LITHO- AND BIOSTRATIGRAPHY OF THE EOCENE DEPOSITS FROM ISTRIA BASIN NORTHERN EDGE (WESTERN BLACK SEA)

Eliza M. ANTON[1,2], Ioan MUNTEANU[3], Corneliu DINU[2], Mihaela C. MELINTE-DOBRINESCU[1]

[1]*National Institute of Marine Geology and Geo-Ecology (GeoEcoMar), 23-25 Dimitrie Onciul St., 024053 Bucharest, Romania*
e-mail: antoneliza@geoecomar.ro
[2]*University of Bucharest, Faculty of Geology and Geophysics, Traian Vuia 6, Bucharest, Romania*
[3]*Repsol S.A., UK Exploration team, Mendez Alvaro 44, Madrid, Spain*

Abstract. This study aims to bring new constraints on the Eocene stratigraphy of the northern edge of Istria Basin, located in Western Black Sea. For achieving our goal, we have studied several core reports containing the description of the lithology and microfossils assemblages (foraminifera, ostracods and calcareous nannofossils) from 3 wells drilled in the northern Istria Basin. Thus, we were able to identify lithological and biostratigraphic constraints, allowing to generate a coherent correlation scheme for the Eocene deposits, with precise age assignment and advanced models of the IB evolution during the Eocene. The lithology of the 3 wells, situated in the Sinoe, Lebăda West and Lebăda East areas, is mainly represented by calcareous sandstones and siliciclastic ones. The biostratigraphy indicates that the deposits of the Sinoe and Lebăda West wells are Middle Eocene in age (mostly the upper part), while in the Lebăda East well a late Early to Middle Eocene age was assigned.

Key words: Western Black Sea Basin; Palaeogene; wells; calcareous nannofossils; foraminifera

1. INTRODUCTION

The change of palaeoenvironment settings during a basin history is a common fact. In turn, the basin evolution is related to different tectonic forces that created, developed and finally closed it (Allen & Allen, 2005). After its closure, as the tectonic forces disappeared, only the deformed basin fill and associated structures remains. Therefore, the basin fill analysis provides useful lithostratigraphic information, as the lithology can be deducted from wells and extrapolated on seismic data. The age of different lithological units, is commonly based on biostratigraphic elements and/or sequence stratigraphy models for basin wide age propagation, allowing a proper understanding of its kinematics from creation to closure. The macro- and micropalaeontologic contents usually reflect the palaeoenvironment settings and any changes, such as salinity, temperature and nutrient input, affected the faunas and floras during geological time. The accurate identification of fossil assemblages are very useful in the age assignment and paleoenvironmental reconstruction. In a long run, deciphering the biostratigraphy is essential in elaborating the scenario of the basin evolution in different tectonic regimes. These principles may be successfully applied to any basin analysis as is the case for Istria Basin (IB), a sub-basin located in the Western Black Sea Basin (WBSB) (Fig. 1).

The IB opened during the Early Cretaceous (Barremian-Albian), extended within the Late Cretaceous-Early Eocene interval and inverted during the Middle Eocene-Miocene (Fig. 2) (Görür, 1988, 1997; Nikishin *et al.*, 2003, 2015; Hippolyte *et al.* 2010; Munteanu *et al.*, 2011). Hence, the Eocene deposits of the IB recorded the transition from extension to compression of the WBSB and provide useful keys for deciphering the basin evolution, including palaeoenvironmental and palaeogeographic settings. The IB sedimentary filling comprises a Cretaceous-Cenozoic successions, mirroring a polyphase deposition and subsidence (Boote, 2017). Main geological events of this sub-basin are represented by the Barremian-Albian rifting, major incisions caused by tectonic inversion within the Eocene-Oligocene boundary and also in the Middle and Late Miocene (Dinu *et al.* 2005; Boote, 2017).

We focus in this paper on the litho- and biostratigraphy of the Eocene sediments, encountered in most of the offshore hydrocarbon bearing structures, from the Romanian shelf with some noticeable examples, like Lotus, Sinoe (some of the wells), Lebăda, Pescăruş (some of the wells), Egreta and Orion areas (Ionescu, 2000; Ionescu, 2006). These basins contain important evidence about the IB development during the Eocene times (Fig. 1). Since the last decades, significant stratigraphic thick and widespread Eocene sediments were identified based on the drilling data (cuttings, cores and petrophysical log signatures) and seismic lines. In the northern edge of the IB, the Eocene deposits are very well developed and sometimes reach almost 2,000 m stratigraphic thickness (Ionescu, 2002).

2. GEOLOGICAL SETTING

The IB, as part of the WBSB (Fig. 1), developed starting since the Early Cretaceous, when the extensional opening of the Western Black Sea back-arc basin took place, in the overall subduction of the Neotethys Ocean under the Anatolian plate (Yilmaz *et al.*, 1997; Okay & Tüysüz, 1999). The exact age of WBSB opening is still uncertain, however on the Romanian shelf there are arguments for a Barremian age of the initial opening, with a well-established continental rifting during the Aptian and an oceanic phase in the Albian (Görür, 1988; Ţambrea, 2007; Munteanu *et al.*, 2011).

The WBSB rifting and expansion continued during the Late Cretaceous; an oceanic crust already formed in the centre of the WBSB and a passive margin of the previous extended areas developed (Belousov *et al.*, 1988; Nikishin *et al.*, 2015). For the WBSB, the extensional phase continued up to the Middle Eocene (Munteanu *et al.*, 2011), involving not only the central part of the basin, but also reactivating former Cretaceous basins, like Lebăda-Heracleea and Delfin half-

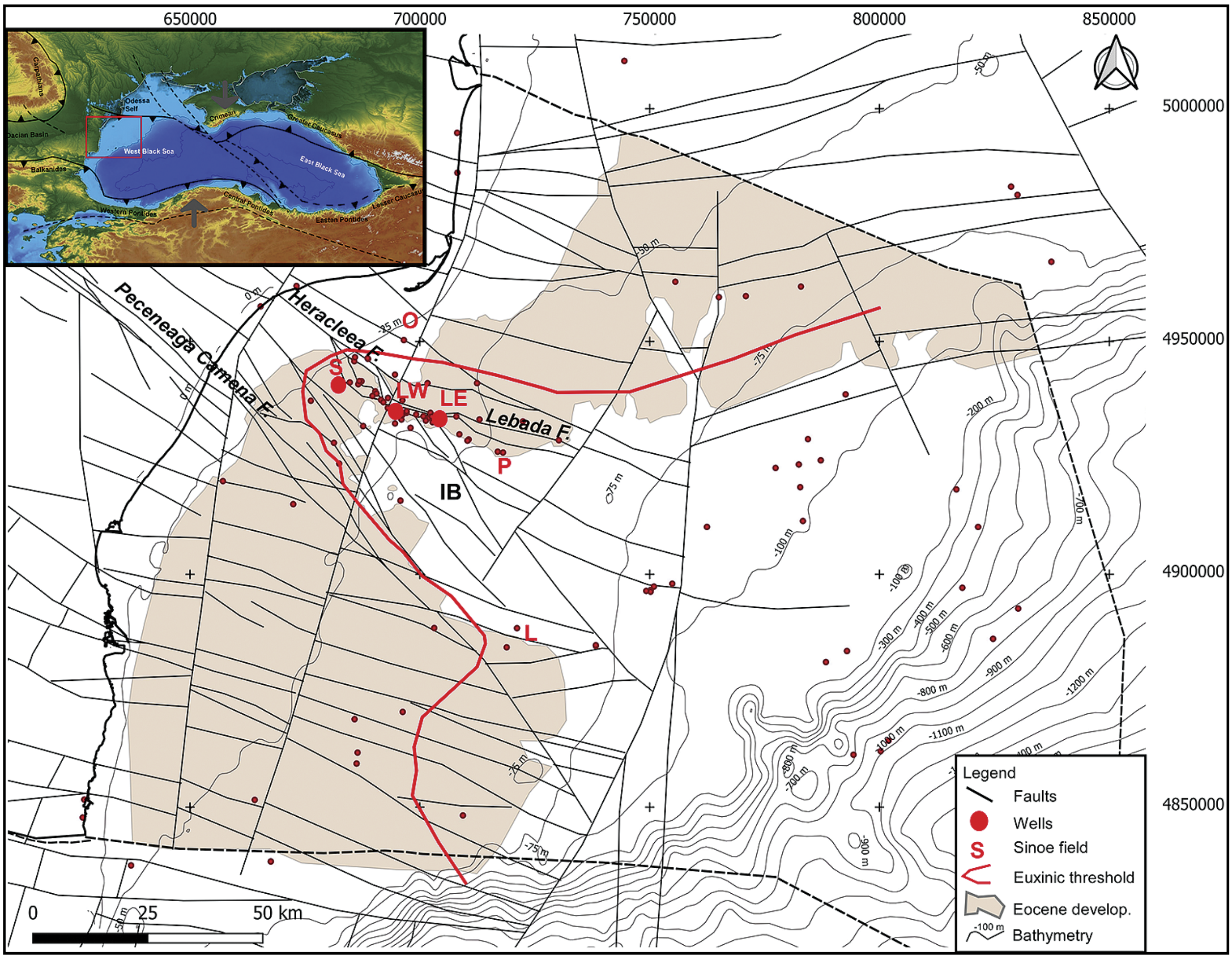

Fig. 1. Tectonic map of the Romanian Black Sea shelf (adapted from Dinu *et al.*, 2005; Munteanu *et al.*, 2011). The Eocene deposits distribution was adapted from Ţambrea (2007), Ţambrea *et al.*, 2002 and interpretation given herein. Inset tectonic sketch of the Western Black Sea region after Munteanu, 2012. Istria Basin (contour with red line) includes structures names: L - Lotus, LE - Lebăda East, LW - Lebăda West, O - Orion, P - Pescăruş, S - Sinoe. Bathymetry from GEBCO.

grabens (Ionescu, 2000; Dinu *et al.*, 2005; Krezsek *et al.*, 2017). In the Middle Eocene, the entire WBSB margin was inverted, due to the collision of the Taurides and Pontides in the south (Okay *et al.*, 1994). The far field transfer of collisional stresses, from Pontides into the WBSB back-arc, generated a coherent fold and trust belt, involving the Lebăda-Heracleea thrust, which constituted the border faults of the IB (Figs. 1 and 2, see also Munteanu *et al.*, 2011). The ongoing compression shaped the WBSB until the Middle Miocene times (Sarmatian *s.l.* - regional stage of Eastern Paratethyan domain) and, afterwards, the rapid sinking of the central part of the basin triggered a large-scale shelf progradation (Dinu *et al.*, 2005).

The current distribution of Eocene deposits along the Romanian Black Sea shelf is controlled by lateral continuation of several prograding sequences and the localized erosion of the shelf edge (Fig 2). This erosion incised deep into pre-existing strata, especially in the IB (Ţambrea *et al.*, 2002). Within the earliest Oligocene (in the lower part of the Rupelian stage), a large-scale foredeep type erosion has been subsequently enhanced (Ionescu, 2000; Dinu *et al.*, 2005). Hence, an isolation of the Black Sea basin is hypothesized, mirroring the appearance of compressional related fold and thrust belt barriers, *i.e.*, the Balkanides-Pontides and Crimea-Caucasus ones (Fig. 1).

The aforementioned belts blocked the communication between the Black Sea and the open ocean, leading to the formation of the Oligocene to Miocene Maykop anoxic sedimentation, characteristically for the Eastern Parathetyan domain (Popov *et al.*, 1993 and 2004; Vincent *et al.*, 2007; Munteanu, 2012). The origin of this unconformity has generated a long debate. However, the most recent studies (Munteanu *et al.*, 2011) linked it to the general inversion of the Black Sea that affected the previous extensional structures, such as IB.

The IB sedimentary cover is composed by the following major lithostratigraphic units, categorized according to the Barremian-Albian opening phase (after Ionescu, 2000; Ţambrea *et al.*, 2002; Ţambrea, 2007; Dinu *et al.*, 2005; Munteanu *et al.*, 2011):

- Pre-rift: Lower Triassic volcanic breccias, andesites and basalts; bioclastic limestones from Middle Triassic; bioclastic limestones from Upper Triassic; Middle Jurassic black argillites; Berriasian-Valanginian coarse sandstones, greywackes, marls and black shales;
- Syn-rift: Barremian-Aptian calcareous; quartzose and lithic sandstones, lower Albian sandstones and conglomerates with limestone intercalations, upper Albian with greywacke and lithic sandstones, and Cenomanian marls and sandy marls;
- Post-rift: Turonian bioclastic limestones and marls, Coniacian – Santonian limestones and calcareous sandstones, Campanian compact bioclastic limestones, Maastrichtian bioclastic limestones, Eocene alternating calcareous, quartzose and lithic sandstones, Oligocene bituminous shales (Maykopian anoxic facies), Badenian-Sarmatian bioclastic limestones and marls, Pontian shales, Dacian sandy marls and sands, Upper Pliocene to Quaternary unconsolidated sands and gravels. From the Upper Cretaceous (*i.e.*, the Turonian stage) onwards, the IB functions as a passive margin. This is due to the fact that the local extensional phase ended.

According to Ionescu (2000), the IB represented a high subsiding basin where only the Eocene deposits surpass 1500 m in stratigraphic thickness. Well contoured prograding shelves bordered the south-west, west and northern areas of this basin. Ionescu (2000) has separated for Eocene sequence two main facies types: carbonate and argillaceous-carbonate.

The carbonate facies consists of grey, compact, micritic, argillaceous limestones with transition to grey, siltic and sandy marlstones. The marlstones are more frequent at the base of the Eocene sequences. Microscopic analysis on thin sections revealed varied content in bioclasts, either diagenized or silicified.

The carbonate facies can also be encountered onshore Black Sea (in the South Dobrogea region, eastern part of the Moesian Platform), according to Bombiţă (1963), but with more proximal characteristics. In the Bulgarian offshore, the Eocene is made by grey-white marlstones alternating with white, sandy, glauconitic and nummulitic limestones (synthesis in Georgiev, 2012).

The second facies distinguished by Ionescu (2000), namely, the carbonate-argillaceous one is characterised by considerably reduced thickness (~200 m), with a large spatial distribution. Lithologically, it is represented by grey, greenish and blackish, compact, calcareous mudstones. Microscopic analysis from core and cuttings reports highlighted the presence of calcareous and siliceous diagenized bioclasts, glauconite and pyrite aggregates or disseminated, organic matter. The argillaceous-carbonate facies is common for Upper Eocene.

3. MATERIALS AND METHODS

Our data are based on the information gathered from 3 boreholes drilled for hydrocarbons in the IB, distributed in Sinoe, Lebăda West and Lebăda East areas, on the Romanian offshore (Fig. 1). They provided significant lithostratigraphic information, especially due to the availability of the 29 core reports. They are dating from the last three decades of the previous century, were created by DGAPG – ICPPG Campina, currently belonging to NAMR (Romanian National Agency of Mineral Resources) and were provided by OMV PETROM S.A. Company. The reports contain detailed written macroscopic and microscopic observations, representing the key pins for our study. Beside the core reports, we have integrated the cuttings descriptions and the master log information, in order to generate a lithostratigraphic column for each of the three wells, with a focus on the Eocene deposits (Figs.3 - 7). We have used for describing the Eocene lithology Folk (1974) and Tucker (2001) sedimentary rock classifications. Therefore, all the information was updated to the newest terminology and reinterpreted.

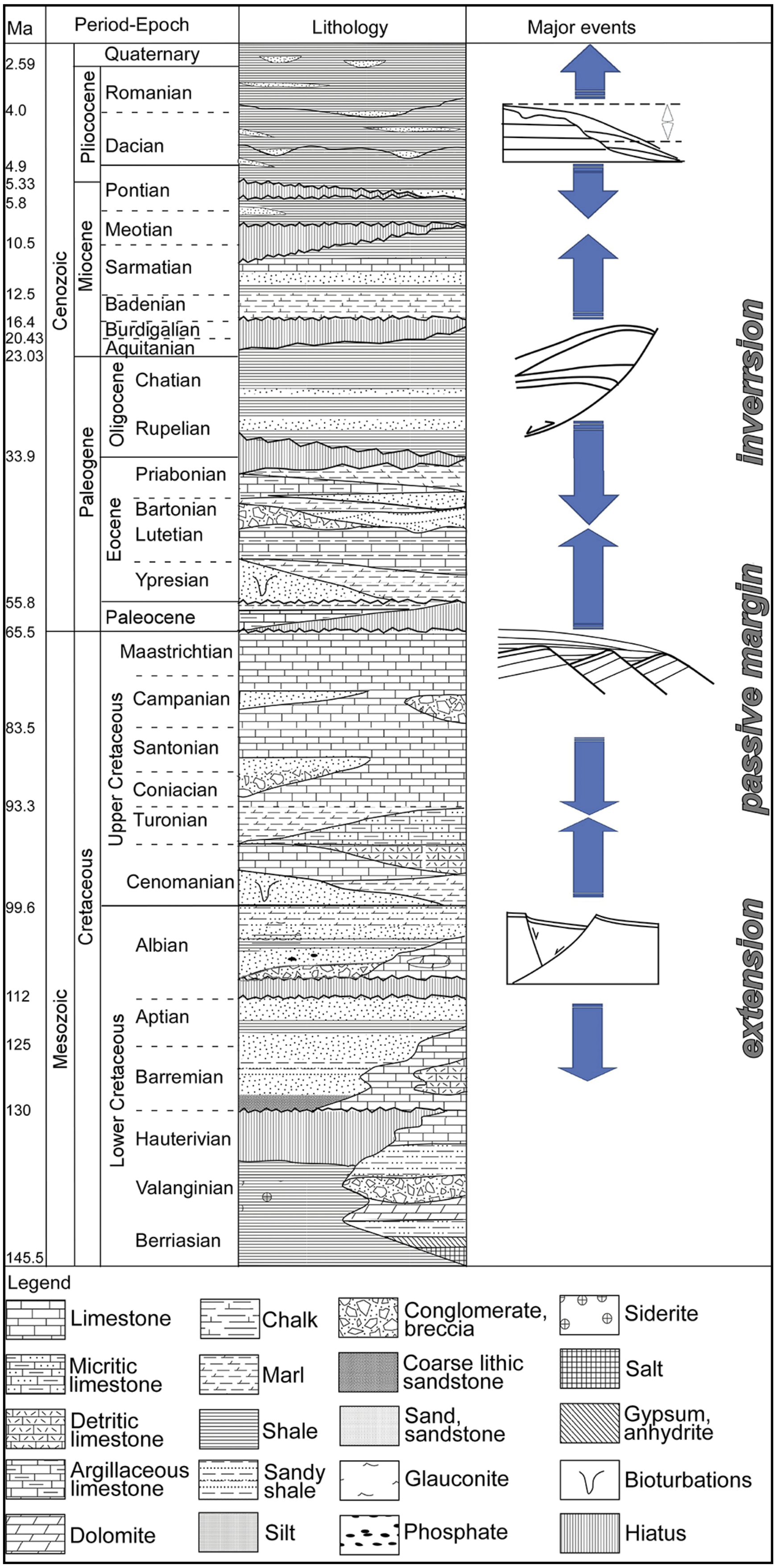

Fig. 2. Tectono-stratigraphic chart of the Romanian Black Sea shelf (adapted from Dinu *et al.*, 2005; Munteanu *et al.*, 2011).

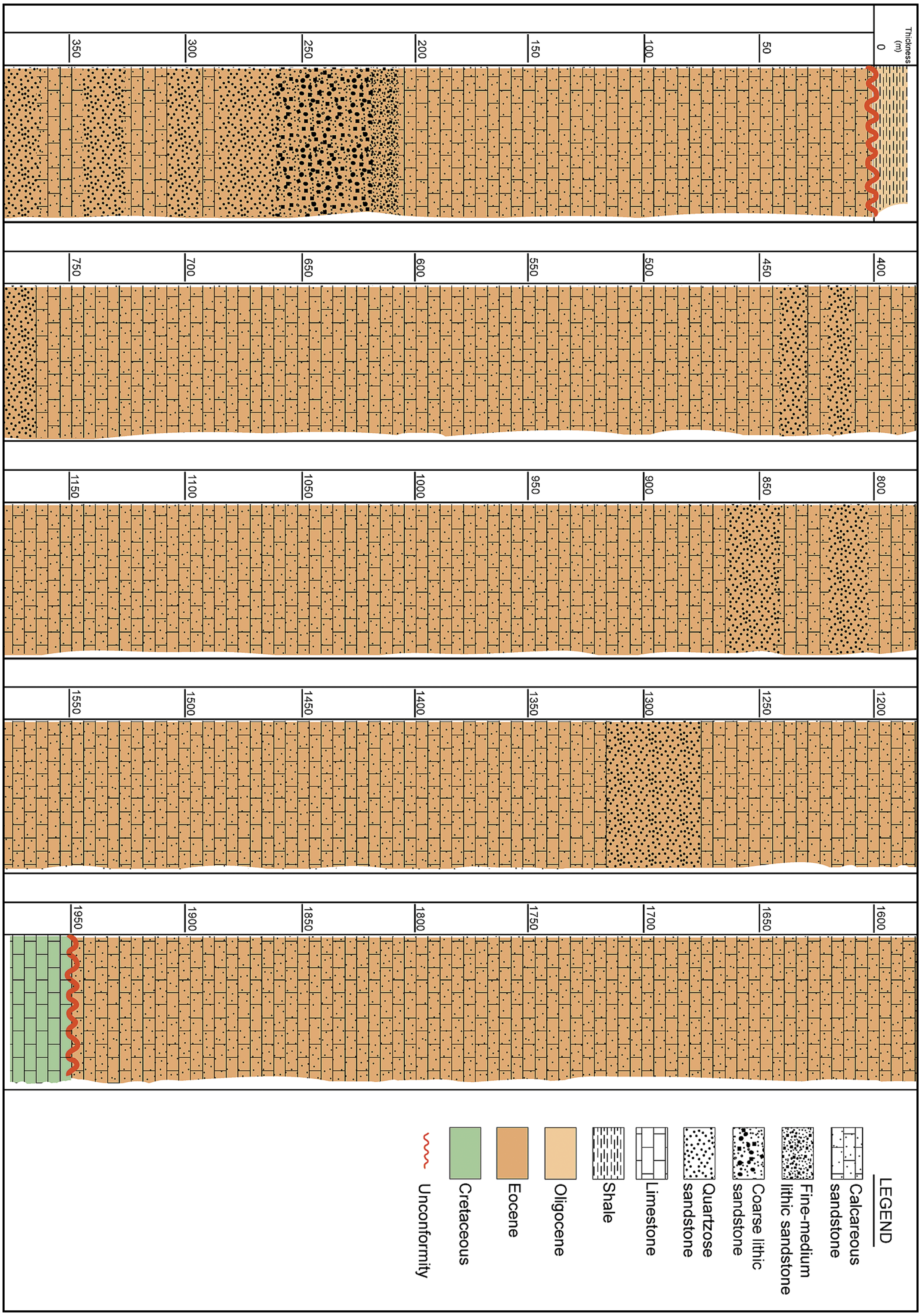

Fig. 3. Lithology of the Sinoe well based on the well logging data, mechanical cores and cuttings reports. The thickness of Eocene succession starts with 0 m at the base Oligocene unconformity.

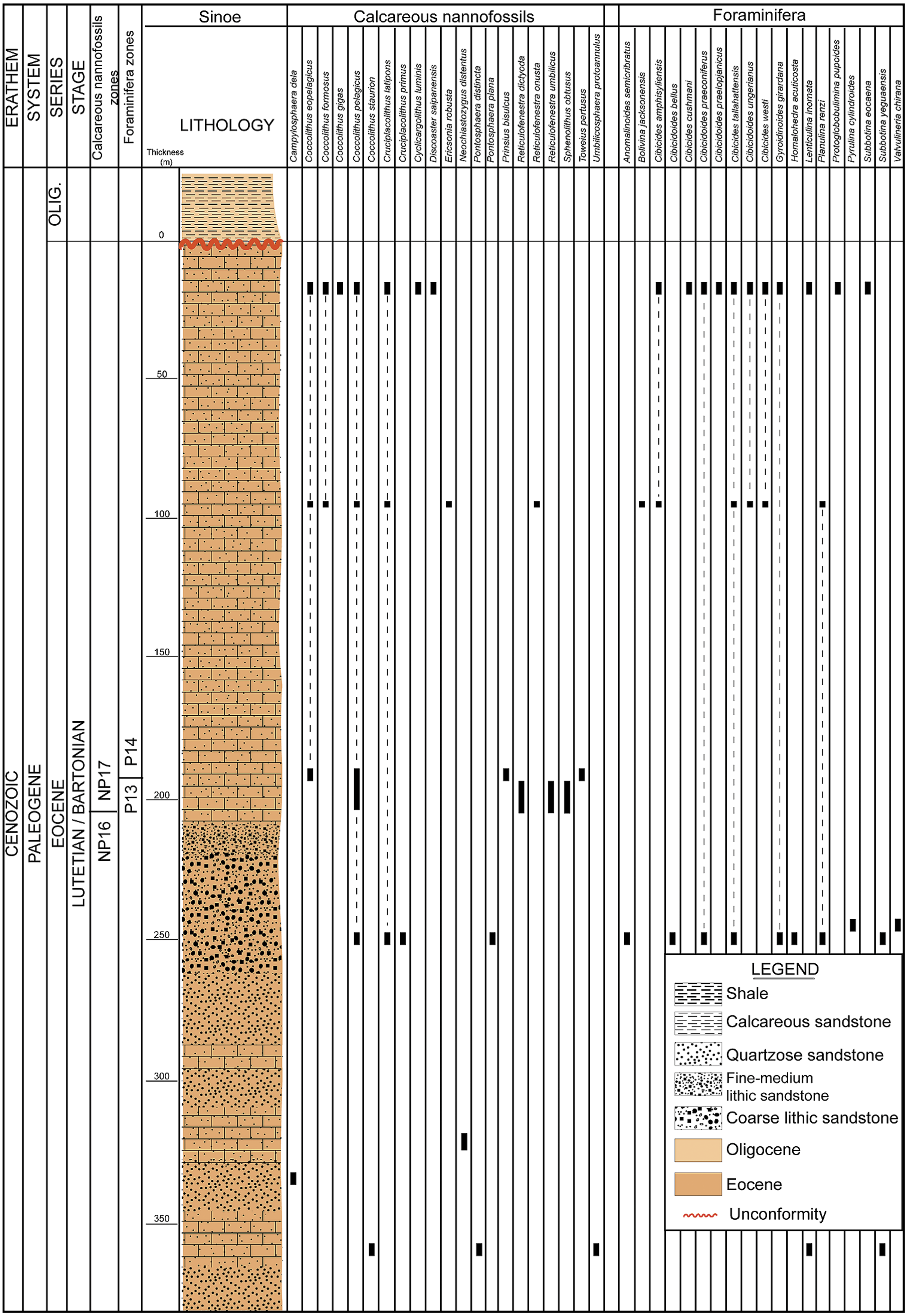

Fig. 4. Lithostratigraphy and biostratigraphy based on calcareous nannofossils and foraminifera of the Sinoe well.

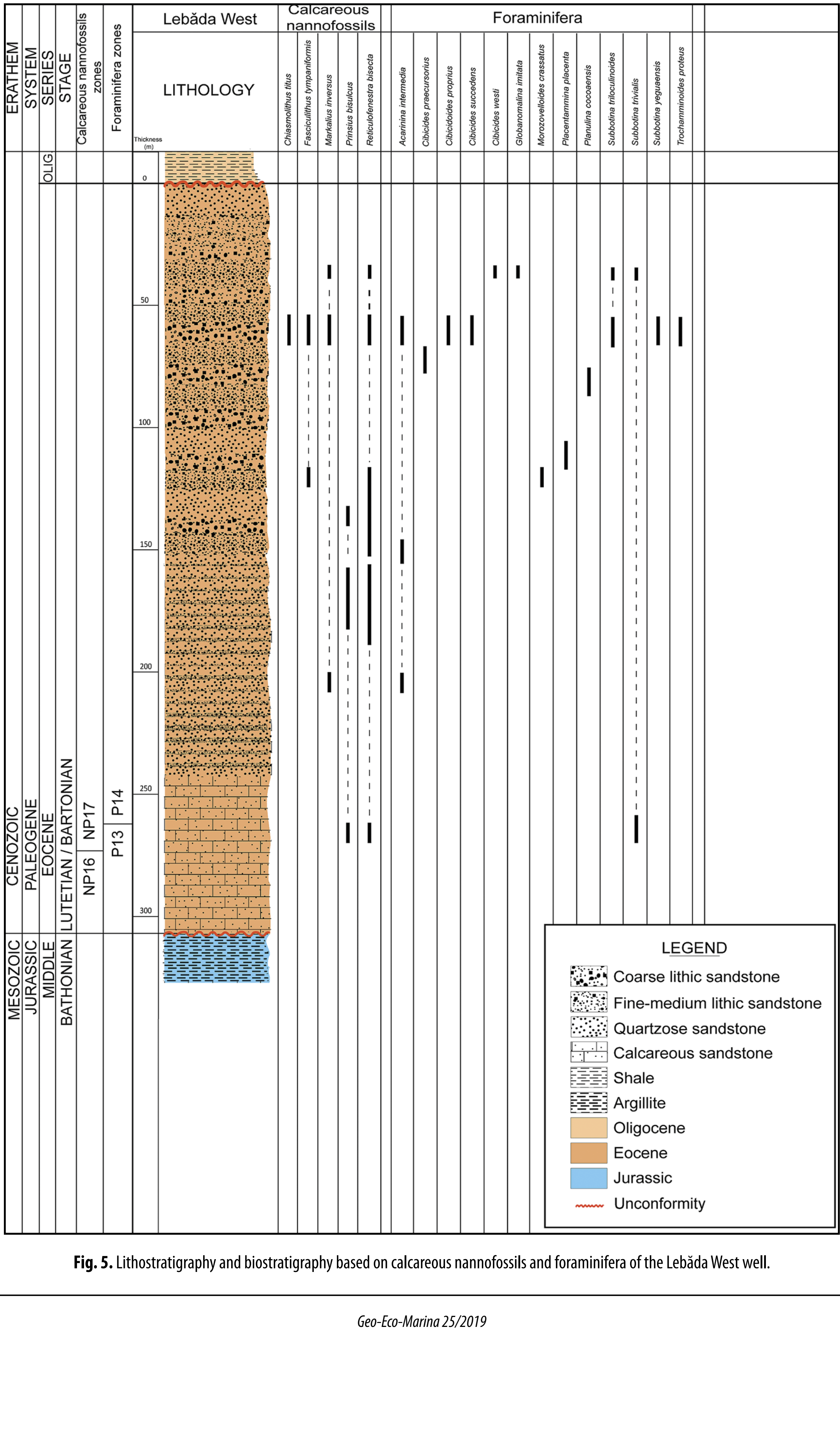

Fig. 5. Lithostratigraphy and biostratigraphy based on calcareous nannofossils and foraminifera of the Lebăda West well.

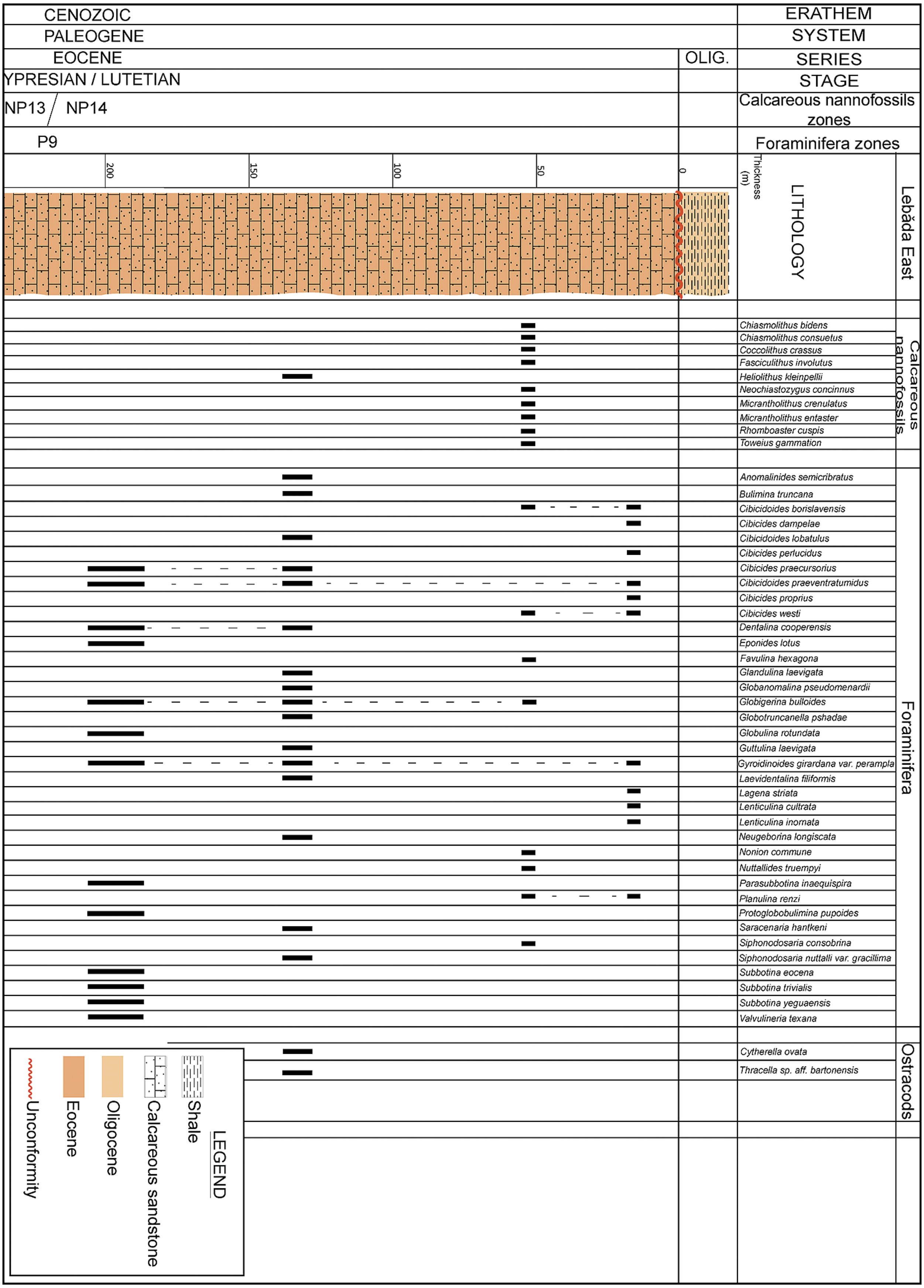

Fig. 6. Lithostratigraphy and biostratigraphy based on calcareous nannofossils and foraminifera of the Lebăda East well.

Regarding the biostratigraphy, though many reports are very old, we have updated the taxonomy according with works of Blow (1969); Berggren & van Couvering (1974), Tourmakine & Luterbacher (1985), Bolli (1985), Chaisson & Pearson (1997) and Wade *et al.* (2011) for planktonic foraminifera, Bindiu (2013) and Kaminski *et al.* (2006) for agglutinated foraminifera and Holbourn *et al.* (2013) for benthic foraminifera. The biostratigraphy based on planktonic foraminifera follows herein two different biozonations. We have selected: (i) the Atlantic Paleogene P-biozones established by Blow (1969, 1979) and also used by Kennet & Srinivasan (1983), Berggren *et al.* (1995), Chaisson & Pearson (1997) and Pearson & Chaisson (1997) and (ii) the Atlantic E-biozones for Eocene and O-biozones for Oligocene which were compiled by Berggren *et al.* (1995), Pearson & Berggren (2006) and Wade *et al.* (2011).

For calcareous nannofossils, we followed the taxonomic concepts of Perch-Nielsen (1985) and for biostratigraphy NP (Nannoplankton Paleogene) zones of Martini (1971). Supplementary data regarding the calcareous nannofossils taxonomy were taken from www.mikrotax.org. Biostratigraphy and absolute ages follow also Agnini *et al.* (2006) and Gradstein *et al.* (2012).

4. LITHOSTRATIGRAPHY

The core reports allowed us to compile lithostratigraphic columns for the Eocene sedimentary successions from IB (Figs. 3-7). The Eocene lithologic successions show a large spatial and temporal variability (Ţambrea *et al.*, 2002). Since this variability is important for understanding the IB sedimentological evolution, a detailed description of the three main depocenters, Sinoe, Lebăda West and Lebăda East is given below and synthetized in lithostratigraphic columns (Figs. 3-7).

The overall lithology is defined by sandstones with thin intercalations of shales and limestones. In this study, we grouped the sandstones in four main lithotypes: fine to medium lithic, coarse lithic, calcareous and quartzose (Figs. 3-7). For consistency with previous published studies, we use the "calcareous sandstones" term to describe sandstones with high calcareous clast content and bioclasts (for example, the lithology description of Lebăda East well).

4.1. Sinoe well lithology

In the Sinoe area, thick Eocene deposits are discordantly disposed on Cretaceous sediments and are overlain by Oligocene ones (Fig. 3). The most complete Eocene successions in all 3 investigated boreholes belong to this area. The Eocene deposits reach approximately 2,000 m in stratigraphic thickness in the investigated well, but the apparent strata dipping varies from 5 to 10° and our description is based on this apparent thickness.

Based to the core descriptions, several lithological successions were identified, as follows (older first): (i) The lowermost part of the Eocene succession (620 m thick) is made by grey to light grey, fine-grained, compact, calcareous sandstones with splintery fracture containing also very fine laminae of argillaceous material; (ii) The above-mentioned succession is covered by 46 m of quartzose sandstones. In the rock mass there are frequently diagenized calcareous and siliceous organisms; the rock cement is constituted from micrite, contaminated with argillaceous material; (iii) Upwards, 430 m of thick grey, fine grained, well cemented, calcareous sandstones occur (affected by random oriented fissures filled with calcite crystals and pigmented by glauconite); (iv) The next succession is made by 78 m of alternating grey, calcareous sandstones and dm-thick grey, quartzose sandstones; (v) Above, 309 m of calcareous sandstone were deposited; (vi) The following 220m are made by alternating calcareous sandstones and quartzose sandstones; (vii) The next 43 m are represented by coarse lithic sandstones, poorly sorted, with white, grey and black, rounded quartz grains, alkaline and plagioclase feldspars, chlorite, rare zircon, as well as quartzites, igneous rocks, porphyres and limestone fragments; (viii) The uppermost succession (207m) is constituted from calcareous sandstones.

4.2. Lebăda West well lithology

In the Lebăda West well, the Eocene deposits are discordantly disposed over the Middle Jurassic argillites and are covered by Oligocene bituminous shales. The total thickness of the Eocene sediments reaches 306 m (Fig. 5).

The following lithology was identified based on core description (older first): (i) The oldest 60 m are composed of grey to light grey, fine-grained, compact, calcareous sandstones; (ii)The following 80 m are represented by thick grey, medium to coarse grained, well cemented, quartzose sandstones with intercalated thin layers of coarse-grained coarse lithic sandstones that contain clasts of shales and limestones in a carbonate matrix; (iii) The next interval is dominated by 166 m thick alternating of coarse-grained lithic sandstones and quartzose sandstones.

In all the investigated core reports of the Lebăda West well, the sandstones are described as having a micritic cement. However, according with the classification of Folk (1974) and Tucker (2001), these sediments can be categorized as siliciclastic rather than carbonatic rocks.

4.3. Lebăda East well lithology

In the Lebăda East well (Fig. 6), the Eocene succession reaches up to 250 m in thickness, being dominated by grey, microgranular, slightly argillaceous, calcareous sandstones. Frequently, these calcareous sandstones contain microfauna remains, dominated by foraminifera tests or moulds, as well as echinoid spines, sponges spicules and radiolarians. An incipient stage of diagenetic recrystallization, mainly a silicification process that affected especially the fossil remains, is often mentioned. The rocks show a massive or stratified texture, the latter one being characterized by intensely diagenized layers, rich in microfossil fragments, affected by mm-thick fissures filled with sparite. Very rare intercalations of limestone are noticed.

5. BIOSTRATIGRAPHY

In the Eocene sediments intercepted by the 3 wells of IB (Sinoe, Lebăda West and Lebăda East), a number of 28 species of calcareous nannofossils, 62 species of foraminifera and only 2 species of ostracods were reported. We are discussing below the biostratigraphical aspects of the boreholes, based on available micropaleontological core reports.

5.1. Micropaleontology of Sinoe Well

In the Sinoe Well, a relevant microfaunal assemblages are reported only from the upper part of the succession (Fig. 4).

The diversified benthic foraminiferal assemblages are represented by the following taxa: *Anomalina parvula* Grzybowski, *Bolivina jacksonensis* Cushman & Applin, *Cibicides amphisyliensis* (Andreae), *Cibicidoides bellus* Thalmann, *Cibicides cushmani* Nuttall, *Cibicidoides praeconiferus* Mjatliuk, *Cibicidoides praelopjanicus* Mjatliuk, *Cibicides tallahattensis* Bandy, *Cibicidoides ungerianus* d'Orbigny, *Cibicides westi* Howe, *Gyroidinoides girardana* Reuss, *Homalohedra acuticosta* Reuss, *Lenticulina inornata* d'Orbigny, *Planulina renzi* Cushman & Stainforth, *Protoglobobulimina pupoides* d'Orbigny, *Pyrulina cylindroides* Roemer and *Valvulineria chirana* Cushman & Stone. The planktonic foraminifera are represented only by *Subbotina eocaena* Guembel and *Subbotina yeguaensis* Weinzierl & Applin.

Along with the foraminifera assemblages, the following calcareous nannofossils were described: *Campylosphaera dela* (Bramlette & Sullivan, 1961) Hay & Mohler, 1967, *Coccolithus eopelagicus* (Bramlette & Riedel, 1954) Bramlette & Sullivan, 1961, *Coccolithus formosus* (Kamptner, 1963) Wise, 1973, *Coccolithus gigas* Bramlette & Sullivan, 1961, *Coccolithus pelagicus* (Wallich 1877) Schiller, 1930, *Coccolithus staurion* Bramlette & Sullivan, 1961, *Cruciplacolithus latipons* Romein, 1979, *Cruciplacolithus primus* Perch-Nielsen 1977, *Cyclicargolithus luminis* (Sullivan, 1965) Bukry, 1971, *Discoaster saipanensis* Bramlette & Riedel, 1954, *Ericsonia robusta* (Bramlette & Sullivan, 1961) Edwards & Perch-Nielsen, 1975, *Neochiastozygus distentus* (Bramlette & Sullivan, 1961) Perch-Nielsen, 1971, *Pontosphaera distincta* (Bramlette & Sullivan, 1961) Roth & Thierstein 1972, *Pontosphaera plana* (Bramlette & Sullivan, 1961) Haq, 1971, *Prinsius bisulcus* (Stradner, 1963) Hay & Mohler, 1967, *Reticulofenestra dictyoda* (Deflandre in Deflandre & Fert, 1954) Stradner in Stradner & Edwards, 1968, *Reticulofenestra onusta* (Perch-Nielsen, 1971) Wise, 1983, *Reticulofenestra umbilicus* (Levin, 1965) Martini & Ritzkowski, 1968, *Sphenolithus obtusus* Bukry, 1971, *Toweius pertusus* (Sullivan, 1965) Romein, 1979 and *Umbilicosphaera protoannulus* (Gartner, 1971) Young & Bown 2014. In the well reports, sponge spicules, echinoid spines, radiolarians, undetermined foraminifera and ostracod fragments are also mentioned. Hence, the microfaunas of the Sinoe Well is dominated by the benthic foraminifera, from which the Cibicides genus prevails. The planktonic foraminifera are represented only by two species belonging to the Subbotina genus.

According to Blow (1969), Berggren & Van Couvering (1974) and Tourmakine & Luterbacher (1985), *Subbotina eocaena* has a long range with the FO (first occurrence) situated at the base of the foraminifera zone P8 (equivalent of E6 biozone) in the Lower Eocene, *i.e.*, the upper Ypresian (Gradstein *et al.*, 2012). In Wade *et al.* (2018) and Olsson *et al.* (2006) indicate that the LO (last occurrence) of *Subbotina eocaena* is situated in the middle part of the P22 biozone (or at the end of O6 equivalent biozone) which is placed within the Upper Oligocene, in the Chattian stage.

Subbotina yeguaensis has its FO at the beginning of P9 (E7) foraminifera zone (Blow, 1969; Berggren & Van Couvering, 1974; Tourmakine & Luterbacher, 1985; Berggren *et al.*,1995; Olsson *et al.*, 2006) that correspond to the Middle Eocene *pro parte* (late Lutetian - early Bartonian interval) and the LO at the top P17 (E16) assigned to the Upper Eocene (late Priabonian).

Regarding the calcareous nannofossils from the Sinoe well, some taxa are long-ranging, other have their FOs within the Paleocene or Lower Eocene, but a small group of taxa are biostratigraphically significant (Fig. 4). Within the later mentioned group is comprised *Sphenolithus obtusus* Bukry, 1971. This nannofossil has a very short range, within NP17 zone (Bown & Dunkley Jones, 2012) that covers the early Bartonian to early Priabonian interval (late Middle Eocene to early Late Eocene). Combining the foraminifera and calcareous nannoplankton species ranges, we assume that the Eocene deposits of the Sinoe well are late Lutetian to Bartonian in age (Middle Eocene).

5.2. Micropaleontology of Lebăda West well

In the Lebăda West well (Fig. 5), microfaunas, consisting of benthonic and planktonic foraminifera, as well as calcareous nannofossils, are reported.

The benthic foraminiferal assemblages comprise calcareous taxa represented by *Cibicides precursorius* Schwager, *Cibicidoides proprius* Brotzen, *Cibicides succedens* Brotzen, *Cibicides westi* Howe and *Planulina cocoaensis* Cushman, as well as few agglutinated species like *Placentammina placenta* (Grzybowski) and *Trochamminoides proteus* Karrer. The planktonic foraminifera are better represented in this well by *Acarinina intermedia* Subbotina, *Globanomalina imitata* Subbotina, *Morozovelloides crassatus* (Cushman), *Subbotina triloculinoides* (Plummer), *Subbotina trivialis* (Subbotina) and *Subbotina yeguaensis* (Weinzierl & Applin).

Other fossil remains are represented by algae fragments, *Lithothamnium* fragments, fish bones, bryozoan fragments, echinoid spines and sponge spicules. Ostracods fragments and radiolarians are also present.

From the identified planktonic foraminifera, *Morozovelloides crassatus* is significant biostratigraphically. According to various authors, such as Blow (1969, 1979), Kennet & Srinivasan (1983), Berggren *et al.* (1995), Chaisson &Pearson (1997), Pearson & Chaisson (1997) and Pearson & Berggren, 2006, the aforementioned species has its FO in the P9 (E7b) planktonic foraminiferal zone, within the base of the Lutetian stage and the LO at the base of P15 and respectively the boundary between E13/E14 zones that correspond to the late Bartonian interval (Blow 1969, 1979; Kennet & Srinivasan,1983; Berggren *et al.*, 1995, Chaisson & Pearson,1997, Pearson & Chaisson, 1997 and Pearson & Berggren, 2006).

Subbotina yeguaensis occurs also in Lebăda West well. Other encountered planktonic foraminifera are distributed in general within the whole Eocene, while the reported agglutinated foraminifera are long-ranging. For instance, *Trochamminoides proteus* occurred in the Late Cretaceous (Campanian) and became extinct in the Upper Eocene (Kaminski *et al.*, 2006). Hence, we may not exclude that some of the long-range benthic foraminifera and possibly the planktonic ones are reworked.

The calcareous nannofossils assemblages are represented by: *Chiasmolithus titus* Gartner, 1970, *Fasciculithus tympaniformis* Hay & Mohler in Hay *et al.*, 1967, *Markalius inversus* (Deflandre in Deflandre & Fert, 1954) Bramlette & Martini, 1964, *Prinsius bisulcus* (Stradner, 1963) Hay & Mohler, 1967 and *Reticulofenestra bisecta* (Hay, Mohler & Wade, 1966) Roth, 1970 (Fig. 5). From the nannofossil biostratigraphy point of view, significant taxa described in the core reports include *Chiasmolithus titus* and *Reticulofenestra bisecta*. Perch-Nielsen (1985) indicated that *Chiasmolithus titus* firstly occurs within the NP15 zone of Martini (1971), at the base of the Lutetian stage (early Middle Eocene) and has the LO at the base of the Oligocene (early Rupelian) in the NP21 biozone of Martini (1971). The nannofossils workers agree that *Reticulofenestra bisecta* has its FO in the Middle Eocene (upper part), within the NP17 and vanished within the earliest Miocene (NN1 that is the base of the Aquitanian) according to Martini (1971), Perch-Nielsen (1985), Young (1998), among many others.

Taking into account the aforementioned data, the boundary between the NP16 and NP17 nannofossil biozones is placed at the FO of *Reticulofenestra bisecta* that is several meters below the assumed boundary between the P13 and P14 foraminiferal zones (Fig. 5). Hence, we assume a Middle Eocene age (Lutetian – Bartonian in age). Other taxa reported from the well, such as *Fasciculithus tympaniformis* and *Prinsius bisulcus*, are most probably reworked, as they are restricted to the Paleocene-Early Eocene interval (Perch-Nielsen, 1985).

5.3. Micropaleontology of Lebăda East well

In comparison with the previously two investigated wells, in Lebăda East well, more diversified microfossil assemblages are mentioned (Fig. 6). The sampled intervals contain a diverse assemblage represented by 40 benthic and planktonic foraminifera species, recorded in the uppermost ~200 m.

The benthic foraminiferal assemblages comprise: *Anomalinoides semicribratus* (Beckmann), *Bulimina truncana* Guembel, *Bulimina pupoides* d'Orbigny, *Cibicidoides borislavensis* Ayzenshtat, *Cibicides dampelae* Bykova & Khramaya, *Cibicidoides lobatulus* (Walker & Jacob), *Cibicides perlucidus* Nuttall, *Cibicides praecursorius* (Schwager), *Cibicidoides praeventratumidus* Maslakova, *Cibicides proprius* Brotzen, *Cibicides westi* Howe, *Dentalina cooperensis* Cushman, *Eponides lotus* (Schwager), *Favulina hexagona* (Williamson), *Glandulina laevigata* d'Orbigny, *Globulina rotundata* (Bornemann), *Guttulina laevigata* d'Orbigny, *Gyroidinoides girardana* (Reuss), *Laevidentalina filiformis* (d'Orbigny), *Lagena striata* (d'Orbigny), *Lenticulina cultrata* (Montfort), *Lenticulina inornata* (d'Orbigny), *Neugeborina longiscata* (d'Orbigny), *Nonion commune* (d'Orbigny), Nuttallides truempyi (Nuttall), *Planulina renzi* Cushman, *Saracenaria hantkeni* Cushman, *Siphonodosaria consobrina* (d'Orbigny), *Siphonodosaria nuttalli var. gracillima* (Cushman & Jarvis) and *Valvulineria texana* Cushman. As planktonic foraminifera, *Parasubbotina inaequispira* (Subbotina), *Protoglobobulimina pupoides* (d'Orbigny), *Subbotina eocaena* (Guembel), *Subbotina trivialis* (Subbotina) and *Subbotina yeguaensis* (Weinzierl and Applin*)* may be listed. Two species of ostracods, *Cytherella ovata* Roemer and *Thracella* sp. aff. *bartonensis* (Jones) are present.

The calcareous nannofossils are represented by *Chiasmolithus bidens* (Bramlette & Sullivan, 1961) Hay & Mohler, 1967, *Chiasmolithus consuetus* (Bramlette & Sullivan, 1961) Hay & Mohler, 1967, *Coccolithus crassus* Bramlette & Sullivan 1961, *Fasciculithus involutus* Bramlette & Sullivan, 1961, *Heliolithus kleinpellii* Sullivan, 1964, *Neochiastozygus concinnus* (Martini, 1961) Perch-Nielsen, 1971, *Micrantholithus crenulatus* Bramlette & Sullivan, 1961, *Micrantholithus entaster* Bramlette & Sullivan 1961, *Rhomboaster cuspis* Bramlette & Sullivan, 1961 and *Toweius gammation* (Bramlette & Sullivan, 1961) Romein, 1979. As in Sinoe and Lebăda West wells, other fossil remains, consisting of echinoid spines, sponge spicules, unidentified foraminifer and ostracod fragments, along with radiolarians are present.

Schnitker (2007) mentioned in the DSDP 48 site report (Bay of Biscay), the presence of similar benthic foraminifera assemblages with *Anomalinoides semicribratus*, *Gyroidinoides girardana*, *Protoglobobulimina pupoides*, *Cibicidoides perlucidus*, *Gyroidinoides girardana*, *Nuttallides truempyi*, *Planulina renzi*, assigned to the early Middle Eocene (Lutetian).

Parasubbotina inequispira has its FO, according to Blow (1969), Berggren & Van Couvering (1974) and Tourmakine & Luterbacher (1985), at the base of P8 foraminifera zones (equivalent with the base of E6 in the Pearson & Berggren, 2006). Its LO is situated at the top of P12, and respectively E11 foraminiferal zones that cover the late Ypresian – late Lutetian (possible early Bartonian too) time interval (Blow, 1969; Berggren & Van Couvering, 1974, Tourmakine & Luterbacher, 1985; Pearson & Berggren, 2006; Gradstein *et al.,* 2012)

Among the calcareous nannofossils, *Coccolithus crassus,* according to Wei (1993), has its FO at the base of NP13, and its LO at the end of NP14, which refers to the interval between the upper Ypresian and the lower Lutetian. *Toweius gammation* has its first occurrence in the base of NP11 and its las occurrence at the end of NP14.

Taking into account the aforementioned arguments, we assume a late Early to early Late Eocene age, respectively, the upper Ypresian to Lutetian interval covered the NP13 and NP14 nannofossil zones. This age is also supported by the co-occurrence of the foraminifer species *Parasubbotina inaequispira* and *Subbotina yeguaensis* (Fig. 6).

6. DISCUSSION

According to Tucker (2001), the rock clasts from the lithic sandstones are generally derived from supracrustal rocks undergoing rapid uplift and erosion and this fact is supported by the Eocene uplift of the Lebăda West area. The nature of rock fragments in the lithic sandstones may change through time reflecting uplift in the source area and the availability of the surrounding sediment source. The same author, as aforementioned, claims that quartz arenites (the "quartzose sandstones" term used in this paper), which might have been produced by current reworking, were deposited on stable cratons and passive margins of low relief, which, generally, produce quartzose sands from the recycling of earlier sedimentary strata. In theory, these statements fit IB tectonic context during the Middle to Late Eocene intervals.

The most common rock type in the Eocene successions are the calcareous sandstones which contain up to 50% $CaCO_3$. In general, a sandstone with siliciclastic grains, cemented by calcite have been referred herein as calcareous sandstone. This type of lithology occurs in carbonate-producing areas where there is a large influx of terrigenous clastics and they pass laterally into limestones or towards the source of the siliciclastic sediment into purer sandstones (Tucker, 2001). In the studied well reports, all the calcareous sandstone samples are medium to highly diagenized and affected by fractures filled with sparite, micrite or argillaceous material. The presence of stylolites might indicate the effects of pressure dissolution, with sutured grain contacts.

Considering the siliciclastic rocks features, we assume that the Eocene depositional setting of the IB was a shelf area. Ionescu (2000) suggested that the Eocene alternating calcareous dominated deposits and coarser sandstones occurrences are mostly linked to the sea level fluctuations, rather than the tectonic factors and related subsidence processes. The author also mentioned that the Eocene "carbonate platform and ramp" are created on an existing Cretaceous palaeorelief, which would further be the basis for the thick Oligocene anoxic deposits (*i.e.* the Maykopian facies, Popov *et al.*, 2004), found in all 3 wells herein presented, at the top of the Eocene successions (Fig. 7).

In the core reports of the investigated wells, the Eocene microfauna (mainly foraminifera and a few ostracods), along with calcareous nannofossils, are always accompanied by bryozoans, sponges, algae, radiolarians, diatoms and dinoflagellates fragments. Considering the high number of Cretaceous reworked taxa in Eocene sediments, it is very possible that the Cretaceous strata might have constituted the shelf break walls and represented the main source of sediments for the Eocene deposits (Ionescu, 2000).

The presence of bryozoan fragments along with many *Cibicides* spp. suggests that the former ones provided shelter for these epifaunal foraminifera, as they attach themselves on the bryozoan trabeculae (Murray, 2006). It was observed that the present-day Cibicidae are often abundant in cool waters and prefer higher latitudes (Murray, 2006). In general, the presence in large numbers of benthic foraminifera species, in comparison with the planktonic ones are indicative for an inner shelf (Wang, 2014). However, the present-day survivors of Cibicidae that evolved from Paleogene genera do not have many particularities in common regarding their depositional environment, bathymetric and feeding preferences. Thus, we are not able to describe with a high confidence the Eocene microfaunal ecology. However, their existence both nowadays and during various Eocene stages provides enough information to capture details regarding their way of life. Taking into account the afore mentioned information, we consider that the sediments of the IB were deposited on shelf area, not very steep, a transitional zone from shallow to deeper water. The last assumption is also supported by the presence of the calcareous nannofossils in the studied wells, as it is known that this group of organisms mostly prefer the open marine setting (Tappan, 1980).

The observed large thickness variation, from Sinoe to Lebăda sites, is most probably a consequence of different structural settings of the two areas. In Sinoe, the analysed well was drilled in the hanging-wall of an inverted normal fault filled with Middle to Upper Eocene deposits and was subsequently inverted by high angle thrust fault during Late Eocene-Oligocene times (Munteanu *et al.*, 2011). In contrast, in Lebăda, the wells drilled in the uplifted normal fault foot-wall, show a considerable reduced thickness in comparison with Sinoe (Munteanu *et al.*, 2011).

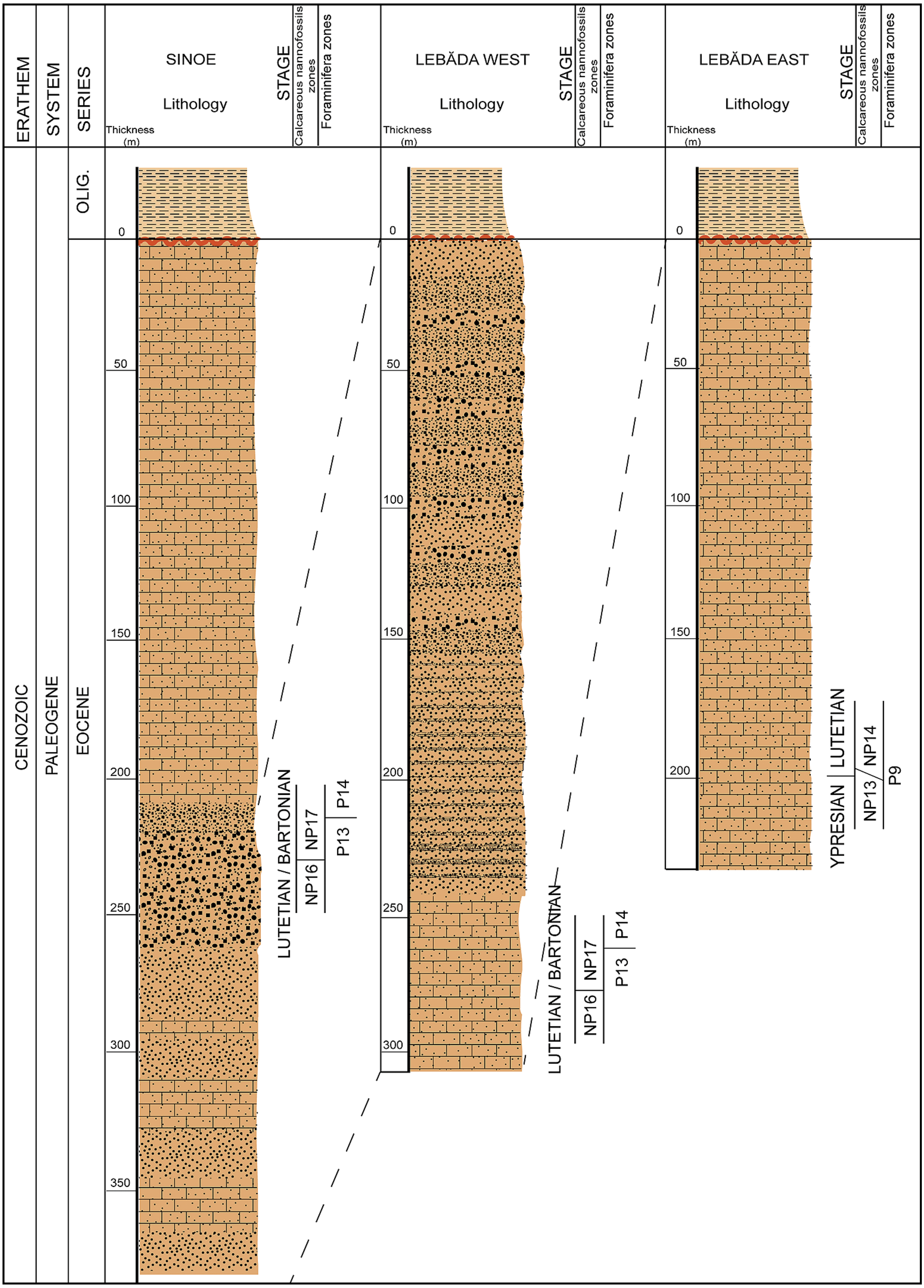

Fig. 7. Correlation of the Eocene deposits from the investigated wells (Sinoe, Lebăda West and Lebăda East) in the IB.

7. CONCLUSIONS

By using data from 3 wells (including core and cuttings reports), we have compiled 3 lithostratigraphic columns in which we unfold detailed lithology and sampled intervals, along with the containing microfaunas and nannofossils. Based on these data, we have made a correlation among the wells based on biostratigraphy. We conclude that the Sinoe and Lebada West investigated intervals are Middle Eocene (late Lutetian to Bartonian) in age, while the Lebada East successions are older, late Early Eocene to early Middle Eocene in age (*i.e.*, late Ypresian to Lutetian).

Regarding the Late Eocene (Priabonian), we were not able to identify this age based on found data in core reports. Hence, two alternatives can be inferred: (i) a subsequent removing during Early Oligocene times as suggested by Tambrea (2002) and (ii) another possibility is linked to sea-level fluctuation.

The last assumption is in agreement with a large drop of the sea-level, triggering the erosion in the IB during the Eocene - Oligocene boundary interval. This event was already recognized in several Paratethyan sub-basins at the Oligocene-Eocene boundary interval (Popov *et al.*, 2004; Munteanu *et al.*, 2011; Tari *et al.*, 2014).

Our results show that the erosion level increased towards East, removing the entire Upper Eocene, *i.e.*, Priabonian, from Lebăda West well and even upper part of the Middle Eocene in Lebăda East and Sinoe wells (Fig. 7).

This might be a consequence of different tectonic position of these areas, with larger uplift of Lebăda East in comparison with Lebăda West and Sinoe areas, corresponding with the Eocene-Oligocene inversion as suggested by Munteanu *et al.*, 2011 (and reference therein).

On the other hand, the hypothesis of an important sea level drop during Upper Eocene times, with subaerial erosion and development of large-scale canyons system at the shelf to slope transition (Boote, 2017), such as the Pliocene - Quaternary Viteaz Canyon (observed presently) (Popescu *et al*., 2001) may not be neglected. Therefore, a more regional integration with other well data and the calibration with well logs and seismic data is necessary to fully understand the processes that have led to the development of the Eocene unconformities, especially the one from the base of the Oligocene.

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