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Biostratigraphic constraints for a Lutetian age of the Harrersdorf Unit (Rhenodanubian Zone): Implication for basement structure of the northern Vienna Basin (Austria)

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Abstract: The formations underlying the Neogene infill of the Vienna Basin are still poorly documented. Until now correlation of subsurface lithostratigraphic units with those of the Rhenodanubian nappe system and the Magura nappe system, outcropping at the basin margins, has been based on extrapolations. A recent drilling campaign in the Bernhardsthal oil field of the northern Vienna Basin in Austria reached the pre-Neogene basement and provided cuttings for biostratigraphic and paleoecological analyses. Based on these data, acquired by using detailed micro- and nanno-paleontological analyses, a Lutetian age (middle Eocene) and a bathyal depositional environment for the Flysch of the Harrersdorf Unit was documented. The lithological similarity of the drilling with the Steinberg Flysch Formation of the Greifenstein Nappe and its Lutetian age suggests, that the middle Eocene part of the Harrersdorf Unit represents a continuation of the Greifenstein Nappe of the Rhenodanubian Flysch, rather than a frontal part of the Rača Nappe of the Magura Flysch as previously thought.

Keywords: Eocene, Vienna Basin, Rhenodanubian Flysch, Harrersdorf Unit, biostratigraphy.

Introduction

During recent hydrocarbon prospection in the northern Vienna Basin, the Austrian oil company OMV drilled explorative boreholes in the Bernhardsthal oilfield in NW Austria close to the Czech border (Fig. 1) (see Harzhauser et al. 2018a for a geological overview and description of the Neogene deposits). Wessely et al. (1993) interpreted the pre-Neogene basement of the Bernhardsthal oilfield as Cretaceous to Eocene flysch. This interpretation was based solely on unpublished internal reports of the OMV and by extrapolation of drilling data from the Steinberg area. Within the current drilling campaign, the Bernhardsthal 11 borehole (Be 11) reached these pre-Neogene units, which have not been described so far in terms of biostratigraphy.

Neogene deposits are documented in the Bernhardsthal 11 borehole down to ~2745 m (own data). Deep-water deposits of the lower Miocene Lužice Formation (Kováč et al. 2004) represent these basal Neogene units. Below this level, down to 3140 m, the pelitic facies of the Lužice Formation is replaced by an about 400-m-thick succession of flysch-type deposits of grey to dark grey marly shales alternating with glauconitic sandstone. The first thin sections were produced already during the drilling campaign and pointed to the presence of pre-Neogene foraminifera, but a more precise age assignment was impossible at the time. Therefore, OMV initiated detailed paleontological analyses of the microfauna and the calcareous nannoplankton to clarify the age and depositional setting of this enigmatic interval.

Geographical and geological setting

The Bernhardsthal 11 borehole (48°41'18.45" N, 16°50' 53.25" E) is situated in the northern Vienna Basin, which is an about 200 km long and 55 km wide, rhomboid pull-apart basin (Royden 1985; Wessely 1988, 2006), covering large parts of eastern Austria and extending into the Czech Republic in the North and Slovakia in the East (see Kováč et al. 2004 and Wessely 2006 for description). Due to complex fault systems, the basin was internally subdivided into a series of horst and graben systems (Kröll & Wessely 1993; Vass 2002). Due to these structural elements, its Neogene basin-fill is an important target for hydrocarbon exploration (Hamilton et al. 1999). One of the major oil and gas fields in the Vienna Basin is the Bernhardsthal oil field in NE Austria close to the Czech Republic border (Harzhauser et al. 2018a).

Within the Bernhardsthal oil field, the Miocene basin fill is in the direct vicinity and sphere of influence of the Steinberg fault (Fig. 1), roughly striking in a SSW–NNE direction with the Bernhardsthal field in the NNW. Due to their economic importance, numerous boreholes have penetrated the Neogene deposits (Kröll & Wessely 1993; Harzhauser et al. 2018a).

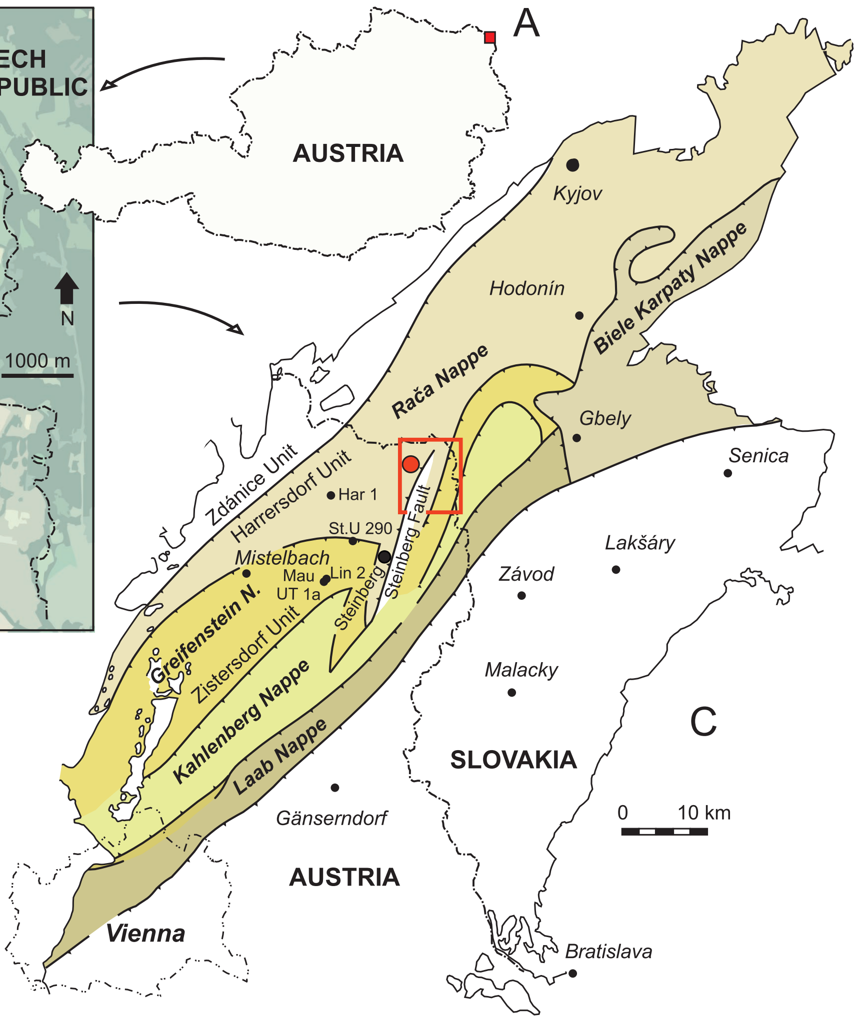

Fig. 1. A — Geographical and geological setting of the study area at the Austrian–Czech boundary; **B** — position of the Be 11 borehole; **C** — Subsurface distribution of the Rhenodanubian and Magura flysch units in the northern Vienna Basin, compiled from Rammel (1989) and Wessely et al. (1993). The location of Be 11 is shown in the red insert. Note that the boundary between Greifenstein und Rača Nappe nappes as proposed by Wessely et al. (1993) is hypothetical and the Harrersdorf Unit might rather represent a continuation of the Greifenstein Nappe.

Material and methods

Sixteen cutting samples from the Bernhardsthal Be 11 core interval from 2745 to 3140 m were analysed (see Fig. 2 for sample position). The sedimentological analysis is based on on-site logging, visual analysis of core samples and cuttings. Core samples and cuttings from the core interval above 2745 m contained early Miocene microfaunas (Harzhauser et al. 2018b) and are not discussed here. Cuttings were taken and cleaned on-site. To widen the sampling interval of the cuttings, four consecutive cutting samples with a standard sample distance of 2.5 m were washed and sieved together (e.g. 2747.5, 2750, 2752.5, 2755 m). Each sample was treated with diluted H_2O_2 (12 %) for several hours and washed afterwards with tap water and sieved through a set of standard sieves. The samples were dried at 40 °C and then split with a microsplitter (as described in Rupp 1986). The specimens were picked and counted for size fractions 500–250 μm, 250–125 μm and 125–63 μm. For identification of foraminifers several different publications were used (e.g., Papp et al. 1973; Loeblich & Tappan 1987; Cicha et al. 1998; Rögl & Spezzaferii 2003; Bubík & Kaminski 2004; Bindiu-Haitonic et al. 2017).

In addition, cutting samples from 2855 m, 2930 m, 2945 m, 3040 m, 3070 m and 3100 m were analysed for calcareous nannoplankton, following standard preparation methods as described in Perch-Nielsen (1985). The standard nannoplankton zonation of Martini (1971) was used for biostratigraphic attribution of investigated material. All samples are barren of macrofossils. SEM (scanning electron microscope) micrographs were taken at the Natural History Museum Vienna. All illustrated foraminifers are stored in the micropaleontological collection of the Natural History Museum Vienna; nannoplankton samples are stored in the Geological Survey, Vienna. Lists of all recorded calcareous nannoplankton and foraminiferal taxa are given in Tables 1 and 2, including authors and years of description. To warrant readability, authors and years of descriptions are not repeated in the following text.

Sedimentological data were logged on-site during drilling by OMV. In addition, wire-log data were provided by OMV for analysis (GR=natural gamma radiation, RES=resistivity).

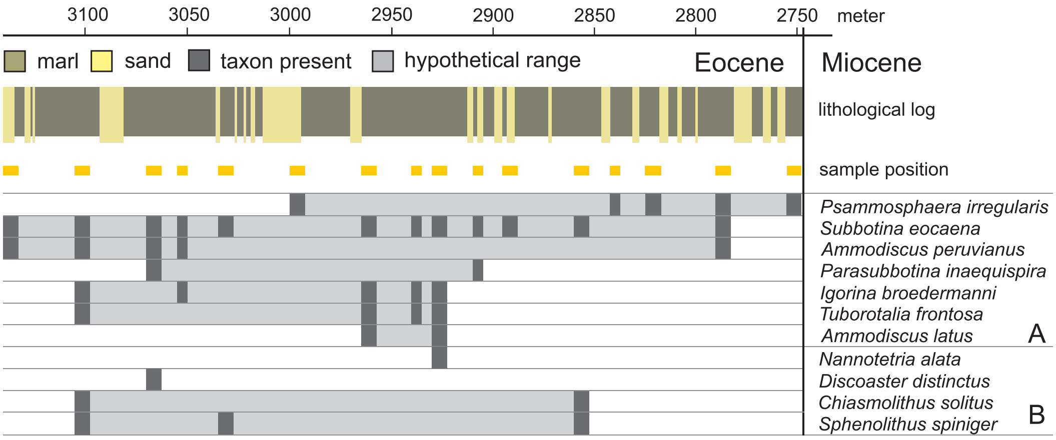

Fig. 2. The Eocene part of Be 11 with sample positions. The occurrences of important foraminiferal taxa (**A**) and calcareous nannoplankton taxa (**B**) correlated with the lithological log.

Results

Lithology and wire-log pattern

Grey to dark grey marly shales, intercalated by thin glauconitic sandstone layers characterize the studied part of the Be 11 core (2745–3140 m) (Fig. 2). This lithological alternation is expressed in wire-logs by serrated shale-line intervals alternating with cylinder-shaped or funnel shaped sand bodies (e.g. 2990–3120 m, 3000–3025 m). No trends or cyclicities can be seen and a spectral analysis failed to detect any significant periods. The wire-log patterns differ considerably from those of the overlying Miocene deposits, which display a strikingly cyclic succession of bell-shaped intervals (Fig. 3).

Micropaleontological data

Calcareous nannoplankton: The samples yield a moderately diverse assemblage of 51 taxa; individual samples contained 11 to 23 taxa (Table 1; Fig. 4A–R). The Neogene is represented by typical lower Miocene taxa (4 in total) *Helicosphaera ampliaperta, Helicosphaera carteri, Helicosphaera scissura* and *Reticulofenestra excavata*. Paleogene nannofossils are represented by 37 and Cretaceaous by 5 taxa (*Arkhangelskiella cymbiformis, Cribrosphaerella ehrenbergii, Micula staurophora, Prediscosphaera cretacea, Watznaueria barnesiae*) whereas 5 taxa have long stratigraphical ranges (*Braarudosphaera bigelowii, Coccolithus pelagicus, Cyclicargolithus floridanus, Reticulofenestra minuta, Sphenolithus moriformis*).

Coccolithus formosus (Fig. 4D), *Coccolithus pelagicus* (Fig. 4E), *Reticulofenestra dictyoda* and *Cyclicargolithus floridanus* (Fig. 4F–G) occur in all samples. *Nannotetrina alata* (Fig. 4Q–R), *Discoaster distinctus* (Fig. 4P), *Chiasmolithus solitus, Reticulofenestra umbilicus, Lophodolithus nascens* and *Sphenolithus spiniger* are present taxa as well. Other species, documented from the lowermost sample (3100 m) to the top sample (2885 m) are *Sphenolithus moriformis* (Fig. 4M), *Chiasmolithus grandis*, *Zygrhablithus bijugatus*, *Chiasmolithus oamaruensis* and *Discoaster kuepperi*.

Foraminifera: The core interval 2745–3140 m provided only moderately to poorly preserved foraminifers. In total, 42 foraminiferal taxa have been identified (Table 2, Figs. 5A–L, 6A–L, 7A–L). The maximum diversity ranges around 21–15 taxa in samples 2922.5–2930 m, 2935–2940 m and 2957.5–2965 m; all other samples display a very low diversity ranging from 3 to 10 taxa. Planktic foraminifera are more frequent and represented by small sized specimens of *Subbotina eocaena* (Fig. 5D–G), *Igorina salisburgensis* (Fig. 5C), *Igorina broedermanni* (Fig. 5B), *Acarinina bullbrooki* (Fig. 5A), *Turborotalia frontosa* (Fig. 5L), *Pseudohastigerina wilcoxensis* (Fig. 5H), *Globorotaloides eovariabilis* (Fig. 5J), *Parasubbotina inaequispira* (Fig. 5K) and *Pseudohastigerina* sp. (Fig. 5I). The most abundant benthic taxa are *Glomospira charoides* (Fig. 6D–E), *Glomospira gordialis* (Fig. 6F), *Ammodiscus peruvianus* (Fig. 6B), *Ammodiscus tenuissimus*, *Ammodiscus cretaceous* (Fig. 6C), *Lituotuba lituiformis* (Fig. 6A), *Psammosphaera irregularis* (Fig. 6G–H), *Karrerulina conversa* (Fig. 6J), *Bathysiphon saidi* and *Bathysiphon* sp. and are accompanied by *Melonis pompilioides* (Fig. 7C–D), *Cibicides westi* (Fig. 7G), *Cibicidoides* sp. (Fig. 7F), *Pullenia* sp. (Fig. 7I), *Anomalinoides* sp. (Fig. 7H), *Rhabdammina* sp. (Fig. 7J), *Psammosiphonella* sp. (Fig. 7K) and *Caucasina coprolithoides* (Fig. 6K).

Discussion

Biostratigraphy and paleoecology

Calcareous nannoplankton: Assemblages are characterized by the high number of species which display a stratigraphic overlap during the middle Eocene. *Nannotetrina alata* and *Discoaster distinctus* are restricted to the Lutetian and are

Table 1: Calcareous Nannoplankton taxa from the Be 11 borehole (1/0=presence/absence).

Species	**2855**	**2930**	**2945**	**3040**	**3070**	**3100**
Arkhangelskiella cymbiformis Vekshina, 1959	1	0	0	0	0	0
Blackites sp.	0	0	0	0	0	1
Braarudosphaera bigelowii (Gran & Braarud 1935) Deflandre, 1947	1	0	0	0	0	0
Campylosphaera dela (Bramlette & Sullivan, 1961) Hay & Mohler, 1967	0	0	0	0	0	1
Chiasmolithus grandis (Bramlette & Riedel, 1954) Radomski, 1968	0	1	0	1	1	1
Chiasmolithus oamaruensis (Deflandre, 1954) Hay *et al.*, 1966	1	0	0	1	0	1
Chiasmolithus solitus (Bramlette and Sullivan, 1961) Locker, 1968	1	0	0	0	0	1
Chiasmolithus sp.	0	0	1	0	0	0
Coccolithus formosus (Kamptner, 1963) Wise, 1973	1	1	1	1	1	1
Coccolithus pelagicus (Wallich 1877) Schiller, 1930	1	1	1	1	1	1
Cribrocentrum erbae Fornaciari, Agnini, Catanzariti and Rio in Fornaciari et al. 2010	0	0	0	1	0	0
Cribrosphaerella ehrenbergii (Arkhangelsky, 1912) Deflandre in Piveteau, 1952	1	0	0	0	0	0
Cyclagelosphaera margerelii Noël, 1965	0	1	0	0	0	0
Cyclicargolithus floridanus (Roth & Hay, *in* Hay *et al.*, 1967) Bukry, 1971	1	1	1	1	1	1
Dictyococcites hesslandii Haq 1971 1	0	0	0	1	1	0
Discoaster barbadiensis Tan, 1927	0	0	0	0	0	1
Discoaster deflandrei Bramlette & Riedel, 1954	0	0	0	1	0	0
Discoaster distinctus Martini, 1958	0	0	0	0	1	0
Discoaster kuepperi Stradner, 1959	1	0	1	0	0	1
Discoaster lodoensis Bramlette & Riedel, 1954	1	0	1	0	0	1
Helicosphaera ampliaperta Bramlette and Wilcoxon, 1967	1	0	0	0	0	0
Helicosphaera bramlettei (Müller, 1970) Jafar & Martini, 1975	0	0	0	0	1	1
Helicosphaera euphratis Haq, 1966	1	0	0	1	0	0
Helicosphaera seminulum Bramlette & Sullivan, 1961	0	0	0	0	0	1
Isthmolithus recurvus Deflandre *in* Deflandre and Fert, 1954	0	0	0	1	0	0
Lophodolithus mochlophorus Deflandre *in* Deflandre & Fert, 1954	0	0	0	1	0	1
Lophodolithus nascens Bramlette & Sullivan, 1961	0	1	0	0	0	0
Micrantholithus sp.	0	0	0	1	0	1
Micula staurophora (Gardet, 1955) Stradner, 1963	1	0	0	0	0	0
Nannotetrina alata (Martini, in Martini & Stradner 1960) Haq and Lohmann, 1976	0	0	1	0	0	0
Neochiastozygus sp.	1	0	0	0	0	0
Pontosphaera exilis (Bramlette & Sullivan, 1961) Romein, 1979	0	1	0	1	0	0
Pontosphaera sp.	1	0	0	0	0	0
Reticulofenestra dictyoda (Deflandre *in* Deflandre & Fert, 1954) Stradner *in* Stradner & Edwards, 1968	1	1	1	1	1	1
Reticulofenestra hillae Bukry & Percival, 1971	0	1	0	1	0	0
Reticulofenestra minuta Roth, 1970	0	0	0	1	0	0
Reticulofenestra sp.	0	0	0	0	0	1
Reticulofenestra umbilicus (Levin, 1965) Martini & Ritzkowski, 1968	0	0	1	1	1	0
Sphenolithus dissimilis Bukry and Percival, 1971	0	1	0	0	0	0
Sphenolithus editus Perch-Nielsen *in* Perch-Nielsen *et al.*, 1978	0	0	1	1	0	0
Sphenolithus moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967	1	1	0	1	1	1
Sphenolithus radians Deflandre *in* Grassé, 1952	1	1	1	0	0	0
Sphenolithus spiniger Bukry, 1971	1	0	0	1	0	1
Thoracosphaera saxea Stradner, 1961	0	0	0	0	1	0
Toweius callosus Perch-Nielsen, 1971	0	0	1	0	0	0
Toweius rotundus Perch-Nielsen *in* Perch-Nielsen *et al.*, 1978	0	0	0	1	0	0
Toweius sp.	1	0	0	0	0	0
Tribrachiatus orthostylus Shamrai, 1963	0	0	0	0	0	1
Watznaueria barnesiae (Black *in* Black & Barnes, 1959) Perch-Nielsen, 1968	1	0	0	1	0	0
Watznaueria fossacincta (Black, 1971) Bown *in* Bown & Cooper, 1989	0	0	1	0	0	0
Zygrhablithus bijugatus (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959	1	0	1	1	1	0

typical for the standard Calcareous Nannoplankton Zone NP15 (Martini 1971). *Lophodolithus nascens* appears already during the Selandian Zone NP6 and has its last occurrence during the Lutetian Zone NP15 (Perch-Nielsen 1985) and *Sphenolithus spiniger* ranges from the latest Ypresian NP14 zone to the Bartonian Zone NP17 (Perch-Nielsen 1985; Fornaciari et al. 2010). Similarly, the occurrence of *Chiasmolithus solitus*, ranging from the Thanetian Zone NP9 to the Lutetian Zone NP16 (Perch-Nielsen 1985; Vandenberghe et al. 2012), does not contradict a Lutetian age (Bramlette & Sullivan 1961).

At first sight, a Priabonian age might be assumed based on the occurrences of *Chiasmolithus oamaruensis* (2855, 3040, 3100 m depth), *Isthmolithus recurvus* (3040 m depth),

Table 2: Foraminifera taxa from the Be 11 borehole (1/0=presence/absence).

Species	**2747.5 – 2755**	**2782.5 – 2790**	**2817**	**2845 – 2850**	**2852.5 – 2860**	**2887.5 – 2895**	**2905 – 2910**	**2922.5 – 2930**	**2935 – 2940**	**2957.5 – 2965**	**2992.5 – 3000**	**3075.5 – 3035**	**3050 – 3055**	**3062.5 – 3070**	**3097.5 – 3105**	**3132.5 – 3140**
Acarinina bullbrooki (Bolli, 1957)	0	0	0	0	0	0	0	1	1	1	0	0	1	0	1	0
Ammobaculites sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
Ammodiscus cretaceus (Reuss, 1845)	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0
Ammodiscus peruvianus (Berry, 1928)	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1
Ammodiscus tenuissimus Grzybowski, 1898	0	0	0	1	1	0	1	0	0	0	0	0	0	1	1	0
Anomalinoides sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Bathysiphon saidi (Anan, 1994)	0	0	1	0	0	1	1	1	1	1	0	0	0	1	1	1
Bathysiphon sp. 1	0	0	0	1	0	0	0	0	1	0	1	1	0	1	1	1
Bathysiphon sp. 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Caucasina coprolithoides (Andreae, 1884)	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0
Cibicides westi (Howe, 1939)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Cibicidoides pseudoungerianus (d'Orgigny, 1846)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Cibicidoides sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
Cibicidoides ungerianus (d'Orgigny, 1846)	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
Dentalina sp.	1	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0
Globocassidulina oblonga (Reuss, 1850)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Globorotaloides eovariabilis Huber & Pearson, 2006	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Glomospira charoides (Jones and Parker, 1860)	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1
Glomospira gordialis (Jones and Parker, 1860)	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	1
Gonatosphaera inflata Bermúdez, 1949	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Gyroidinoides sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Haplophragmoides walteri (Grzybowski, 1898)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Heterolepa dutemplei (d'Orbigny, 1846)	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Hormosina veloscoensis (Cushman, 1926)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Igorina broedermanni (Cushman & Bermúdez, 1949)	0	0	0	0	0	0	0	1	1	1	0	0	1	0	1	0
Igorina salisburgensis (Gohrbandt, 1967)	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0
Karrerulina conversa (Grzybowski, 1901)	0	0	0	0	1	0	1	0	1	1	0	1	0	0	1	1
Lenticulina cf. *inornata* (d'Orbigny, 1846)	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0
Lituotuba lituiformis (Brady, 1879)	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
Melonis pompilioides (Fichtel & Moll, 1798)	0	0	0	0	1	0	0	0	1	1	0	0	1	0	0	0
Parasubbotina inaequispira (Subbotina, 1953)	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
Pleurostomella alazanensis Cushman, 1925	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Psammosiphonella sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Psammosphaera irregularis (Grzybowski, 1896)	1	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0
Pseudohastigerina sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
Pseudohastigerina wilcoxensis (Cushman & Ponton, 1932)	0	0	0	0	0	1	0	1	1	0	0	0	0	1	1	0
Pullenia bulloides (d'Orbigny, 1826)	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1
Pullenia sp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Rhabdammina sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Subbotina eocaena (Guembel, 1868)	0	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1
Tuborotalia frontosa (Subbotina, 1953)	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0
Uvigerina eocaena Gümbel, 1868	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Reticulofenestra. umbilicus (2945, 3040, 3070 m depth) and *Cribrocentrum erbae* (3040 m depth) (Perch-Nielsen 1985; Vandenberghe et al. 2012). These Priabonian taxa, however, are scarce and are contrasted by a large number of nannoplankton specimens of Lutetian age. Moreover, a Priabonian age would be in conflict with the foraminiferal data (see below). Therefore, several cuttings from the overlying Miocene deposits have been checked for Priabonian species, which indeed were frequently found (Harzhauser et al. 2018b). This suggests major reworking of upper Eocene nannoplankton during the Miocene. Consequently, the scarce Priabonian taxa are interpreted as borehole contamination due to downfall during the drilling process.

Aside from Priabonian contamination, the assemblages also yield Cretaceous and lower Eocene nannoplankton. Reworking of Mesozoic nannoplankton (especially from Upper Cretaceous units) is documented throughout the core interval by the occurrence of species, such as *Arkhangelskiella cymbiformis*, *Cribrosphaerella ehrenbergii*, *Cyclagelosphaera margerelii*, *Micula staurophora*, *Watznaueria barnesiae* and *Watznaueria fossacincta* (e.g., Bown & Cooper 1998; Lees & Bown 2005). Similarly, lower Eocene strata became eroded, as indicated by the occurrence of *Discoaster kuepperi*, *Discoaster lodoensis*, *Toweius rotundus* and *Sphenolithus editus* (Perch-Nielsen 1985; Vandenberghe et al. 2012). The uppermost samples from 2855 and 2930 m contain scarce *Helicosphaera ampliaperta*

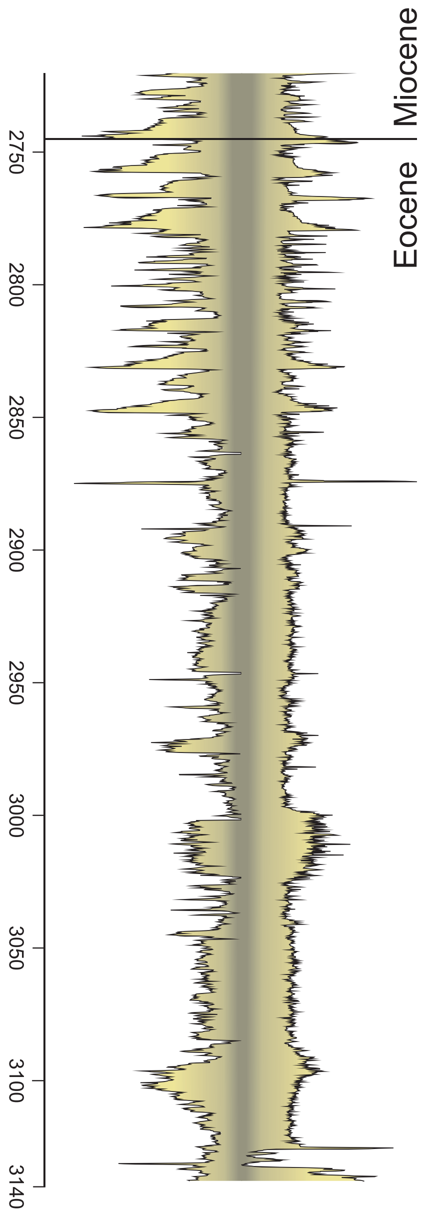

Fig. 3. Wire-logs (GR=natural gamma radiation, RES=resistivity) of Be 11.

and *Sphenolithus dissimilis, which are* lower Miocene taxa (Young 1998; Raffi et al. 2006; Bergen et al. 2017), indicating further downhole contamination from lower Miocene sediments (Harzhauser et al. 2018b).

Foraminifera: The foraminiferal assemblages from core interval 2745–3140 m contain mainly taxa, which are restricted to the Ypresian and Lutetian. Species, such as *Igorina salisburgensis*, *Igorina broedermanni*, *Acarinina bullbrooki*, *Turborotalia frontosa*, *Pseudohastigerina wilcoxensis* and *Parasubbotina inaequispira*, characterize the plankton biozones E7–E8 (Berggren & Pearson 2005; Berggren et al. 2006; Olsson & Hemleben 2006; Pearson et al. 2006). Stratigraphically wider ranges are covered by the planktic *Subbotina eocaena* (highest occurrence 2782.5–2790 m), which ranges from the Ypresian to the Chattian (Wade et al. 2018), the agglutinated foraminifer *Psammosphaera irregularis* (highest occurrence: cuttings 2747.5–2755 m), which ranges from the Cretaceous to the Priabonian (Kaminski & Gradstein 2005; Kaminski & Ortiz 2014; Benedetti 2017) and by the planktic *Globorotaloides eovariabilis,* which ranges from the Ypresian to the Chattian (Pearson & Wade 2009) or even to the Aquitanian (Coxall & Spezzaferri 2018). Therefore, the stratigraphic ranges of the foraminifera species display a distinct overlap during the Lutetian.

In terms of ecological requirements, the assemblage is typical for deep-water sedimentary successions as described by Golonka & Waśkowska (2012). Especially the high abundance of planktic and agglutinated foraminifera is a clear indicator for bathyal to lower bathyal water conditions (Armstrong & Brasier 2005). Additionally, the abundance of *Psammosphaera irregularis, Ammodiscus* and *Glomospira* indicate upper to lower bathyal environments with reduced oxygen levels (Murray 1991, 2006; Kaminski & Gradstein 2005; Cimerman et al. 2006; Grunert et al. 2013; Kaminski & Ortiz 2014; Benedetti 2017).

Correlation with Eocene subsurface units in the northern Vienna Basin

Based on data from internal OMV reports, Rammel (1989), Wessely et al. (1993) and Wessely (1993, 2006) extrapolated the distribution of subsurface units of the Rhenodanubian and Magura nappe systems in the northern Vienna Basin. According to these maps, borehole Be 11 is situated on the Harrersdorf unit, which is correlated by the above mentioned authors with the Rača nappe of the Magura nappe system (Fig. 1). South of this unit, the Rhenodanubian nappe system is represented, especially by the Greifenstein Nappe, which stretches from the area of the Vienna Basin and the Korneuburg Basin in a NE direction up to the Steinberg region (Wessely 1993, 2006). Numerous drillings around the Steinberg and along the Steinberg Fault reached this nappe and allowed a lithostratigraphic subdivision. The subsurface extension of the Greifenstein Nappe is unknown. Nevertheless, Hamilton et al. (1990) and Picha et al. (2006) assumed a separation from the Rača Nappe, which is part of the Magura Nappe System, by a thrust in the area of the northern Vienna Basin. On their subsurface map of the Vienna Basin, Wessely et al. (1993) placed the boundary between these nappes along a line running from north of the Steinberg in the east to the Mistelbach area in the west (Fig. 1). No seismic data or surveys on the structural geology, however, have been published so far to support this hypothesis.

Greifenstein Nappe (Rhenodanubian nappe system): In its easternmost distribution area, the Rhenodanubian nappe system consists of the Greifenstein and Laab nappes (note that the "Kahlenberg nappe" was recognized as equivalent of the Greifenstein Nappe by Egger 2013). The sedimentary succession of the Greifenstein Nappe has been lithostratigraphically formalized as the Greifenstein Group by Egger (2013) with

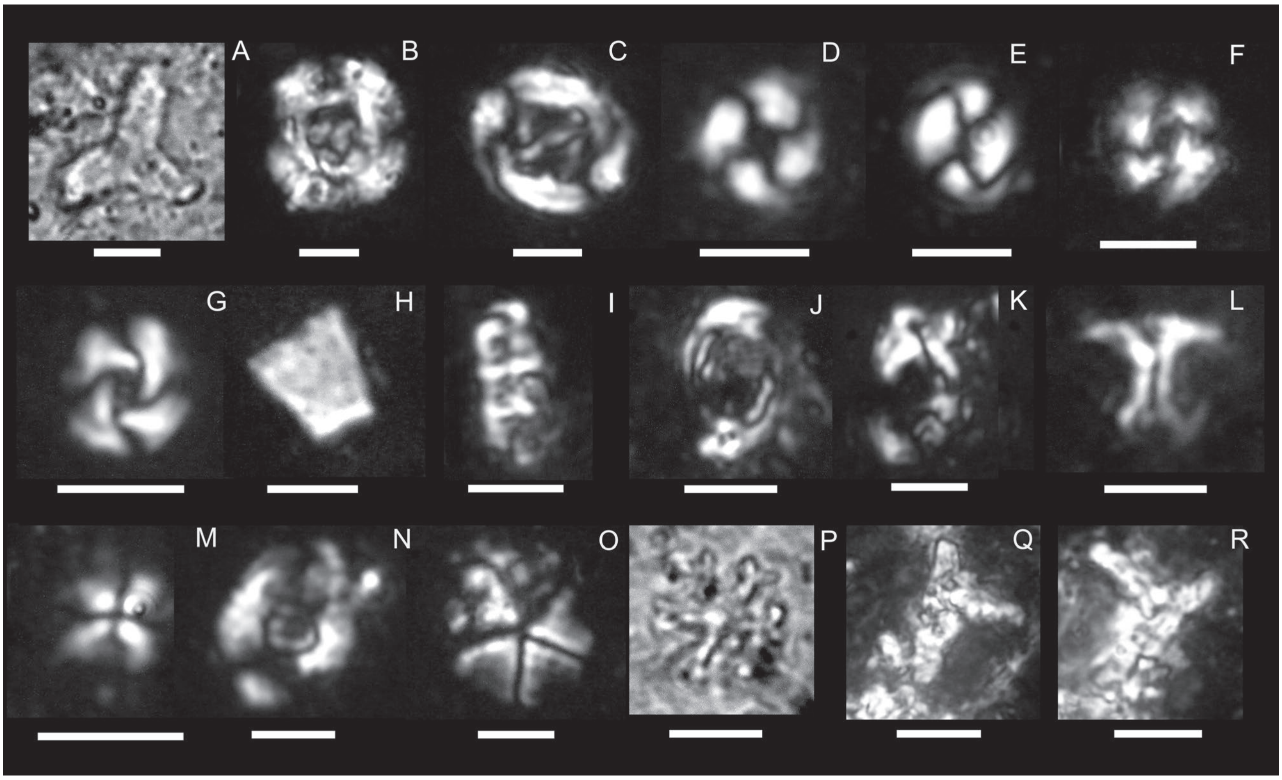

Fig. 4. Calcareous Nannoplankton from Be 11. **A** — *Tribrachiatus orthostylus* Shamrai, 1963 (3100 m); **B** — *Reticulofenestra umbilicus* (Levin, 1965) Martini & Ritzkowski, 1968 (3040 m); **C** — *Chiasmolithus solitus* (Bramlette & Sullivan, 1961) Locker, 1968 (3100 m); **D** — *Coccolithus formosus* (Kamptner, 1963) Wise, 1973 (3100 m); **E** — *Coccolithus pelagicus* (Wallich 1877) Schiller, 1930 (3040 m); **F–G** — *Cyclicargolithus floridanus* (Roth & Hay, *in* Hay *et al.*, 1967) Bukry, 1971 (3040 m); **H** — *Braarudosphaera bigelowii* (Gran & Braarud, 1935) Deflandre, 1947 (2855 m); **I** — *Isthmolithus recurvus* Deflandre *in* Deflandre & Fert, 1954 (3040 m); **J** — *Campylosphaera dela* (Bramlette & Sullivan, 1961) Hay & Mohler, 1967 (3100 m); **K** — *Helicosphaera ampliaperta* Bramlette & Wilcoxon, 1967 (2855 m); **L** — *Discoaster kuepperi* Stradner, 1959 (2945 m); **M** — *Sphenolithus moriformis* (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967 (3100 m); **N** — *Helicosphaera seminulum* Bramlette & Sullivan, 1961 (3100 m); **O** — *Micrantholithus flos* Deflandre *in* Deflandre & Fert, 1954 (3040 m); **P** — *Discoaster distinctus* Martini, 1958 (3070 m); **Q–R** — *Nannotetrina alata* (Martini, in Martini & Stradner 1960) Haq and Lohmann, 1976 (2945 m); scale bar=5 µm.

the Greifenstein Formation as the youngest unit. In surface outcrops, the Greifenstein Formation terminates within the Ypresian standard nannoplankton Zone NP13 (Egger 2013; Egger & Wessely 2014; Egger & Ćorić 2017).

The assumed equivalents of the Greifenstein Nappe in the Steinberg area are united in the Zistersdorf Group, which comprises the Upper Cretaceous Altlengbach Formation and the Paleogene Glauconitic Sandstone and the Steinberg-Flysch formations (Rammel 1989; Wessely 2006). The up to 750-m-thick Glauconitic Sandstone formation (GSf) comprises several thick units of light grey to greenish grey glauconite-bearing sandstone, partly with nummulitids and polymict pebbles, subdivided by thinner intercalations of variegated shales and marly shales (Grill 1968; Hekel 1968). Rammel (1989) subdivided the GSf into three main sandstone-dominated subunits separated by two pelite-dominated intercalations. The correlation of these units with biostratigraphic data of Hekel (1968) revealed a Thanetian to Ypresian age for the GSf. Similarly, the analysis of the foraminiferal assemblages by Küpper (1961) pointed to a late Paleocene to early Eocene age. The depositional environment was interpreted by Rammel (1989) as deep sea fans system with numerous channels. A correlation of the GSf with the unit drilled in Be 11 (2745–3140 m depth) can be excluded based on the biostratigraphic data and also by the wire-log pattern of the GFS, which is characterized by up to 200-m-thick, cylinder-shaped units (representing the sandstone packages).

The GSf is overlain by the Steinberg-Flysch formation (SFf), which comprises an up to 1500-m-thick succession of dark grey and greenish grey shales and marly shales with subordinate intercalations of thin layers of glauconitic sandstones (Grill 1968; Wessely 2006). According to the few available data, the basal parts of the SFf contain Ypresian foraminifera (Grill 1968), whereas the upper part ranges into the Lutetian (Hekel 1968; Rammel 1989). The depositional environment is interpreted as a distal deep-sea fan system (Wessely 2006). Consequently, the Be 11 record (2745–3140 m depth) is a time-equivalent of the SFf and has a similar lithology.

North of the Steinberg, the up to 2500-m-thick Harrersdorf Unit (Wessely 2006) is either interpreted as the frontal part of the Rača Nappe in Austria (Hamilton et al. 1990) or as a continuation of the Greifenstein Nappe (Rammel 1989). Drillings,

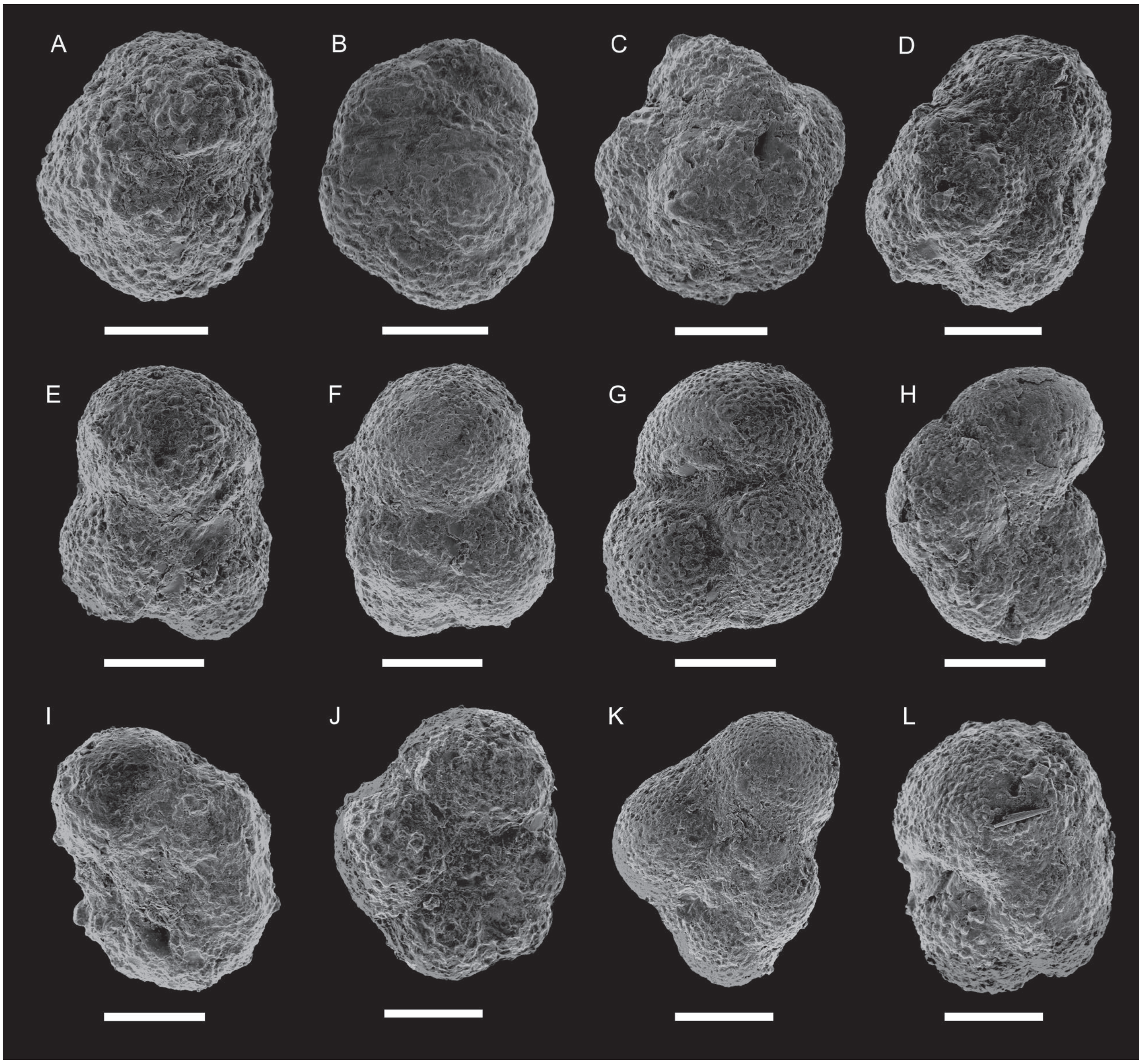

Fig. 5. Planktic Eocene foraminifera from Be 11. **A** — *Acarinina bullbrooki* (Bolli, 1957) (2935–2940 m); **B** — *Igorina broedermanni* (Cushman & Bermúdez, 1949) (2935–2940 m); **C** — *Igorina salisburgensis* (Gohrbandt, 1967) (2935–2940 m); **D–G** — *Subbotina eocaena* (Guembel, 1868) (2935–2940 m) (3062.5–3070); **H** — *Pseudohastigerina wilcoxensis* (Cushman & Ponton, 1932) (2935–2940 m); **I** — *Pseudohastigerina* sp. (2935–2940 m); **J** — *Globorotaloides eovariabilis* Huber & Pearson, 2006 (2922.5–2930 m); **K** — *Parasubbotina inaequispira* (Subbotina, 1953) (3062.5–3070 m); **L** — *Turborotalia frontosa* (Subbotina, 1953) (2935–2940 m); scale bar=100 µm.

which reached the Harrersdorf Unit are Harrersdorf 1 (5136 m), Maustrenk Uet1a (6563 m), Linenberg 2 (4711 m) and St. Ulrich 290 (3000 m) (Fig. 1) (Wessely et al. 1993), but no sedimentological and paleontological data have been published so far. Rammel (1989) documented a continuation of the GSf into the Harrersdorf Unit based on well-log correlations of Harrersdorf 1 with drillings from the Steinberg area. This suggests a close relation of the Harrersdorf Unit with the Zistersdorf Group of the Greifenstein Nappe.

Rača Nappe (Magura nappe system): In its south-western most distribution area, the Magura nappe system is divided into the Rača, Bystrica and Biele Karpaty nappes (Picha et al. 2006). Of these, only the Rača Nappe stretches in the south into the Austrian part of the Vienna Basin (Wessely et al. 1993; Wessely 2006). Although the tectonic affiliation of the Harrersdorf Unit with the Rača Nappe remains ambiguous, the lithostratigraphic correlation between the Greifenstein and Rača nappes is roughly established. Eliáš et al. 1990; Adamová & Schnabel (1999) and Picha et al. (2006) provided detailed summaries of the geology and lithostratigraphy of the Rača Nappe in the Western Carpathian Flysch belt (see Picha et al. 2006, fig. 17 for a scheme of the Rača Nappe). The mostly Paleocene Soláň Formation yields the oldest post Cretaceous deposits. This nearly 3000-m-thick formation comprises

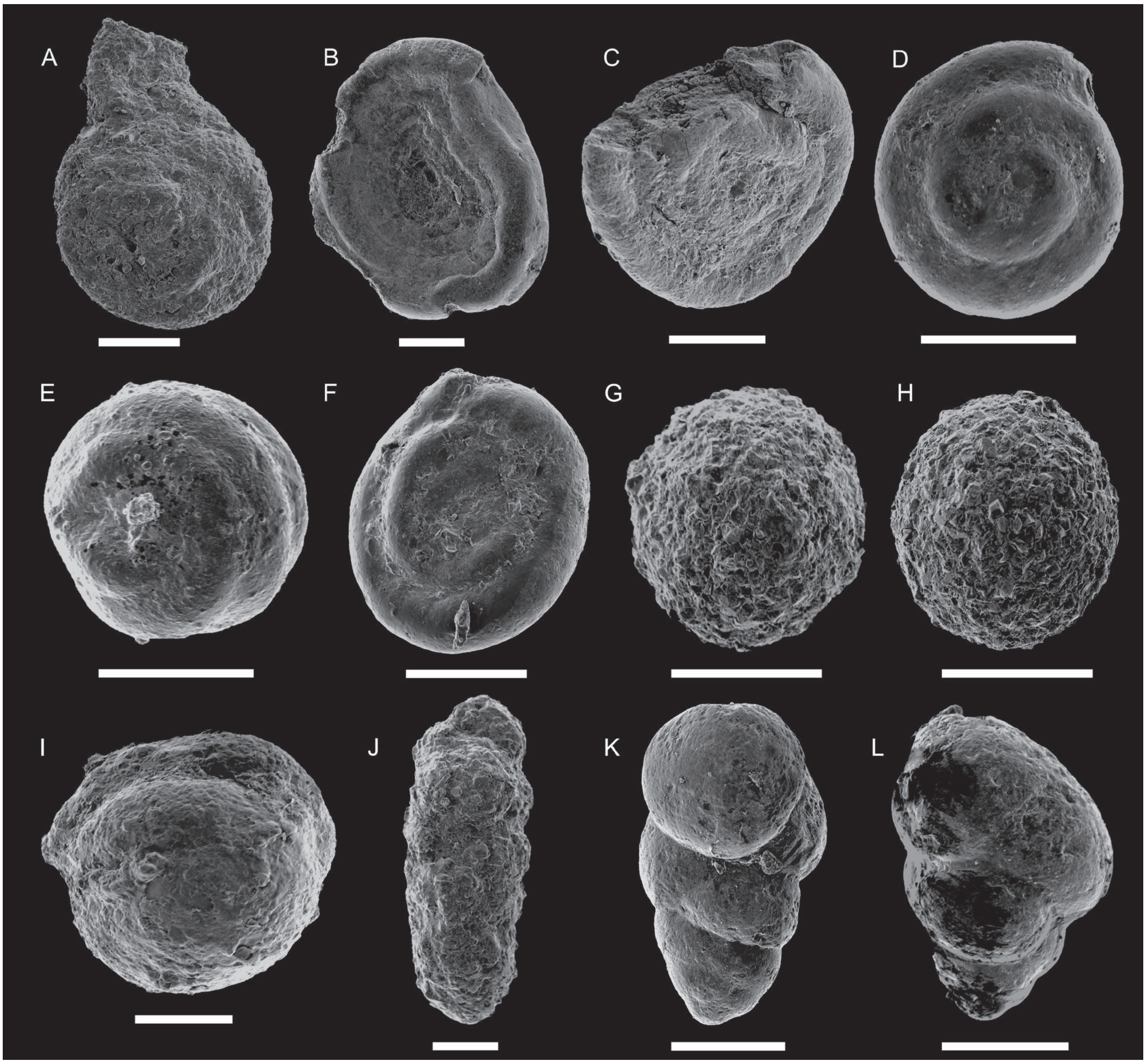

Fig. 6. Benthic Eocene foraminifera from Be 11. **A —** *Lituotuba lituiformis* (Brady, 1879) (2957.5–2965 m); **B —** *Ammodiscus peruvianus* (Berry, 1928) (3062.5–3070 m); **C —** *Ammodiscus cretaceus* (Reuss, 1845) (2817 m); **D–E —** *Glomospira charoides* (Jones and Parker, 1860) (2957.5–2965 m); **F —** *Glomospira gordialis* (Jones and Parker, 1860) (2957.5–2965 m); **G —** *Psammosphaera irregularis* (Grzybowski, 1896) (2782.5–2790 m); **H —** *Psammosphaera irregularis* (Grzybowski, 1896) (2817 m); **I —** *Pullenia bulloides* (d'Orbigny, 1826) (2922.5–2930 m); **J —** *Karrerulina conversa* (Grzybowski, 1901) (2922.5–2930 m); **K —** *Caucasina coprolithoides* (Andreae, 1884) (2817 m); **L —** *Bulimina* sp. (2782.5–2790 m); scale bar=100 μm.

shales and sandstones with a general coarsening upward trend (Picha et al. 2006). According to Rammel (1989), the Soláň Formation can be correlated with the Altlengbach Formation and Thanetian parts of the GSf of the Greifenstein Nappe.

The Soláň Formation is overlain by the 300-m-thick Eocene Beloveža Formation, which comprises greenish grey to reddish shales with sandstone intercalations. Its stratigraphic interval is assumed to range from the Paleocene to middle Eocene (Picha et al. 2006), but seems to be mainly of Lutetian age (see Golonka & Waśkowska 2012 for its equivalent in the Polish Flysch Carpathians). Rammel (1989) correlated this formation with the upper part of the GSf and assumed an Ypresian age. The uppermost unit of the Rača Nappe is the 2500-m-thick Zlin Formation (including the underlying sandy Luhačovice Member) of the middle to late Eocene and early Oligocene age. The formation is dominated by sandstones and conglomerates, which formed as proximal parts of turbiditic fans and by calcareous shales (Picha et al. 2006).

Tectonic affiliation: Rammel (1989) correlated the Steinberg-Flysch formation of the Greifenstein Nappe with the Zlin formation. The age of the Be 11 record (2745–3140 m depth) would allow a comparison of both formations. The pelitic lithology of Be 11, however, makes a direct correlation with the Zlin formation rather unlikely. Thus, leads to

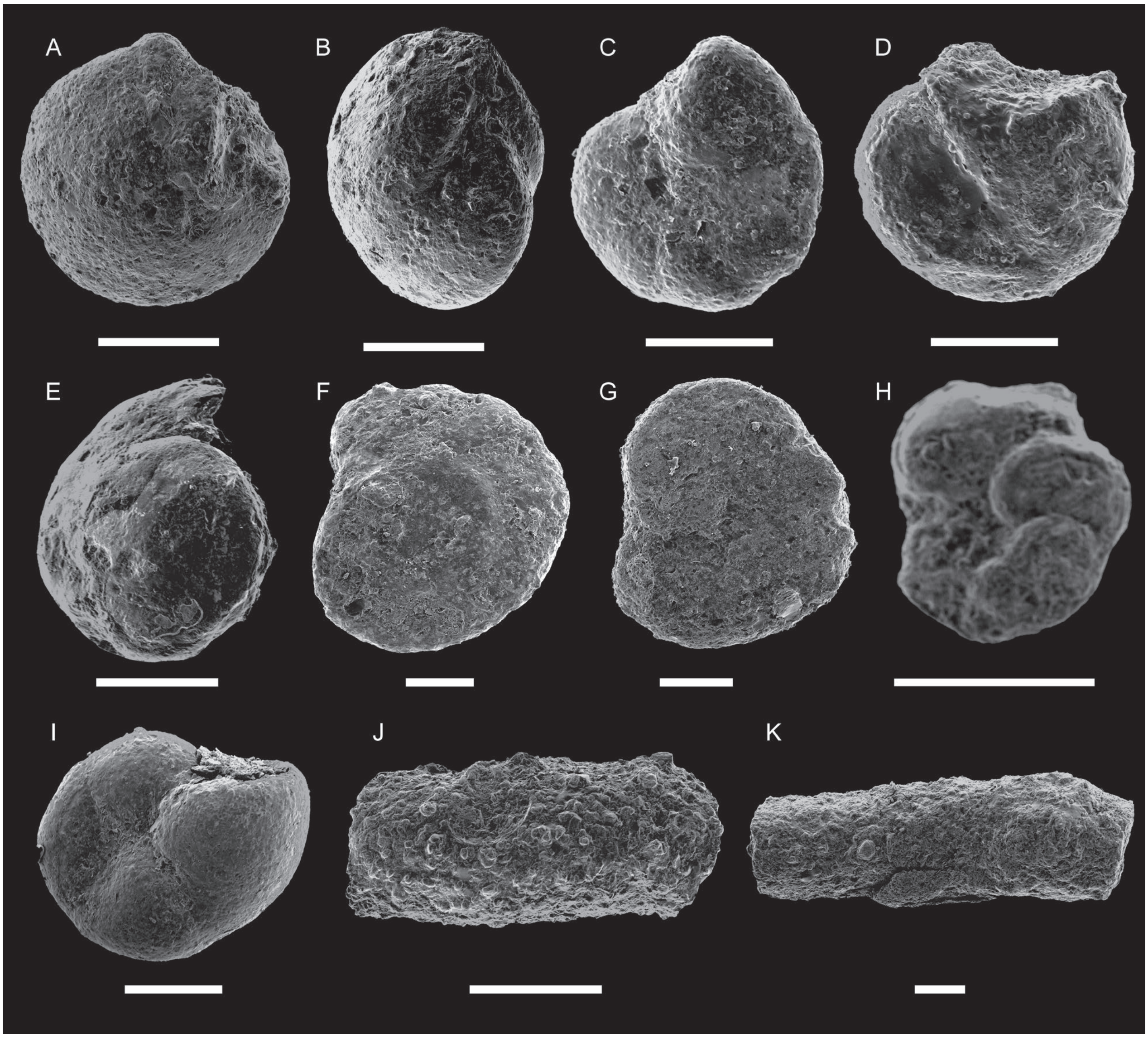

Fig. 7. Benthic Eocene foraminifera from Be 11. **A–B — ***Lenticulina* cf. *inornata* (2922.5–2930 m); **C–D — ***Melonis pompilioides* Römer, 1838 (3032–3140 m), (2957.5–2965 m); **E — ***Heterolepa dutemplei* (d'Orbigny, 1846) (2782.5–2790 m); **F — ***Cibicidoides* sp. (3062.5–3070 m); **G — ***Cibicides westi* (Howe, 1939) (3032–3140 m); **H — ***Anomalinoides* sp. (2922.5–2930 m); **I — ***Pullenia* sp. (2957.5–2965 m); **J — ***Rhabdammina* sp. (2922.5–2930 m); **K — ***Psammosiphonella* sp. (2922.5–2930 m); scale bar = 100 µm.

the assumption that the Lutetian units of Be 11 represent a continuation of the Steinberg Flysch formation in the Harrersdorf Unit. In consequence, this unit must be regarded as a continuation of the Greifenstein Nappe of the Rhenodanubian nappe system rather than as part of the Rača Nappe of the Magura nappe system. Some paleontological similarities of the Be 11 record can be stated with the middle Eocene Beloveža Formation from the Polish and Slovak part of the Rača Nappe as described by Golonka & Waśkowska (2012). Most of the genera and five species (*Ammodiscus tenuisimus, A. peruvianus, Glomospira charoides, H Haplophragmoides walteri, Karrerulina conversa*) described by Golonka & Waśkowska (2012) also appear in Be 11. Both assemblages indicate identical bathyal depositional environments (Murray 1991, 2006; Kaminski & Gradstein 2005). These biotic similarities, however, are rather an expression of similar age and near-identical paleoecological conditions and are not a strong support to affiliate the Harrersdorf Unit with the Rača Nappe.

A relationship with the Waschberg–Ždánice Unit is unlikely due to the geographical distance of the surface distribution of the Waschberg–Ždánice Unit outcrops (see maps in Grill 1968; Schnabel 2002). Subsurface data revealed the presence of the isolated Waschberg–Ždánice Unit below the Flysch nappes as seen along the escarpment Steinberg fault (Wessely et al. 1993). Within the Waschberg–Ždánice Unit Paleocene and Eocene formations, such as the Paleocene glauconitic and marly sands of the Bruderndorf beds, the lower Eocene Waschberg-Limestone, the ferruginous middle Eocene sandstones of the Haidhof beds and the glauconitic and calcareous sand of the upper Eocene Reingrub Formation have been documented (Krhovsky et al. 2001). Larger foraminifera from Eocene units, studied by Torres-Silva & Gebhardt (2015), confirmed the occurrence of Ypresian to basal Lutetian, Bartonian and Priabonian assemblages, which point to a depositional environment in the inner to middle shelf between 70 to 200 m water depth (Torres-Silva & Gebhardt 2015). Deeper marine offshore facies, comparable to Be11, is confined to small occurrences of Lutetian marls (Egger et al. 2007) and Priabonian *Globigerina* marls (Grill 1968; Wessely 2006). None of these lithological units can be directly correlated with the shales of Be 11, either because of their completely different litho-facies and/or because of their different age. The Lutetian marls of Niederhollabrunn, described by Egger et al. (2007), would be the most similar unit in the surface Waschberg–Ždánice Unit, but they do not represent a turbiditic depositional system. Finally, a flysch cover of subsurface Waschberg–Ždánice Unit units must be expected in the study area.

Conclusions

The Be 11 borehole in the northern part of the Vienna Basin reached the pre-Neogene units at a depth of about 2745 m, indicated by a strong change in wire log patterns from highly cyclic bell-shaped Neogene GR and RES logs to a succession of cylinder- and funnel-shaped wire-log patterns, lacking any cyclicity. In addition, the predominant lithology changes from silty-sandy clays to marly shales. The drilled virtual thickness of the pre-Neogene unit attains nearly 400 m.

The shales and glauconitic sandstones lack any macrofauna and the microfauna is moderately to poorly preserved and of low diversity. Both, foraminifers and calcareous nannoplankton are clearly indicative for an Eocene age. The nannoplankton assemblage yields two distinct species (*N. alata* and *D. distinctus*) which have not been found in the Miocene samples of the borehole and therefore represent autochthonous species which allow a correlation with the Lutetian standard nannoplankton Zone NP15 spanning over an interval from 43.6 to 47.4 Ma. Nannoplankton assemblages representing reworked taxa were found throughout the succession that indicates reworking of older strata during the middle Eocene and downfall during drilling resulting in borehole contamination. Similarly, a large part of the foraminifera indicate a Lutetian age and are representative for the plankton biozones E7–E8 as defined by Berggren & Pearson (2005), spanning an interval from 45.8–50.4 Ma. Therefore, the stratigraphic overlap of these biozones allows a restriction of the depositional time of the turbidites of the Harrersdorf Unit to an interval ranging from 45.8–47.4 Ma.

The Flysch of the Harrersdorf Unit was variously interpreted as the front of the Rača Nappe of the Magura Flysch (Wessely et al. 1993; Hamilton et al. 1999) or as continuation of the Rhenodanubian Greifenstein Nappe (Rammel 1989). Our results might support the latter interpretation as the lower Eocene Glauconitic Sandstone formation can be traced from the Greifenstein Nappe in the Steinberg area up to the Harrersdorf Unit (Rammel 1989) and due to the lithological similarities of the Be 11 record with that of the coeval Steinberg Flysch formation. Nevertheless, an unambiguous correlation is missing, as the Lutetian age of the Steinberg Flysch formation contrasts with the Ypresian age of the uppermost parts of the Greifenstein Formation in the surface distribution of the Greifenstein Nappe.

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