Hydrocarbon potential of the Oligocene and Miocene sediments from the Modrany-1 and Modrany-2 wells (Danube Basin, Slovakia)

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Abstract: The Oligocene Tard and Kiscell formations represent classical source rock examples in the Hungarian part of the Danube Basin. Similar sediments recorded in the Slovak part of the Danube Basin were studied by Rock-Eval pyrolysis in this paper, while their stratigraphic position was supported by the foraminiferal and nannoplankton biostratigraphy. Result obtained from MOD-1 and MOD-2 wells show that the Oligocene sediments are immature (T_{max} < 432 °C). They contain mixed kerogen type II/III as well as coaly matter and show lower hydrocarbon potential (TOC 1.38–1.57 wt %; HI 164–345 mg HC/g TOC; PP 4.60–5.59 mg HC/g rock). Composition of organic matter confirms correlation with Hungarian Kiscell Fm. The Neogene sediments are immature and have a poor petroleum potential. One exception is present in Pannonian sediments with kerogen type II/III, relatively high TOC (0.98 wt %) and hydrogen index (HI= 424 mg HC/g TOC). Fair petroleum potential (PP 4.36 mg HC/g rock) shows that some horizons (Tortonian) can be potentially perspective in the deeper buried part of the basin.

Keywords: Danube Basin, Rock-Eval, hydrocarbon potential, biostratigraphy

1. INTRODUCTION

The Danube Basin belongs to the Pannonian basin system (Fig. 1a) and during the Oligocene and early-middle Miocene it was a part of the Central Paratethys Sea. Subsequently the main marine corridors were cut off and the area became a part of the vast Lake Pannon (Kováč et al., 2017). Hydrocarbon exploration in the Slovak part of the Danube Basin started in 1952 and discovered small accumulations of natural gas with predominance of methane. The exploration did not continue until the early 90´s (Milička, 2017). Oil traces have been recorded in several wells in the Blatné and Želiezovce partial depressions during this period (Pereszlényi et al., 1993; Milička et al., 2015; Milička, 2017).

The lower Oligocene (Kiscellian) sediments are in Hungary divided to the Tard Fm. and the Kiscell Fm. (Tari et al., 1993). The main source rocks are the Tard clays with minor source potential in the overlying the Kiscell Fm. (Tari et al., 1993; Milota et al., 1995; Badics & Vető, 2012; Bechtel et al., 2012). Laminated marls and shales of the Tard Fm. are considered as the best oil-prone rocks of the entire Hungarian Oligocene sequence; however, the organic matter is thermally immature (Bechtel et al., 2012). While the Tard Formation contains kerogen type II, the Kiscell Fm. contains kerogen type II/III (Milota et al., 1995; Bechtel et al., 2012). Hydrocarbon potential of the Tard Clay sediments is more than 5–7 kg HC t^{-1} rock (Milota et al., 1995). The overlaying Kiscell Clay Formation has fair source quality, but the average organic carbon and bitumen contents is much lower (<1 wt % TOC; HI <200 mg HC/g TOC). Mentioned studies are focused only on the Tard clay and data about the Kiscell Fm. are insufficient.

The Želiezovce depression (south-eastern part of the Slovak Danube Basin; Fig. 1b) is in close vicinity to the Hungarian Oligocene source rock and several wells yield potentially similar Oligocene sediments (Biela, 1978; Franko et al., 2011; Zlinská, 2016; Kováč et al., 2018). This paper intends to refine the previous results about petroleum potential of the Oligocene sediments (Pereszlényi et al., 1993; Milička et al., 2015; Milička, 2017) with support of new biostratigraphic data. The aims of paper are to evaluate richness, quality and maturation of the Oligocene rocks in Slovak part of the Danube Basin. Moreover, the study will also attempt to pinpoint additional source rock candidates in all younger sediments that are presented in the study area.

2. GEOLOGICAL SETTINGS

The Danube Basin represents the northwestern part of the Pannonian Basin System (Fig. 1a). The basin *sensu stricto* was opened as a back-arc (Kováč, 2000; Horváth et al., 2015) or an intra-arc basin (Vass, 2002) during the Miocene. The depocenter is composed of several partial sub-basins (depressions), and this study focuses on the southeastern one, which is referred to as the Želiezovce depression (Fig. 1b). In this part of the Danube Basin, the basement rocks are composed of Paleozoic and Mesozoic units of the Transdanubian range and Central Western Carpathians,

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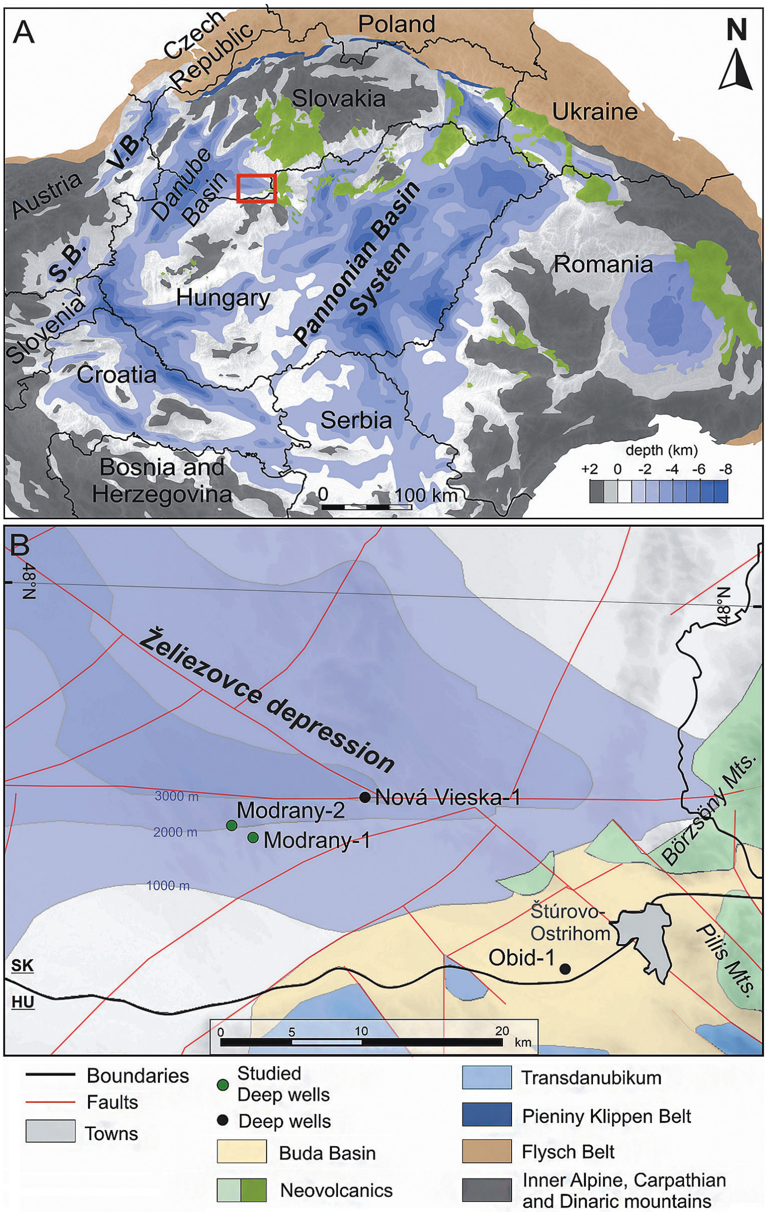

Fig. 1. A) Position of the study area in the Alpine-Carpathian-Pannonian system. B) Map of Želiezovce depression (Danube Basin) with deep wells marked (Fusán, 1987; Horváth et al., 2015).

which are divided by the Hurbanovo-Diósjenő fault (Fusán et al, 1987; Hók et al., 2014; Klučiar et al., 2016). The Oligocene sediments occur along mentioned line and represent of the Buda retro-arc Basin remnants (Tari et al., 1993; Kováč et al., 2018). These sediments were previously ranked to the Číž Formation (Vass, 2002) while present time they are correlated with the Kiscell Fm. (Kováč et al., 2018). The extend of the Oligocene sediments is documented in the several wells (Modrany-1, Modrany-2, Nová Vieska-1 wells and Obid well series; Biela, 1978; Kováč et al., 2018). They crop out in the Burda Mts. The proximal shelf depositional environment was specified to a seacoast marsh and lagoon (Kováč et al., 2018; Vlček et al., 2019). The Oligocene sediments were then incorporated into the younger back-arc Danube Basin. The Neogene fill is more than 3000 m thick (Kováč et al., 2018) and the succession starts with the offshore volcano-sedimentary deposits of the Bajtava-Špačince Formation (early Badenian-stable submarine platform environment; Fig. 2). The basin was gradually filled up during Serravallian by sediments of the Pozba-Vráble formations (late Badenian-Sarmatian; deltaic and shelf environment; Fig. 2). After a short hiatus, the late Miocene (Pannonian) formations follow (Kováč et al., 2018). They are represented by the Ivanka Formation which yields muddy sediments of a stable submarine platform, sandy turbidite deposits and muddy deposits of the shelf-break slope (Fig. 2). These are followed by sandy deltaic strata of the Beladice Formation and by mostly muddy alluvial sediments of the Volkovce Formation. A thin cover of alluvial Quaternary gravels concludes the basin infill (Šujan et al., 2018).

3. METHODS

3.1. Biostratigraphy

Foraminifers (Modrany-1, 9 samples; Modrany-2, 14 samples) were gained from 200 g of dried well core material and treated with H_2O_2 (10 %) and subsequently washed using sieves with a mesh size of 1.25 and 0.071 mm. Some of the very compacted clay samples were additionally treated by Rewoquat. Finally, 250 specimens were picked if possible (planktic and benthic). If fewer specimens were present, all foraminifera tests have been picked from two standardized residuum loads. Combination of the binocular stereoscopic microscope Olympus SZ75, the biological polarizing microscope (Comenius University in Bratislava) and the scanning electron microscope QUANTA FEG 250 (Institute of Electrical Engineering, SAS) were used to determine and image the foraminifers. Determination of foraminifers followed Loeblich & Tappan (1992), Cicha et al. (1998) and Holbourn et al. (2013). The major problem of foraminiferal determination was dissolution of foraminiferal tests and presence of calcite molds mostly without original calcite wall. Due to the poor preservation some tests stay in open nomenclature. Paleoecological parameters of the obtained foraminiferal assemblage were evaluated based on the presence and dominance of taxa exhibiting special environmental significance (Boltovskoy, 1976; Boltovskoy & Wright, 1976; Spezzaferri et al., 2004; Murray, 2006).

Calcareous nannofossils from Modrany-1 (MOD-1) and Modrany-2 (MOD-2) wells were obtained from 38 samples. Smear slides were prepared using standard method (Bown, 1998). Calcareous nannofossils were counted in 300 fields of view, by using Olympus BX 50, objective with 100x magnification and oil immersion. Camera Olympus Infinity 2, with QuickPHOTO CAMERA 2.3 software was used for the photographic record. Nannofossils determination is supported by MIKROTAX webpage, Young et al. (2017).

3.2. Rock-Eval pyrolysis

From the Modrany-1 and Modrany-2 wells, 11 fine grained samples were analyzed by Rock-Eval 6 pyrolysis (Lafargue et al. 1990) at the Oil and Gas Institute – National Research Institute in Cracow, Poland. Several important parameters were determined: S1 free hydrocarbons (mg HC/g rock), S2 pyrolytic hydrocarbons (mg HC/g rock), S3 pyrolytic CO_2 (mg CO_2/g rock), T_{max} maximum of pyrolytic S2 curve (°C), as well as the Hydrogen, Oxygen and production indexes. The hydrogen index (HI) is the ratio of pyrolytic hydrocarbons and total organic carbon (mg HC/g TOC). The oxygen index (OI) is the ratio of pyrolytic CO_2 and grams of TOC (mg CO_2/g TOC). The production index (PI) is defined as S1/(S1+S2) (Espitalié et al., 1984; Lafargue et al. 1998; Behar et al., 2001). The petroleum potential is calculated as the sum of S1 and S2 (Tab. 1) (Peters, 1986; Peters & Cassa, 1994).

4. RESULTS

4.1. Biostratigraphy

Sediments in the depth of 2105–1855 m (MOD-1) and 2305–2164 m (MOD-2) include calcareous nannoplankton *Reticulofenestra lockeri*, *R. ornata*, *R. stavensis*, *R. bisecta*, *Zygrhablithus bijugatus* and *Lanternithus minutus* (Fig. 3; Suppl. 1, 2) together with the last occurrence of *Coccolithus formosus*, *Discoaster tanii*, *Lanternithus minutus*, *R. umbilicus* in the depth of 2164 m (MOD-2). Foraminifera assemblage yield the genus *Subbotina* (*S. tecta*, *S. corpulenta*, *S. angiporoides*; Fig. 4). Therefore, the sediments are ranked to the Oligocene. Cretaceous and Paleogene redeposits are observed.

Sediments in the depth of 2117–2110 m (MOD-2) include *Helicosphaera ampliaperta*, *Sphenolithus heteromorphus*, *Helicosphaera carteri* and *Umbilicosphaera rotula* (Suppl. 1) what ranks them to the Badenian part of the NN4 Zone (Martini, 1971).

In the depth of 1755–1100 m (MOD-1) and 2009–1356 m (MOD-2) the NN5 zone nannofossil association was recognized based on *Reticulofenestra minuta*, *R. haqii*, *Braarudosphaera*

Tab. 1. Correlation of the parameters describing the petroleum potential. Modified from Peters (1986).

	TOC (wt %)	PP = S_1+S_2 (mg HC/g rock)
Poor	< 0.5	< 3
Fair	0.5 – 1.0	3.0 – 6.0
Good	1.0 – 2.0	6.0 – 25.0
Very Good	> 2.0	> 25

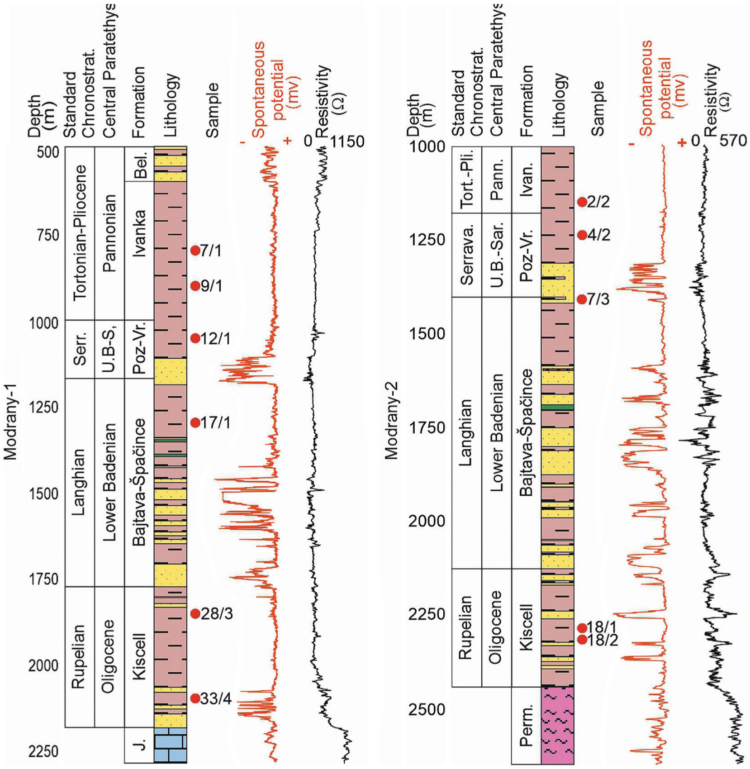

Fig. 2. Lithostratigraphy of Modrany-1, Modrany-2 wells with marked Rock-Eval samples as red dots.

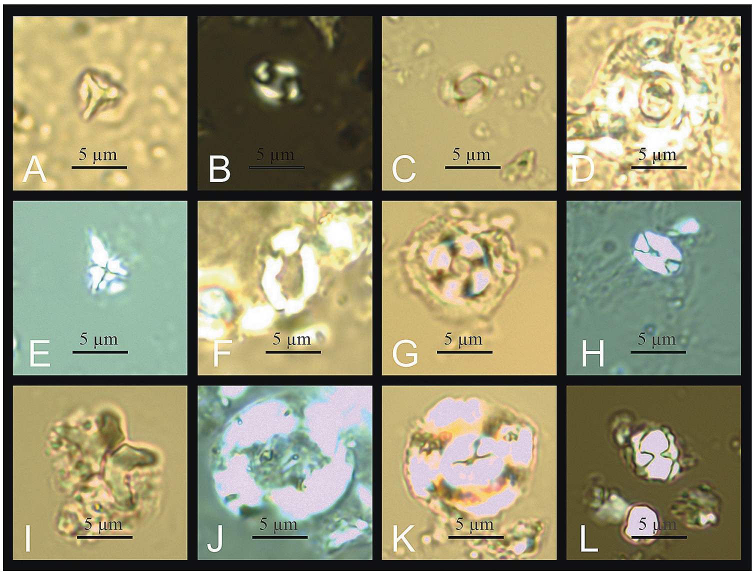

Fig. 3. Nannofossils from Modrany-1 and 2 wells (c=core, b=box): A – *Isolithus semenenko* (Luljeva, 1989), MOD-1, c9, b1, 900-905 m; B – *Reticulofenestra tegulata* (Bona & Gal, 1985) Coric & Gross, 2004, MOD-2, c2, b3, 1154-1159 m; C – *Reticulofenestra pseudoumbilicus* (Gartner, 1967) Gartner, 1969, MOD-1, c12, b1, 1050-1056 m; D – *Calcidiscus premacintyrei* (Theodoridis, 1984), MOD-2, c3, b1, 1208-1211 m; E – *Sphenolithus heteromorphus* (Deflandre, 1953), MOD-1, c17, b1, 1298-1303 m; F – *Helicosphaera ampliaperta* (Bramlette & Wilcoxon, 1967), MOD-2, c15, b1, 2110-2117 m; G – *Coccolithus formosus* (Kamptner, 1963) Wise, 1973, MOD-2, c18, b1, 2305-2308 m; H – *Lanternithus minutus* (Stradner, 1962), MOD-1, c28, b1, 1855-1859 m; I – *Discoaster tanii* (Bramlette & Riedel, 1954), MOD-2, c18, b1, 2305-2308 m; J – *Reticulofenestra umbilicus* (Levin, 1965) Martini & Ritzkowski, 1968, MOD-2, c16, 2164-2167 m; K – *Reticulofenestra stavensis* (Levin & Joerger, 1967) Varol, 1989, MOD-2, c18, b1, 2305-2308 m; L – *Zygrhablithus bijugatus* (Deflandre in Deflandre & Fert, 1954) Deflandre, 1959, MOD-1, c31, b3, 1900-1995 m.

bigelowii parvula, *Discoaster variabilis*, *Helicosphaera walbersdorfensis*, *H. waltrans*, *Umbilicosphaera rotula*, *U. jafari* and *Thoracosphaera* sp. The acme of *Sphenolithus heteromorphus* is associated with *Calcidiscus*, *Calcidiscus* sp., *C. leptoporus*, *C. tropicus*, *Discoaster exilis*, *D. deflandrei*. *C. pelagicus*, *Cyclicargolithus floridanus*. *C. premacintyrei* (Suppl. 1). This age range is confirmed by foraminiferal assemblage where Langhian (early Badenian) index foraminiferal species *Globigerinoides bisphaericus*, *Praeorbulina sicana and Praeorbulina circularis* starts from the depth of 2009 m (MOD-2). Presence of *Orbulina suturalis*-acme (MOD-2 1507 m; MOD-1 1303 m) indicates an age of 14.6 Ma or younger (Abdul Aziz et al., 2008). Occurrence of planktonic *Globoturborotalitalids*, *Globigerininds* and *Asterigerinata planorbis* increases upward. Benthic species like *Hoeglundina*, *Bolivina*, *Uvigerina*, *Melonis*, *Spiroplectammina*, *Heterolepa*, *Bulimina* sp., *Bathysiphon*, *Ammobaculites*, *Neoconorbina terquemi*, *Valvulineria* sp., *Reophax*, *Textularia* and abundant miliolid forams are present. The coarse-grained interval appearing in the depth of 1400–1315 m (MOD-2; Fig. 2) is placed on the base of the late Badenian-Sarmatian cycle in this study, and the foraminiferal assemblage obtained within is considered to be a redeposit.

Nannofossils assemblage of the late Badenian NN6 Zone is indicated in the depth of 1103–1050 m (MOD-1) and 1297–1208 m (MOD-2) by *Braarudosphaera bigelowii parvula*, *C. leptoporus*, *Calcidiscus* sp, *C. pelagicus*, *C. premacintyrei C. tropicus*, *D. variabilis*, *Helicosphaera walbersdorfensis*, *Pontosphaera japonica*, *R. pseudoumbilicus*, *R. haqii*, *R. minuta*, *U. rotula*, *D. musicus*, *Discoaster* sp., *Holodiscolithus macroporus*, *Sphenolithus abies*, *H. wallichii*, (Suppl. 1). The presence of *S. heteromorphus* and *H. waltrans* together with the damaged and sorted foraminiferal tests indicate redeposition. This stratigraphic ranking is confirmed by planktonic foraminifera assemblage like *Globigerina bulloides*, *Globoturborotalita quinqueloba*, *Globorotalia* sp., *G. bykovae* and *Velapertina indigena*. Additionally, first occurrence of *Globoturborotalita druryi* originally described as middle Badenian (Cicha et al., 1975; CPN8) can be connected with the late Badenian age according to Kováč et al. (2018). Last occurrence (LO) of *Orbulina universa* was documented. Benthic assemblage is diversified and consists of: *Bolivina*, *Bulimina*, *Cassidulina*, *Valvulineria*, *Nonion*, *Melonis*, *Uvigerina*, *Hoeglundina*, *Lenticulina*, *Pullenia*, *Asterigerina*, *Lobatula* and agglutinated forms.

Following interval (MOD-1 1105–900 m; MOD-2 1159–1104 m) contains low diversified nannofossil assemblage of *Reticulofenestra tegulata* and *Isolithus semenenko* which together with foraminifera *Trochammina kibleri* document early Pannonian (Tortonian) age. In the depth of 1103 m (MOD-2) only reworked *Heterolepa dutemplei* was found.

In summary, based on these results the strata from the Modrany-1 and Modrany-2 wells can be divided into:

1.) Oligocene (MOD-1 depth of 1995–1855 m and MOD-2 2445–2140 m); Biostratigraphic markers indicate the NP 21-23 biozone what would rank the sediments into Priabonian-Kiscellian (Rupelian) boundary, which correlates with the Tard Fm. However, the Tard Fm. is limited into the basinal part and is linked with intra Oligocene denudation (Tari et al. 1993; Sztanó & Tari, 1993). Nevertheless, the encountered sediments are transgressive what is supported by onlap onto the pre-Cenozoic basement. Therefore, it is most likely that associations were redeposited from the Tard Fm. into to Kiscell Fm. (Kováč et al. 2018).

2.) Early Badenian /Langhian/ Bajtava-Špačince fms. which occur in the depth of 2140–1400 m (MOD-2) and 1760–1298 m (MOD-1).

3.) Late Badenian-Sarmatian /Serravallian/ Pozba-Vráble fms. present in the depth interval of 1400–1180 m (MOD-2) and 1103–1050 m (MOD-1).

4.) Finally, sediments up from the depth of 1180 m (MOD-2) and 1005 m (MOD-1) are ranked to Pannonian (Tortonian). The Pannonian formations (Ivanka, Beladice and Volkovce fms.) were divided based mostly on the correlation with the data of Kováč et al. (2018).

4.2. Rock-Eval pyrolysis

Rock-Eval pyrolysis allows detailed characterization of the organic matter in sediments, mainly gives information about thermal maturity, petroleum potential and kerogen type. Rock-Eval

Tab. 2. Rock-Eval parameters from the Modrany-1 and Modrany-2 wells.

Well	Stratigraphy	Depth	TOC	S1	S2	S3	T_{max}	HI	OI	PI	S2/S3	Kerogen	PP
MOD-1		(m)	(wt %)		(mg HC/g rock)		(°C)					type	(S1+S2)
7/1	Tortonian	801	0.48	0.04	0.47	0.94	428	98	196	0.07	0.50	III	0.51
9/1	Tortonian	900	0.90	0.06	1.55	0.60	430	172	67	0.04	2.58	III–IV	1.61
12/1	Serravallian	1050	0.89	0.03	1.00	0.75	426	112	84	0.03	1.33	III–IV	1.03
17/1	Langhian	1298	0.81	0.03	0.70	1.05	430	86	130	0.03	0.67	IV	0.73
28/3	Rupelian	1857	1.38	0.09	4.51	1.00	428	327	72	0.02	4.51	III	4.60
33/4	Rupelian	2105	2.74	0.10	4.50	0.99	412	164	36	0.02	4.55	III	4.60
MOD-2													
2/2	Tortonian	1157	0.98	0.20	4.16	0.60	429	424	61	0.05	6.93	II	4.36
4/2	Serravallian	1255	0.80	0.02	0.86	0.79	431	108	99	0.03	1.09	III	0.88
7/3	Langhian	1408	0.58	0.03	0.72	0.92	430	124	159	0.04	0.78	III	0.75
18/1	Rupelian	2305	1.50	0.10	4.74	0.59	432	316	39	0.02	8.03	II–III	4.84
18/2	Rupelian	2308	1.57	0.18	5.41	0.73	431	345	46	0.03	7.41	II–III	5.59

parameters of the sediments from the studied wells (MOD-1 and MOD-2) are plotted in Figures 5, 6 and displayed, classified in the Tab. 2.

For the Oligocene samples (Kiscell Fm.), S1 values varies from 0.09 to 0.18 mg HC/g rock (average 0.12 mg HC/g rock), S2 from 4.50 to 5.41 mg HC/g rock (avg. 4.79 mg HC/g rock), S3 from 0.59 to 1.00 mg CO_2/g rock (avg. 0.83 mg CO_2/g rock). The hydrogen index (HI) reaches relatively high values of 164–345 mg HC/g TOC (avg. 288 mg HC/g TOC). On the other hand, oxygen index (OI) attains low values of 36–72 mg CO_2/g TOC (avg. 48 mg CO_2/g TOC). T_{max} varies between 412 and 432 °C (avg. 426 °C), and production index (PI) between 0.02 and 0.03 (avg. 0.02). The petroleum potential (PP) ranked to 4.60–5.59 mg HC/g rock (avg. 4.91 mg HC/g rock), S2/S3 ratio reaches 4.51–8.03 (avg. 6.13). The Kiscell Fm. is relatively rich in TOC attaining values of 1.38–2.74 wt % (avg. 1.80 wt %).

Two samples were analyzed from the Bajtava-Špačince formations (Langhian). These sediments are characterized by S1 values of 0.03 mg HC/g rock, S2 0.70–0.72 mg HC/g rock and S3 0.92–1.05 mg CO_2/g rock. HI is very low 86 and 124 mg HC/g TOC (avg. 105 mg HC/g TOC), while values of oxygen index (OI) are high 130–159 mg CO_2/g TOC (avg. 145 mg CO_2/g TOC). T_{max} from both samples are equal (430 °C) and values of production index (PI) are 0.03–0.04. The calculated petroleum potential index is very low 0.73–0.75 mg HC/g rock (avg. 0.74 mg HC/g rock) and S2/S3 ratio is 0.67 and 0.78 (avg. 0.72). The TOC values of the Bajtava-Špačince fms. are 0.58 wt% and 0.81 wt% with average of 0.70 wt%.

The Pozba-Vráble fms. (Serravallian) is represented by two samples. The samples show S1 0.02 and 0.03 mg HC/g rock, S2 0.86–1.00 mg HC/g rock (avg. 0.93 mg HC/g rock) and S3 0.75–0.79 mg CO_2/g rock (avg. 0.77 mg CO_2/g rock). The both calculated indexes HI (112–108 mg HC/g TOC; avg. 110 mg HC/g TOC) and OI (84–99 mg CO_2/g TOC; avg. 92 mg CO_2/g TOC) are low. T_{max} values 426–431 °C (avg. 429 °C) as well as PI index 0.03 are low. The petroleum potential is 0.88–1.03 mg HC/g rock (avg. 0.96 mg HC/g rock) and S2/S3 ratio is 1.09–1.33 (avg. 1.21). TOC shows values 0.80–0.89 wt % (avg. 0.85 wt %).

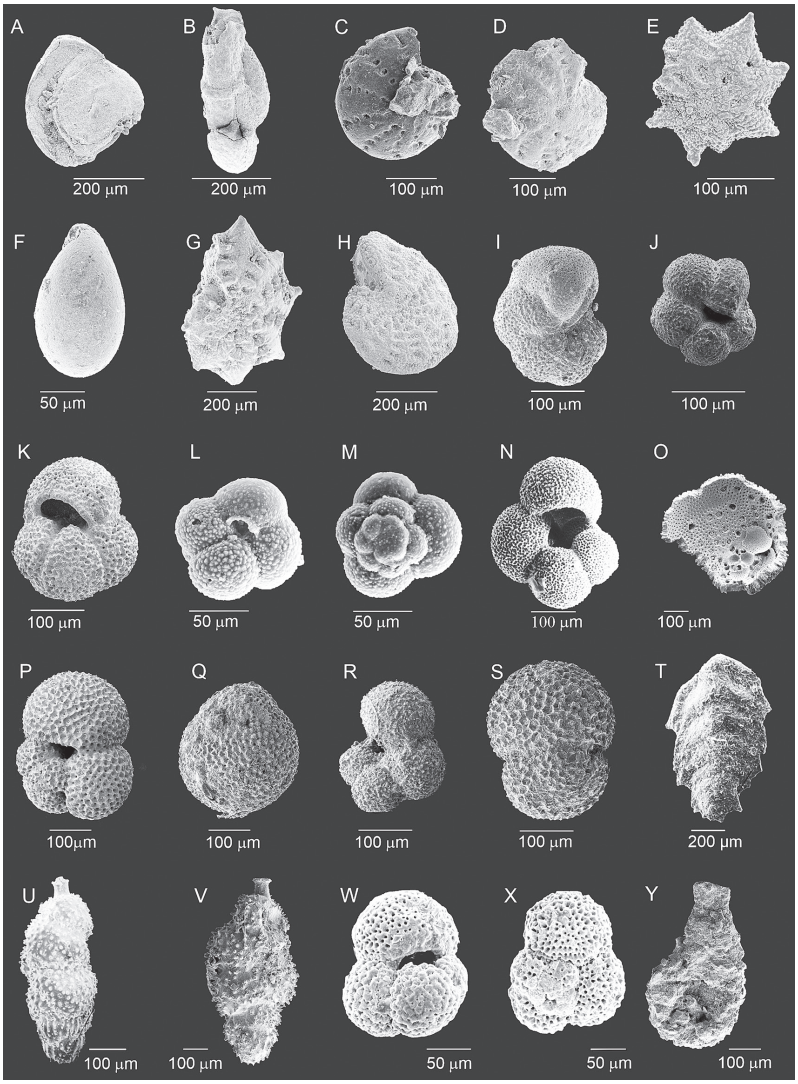

Fig. 4. Selected foraminifera from Modrany-1 and 2 wells (c=core, b=box): A – *Miliolinella* sp., MOD-1, c12, b4, 1050-1056 m; B – *Articulina* sp., MOD-1, c12, b4, 1050-1056 m; C – *Elphidium flexuosum* (d'Orbigny, 1846), MOD-1, c12, b3, 1050-1056 m; D – *Elphidium flexuosum* (d'Orbigny, 1846), MOD-2, c7, b2, 1404-1408 m; E – *Elphidium aculeatum* (d'Orbigny, 1846), MOD-2, c4, b1, 1253-1258 m; F – *Elphidium aculeatum* (d'Orbigny, 1846), MOD-1, c12, b3, 1050-1056 m; G – *Fissurina laevigata Reuss*, 1850, MOD-2, c4, b1, 1253-1258 m; H – *Elphidium macellum* (Fichtel & Moll, 1798), MOD-2, c6, b2, 1356-1358 m; I – *Globorotalia bykovae* (Aisenstat in Subbotina, Pishvanova & Ivanova, 1960), MOD-2, c8, b2, 1505-1509 m; J – *Turborotalita quinqueloba* (Natland, 1938), MOD-2, c2, b3, 1154-1159 m; K – *Globoturborotalita druryi* (Akers, 1955), MOD-2, c7, b2, 1404-1408 m; L, M – *Globigerinita uvula* (Ehrenberg, 1861), MOD-2, c4, b1, 1253-1258 m; N – *Globigerina bulloides* (d'Orbigny, 1826), MOD-2, c5, b1, 1297-1300 m; O – *Orbulina universa* (d'Orbigny, 1839), MOD-2, c4, b1, 1253-1258 m; P – *Trilobatus quadrilobatus* (d'Orbigny, 1846), MOD-2, c4, b1, 1253-1258 m; Q – *Orbulina suturalis* (Brönnimann, 1951), MOD-2, c8, b2, 1505-1509 m; R – *Globigerina regularis* (d'Orbigny, 1846), MOD-2, c5, b1, 1297-1300 m; S – *Trilobatus bisphericus* (Todd, 1954), MOD-2, c5, b1, 1297-1300 m; T – *Spirorutilus carinatus* (d'Orbigny, 1846), MOD-2, c14, b3-4, 2005-2009 m; U – *Uvigerina asperula* (Cžjžek, 1848), MOD-2, c2, b3, 1154-1159 m; V – *Uvigerina aculeata* (d'Orbigny, 1846), MOD-2, c14, b3-4, 2005-2009 m; W, X – *Subbotina* sp., MOD-2, c18, b1, 2305-2308 m; Y – *Lagenammina atlantica* (Cushman, 1944), MOD-1, c17, b1, 1298-1303 m.

The Pannonian samples (Ivanka Fm.) show S1 values ranging between 0.04 and 0.20 mg HC/g rock (avg. 0.10 mg HC/g rock), S2 between 0.47 and 4.16 mg HC/g rock (avg. 2.06 mg HC/g rock) and S3 reaching 0.60 and 0.94 mg CO_2/g rock (avg. 0.71 mg CO_2/g rock). The HI values range from 98 to 424 mg HC/g TOC, while the OI values from 61 to 196 mg CO_2/g TOC. T_{max} of the Pannonian samples vary between 428 and 430 °C (avg. 429 °C) and PI between 0.04–0.07 (avg.

0.05). PP show values from 0.51 to 4.36 mg HC/g rock (2.16 mg HC/g rock) and S2/S3 ratio varies from 0.50 to 6.93 (3.34). The Pannonian sediments have moderate TOC (0.48–0.98 wt %; avg. 0.79 wt %).

In summary, based on Rock-Eval pyrolysis results from the Modrany-1 and Modrany-2 wells, the Oligocene sediments have higher S1, S2, S3, PP, HI and TOC values with lower OI than Neogene samples, while the T_{max} values are very similar for the Oligocene and Neogene sediments.

5. DISCUSSION

Kerogen types and petroleum potential

Data from Rock-Eval pyrolysis provide information about kerogen types and petroleum potential of sedimentary strata in the southeastern Danube Basin.

In the Oligocene (Kiscell Fm.; Fig. 5) the analysis identifies kerogen type II/III dominated by mixture of terrestrial and marine organic matter derived from higher land plants together with phytoplankton. The TOC values greater than 1.5 wt.% indicate good organic richness and fair petroleum generation potential (Fig. 6). The higher S2/S3 ratio (>5; see Table 1) and low values of OI indicate coaly material (Peters, 1986) which is consistent with the littoral environment of deposition (Kováč et al., 2018). The current results documented higher TOC and HI values than in Hungary. The previous analyses (Milička, 2017) from these wells showed similar values of TOC, S1 and S2 (Fig. 7). On the other hand, values in the Nová Vieska-1 and Obid-1 wells shows poor petroleum potential only with few exceptions (Fig. 7). Extreme high values of TOC and S2 in Obid-1 well can be explained by the presence of coaly detritus-rich layer, which was also confirmed by biomarkers and microscopy (Milička, 2017).

The Paleogene sediments from Danube Basin (Slovak part) are in passive maturity stage and their burial depth do not exceed the immature zone which is confirmed by T_{max} < 432 °C, in accordance with previous works (Pereszlényi et al., 1993; Milička et al., 1996, 2015; Milička, 2017). The mature stage from the

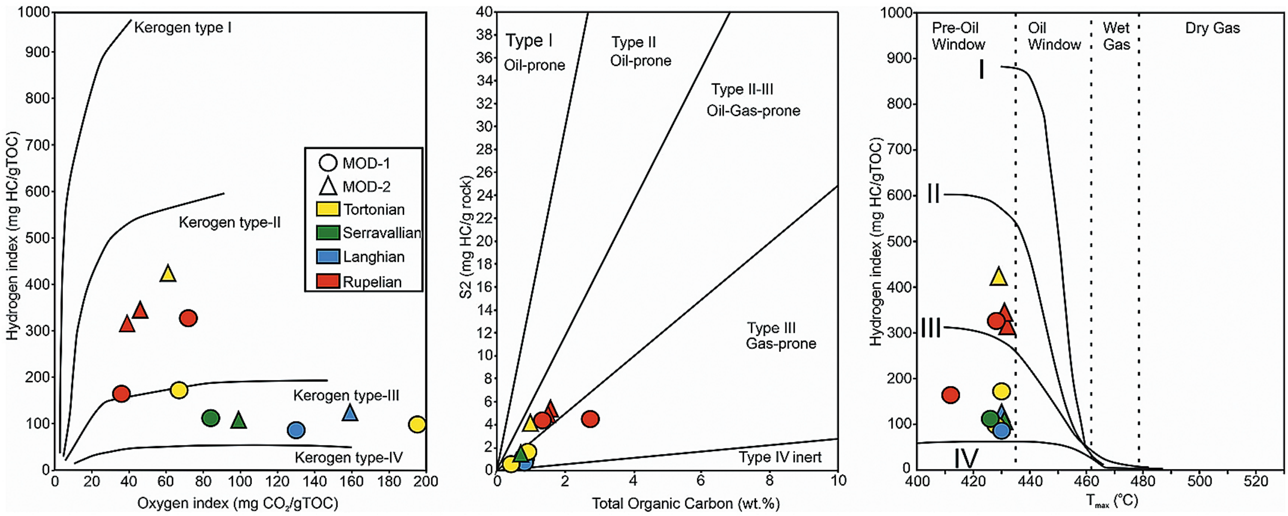

Fig. 5. Plots of Hydrogen Index (HI) versus Oxygen index (OI), Peak S2 versus TOC and Hydrogen Index (HI) versus Tmax outlining kerogen type and thermal maturity of sediments from the Modrany-1 and 2 wells. Modified according to Espitalié et al. (1984) and Peters (1986).

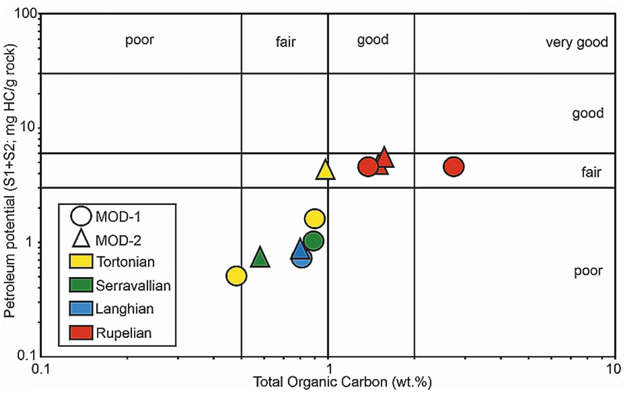

Figure 6. Plot of PP (S1+S2) versus TOC showing quality of organic matter in sediments from Modrany-1 and 2 wells.

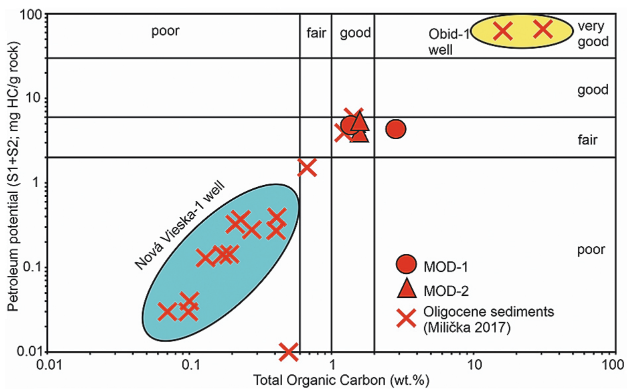

Figure 7. Summary petroleum potential diagram for Oligocene sediments from Slovakian part of Danube Basin. Based on earlier observations (Milička, 2017) and this study.

Danube Basin starts in the depth of about 2500 m (Pereszlényi et al., 1993; Milička et al., 2015; Milička, 2017). One exception is the Nová Vieska-1 well, where Oligocene sediments are very close to thermally matured stage (average T_{max} 433°C), which correspond with burial depth (above 2600 m). However, the thickness of Oligocene sediments, which can be buried deeper is irrelevant for petroleum prospection.

Brackish, euxinic Tard Fm. includes kerogen type II and III in Hungary (Tari et al., 1993; Milota et al., 1995). This kerogen was most likely redeposited to the sands and clay of the Kiscell Fm. This is consistent with previous study of Kováč et al. (2018), who suggested redeposition based on presence of coal beds which should not appear in the Tard Fm. and are typical for Kiscell Fm. The results from Rock-Eval analysis in this study confirm this claim, since the Oligocene sediments include mixed kerogen type II/III and abundant coal seams.

The Neogene sediments yield low TOC values (under 1 wt.%). These findings are consistent with earlier observations (Pereszlényi et al., 1993; Milička et al., 2015; Milička, 2017). A few intervals occur with elevated organic richness, e.g. in Pannonian (Tortonian) immature sediments of the Ivanka Fm. (T_{max} 429 °C) in MOD-2 well (1157 m) with TOC values of 0.98wt.%. The HI values (424 mg HC/g TOC) values (Fig. 5) suggest kerogen type II. Similar fair-good source rocks were described also in KOL-2 well by Milička (2017). The Pannonian (Tortonian) source rocks occur at depth of 3500 m in the deeper part of the Gabčíkovo depression (Sztanó et al., 2016) of the Danube Basin, where they reach the oil window maturity.

6. CONCLUSIONS

Rock-Eval pyrolysis shows that the Oligocene sediments from the Želiezovce depression (Danube Basin) are immature and have a fair hydrocarbons generation potential due to the presence of coaly matter. The presence of kerogen type II/III indicates that the studied mudstones could act as source rocks of light oil and gas in the deeper basin. The known extent of the Oligocene sediments does not reach the predicted oil window. Present results support the sedimentological studies, which correlate the examined succession with the Hungarian Kiscell Fm.

Neogene sediments contain source rock intervals with kerogen type III and IV and poor to fair generative potential. In the Želiezovce depression Pannonian sediments (Ivanka Fm.) are locally more abundant in kerogen type II and could act as oil and gas source rocks in the central deep part of the basin. The studied sediments represent the immature shallower part of the basin fill.

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Suppl. 1. Key biostratigraphic data from the: a) Modrany-1 well and b) Modrany-2 well: F- foramanifera, N- nannofossils

a) Modrany-1 well

Depth (m)	Core/box	Discipline	Zone/Subzone	Event
900-905	9/1	N	Pannonian/Tortonian	**Acme** *Isolithus semenenko*
955-960	10	N	Pannonian/Tortonian	*Reticulofenestra tegulata*
1000-1005	11/1/50 cm	N	Pannonian/Tortonian	*Calcidiscus pataecus, Coccolithus pelagicus, Helicosphaera carteri*
1000-1005	11/4	N	Pannonian/Tortonian	**Acme** *Isolithus semenenko*
1000-1005	11/5	N	Pannonian/Tortonian	***Acme*** *Isolithus semenenko*
1050-1056	12/1	N	Early Sarmatian/Serravallian (NN6)	*Reticulofenestra pseudoumbilicus, Coccolithus pelagicus, Holodiscolithus macroporus*
1050-1056	12/2/50 cm	F	Early Sarmatian/Serravallian (NN6)	*Globigerina sp. indet., Elphidium crispum, Heterolepa dutemplei, Elphidium aculeatum, E. josephinum, Schackoinella imperatoria, Bolivina sarmatica, Nodobaculariella* sp. *Sinuloculina consobrina, Anomalinoides dividens*
		N		*Coccolithus pelagicus, Cyclicargolithus floridanus, Reticulofenestra pseudoumbilicus, Syracosphaera* sp.
		Other		thin shelled ostracods, fish scales and bones
1050-1056	12/3	F	Early Sarmatian/Serravallian (NN6)	*Bolivina sarmatica, Sinuloculina consobrina, Anomalinoides dividens,*
1050-1056	12/4	F	Early Sarmatian/Serravallian (NN6)	*Elphidium crispum, Globigerinoides sp. indet. ?, Anomalinoides badenensis/dividens, Bolivina sarmatica, Elphidium josephinum, Articulina sp. indet., Milliolina* sp. Indet.
		Other		*Leiosphaera* sp., pyritized diatoms
1050-1056	12/5	N	Early Sarmatian/Serravallian (NN6)	*Coronocyclus nitescens, Discoaster exilis, Reticulofenestra haqii, R. minuta, R. pseudoumbilicus, Thoracosphaera* sp.
1098-1103	13/1	F	Late Badenian/Serravallian (NN6)	*Globigerina bulloides, G. diplostoma, Trilobatus trilobus, Melonis, Valvulineria, Praeglobobulimina, Globocassidulina, Textularia laevigata, Martinotiella comunis.*
		N		*Coccolithus pelagicus, Cyclicargolithus floridanus, Discoaster variabilis, Helicosphaera carteri, H. walbersdorfensis, Reticulofenestra minuta, R. pseudoumbilicus, Pontosphaera multipora*
		Other		bryozoans, algae
1298-1303	17/1	F	Early Badenian/Langhian (NN5)	*Globigerina bulloides, G. diplostoma, Trilobatus trilobus, G. transsylvanica, G. bykovae, T. quadrilobatulus, T. trilobus, Reophax, Bathysiphon, Textularia.*
		N		*Braarudosphaera bigelowii parvula , Coccolithus pelagicus, Coccolithus miopelagicus Discoaster sp., Micrantholithus vesper, Micrantholithus sp., Helicosphaera carteri, H. vedderi, H. waltrans?, Pontosphaera latelliptica, P. multipora, Sphenolithus heteromorphus*
		Other		echinoderms spines and plates
1298-1303	17/2	F	Early Badenian/Langhian (NN5)	**Acme** *Orbulina suturalis,* **Acme** *O. universa, G. transsylvanica, G. bykovae, T. quadrilobatulus, T. trilobus*
		N		*Braarudosphaera bigelowii parvula , Coccolithus pelagicus, Calcidiscus tropicus, Helicosphaera carteri, Pontosphaera multipora, Reticulofenestra haqii, R. pseudoumbilicus, Umbilicosphaera rotula, U. jafari*
		Other		echinoderms spines and plates
1298-1303	17/3	F	Early Badenian/Langhian (NN5)	*G. transsylvanica, T. quadrilobatulus, T. trilobus, Melonis, Valvulineria, Praeglobobulimina, Globocassidulina, Lenticulina, Lagena, Dentalina, Asterigerinata, Lobatula, Cibicides*
		Other		ostracod valves and echinoderms spines and plates
1402-1406	19/1	N	Early Badenian/Langhian (NN5)	*Braarudosphaera bigelowii, Coccolithus miopelagicus, Coccolithus pelagicus, Helicosphaera carteri, H. walbersdorfensis*
		Other		poriferan spicules
1698-1702	25/2	F	Early Badenian/Langhian (NN5)	*Nonion commune, Lenticulina sp. Div., Bolivina dilatata*
		N		*Braarudosphaera bigelowii parvula, Coccolithus pelagicus, Thoracosphaera* sp.
		Other		rests of mollusks, fish bones
1755-1760	26/1	N	Early Badenian/Langhian (NN5)	*Coccolithus pelagicus, Helicosphaera carteri, H. walbersdorfensis, Reticulofenestra haqii*
1855-1859	28/1	N	Kiscellian/Rupelian (NP 22?-23)	*Reticulofenestra bisecta, Reticulofenestra stavensis, Zygrhablithus bijugatus,* **LO** *Lanternithus minutus*
1900-1995	31/3	N	Priabonian-Kiscellian/Rupelian (NP 21)	*Coccolithus formosus, Coccolithus pelagicus, Cyclicargolithus floridanus, Reticulofenestra bisecta, Reticulofenestra sp., Sphenolithus moriformis, Zygrhablithus bijugatus, Lanternithus minutus,*

b) Modrany-2 well

Depth (m)	Core	Discipline	Zone/Subzone	Event
1100-1104	1/1/50 cm	F	Early Pannonian/Tortonian	*Heterolepa dutemplei*
1154-1159	2/3/50 cm	F	Early Pannonian/Tortonian	*Trochammina kibleri*
		N		*Reticulofenestra tegulata, Isolithus semenenko*
		Other		Ostracods, Shark teeth
1208-1211	3/1/50 cm	F	Early Sarmatian/Serravallian (NN6)	*Velapertina indigena, Globoturborotalita quinqueloba, Globorotalia sp., Uvigerina, Nonion, Bolivina, Lenticulina* sp.
		N		*Calcidiscus premacintyrei, C. leptoporus, C. tropicus, H. walbersdorfensis, H. wallichi, H. macroporus, R. haqii, R. minuta, R. pseudoumbilicus*
		Other		Foraminiferal tests
1253-1258	4/1/50 cm	F	Late Badenian/Serravallian (NN6)	**FO** *Globoturborotalita druryi*, **LO** *Orbulina universa, Bolivina, Bulimina, Cassidulina, Valvulineria, Melonis, Uvigerina, Cassidulina, Hoeglundina, Lenticulina, Pullenia*
		N		*Braarudosphaera bigelowii parvula, C. pelagicus, C. premacintyrei, C. tropicus, D. musicus, D. variabilis?, Holodiscolithus macroporus, Reticulofenestra. pseudoumbilicus, Sphenolithus abies*
1297-1300	5/1/50 cm	F	Late Badenian/Serravallian (NN6)	*Globigerina bulloides, Globorotalia bykovae, Asterigerina, Lobatula*
		N		*Calcidiscus sp., C. tropicus, D. variabilis, Helicosphaera walbersdorfensis, Pontosphaera japonica, R. pseudoumbilicus, U. rotula*
1356-1358	6/1/50 cm	F	Early Badenian/Langhian (NN5)	*Neoconorbina terquemi, Valvulineria sp., Asterigerinata planorbis*
		N		*C. leptoporus, C. premacintyrei, C. tropicus, Helicosphaera walbersdorfensis, H. waltrans, Sphenolithus heteromorphus*
1404-1408	7/1/50 cm	F	Early Badenian/Langhian (NN5)	*Globoturborotalita, Globigerina, Neoconorbina terquemi, Valvulineria* sp.
1505-1509	8/2/50 cm	F	Early Badenian/Langhian (NN5)	**FO** *Orbulina suturalis, Dentoglobigerina, Globorotalia, Globigerinoides* spp., *Bulimina* sp., *Bathysiphon, Ammobaculites*
1796-1801	12	N	Early Badenian/Langhian (NN5)	*Calcidiscus leptoporus, Calcidiscus* sp., *D. variabilis, Helicosphaera walbersdorfensis, H. scissura, R. haqii, R. minuta*
1901-1906	13/1/50 cm	N	Early Badenian/Langhian (NN5)	***Acme*** *Sphenolithus. heteromorphus, Calcidiscus sp., C. leptoporus, C. tropicus, Discoaster exilis, D. deflandrei. C. pelagicus, Cyclicargolithus floridanus, R. minuta*
2005-2009	14/3-4/50 cm	F	Early Badenian/Langhian (NN5)	*Globigerinoides bisphaericus, Praeorbulina sicana, Praeorbulina circularis, Globigerinoides spp., Praeorbulina* sp, *Hoeglundina, Bolivina, Uvigerina, Spiroplectammina, Heterolepa, Melonis*
		N		*Reticulofenestra minuta, R. haqii, Braarudosphaera bigelowii parvula, Discoaster variabilis, Helicosphaera walbersdorfensis, H. waltrans, Sphenolithus heteromorphus, Umbilicosphaera rotula, U. jafari,*
2110-2117	15/1/50 cm	N	Early Badenian/Langhian (NN4)	*Helicosphaera ampliaperta, Sphenolithus heteromorphus, Helicosphaera carteri, Umbilicosphaera rotula*
2164-2167	16	N	Priabonian-Kiscellian/Rupelian (NP 21)	**LO** *Coccolithus formosus*, **LO** *Discoaster tanii*, **LO** *Lanternithus minutus*, **LO** *Reticulofenestra umbilicus*
2305-2308	18/1/50 cm	F	Priabonian-Kiscellian/Rupelian (NP 21)	*Subbotina. tecta, S. corpulenta, S. angiporoides,*
		N		*Reticulofenestra lockeri, R. ornata, R. stavensis, R. bisecta, Coccolithus formosus, Discoaster tanii, Lanternithus minutus, R. umbilicus*

Suppl. 2. Complete fauna list: a) Foraminifera; b) Nannofossils

a) Foraminifera

Adelosina pulchella (d'Orbigny, 1826)
agglutinate indet.
Ammobaculites agglutinans (d'Orbigny, 1846)
Ammonia parkinsoniana (d'Orbigny, 1839)
Ammonia viennensis (d'Orbigny, 1846)
Ammoscalaria sp.
Amphistegina sp.
Angulogerina sp.
Asterigerinata mamilla (Williamson, 1858)
Asterigerinata sp.
Aubignyna perlucida (Heron-Allen & Earland, 1913)
Bathysiphon filiformis Sars, 1872
Bathysiphon sp.
Bathysiphon taurinensis Sacco, 1893
Biasterigerina planorbis (d'Orbigny, 1846)
Bigenerina agglutinans d'Orbigny, 1846
Bolivina antiqua d'Orbigny, 1846
Bolivina dilatata Reuss, 1850
Bolivina dilatata subsp. *brevis* Cicha & Zapletalová, 1963

Bolivina fastigia Cushman, 1936
Bolivina hebes Macfadyen, 1930
Bolivina pokornyi Cicha & Zapletalová, 1963
Bolivina pseudoplicata Heron-Allen & Earland, 1930
Bolivina sp.
Bulimina aculeata d'Orbigny, 1826
Bulimina elegans d'Orbigny in Parker, Jones & Brady, 1865
Bulimina elongata d'Orbigny, 1846
Bulimina intonsa Livental, 1953
Bulimina striata d'Orbigny in Guérin-Méneville, 1832
Bulimina subulata Cushman & Parker, 1937
Cancris auricula (Fichtel & Moll, 1798)
Cassidulina globosa Hantken, 1875
Cassidulina laevigata d'Orbigny, 1826
Cassigerinella sp.
Caveastomella adolphina (d'Orbigny, 1846)
Cibicides crassiseptatus Łuczkowska, 1960
Cibicidoides boueanus ornatus (Cicha & Zapletalová, 1958)
Cibicidoides lobatulus (Walker & Jacob, 1798)
Cibicidoides pseudoungeriana (Cushman, 1922)
Cibicidoides pseudoungerianus ornatus (Cicha & Zapletalová, 1958)
Cibicidoides ungerianus (d'Orbigny, 1846)
Cyclammina karpatica Cicha & Zapletalová, 1963
Cycloforina badenensis (d'Orbigny, 1846)
Dentoglobigerina altispira (Cushman & Jarvis 1936)
Discorbis sp.
Dorothia scabra (Brady, 1884)
Elphidium aculeatum (d'Orbigny, 1846)
Elphidium crispum (Linnaeus, 1758)
Elphidium fichtelianum (d'Orbigny, 1846)
Elphidium flexuosum (d'Orbigny, 1846)
Elphidium macellum (Fichtel & Moll, 1798)
Epistominella exigua (Brady, 1884)
Favulina hexagona (Williamson, 1848)
Fissurina laevigata Reuss, 1850
Fursenkoina subacuta (d'Orbigny, 1852)
Gaudryina megagranosa Venglinsky, 1953
Gaudryina sp.
Globigerina bulloides d'Orbigny, 1826
Globigerina falconensis Blow, 1959
Globigerina regularis d'Orbigny, 1846
Globigerinella calida (Parker, 1962)
Globigerinella obesa (Bolli, 1957)
Globigerinella wagneri (Rögl, 1994)
Globigerinidae 4-cham. sp. div. indet
Globigerinita uvula (Ehrenberg, 1861)
Globigerinoides sp. div. indet.
Globocassidulina crassa (d'Orbigny, 1839)
Globocassidulina subglobosa (Brady, 1881)
Globorotalia (Turborotalia) transsylvanica Popescu 1970
Globorotalia acrostoma subsp. *partimlabiata* Ruggieri & Sprovieri, 1970
Globorotalia bykovae (Aisenstat in *Subbotina*, Pishvanova & Ivanova, 1960)
Globorotalia scitula (Brady, 1882)
Globoturborotalita decoraperta (Takayanagi & Saito, 1962)
Globoturborotalita druryi (Akers, 1955)
Globoturborotalita woodi (Jenkins, 1960)
Guttulina austriaca d'Orbigny, 1846
Hansenisca soldanii (d'Orbigny, 1826)
Haplophragmoides sp.
Haplophragmoides fragile Höglund, 1947
Haplophragmoides wilsoni Smith, 1948
Haynesina depressula (Walker & Jacob, 1798)
Heterolepa dutemplei (d'Orbigny, 1846)
Hoeglundina elegans (d'Orbigny, 1826)
Lagenammina atlantica (Cushman, 1944)
Lagenammina difflugiformis (Brady, 1879)
Lagenammina sp.
Lenticulina calcar (Linnaeus, 1758)
Lenticulina cultrata (Montfort, 1808)
Lenticulina sp.
Martinottiella communis (d'Orbigny, 1846)
Melonis pompilioides (Fichtel & Moll, 1798)
Miliammina fusca (Brady, 1870)
Miliolidae sp. div. Indet.
Neoconorbina terquemi (Rzehak, 1888)
Nodosaria elegans Neugeboren, 1852
Nodosaria sp.
Nonion commune (d'Orbigny, 1846)
Nonion sp.
Nonionella miocenica Cushman, 1926
Orbulina sp. indet
Orbulina suturalis Brönnimann, 1951
Orbulina universa d'Orbigny, 1839
Paragloborotalia siakensis (LeRoy, 1939)
Plectofrondicularia digitalis (Neugeboren, 1850)
Praeorbulina circularis (Blow, 1956)
Praeorbulina glomerosa (Blow, 1956)
Protoglobobulimina pupoides (d'Orbigny, 1846)
Pseudononion japonicum Asano, 1936
Pseudotriplasia sp.
Pullenia bulloides (d'Orbigny, 1846)
Pyramidulina raphanistrum (Linnaeus, 1758)
Quinqueloculina agglutinans d'Orbigny, 1839
Quinqueloculina seminula (Linnaeus, 1758)
Quinqueloculina sp.
Reophax fusiformis (Williamson, 1858)
Reophax scorpiurus Montfort, 1808
Reophax sp.
Reticulophragmium venezuelanum (Maync, 1952)
Rosalina bradyi (Cushman, 1915)
Rotalia sp.
Saccammina sp.
Sagrina dertonensis (Gianotti, 1953)
Sahulia conica (d'Orbigny, 1839)
Saracenaria arcuata (d'Orbigny, 1846)
Sphaeroidina bulloides d'Orbigny in Deshayes, 1828
Sigmoilopsis schlumbergeri (Silvestri, 1904)
Siphonina reticulata (Czjžek, 1848)
Spincterules anaglyptus Loeblich & Tappan, 1987
Spiroloculina canaliculata d'Orbigny, 1846
Spirorutilus carinatus (d'Orbigny, 1846)

Spirosigmoilina tenuis (Czjžek, 1848)
Stilostomella sp.
Subbotina sp.
Tenuitella munda (Jenkins, 1966)
Textularia sp.
Textularia gramen d'Orbigny, 1846
Textularia mariae d'Orbigny, 1846
Textularia pala Czjžek, 1848
Trifarina angulosa (Williamson, 1858)
Trilobatus bisphericus (Todd, 1954)
Trilobatus quadrilobatus (d'Orbigny, 1846)
Trilobatus sicanus (de Stefani 1952)
Trilobigerina triloba (Reuss, 1850)
Triloculina gibba d'Orbigny, 1826
Triloculina sp.
Trochammina kibleri Venglinsky, 1961
Trochammina sp.
Turborotalita quinqueloba (Natland, 1938)
Uvigerina aculeata d'Orbigny, 1846
Uvigerina acuminata Hosius, 1895
Uvigerina asperula Czjžek, 1848
Uvigerina brunnensis Karrer, 1877
Uvigerina grilli Schmid, 1971
Uvigerina macrocarinata Papp & Turnovsky, 1953
Uvigerina peregrina Cushman, 1923
Uvigerina semiornata d'Orbigny, 1846
Uvigerina venusta Franzenau, 1894
Valvulineria bradyana (Fornasini, 1900)
Valvulineria complanata (d'Orbigny, 1846)
Valvulineria sp.

b) Nannofossils

Ahmuellerella octoradiata (Górka, 1957) Reinhardt & Górka, 1967
Arkhangelskiella cymbiformis Vekshina, 1959
Blackites inflatus (Bramlette & Sullivan, 1961) Kapellos & Schaub, 1973
Blackites spinosus (Deflandre & Fert, 1954) Hay & Towe, 1962
Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre, 1947
Braarudosphaera bigelowii parvula (Gran & Braarud, 1935) Deflandre, 1947
Braarudosphaera sequela Self-Trail, 2011
Calcidiscus leptoporus (Murray & Blackman, 1898) Loeblich & Tappan, 1978
Calcidiscus premacintyrei Theodoridis, 1984
Calcidiscus protoannulus (Gartner, 1971) Loeblich & Tappan, 1978
Calcidiscus sp. Kamptner, 1950
Calcidiscus tropicus 6-7 μm (Kamptner, 1955) Varol, 1989 *sensu* Gartner, 1992
Calcidiscus tropicus 8-9 μm (Kamptner, 1955) Varol, 1989 *sensu* Gartner, 1992
Calciosolenia fossilis (Deflandre in Deflandre & Fert, 1954) Bown in Kennedy et al., 2000
Calculites obscurus (Deflandre, 1959) Prins & Sissingh in Sissingh, 1977
Clausicoccus sp. Prins, 1979
Coccolithus eopelagicus (Bramlette & Riedel, 1954) Bramlette & Sullivan, 1961
Coccolithus formosus (Kamptner, 1963) Wise, 1973
Coccolithus miopelagicus Bukry, 1971
Coccolithus pelagicus (Wallich, 1877) Schiller, 1930
Coronocyclus nitescens (Kamptner, 1963) Bramlette & Wilcoxon, 1967
Cribrosphaerella ehrenbergii (Arkhangelsky, 1912) Deflandre in Piveteau, 1952
Cyclicargolithus abisectus (Müller, 1970) Wise, 1973
Cyclicargolithus floridanus (Roth & Hay, in Hay et al., 1967) Bukry, 1971
Discoaster barbadiensis Tan, 1927
Discoaster deflandrei Bramlette & Riedel, 1954
Discoaster druggi Bramlette & Wilcoxon, 1967
Discoaster exilis Martini & Bramlette, 1963
Discoaster mohleri Bramlette & Percival, 1971
Discoaster multiradiatus Bramlette & Riedel, 1954
Discoaster musicus Stradner, 1959
Discoaster sp. Tan, 1927
Discoaster tanii Bramlette & Riedel, 1954
Discoaster variabilis Martini & Bramlette, 1963
Eiffellithus eximius (Stover, 1966) Perch-Nielsen, 1968
Eiffellithus turriseiffelii (Deflandre in Deflandre & Fert, 1954) Reinhardt, 1965
Ellipsolithus macellus (Bramlette & Sullivan, 1961) Sullivan, 1964
Ericsonia robusta (Bramlette & Sullivan, 1961) Edwards & Perch-Nielsen, 1975
Fasciculithus sp. Bramlette & Sullivan, 1961
Helicosphaera ampliaperta Bramlette & Wilcoxon, 1967
Helicosphaera bramlettei (Müller, 1970) Jafar & Martini, 1975
Helicosphaera carteri (Wallich, 1877) Kamptner, 1954
Helicosphaera euphratis Haq, 1966
Helicosphaera intermedia Martini, 1965
Helicosphaera scissura Miller, 1981
Helicosphaera sp. Kamptner, 1954
Helicosphaera walbersdorfensis Müller, 1974
Helicosphaera wallichii (Lohmann, 1902) Okada & McIntyre, 1977
Helicosphaera waltrans Theodoridis, 1984
Holodiscolithus macroporus (Deflandre in Deflandre & Fert, 1954) Roth, 1970
Chiasmolithus sp. Hay et al., 1966
Isolithus semenenko Luljeva, 1989
Lanternithus minutus Stradner, 1962
Lanternithus sp. Stradner, 1962
Lucianorhabdus cayeuxii Deflandre, 1959
Markalius inversus (Deflandre in Deflandre & Fert, 1954) Bramlette & Martini, 1964
Micrantholithus sp. Deflandre in Deflandre & Fert, 1954
Micula staurophora (Gardet, 1955) Stradner, 1963
Nannoconus sp. Kamptner, 1931
Nannoconus steinmannii Kamptner, 1931

Neococcolithes dubius (Deflandre in Deflandre & Fert, 1954) Black, 1967
Neochiastozygus sp. Perch-Nielsen, 1971
Pemma sp. Klumpp, 1953
Pontosphaera exilis (Bramlette & Sullivan, 1961) Romein, 1979
Pontosphaera japonica (Takayama, 1967) Nishida, 1971
Pontosphaera latelliptica (Báldi-Beke & Báldi, 1974) Perch-Nilesen, 1984
Pontosphaera multipora (Kamptner, 1948 ex Deflandre in Deflandre & Fert, 1954) Roth, 1970
Pontosphaera pulcheroides (Sullivan, 1964) Romein, 1979
Pontosphaera pulchra (Deflandre in Deflandre & Fert, 1954) Romein, 1979
Pontosphaera sp. Lohmann, 1902
Prediscosphaera cretacea (Arkhangelsky, 1912) Gartner, 1968
Pseudotriquetrorhabdulus sp. Wise in Wise & Constans, 1976
Reinhardtites sp. Perch-Nielsen, 1968
Retecapsa crenulata (Bramlette & Martini, 1964) Grün in Grün & Allemann, 1975
Reticulofenestra bisecta (Hay, Mohler & Wade, 1966) Roth, 1970
Reticulofenestra haqii Backman, 1978
Reticulofenestra hillae Bukry & Percival, 1971
Reticulofenestra lockeri Müller, 1970
Reticulofenestra minuta Roth, 1970
Reticulofenestra ornata Müller, 1970
Reticulofenestra pseudoumbilicus (Gartner, 1967) Gartner, 1969
Reticulofenestra pseudoumbilicus 6-7 μm (Gartner, 1967) Gartner, 1969
Reticulofenestra reticulata (Gartner & Smith, 1967) Roth & Thierstein, 1972
Reticulofenestra sp. Hay, Mohler & Wade, 1966
Reticulofenestra stavensis (Levin & Joerger, 1967) Varol, 1989
Reticulofenestra tegulata (Bona & Gal, 1985) Coric & Gross, 2004
Reticulofenestra umbilicus (Levin, 1965) Martini & Ritzkowski, 1968
Rhabdosphaera sicca (Stradner, 1963) Fuchs & Stradner, 1977
Rhabdosphaera sp. Haeckel, 1894
Rhagodiscus splendens (Deflandre, 1953) Verbeek, 1977
Rucinolithus hayi Stover, 1966
Sphenolithus abies Deflandre in Deflandre & Fert, 1954
Sphenolithus conicus Bukry, 1971
Sphenolithus heteromorphus Deflandre, 1953
Sphenolithus moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967
Sphenolithus predistentus Bramlette & Wilcoxon, 1967
Sphenolithus radians Deflandre in Grassé, 1952
Sphenolithus sp. Deflandre in Grassé, 1952
Syracosphaera pulchra Lohmann, 1902
Syracosphaera sp. Lohmann, 1902
Thoracosphaera sp. Kamptner, 1927
Toweius gammation (Bramlette & Sullivan, 1961) Romein, 1979
Triquetrorhabdulus rugosus Bramlette & Wilcoxon, 1967
Triquetrorhabdulus sp. Martini 1965 emend Young & Bown, 2014
Umbilicosphaera bramlettei (Hay & Towe, 1962) Bown et al., 2007
Umbilicosphaera jafari Müller, 1974
Umbilicosphaera rotula (Kamptner, 1956) Varol, 1982
Umbilicosphaera sp. Lohmann, 1902
Uniplanarius sissinghii (Perch-Nielsen, 1986) Farhan, 1987
Uniplanarius sp. Hattner & Wise, 1980
Watznaueria barnesiae (Black in Black & Barnes, 1959) Perch-Nielsen, 1968
Zeugrhabdotus sp. Reinhardt, 1965
Zygrhablithus bijugatus (Deflandre in Deflandre & Fert, 1954) Deflandre, 1959