Maastrichtian, indicate cooler water surfaces. A more significant cooling could be assumed in the Early Oligocene, occuring at the same time with the separation of the Paratethys Realm, and with the appearance of endemic nannofloras in the Black Sea offshore area.

Key words: Cretaceous - Paleogene - Neogene, litho- and biostratigraphy, nannofloras, NW Black Sea

INTRODUCTION

The area on which this study is focused comprises both the onshore and the offshore zone of the Southern Romanian Black Sea region (Figure1). This area belongs, in terms of tectonic evolution, to the Eastern extension of the Moesian Platform (the Dobrogea sector - including both the Central and the Southern Dobrogea, according to Săndulescu, 1984). The analyzed onshore wells are placed in Southern Dobrogea, a subsided block, which is separated from the uplifted block of the Central Dobrogea by the Capidava - Ovidiu Fault (Dinu *et al*., 2002).

Pioneer investigations of this region have started as early as the second half of the XIXth century and the beginning of the XXth century (Reuss, 1865; Peters, 1867; Anastasiu, 1898; Simionescu, 1906 and Macovei, 1911). Detailed studies of the lithology and palaeobiology of the Cretaceous - Cenozoic sediments cropping out in the Southern Dobrogea were published, in the second half of the last century, by Chiriac (1968), Tătărâm *et al*. (1977), Neagu *et al*. (1977), Neagu (1986, 1987), Bărbulescu & Neagu (1988), Ion *et al*. (1998) and Avram *et al*., 1988 (among others).

If there is a remarkable amount of data available for the surface stratigraphy of Southern Dobrogea, the data concerning the subsurface of Southern Dobrogea are scarce. One of the first published studies on this topic is by Băncilă (1973). In the ’80s, the drilling of 22 wells, in the Southern Dobrogea area, revitalized the investigation of the subsurface of the Southern Romanian Black Sea onshore. Stratigraphical investigations of these drillings generated new data on Cretaceous subsurface deposits of this region (Avram *et al*., 1993; Ion *et al*., 1998).

This study aims to provide a reconstruction of the depositional history of the Southern Romanian Black Sea area, based on the detailed lithological and palaeontological analyses of 22 onshore drillings. Investigations of the Cretaceous - Cenozoic sequences, of one well (Tandala), drilled offshore in the Southern Romanian Black Sea territory (Fig. 1), were also completed.

MATERIAL AND METHODS

Detailed investigations were completed of 22 drillings onshore in the Southern Romanian Black Sea and of one drilling offshore in the Southern Romanian Black Sea (Fig. 1).

Lithological and sedimentological analyses, as well as preliminary micropalaeontological data were previously published by teams of scientists, including the author of this paper (Avram *et al*. 1993; Ion *et al*., 1998; Popescu *et al*., 1998).

Apart from a new interpretation of the data acquired, detailed calcareous nannoplankton studies, on the Black Sea onshore and offshore drillings, were also carried out. Both qualitative and quantitative analyses were done. On each smear-slide, 300 specimens were counted, the investigation being completed to 200 fields of view. The diversity was estimated as the number of the total taxa in each sample, while the abundance was considered as the number of nannofossils in one field of view. The nannofloral taxonomy follows Perch-Nielsen (1985a, 1985 b).

RESULTS

Early Cretaceous

The oldest deposits traversed by the studied onshore drillings belong to the Cernavodă Formation and yielded two main facies: a North-Western facies, mainly composed of evaporitic rocks, variegated clays, marls and sandstones (the Amara Member, 150-180 m thick) and a South-Eastern one, mainly made by calcarenites and calcilutites (the Alimanu Member, 150-180 m thick) – figure 2.

The two units described above are Early Berriasian - Late Valanginian, as proved by the identified calcareous nannofloral assemblages. The successive first occurrences (FO) of the nannofossils *Cretarhabdus angustiforatus* (Black) Bukry and *Calcicalathina oblongata* (Worsley) Thierstein led to the identification of the NK1, NK2 and NK3 Calcareous Nannoplankton Zones of Bralower *et al*. (1989). The deepest Berriasian deposits were recorded at 397 m (drilling 19), while the uppermost Berriasian sediments were identified at 55 m (drilling 8).

The quantitative studies focused on four taxonomical groups : (1) *Watznaueria barnesae*, an extreme cosmopolitan species, resistant to diagenesis; (2) the Tethyan *Nannoconus* species, oligotrophic taxa, indicating warm surface waters (Melinte and Mutterlose, 2001); (3) Tethyan taxa, especially confined to low to middle latitudes (other then *Nannoconus*), including *Polycostella senaria* Thierstein, *Diazomatolithus leh-*

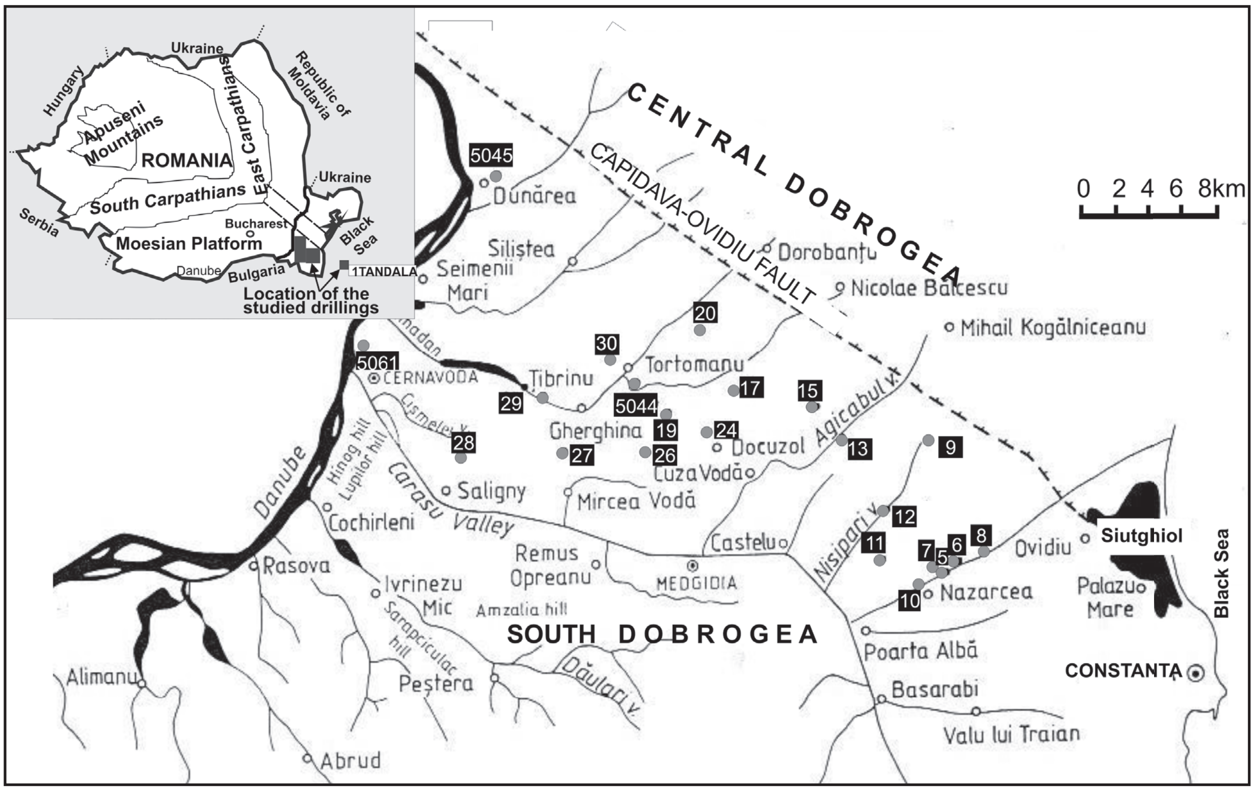

Fig.1 Studied drillings in the Southern part of the Romanian Black Sea onshore and offshore (modified after Avram *et al.*, 1993; Ion *et al.*, 1998)

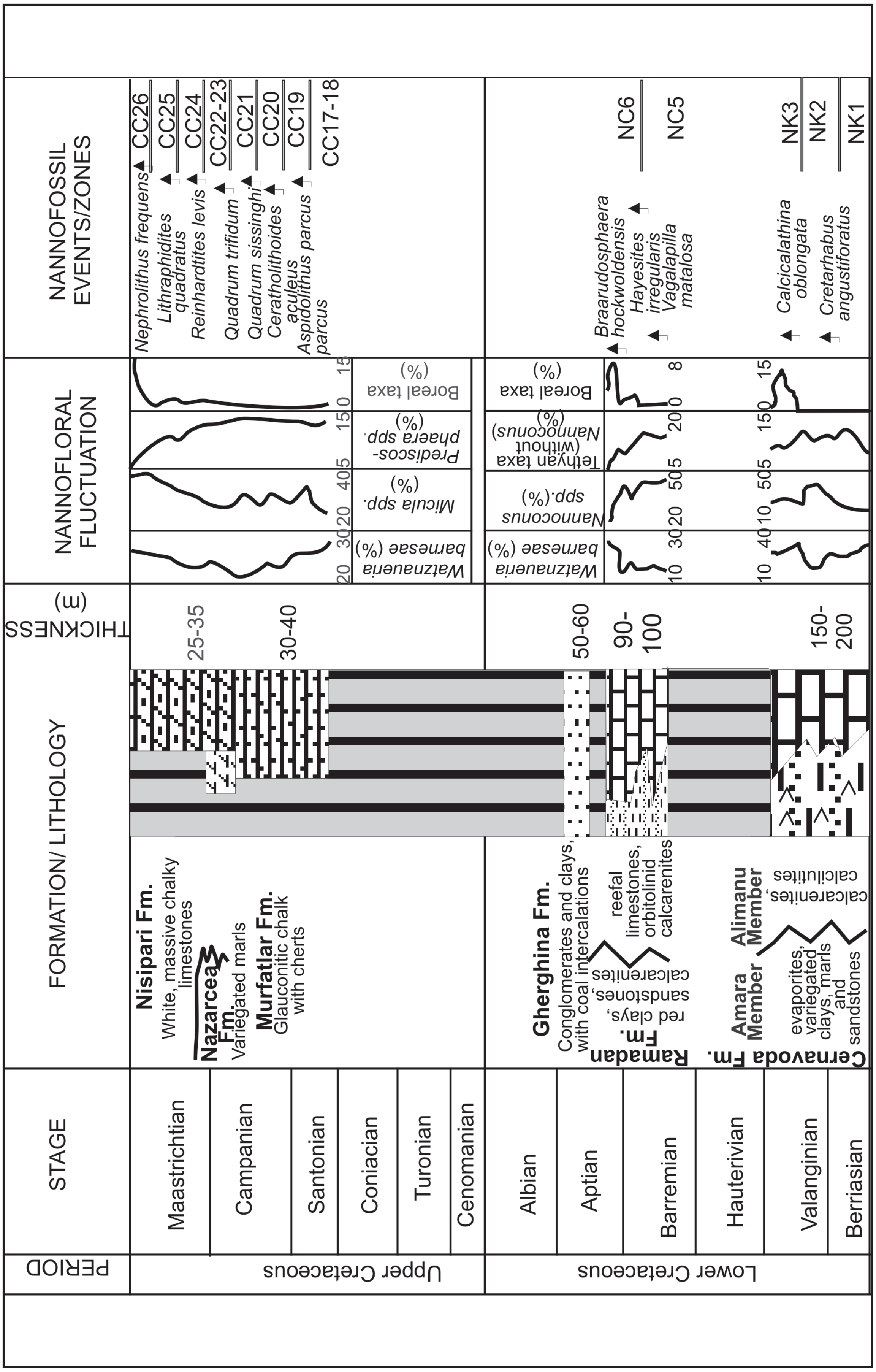

Fig. 2 Composite lithology and biostratigraphy of the studied drillings from the Southern Romanian Black Sea onshore

manii Noël and *Conusphaera mexicana* Trejo; (4) Boreal taxa (*sensu* Mutterlose, 1992) including *Micrantholithus speetonensis* Perch-Nielsen, *Sollasites horticus* (Stradner) Čepek and Hay, *S. lowiei* (Bukry) Rood *et al*., and *Crucibiscutum salebrosum* (Black) Jakubowski, nannofossils which indicate relatively cool water surfaces.

Similar to other Romanian sections (*e.g*. the Carpathian Domain - Melinte and Mutterlose, 2001), the Berriasian of the Black Sea onshore is characterized by nannofloral assemblages dominated by *Watznaueria barnesae* (Black) Perch - Nielsen (yielding an abundance of 20-30%) and *Nannoconus* spp. (with an equivalent abundance of 20-30%) – Figure 2. The cosmopolitan species are, within most of the Berriasian, more abundant than the Tethyan ones (*Nannoconus* spp., *Polycostella senaria*, *Diazomatolithus lehmanii* and *Conusphaera mexicana*). The Late Berriasian - Early Valanginian nannofloras (lower part of the NK2 Calcareous Nannoplankton Zone) are dominated by the Tethyan taxa (the abundance of *Nannoconus* is almost 50%). In the Late Valanginian, there was a shift in the abundance of nannoconids. The event is synchronous with the appearance of the Boreal taxa, which represent up to 12% from the assemblages. High fertility proxies, as *Biscutum constans* (Gorka) Black, *Diazomatolithus lehmanii* and *Zeugrhabdothus erectus* (Deflandre) Reinhardt, increase in abundance (amounting jointly to 15%) within the Late Valanginian.

In the investigated offshore drilling (Tandala), the oldest recorded deposits are latest Jurassic - earliest Cretaceous (Tithonian - Valanginian) in age and 120 m thick. In terms of lithology, these sediments are similar to the Lower Cretaceous South - Eastern facies of the studied onshore drillings – *i.e.* calcarenites and calcilutites with frequent dasycladacean algae belonging to the Alimanu Member (Cernavoda Formation). The latest Jurassic (Tithonian) age was assigned based on foraminiferal assemblages containing *Topalodiscorbis* sp. and mililoids (Neagu *in* Avram *et al*., 1993) and also based on the presence of the *Crassicolaria* Calpionellid Zone. The Berriasian-Valanginian age is argued by the foraminiferal assemblages with *Pseudocyclammina litus* and *Trocholina alpina* – Neagu *in* Avram *et al.*, 1993 and also by the identification of the NK1 and NK2 Calcareous Nannoplankton Zones (Fig. 3).

The qualitative investigations of earliest Cretaceous nannofloras revealed similar trends to those recorded onshore of the Black Sea in the calcareous nannoplankton fluctuations; high abundance of the Tethyan species (including *Nannoconus*) within the Berriasian and Early Valanginian, and their significant decrease, within the Late Valanginian, together with the occurrence of Boreal taxa and increase of *Watznaueria barnesae*.

The next lithological unit (in the stratigraphical succession) traversed by the studied onshore drillings is the Ramadan Formation (90-100 m thick), which displayed two main facies (Fig. 2). There occur red clays, sandstones and locally, calcarenites in the Western part of the surveyed area; and reefal limestones and calcarenites rich in orbitolinids and miliolids in its Eastern part. Comparing with the subjacent Lower Berriasian - Upper Valanginian calcarenites of the Cernavoda Formation, mainly containing dasycladacean algae, the most abundant microfossil of the Ramadan Formation are the arenaceous foraminifers, as well as the miliolids and orbitolinids (Neagu, 1986; Avram *et al*., 1993). The deepest recorded level of the Ramadan Formation is 220 m (Well 24), while the topmost is 48 m deep (Well 11).

The identified nannofloras indicate, for the Ramadan Formation, a Late Barremian - earliest Aptian age, based on the successive FOs of the nannofossils *Vagalapilla matalosa* (Stover) Thierstein, *Hayesites irregularis* (Thierstein) Covington & Wise and *Braarudosphaera hockwoldensis* Black. The latest bio-event approximates, in the Tethyan Realm (including the nowadays Romanian territory), the Barremian-Aptian boundary interval (Barragan and Melinte, 2006).

The quantitative nannofloral studies focused on four taxonomical groups : (1) *Watznaueria barnesae*, an eurytopic cosmopolitan and ecologically robust form, one of the first species to settle in new biotopes; (2) *Nannoconus* spp., taxa which are believed to be restricted to lower photic zone and controlled by fluctuations of nutricline depth (Erba,1994). High abundance of *Nannoconus* indicates deep chlorophyll maximum zone (DCM), with increased productivity of the lower photic zone and high surface water temperatures (Melinte and Mutterlose, 2001; Bersezio *et al*., 2002); (3) Tethyan taxa (other than nannoconids), which are also especially confined to low to middle latitudes, including *Assipetra terebrodentarius* (Applegate *et al*. *in* Covington and Wise) Rutledge and Bergen *in* Bergen, *Hayesites irregularis*, *Conusphaera mexicana*, and *C. rothii* (Thierstein) Jakubowski, (4) Boreal taxa (*sensu* Mutterlose, 1992) including *Sollasites horticus*, *Crucibiscutum salebrosum*, *Zeugrhabdotus sysiphus* (Gartner) Crux and *Vagalapilla matalosa*, species indicating relatively cool water surfaces.

The Late Barremian nannofossil assemblages (upper part of NC5 Calcareous Nannoplankton Zone of Roth's Zonation, 1978) are dominated by the Tethyan taxa, which make up, together with *Nannoconus* spp. almost 70% of total nannofloras – Figure 2. Within the latest Barremian (around the boundary between the NC5/NC6 Calcareous Nannofossils Zones of Roth, 1978) there was a significant shift in the Tethyan taxa (from 70% up to 45%). This bioevent is coincident with an increased abundance of cosmopolitan nannofossil *Watznaueria barnesae* and of Boreal taxa. The shift in the Tethyan calcareous nannoplankton is even more pronounced within the earliest Aptian (lower part of the NC6 Calcareous Nannoplankton Zone). That is an interval in which they represent only 25% of nannofloras – Figure 2.

In the Tandala Well, reefal limestones and calcarenites (80 m thick), rich in orbitolinids and miliolids were identified. The Hauterivian – Aptian age of the above-described succession was formerly confirmed based on the presence of

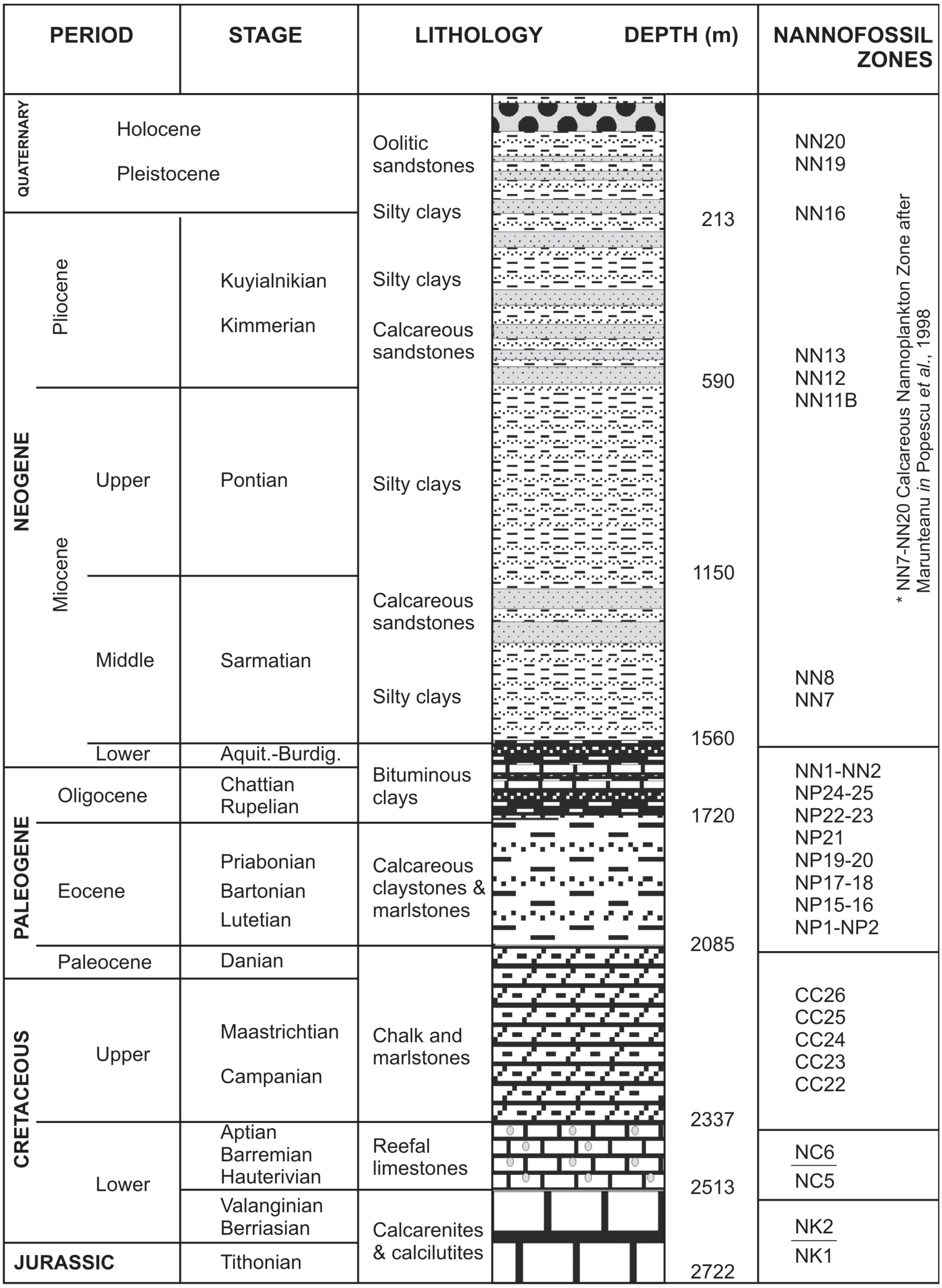

Fig.3 Lithostratigraphy of the Cretaceous-Cenozoic deposits traversed by the Tandala Well (Southern Romanian Black Sea offshore)

foraminiferal assemblages (*Neotrocholina paucigranulata*, *Gavelinella barremiana*, *Epistomina carpenteri* Assemblage – according to Neagu *in* Avram *et al*., 1993). Based on calcareous nannoplankton investigations, these deposits are Late Hauterivian - earliest Aptian in age (an interval covered by the NC5 and NC6 Calcareous Nannoplankton Zones of Roth, 1978). The nannofloral quantitative analyses of the offshore sediments revealed a trend similar to the one in the onshore deposits. The Hauterivian - Barremian nannofloras are dominated by Tethyan taxa. The Boreal nannofossils occurred within the latest Barremian and the warm water nannofossils (including the nannoconids) decreased significantly within the earliest Aptian.

The Ramadan Formation is unconformably overlain, in the Southern offshore of the Black Sea, by the Gherghina Formation, which is mainly constituted by sands with thin coal lenses and kaolinitic clays. The Gherghina Formation (50-60 m thick) was encountered in the onshore drillings 10, 11, 13, and 15, the deepest level where it was recorded being 182 m (Well 13), while its uppermost level is 50 m deep (Well 11). This lithological unit is Middle - Late Aptian in age, based on the identification of charophyte assemblages, containing among other taxa, *Atopochara trivolvis trivolvis* Pech, *A. trivolvis tricheta* (Pech) Grambast, *Clavator harrisi* Peck, *Nodosoclavatus adnatus* Martin-Closas & Grambast-Fessart, *Pseudoglobator paucibracteatus* Martin-Closas & Grambast-Fessart and *Perimneste horrida* Grabast (Iva, 1990).

Late Cretaceous

The Upper Cretaceous deposits were identified in the onshore area of the Black Sea in the wells 6, 7, 8, 9, 10 and 12 (Fig. 1). The oldest Upper Cretaceous lithostratigraphical unit discovered (in drillings 8 and 10) is the Murfatlar Formation, made up of grey-whitish argillaceous chalks, with reddish mottled clays in the lower part, overlain by yellowish clays and whitish, massive chalky limestones towards the top (Ion *et al*., 1998). The Murfatlar Formation is 30-40 m thick, with its deepest level situated at 113 m (in Well 9), while its topmost level is placed 12 m deep (in Well 10). The calcareous nannoplankton assemblages, characteristic of CC18, CC19 and CC20 Calcareous Nannoplankton Zones (of the Sissingh's Zonation, 1977) argue for a Santonian – early Late Campanian age (Fig. 2).

The next stratigraphical unit is the Nazarcea Formation (found in the drillings 6, 7, 8, 9 and 12). Its deepest level is 113 m (in drilling 9) while its uppermost level is 10 m deep (Well 8). The Nazarcea Formation (from 20 to 45 m thick) is composed of reddish marls, gray-yellowish marls and clays, as well as kaolinitic clays. The Nazarcea Formation was assigned to the Early Maastrichtian, based on its charophyte content (according to Iva *in* Ion *et al*., 1998).

The youngest Upper Cretaceous unit found in the studied drillings of the Black Sea onshore is the Nisipari Formation, which was encountered in the drillings 8, 9 and 10. It is 10-25 m thick. The deepest level where it was identified is 68 m (in the drilling 9) while the topmost is 3 m (in the drilling 10). The Nisipari Formation is made by chalky marls and clays, overlain by glauconitic sands, and whitish massive chalky limestones. The age of this formation, *i.e.* latest Campanian - Late Maastrichtian is proved by the identification of the CC22-CC26 Calcareous Nannoplankton Zones of the Sissingh's Zonation (1977) – Figure 2. This formation was attributed the same age based on planktonic and benthic foraminifers (Ion *et al*., 1998).

It must be noted that the youngest deposits traversed by the 22 investigated wells, in the onshore area of the Black Sea, are Neogene in age, and were not subject of this study.

The quantitative Late Cretaceous nannofloral analyses focused on four taxonomical groups: (1) *Watznaueria barnesae*, an eurytopic cosmopolitan and ecologically robust form; (2) *Micula* spp., the dominant genus in the Upper Cretaceous nannofloral assemblages. The genus Micula is mainly represented by *Micula decussata* Vekshina (80%). Within the Upper Maastrichtian deposits, *Micula murus* (Martini) Bukry and *M. prinsii* Perch-Nielsen also frequently occur. The species of this genus are mostly confined to low to middle latitudes, indicating also an oligotrophic environment; (3) *Prediscosphaera* spp., another prevailing component of the recorded calcareous nannoplankton is mainly represented by the species *P. cretacea* (Arkhangelsky) Gartner. *P. stoveri* (Perch-Nielsen) Shafik & Stradner was considered along with the Boreal taxa; (4) the Boreal taxa are represented by *Nephrolithus frequens* Górka, *Cribrosphaerella daniae* Perch-Nielsen, *Kamptnerius magnificus* Deflandre and *Prediscosphaera stoveri* – nannofosils mostly confined to high latitudes and particularly cool surface waters (Worsley and Martini, 1970).

The Santonian (the lower part of the Murfatlar Formation) is dominated by *Watznaueria barnesae* and *Micula* spp., which jointly amount to more than 50% of nannofloras. In the latest Santonian, there is an increase in the abundance of *Micula* spp (up to 35%), synchronously with the shift in abundance of *Watznaueria barnesae*. This trend continues into the upper part of the Murfatlar Formation (Early Campanian in age). There is a significant change in the nannofloral composition within the Late Campanian - earliest Maastrichtian (the Nazarcea Formation), when the abundance of *W. barnesae* reaches a peak of 40% - Figure 2. Concurrently, the abundance of genera *Micula* and *Prediscosphaera* sharply decreases. A significant fluctuation in the abundance of the calcareous nannofloras took place within the Late Maastrichtian (CC24, CC25 and CC26 Calcareous Nannoplankton Zones). It was then that the assemblages were, once again, clearly dominated by the genera Micula and Prediscosphaera, jointly amounting to more than 50% of the nannofloras. The latest Maastrichtian (upper part of the Nisipari Formation) is characterized by an increase in Boreal taxa (up to 15%), along with a decrease in *Micula* spp. and *Prediscosphaera* spp., and mostly constant values of *Watznaueria barnesae* (around 30%).

The Upper Cretaceous deposits identified in the Black Sea offshore area (within the Tandala Well) consist of chalky marlstones and claystones, as well as white chalky limestones, yielding a remarkable high calcareous nannoplankton content. More than 80 nannofloral taxa were recorded, with an average abundance of 25 taxa/field of view. The calcareous nannoplankton analyzes led to the identification of the CC20, CC21, CC22, CC23, CC24, CC25 and CC26 Calcareous Nannoplankton Zones, spanning over the late Early Campanian - latest Maastrichtian interval – Figure 3. The whole Upper Cretaceous succession identified in the Tandala Well is 95 m thick. The Campanian calcareous nannofloras are dominated by Tethyan taxa - *Ceratolithoides aculeus* (Stradner) Prins & Sissingh in Sissingh, *Quadrum sissinghi* Perch-Nielsen and *Quadrum trifidum* (Stradner *in* Stradner & Papp) Hattner & Wise, which together with the Micula and Prediscosphaera genera amount to over 60% of nannofloras. The Early Maastrichtian calcareous nannoplankton assemblages mainly consist of cosmopolitan taxa, while in the latest Maastrichtian, the Boreal nannofossils represent a significant component of the nannofloras (almost 20%).

The calcareous nannoplankton investigations yielded a continuous sedimentation, in the chalk deposits of the Tandala Well, within the Cretaceous/Tertiary boundary interval. This finding is supported by the identification of the nannofloral mass extinction within the upper part of the chalky limestones. Over 95% of the Cretaceous calcareous nannoplankton have disappeared: that bioevent was previously recorded not only in other Romanian sections across the K/T Boundary (Melinte, 1999), but also in other continuous K/T successions of the Tethyan Realm (*e.g*. Spain – Lamolda *et al*., 2005; Italy – Monechi & Thierstein, 1985; Tunisia - Gardin, 2002).

The occurrence of the nannofossil *Biantolithus sparsus* Bramlette & Martini, together with a recorded acme of *Markalius inversus* (Deflandre in Deflandre & Fert) Bramlette & Martini, led to the identification of the NP1 Calcareous Nannoplankton Zone of the Martini's Zonation (1971) - earliest Paleocene (Early Danian) in age.

Paleogene

The Paleogene deposits were encountered only in the Black Sea offshore area, in the Tandala Well.

The earliest Paleocene (Early Danian) is characterized by chalky limestone deposits, as previously described. These deposits are overlain by calcareous claystones and marlstones, interbedded with thin (cm) calcarenites (Fig. 3). The presence of the NP15, NP16, NP17, NP18, NP19, NP20 and NP21 Calcareous Nannoplankton Zones of Martini's Zonation (1971) suggest continuous sedimentation within the Middle - Late Eocene interval (corresponding to the Lutetian, Bartonian and Priabonian stages). The total thickness of the Eocene deposits is 365 m.

The quantitative calcareous nannoplankton analyzes focus on four taxonomical groups : (1) *Sphenolithus spp*., taxa confined to warm well oxygenated surface waters and open marine environments (Aubry, 1992); (2) *Discoaster spp*., nannofossils mostly confined to warm water surfaces and open-marine settings; (3) *Zygrhablithus bijugatus* Deflandre, *Lanternitus minutus* Stradner, *Orthozygus aureus* (Stradner) Bramlette & Wilcoxon and *Isthmolithus recurvus* Deflandre, holococcoliths abundant in near-shore environments (Krhovsky *et al*., 1992); (4) *Dictyococcites bisectus* (Hay, Mohler & Wade) Bukry & Percival and *Cyclicargolithus floridanus* (Roth & Hay) Bukry, cosmopolitan taxa, which proliferate remarkably under stable marine conditions, tolerating slight salinity fluctuations.

The Middle Eocene nannofloras are generally dominated by warm water taxa (the genera *Sphenolithus* and *Discoaster*), which jointly amount to 40% of nannofloras. Both the euthrophic nannofossils *Dictyococcites bisectus* and *Cyclicargolithus floridanus* represent up to 35%. Meanwhile, the abundance of the holococcoliths decreases to 10%.

The Late Eocene nannofloral abundance, recorded in the Tandala Well, is similar to that identified within the Middle Eocene deposits traversed by this drilling. A significant shift of Tethyan taxa (*Spehenolithus* and *Discoaster*) to 10% took place within the latest Eocene (Late Priabonian). The holococcoliths become significantly abundant (up to 30%), while the *D. bisectus* and *C. floridanus* jointly amount to 50% of nannofloras.

The youngest Paleogene sediments recorded in the Tandala Well are bituminous clays (160 m thick), with numerous fish remains (mainly scales). Such deposits are described in the Carpathian Domain as "dysodilic shales". Two distinct laminitic limestones (the oldest one, at the lower part of the bituminous clays, is 40 cm thick and the youngest, 30 cm thick, towards the middle part), were identified.

According to nannofloral content, the bituminous clays were assigned to the NP21 (pars), NP22, NP23, NP24, NP25, NN1 and NN2 Calcareous Nannoplankton Zones Martini's Zonation (1970), spanning the Oligocene -earliest Miocene interval (the Rupelian, Chattian, Aquitanian and Early Burdigalian stages).

The quantitative nannofloral studies focused on four taxonomical groups : (1) *Sphenolithus* spp., taxa confined to warm well oxygenated surface waters and to open marine environments; (2) *Helicosphaera* spp., nannofossils mostly related to warm surface waters and near-shore environments (Krhovský *et al*., 1992); (3) *Dictyococcites bisectus* and *Zygrhablithus bijugatus*, cosmopolitan species, frequent in near-shore environments (Krhovský *et al*., 1992), that bloom whenever the nutrient input increases (Melinte, 2005); (4) *Pontosphaera* spp., euthrophic taxa (Aubry, 1992) which proliferated under stable marine conditions and tolerated only slight salinity fluctuations.

The Eocene/Oligocene boundary interval exhibited a significant decline in the abundance of warm water nannofossils (species of *Sphenolithus* and *Discoaster*) which resulted in their disappearance. The Early Rupelian nannofloras are characterized by the dominance of cosmopolitan taxa, such as *Dictycoccites bisectus*, *Zygrablithus bijugatus* and *Cyclicargolithus floridanus*.

There was an occurrence of endemic nannofossils (restricted to the Paratethys Realm), such as *Transversopontis fibula* Gheta, *T. latus* Müller and *Reticulofenestra ornata* Müller, within the Rupelian deposits of the Tandala Well. The endemic nannofossils have a remarkable abundance amounting to over 80% of all recorded nannofloras within the oldest level of the laminitic limestone (placed at the lower part of the bituminous clays of the Tandala Well).

The warm water taxa (*Sphenolithus* spp.) reoccur in the Late Oligocene (within the Chattian stage – NP24 Nannoplankton Zone), where they represent up to 35% of nannofloras. In the upper Chattian (NP25 Calcareous Nannoplankton Zone), the total abundance of *Sphenolithus* significantly drops to 5%, to later increase to over 20% within the Oligocene/Miocene boundary interval (NN1 Nannofossil Zone). *Helicosphaera* spp. varies from 5 to 35% of calcareous nannoplankton assemblages in the Oligocene deposits traversed by the Tandala Well, with the maximum evidenced in the uppermost Chattian (NP25 Calcareous Nannoplankton Zone), and the minimum in the Rupelian, (NP23b Calcareous Nannoplankton Zone). *Dictyococcites bisectus* and *Zygrhablithus bijugatus* are also abundant in Oligocene nannofloras of the Tandala Well. The abundance of these species strongly fluctuates, from 35% (in the lower Rupelian – NP23 Calcareous Nannoplankton Zone) to 70% in the Lower Chattian (NP24 Calcareous Nannoplankton Zone), with the maximum recorded within the youngest laminitic limestone level. The lowest abundance of the genus Pontosphaera (5%) was also observed in the Lower Oligocene deposits (belonging to the NP23 Calcareous Nannoplankton Zone), while its highest percentage (30%) was recorded in the Upper Oligocene sediments (assigned to the NP25 Calcareous Nannoplankton Zone).

Neogene

The oldest Neogene deposits, traversed by the Tandala Well, are bituminous clays (Aquitanian - Early Burdigalian in age), lithologically similar to the Oligocene deposits. The earliest Miocene (Early Aquitanian) calcareous nannoplankton assemblages are characterized by strong reworkings, from Cretaceous, Eocene and Oligocene. Only 20% of the total nannofloras characterizing the NN1 Calcareous Nannofloral Zone of Martini's Scheme (1971), are *in situ*, the most common taxa being *Helicosphaera scissura*, *H. mediterranea*, *Coronocyclus nitescens*, *Cyclicargolithus floridanus*, *Sphenolithus moriformis*, *Triquetrorhabdulus carinatus*, *Coccolithus miopelagicus* and small reticulofenestrids.

The 410 m thick overlaying sequence, composed of detrital sediments, was attributed to the Middle Miocene (Lower Sarmatian), based on the identification of the NN7 and NN8 Calcareous Nannoplankton Zones (Mărunţeanu *in* Popescu *et al*., 1998).

The youngest deposits encountered within the Tandala Well, Late Miocene-Pliocene and Pleistocene-Holocene in age, are, lithologically speaking, characterized by the presence of silty clays, with frequent layers of thin calcareous sandstones. Within the Pleistocene, oolitic sandstones were deposited – Figure 3.

The entire previously described sequence yielded macrofaunas (mainly mollusks – Papaianopol *in* Popescu *et al*., 1998), as well as microfaunas (ostracods – Olteanu *in* Popescu *et al*., 1998). These lines of evidence suggest the presence of the Upper Miocene (Pontian, 560 m thick), Pliocene (Kimmerian and Kuyialnikian stages, jointly, 380 m thick) and Pleistocene-Holocene (with a thickness of 213 m).

The identification of the NN11b, NN12, NN13, NN19 and NN20 Calcareous Nannofossil Zones (reported by Mărunţeanu *in* Popescu *et al*., 1998) points to marine influxes during the latest Pontian (Late Bosphorian), Early Pliocene (Early Kimmerian), Late Pliocene (Early Kuialnikian), Early Pleistocene and Holocene.

DISCUSSION

The results obtained so far suggest a very complex depositional history and paleobiogeography of the Southern Romanian Black Sea onshore and offshore areas, during the Cretaceous-Cenozoic times.

It was assumed that a wide carbonate platform has been active in the Eastern part of the Moesian Platform (including the present onshore and offshore areas of the Black Sea Southern Area) since Late Jurassic (Avram *et al*., 1996; Georgescu, 1997; Ion *et al*., 2001). The data presented herein confirms a shallow marine carbonate sedimentation spanning over the latest Jurassic (Tithonian) – earliest Cretaceous (Berriasian – Valanginian – early Hauterivian) interval.

The deposition of the Cernavoda Formation indicates a coastal marine environment in the Eastern part of Southern Dobrogea (the Alimanu Member) and mixed marginal marine and brackish water in its Western part (the sedimentation of the Amara Member). Oligotrophic conditions were established on the water surface during the latest Tithonian – Berriasian – early Valanginian interval, as indicated by the high percentage of *Nannoconus* species, among the nannofloral assemblages. Since this genus seemed to proliferate, during the Early Cretaceous, in the photic zone of the Tethys Ocean (Erba, 1994; Bersezio *et al*., 2002), a high temperature of surface waters, associated with a low fertility of the planktonic organisms, would have existed. The presence of Boreal nannofossils (normally confined to cold water and high latitudes) could be indicative of a Late Valanginian sea-level rise in the investigated area. Also, the Boreal taxa appear together with a significant increase in *Biscutum constans* and *Zygodiscus erectus* (both indicating high fertility conditions at surface waters and upwelling of cooler waters). These biostratigraphical patterns reflect surface water oligotrophic (and stable) conditions within the Tithonian-Early Valanginian interval and eutrophic (and more unstable) ones, during the Late Valanginian interval.

The next sedimentary cycle, observed in the investigated drillings from the Romanian Black Sea onshore and offshore areas, is represented by Upper Barremian - Lower Aptian sediments of the Ramadan Formation, deposited in a marginal marine setting. In the Eastern part of the investigated area (SE part of Southern Dobrogea and Southern Romanian Black Sea offshore area), the Late Barremian - Early Aptian deposits are reefal limestones and calcarenites with orbitolinids, a sedimentation typical of the Urgonian Facies of the Tethys Realm. The Late Barremian surface waters are characterized by high temperature and low fertility, as proved by the remarkable abundance of the Tethyan genus *Nannoconus*. Pronounced shifts of low latitude nannofossils (e.g. *Nannoconus* spp., C*onusphaera* spp. and *Assipetra* spp.) were recorded in two distinct intervals (the latest Barremian and the earliest Aptian). These bioevents, synchronous with a significant increase in high latitude taxa in the nannofloral associations, could be indicative of cooler periods, leading to an instability in the Tethyan ecosystems, and to the occurrence of new, mostly cosmopolitan species.

During the same interval (Late Barremian - Early Aptian), the NW part of the investigated area was occupied by coastal marine sediments – mainly variegated (red, green and gray) clays and sandstones, interbedded with thin conglomerates, indicating a detrital littoral facies.

The next depositional sequence (Middle - Late Aptian), observed in the onshore drillings only, is the Gherghina Formation, accumulated under fluviatile-lacustrine conditions (as proved by its charophyte content). The multicoloured clays of the Gherghina Formation contain a high percentage of kaolinite, among other clay minerals. Its source area (still preserved in North-Dobrogea), is a pre-Cenomanian lateritic weathering crust (Rădan, 1989).

The next sedimentary cycle is Late Cretaceous in age (chalks covering the Santonian *pro parte* - Maastrichtian interval in the onshore drillings and the Campanian - earliest Paleocene interval in the offshore drilling). The chalk deposition indicates an offshore sedimentation.

Furthermore, the marine Albian, Cenomanian and Turonian deposits, exposed in outcrops in Southern Dobrogea, were not identified in the studied drillings.

The NE end of the investigated onshore area accumulated, during the Late Campanian - earliest Maastrichtian interval, continental-lacustrine deposits (mainly variegated clays with charophytes – Ion *et al*., 1998). Presumably, during that time, the Nazarcea-Nisipari area of Southern Dobrogea was an emerged land.

Both in the Southern Romanian Black Sea offshore sector, as well as in the central and SE part of Southern Dobrogea, the Santonian – Late Campanian interval is characterized by abundance and diversity of well preserved calcareous nannoplankton. Within the above-mentioned interval, a high abundance of *Micula* taxa is related to the oligotrophic water surface conditions, exhibiting a stable and warm marine environment. The peak of abundance and diversity of Tethyan taxa (including *Micula* spp., *Quadrum trifidum*, *Q. sissinghi* and *Ceratolithoides aculeus*) occured within the latest Campanian, which could be regarded as the warmest Upper Cretaceous interval in the investigated area.

Notably, the Late Cretaceous climate seems to have been equally warm in both hemispheres, with very low latitudinal gradients (Barron, 1983). But, based on identified calcareous nannoplankton associations from the Southern Romanian Black Sea onshore and offshore areas, two significant cooler phases were identified in the Upper Cretaceous: the oldest within the Early Maastrichtian and the youngest within the latest Maastrichtian. This assumption is made on the dramatic changes of recorded nannofloras: the shift of Tethyan taxa, occuring with assemblages of the taxa normally confined to high latitudes (Boreal species). These facts led to the conclusion that the end of the Cretaceous was already an instable time-span, characterized by rapid changes in marine ecosystems, increasingly eutrophic conditions and particularly cool surface waters.

The Cretaceous sedimentation ends (in the area covered by the onshore drillings) in the latest Maastrichtian. In the Tandala offshore drilling, an apparent continuity was recorded, within the Cretaceous/Tertiary boundary interval, based on micropalaeontological evidences. These are the mass extinctions of Cretaceous foraminifers and nannofloras (Popescu *et al*., 1998), followed by the blooms of calcareous dinoflagellate genus *Thoracosphaera* and of the nannofossil *Braarudosphaera bigelowii*, indicating strong salinity fluctuations. In the investigated offshore drilling there was no trace of the lithological signature of the K/T boundary (*e.g.* ejecta layer, Iridium fallout laminae, microtektites, etc.)

The Upper Cretaceous chalk deposits are overlain, in the Tandala, by Eocene sediments. A marine sequence was recorded within the Middle Eocene (Lutetian) – Early Miocene (Burdigalian) interval in the studied drilling from the Black Sea offshore area.

The Eocene sediments are characterized by a carbonate-rich deposition, related to a shallow shelf environment. It is to be assumed that during the Middle - Late Eocene interval there were warm, well oxygenated surface waters, as indicated by the high frequency of Tethyan nannofloral genera *Discoaster* and *Sphenolithus*, recorded in the studied cores. The progressive shift of warm calcareous nannoplankton taxa, along with the increase in cosmopolitan and mostly eutrophic ones, reflected the climatic deterioration (*i.e.,*progressive cooling) towards the end of the Eocene.

A sharp change in sedimentation was identified in the Tandala Well within the Early Oligocene (Rupelian), the carbonate-rich sediments being replaced by a bituminous clay deposition, probably related to an outer shelf environment. This event is synchronous with a marked global cooling (Savin, 1977; Jovane *et al.*, 2004), as well as with the first separation of the Paratethys Domain (including the present-day Romanian territory) from the Mediterranean Realm (Rusu, 1988; Rögl, 1998).

The Early Oligocene calcareous nannofloral assemblages of the Tandala Well reflected these paleoclimatic and palaeogeographical changes: endemic taxa occurred together with cosmopolitan ones, while the typical Tethyan species vanished. There was high productivity in the surface waters and low oxygen levels in the bottom waters. The Early Rupelian laminitic coccolithic limestones, contain blooms of endemic taxa, as well as of *Braarudosphaera bigelowii*, suggesting a strong decrease in the salinity. Notably, the youngest laminitic coccolithic limestone identified in the Chattian deposits of the Tandala Well contains only blooms of cosmopolitan nannofloras; no endemic taxon was recorded. These facts support a re-connection between the semi-isolated Paratethys basin with the Mediterranean one, within the Late Oligocene. The re-occurrence of the Tethyan taxa, during the same interval, also suggests a warmer period, more stable environmental conditions and probably a higher amount of nutrients at surface waters. These features persist into the earliest Miocene (Aquitanian - Early Burdigalian).

In the Tandala Well, the earliest Miocene sediments are overlain by Middle Miocene (Lower Sarmatian) detrital deposits of an inner shelf. In the Volhinian outcrops of Southern Dobrogea, levels with marine faunas (Ionesi & Ionesi, 1973) and nannofloras are interbedded with brackish faunal levels, indicating strong salinity fluctuations in the Central Paratethys semi-enclosed basin (including the investigated area) and/or several sea-level changes.

The Middle Miocene deposits are followed, in the Tandala Well, by Upper Miocene sediments. All the substages of the Pontian (namely, Odessian, Portafferian and Bosphorian) were separated based on ostracod communities (Olteanu *in* Popescu *et al*., 1998).

The faunal associations indicate prevailing brackish conditions during the Late Miocene, but short marine influxes are present within the Late Pontian (Bosphorian- NN11b Calcareous Nannoplankton Zone, Mărunțeanu *in* Popescu *et al*., 1998). Some authors (Tătărâm *et al*., 1977; Ion *et al*., 2005) consider that the entire Southern Romanian Black Sea onshore and offshore was an emerged land during Pontian times. Moreover, the Dobrogea seems to be a source (a minor one, the main being the Carpathian Domain) of Pontian sediments for the Dacian Basin (Jipa, 2005).

The Pliocene deposits traversed by the Tandala Well onshore are characterized by a continental sedimentation, with minor brackish episodes (Popescu *et al*., 1998). An important change in the sedimentary regime took place within the Pliocene/Pleistocene boundary interval, when the fresh-waters of the Kuyialnikian were replaced, in the Black Sea basin, by a dominant marine Quaternary deposition (Wong *et al*., 1994, Panin, 1997), characterized by very high sedimentation rate (Panin *et al.*, 2005). Brackish marine episodes within the Middle Holocene of the NW Black Sea (where monospecific nannofloral assemblages with *Braarudsophaera bigelowii*) were reported (Oaie *et al*., 2005).

An important transgression took place during the Late Holocene (Olteanu, 2005), marine faunas and floras being recorded in the Tandala Well sediments.

CONCLUSIONS

The Late Jurassic (Tithonian) to Neogene history of the Southern Romanian Black Sea onshore and offshore reflects multiple depositional episodes of different sedimentological regimes, separated by several hiatuses of varying duration. These hiatuses may reflect periods of slow deposition and/or erosion.

- The oldest sedimentary sequence recovered by the studied drillings is latest Jurassic (Tithonian) - earliest Cretaceous (Berriasian - Valanginian) in age. This sequence is followed by a hiatus of more than 15 MA.
- The next depositional cycle, in stratigraphic order, is Late Barremian - Early Aptian in age.
- A hiatus of around 45 MA was evidenced in the studied drilling of the offshore Black Sea area, covering the Early Aptian - Early Campanian interval.
- In the onshore area, after a shorter hiatus (up to 10 MA), a fluvial-lacustrine formation was deposited, within the Middle - Late Aptian interval.
- The Upper Cretaceous sequence covers the Campanian – Earliest Paleocene interval on the offshore drilling and the Santonian - latest Maastrichtian interval.
- In the offshore area, a hiatus, of around 13 MA (earliest Paleocene – Middle Eocene) was pointed out, while in the offshore zone, a hiatus of more than 10 MA (Early Miocene - Middle Miocene) was recognized.
- The next sequence is represented by the Middle Miocene (Lower Sarmatian).
- Offshore, a hiatus up to 4 MA follows.
- The youngest sequence identified (in the offshore Tandala Well) covers the Upper Miocene (Pontian) – Quaternary interval.

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