Miocene lithostratigraphy of the northern and central Vienna Basin (Austria)

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Abstract

For the first time, a concise lithostratigraphic scheme for the lower and middle Miocene (Ottnangian – Badenian) of the northern and central Vienna Basin is proposed, which is based on the integration of core-material, well-log data and seismic information from OMV. For all formations and members type sections are proposed, geographic distribution and thickness are provided, typical depositional environments and fossils are described and age constraints are discussed. This time frame allows for a more reliable calculation of sedimentation rates. This in turn might be important for the reconstruction of the tectonic history of the Vienna Basin as we do not see fundamental differences between the piggy-back stage and the subsequent pull-apart regime. Following lithostratigraphic units are formalized herein and/or are newly introduced: Bockfließ Formation (Ottnangian), Aderklaa Formation, Gänserndorf Member and Schönkirchen Member (Karpatian), Baden Group, Rothneusiedl Formation and Mannsdorf Formation (lower Badenian), Auersthal Formation, Matzen Formation, Baden Formation, Leitha Formation (middle Badenian) and Rabensburg Formation (upper Badenian).

1 Introduction

Since the early 19th century the Vienna Basin was one of the most intensively investigated Neogene Basins of the world. Especially during the pioneer phase of geology and paleontology the deposits and their fossil content served as base for international stratigraphic correlations. A renaissance of geological research was sparked during the 20th century when the Vienna Basin was recognized as the largest oil and gas field of onshore Europe (Hamilton et al., 2000). Geological information from hundreds of drillings and more and more information from 2D and 3D seismics increased our knowledge on the stratigraphic and tectonic situation of the Neogene basin fill of the Vienna Basin (e.g. Kreutzer, 1971, 1974, 1978; Weissenbäck, 1995, 1996). Numerous papers dealt with tectonics, structural geology and depositional environments of the Vienna Basin (e.g. Jiříček and Tomek, 1981; Royden, 1985; Lankreijer et al., 1995; Kováč et al. 2004; Hinsch et al., 2005; Wessely, 2006; Hölzel et al., 2008, 2010; Lee and Wagreich, 2017 and references therein). Very little focus, however, was laid on bringing order into the confused lithostratigraphy of the basin. A major stumbling stone for this task was the historically grown mixture of biostratigraphic, lithostratigraphic and chronostratigraphic terminology in the stratigraphic charts. For example, lower Miocene strata of the northern Vienna Basin were defined by foraminiferal content (e.g. *Cyclammina-Bathysiphon-Schlier*), whereas coeval strata in the central Vienna Basin were named after their geographic occurrence (Bockfließ beds). Similarly, middle Miocene (Badenian) strata were defined according to their foraminiferal assemblages ("eco-biozones" of Grill, 1941, 1943) into which local lithostratigraphic units were squeezed in (e.g. Matzen Sand). Especially, the strongly deviating understanding of authors concerning the content and definition of the eco-biozones increased confusion enormously (e.g. Lower versus Upper Lagenidae Zone) (e.g. Kapounek et al. 1965; Cicha et al., 1998; Hohenegger et al., 2014).

Stratigraphic tables for the Vienna Basin using information from oil industry have been proposed and compiled early by Austrian geologists, such as Janoschek (1942, 1943, 1951), Grill (1943, 1960, 1968), Kapounek et al. (1965), Papp et al. (1973), Kreutzer (1986, 1992, 1993) and many others. The last synthesis of these data was presented by Piller et al. (2004) in the "Stratigraphic Chart of Austria 2004". Simultaneously, Slovak geologists, such as Buday (1946), Buday and Cicha (1956), Špička and Zapletalova (1964) and Špička (1966) developed the foundation of lithostratigraphic schemes for the Slovak part of the Vienna Basin, which was refined later by Vass (2002), Kováč et al. (2004) and Fordinál et al. (2012) (see Fordinál et al. 2012 for much more references). All these papers

discussed lithostratigraphic units but none of these formations and members were established properly to fulfill the criteria for a formalization following Hedberg (1976), Salvador (1994) and Steininger and Piller (1999). Therefore, nearly all lithostratigraphic units listed by Piller et al. (2004), Kováč et al. (2004) and Fordinál et al. (2012) for the Vienna Basin are, so far, only informal terms. Exceptions are Sarmatian and Pannonian formations, which have been formalized by Bartek (1989), Čtyroký (2000), Elečko and Vass (2001) and Harzhauser and Piller (2004). More recently, formations and members were established by Harzhauser et al. (2019) for the lower Miocene deposits of the Mistelbach Halfgraben in the NW Vienna Basin, west of the Steinberg Fault.

Tectonically, the Vienna Basin passed through four distinct phases starting from an early Miocene piggy-back basin stage, a middle to late Miocene pull-apart basin stage, a late Miocene to Pliocene compressional phase with basin inversion, followed by Quaternary basin formation (see Lee and Wagreich, 2017 for references). The changes in tectonic regime are expected to be reflected in changes of regional subsidence and in variations of sedimentation rates (Hölzel et al., 2008; Lee and Wagreich, 2017).

2 Geographic and stratigraphic frame

Geographically we focus on the Austrian part of the northern Vienna Basin ranging from the Steinberg Fault in the west to the Czech/Austrian border in the north and east down to the Matzen/Spannberg Ridge in the south and the central Vienna Basin spanning from the Bisamberg Fault in the west to the Slovak/Austrian border in the east, and from the Matzen/Spannberg Ridge in the north to the Schwechat depression in the south (Fig. 1A). In addition, we discuss lateral equivalents in neighboring areas of the North Alpine-Carpathian Foreland Basin (NACFB), the Mistelbach Halfgraben, the southern Vienna Basin and the Eisenstadt-Sopron Basin. The Mistelbach Halfgraben is separated from the northern Vienna Basin by the Steinberg Fault (Harzhauser et al., 2019); its Miocene lithostratigraphy was described in detail by Harzhauser et al. (2019) and is not repeated herein.

Stratigraphically, we describe all formations resting on the pre-Neogene basement of the Vienna Basin from the Ottnangian to the upper Badenian. Eggenburgian deposits, which have been frequently reported from the Vienna Basin (e.g. Kováč et al., 2004 and references therein), have been based on outdated stratigraphic concepts and represent basal Ottnangian strata (Harzhauser et al., 2017, 2019). Note that nannoplankton fossils described by Andrejeva-Grigorovič and Halásová (2000) point to the presence of the NN3 Zone in the Vienna Basin, which would range partly within the Eggenburgian, according to the zone concept of Raffi et al. (2006). Own data, however, suggest that reworking is a major problem in nannoplankton stratigraphy in the Vienna Basin.

We do not discuss the Sarmatian and Pannonian strata of the Vienna Basin, because their lithostratigraphy has already been formalized and their biostratigraphy is largely solved (see Harzhauser et al., 2004 and Harzhauser and Piller, 2004).

Since the use of stratigraphic terminology and the mixture of different stratigraphic classification schemes produced glaring confusion we try to summarize and explain the most widely used terms. The historical development of Neogene stratigraphy of the Vienna Basin and Central Paratethys was depicted by Papp et al. (1968a, b) and summarized: Burdigalian = Eggenburgian, Lower Helvetian (Helvetian s. str.) = Ottnangian, Upper Helvetian = Karpatian (Carpathian), Tortonian = Badenian, Sarmatian, Pannonian. In addition to this stage concept a "Series" concept was introduced where the "Luschitzer Serie" represents the Upper Eggenburgian and Ottnangian, the "Laaer Serie" the Karpatian, the "Badener Serie" the Badenian, the "Sarmatische Serie" the Sarmatian, and the "Pannonische Serie" the Pannonian. The "Series" concept is a lithostratigraphic concept and a series includes several lithostragraphic units which represent beds (= formations). The series are today, however, intimately linked with chronostratigraphy. In terms of biostratigraphy a correlation with the Mediterranean region was attempted by using planktic microfossils and also molluscs. This correlation works well in the lower Miocene Eggenburgian to Karpatian but due to a high degree of endemism problems arise in the Badenian, Sarmatian and Pannonian and required a local-regional biozonation. The resulting biozones were ecologically defined zones which are only of limited geographical use. Here we will focus only on the Badenian: the pioneer for establishing a Badenian biostratigraphy was Grill, who distinguished 1941 five zones in the Badenian (Tortonian) based on the foraminiferal fauna (from base to top):

1. "Reiche marine Fauna mit sehr starker Betonung der Lageniden u. mit *Planulina wuellerstorfi* (Lanzendorfer Fauna)" (rich marine fauna with high share of lagenids and with *Planulina wuellerstorfi* (Lanzendof Fauna)) (Grill, 1941: 600).
2. "Reiche marine Fauna mit starker Betonung der Lageniden, *Robulus cultratus*" (marine fauna with high share of lagenids, *Robulus cultratus*) (Grill, 1941: 600).
3. "Reiche marine Fauna mit *Spiroplectammina carinata*, wenig Lageniden" (rich marine fauna with *Spiroplectammina carinata*, few lagenids) (Grill, 1941: 600).
4. "Marine Fauna mit *Bolivina dilatata*" (marine fauna with *Bolivina dilatata*) (Grill, 1941: 600).
5. "Oberstes artenarmes Torton mit *Rotalia beccarii* und *Nerita picta*" (uppermost species-poor Tortonian with *Rotalia beccarii* and *Nerita picta*) (Grill, 1941: 600).

In 1943 Grill introduced the term Lageniden-Zone (p. 37), Lagenidenzone (p. 38) (Lagenidae zone).

Papp and Küpper (1952) defined the Unter-Torton as "Lagenidenzone", the Mittel-Torton as "Zone der Sandschaler" and the "Bolivinenzone = Buliminenzone" and the Ober-Torton as "Rotalienzone". Papp and Turnovsky (1953)

splitted the Lagenidenzone into an "Untere Lagenidenzone = Lanzendorfer Fauna" (sensu Grill, 1941) (p. 124), but also mentioned it as the "Niveau der *U. macrocarinata* (= untere Lagenidenzone)" (p. 37) and an "obere Lagenidenzone = Niveau des „Badener Tegels s. str."" Overall, they differentiated five biostratigraphic zones based on the foraminiferal genus *Uvigerina*: untere Lagenidenzone, obere Lagenidenzone, untere Sandschalerzone, obere Sandschalerzone, Buliminen-Bolivinen-Zone.

Similarly, Kapounek et al. (1965) subdivided the "Badener Serie" into the "Untere Lagenidenzone mit *Uvigerina macrocarinata*", the "Obere Lagenidenzone mit *Uvigerina acuminata*", the "Sandschalerzone (einschließlich Matzener Sand)" and the "Rotalien- und Buliminenzone".

This subdivision is partly used herein where the Lower Lagenidae Zone represents the lower Badenian, the Upper Lagenidae Zone and the *Spirorutilus* Zone the middle Badenian and the *Bulimina-Bolivina* Zone the upper Badenian. The *Rotalia* Zone, representing the uppermost Badenian, is preserved only in restricted occurrences. The *Spirorutilus* Zone is also known as *Spiroplectammina* Zone (*Spiroplectammina carinata* Zone) (after an older generic affiliation for *Spirorutilus*) or "Sandschaler Zone" or Zone of agglutinated foraminifera. The Rotalia Zone (*Rotalia* is used as an older synonym for *Ammonia*) is often fused with the *Bulimina-Bolivina* Zone to *Bulimina-Rotalia* Zone, but it is also termed "Verarmungszone" (Zone of pauperization, Impoverished Zone).

In addition to these various stratigraphy systems oil industry (OMV) uses a specific terminology for sand and sandstone horizons because they represent the most important oil reservoirs there (Kreutzer, 1971). For the Badenian the "1.-16. Tortonhorizont" (TH, Tortonian Horizon), for the Sarmatian the "1.-10. Sarmathorizont" (SH, Sarmatian Horizon) and for the Lower Pannonian the "1.-5. Unterpannonhorizont" (UP, lower Pannonian Horizon) are defined. Lower numbers represent higher stratigraphic positions; the lowest horizon is the 16. TH. The middle Badenian contains the 11. TH and the 13.-16. TH, the upper Badenian the 1.-10. TH and the 12. TH. All these horizons are used as important correlation markers. In addition to these sand horizons, in the Badenian of the Matzen field also horizons with enriched coralline red algae occurrences are identified and termed "Nullipora Horizonte" (NPH, Lithothamnia horizons; *Nullipora* is the name used by Reuss (1847) for the first description of a coralline red alga which later was renamed to *Lithothamnion* (Piller, 1994)). The NPHs widely coincide with the TH horizons and occur usually on top of the TH horizons. The most pronounced NPHs occur in the upper Badenian (Kreutzer, 1978).

3 Material and Methods

All proposed formations are based on core material and well-log data from several OMV wells (Fig. 1B). 46 boreholes in the Austrian part of the Vienna Basin have been sampled by us and 595 sediment samples have been analyzed for microfossils (mainly foraminifers, ostracods, otoliths) and macrofossils, such as mollusks, balanids, echinoderms and bryozoans. The full inventory will be published elsewhere. Herein, we refer only to the biostratigraphically and/or paleoecologically relevant taxa.

The well-log data set provided complete spontaneous potential (SP) and resistivity (RES) logs. In addition, 3D seismic data have been made available to us by OMV during analysis. For all wells and designated type sections, material is stored in the core-shed of the OMV in Gänserndorf (Austria). In addition, well-logs, lithological and paleontological data have been integrated from Hladecek (1965), Papp (1967), Kreutzer (1971, 1974, 1978, 1986, 1992, 1993), Fuchs (1990), Fuchs et al. (2001), Weissenbäck (1995, 1996), Harzhauser et al. (2017, 2018, 2019) and internal OMV reports.

4 Results

4.1 Ottnangian

4.1.1 Bockfließ Formation (Figs. 2–3)
Derivation of name: After the village Bockfließ in the central Vienna Basin (N 48°21'40.53", E 16°36'5.57"). Papp et al. (1973, p. 195) introduced the term "Bockfließer Schichten" (Bockfließ Beds).
Synonyms: "brachyhaline Serie" or "brachyhaline facies with *Rzehakia*" (Hladecek, 1965; Kapounek et al., 1965). Brachyhaline Schichten mit *Rzehakia* = „Oncophora-Schichten" (Papp et al., 1973), Bockfließer Schichten.
**Type section:** Designated herein (Fig. 2): Well Matzen 269 (2245–2754 m; cores: 17/6 2270.00–2279.00 m, 18/2 2279.00–2281.70 m, 19/6 2281.70–2290.00 m, 20/4 2315.00–2321.50 m, 21/7 2321.50–2325.30 m, 22/1 2325.30–2333.30 m, 23/6 2354.00–2363.00 m, 24/6 2480.00–2489.00 m, 25/6 2650.00–2659.00 m, 26/7 2659.00–2668.00 m, 27/7 2668.00–2677.00 m, 28/7 2677.00–2686.00 m, 29/7 2686.00–2695.00 m, 30/6 2715.00–2724.00 m, 31/7 2724.00–2733.00 m) (N 48°22'59.37", E 16°42'22.09") (Figs 1–2).
Remarks: Papp et al. (1973) discussed well Bockfließ 78 (N 48°21'48", E 16°36'34") as being characteristic for the Bockfließ Fm. but referred only to a very short interval of 5 m (1948–1953 m) of the total thickness of 323 m (1935–2258 m). Therefore, the short note of Papp et al. (1973) does not meet the requirements for the designation of a type section.
Thickness: The Bockfließ Fm. fills a paleo-relief and is truncated by erosion. Thus, its thickness varies considerably. The maximum thickness of about 500 m is documented from well Matzen 269 (2245–2754 m).
Lithology: The base of the Bockfließ Fm. comprises few meters of flysch clasts, representing a basal transgressional conglomerate (e.g. Spannberg 11: 2441–2447 m). Lignite is documented from the basal units in wells Spannberg 8 (2546 m) and Matzen 260 (2750 m). Upsection follows light and dark grey, mica-rich marly clay with intercalations of marly silt and sand. Some of these pelitic intervals and sand intercalations are continuous and
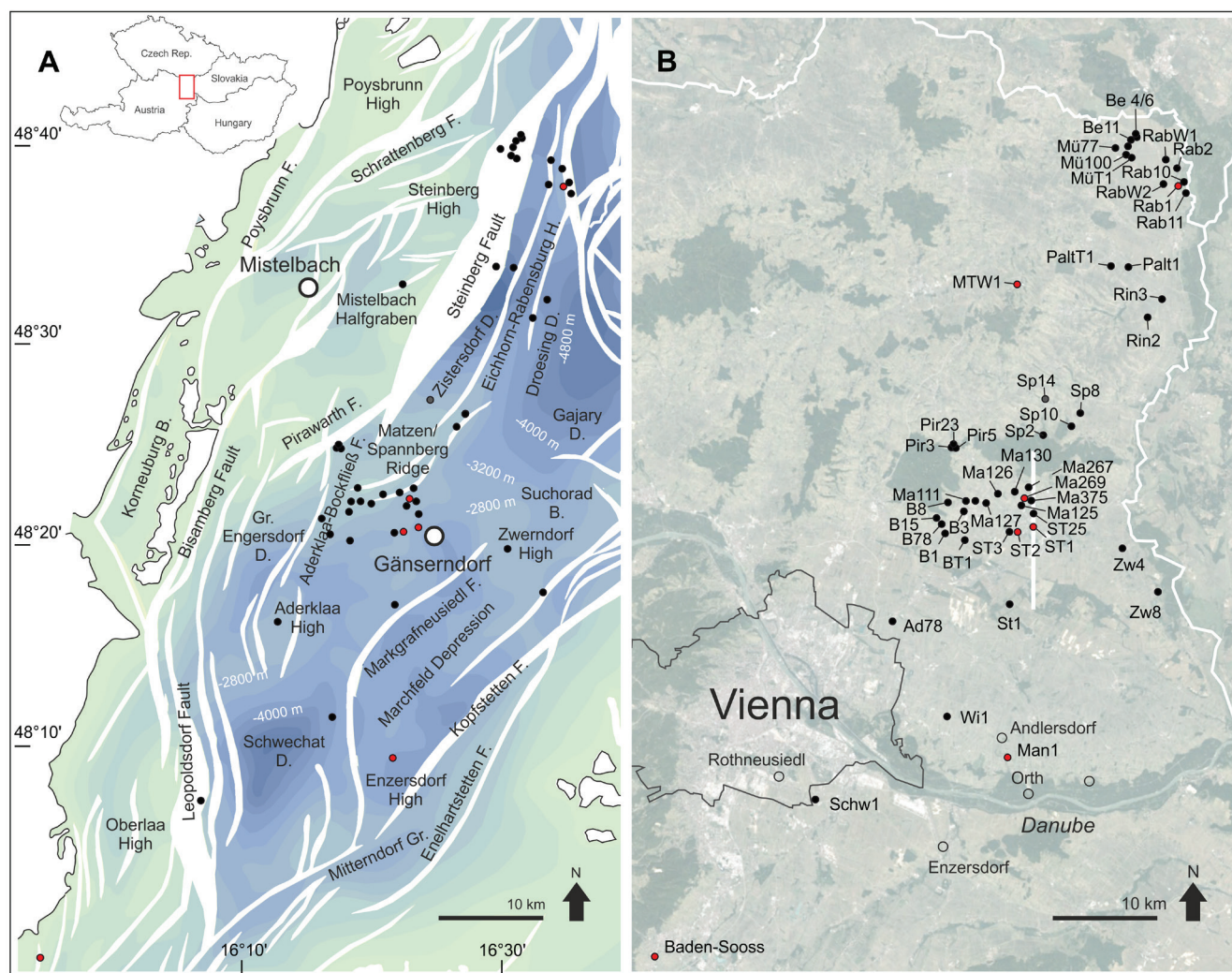
Figure 1: A. Tectonic setting of the central and northern Vienna Basin modified from Kröll and Wessely (1993), Jiříček (2002) and Wessely (2006); black dots correspond to investigated wells. **B.** Position of the mentioned wells, red circles indicate type sections. mentioned in this report. Abbreviations: D: depression; Ad: Aderklaa, B: Bockfließ, Be: Bernhardsthal, Ma: Matzen, Man: Mannsdorf, Mü: Mühlberg, MüT. Mühlberg Tief, Palt: Paltendorf, Pir: Pirawarth, Rab: Rabensburg, Ring: Ringelsdorf, Schw: Schwechat, Sp: Spannberg, ST: Schönkirchen Tief, St: Strasshof, Wi: Wittau, Zw: Zwerndorf. Open circles indicate villages; white line indicates seismic survey shown in Fig. 6 (map generated with Google Earth).

have been used by Hladecek (1965) for cross-correlations between the various wells.

Well-log characteristics: The SP and RES logs of the Bockfließ Fm. display a rather uniform pattern with high amplitudes in the base followed by a shale line interval, which is overlain by a rapid succession of high amplitude logs consisting of partly amalgamated funnel-shaped units, indicating a general coarsening upward trend.

Fossils: The Bockfließ Fm. is rich in fossils, including calcareous nannoplankton, foraminifers, mollusks and decapods. Most data, however, are only available from unpublished internal OMV reports (e.g. Fuchs, 1990) or presented in the unpublished thesis of Hladecek (1965). These data have been re-evaluated by us and supplemented with own results. The foraminiferal assemblages are dominated by *Ammonia tepida* along with elphidiids (e.g. *Elphidium matzenense*) (e.g. Bockfließ 78: 1867–1882 m, Bockfließ 90: 1813–1822 m, 1846–1854 m). Planktonic species are represented by *Globigerina ottnangensis*, *G. praebulloides* and *Globoturborotalia*

woodi (Matzen 270: 2330–2345 m, Bockfließ 78: 201–2020 m). Typical mollusks are the bivalves *Nuculana* sp., *Ostrea digitalina*, *Papillicardium papillosum*, *Corbula gibba*, and *Macoma elliptica* (e.g. Matzen 269: 2480–2489 m, 2650–2659 m, 2668–2677 m, 2677–2686 m). Similar bivalve assemblages with *Crassostrea gryphoides*, *Parvicardium* sp., *Tellina* sp., *Pitaria* sp., *Venus* sp., *Lutraria* sp., and *Lucina columbella* have been documented from Bockfließ 78 (2006–2014 m), Raggendorf 8 (1897–1902 m, 2015–2018 m, 2225–2231 m), Matzen 267 (2314–2332 m, 2487–2500 m) and Matzen 270 (2357–2366 m). Gastropods are comparatively rare and represented by *Terebralia* sp. (Matzen 269: 2750–2759 m), *Turritella terebralis* (Spannberg 14: 2462–2471 m) and *Nassarius* sp., *Bittium* sp. and *Granulolabium* sp. from Spannberg 14 (2409–2418 m).

Depositional environment: Lagoonal-coastal environments are reflected by the lignite bearing basal parts of the formation, yielding mudflat gastropods, such as *Terebralia* sp. The abundance of infaunal bivalve taxa in most parts of the Bockfließ Fm. documents soft bottom conditions in a
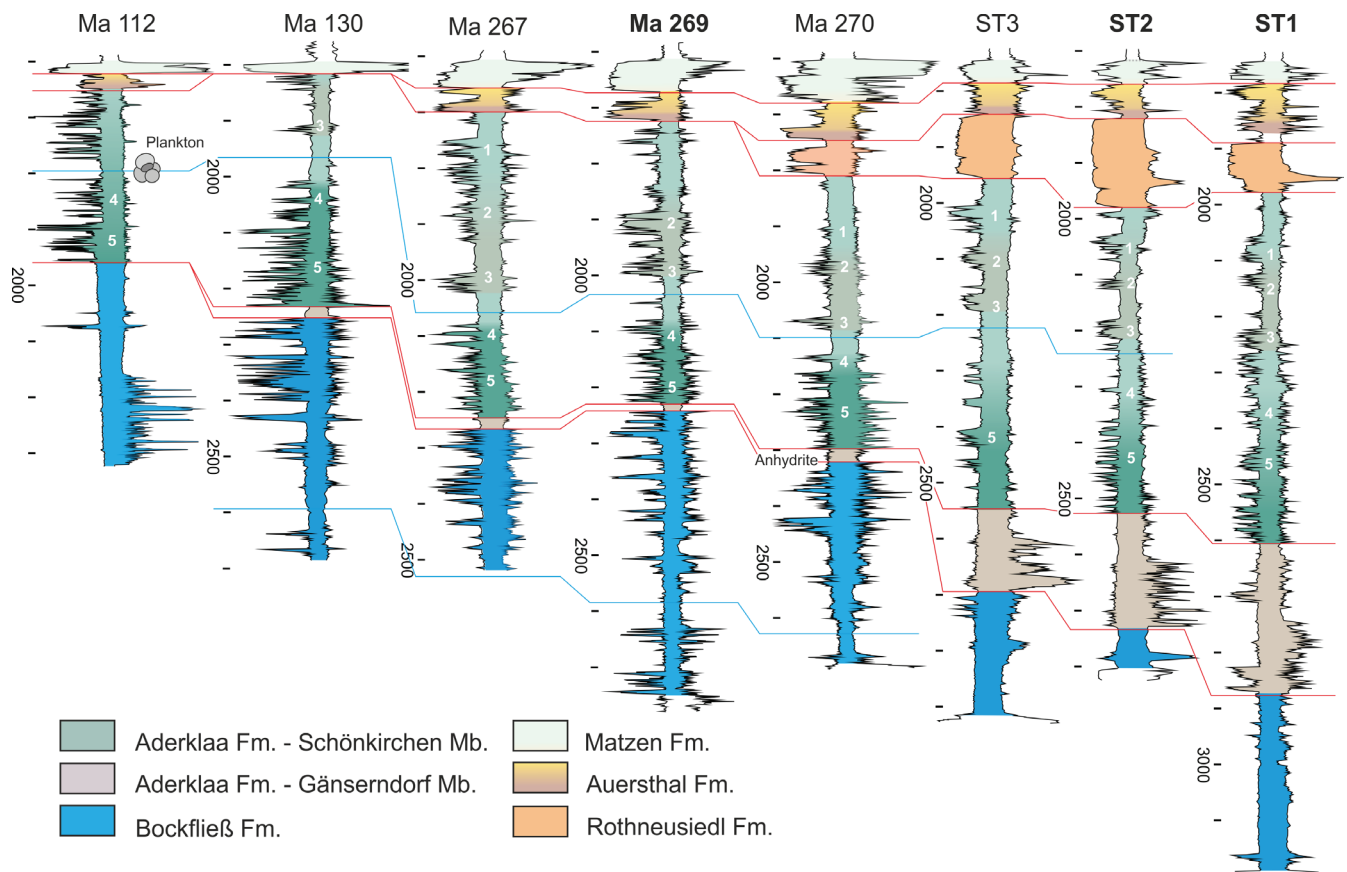
Figure 2: Stratigraphic correlation of Matzen and Schönkirchen wells in the central Vienna Basin. Logs are aligned along the top of the Matzen Fm. Numbers in the Schönkirchen Member correspond to correlative horizons as defined by Hladecek (1965). Red lines indicate sequence boundaries, blue lines are flooding surfaces. Right curve represents the SP-, left curve the RES-log in each well. Pre-Neogene basement is left blank. Type sections are written in bold.

fully marine environment. Additionally, the occurrence of *Magallana gryphoides* indicate the presence of a riverine inlet providing abundant nutrient input and salinity fluctiation in the lagoon (Stenzel, 1971). For all mollusk species a depth-range from the shoreface down to the outer shelf is documented (e.g. Marquet, 2004). Typically, however, *Papillicardium papillosum* is found in coastal shallow water environments, such as lagoons, delta-influenced settings and within the rhizome layers of sea grass (Albano and Sabelli, 2012; Giacobbe, 2012; Weber and Zuschin, 2013). *Corbula gibba* is a specialist for instable bottom conditions, being able to withstand dysoxic conditions (Talman and Keough, 2001). Paratethyan assemblages with high contributions of nuculanids are characteristic for shallow to medium deep sublittoral environments (Báldi, 1973). *Ostrea digitalina* was confined to fully marine conditions (Mandic and Harzhauser, 2003) and is documented to have formed bioherms in protected lagoons with level-bottom conditions (Zuschin et al., 2007). Therefore, a fully marine, inner neritic lagoonal environment with occasionally stressed bottom conditions may be expected as depositional environment. Transport of the mollusk shells can be excluded as *Papillicardium* and some tellinds are found articulated in life-position. The lagoon did not become fully isolated from the open sea, indicated by the sporadic occurrence of globigerinids in upper parts of the formation (e.g. Matzen 270, 2330–2335 m).

Age: Early Miocene (Burdigalian – early Ottnangian).

Biostratigraphy: The nannofossil assemblages point to the nannoplankton zones NN3 or lower NN4; *Sphenolithus conicus* has its last occurrence in NN3 (Bergen et al., 2017) and *Sphenolithus belemnos* ranges from the upper NN2 to the lower NN4 (Hilgen et al., 2012). Overall, the assemblage points to an early Ottnangian age. Nevertheless, reworking is frequent in lower Miocene deposits of the VB and nannoplankton data have to be treated with caution. The foraminiferal and mollusk assemblages are of little biostratigraphic significance but do not contradict this interpretation.

Remarks: The occurrence of the bivalve *Rzehakia*, which was described by Papp et al. (1973) as typical for the Bockfließ Fm., could not be detected herein and was also critically discussed by Schultz (2005). Papp et al. (1973) used the alleged occurrence of *Rzehakia* to correlate the Bockfließ Fm. with the upper Ottnangian "*Rzehakia* beds" of Upper Austria (= *Oncophora* Formation; Pippèrr et al., 2018; = Pixendorf Group of Gebhardt et al. (2013) in Lower Austria). The presence of this bivalve genus, however, has little biostratigraphic significance as it ranges from the Ottnangian to the Badenian (Schultz, 2005).
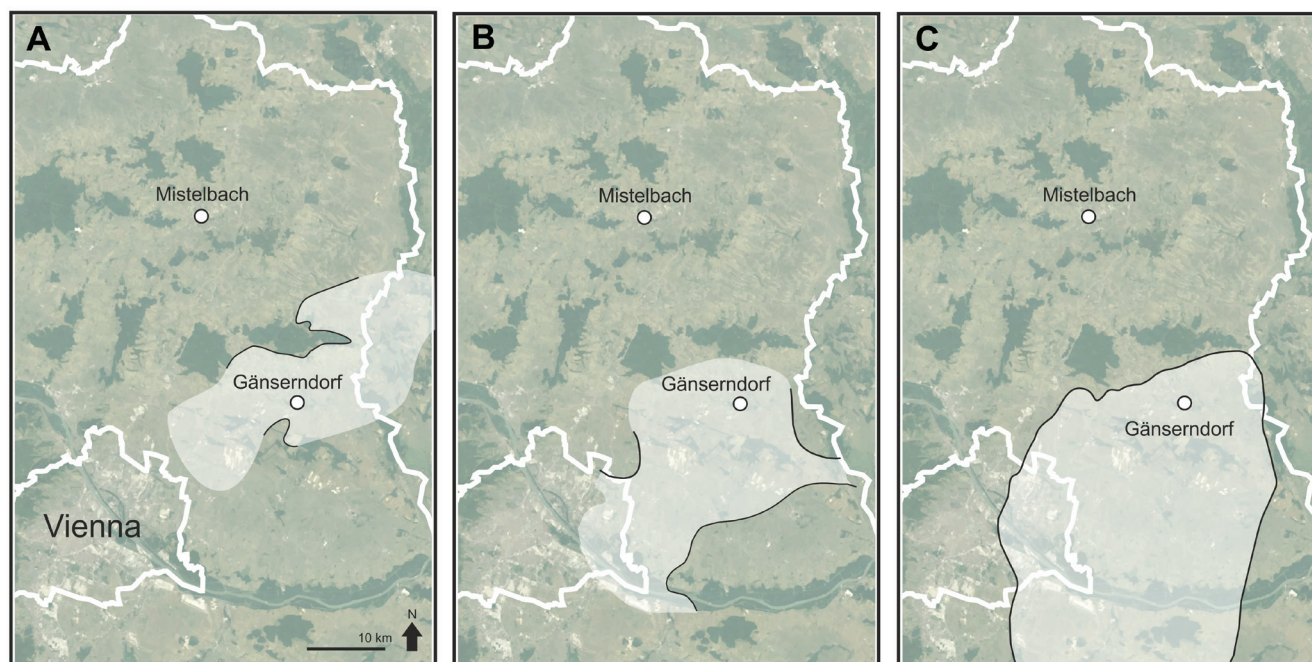
Figure 3: Distribution of the Bockfließ Formation (A), the Gänserndorf Member (B) and the Rothneusiedl Formation (C) based on Hladecek (1965), Weissenbäck (1995) and own data.

Sequence stratigraphy: The Bockfließ Fm. has not been interpreted in terms of sequence stratigraphy so far. Based on its correlation with the Lužice Fm. we assume that the Bockfließ Fm. represents the transgressive systems tract and early high stand systems tract of the 3rd order TB 2.1. cycle of Haq et al. (1988), which is in agreement with Piller et al. (2007).

Underlying units: Pre-Neogene basement (Rhenodanubian Flysch, Mesozoic nappes of the Northern Calcareous Alps).

Overlying units: Aderklaa Fm. south of the Matzen/Spannberg Ridge (Raggendorf-Matzen-Bockfließ-Schönkirchen areas); Badenian units (Matzen Fm., Baden Fm.) north of the Matzen/Spannberg Ridge in the Spannberg area.

Lateral equivalents: The Lužice Fm. of the northern Vienna Basin and Alpine-Carpathian Foredeep is a lateral equivalent and represents more offshore conditions. Based on the nannofossils, the Bockfließ Fm. is probably a time equivalent of the Mistelbach and Kettlasbrunn members of the Lužice Fm. as defined by Harzhauser et al. (2019).

Geographic distribution: The Bockfließ Fm. is restricted to subsurface drillings in the central Vienna Basin and is documented in numerous wells in the area of Spannberg, Prottes, Matzen, Bockfließ, Raggendorf, Schönkirchen, Straßhof, Deutsch-Wagram, Tallesbrunn, and Glinzendorf. North of the Matzen/Spannberg Ridge, the occurrence is limited to a narrow strip. A continuation in eastern direction into the Gajary depression on Slovak territory was described by Kováč et al. (2004, fig. 7a). The Aderklaa High and Aderklaa-Bockfließ Fault form the western boundary and into southern direction, the Bockfließ Fm. pinches out in the Gänserndorf area (Fig. 3A).

Wells: Bockfließ 78 (1948–1953 m), Matzen 125 (2310–2490 m), Matzen 130 (2270–2680 m), Matzen 269 (2245–2754 m), Matzen 267 (2260–2520 m), Matzen 270 (2325–2685 m), Matzen 375 (2330–2720 m), Schönkirchen T1 (2870–3190 m), Schönkirchen T2 (2730–2810 m), Schönkirchen T25 (2720–2935 m), Schönkirchen T3 (2700–2920 m), Spannberg 8 (2400–2643 m), Spannberg 10 (2150–2290 m), Spannberg 14 (2390–2548.6 m); additional core records: Bockfließ 90 (1813–1822 m), Matzen 100 (2072–2079 m), Prottes 16 (2104–2285 m), Prottes 20 (2170–2171 m), Raggendorf 1 (1963–1968 m), Raggendorf 11 (1885–1891 m), Raggendorf 3 (2010–2051 m), Raggendorf 7 (1873–1876 m), Spannberg 11 (2332–2441 m), Spannberg 4 (2150–-2155 m) (for additional records see Hladecek, 1965).

4.1.2 Lužice Formation (Fig. 4)

Derivation of name: After the village Lužice in the northern Vienna Basin in the Czech Republic (N 48°50'27.19", E 17°4'17.07").

Synonyms: Neusiedl Schlier (Kapounek et al., 1965).

Type section: well Maustrenk MTW1 (1300–1505 m; cores: 7/5 1300.00–1305.00 m, 8/1 1350.00–1355.00 m, 9/5 1380.00–1385.00 m, 10/5 1420.00–1424.70 m, 11/5 1458.00–1463.00 m, 12/6 1480.00–1485.00 m) (N 48° 34' 32.08", E 16° 42' 29.77").

Remark: The Lužice Formation is defined in the Mistelbach Halfgraben by its members: Maustrenk Mb., Mistelbach Mb., Kettlasbrunn Mb. and Hobersdorf Mb. (Harzhauser et al., 2019). The designated type section is also type section of the Mistelbach Mb. For description see Harzhauser et al. (2019).
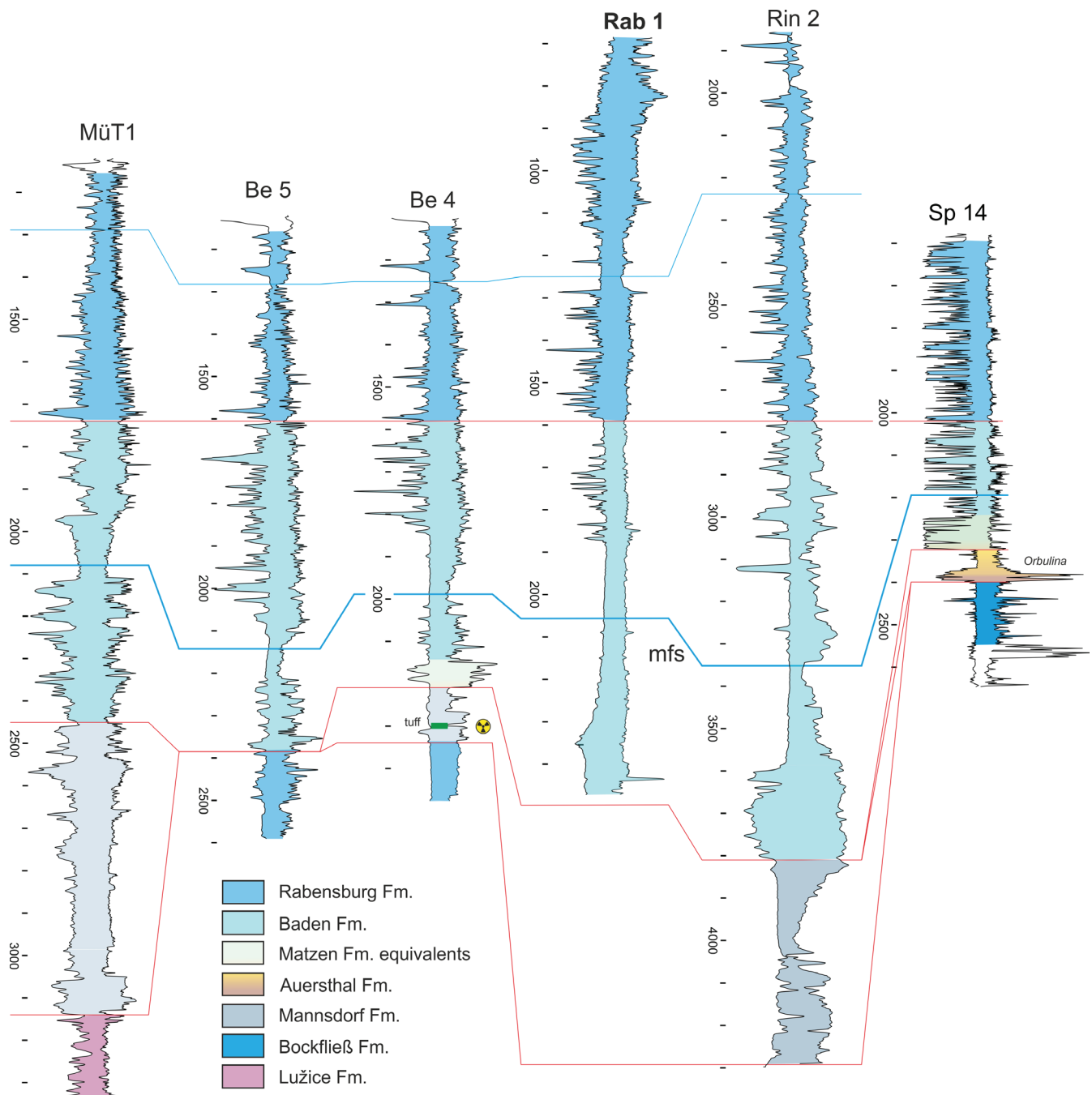
Figure 4: Stratigraphic correlation of Mühlberg, Bernhardsthal, Rabensburg and Ringelsdorf wells in the northern Vienna Basin and a Spannberg well at the northern flank of the Matzen/Spannberg Ridge. Logs are aligned along the boundary between Baden and Rabensburg formations. Red lines indicate sequence boundaries, blue lines are flooding surfaces. Right curve represents the SP-, left curve the RES-log in each well. Pre-Neogene basement is left blank. The maximum flooding surface of the middle Badenian, which is an important marker for OMV correlations is marked as "mfs". Type sections are written in bold.

Thickness: The maximum thickness of the Lužice Fm. attains about 1000 m in the Mistelbach Halfgraben (Harzhauser et al., 2019). East of the Steinberg Fault, in the northern Vienna Basin, the Lužice Fm. is tilted and strongly eroded. Therefore, only lower parts of the formation are preserved with thicknesses ranging around few hundreds of meters (e.g. ~200 m in the Bernhardsthal field).
Lithology: Laminated grey calcareous clays, silt and siltstones with intercalations of sands, referred to as "Schlier" (Kováč et al., 2004).

Well-log characteristics: Shale-line and low amplitude SP- and RES-log patterns are typical.
Fossils: Rich foraminiferal assemblages with *Bathysiphon taurinensis*, *B. filiformis*, *Cyclammina praecancellata* along with *Haplophragmoides vasiceki* and *Trilobatus trilobus* (Cicha et al., 1998; see Harzhauser et al., 2015, 2018 for details).
Depositional environment: Open marine pelagic, partly bathyal environments with high nutrient flux and high sedimentation rates (Grunert et al., 2013, Harzhauser

et al., 2017). A distinct shallowing trend is indicated by the development of *Lenticulina*, *Cibicides* and *Elphidium*-dominated foraminiferal assemblages in the upper part of the Lužice Fm.

Age: Early Miocene (Burdigalian – early Ottnangian).

Biostratigraphy: Early Ottnangian is based on the co-occurrence of *Bathysiphon filiformis*, *Cyclammina bradyi* and *Reticulophragmium karpaticum* (Cicha et al., 1998; Harzhauser et al., 2017). An Ottnangian age is also supported by the occurrence of the bivalve *Pecten hornensis* in basal parts of the Lužice Fm. (Harzhauser et al., 2019).

Sequence stratigraphy: The Lužice Fm. comprises a full 3rd order cycle. Based on its age, it is correlated with the TB 2.1. cycle of Haq et al. (1988) and Piller et al. (2007).

Underlying units: Rhenodanubian Flysch.

Overlying units: The lower Miocene Laa Formation follows in the Mistelbach Halfgraben; in the Austrian part of the northern Vienna Basin, the middle Miocene Mannsdorf or Baden formations discordantly overlay the Lužice Fm.

Lateral equivalents: Bockfließ Fm. in the central Vienna Basin; Wildendürnbach Fm. and Zogelsdorf Fm. in the NACFB (Palzer-Khomenko et al., 2018a, b; Harzhauser et al., 2019).

Geographic distribution: Austrian, Czech and Slovak territories of the northern Vienna Basin and Mistelbach Halfgraben (Buday and Cicha, 1956; Vass, 2002; Kováč et al., 2004; Harzhauser et al., 2018, 2019).

Wells: Mühlberg T1 (3140–3340 m), Bernhardsthal 4 (2340–275 m), Bernhardsthal 5 (2385–2590 m). For drillings in the Mistelbach Halfgraben see Harzhauser et al. (2017, 2019).

Based on its foraminiferal faunas, the investigated samples from these wells can be correlated with the Mistelbach Mb. and parts of the Kettlasbrunn Mb. of the Lužice Formation.

4.2 Karpatian

4.2.1 Aderklaa Formation (Fig. 2)

Derivation of name: After the village Aderklaa in the central Vienna Basin (N 48°17′7.11″, E 16°32′18.96″).

The deposits of the Aderklaa Fm. were recognized during hydrocarbon exploration in the 1940ies. Originally, these sediments were vaguely termed as "schlierähnliche Serie" (schlier-like series at Aderklaa) (Janoschek, 1942, 1943), "Aderklaaer Schlier (Janoschek, 1951) and "Liegendserie von Aderklaa" (lower series of Aderklaa) (Grill, 1943). Later, Grill (1960) established the term "Schichten von Aderklaa" (Aderklaa beds). These Aderklaa beds were separated by Hladecek (1965) into a basal "terrestrial-lacustric series" and an overlaying "limnic series". Since Papp et al. (1973), these two units were named Gänserndorfer Schichten (Gänserndorf beds) and Aderklaaer Schichten (Aderklaa beds). Herein, we consider both lithostratigraphic units as members of a single formation for which we propose Aderklaa Fm. as name. We separate the Aderklaa Fm. into a lower and an upper member, which we define as Gänserndorf Member and Schönkirchen Member.

Synonyms: "schlierähnliche Serie" (Janoschek, 1942, 1943), Aderklaaer Schlier (Janoschek, 1951), "Liegendserie von Adlerklaa" (Grill, 1943), Schichten von Aderklaa (Grill, 1960; Janoschek, 1960), "terrestrisch-lacustrische Serie" (Hladecek, 1965), "limnische Serie" (Hladecek, 1965), Gänserndorfer Schichten p.p. (Papp et al., 1973), Aderklaaer Schichten p.p. (Papp et al., 1973), Aderklaa Formation (Weissenbäck, 1996).

Type section: Designated herein: Well Schönkirchen T1 (1980–2870 m; cores: 4/8 2020.00–2027.00 m, 5/6 2132.00–2137.00 m, 6/6 2227.00–2232.00 m, 7/6 2308.50–2313.50 m, 8/6 2625.00–2630.00 m, 9/5 2730.00–2735.00 m, 10/5 2838.00–2843.00 m) (N 48°21′30.71″, E 16°43′5.50″) (Figs 1–2).

Thickness: The maximum thickness of 1258 m is documented from Wittau Ü1 from the Schwechat Basin. Overall, the thickness varies considerably due to the paleo-relief formed by the underlying Bockfließ Fm. and due to postsedimentary truncation and erosion. A thickness of 500 to 800 m is typical for the Matzen and Schönkirchen areas.

Age: Early Miocene (Burdigalian – Karpatian).

Lithostratigraphic subdivision: The Aderklaa Fm is completely subdivided into the Gänserndorf Member and Schönkirchen Member.

Sequence stratigraphy: The Aderklaa Fm. has not been interpreted in terms of sequence stratigraphy so far and we note that the application of sequence stratigraphy in lacustrine deposits is debatable. The Karpatian stage has been correlated by Piller et al. (2007) with the 3rd order sea level cycle TB 2.2. of Haq et al. (1988). Herein, we interpret the Gänserndorf Mb. as proximal expression of a lowstand systems tract, whereas the Schönkirchen Mb. represents the transgressive and highstand systems tracts including a marine flooding of the wetlands during the maximum flooding (see Discussion chapter). Based on the large thickness, we tentatively consider the whole sequence as 3rd order cycle.

4.2.1.1 Gänserndorf Member (Fig. 2)

The deposits of the Gänserndorf Member were studied by Hladecek (1965) and termed ""terrestrisch-lacustrische Serie". Papp et al. (1973) introduced the term Gänserndorfer Schichten (Gänserndorf beds) for this unit, which was accepted by subsequent authors (e.g. Grill and Janoschek 1980; Rupp, 1986; Jiřiček and Seifert, 1990; Kreutzer, 1993). Weissenbäck (1995) performed a detailed sedimentological analysis and provided first interpretations of the depositional environment. Kováč et al. (2004) discussed this lithostratigraphic unit at formation rank. Herein we define the Gänserndorf beds as member of the Aderklaa Fm.

Derivation of name: After the town Gänserndorf in the central Vienna Basin (N 48°20′26.31″, E 16°43›3.26») (Fig. 1).

Synonyms: terrestrisch-limnische Schichten (Hladecek, 1965), Gänserndorfer Schichten (Papp et al., 1973), Gänserndorf Formation (Weissenbäck, 1996; Wessely, 2006).

Type section: Designated herein: Well Schönkirchen T1 (2610–2870 m; cores: 8/6 2625.00–2630.00 m, 9/5 2730.00–2735.00 m, 10/5 2838.00–2843.00 m) (N 48°21′30.71″, E 16°43′ 5.50″) (Fig. 2: ST1).

Thickness: The unit attains its maximum thickness with 363 m in the well Wittau Ü1. In the Schönkichen field it attains a thickness of up to 260 m (Schönkirchen T1), becomes reduced to few meters in most Matzen wells (130, 125, 167, 269, 270) and is already completely missing in Raggendorf 8 and Matzen 375. The strongly varying thickness results partly from the paleo-relief that truncated and eroded the underlying Bockfließ Fm.

Lithology: The lithology and sedimentology of the Gänserndorf Mb. was described in detail by Weissenbäck (1995) and is summarized in the following: The deposits are characterized by a rapid alternation of conglomerates, sandstones, marly silty clays and subordinate breccias. Conglomerates are monomictic (dolostones) or polymictic (limestones, dolostones, quartz, schist, sandstones, etc.), poorly sorted and moderately rounded with components of up to 10 cm diameter. The light grey fine to medium grained sandstone is usually poorly to moderately sorted, often immature and intercalated by mm-thin clay layers. Flaser- and ripple bedding occasionally occurs in the variegated silty marly clay. Characteristic successions consist of fining-upward-units of thick conglomerates passing into sand-silt and marly clay intercalations. Pieces of anhydrite appear at the base of the formation in the wells Matzen 267 and Bockfließ 78. Continuous layers of evaporites, however, have not been documented so far. The Gänserndorf Mb. passes without unconformity into the Schönkirchen Member (upper part of the Aderklaa Fm) and is separated from the later by its high amount of coarse grained clastics.

Well-log characteristics: SP-logs are characterized by generally rather low amplitudes, which are opposed by strongly serrated RES patterns with high RES-values. This pattern results from the high degree of compaction and cementation of the conglomerates (Weissenbäck, 1995). Overall, an upsection trend towards lower RES values is seen in the studied logs.

Fossils: The Gänserndorf Mb. is poor in fossils. Wells Matzen 267 (2250–2268 m) and Schönkirchen T1 (2840 m, 2730–2735 m, 2625–2630 m) yielded large ostracods (Candonidae, Cytherideidae), hydrobiid, planorbid and helicid gastropods and oogonia of Characeae (Hladecek, 1965; own data).

Depositional environment: The depositional environment of the Gänserndorf Mb. was interpreted by Weissenbäck (1995) as a transition from alluvial fans in its basal part to a braided river system with the main transport direction from SW to NE. Parts of the succession represent overbank-deposits and probably wetland ponds. This is indicated by the frequent occurrence of hydrobiid gastropods and large freshwater ostracods, which were adapted to lentic environments and did not live in the fast flowing river channels. Paleosol formation and the presence of helicid gastropods clearly indicate terrestrial conditions within the floodplains. Moreover, the formation of anhydrite pebbles is a hint to rather dry climatic conditions.

Age: Early Miocene (Burdigalian – Karpatian).

Biostratigraphy: No biostratigraphic marker species are known from the Gänserndorf Mb. It discordantly overlies the Ottnangian Bockfließ Fm. and passes conformably into the overlaying Schönkirchen Mb., which is of Karpatian age. Therefore, we assume a Karpatian age for the Gänserndorf Mb. In addition, the indication for rather dry and warm climate is a hint to a Karpatian rather than an Ottnangian age of this formation. As shown by stable isotope data of oyster shells by Harzhauser et al. (2010) and floral data by Kern et al. (2010), based on high resolution pollen analysis, the Karpatian was characterized by very dry and hot summer seasons, thus differing from the still warm but slightly cooler Ottnangian with higher precipitation (Grunert et al., 2014).

Lithostratigraphically higher rank unit: Aderklaa Formation.

Underlying units: In all herein studied wells, the Gänserndorf Mb. discordantly overlies the Bockfließ Fm.

Overlying units: In all herein studied wells, the Gänserndorf Mb. is overlain by the Schönkirchen Mb.

Lateral equivalents: In the Slovak part of the Vienna Basin, the Šaštín Mb. of the Závod Fm. was discussed by Kováč et al. (2004) to be a lateral equivalent based on the occurrence of anhydrite in both units. Harzhauser et al. (2019) defined the Závod Formation as a member (Závod Member) of the Laa Fm. The coastal marine Týnec Sand (Špička and Zapletalová, 1964) might be a further equivalent on Slovak territory.

Geographic distribution: The Gänserndorf Mb. is only known from subsurface drillings. It is restricted to an about 10 to 20 km wide SW-NW trending area in the central Vienna Basin and was drilled mainly in the Schönau, Andlersdorf, Breitenstetten, Breitensee, Matzen, Schönkirchen and Bockfließ wells (Weissenbäck, 1995). It pinches out towards the Matzen/Spannberg Ridge in the north, towards the Aderklaa High in the northwest, towards the Zwerndorf High in the west and disappears in southeastern direction between the Markgrafneusiedl and the Kopfstetten faults. In the west and southwest, the formation reaches into the Schwechat Basin without reaching up to the Oberlaa High. In total, the Gänserndorf Mb. covers roughly 550 km^2 on Austrian territory (Fig. 3B).

Wells: Bockfließ T1 (2500–2720 m), Matzen 269 (2230–2268 m), Matzen 270 (2300–2320 m), Schönkirchen T1 (2610–2870 m), Schönkirchen T2 (2530–2730 m), Schönkirchen T3 (2550–2700 m), Schönkirchen T41 (2611–2618 m); additional core records: Aderklaa 3 (2683–2701 m), Bockfließ 78 (1810–1940 m), Breitenlee 1 (2814–2823, 2888–2893 m), Deutsch Wagram 3 (3022–3027, 3109–3114 m), Fischamend T1 (3038–3043 m), Gänserndorf T1 (2916–2921 m), Glinzendorf T1 (3113–3118 m), Marchegg 1 (2010–2015 m), Markgrafneusiedel NT1 (3150–3155 m), Straßhof T1 (2743–2748 m), Straßhof T2 (2905–2910 m.

4.2.1.2 Schönkirchen Member (Fig. 2)

This lithostratigraphic unit was introduced by Papp et al. (1973) as Aderklaaer Schichten and treated so far as Aderklaa Fm. in the more recent literature (e.g. Weissenbäck, 1995; Kováč et al., 2004). By integrating also the Gänserndorf Mb. in the Aderklaa Fm., it became necessary to define this unit as new member.

Derivation of name: After the village Schönkirchen in the central Vienna Basin (N 48°21'49.98", E 16°42'3.09").

Synonyms: Aderklaaer Schlier p.p. (Janoschek, 1951), limnische Serie (Hladecek, 1965), Limnische Schichten mit Congerien (Papp et al., 1973), Aderklaaer Schichten (Papp et al., 1973), Aderklaa Formation (Weissenbäck, 1996; Wessely, 2006), ?Grillenberger Kohleserie (Brix and Plöchinger, 1988), ?Hauerbergschichten (Brix and Plöchinger, 1988), Láb beds (Láb Member) in Slovakia (Buday, 1955; Kovac et al., 2004).

Type section: Designated herein: Well Schönkirchen T1 (1980–2610 m; cores: 4/8 2020.00–2027.00 m, 5/6 2132.00–2137.00 m, 6/6 2227.00–2232.00 m, 7/6 2308.50–2313.50 m) (N 48°21'30.71", E 16°43'5.50") (Figs 1–2).

Thickness: A maximum thickness of 1066 m is developed in the Schwechat depression in well Aderklaa 85 (Weissenbäck, 1995). A very high thickness of 895 m is also documented from the well Wittau Ü1. In the Matzen area, the thickness ranges around 500 m.

Lithology: The lithology and sedimentology of the Schönkirchen Mb. was described in detail by Weissenbäck (1995) and is summarized in the following. Drill cores reveal a rather monotonous alternation of strongly cemented light grey to greenish sandstones with marly silt and marly clay; thin gravel layers are occasionally intercalated. The sand is moderately to moderately well sorted, often with graded bedding and frequent plant debris. Lenticular and flaser bedding are typical. Reworked andesitic tuff within the Schönkirchen Mb. was detected in well Orth 1 (3130-3135 m) by Kapounek and Papp (1969).

Well-log characteristics: SP-logs in the Matzen-Schönkirchen area indicate a subdivision into a strongly serrated basal interval with high amplitudes and an overall bell-shaped outline. Bundles of high-amplitude values form serrated intervals separated by short shale line intercalations (intervals 4 and 5 in Fig. 2). This lower part is separated by an up to 100 m thick shale line interval from an upper part with at least three high amplitude bundles of cylindrical to funnel-shaped outline (intervals 1, 2 and 3 in Fig. 2) alternating with shale line intervals. The RES-logs mirror this pattern largely but with lower amplitudes. In the Aderklaa area, this subdivision is less prominent and low amplitude patterns prevail.

Fossils: Large ostracods are the most common fossils in the Schönkirchen Mb. (Candonidae, Cytherideidae, Hemicytheridae). Mollusks are represented by the terrestrial helicid gastropod *Megalotachea silvana* (e.g. Matzen 273: 2070 m). The pachychilid gastropod *Tinnyea lauraea* along with hydrobiids are known from Schönkirchen T1 (2020–2027 m). Hydrobiids are also documented from Matzen 269 (2056–2065 m). The neritid gastropods *Theodoxus crenulatus* and

Vitta pachii were documented from Raggendorf 8 (1770–1792 m). Bivalves are documented by the dreissenid *Andrusoviconcha neumayri* (e.g. Aderklaa 78: 2757–2766 m, Bockfließ 90: 1770–1779 m, Straßhof 1: 2405–2414 m) and *Trigonipraxis* cf. *kucici* (= *Congeria antecroatica* sensu Papp, 1967) (Aderklaa 78: 2757–2766 m); unidentified dreissenids occur also in Raggendorf 8 (1770–1792 m) (Hladecek, 1965; Papp, 1967; own data). An important finding are marine foraminifera in Matzen 112 (1805 m) comprising *Ammonia beccarii, Bulimina schischkinskayae, Globigerina bulloides, Globigerinella regularis, Globorotalia transsylvanica, Hanzawaia buoana,* and *Nonion commune.* Hydrobiid gastropods, dreissenid bivalves and a low diverse foraminiferal fauna was also recorded from the Láb beds on Slovak territory (Fordinál et al., 2012).

Depositional environment: The detailed sedimentological analysis by Weissenbäck (1995) revealed the Schönkirchen Mb. as deposits of a meandering river system with channels and flood plains. According to Weissenbäck (1995), the sandy intervals represent largely point-bars and pelitic intervals formed in oxbow lakes. A flood plain depositional environment is also indicated by the fossil content with large sized ostracods and hydrobiids, which might have dwelled in the flood plain lakes. Inhabitants of fluvial environments are represented by the gastropod Tinnyea. The most diverse fauna derives from the basal parts of the Schönkirchen Mb. in the Raggendorf 8 well, where dreissenid bivalves, hydrobiids and theodoxids have been detected along with the neritid Vitta pachii. This gastropod is occurring in the Korneuburg Basin in coastal mudflats and is unknown from freshwater settings (e.g. Zuschin et al., 2014). A comparable assemblage was described by Harzhauser et al. (2016) from Rupelian marsh land deposits of Turkey, where dreissenids, hydrobiids and Vitta co-occurred in the landward part of the mangrove fringe. Therefore, its occurrence in the basal parts of the Schönkirchen Mb. indicates the proximity to the shoreline. At least one short marine flooding of the wetland by the Paratethys Sea is documented by the occurrence of marine foraminifers in well Matzen 112.

Age: Early Miocene (Burdigalian – Karpatian).

Biostratigraphy: No biostratigraphic marker species are known from the Schönkirchen Mb. Nevertheless, the occurrence of *Vitta pachii* is only known from Karpatian deposits so far (Harzhauser, 2002). In addition, *Andrusoviconcha neumayri* is also recorded from the Karpatian of the Laa Fm. (Harzhauser and Mandic, 2009) and *Trigonipraxis kucici* is a Karpatian species as well (de Leeuw et al., 2011). The foraminiferal assemblage has little biostratigraphic significance, but the presence of *Globorotalia transsylvanica* and *Globigerinella regularis* excludes an Ottnangian age (according to the ranges given in Cicha et al., 1998).

Lateral equivalents: The Láb beds (= Láb Ostracod member, Buday and Cicha, 1956) are a lateral equivalent in the Slovak part of the Vienna Basin (Kováč et al., 2004, Fordinál et al., 2012). The Grillenberger Kohleserie (Brix and Plöchinger, 1988), representing lignites and marls in the area of Grillenberg, Kleinfeld and Jauling (Lower

Austria) along the southwestern margin of the Vienna Basin, might be a lateral equivalent of the Schönkirchen Mb., but a reliable dating is missing so far and Janoschek (1951, 556) even proposed a middle Miocene age. Similarly, the Hauerbergschichten (Brix and Plöchinger, 1988), representing up to 2 m of freshwater limestone at Gainfarn in the southern Vienna Basin might be a time equivalent.

The Závod Mb. is a time equivalent of upper parts of the Schönkirchen Member in the Mistelbach Halfgraben, the Korneuburg Basin and the Slovak part of the VB but represents shallow to middle neritic marine depositional environments (Kováč et al., 2004; Harzhauser et al., 2019).

Lithostratigraphically higher rank unit: Aderklaa Formation.

Underlying units: The Schönkirchen Mb. concordantly overlies the Gänserndorf Mb. or discordantly overlies the Bockfließ Fm.

Overlying units: In most of the studied wells, the Schönkirchen Mb. is discordantly overlain by the Rothneusiedl Fm. In some wells close to the Matzen/Spannberg Ridge, it is overlain directly by the Matzen Fm.

Geographic distribution: The Schönkirchen Mb. is only known from subsurface drillings. In the north, it pinches out along the Matzen/Spannberg Ridge. Towards the east, it reaches via the Suchorad Basin to the Záhorie Lowlands on Slovak territory (= Láb beds), where it is recorded from drillings at Malacky, Láb, Jakubov, Suchohrad, Vysoká pri Morava, and Lozorno (Fórdinal et al., 2012). Thus, the Malé Karpaty mountains form the easternmost border, whereas the Kopfstetten Fault and the Enzersdorf High delimit this member towards the southeast.

In the south, the Schönkichen Mb. reaches into the Schwechat Basin attaining there its maximum thickness. The Aderklaa High and the Leopoldsdorf Fault represent northwestern and western boundaries of the Schönkichen Mb. Strauss et al. (2006) discuss a continuation of the Aderklaa Fm. (undifferentiated) into the southern Vienna Basin down to the northern margin of the Leitha Mountains. These deposits are documented in seismic surveys (Strauss et al., 2006) and drilled by well Wienerherberg 1, where these deposits attain a thickness of about 200 m. Including this southern distribution, the Aderklaa Fm. covers an area of more than 1000 km^2.

Wells: Aderklaa 78 (2005–2810 m), Bockfließ T1 (2000–2500 m), Matzen 112 (1650–1960 m), Matzen 375 (1885–2330 m), Matzen 269 (1730–2235 m), Matzen 267 (1700–2250 m), Schönkirchen T1 (1980–2600 m), Schönkirchen T2 (1990–2530 m), Schönkirchen T3 (1960–2550 m), Schönkirchen T25 (1870–2410 m); additional core records: Baumgarten 6 (2578–2581 m), Breitenlee 1 (2435–2667 m), GlinzendorfT1 (2709–3070 m), Maria Ellend 1 (2650–2655 m), Orth 1 (2899–3135 m), Schönau 1 (2704–3021 m).

4.3 Badenian

4.3.1 Baden Group

The various Badenian deposits of the Vienna Basin were united in the Baden Group on the "Stratigraphic Chart of Austria 2004" (Piller et al., 2004). The chart, however, listed only the most important formations and a formalization was missing so far.

Derivation of name: After the town Baden in the central Vienna Basin (N 48°00′29.00″, E 16°14′03.72″).

Type section: Designated herein: The 102-m-long scientific core from the abandoned brick yard Baden/Sooss near the town Baden (Lower Austria), south of Vienna (N 47°59′24″, E 16°13′44″) (see Baden Formation below for discussion and references).

Thickness: The maximum thickness of the Baden Group, based on the maximum thicknesses of its formations, ranges around 3300 m.

Lithostratigraphic subdivision: Auersthal Fm. ("Auersthaler Schichten"), Baden Fm., Leitha Fm., Mannsdorf Fm., Matzen Fm. ("Matzen Sand"), Rabensburg Fm., Rothneusiedl Fm. ("Rothneusiedler Konglomerat", "Aderklaaer Konglomerat"), Sandberg Mb.

Informal lithostratigraphic units: Aderklaa bentonite main marker ("Aderklaa Hauptmarker"), Aderklaa Sand ("Aderklaaer Sand"), Andlersdorf conglomerate ("Andlersdorfer Konglomerat"), Devinska Nová Ves Fm., Enzesfeld sand ("Enzesfelder Sande"), Gainfarn breccia ("Gainfarner Bekzie"), Gainfarn sand ("Gainfarner Sande"), Hrušky Fm. ("Hrušecke vrstvy"), Iváň Fm., Jakubov Fm. ("Jakubovske vrstvy"), Kúty Member ("Kutske vrstvy"), Lab sand, Lanžhot Fm. ("Lanzhotske vrstvy"), Lindabrunn conglomerate ("Lindabrunner Konglomerat"), Matzen bentonite main marker ("Matzen Hauptmarker"), St. Margarethen limestone ("St. Margarethener Kalksandstein"), Studienka Fm. ("Studienske vrstvy"), Vöslau (Baden) conglomerate ("Vöslauer (Badener) Konglomerat"), Žižkov beds ("Žižkovske vrstvy"), Zohor conglomerate, Zwerndorf sand ("Zwerndorfer Sand").

Fossils: See description of formations below.

Depositional environment: See description of formations below.

Age: Middle Miocene (Badenian, Langhian – early Serravallian).

Biostratigraphy: The Baden Group spans the calcareous nannoplankton zones NN4 (upper part), NN5 and NN6 (Kováč et al., 2004), the foraminiferan plankton zones M5, M6 and M7 (Hohenegger et al., 2014) and comprises the regional benthic foraminiferal eco-biozones Lower and Upper Lagenidae Zone, *Spirorutilus* Zone and *Bulimina-Bolivina* Zone (Cicha et al., 1998).

Sequence stratigraphy: The Baden Group comprises three 3rd order cycles, termed Ba1, Ba2 and Ba3 by Strauss et al. (2006). These cycles are correlated with the global TB 2.3., TB 2.4. and TB 2.5. cycles of Haq et al. (1988) (Strauss et al., 2006; Piller et al., 2007; Hohenegger et al., 2014).

Underlying units: Pre-Neogene units (e.g. Rhenodanubian Flysch, Magura Flysch, Mesozoic nappes of the Northern Calcareous Alps); Ottnangian formations (Bockfließ Fm., Lužice Formation); Karpatian formations (Aderklaa Fm.).

Overlying units: Sarmatian formations (Holic Fm.) in most of the distribution area; Quaternary deposits along basin margins and the southern Vienna Basin.

Lateral equivalents: Equivalents of the Baden Group are distributed throughout the area of the former Paratethys Sea. Herein we list only equivalents in adjacent depositional

areas: Grund Fm. and Mailberg Fm. in the Austrian part of the NACFB (Roetzel, 2009). Baden Clay Fm., Rákos Limestone and Szilàgy Clay Marl Fm. in the Hungarian part of the Eisenstadt-Sopron Basin and the Hungarian Kisalföld basins (Császár, 1997). Špačince Fm. and Báhoň Fm. in the northern Danube Basin in Slovakia (Vass, 2002).

Geographic distribution: Throughout the Vienna Basin.

4.3.1.1 Rothneusiedl Formation

Derivation of name: After the village Rothneusiedl, a cadastral district of Vienna, in the central Vienna Basin (N 48°8′27.11″, E 16°22′28.10″).

   This formation was first recognized by Janoschek (1943), who already discussed an unconformity at its base. Later, Janoschek (1951) introduced the terms "Rothneusiedel Konglomerat (Rothneusiedel Conglomerate) and "Aderklaaer Konglomerat" (Aderklaa Conglomerate) for this unit, which are synonyms. The term Aderklaa Conglomerate was adopted by all subsequent authors (e.g. Kapounek et al., 1965; Kapounek and Papp, 1969; Papp et al., 1973; Kreutzer and Hlavatý, 1990). The name Aderklaa Conglomerate Fm., however, is unfavorable as it is nearly eponymous with the Aderklaa Fm. Although the term "Aderklaa Konglomerat" is very well established in the geological literature and widely used in applied geology, we propose to replace it by its synonym Rothneusiedl Fm.

Synonyms: Aderklaaer Konglomerat (Janoschek, 1951), Aderklaa Conglomerate (Weissenbäck, 1996), Aderklaa conglomerate Member (Kováč et al., 2004), Rothneusiedler Konglomerat (Janoschek, 1951).

Type section: Designated herein (Fig. 2): well Schönkirchen T2 (1825–1980 m) (N 48°21′10.84″, E 16°41′52.24″) (Fig. 1–2). Papp et al. (1973) mentioned wells Aderklaa 96 and Breitenlee 3 as typical, without designating a formal type section.

Thickness: The maximum thickness was documented from the Schwechat and Marchfeld depressions attaining about 369 m in well Mannsdorf T1 and 350–360 m at Andlersdorf and Breitstetten (Kapounek and Papp, 1969). In the Schönkirchen area, a thickness of up to 150 m is typical, whereas the thickness decreases rapidly towards the Matzen/Spannberg Ridge.

Lithology: The lithology and sedimentology of the Rothneusiedl Fm. was described in detail by Weissenbäck (1995) and is summarized in the following. Moderately cemented to loose, massive, clast-supported conglomerates composed of poorly to moderately rounded, medium to coarse gravel with frequent cobbles. The sediment is polymict with limestones, dolostones and various crystalline components. Intercalations of fine sand and silty marly clay are subordinate but increase in thickness in the Ollersdorf-Prottes area, where sand nearly replaces the conglomerates (Kapounek and Papp, 1969). No bedding and sedimentary structures are recognizable in the conglomerates. The amount of limestones relative to crystalline components increases strongly from SW to NE.

Well-log characteristics: The Rothneusiedl Fm. is recognized easily in well-logs by the sudden increase in SP-logs with sharp boundary towards the underlying Aderklaa Fm. In profile, the SP-logs are either strongly serrated within a high negative amplitude spectrum or cylinder shaped with rare intercalations of lower values, probably correlating with thin sand layers. RES-logs are partly mirroring SP-patterns but often are interrupted by high amplitude intervals, which lack counterpart in the SP-log. These intervals might indicate strongly cemented conglomerate layers. The top of the Rothneusiedl Fm. is often indicated by a sudden transition into shale line logs (so-called Lower Lagenidae Zone in internal OMV-reports).

Fossils: Grill (1943) documented Badenian fully marine lagenid-assemblages from upper parts of the Rothneusiedl Conglomerate in the Oberlaa area. No detailed faunal lists are available.

Depositional environment: The main part of the Rothneusiedl Fm. was interpreted by Weissenbäck (1995) as deposits of a braided river with numerous amalgamating channels and bars. Increasing amount of sand intercalations in its northern distribution area and the decrease of crystalline components in northeastern direction suggests drainage into northern-northeastern direction. Marine influence in this distal area is documented by marine foraminifers in the Oberlaa area (Grill, 1943), heralding the first Badenian transgression.

Age: Middle Miocene (early Langhian – early Badenian). The age of the Rothneusiedl Fm. was discussed controversially. Kapounek et al. (1965), Kapounek and Papp (1969), Papp et al. (1973), and Jiříček and Seifert (1990) interpreted the unit as terminal phase of the Karpatian, whereas Janoschek (1943, 1951), Kreutzer and Hlavatý (1990), Kreutzer (1992), Kováč et al. (2004), and Strauss et al. (2006) discussed it as basal Badenian. The latter view was supported by seismic data, indicating a major unconformity and hiatus between the Rothneusiedl Fm. and the underlying Bockfließ and Aderklaa formations. Based on sequence stratigraphic models, Weissenbäck (1995, 1996) documented the basal Badenian position of the Rothneusiedl Fm. In addition, the presence of lagenid-rich foraminiferal assemblages in the upper part of the Rothneusiedl conglomerate proof the Badenian age (Grill, 1943).

Biostratigraphy: Rögl et al. (2008) reported nannoplankton zone NN5 with *Helicosphaera waltrans* from the assumed upper part of Rothneusiedl Fm. in well Aderklaa 40 (2168 –2248 m). This interval, however, is already part of the distinctly younger Auersthal Fm. Based on the stratigraphic position, we assume an early Badenian age for the Rothneusiedl Fm. predating the FOD of *Orbulina* and corresponding to nannoplankton Zone NN4.

   In respect to the Vienna Basin ecobiostratigraphy it belongs to the Lower Lagenidae Zone.

Sequence stratigraphy: The Rothneusiedl Fm. represents lowstand systems tract deposits of the Badenian Sequence Ba1 of Strauss et al. (2006).

Lithostratigraphically higher rank unit: Baden Group.

Underlying units: Deposits of the Aderklaa Fm. underlay discordantly the Rothneusiedl Fm. in the central Vienna Basin and probably also in the southern Vienna Basin (Strauss et al., 2006).

Overlying units: The Rothneusiedl Fm. is generally overlain by other Badenian deposits. Pelites of the Mannsdorf Fm., usually referred to as "Lower Lagenidae Zone" in internal OMV reports (e.g. Kapounek et al., 1965; Kapounek and Papp, 1969; Weisenbäck, 1995, 1996), overly the Rothneusiedl Fm. in wells Matzen 375, Aderklaa 78, Wittau 1, Orth 1, and Mannsdorf 1 (among others). In the Matzen and Schönkirchen area, the Rothneusiedl Fm. is usually overlain by the Matzen Fm. and by the Leitha Fm. along the Leitha Mountains (e.g. Mannersdorf) (Wiedl et al., 2012).

Lateral equivalents: Within the Vienna Basin, the dolomitic Gainfarn breccia (Wessely et al., 2007) is a proximal and monomictic equivalent along the western margin of the southern Vienna Basin. In the SE Vienna Basin an equivalent was described from Mannersdorf (Fencl, 2005; Wiedl et al., 2012). The about 100-m-thick Rust Fm. in the Rust Hills may be an equivalent (Häusler et al., 2014) in the Eisenstadt-Sopron Basin. The unnamed 105-m-thick marine clastics in the Roggendorf 1 well, described by Ćorić and Rögl (2004), is an equivalent in the Alpine-Carpathian Foredeep. The incision and at least parts of the sedimentary fill of the Mistelbach and Iváň canyons, described by Dellmour and Harzhauser (2012) and Harzhauser et al. (2017, 2019), are time equivalents as well. Vass (2002) correlated also the conglomerates and breccias with rare anhydrite of the Kúty Member (Kutske vrstvy; Špička, 1966) in the Kúty Graben in the Slovak Republic with the Rothneusiedl Fm., but these deposits may also be equivalents of the Auersthal Fm. (see below).

Geographic distribution: The Rothneusiedl Fm. is only known from subsurface drillings (aside from a potential local occurrence at Mannersdorf, Wiedl et al., 2012) and displays a wide distribution in the central and southern Vienna Basin (Fig. 3C). In the north, it is delimited by the Matzen/Spannberg Ridge and is already missing in several Matzen wells. It appears on the Aderklaa High in the northwest and the Zwerndorf High in the northeast. In the west it is largely limited by the Leopoldsdorf Fault, aside from a small occurrence on the Oberlaa High, termed "Rothneusiedler Konglomerat" (Janoschek, 1951). The Rothneusiedl Fm. covers the Schwechat and Marchfeld depressions, crosses the Engelhardstetten Fault in the southeast and pinches out along the Leitha Mountains in the south (Kapounek and Papp, 1969; Weissenbäck, 1995; Strauss et al., 2006). Kröll (1984) reports its distribution in the southern Vienna Basin down to Wiener Neustadt. In total, the Rothneusiedl Fm. covers an area of at least 950 km2. Wessely et al. (2007) discussed the presence of the Rothneusiedl Fm. even along the western margin of the southern Vienna Basin in the Bad Vöslau area (based on seismic surveys), which might suggest an even much wider distribution of the formation.

Wells: Aderklaa 78 (1890–2000 m), Bockfließ T1 (1870–1990 m), Matzen 270 (1765–1810 m), Schönkirchen T1 (1895–1980 m), Schönkirchen T2 (1825–1980 m), Schönkirchen T3 (1845–1960 m), Wittau 1 (2690–2700 m); additional core records: Andlersdorf 1 (3111–3407 m), Breitensee Ü1 (1324–1329 m), Eckartsau 1 (1700–1702 m), Glinzendorf T1 (2475–2480 m), Orth 1 (2694–2699 m), Schönau 1 (2475–2580 m), Schönkirchen T26 (1850–1859 m).

4.3.1.2 Mannsdorf Formation (Figs 4–5)

Derivation of name: After the village Mannsdorf an der Donau in the Vienna Basin (N 48°09'09.90", E 16°39'37.05").

Synonyms: Tegel, Lower Lagenindae Zone p.p.

Type section: Designated herein: well Mannsdorf 1 (2440–2575 m; cores: 26/3 2477.00–2481.00 m, 27/1 2505.00–2509.00 m, 28/1 2570,00–2572,00 m) (N 48°9'42.97", E 16°41'3.82") (Figs. 1, 5).

Thickness: The maximum thickness of 685 m is documented from well Mühlberg T1 followed by well Ringelsdorf 2 with 479 m. Both sections seem to be influenced by synsedimentary subsidence and, therefore, the recorded thickness might be untypical. The preserved thickness varies considerably from well to well ranging from few tens of meters, e.g. Matzen 375 (35 m), Rabensburg 10 (50 m) to < 300 m, e.g. Bernhardsthal 4 (120 m), Wittau 1 (240 m), Aderklaa 78 (280 m) and the formation is even missing in some wells (e.g., in the Matzen area (Fig. 2)).

Lithology: Blue-grey clay, marl and silt, partly with thin silt and fine-sand layers ("Tegel"), sandstone layers, rare tuffitic layers are recorded from well Bernhardsthal 4.

Well-log characteristics: Shale-line logs are typical in the central Vienna Basin, indicated by a sudden decrease in SP- and RES-logs from the underlying pre-Neogene units and the high amplitude Rothneusiedl Fm. Strongly serrated logs, indicating frequent sand layers, may also occur (e.g. Ad 78). Broad cylinder- and funnel-shaped well-logs, suggesting rapid sediment transport, occur at Mühlberg T1 along the Steinberg Fault.

Fossils: The foraminiferan faunal composition is dominated by *Lenticulina inornata, Paragloborotalia mayeri, Globigerinella regularis, Tenuitellinata angustiumbilicata, Globoturborotalita druryi, Turborotalia quinqueloba, Lobatula lobatula, Trilobatus trilobus,* and *Globigerina praebulloides*. A subtropical evergreen broadleaved forest was identified from the hinterland of the Vienna Basin at that time (Rybár et al., 2019).

Depositional environment: The foraminiferal fauna suggests an outer neritic to upper bathyal depositional environment with high nutrient content and connection to the open sea. No inner neritic to coastal assemblages were detected in the lower Badenian samples.

Age: Middle Miocene (early Langhian - early Badenian), between c. 15.2 and 14.8 Myr.

An absolute age is available for a tuff layer in well Bernhardsthal 4, which indicates an age of 15.12 ± 0.19 Ma (Be4 tuff of Sant et al., 2020). The Kuchyňa tuff, from a small outcrop along the western part of the Malé Karpaty Mountains at the eastern margin of the Vienna Basin was dated by Rybár et al. (2019) at 15.23 ± 0.04 Ma. Based on these data, Sant et al. (2020) discussed a flooding of the Vienna Basin around 15.2 Ma. The position of the Be 4 tuff within the Mannsdorf Fm., however, is unclear and there is no reason to assume that the tuff is at the base of the formation. Note that Sant et al. (2020, fig. 10) erroneously
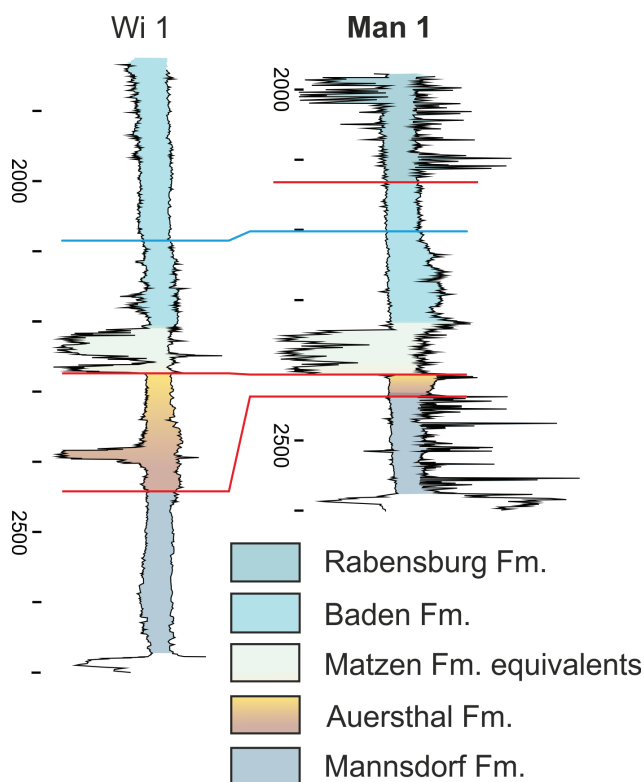
Figure 5: Stratigraphic correlation of Wittau and Mannsdorf wells in the southern part of the central Vienna Basin. Logs are aligned along the top of the Matzen Fm. Red lines indicate sequence boundaries, blue lines are flooding surfaces. Right curve represents the SP-, left curve the RES-log in each well. Pre-Neogene basement is left blank. Type sections are written in bold.

placed the Be4 tuff into the "Aderklaa conglomerate" (= Rothneusiedl Fm.). Consequently, the scheme of Sant et al. (2020) strongly deviates from our scheme. In the text, however, it is clearly stated that the tuff is intercalated in clay with planktic foraminifers (Sant et al., 2020: 169). Thus, the Be4 tuff forms part of the Mannsdorf Fm.

An age for the upper boundary of the Mannsdorf Fm. can be expected around 14.8 Ma, based on the absence of *Orbulina* and on the finding of an *in-situ* moldavite at Immendorf in the upper part of the coeval Grund Fm. (Roetzel, 2009). The FOD of *Orbulina* in the Mediterranean is recorded by Iaccarino et al. (2011) at 14.56 Ma. and the Ries Impact, which ejected the moldavite, is dated at around 14.8 Ma (Schmieder et al., 2018).

Biostratigraphy: Samples from the Mannsdorf Fm. were the base for the description of the Lanzendorf Fauna by Grill (1941) what later on became the Lower Lagenidae Zone. *Uvigerina macrocarinata* and *Praeorbulina glomerosa circularis* are index fossils for the Lower Lagenidae Zone according to Papp (1963) and Papp et al. (1978) but, in fact, these species are rare and were completely missing in all herein analyzed samples.

Sequence stratigraphy: The Mannsdorf Fm. represents the transgressive systems tract of the Badenian Sequence Ba1 of Strauss et al. (2006).

Lithostratigraphically higher rank unit: Baden Group.

Underlying units: Lower Ottnangian Lužice Fm. in Mühlberg and Bernhardsthal fields; Rothneusiedl Fm. in Matzen and Aderklaa fields; pre-Neogene basement in Schwechat and Mannsdorf area.

Overlying units: Baden Fm., Matzen Fm. in the northern Vienna Basin; Auersthal Fm. in the central Vienna Basin. Between the Mannsdorf Fm. and all overlying formations exists a hiatus.

Lateral equivalents: The Devinska Nová Ves Fm. (Fordinál et al., 2012; Rybár et al., 2019) is a terrestrial equivalent at the eastern margin of the Vienna Basin. The Grund Fm. represents an age equivalent in the North-Alpine Foreland Basin (but not the slightly younger Gaindorf and Mailberg formations).

In the Slovak part of the Vienna Basin, the lowermost Badenian deposits are united in the up to 600-m-thick Lanžhot Formation (Kováč et al., 2004). Fordinál et al. (2012) report *Orbulina suturalis* from basal parts of the Lanžhot Fm. and, therefore, it is most likely not a temporal equivalent of the Mannsdorf Fm. Similarly, Brzobohatý and Stráník (2012) report *Orbulina suturalis* from the Lanžhot Beds in the Sedlec well (Czech Republic).

Geographic distribution: No surface outcrops; the Mannsdorf Fm. occurs in numerous wells in the northern and central Vienna Basin. The distribution area, however, is discontinuous and even close-by wells differ strongly in thickness and cannot be clearly correlated.

Remarks: The distribution of the Mannsdorf Fm. is very patchy. In respect to the outer neritic to upper bathyal depositional environment, such a discontinuous distribution is unlikely, and a much wider original distribution area can be expected. Seismic flattening based on a mid-Badenian maximum flooding surface (mfs in Fig. 4), revealed the patches as small depressions of an early middle Miocene paleorelief. This former geometry was lost thereafter during the mid-Badenian tectonic reorganization of the Vienna Basin.

Wells: Mannsdorf 1 (2440–2575 m), Wittau 1 (2440–2680 m), Aderklaa 78 (1610–1890 m), Matzen 375 (1790–1825 m), Pirawarth 005 (2020–2100 m), Ringelsdorf 002 (3815–4294 m), Rabensburg 010 (2330–2380 m), Bernhardsthal 4 (2200–2330 m), Mühlberg T1 (2455–3140 m).

4.3.1.3 Auersthal Formation (Figs 2, 5)
Derivation of name: After the market town Auersthal in the central Vienna Basin (N 48°22'25.89", E 16°38'10.05").

The term "Auerstaler Konglomerat" (Auersthal Conglomerate) has been proposed by Papp et al. (1973, p. 198) for conglomerate and sand with flysch and crystalline components overlaying the Bockfließ, Aderklaa and Rothneusiedl formations.

Synonyms: Auerstaler Konglomerat (Papp et al., 1973), Auersthaler Schichten (Kröll, 1984; Kreutzer, 1986), Auerstal Member (Kováč et al., 2004), Upper Lagenidae Zone p.p.; Slovakia: Kúty Member of the Lanžhot Fm. (Fordinál et al., 2012).

Type section: Designated herein: well Matzen 269 (1675–1730 m: core: 13/1 1706.00–1708.50 m) (N 48°22'59.37", E 16°42'22.09") (Figs 1–2).

Thickness: The maximum thickness of about 160 m is known from the Schwechat area in Wittau 1. Typically, the Auersthal Fm. attains about 40 to 120 m in the Matzen, Aderklaa and Schönkirchen fields and generally pinches out towards the Matzen/Spannberg Ridge.

Lithology: A succession of conglomerates and sand with marl intercalations; flysch components prevail.

Well-log characteristics: Basal parts are frequently characterized by very broad, blocky cylinder shaped SP-logs, often opposed by strongly serrated RES-logs. Upsection passing abruptly into strongly serrated, amalgamated funnel-shaped logs frequently forming a rough fining upward trend; shale line intervals may also be developed (Wittau 1) suggesting a more distal position.

Fossils: A rich marine microfauna dominated by *Trilobatus (Globigerinoides) trilobus, Spirorutilus carinatus, Heterolepa dutemplei, Lenticulina inornata, Nonion commune, Globigerina bulloides,* and *Orbulina suturalis* was detected in Mannsdorf 1 (2428 m), Matzen 127 (1695 m) and Wittau 1 (2291 m).

Depositional environment: A coastal marine delta with channels (Kreutzer and Hlavatý, 1990; Kreutzer, 1993) shedding into an outer neritic marine habitat. The outer neritic foraminiferal assemblage is in strong contrast to the occurrence of freshwater ostracods reported by Wessely (2006). In respect to the deep erosion of the Auersthal Fm., which truncated parts of the freshwater deposits of the Karpatian Schönkirchen Mb., it is not unlikely that the freshwater fossils have been reworked from Karpatian strata. Similarly, indications for an alternation of marine and limnic conditions (Papp et al., 1973; Wessely, 2006) may result from reworking of Karpatian freshwater deposits.

Age: Middle Miocene (Langhian - middle Badenian); younger than 14.56 Ma based on the frequent occurrence of *Orbulina*.

Biostratigraphy: Nannoplankton zone NN5 with *Helicosphaera waltrans*. In respect to the Vienna Basin eco-biostratigraphy it belongs to the Upper Lagenidae Zone (Papp et al., 1973; Kröll, 1984; Kreutzer, 1986).

Sequence stratigraphy: The Auersthal Fm. represents the lowstand systems tract of the Badenian Sequence Ba2 of Strauss et al. (2006).

Lithostratigraphically higher rank unit: Baden Group.

Underlying units: The Auersthal Fm. has a strong erosive base and displays a clear N-S trend. It rests directly on the Schönkirchen Mb. of the Aderklaa Fm. in the northern Matzen field, on the Rothneusiedl Fm. in the southern Matzen and Schönkirchen fields and on the lower Badenian Mannsdorf Fm. in the Aderklaa and Schwechat areas. In the Slovak territory, the probably equivalent Kúty beds overlay the Láb beds (=Schönkirchen Mb.) (Fordinál et al., 2012).

Overlying units: In all wells overlain by the Matzen or Baden formations.

Lateral equivalents: No lateral equivalents are known from the Austrian part of the Vienna Basin. Only the Andlersdorf conglomerate (Kapounek et al., 1965; Kapounek and Papp, 1969) might be a lateral equivalent, but this

will need confirmation by seismic data. On Slovak territory, the about 150-m-thick Zohor conglomerate (Vass et al., 1988) from Devínska Nová Ves, correlated with the Calcareous Nannoplankton Zone NN5 by Fordinál et al. (2012), might be a temporal equivalent. Similarly, the Kúty beds (Kutske vrstvy; Špička, 1966) may represent temporal and genetical equivalents in the northern and central Záhorie Lowlands in Slovakia. Fordinál et al. (2012) describe the Kúty Member as mixture of sandstone, gravel and variegated clays of up to 250 m thickness in the Malacky region. Like the Auersthal Fm., the Kúty Member already contains *Orbulina suturalis* (Fordinál et al., 2012). The Kúty Member grades into the pelites of the Lanžhot Fm. In addition, the Žiškov Mb. of Buday (1946) and Fordinal et al, (2012) might represent a lateral equivalent.

Geographic distribution: Only subsurface in the central Vienna Basin, spanning from the Matzen/Spannberg Ridge south to the Schwechat depression and to the Mannsdorf region, where only a thickness of about 30 m is recorded.

Wells: Schönkirchen T32 (1765–1840 m), Aderklaa 28 (1740–1810 m), Aderklaa 40 (2168–2248 m), Mannsdorf 1 (2410–2440 m), Matzen 112 (1622–1650 m), Matzen 127 (1670–1790 m), Matzen 127 (1740–1820 m), Matzen 267 (1660–1700 m), Matzen 269 (1675–1730 m), Matzen 270 (1680–1750 m), Matzen 375 (1680–1790 m), Schönkirchen T1 (1785–1870 m), Schönkirchen T2 (1760–1820 m), Schönkirchen T25 (1765–1840 m), Schönkirchen T3 (1790–1845 m), Wittau 1 (2280–2440 m).

Remarks: Since Papp et al. (1973), the Auersthal Fm. has only rarely been mentioned (e.g. Kreutzer and Hlavatý, 1990; Kreutzer, 1986, 1992, 1993; Wessely, 2006). Kreutzer (1992, 1993) discussed the deposits as part of a Badenian lowstand systems tract and as incised valley fill.

4.3.1.4 Matzen Formation (Figs 2, 5)

Due to its economic importance as the most productive play in the Vienna Basin, this unit was discussed in numerous internal OMV reports and papers (e.g. Kölbl, 1959, 1966; Kreutzer and Hlavatý, 1990; Kreutzer, 1986, 1993; Hamilton and Johnson, 1999; Hamilton et al., 2000; Fuchs et al., 2001; Wessely 2006), usually referred to as "Matzen Sand". In older literature, however, it was described as 16th TH (= "sixteenth Tortonian Horizon" based on an erroneous correlation of the Langhian/Serravallian strata of the Vienna Basin with the Mediterranean Tortonian).

Derivation of name: After the village Matzen in the central Vienna Basin (N 48°24'4.38", E 16°41'42.33").

Synonyms: Matzener Sand (Kröll, 1984), 16. Tortonhorizont (16th Tortonian Horizon) (Kreutzer, 1971), Matzen Sand, Zwerndorf Sand (Weissenbäck, 1996), Matzen sands Member (Kováč et al., 2004), Upper Lagenidae Zone – *Spiroplectammina* Zone p.p., Zwerndorf Member (Kováč et al., 2004).

Type section: Designated herein: well Matzen 269 (1619–1673 m; cores: 8/3 1624.00–1628.00 m, 9/7 1628.00–1636.80 m, 10/10 1636.90–1645.90 m, 11/10 1645.90–1655.00 m, 12/4 1655.00–1664.00 m) (N 48°22'59.37", E 16°42'22.09") (Figs 1–2).

Thickness: The Matzen Fm. typically attains a thickness around 20–50 m in the Bockfließ and Schönkirchen fields and grows to 70 m in the Matzen area (e.g. Matzen 270: 1602–1672 m). It pinches out in S-N direction towards the Matzen/Spannberg Ridge and appears again north of the Matzen/Spannberg Ridge, where it attains a thickness of about 105 m. The maximum thickness of the Matzen Fm. is 140 m (Kreutzer, 1986; Kreutzer and Hlavatý, 1990).

Lithology: Fine to coarse sand, moderately to well sorted, strongly bioturbated, often oil impregnated. Marl layers, silty fine-sand layers and ripple ripple-cross stratification may occur. Intercalations of thin corallincean limestones have been described by Kreutzer (1978).

Well-log characteristics: Broad, blocky cylinder-shaped well logs with moderate serrations. SP-logs may indicate a minor, stepwise fining upward trend, opposed by strong RES-values. The top is distinctly indicated by the abrupt switch to the shale-line interval of the overlaying marls of the Baden Fm.

Fossils: A rather low diverse, marine microfauna with *Heterolepa dutemplei, Lenticulina inornata, Spirorutilus carinatus, Cibicidoides ungerianus, Cibicidoides pachyderma, Martinotiella communis, Anomalinoides badenensis,* and *Melonis pompilioides*. Macrofossils are poorly preserved including frequent plant debris, pectinid and cardiid bivalves, balanids and tubes of *Ditrupa*. A detailed micropaleontological study on the Matzen Fm. was published by Rupp (1986).

Depositional environment: Coastal marine environments with sand dunes and shoreface settings of a sand rich braid or fan delta (Fuchs et al., 2001). Rupp (1986) reported an inner neritic depositional environment, whereas the herein studied foraminiferal assemblages suggest a deeper setting in the middle to outer neritic. Rupp (1986), however, reported a rapid deepening within the Matzen Fm. and our samples may derive from its upper parts.

Age: Middle Miocene (Langhian - middle Badenian); younger than 14.56 Ma based on the frequent occurrence of *Orbulina suturalis*.

Biostratigraphy: In respect to the Vienna Basin ecobiostratigraphy it belongs to the *Spirorutilus* Zone (Kapounek et al., 1965: Sandschalerzone; Kreutzer, 1986: Sandschalerzone, *Spiroplectammina* Zone) or the Upper Lagenidae Zone – *Spirorutilus* (*Spiroplectammina*) Zone (Rupp, 1996; Weissenbäck, 1996).

Sequence stratigraphy: The Matzen Fm. represents the initial transgressive systems tract of the Badenian Sequence Ba2 of Strauss et al. (2006).

Lithostratigraphically higher rank unit: Baden Group.

Underlying units: The Matzen Fm. is a transgressive unit overlying older units discordantly from south to north starting with the Auersthal Fm. in the Matzen to Schönkirchen fields, the Bockfließ and Aderklaa formations, in the Bockfließ field, and even Rhenodanubian Flysch along the Matzen/Spannberg Ridge.

Overlying units: The Matzen Fm. is overlain throughout by marls of the Baden Fm.

Lateral equivalents: The nearly 300-m-thick Zwerndorf Sand is a genetic equivalent of the Matzen Fm. (e.g. Zwerndorf 4: 1518–1800 m). It displays a NW–SE orientation between Dürnkrut and Zwerndorf and was transported from NW (Kreutzer, 1986). Its stratigraphic position is confined by the Matzen bentonite main marker, which lies both on the Zwerndorf Sand on top of the Matzen Fm. (Kreutzer, 1986). An equivalent of the Matzen Fm. reaches also into the Schwechat depression (Wittau 1: 2210–2278 m) and the Mannsdorf area (Mannsdorf 1: 2340–2410 m).

A surface outcrop of an equivalent of the Matzen Fm. with huge fossiliferous sand-dunes is exposed in the Eisenstadt-Sopron Basin at Donnerskirchen at Eisenstadt, representing the distal parts of the Hartl Fm. (Kroh et al., 2003).

A time equivalent in the Slovak territory might be represented by the 150-m-thick Žižkov beds (Buday, 1946), which are described by Fordinál et al. (2012) (as Žižkov Member) as a transgressive unit of gravel, sand and clayey sand, partly with reworked Karpatian fossils. This correlation, however, will need confirmation. The distribution area of the Žižkov beds around Lakšárska Nová Ves and Borský Mikuláš in the Záhorie Lowlands is about 30 km N-E of the distribution of the Matzen Fm. around the Matzen/Spannberg Ridge and both units will most probably represent separate sedimentary bodies.

Geographic distribution: Wide subsurface distribution in the central and southern Vienna Basin. Traditionally, only deposits in the Matzen area have been described as "Matzen Sand". Herein, however, we include also its equivalents north of the Matzen/Spannberg Ridge (e.g. Spannberg 10: 1960–2066, Spannberg 14: 2233–2340), where the Matzen Fm. attains about 105 m thickness. These units share the same lithology, well-log patterns and lithostratigraphic position.

Wells: Bockfließ 78 (1615–1660 m), Bockfließ 003 (1632–1660 m), Matzen 112 (1603–1623 m), Matzen 267 (1602–1658 m), Matzen 269 (1619–1673 m), Matzen 270 (1602–1672 m), Matzen 127 (1700–1740 m), Matzen 325 (1607–1680 m), Schönkirchen T1 (1746–1782 m), Schönkirchen T25 (1682–1762 m).

4.3.1.5 Baden Formation (Figs 4–5)

Derivation of name: After the town Baden in the central Vienna Basin (N 48°00'29.00", E 16°14›03.72»).

Synonyms: Badener Tegel, Badener Serie (Kapounek et al., 1960; Papp, 1963); Slovakia: Lanžhot Fm. p.p., Jakubov Fm. (Fordinál et al., 2012). Baden Clay Formation in the Hungarian part of the Eisenstadt-Sopron Basin (Császár, 1997).

Type section: Designated herein: The 102-m-long scientific core from the abandoned brick yard Baden/Sooss near the town Baden (Lower Austria), south of Vienna (N 47°59'24", E 16°13'44"). This core represents only the uppermost part of the formation and a relatively marginal position within the VB but is sedimentologically and paleontologically well studied and correlated by means of biostratigraphy and astrochronology (Báldi and Hohenegger, 2008; Rupp and Hohenegger, 2008;

Hohenegger et al. 2008, 2009a, b, 2014; Hohenegger and Wagreich, 2012).

Remarks: The brick yard Sooss (also: Baden-Sooss), c. 2 km S of the railway station of Baden, where "Badener Tegel" is outcropping, was designated by Papp (1963, p. 229) as type locality of the "Badener Serie" (former: "Tortonian in the Vienna Basin"). Later, Papp et al. (1978) when reorganizing the stratigraphic system of the Parathethys defined the "Badener Serie" as Badenian Stage. The brick yard Sooss was defined as holostratype for this stage (Papp and Steininger, 1978). The brick yard was abandoned, used as a waste dump and offers currently very poor outcrops. In 2002, in the area of the former clay pit, a scientific core was drilled (Wagreich et al., 2008) (see above).

Reference section: As reference section for the Baden Fm. we designate herein well Ringelsdorf 2 (2770–3815 m; cores: 8/6 2823.00–2828.00 m, 9/6 2937.00–2942.00 m, 10/5 3027.00–3032.00 m, 11/5 3152.00–3157.00 m, 12/5 3243.00–3248.00 m, 13/6 3370.00–3375.00 m, 14/6 3471.00–3476.00 m, 15/6 3541.00–3546.00 m, 16/6 3592.00–3597.00 m, 17/6 3649.00–3654.00 m, 18/6 3767.00–3772.00 m) (N 48°32′11.32″, E 16° 51′ 59.90″). This well section represents a full cycle in terms of sequence stratigraphy with a basal lowstand sand, a rapid deepening during the transgressive systems tract culminating in a distinct shale-line interval around the maximum flooding surface and a coarsening upward trend of the highstand systems tract in its upper part. Moreover, underlying (Mannsdorf Fm.) and overlying (Rabensburg Fm.) units are lithostratigraphically and biostratigraphically defined.

Thickness: The maximum thickness of the Baden Fm. ranges around 1120 m in the Rabensburg field (Rabensburg 2: 1300–2420 m) and around 1045 m in the Ringelsdorf field (Ringelsdorf 2: 2770-3815 m). In the well Zistersdorf Übertief 2Aa a maximum thickness of 2450 m was recorded (OMV data).

Lithology: Blue-grey to green-grey clay and marl with silt and fine sand intercalations (so-called "Tegel"). Thin corallinacean limestones may be intercalated; bioturbation is frequent.

Well-log characteristics: The Baden Fm. has a characteristic well-log pattern, which allows a correlation across wide areas of the Vienna Basin. It is indicated by an abrupt transition from the blocky patterns of the Matzen Fm. into a long shale line interval with a nearly smooth SP-log and a low amplitude RES-log. Many wells show a clear fining upwards trend within this shale line interval culminating in a distinct incision, marking the maximum flooding surface. This horizon is one of the most characteristic and constant features in the Vienna Basin and is used as marker horizon by OMV geologists. Above follows a rapid coarsening indicated by strongly serrated, high-amplitude SP-logs and serrated RES-logs of somewhat lower amplitudes.

Fossils: This formation contains some of the most outstanding fossiliferous localities of the Vienna Basin, which are emblematic for the Badenian stage of the Central Parathethys. Hundreds of invertebrate and vertebrate species have been recorded since the 19th century from the localities Baden, Bad Vöslau, Baden-Sooss, Gainfarn (Austria) and Mikulov (Czech Republic) (see Papp et al., 1978 and Rögl et al., 2008 for an overview).

Depositional environment: Basinal settings represent normal marine inner to middle neritic environments, often with a rich benthic mollusk fauna; the type section reflects a mean water depth around 250 m (Hohenegger et al., 2008). Outer neritic to upper bathyal environments established along tectonically active zones such as the Steinberg Fault in the Mühlberg area (Harzhauser et al., 2019). Sea grass meadows are typical in nearshore environments (Zuschin et al., 2007; Harzhauser et al., 2019).

Age: Middle Miocene (late Langhian – middle Badenian); younger than 14.91 Ma (Nannoplankton Zone NN5) and younger than 14.56 Ma (Planktonic Foraminifer Zone M6). The type section Baden-Sooss was astronomically tuned to 14.221 and 13.982 Ma by Hohenegger and Wagreich (2012). No absolute dating is available to support this estimate but based on the absence of *Helicosphaera waltrans* in the section, its maximum possible age is set to 14.357 Ma. The section is atributed to the Upper Lagenidea Zone by Papp et al. (1978).

The oil bearing plays, called 13th to 15th TH (= "Tortonian Horizons") in OMV reports, are parts of the Baden Fm. (Kreutzer, 1971). The Baden Fm. contains two important bentonite layers. The "Matzen Hauptmarker (MHM)" (= Matzen bentonite main marker) is slightly above the Matzen Fm. in the base of the Baden Fm. (between 16th and 15th TH of OMV nomenclature) and the "Aderklaa Hauptmarker (AHM)" (= Aderklaa bentonite main marker) coincides roughly with the boundary from Lagenidae to *Spirorutilus* Zone (Kreutzer, 1986). Both are recognized easily in well-logs by their high conductivity.

Biostratigraphy: The occurrence of the calcareous nannofossil *Sphenolithus heteromorphus* and the absence of *Helicosphaera ampliaperta* point at Zone NN5 (Ćorić and Hohenegger, 2008), the occurrence of *Orbulina suturalis* indicates planktonic foraminiferal zone M6 (Rögl et al., 2008).

In terms of classical ecobiostratigraphy of the Vienna Basin the Upper Lagenidae Zone and the *Spirorutilus* Zone (following the ideas of Grill, 1941) were based on samples of the Baden Fm.

Sequence stratigraphy: The Baden Fm. comprises sediments of the transgressive systems tract and the highstand systems tract of the Badenian Sequence Ba2 of Strauss et al. (2006).

Lithostratigraphically higher rank unit: Baden Group.

Underlying units: Matzen Fm. in the central Vienna Basin, Bockfließ, Lužice and Mannsdorf formations in northern Vienna Basin.

Overlying units: Rabensburg Fm. in all studied drillings; the Baden Fm. forms the landscape in the Baden region south of Vienna and is partly covered by Quaternary deposits.

At the type locality the Baden Fm. is discordantly overlain by Sarmatian pelitic sediments separated by a fault (Papp and Steininger, 1978, p. 140, Abb. 30).

Lateral equivalents: The "Aderklaaer Sand" (Aderklaa Sand) is a sand rich intercalation within the Baden Fm. It is

overlain by the Aderklaa bentonite main marker and bears foraminiferal assemblages typical for the Upper Lagenidae Zone (Kreutzer, 1986; Weissenbäck, 1996). 15th to 13th TH horizons of OMV nomenclature. The "Vöslauer (Badener) Konglomerat" (Vöslau (Baden) conglomerate) and the "Gainfarner Bekzie" (Gainfarn breccia) (Brix and Plöchinger, 1988) are local coarse clastic equivalents at the western margin of the Vienna Basin. The "Gainfarner Sande" (Gainfarn sand) and "Enzesfelder Sande" (Enzesfeld sand) are very fossil rich coastal deposits (Brix and Plöchinger, 1988).

Shallow water carbonate rocks of the Leitha Formation around the southern part of the Leitha Mountains and the margin of the Vienna Basin as well as on paleo-topographic highs in the northern Vienna Basin (e.g. Steinberg area) (see also below).

At least parts of the Lanžhot Fm., as described by Fordinál et al. (2012) and Brzobohatý and Stráník (2012), which are correlated with the Lagenidae Zone and contain *Orbulina suturalis*, are time equivalents or even represent a full equivalent of the Baden Fm. Most probably, this part of the Lanžhot Fm. represents the shale-line interval of the transgressive systems tract of the Baden Fm. The up to 1000-m-thick pelitic Jakubov Fm. (Fordinál et al., 2012) is an equivalent of the Baden Fm. in the Záhorie Lowlands on Slovak territory. It corresponds to the *Spirorutilus carinatus*-dominated interval of the Baden Fm. Important lateral temporal equivalents are the landscape forming corallinacean limestones of the Leitha Fm. In the Czech part of the Vienna Basin, especially in the Mikulov area, the Hrušky Fm. of Picha et al. (2006) and Schultz et al. (2010) corresponds to the Baden Fm.

Geographic distribution: The Baden Fm. has a wide distribution and occurs throughout the investigation area and also in the Mistelbach Halfgraben (e.g. Hohenrupperpersdorf 24: 270–740 m) as well as in the southern Vienna Basin (where the type locality is located).

Wells: Mühlberg T1 (1740–2450 m), Bernhardsthal 5 (1610–2385 m), Bernhardsthal 4 (1580–2200 m), Rabensburg 1 (1590–2470 m), Rabensburg 2 (1300–2420 m), Ringelsdorf 2 (2770–3815 m), Matzen 127 (1605–1700 m), Aderklaa 78 (1385–1670 m), Schwechat 1 (1615–2160).

4.3.1.6 Leitha Formation

Derivation of name: Named after the hill range called "Leitha Mountains" between the river Leitha and Lake Neusiedl (Lower Austria – Burgenland). The name "Leithakalk" was already mentioned by Keferstein (1828), but he commingled Badenian and Sarmatian limestones. The name was since then widely used and refers to and is restricted to the Badenian corallinacean limestones in the Vienna and Eisenstadt-Sopron basins (e.g. Tollmann, 1955, 1985; Steininger and Papp, 1978; Dullo, 1983; Piller et al., 1996, Wiedl et al., 2012, 2013).

Synonyms: Leithakalk, Nulliporenkalk, Nulliporakalk, Lithothamnienkalk, Lithothamnion limestone, Corallinaceenkalk (e.g. Keferstein, 1828; Fuchs, 1894; Wessely, 1983; Brix and Plöchinger, 1988; Sauer et al., 1992; Piller, 1994).

Remarks: The term "Leitha Limestone" was also applied to Miocene corallinacean limestones outside the Vienna and Eisenstadt-Sopron basins; e.g. Studencki (1988) used the term to describe the lithofacies of the Polish Pinczow Limestones. Friebe (1990, 1991) was the first author, who applied a strict lithostratigraphic concept and introduced the Weißenegg Fm. as lithostratigraphic unit for the "Leitha Limestones" of the Styrian Basin (see also Riegl and Piller, 2000 for discussion).

Type section: Fenk quarry close to Großhöflein in Burgenland (N 47°50′45.78″, E 16°28′34.60″) (Eisenstadt-Sopron Basin, Burgenland, Austria). This section was proposed by Steininger and Papp (1978) as faciostratotype of the "Leitha Limestone" and described in detail by Riegl and Piller (2000). The Fenk quarry is abandoned but still accessible.

Thickness: According to Tollmann (1985), the Leitha Fm. attains a thickness of up to 50 m based on outcrop data in the southern Leitha Mountains. A maximum subsurface thickness of 120 m is reported by Dlabač (1971) from the Láb region in the Slovak part of the Vienna Basin.

Lithology: The Leitha Fm. is characterized by whitish to light-yellowish, usually well cemented, corallinacean limestones with coralline red algae in various growth forms, ranging from rhodolite facies to maërl-types. Corals are subordinate, forming local coral carpets; *Isognomon/Hyotissa* beds are frequent (Riegl and Piller, 2000), whereas marl intercalations are rare and thin. Some typical microfacies types are bioclastic algal debris facies, bioclastic rhodolite debris, bioclastic algal mollusk, and foraminiferal algal debris (Dullo, 1983; Piller and Kleemann, 1991; Wiedl et al., 2012, 2013).

Fossils: The Leitha Fm. is exceptionally rich in fossils. Coralline red algae, such as *Lithothamnion, Spongites, Mesophyllum, Lithophyllum, Phymatolithon,* and *Sporolithon*, are the most important rock-forming elements (Hrabovský, 2013) along with various foraminifers (e.g. *Amphistegina, Acervulina,* miliolids, alveolinids) and celleporiform bryozoans. Corals are represented mainly by *Porites*, accompanied by *Tarbellastraea, Caulastrea, Acanthastrea,* and *Stylocora*. Mollusks (*Hyotissa, Isognomon, Gigantopecten, Pinna, Periglypta, Lithophaga, Pholadomya*) and echinoderms (*Clypeaster, Parascutella, Echinolampas*) are further important fossils; see Piller and Kleemann (1991), Riegl and Piller (2000) and Wiedl et al. (2012, 2013) for more detailed surveys.

Depositional environment: Shallow marine, subtropical carbonate ramps and shoals with coral carpets, sea grass meadows, rhodolite pavements and maërl bottoms. The typical depositional depth ranged from <10 m down to ~60 m in a generally low hydrodynamic setting (Riegl and Piller, 1991; Wiedl et al., 2012, 2013).

Age: Middle Miocene (late Langhian - middle Badenian); younger than 14.91 Ma based on correlation with calcareous nannoplankton Zone NN5 (Wiedl et al., 2013).

Biostratigraphy: The presence of the calcareous nannofossil *Sphenolithus heteromorphus* in a marly layer of the Fenk Quarry restricts the type locality to the NPZ NN5 and the Upper Lagenidae – *Spirorutilus* zones (Wiedl et

al., 2013). Based on the foraminiferal species *Uvigerina venusta* and *U. liesingensis* Steininger and Papp (1978) placed the Fenk Quarry into the Upper Badenian *Bulimina-Bolivina* zone but the uvigerinid foraminifers seem less reliable markers (compare Haunold, 1995).

Lithostratigraphically higher rank unit: Baden Group.

Underlying units: In many cases, pre-Neogene units form the base of the Leitha Fm., e.g. Lower Austroalpine crystalline and Triassic dolomite in the Leitha Mountains (Pascher and Brix, 1994, Wiedl et al., 2013), Triassic dolomite breccias in Bad Vöslau (Piller and Vavra, 1991) and Rhenodanubian Flysch in the Steinberg area (Grill, 1968). In the Eisenstadt area (Eisenstadt-Sopron Basin), the middle Badenian siliciclastic Hartl Fm. (Kroh et al., 2003) underlays the Leitha Fm. In the Mannersdorf quarries, the Leitha Fm. develops above coarse siliciclastics of Badenian age (Wiedl et al., 2012).

Overlying units: The Leitha Fm. forms the surface of the landscape and overlying units have mostly been eroded aside from lower Sarmatian relics ("detrital Leitha Limestone, Holic Fm., Harzhauser and Piller, 2004).

In subsurface occurrences, the Leitha Fm. is overlain by unnamed upper Badenian deposits (e.g. Göttlesbrunn Horst, Strauss et al., 2006).

Lateral equivalents: The Baden Fm. is a pelitic equivalent in basinal settings. The Jakubov Fm. sensu Fordinál et al. (2012) is the pelitic equivalent on Slovak territory and the limestones of the Stupava Member of the Jakubov Fm. are a full equivalent (Hrabovský and Fordinál, 2013). Coeval corallinacean limestones are the Mailberg Fm. in the North Alpine Foreland Basin (Mandic, 2004) and the Weißenegg Fm. in the Styrian Basin (Friebe, 1990, 1991).

Geographic distribution: The type area of the Leitha Fm. is situated around the southwestern Leitha Mountains. This occurrence is bound in the east by a roughly N-S striking fault line running from Mannersdorf in the north to Donnerskirchen in the south (see fig. 9 in Wiedl et al., 2014). The Leitha Fm. occurs also along the margins of the Vienna Basin; e.g. Wöllersdorf, Baden, Bad Vöslau (Austria), Mikulov (Czech Republic), Borský Mikuláš (Slovakia) (Grill, 1968; Čtyroký et al., 1985, Fuchs and Grill, 1984; Fordinál et al., 2012). Further occurrences formed on paleo-topographic highs (e.g. Maustrenk and Prinzendorf in the Steinberg area, Grill, 1968; Matzen field, own data). Subsurface occurrences are documented from the Göttlesbrunn area in the southern Vienna Basin (Strauss et al., 2006).

Outcrops: Central Vienna Basin: Prinzendorf Steinberg-cave (Lower Austria, N 48°35′1.01″, E 16°43′13.97″) (Mayer et al., 1989); Vrchná hora close to Stupava (Slovakia, N 48°15′39.13″, E 17°2′47.87″) (Hrabovský, 2013). Southern Vienna Basin: Baden Rauchstallbrunngraben (Lower Austria, N 48°0′0.86″, E 16°12′1.79″ (Piller and Vavra, 1991, Piller et al., 2007); Mannersdorf (Lower Austria, N 47°58′20.00″, E 16°36′51.02″) (Wiedl et al., 2012), Loretto Teufelsloch (Lower Austria, N 47°53′47.08″, E 16°31′46.21″) (own data). Eisenstadt-Sopron Basin: Müllendorf (Burgenland, N 47°51′30.23″, E 16°26′54.58″) (Wiedl et al., 2013); Großhöflein, Fenk quarry (Burgenland, N 47°50′45.78″, E 16°28′34.60″) (Riegl and Piller, 2000).

4.3.1.7 Rabensburg Formation (Figs 4–5)

Derivation of name: After the village Rabensburg in the northern Vienna Basin (N 48°38′59.45″, E 16°54′04.27″).

Remarks: In the Slovak part of the Vienna Basin this formation is termed Studienske vrstvy (Studienka beds) by Špička, (1966) and Studienka Fm. by Kováč et al. (2004), Hyžný et al. (2012) and Fordinál et al. (2012), which was also adopted by Piller et al. (2004) and Harzhauser et al. (2017, 2019) for the Austrian part of the Vienna Basin. A formalization of the Studienka Fm., however, is lacking so far. A well described section in the Studienka Fm. is a clay-pit at Devínska Nová Ves near Bratislava (Kováčová and Hudáčková, 2009; Košťák et al., 2018). Despite the good accessibility, this only 12-m-thick section is inadequate to serve as a type section for a formation of up to 1000 m thickness. Similarly, the only 20-m-thick section at Walbersdorf near Mattersburg (Burgenland) has been studied in detail by Bachmayer and Weinfurter (1965), Rögl and Müller (1976) and Rupp (1986) but is too short to serve as type section and is now recultivated. Therefore, we prefer to name this formation after the deposits in the Rabensburg and Bernhardsthal fields in the northern Vienna Basin, where the largest thickness is observed.

Synonyms: Badener Serie p.p. (Kreutzer, 1971), *Bulimina-Bolivina* Zone, Bulimina-Rotalia Zone, Rotalien-Zone, Studienka Formation. The 1st to 10th and maybe also the 12th TH ("Tortonian Horizon") of OMV nomenclature are part of the Rabensburg Fm. (Kreutzer, 1971).

Type section: Designated herein: well Rabensburg 1 (690–1585 m; cores: 1/1 700.00–705.00 m, 2/1 1060.00–1065.00 m, 3/2 1103.50–1108.50 m, 4/1 1150.00–1155.00 m, 5/1 1200.00–1205.00 m, 6/2 1200.00–1253.50 m, 7/1 1250.00–1253.50 m, 8/2 1290.00–1295.00 m, 9/2 1355.00–1360.00 m, 10/2 1495.00–1500.00 m, 11/1 1530.00–1535.00 m) (N 48°38′53.86″, E 16°54′43.02″) (Figs 1, 4).

Thickness: A maximum thickness of 1000 m is recorded from the Paltendorf-Ringelsdorf field and up to 900 m are drilled in the Rabensburg field; usually, however, strong Sarmatian erosion reduces the thickness considerably. In the Záhorie Lowlands in Slovakia the equivalent Studienka Fm. attains up to 900 m thickness (Fordinál et al., 2012).

Lithology: Dark-grey to green-grey, partly laminated clay, marl and silty marl with sand and numerous corallinacean limestone intercalations (Kreutzer, 1978); gravel intercalations have been described especially from the upper parts in the Matzen field (Kreutzer, 1974). In the Bernhardsthal field, thin lignite seems and characeen-limestones occur in basal parts of the formation. Anhydrite was found in cuttings of the basal parts of the formation in the Mühlberg field (Harzhauser et al., 2018).

Well-log characteristics: The Rabensburg Fm. has a characteristic well log pattern consisting of a rapid succession of high amplitude and high frequency SP-logs opposed by similar, only slightly less serrated RES-logs. Shale line intervals are nearly absent and very short.

Fossils: The Rabensburg Fm. is exceptionally rich in marine fossils including numerous foraminifers, mollusks and vertebrates (e.g. Rupp, 1986; Kováčová and Hudáčkova,

2009; Hyžný et al., 2012; Harzhauser et al., 2019; Košťák et al., 2018). Basinal foraminiferal assemblages are characterized by *Bulimina elongata, Bolivina dilatata, Bulimina schischkinskayae, Bolivina antiqua,* and *Bulimina striata*. Lagoonal settings are strongly dominated by *Ammonia*.

Depositional environment: The Rabensburg Fm. comprises a broad range of marine depositional environments. Dysoxic bottom water conditions prevailed in basinal environments, reflected in laminated deposits (Kováčová and Hudáčková, 2009). Periodically, these dysoxic conditions even reached to the surrounding corallinacean shoals (Schmid et al., 2001). Coastal to inner neritic settings were often dominated by mudflats and lagoonal environments with a rich mollusk fauna (Harzhauser et al., 2019) laterally alternating with agitated shoreface and foreshore settings (Hyžný et al., 2012).

Age: Middle Miocene (Serravallian - late Badenian); younger than 13.53 Ma based on NP Zone NN6 (Hudáčková et al., 2000; Jamrich and Halásová, 2010).

Biostratigraphy: Based on *Discoaster exilis* the deposits in Devínska Nová Ves (Slovakia) were correlated with the Nannoplankton Zone NN6 (Jamrich and Halásová, 2010).

The frequent occurrence of buliminids and bolivinids were the reason for establishing the upper Badenian ecobiostratigraphic zone "Marine Fauna mit Bolivina dilatata" by Grill (1941) which became later on the *Bulimina-Bolivina* Zone (Papp and Turnovsky, 1953).

Sequence stratigraphy: The Rabensburg Fm. comprises sediments of the transgressive systems tract and the highstand systems tract of the Badenian Sequence Ba3 of Strauss et al. (2006).

Lithostratigraphically higher rank unit: Baden Group.

Lithostratigraphic subdivision: The heterogenous lithologies (e.g. lignites in the Bernhardsthal area) might justify a definition of members within the Rabensburg Fm. One member was formalized along the western margin of the Malé Karpaty by Baráth et al. (1994) near Devinska Nová Ves (Slovakia) as Sandberg Mb. (of the Studienka Fm.). The Sandberg Mb. comprises coastal marine sand and gravel (Fordinál et al., 2012).

Underlying units: Baden Fm.

Overlying units: Subsurface overlain by the lower Sarmatian Holic Fm. with marked erosive relief; occasionally the upper Sarmatian Skalica Fm. may lie directly with erosional contact on the Rabensburg Fm. Surface outcrops occur around Bratislava.

Lateral equivalents: The unnamed corallinacean limestones in the northeastern part of the Leitha Mountains (Wiedl et al., 2014) and the corallinacean limestones of St. Margarethen in the Rust Mountains (Dullo, 1983; Schmid et al., 2001) (= Rákos Limestone Formation of Császár, 1997) are equivalents of the Rabensburg Fm., which formed on agitated shoals (Wiedl et al., 2014).

Remark: Schmid et al. (2001) dated the corallinacean limestones of St. Margarethen as NN5, based on the rare occurrence of *Helicosphaera waltrans*. The foraminferal fauna, however, was correlated with the upper Badenian *Bulimina-Bolivina* Zone. Therefore, we assume that

the nannoplankton was partly reworked, which is supported by the observed reworking of middle Badenian limestones. The "Lindabrunner Konglomerat" (Lindabrunn conglomerate) has been described by Brix and Plöchinger (1988) as coeval coarse grained coastal unit.

Geographic distribution: Wide subsurface distribution throughout the northern and southern Vienna Basin and also in the Mistelbach Halfgraben (e.g. Poysdorf 1: 310–485 m). Surface outcrops are exposed close to Bratislava (Devinska Nová Ves: Jamrich and Halásová, 2010; Hyžný et al., 2012).

Wells: Mühlberg 77 (1110–1760 m), Mühlberg T1 (1160–1740 m), Mühlberg 100 (1160–1700 m), Bernhardsthal 5 (1160–1700 m), Bernhardsthal 7 (1120–1590 m), Bernhardsthal 6 (1120–1550 m), Rabensburg 1 (690–1585 m), Rabensburg 2 (995–1300 m), Rabensburg 011 (1950–2150 m), Paltendorf 1 (1805–2800 m), Paltendorf T1 (1775–2770 m), Ringelsdorf 2 (1820–2770 m), Spannberg 8 (1560–2010 m), Aderklaa 78 (1320–1385 m), Matzen 126 (1180–1540 m).

5 Discussion

The lowermost Neogene units found in the central Vienna Basin can be attributed to the coastal-lagoonal Bockfließ Fm., which is of early Ottnangian age. In the Bernhardsthal-Mühlberg-Rabensburg area in the northern Vienna Basin, the oldest deposits are represented by the open marine Lužice Fm. A transitional position is represented by the Steinberg wells, where deeper marine faunas indicate the transition from the shallow lagoonal conditions of the Bockfließ Fm. towards the open marine Lužice Fm. The geographic gap between both occurrences is most probably a result from later erosion during tectonic movements around the Karpatian-Badenian boundary (Weissenbäck, 1995; Wessely, 2000; Harzhauser et al., 2019). The micro- and macrofaunas of both formations point to fully marine conditions. No indications of a connection to the Ottnangian *Rzehakia* faunas (= *Oncophora* beds in older literature) was detected. These developed in the North Alpine Foreland Basin during the late Ottnangian or even later following the age model of Hofmayer et al. (2019). At that time the Matzen area was dry land or the respective deposits have been eroded.

No marine deposits of Karpatian age were detected in the wells of the Austrian part of the northern Vienna Basin. Such marine sediments are confined to the Korneuburg Basin, the Mistelbach Halfgraben, the adjacent Alpine-Carpathian Foredeep (Harzhauser et al., 2017) and the Slovak part of the north-eastern Vienna Basin (Kováč et al., 2004). In the central and southern Vienna Basin, Karpatian deposits are represented by the Aderklaa Fm., which is strongly tilted (Fig. 6). The Aderklaa Fm. can be separated into the basal Gänserndorf Mb., reflecting alluvial fans, and the Schönkirchen Mb., which reflects various wetland environments with floodplains, braided rivers and lakes. Despite the geographic gap between the marine and freshwater deposits, both areas most probably formed a continuous sedimentation area during the Karpatian. This is documented by brackish-marine

gastropods in basal parts of the Schönkirchen Mb. and by the occurrence of Karpatian foraminifers in a single horizon of the Schönkirchen Mb. The position of this horizon in the wire-logs suggests a coincidence with a flooding of the wetlands. This in turn, allows for the first time to interpret the Aderklaa Fm. from the viewpoint of sequence stratigraphy. Thus, the Gänserndorf Mb. corresponds to a LST, which passes into the TST of the lower Schönkirchen Mb. This is also reflected by the fining upward trends in the wire-logs. The full flooding of the wetlands is expressed by the maximum flooding surface and the occurrence of marine plankton. The subsequent HST is indicated by the onset of coarsening upward patterns in the wire logs but is frequently truncated by erosion.

The total thickness of this cycle attains up to 1400 m, which rivals or even surpasses the thickness of the Karpatian Laa Fm. in the Mistelbach Halfgraben and Alpine-Carpathian Foreland Basin. Therefore, we tentatively assume, that the Aderklaa Fm. spans the entire Karpatian because restricting the Aderklaa Fm. only to the late Karpatian would result in an extraordinarily high sedimentation rate of 2 m/kyr. Biostratigraphic data to support either of these interpreatations, however, are missing.

Tectonic movements around the Karpatian-Badenian boundary and in the early Badenian, termed Styrian Tectonic Phase (Stille, 1924; Rögl et al., 2007; Hohenegger et al., 2009), coincided with strong uplift and tilting of lower Miocene strata. After this erosive phase, sedimentation started with the lower Badenian Rothneusiedl Fm. (Fig. 6). The stratigraphic position strongly suggests that these braided river deposits can be linked to the canyon and channel systems of the Mistelbach Halfgraben and North Alpine-Carpathian Foreland Basin, as described by Dellmour and Harzhauser (2012) and Harzhauser et al. (2017, 2019). The Roggendorf conglomerates in the NACFB (Ćorić and Rögl, 2004) are most probably an equivalent, representing a W-E trending feeder.
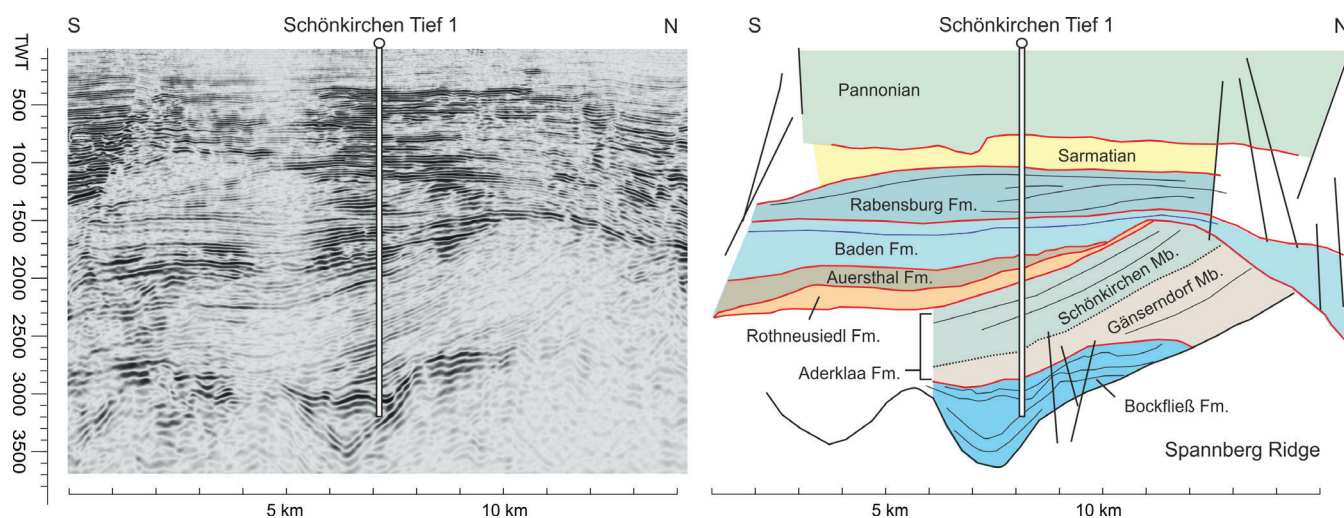
The Matzen/Spannberg Ridge forms the northern limit of the Rothneusiedl Fm. Along this tectonic feature the formation pinches out. Therefore, the Matzen/Spannberg Ridge developed during tectonic movements in the early middle Miocene and was no barrier towards the central and southern Vienna Basin during the early Miocene as suggested in nearly all stratigraphic schemes (e.g. Kreutzer, 1993).

The lower Badenian Mannsdorf Fm. represents open marine settings, partly indicating even upper bathyal conditions. Its geographic patchiness and the absence of any shallow water deposits, suggests, that only erosional relics of a formerly widely distributed deposit are preserved. Flattening of the marked reflector indicating the middle Badenian maximum flooding surface (mfs in Fig. 4) clearly proofs this interpretation and reveals the remnants as lower Badenian paleobasins.

In terms of sequence stratigraphy, the lower Badenian deposits indicate a LST, represented by the Rothneusiedl Fm. and the subsequent transgression reflected by the marls of the Mannsdorf Fm. (BA1 sequence of Strauss et al., 2006). A separation into TST, mfs and HST of the Mannsdorf Fm. based only on well-logs is difficult due to the insufficient data available.

Note that the exact timing of the onset of sedimentation is still unclear. The age of the early Badenian can be constrained for the first time by the tuff age from the Bernhardsthal field (15.12 Ma., Sant et al., 2020), the occurrence of a Ries-Impact moldavite at Immendorf (Grund Fm.) in the NAFB (Ries-Impact = 14.8 Ma. Schmieder et al., 2018), and the absence of *Orbulina* (< 14.56 Ma., Iaccarino et al., 2011). In addition, the age of the Kuchyňa tuff (15.2 Ma.), at the eastern margin of the Vienna Basin supports the estimate (Rybár et al., 2019).

Therefore, the sedimentation of the Mannsdorf Fm. started before 15.2 Ma. Taking the 350 m thick Rothneusiedl Fm. into account, requires additional time. Herein, we draw the onset of the Badenian sedimenattion at

Figure 6: Seismic interpretation of a N-S seismic line showing the tilted lower Miocene strata along the Matzen/Spannberg Ridge; note that the Matzen Fm. is not depictable due to the low thickness.
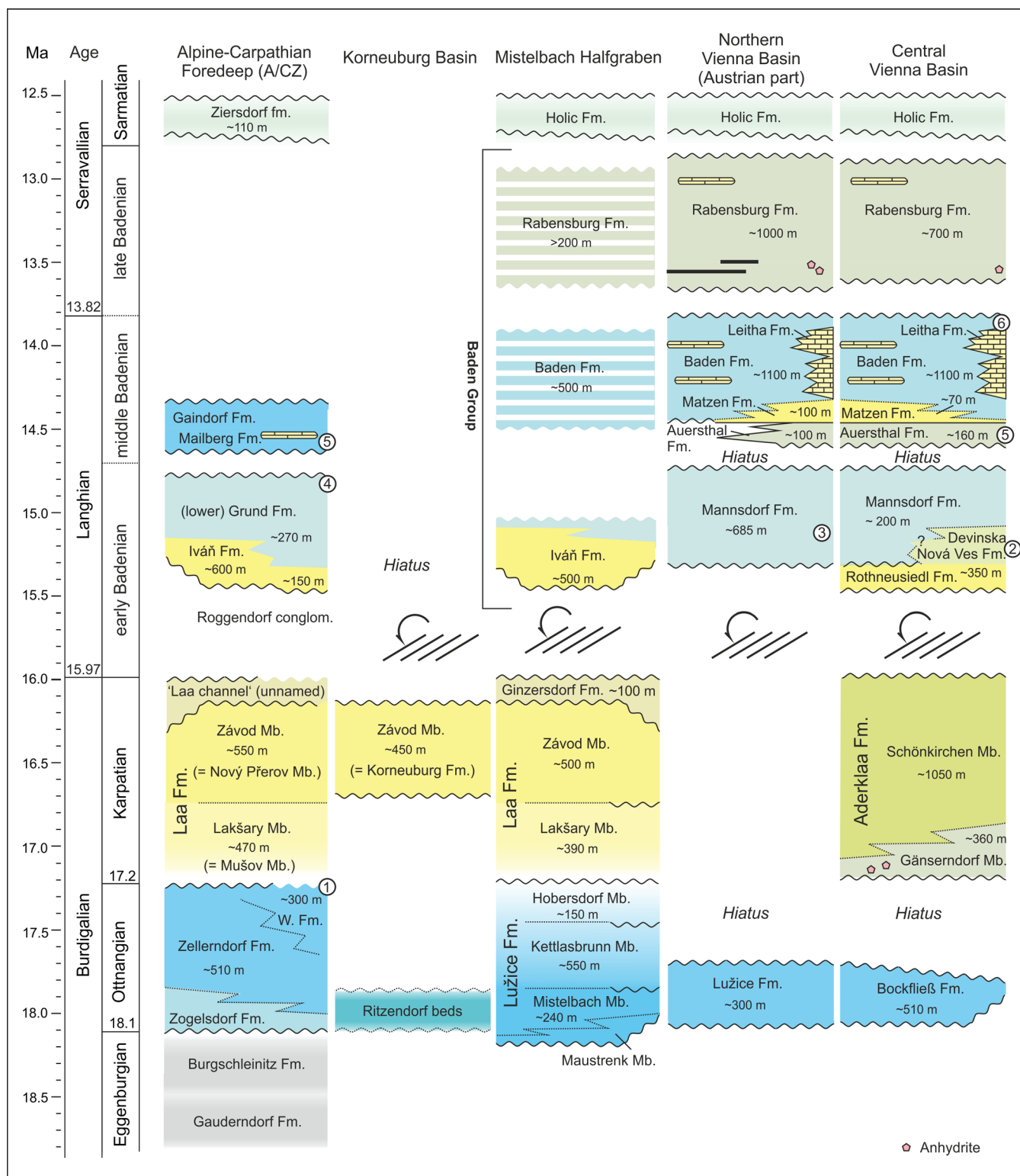
Figure 7: New lithostratigraphic scheme for the Austrian parts of the northern and central Vienna Basin and correlation with adjacent basins (after Harzhauser et al., 2019); W. Fm.: Wildendürnbach Fm. (Palzer-Khomenko et al., 2018a); 1: Straning tuff (Roetzel et al., 2014); 2: Kuchyňa tuff (Rybár et al., 2019); 3: Be 4 tuff (Sant et al., 2020); 4: Ries Impact (Schmieder et al., 2018); 5: FOD *Orbulina* in the Mediterranean Sea (Iaccarinio et al., 2011); 6: Baden-Soos core (Hohenegger and Wagreich, 2012). Note that the spatial relation between the marine Mannsdorf Fm. and the terrestrial Devinská Nova Ves Fm. is hypothetical.

Note 1: the Badenian of the Mistelbach Halfgraben is not well resolved yet; during the Badenian, the Mistelbach Halfgraben was an uplifted block and sedimentation was strongly discontinuous.

Note 2: Karpatian deposits are missing in the Austrian part of the northern VB, but are represented by the Laa Fm. in the Slovak part of the basin (Kováč et al., 2004).

around 15.4 Ma (Fig. 7) but a slightly younger age cannot be excluded with the available data.

Another hiatus is obvious between the early and middle Badenian; this is indicated by strong erosion and tilting of the lower Badenian Mannsdorf Fm. The middle Badenian cycle starts with the coarse siliciclastics of the Auersthal Fm., which can be dated for the first time to be younger than 14.56 Ma based on the occurrence of *Orbulina*. It is rapidly overlain by the sand of the Matzen Fm., which quickly passes into the pelites of the Baden Fm. The depositional environment of the Baden Fm. ranged from upper bathyal to outer neritic to coastal marine but open marine conditions prevailed in the Vienna Basin. In terms of sequence stratigraphy, the Auersthal Fm. can be explained as LST, overlain by the sands of the initial TST (Ba 2 sequence of Strauss et al., 2006). The rapid deepening is indicated by the long shale line interval seen in all wire-logs, culminating in a pronounced mfs, which is used as marker throughout the Vienna Basin in seismic analysis by OMV (mfs in Fig. 4). The HST is indicated by the serrated high amplitude SP-logs.

Interestingly, the frequently used ecobiozones Upper Lagenidae Zone and *Spirorutilus* Zone fall both completely within the middle Badenian and are both present in the Baden Fm. These "zones" form an ecological succession due to the deepening of the basin. In the southern Pannonian Basin, however, the *Spirorutilus* Zone has been magnetostratigraphically constrained to 13.8—13.6 Ma (Mandic et al., 2019). Consequently, the *Spirorutilus* zone in the southern Pannoninan Basin largely coincides with parts of the upper Badenian.

The upper Badenian is represented by the up to 1000-m-thick Rabensburg Fm. The depositional environment was generally shallower compared to the middle Badenian and middle to inner neritic settings prevailed. In wire-logs and seismic surveys, it is characterized by high amplitude and high frequency patterns and prograding sigmoidal sedimentary bodies. In terms of sequence stratigraphy, the upper Badenian represents a single cycle (Ba3 of Strauss et al., 2006) with a short TST, moderately developed mfs and thick HST, which is often truncated in thickness by the subsequent Sarmatian deposits. The LST of the upper Badenian cycle is difficult to detect in wire-logs, due to the weak separation from the HST logs of the middle Badenian. Regionally, the occurrence of lignite and anhydrite indicates the onset of the upper Badenian (Harzhauser et al., 2018).

The Badenian stage is traditionally subdivided into a lower, middle and upper Badenian (Papp et al., 1978; Strauss et al., 2006; Piller et al., 2007). Hohenegger et al. (2014) followed a subdivision into an early, mid and late Badenian age but distinguished only two substages. This concept was also adopted by Sant et al. (2020). These papers lacked seismic information and were mainly (though not exclusively) based on surface outcrops. Our seismic and well-log data, however, clearly document three depositional cycles in the Vienna Basin. Therefore, we prefer to maintain the threefold system.

Sedimentation rates

Assuming that the 510-m-thick Bockfließ Fm. spans about half of the Ottnangian, would result in a sedimentation rate of ~ 1.0 m/kyr. This estimate is not unrealistic compared to the sedimentation rate of the Lužice Fm. in the adjacent Mistelbach Halfgraben, which ranges around 0.9 m/kyr (Harzhauser et al., 2019).

Given a duration of the Karpatian of 1.2 Ma, a thickness of 1400 m would result in a gross sedimentation rate of ~1.2 m/kyr. This rate will surely be an overestimate, as the maximum thickness of the alluvial fans of the Gänserndorf Mb., might be local phenomena. Excluding these deposits results still in a high sedimentation rate of ~ 0.9 m/kyr. As the depositional environment was a nearly flat floodplain slightly above sea level, this rate requires a significant subsidence during the piggy-back stage of the Vienna Basin as also indicated by Lee and Wagreich, (2017) who calculated subsidence rates of >1m/kyr.

We assume that the early Badenian deposition in the central and northern Vienna Basin ranged roughly from ~15.5 to ~14.7 Ma corresponding to a duration of ~ 0.8 Myr. Given a maximum thickness of at least 685 m for the Mannsdorf Fm. results in a sedimentation rate of ~ 0.9 m/kyr. As the total thickness of the Mannsdorf Fm. is most probably underestimated, the sedimentation rate might have been even higher. Applying the assumed age for the early Badenian flooding at 15.2 Ma of Sant et al. (2020) would even require sedimentation rates up to 1.4 m/kyr.

The maximum thickness of middle Badenian deposits in the central Vienna Basin attains ~1300 m. This estimate, however, is based on wells in a tectonically active position and might be untypical. A more representative succession is the Rabensburg 2 well in which the well-logs capture a full succession of LST, TST, mfs and HST. In this well, the middle Badenian attains about 900 m thickness. The middle Badenian in our stratigraphic model has a duration of about 0.8 Myr, which results in a high sedimentation rate of ~1.1 m/kyr. This value is nearly identical with the estimate of Hölzel et al. (2008) but is in contrast with results of Hohenegger and Wagreich (2012), who calculated a sedimentation rate of ~0.5 m/kyr for the upper part of the Baden Fm. in the Baden-Sooss core, which has a marginal position, even with a gravel horizon inbetween, and near to the marginal faults of the basin.

This low sedimentation rate would result in a total thickness of about 400 m for the entire Baden Fm., which is an obvious underestimation in respect to the well data (for the northern and central Vienna Basin). Applying the sedimentation rate of Hohenegger and Wagreich (2012) to Rab 2 would result in a duration of 1.8 Myr for the middle Badenian, which is distinctly too long.

Thus, the estimate of Hohenegger and Wagreich (2012) is not applicable to a basinal setting in the subsiding lows. In contrast, our data support the calculations of Lee and Wagreich (2017), who assumed subsidence rates of up to 1m/kyr for the middle Badenian.

The time frame of the late Badenian is constrained by the Langhian/Serravallian boundary at 13.82 Ma and by

the Badenian/Sarmatian boundary around 12.7 Ma. Thus, the late Badenian had a maximum duration of ~1 Myr, which results in a sedimentation rate of up to 1 m/kyr in the northern Vienna Basin.

6 Conclusions

For the first time, we propose a concise lithostratigraphic scheme for the northern and central Vienna Basin (Fig. 7). The lower Miocene can be separated into two Ottnangian formations (Lužice Fm., Bockfließ Fm.). Upper Ottnangian deposits seem to be missing either due to non-deposition or subsequent erosion. The Karpatian is represented in the central Vienna Basin by the Aderklaa Fm. and its members (Gänserndorf Mb., Schönkirchen Mb.) but was eroded largely in the northern Vienna Basin. The middle Miocene Baden Group reveals a complex succession of fluvial, coastal neritic to open marine deposits with distinct and widespread lithologies, which are separated herein into the Rothneusiedl Fm., the Mannsdorf Fm., the Auersthal Fm., the Matzen Fm., the Baden Fm., the Leitha Fm., and the Rabensburg Fm.

Major disruptions of sedimentation coinciding with tilting and erosion took place during the terminal Ottnangian, the Karpatian/Badenian boundary and the terminal early Badenian. The erosion between the middle and upper Badenian and upper Badenian and Sarmatian are comparatively less severe and sedimentary contacts are generally conformable.

Our results suggest high sedimentation rates ranging roughly around 1 m/kyr for the marine Ottnangian, the lacustrine Karpatian and the marine early, middle and late Badenian. We do not see major differences between the piggy-back stage and the pull-apart stage of the basin. Therefore, these results challenge the subsidence analyses by Lankrejer et al. (1995), Hölzel et al. (2008) and Lee and Wagreich (2017), who propose major shifts in sedimentation rates with several "pulses". The vague chronostratigraphic constraints and numerical ages in these analyses might partly have led to misinterpretations.

Concluding, the strict stratigraphic concept as proposed herein is a proper base for new calculations of subsidence histories.

References

Albano, P.G., Sabelli, B., 2012. The molluscan assemblages inhabiting the leaves and rhizomes of a deep water *Posidonia oceanica* settlement in the central Tyrrhenian Sea. Scientia Marina, 76/4, 721–732. https://doi.org/10.3989/scimar.03396.02C

Andrejeva-Grigorovic A., Halasova E., 2000. Calcareous Nannofossils biostratigraphy of the Early Miocene sediments in the Vienna Basin NE part (Slovakia) Slovak Geological Magazine, 6/2–3, 101–105.

Bachmayer, F., Weinfurter, E., 1965. *Bregmaceros*-Skelette Pisces mit in situ erhaltenen Otolithen aus den tortonischen Ablagerungen von Walbersdorf. Senckenbergiana Lethaea, 46a, 19–33.

Báldi, K., Hohenegger, J., 2008. Paleoecology of benthic foraminifera of the Baden-Sooss section Badenian, Middle Miocene, Vienna Basin, Austria. Geologica Carpathica, 59/5, 411–424. http://www.geologicacarpathica.com/browse-journal/volumes/59-5/article-455/

Báldi, T. 1973. Mollusc fauna of the Hungarian Upper Oligocene Egerian. Akadémiai Kiadó, Budapest, 511 pp.

Baráth, I., Nagy, A., Kováč, M., 1994. Sandberské vrstvy - vrchnobádenské marginálne sedimenty východného okraja Viedenskej panvy. Geologické práce, Správy, 99, 59–66.

Bartek, V., 1989. Nové litostratigrafické členenie vrchného panónu a pontu v slovenskej časti Viedenskej panvy. Mineralia Slovaca, 21/3, 275–281.

Bergen, J. A., de Kaenel, E., Blair, S., Boesiger, T., Browning, E., 2017. Oligocene-Pliocene taxonomy and stratigraphy of the genus *Sphenolithus* in the circum North Atlantic Basin: Gulf of Mexico and ODP Leg 154. Journal of Nannoplankton Research, 37 (2-3), 77–112.

Brix, F., Plöchinger, B., 1988. Erläuterungen zu Blatt 76 Wiener Neustadt. Geologische Karte der Republik Österreich 1:50000. Verlag der Geologischen Bundesanstalt, Wien, 85 pp.

Brzobohatý, R., Stráník, Z., 2012. Paleogeography of the Early Badenian connection between the Vienna Basin and the Carpathian Foredeep. Central European Journal of Geosciences, 4/1, 126–137, https://doi.org/10.2478/s13533-011-0045-z

Buday, T., 1946. Nékolik poznámek k stratigrafii a paleogeografii tortonu v západní části dolnomoravského úvalu. Věstnik Státního Geologického Ústavu Československé Republiky, Prague, 21/3–6, 145–152.

Buday, T., Cicha, J., 1956. Nové názory na stratigrafii spodniho a stredniho miocenu Dolnomoravského úvalu a Považi. Geologické práce, Zošit, 43, 5–56.

Cicha, I., Rögl, F., Rupp, C. and Čtyroký, J., 1998. Oligocene-Miocene foraminifera of the Central Paratethys. Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft, 549, 1–325.

Ćorić, S., Rögl, F., 2004. Roggendorf-1 borehole, a key-section for Lower Badenian transgressions and the stratigraphic position of the Grund Formation Molasse Basin, Lower Austria. Geologica Carpathica, 55, 165–178.

Ćorić, S., Hohenegger, J., 2008. Quantitative analyses of calcareous nannoplankton assemblages from the Baden-Sooss section Middle Miocene of Vienna Basin, Austria. Geologica Carpathica, 59, 447–460. http://www.geologicacarpathica.com/browse-journal/volumes/59-5/article-457/

Csaszar, G., 1997. Basic lithostratigraphic units of Hungary, charts and short descriptions. Geological Institute of Hungary, Budapest, 114 pp.

Čtyroký, P. 2000. Nové litostratigafické jednotky pannonu vídeòské pánve na Moravì. Vistník Èeského geologického ústavu, 75, 159–170.

Čtyroký, P., Havlíček, P., Stráník, Z., Pálenský, P., 1995. Geologická a přírodovědná mapa CHKO a BR Pálava. Geologische und naturwissenschaftliche Karte des Landschaftsschutzgebietes (CHKO) und des Biosphärenreservates (BR) Pálava. 1: 25.000. Český geologický ústav, Praha.

De Leeuw, A., Mandic, O., Krijgsman, W., Kuiper, K., Hrvatović, H., 2011. A chronostratigraphy for the Dinaride Lake System deposits of the Livno-Tomislavgrad Basin: the rise and fall of a long-lived lacustrine environment. Stratigraphy, 8, 29–43.

Dellmour, R., Harzhauser, M., 2012. The Iván Canyon, a large Miocene canyon in the Alpine-Carpathian Foredeep. Marine and Petroleum Geology, 38, 83–94. https://doi.org/10.1016/j.marpetgeo.2012.07.001

Dlabač, M., 1971. Dvé studie o sedimentaci v badenu (torton) Vídeňské pánve na Slovensku. Geologické práce, Správy, 56, 89–108.

Dullo, W.C., 1983. Diagenesis of fossils of the Miocene Leitha Limestone of the Paratethys, Austria: An example for faunal modifications due to changing diagenetic environments. Facies, 8, 1–112. https://doi.org/10.1007/BF02536740

Elečko, M., Vass, D. 2001. Litostratigrafické jednotky usadenín sarmatského veku vo viedenskej panve. Mineralia Slovaca, 33, 1–6.

Fencl, M., 2005. Sedimentologie der klastischen Miozän-Abfolge in Mannersdorf am Leithagebirge (Nieder-österreich). unpublished Master thesis, University Vienna. 54 pp., Vienna.

Fodor, L., 1995. From transpression to transtension: Oligocene–Miocene structural evolution of the Vienna Basin and the East Alpine–Western Carpathian junction. Tectonophysics, 242, 151–182. https://doi.org/10.1016/0040-1951(94)00158-6

Fordinál, K., Maglay, J., Elečko, M., Nagy, A., Moravcová, M., Vlačiky, M., Kohút, M., Németh, Z., Bezák, V., Polák, M., Plašienka, D., Olšavský, M., Buček, S., Havrila, M., Hók, J., Pešková, I., Kucharič, L., Kubeš, P., Malík, P., Baláž, P., Liščák, P., Madarás, J., Šefčík, P., Baráth, I., Boorová, D., Uher, P., Zlínska, A., Žecová, K., 2012. Explantions for the geological map of the Vienna Basin, 1:50 000. State Geological institute of Dionýz Štúr, Bratislava, 232 pp. (in Slovak).

Friebe, J.G., 1990. Lithostratigraphische Neugliederung und Sedimentologie der Ablagerungen des Badeniens (Miozän) um die Mittelsteirische Schwelle (Steirisches Becken, Österreich). Jahrbuch der Geologischen Bundesanstalt, 133, 223–257.

Friebe, J.G., 1991. Carbonate sedimentation within a siliciclastic environment: the Leithakalk of the Weißenegg Formation (Middle Miocene, Styrian Basin, Austria). Zentralblatt für Geologie und Paläontologie, 1990/11, 1671–1687.

Fuchs, R., 1990. Multistratigraphische Untersuchungen in den Bockfliesser Schichten des Zentralen Wiener Beckens. OMV-Report, Vienna, 28 pp.

Fuchs, R., Ramberger, R., Veit. C., 2001. Renaissance des größten Öl- und Gasfeldes in Österreich Wiener Becken. Erdöl, Erdgas, Kohle, 117, 528–540.

Fuchs, T., 1894. Ueber abgerollte Blöcke von Nulliporen-Kalk im Nulliporen-Kalk von Kalsersteinbruch. Zeitschrift der Deutschen Geologischen Gesellschaft, 46/1, 126–130.

Fuchs, W., Grill, F. 1984. Geologische Karte von Wien und Umgebung 1:200.000. Geologie der Österreichischen Bundesländer. Geologische Bundesanstalt, Wien.

Gebhardt, H., Ćorić, S., Krenmayr, H.-G., Steininger, H. and Schweigl, J., 2013. Neudefinition von lithostratigraphischen Einheiten des oberen Ottnangium Untermiozän in der alpin-karpatischen Vortiefe Niederösterreichs: Pixendorf-Gruppe, Traisen-Formation und Dietersdorf-Formation. Jahrbuch der Geologischen Bundesanstalt Wien 153, 1–4, 15–32.

Giacobbe, S., 2012. Biodiversity loss in Sicilian transitional waters: the molluscs of Faro Lake. Biodiversity Journal, 3/4, 501–510.

Grill, R., 1941. Stratigraphische Untersuchungen mit Hilfe von Mikrofaunen im Wiener Becken und den benachbarten Molasse-Anteilen. Oel und Kohle, 37, 595–602.

Grill, R., 1943. Über mikropaläontologische Gliederungsmöglichkeiten im Miozän des Wiener Beckens. Mitteilungen der Reichsanstalt für Bodenforschung, 6, 33–44.

Grill, R., 1960. Untergrenze und Gliederung des Miozäns im Wiener Becken. Mitteilungen der Geologischen Gesellschaft in Wien (Verhandlungen des Comité du Néogène Méditerranéen, 1. Tagung in Wien, 10.-20 Juli 1959), 52 (1959), 15–132.

Grill, R., 1968. Erläuterungen zur geologischen Karte des nord-östlichen Weinviertels und zu Blatt Gänserndorf. Geologische Bundesanstalt, Vienna, 155 pp

Grill, R., Janoschek, W., 1980. Erdöl und Erdgas. In: Oberhauser, R., (Ed.), Der geologische Aufbau Österreichs, Springer Verlag, Wien-New York, pp. 556–574,

Grunert, P., Tzanova, A., Harzhauser, M., Piller, W.E., 2014. Mid-Burdigalian Paratethyan alkenone record reveals link between orbital forcing, Antarctic ice-sheet dynamics and European climate at the verge to Miocene Climate Optimum. Global and Planetary Change, 123, 36–43. https://doi.org/10.1016/j.gloplacha.2014.10.011

Grunert, P., Hinsch, R., Sachsenhofer, R.F., Bechtel, A., Ćorić, S., Harzhauser, M., Piller, W.E., Sperl, H., 2013. Early Burdigalian infill of the Puchkirchen Trough (North Alpine Foreland Basin, Central Paratethys): Facies development

and sequence stratigraphy. Marine and Petroleum Geology, 39, 164–186. https://doi.org/10.1016/j.marpetgeo.2012.08.009

Hamilton, W., Johnson, N. 1999. The Matzen Project; rejuvenation of mature field. Petroleum Geoscience, 5, 119–125, https://doi.org/10.1144/petgeo.5.2.1190

Hamilton, W., Wagner, L., Wessely, G. 2000. Oil and Gas in Austria. Mitteilungen der Österreichischen Geologischen Gesellschaft, 92, 235–262.

Haq, B.U., Hardenbol, J., Vail, P.R., 1988. Mesozoic and Ceno-zoic chronostratigraphy and cycles of sealevel changes. In: Wilgus, C.K., (ed.), Sea-level changes - an integrated approach. Society of Economic Paleontologists and Mineralogists, Special Publications, 42, pp. 71–108.

Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T.,Graciansky, P.-C., Vail, P.R., 1998. Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins. In: Graciansky, C.-P., Hardenbol, J., Jacquin, T. and Vail, P.R., (eds.), Mesozoic and Cenozoic sequence stratigraphy of European basins. Society for Sedimentary Geology Special Publication, 6, 3–13.

Harzhauser, M., 2002. Marine und brachyhaline Gastropoden aus dem Karpatium des Korneuburger Beckens und der Kreuzstettener Bucht Österreich, Untermiozän. Beiträge zur Paläontologie, 27, 61–159.

Harzhauser, M., Mandic, O., 2009. Neogene dreissenids in Central Europe: evolutionary shifts and diversity changes. Chapter 2. In: van der Velde, G., Rajagopal, S. and bij de Vaate, A. (Eds.), The Zebra Mussel in Europe. Backhuys Publishers, Leiden/Margraf Publishers, Weikersheim. pp. 11–29.

Harzhauser, M., Piller, W.E., 2004. Integrated stratigraphy of the Sarmatian Upper Middle Miocene in the western Central Paratethys. Stratigraphy, 1/1, 65–86.

Harzhauser, M., Piller, W.E., 2007. Benchmark data of a changing sea. – Palaeogeography, Palaeobiogeography and Events in the Central Paratethys during the Miocene. Palaeogeography, Palaeoclimatology, Palaeoecology, 253, 8–31. https://doi.org/10.1016/j.palaeo.2007.03.031

Harzhauser, M., Daxner-Höck, G., Piller, W.E., 2004. An integrated stratigraphy of the Pannonian Late Miocene in the Vienna Basin. Austrian Journal of Earth Sciences, 9596, 6–19.

Harzhauser, M., Piller, W.E., Müllegger, S., Grunert, P., Micheels, A., 2010. Changing seasonality patterns in Central Europe from Miocene Climate Optimum to Miocene Climate Transition deduced from the *Crassostrea* isotope archive. Global and Planetary Change, 76, 77–84. https://doi.org/10.1016/j.gloplacha.2010.12.003

Harzhauser, M., Theobalt, D., Strauss, P., Mandic, O., Piller, W. E. 2019. Seismic-based lower and middle Miocene stratigraphy in the northwestern Vienna Basin Austria. Newsletter on Stratigraphy, 52, 221–224. https://doi:10.1127/nos/2018/0490

Harzhauser, M., Mandic, O., Büyükmeriç, Y., Neubauer, T.A., Kadolsky, D., Landau, B.M., 2016. A Rupelian mangrove swamp mollusc fauna from the Thrace Basin in Turkey. Archiv für Molluskenkunde, 145, 23–58.

Harzhauser, M., Theobalt, D., Strauss, P., Mandic, O., Carnevale, G., and Piller, W. E., 2017. Miocene biostratigraphy and paleoecology of the Mistelbach Halfgraben in the northwestern Vienna Basin Lower Austria. Jahrbuch der Geologischen Bundesanstalt, 157, 57–108.

Harzhauser M., Grunert P., Mandic O., Lukeneder P., García Gallardo Á., Neubauer T.A., Carnevale G., Landau B.M., Sauer R., Strauss P., 2018. Middle and Late Badenian palaeoenvironments in the northern Vienna Basin and their potential link to the Badenian Salinity Crisis. Geologica Carpathica, 69, 129–168. https://doi.org/10.1515/geoca-2018-0009

Haunold, T.G., 1995. Zur Taxonomie, Systematik und stratigraphischen Bedeutung uvigerinider Foraminiferen im Neogen des Wiener Beckens und benachbarter Gebiete – 40 Jahre nach Papp & Turnovsky (1953). Jahrbuch der Geologischen Bundesanstalt, 138, 67–87.

Häusler, H., Scheibz, J., Chwatal, W., Kohlbeck, F., 2014. Coeval Lower Miocene subsidence of the Eisenstadt Basin and relative updoming of its Austroalpine frame: implications from high-resolution geophysics at the Oslip section (Northern Burgenland, Austria). International Journal of Earth Science, 104, 475–493. https://doi.org/10.1007/s00531-014-1084-8

Hedberg, H.D., 1976. International stratigraphic guide. John Wiley, New York, 200 pp.

Hilgen, F.J., Lourens, L.J., Van Dam, J.A., 2012. The Neogene Period. In: Gradstein, F.M., Ogg, J.G., Schmitz, M.D. and Ogg, G.M. (eds.), The Geologic Time Scale 2012, Volume 1. Elsevier, Amsterdam, pp. 923–978.

Hinsch, R., Decker K., Peresson, H., 2005. 3-D seismic interpretation and structural modeling in the Vienna Basin: implications for Miocene to recent kinematics. Austrian Journal of Earth Sciences, 97, 38–51.

Hladecek, K., 1965. Zur Schichtfolge und Lagerung des Helvets von Matzen. PhD-Thesis, University of Vienna, 106 pp.

Hofmayer, F., Kirscher, U., Sant, K., Krijgsman, W., Fritzer, Th., Jung, D., Weissbrodt, W., Reichenbacher, B., 2019. Three dimensional geological modeling supports a revised Burdigalian chronostratigraphy in the North Alpine Foreland Basin. International Journal of Earth Sciences, 108, 2627–2651. https://doi.org/10.1007/s00531-019-01780-0

Hohenegger, J., 2005. Estimation of environmental paleogradient values based on presence/absence data: a case study using benthic foraminifera for paleodepth estimation. Palaeogeography, Palaeoclimatology, Palaeoecology, 217, 115–130. https://doi.org/10.1016/j.palaeo.2004.11.020

Hohenegger, J., Wagreich, M., 2012. Time calibration of sedimentary sections based on insolation cycles using combined cross-correlation: dating the gone Badenian stratotype Middle Miocene, Paratethys, Vienna Basin, Austria as an example. International Journal of Earth Sciences, 101, 339–349. https://doi.org/10.1007/s00531-011-0658-y

Hohenegger, J, Ćorić, S., Wagreich, M., 2014. Timing of the Middle Miocene Badenian Stage of the Central Paratethys. Geologica Carpathica, 65/1, 55–66. https://doi.org/10.2478/geoca-2014-0004

Hohenegger, J., Andersen, N., Báldi, K., Ćorić, S., Pervesler, P., Rupp, C., Wagreich, M., 2008. Paleoenvironment of the Early Badenian Middle Miocene in the southern Vienna Basin Austria – multivariate analysis of the Baden-Sooss section. Geologica Carpathica, 59, 461–487. http://www.geologicacarpathica.com/browse-journal/volumes/59-5/article-458/

Hohenegger J., Rögl F., Ćorić S., Pervesler P., Lirer F., Roetzel R.,Scholger R., Stingl K., 2009. The Styrian Basin: a key to the Middle Miocene (Badenian/Langhian) Central Paratethys transgressions. Austrian Journal of Earth Sciences, 102, 102–132.

Hohenegger, J., Ćorić, S., Khatun, M., Pervesler, P., Rögl, F., Rupp, C., Selge, A., Uchman, A., Wagreich, M., 2009a. Cyclostratigraphic dating in the Lower Badenian Middle Miocene of the Vienna Basin Austria: the Baden-Sooss core. International Journal of Earth Sciences, 98, 915–930. https://doi.org/10.1007/s00531-007-0287-7

Hohenegger, J., Pervesler, P., Uchman, A. and Wagreich, M., 2009b. Upper bathyal trace fossils document palaeoclimate changes. Terra Nova, 21, 229–236. https://doi.org/10.1111/j.1365-3121.2009.00878.x

Hölzel, M., Wagreich, M., Faber, R., Strauss, P., 2008. Regional subsidence analysis in the Vienna Basin (Austria). Austrian Journal of Earth Sciences, 101, 88–98.

Hölzel, M., Decker, K., Zámolyi, A., Strauss, P., Wagreich, M., 2010. Lower Miocene structural evolution of the central Vienna Basin (Austria). Marine and Petroleum Geology 27, 666–681. https://doi.org/10.1016/j.marpetgeo.2009.10.005

Hrabovský, J., 2013. Negenikulátne koralinné riasy (Corallinales, Sporolithales, Rhodophyta) z litotamniových vápencov lokality Vrchná hora pri Stupave (Viedenská panva, Slovensko). Mineralia Slovaca, 45, 23–34.

Hrabovský, J., Fordinál, K., 2013. Paleoekologické zhodnotenie riasových vápencov z lokality Stupava-Vrchná hora (Viedenská panva, Slovensko). Mineralia Slovaca, 45, 11–22.

Hyžný, M., Hudáčková, N., Biskupič, R., Rybár, S., Fuksi, T., Halásová, E., Zágoršek, K., Jamrich, M., Ledvák P., 2012. Devínska Kobyla – a window into the Middle Miocene shallow-water marine environments of the Central Paratethys (Vienna Basin, Slovakia). Acta Geologica Slovaca, 4/2, 95–111.

Iaccarino, S.M., Di Stefano, A., Foresi, L.M., Turco, E., Baldassini, N., Cascella, A., Da Prato, S., Ferraro, L., Gennari, R., Hilgen, F.J., Lirer, F., Maniscalco, R., Mazzei, R., Riforgiato, F., Russo, B., Sagnotti, L., Salvatorini, G., Speranza, F., Verducci, M., 2011. High-resolution integrated stratigraphy of the upper Burdigalian-lower Langhian in the Mediterranean: the Langhian historical stratotype and new candidate sections for defining its GSSP. Stratigraphy, 8/2–3, 199–215.

Jamrich, M., Halásová, E., 2010. Vývoj spoločenstiev vápnitých nanofosílií Viedenskej panvy ako odraz paleoenvironmentálnych zmien počas vrchného bádenu (Devínska Nová Ves – tehelňa). Acta Geologica Slovaca, 2, 2, 123–140.

Janoschek, R., 1942. Die bisherigen Ergebnisse der erdölgeologischen Untersuchungen im inneralpinen Wiener Becken. Oel und Kohle, 38, 125–150.

Janoschek, R., 1943. Das Inneralpine Wiener Becken. In: Schaffer, F.X. (ed.), Geologie der Ostmark, Franz Deuticke, Wien, pp. 427–514.

Janoschek, R., 1951. Das Inneralpine Wiener Becken. In: Schaffer, F.X. (ed.), Geologie von Österreich, 2. Auflage, Franz Deuticke, Wien, pp. 525–693.

Jiříček, R., 2002. The evolution of the Molasse in the Alpine-Carpathian Foredeep and the Vienna Basin. Exploration Geophysics, Remote sensing and environment, 9, 179 p.

Jiříček, R., Seifert, P., 1990. Palaeogeography of the Neogene in the Vienna Basin and the adjacent part of the foredeep. In: Mináříková, D. and, Lobitzer, H., (eds.), Thirty Years of Geological Cooperation between Austria and Czechoslovakia. Cesky Geologicky Ustav, Praha, pp. 89–105.

Jiříček, R., Tomek, Č., 1981. Sedimentary and structural evolution of the Vienna Basin. Earth Evolution Science, 3–4, 195–204.

Kapounek, J., Papp, A., 1969. Der Vulkanismus in der Bohrung Orth 1 und die Verbreitung von Grobschüttungen zwischen dem Spannberger Rücken und der Donau. Verhandlungen der Geologischen Bundesanstalt, 1969, 114–123.

Kapounek, J., Kröll, A., Papp, A., Turnovsky, K., 1965. Die Verbreitung von Oligozän, Unter- und Mittelmiozän in Niederösterreich. Erdoel-Erdgas-Zeitschrift, 81/4, 109–115.

Keferstein, C., 1828. Beobachtungen und Ansichten über die geognostischen Verhältnisse der nördlichen Kalk-Alpenkette in Oesterreich und Baiern. Teutschland, geognostisch-geologisch dargestellt und mit Charten und Durchscnittszeichnungen. Verlag des Landes-Industrie-Comptoirs. Weimar, 5/3, 425 pp.

Kern, A., Harzhauser, M., Mandic, O., Roetzel, R., Ćorić, S., Bruch, A.A., Zuschin, M., 2010. Millennial-scale vegetation dynamics in an estuary at the onset of the Miocene Climate Optimum. Palaeogeography, Palaeoclimatology, Palaeoecology, 304, 247–261. https://doi.org/10.1016/j.palaeo.2010.07.014

Kölbl, L., 1959. Art und Verteilung der Sedimentkörper im Torton des Erdölfeldes Matzen Wiener Becken. Eclogae Geologicae Helvetiae, 51/3, 999–1009.

Kölbl, L., 1966. Geologische Studie über die Bildung der tortonen Zwischenhorizonte von Matzen und die Entstehung ihrer Lagerstätten. Erdöl-Erdgas Zeitschrift, 82, 45–65.

Košťák, M., Schlögl, J., Culkac, A., Tomašových, A., Mazucha, M., Hudáčková, N., 2018. The unique preservation of Sepia soft tissues in the Miocene deposits Serravallian,

Vienna Basin: Implications for the origin of microbodies in the fossil record. Palaeogeography Palaeoclimatology Palaeoecology, 493, 111–118. https://doi.org/10.1016/j.palaeo.2018.01.005

Kováč, M., Baráth, I., Harzhauser, M., Hlavatý, I., Hudáčková, N., 2004. Miocene depositional systems and sequence stratigraphy of the Vienna Basin. Courier des Forschungs-Instituts Senckenberg, 246, 187–212.

Kováčová, P., Hudáčkova, N., 2009. Late Badenian foraminifers from the Vienna Basin Central Paratethys: stable isotope study and paleoecological implications. Geologica Carpathica, 60/1, 59–70. https://doi.org/10.2478/v10096-009-0006-3

Kreutzer, K., 1971. Mächtigkeitsuntersuchungen im Neogen des Ölfeldes Matzen, Nieder-Österreich. Erdöl-Erdgas-Zeitschrift, 87, 38–49.

Kreutzer, N., 1974. Lithofazielle Gliederung einiger Sand- und Schotter-Komplexe des Sarmatien und obersten Badenien im Raume von Matzen und Umgebung (Wiener Becken). Erdoel-Erdgas-Zeitschrift, 90, 114–127.

Kreutzer, N., 1978. Die Geologie der Nulliporen (Lithothamnien)-Horizonte der miozänen Badener Serie des Ölfeldes Matzen (Wiener Becken). Erdoel-Erdgas-Zeitschrift, 94, 129–145.

Kreutzer, N., 1986. Die Ablagerungssequenzen der miozänen Badener Serie im Feld Matzen und im zentralen Wiener Becken. Erdöl, Erdgas, Kohle, 102/11, 492–503.

Kreutzer, N., 1992. Matzen Field – Austria. Vienna Basin. A field study for the Treatise of Petroleum Geology. AAPG, Tulsa, pp. 57–97.

Kreutzer, N., 1993. Das Neogen des Wiener Beckens. In: Brix, F. and Schultz, O. eds., Erdöl und Erdgas in Österreich. Naturhistorisches Museum Wien und F. Berger, Horn., pp. 232–248.

Kreutzer, K., Hlavatý, V., 1990. Sediments of the Miocene mainly Badenian in the Matzen area in Austria and in the southern part of the Vienna Basin in Czechoslovakia. In: Minarikove, D. and Lobitzer, H. (eds.): Thirty years of geological cooperation between Austria and Czechoslovakia. UUG, Praha, pp. 110–123.

Kroh, A., Harzhauser, M., Piller, W.E., Rögl, F., 2003. The Lower Badenian Middle Miocene Hartl Formation Eisenstadt-Sopron Basin, Austria. Österreichische Akademie der Wissenschaften, Schriftenreihe Erdwissenschaftliche Kommissionen, 16, 87–109.

Kröll, A., 1984. Die Erdöl- und Erdgasregion Matzen/Schönkirchen aus geologischer Sicht. Erdöl-Erdgas, 100, 185–195.

Kröll A., Wessely G., 1993. Strukturkarte - Basis der tertiären Beckenfüllung 1:200.000. Erläuterung zu den Karten über den Untergrund des Wiener Beckens und der angrenzenden Gebiete. Geologische Bundesanstalt, Wien.

Lankreijer, A., Kováč, M., Cloetingh, S., Pitoňák, P., Hlôška, P., Biermann, C., 1995. Quantitative subsidence analysis and forward modelling of the Vienna and Danube basins: thin-skinned versus thick-skinned extension. Tectonophysics, 252, 433–451. https://doi.org/10.1016/0040-1951(95)00099-2

Lee, E.J., Wagreich, M., 2017. Polyphase tectonic subsidence evolution of the Vienna Basin inferred from quantitative subsidence analysis of the northern and central parts. International Journal of Earth Sciences, 106, 687–705. https://doi.org/10.1007/s00531-016-1329-9

Mandic, O., 2004. Foraminiferal paleoecology of a submarine swell - the Lower Badenian (Middle Miocene) of the Mailberg Formation at the Buchberg in the Eastern Alpine Foredeep: initial report. Annalen des Naturhistorischen Museums in Wien, 105A, 161–173.

Mandic, O., Harzhauser, M., 2003. Molluscs from the Badenian Middle Miocene of the Gaindorf Formation Alpine Molasse Basin, NE Austria - taxonomy, paleoecology and biostratigraphy. Annalen des Naturhistorischen Museums Wien, 104A, 85–127.

Mandic, O., Sant, K., Kallanxhi, M.-E., Ćorić, S., Theobalt, D., Grunert, P., De Leeuw, A., Krijgsman, W., 2019. Integrated bio-magnetostratigraphy of the Badenian reference section Ugljevik in southern Pannonian Basin - implications for the Paratethys history (middle Miocene, Central Europe). Global and Planetary Change, 172, 374–395. https://doi.org/10.1016/j.gloplacha.2018.10.010

Marquet, R. 2004. Ecology and evolution of Pliocene bivalves from the Antwerp Basin. Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre, 74 Supplementum, 205–212.

Mayer, A., Pavuza, R., Wirth, J., 1989. Die Höhlen des Steinberges im Weinviertel (Niederösterreich). Die Höhle. Zeitschrift für Karst- und Höhlenkunde, 40/2, 37–49.

Palzer-Khomenko, M., Wagreich, M., Knierzinger, W., Meszar, M.-E., Gier, S., Kallanxhi, M.-E., Soliman, A., 2018a. A calcite crisis unravelling Early Miocene (Ottnangian) stratigraphy in the North Alpine-Carpathian Foreland Basin: A litho- and chemostratigraphic marker for the *Rzehakia* Lake System. Geologica Carpathica, 69/4, 315–334. https://doi.org/10.1515/GEOCA-2018-0019

Palzer-Khomenko, M., Wagreich, M., Kallanxhi, M.-E., Soliman, A., Knierzinger, W., Meszar, M.-E., Gier, S., 2018b. Facies, palaeogeography and stratigraphy of the lower Miocene Traisen Formation and Wildendürnbach Formation (former "*Oncophora* Beds") in the Molasse Zone of Lower Austria. Austrian Journal of Earth Sciences, 111/1, 75–091. https://doi.org/10.17738/ajes.2018.0006

Papp, A., 1963. Die biostratigraphische Gliederung des Neogens im Wiener Becken. Mitteilungen der Geologischen Gesellschaft Wien, 56, 1, 225–317.

Papp, A., 1967. Mollusken aus dem Aderklaaer Schlier. Annalen des Naturhistorischen Museums in Wien. 71, 341–346.

Papp, A., Küpper, K., 1952. Über die Entwicklung der Heterosteginen im Torton des Wiener Beckens. – Anzeiger der mathematisch-naturwissenschaftlichen Klasse der Österreichischen Akademie der Wissenschaften, 89/10, 110–118.

Papp, A., Turnovsky, K., 1952. Die Entwicklung der Uvigerinen im Vindobon (Helvet und Torton) des Wiener

Beckens. – Jahrbuch der Geologischen Bundesanstalt, 96, 117–142.

Papp, A., Steininger, F. 1978. Holostratotypus des Badenien. In: Papp, A., Cicha, I., Senes, J. and Steininger, F., (eds.), M4 Badenien (Moravien, Wielicien, Kosovien). Chronostratigraphie und Neostratotypen: Miozän der zentralen Paratethys. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava, 6, pp. 138–145.

Papp A., Rögl F., Seneš J., 1973. M2, Ottnangien: Die Innviertler, Salgótarjáner, Bántapusztaer Schichtengruppe und die *Rzehakia* Formation. Chronostratigraphie und Neostratotypen: Miozän der zentralen Paratethys. Verlag der Slowakischen Akademie der Wissenschaften, 3, 841 pp.

Papp, A., Cicha, I., Senes, J., Steininger, F., 1978. M4 Badenien Moravien, Wielicien, Kosovien. Chronostratigraphie und Neostratotypen: Miozän der zentralen Paratethys. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava, 6, 594 pp.

Papp, A., Grill, R., Janoschek, R., Kapounek, J., Kollmann, K., Turnovsky, K., 1968a. Zur Nomenklatur des Neogens in Österreich (Mit einer stratigraphischen Tabelle). Verhandlungen der Geologischen Bundesanstalt, 1968/1-2, 9–18.

Papp, A., Grill, R., Janoschek, R., Kapounek, J., Kollmann, K., Turnovsky, K., 1968b: Nomenclature of the Neogene of Austria (With a Stratigraphic Chart). Verhandlungen der Geologischen Bundesanstalt, 1968/1-2, 19–27.

Pascher, G.A., Brix, F., 1994. Geologische Karte der Republik Österreich ÖK 77 Eisenstadt 1:50.000. Geologische Bundesanstalt, Wien.

Picha, F.J., Stráník, Z., Krejčí, O., 2006. Geology and hydrocarbon resources of the Outer Western Carpathians and their foreland, Czech Republic. In: Golonka, J. and Picha, F.J. (eds.), The Carpathians and their foreland: Geology and hydrocarbon resources. AAPG Memoir, 84, 49–175.

Piller, W.E., 1994. *Nullipara ramosissima* Reuss, 1847 - a re-discovery. Beiträge zur Paläontologie, 19, 181–189.

Piller, W.E., Kleemann, K., 1991. Middle Miocene Reefs and related fades in Eastern Austria. I) Vienna Basin. VI. International Symposium on Fossil Cnidaria including Archaeocyatha and Porifera. Excursion-Guidebook, Excursion B4, Geologisch-Paläontologisches Institut und Museum Münster, Münster, 28 pp.

Piller, W.E., Vavra, N. 1991. Das Tertiär im Wiener- und Eisenstädter Becken. In: Roetzel, R. and Nagel, D., (eds.), Exkursionen im Tertiär Österreichs, Molassezone – Waschberg Zone – Korneuburger Becken – Wiener Becken – Eisenstädter Becken. Österreichische Paläontologische Gesellschaft, Wien, pp. 161–216.

Piller, W.E., Decker, K., Haas, M., 1996. Sedimentologie und Beckendynamik des Wiener Beckens. Exkursionsführer SEDIMENT'96, 11. Sedimentologentreffen Wien, Exkursion A1. Berichte der Geologischen Bundesanstalt, 33, 41 pp.

Piller, W.E., Harzhauser, M., Mandic, O., 2007. Miocene Central Paratethys stratigraphy - current status and future directions. Stratigraphy, 4, 2/3, 151–168.

Piller, W.E., Kroh, A., Mandic, O., 2007. Der Rauchstallbrunngraben – ein alter Exkursionspunkt. In. Hoffmann, T. (Ed.), Wanderungen in die Erdgeschichte 22 – Wien, Niederösterreich, Burgenland Friedrich Pfeil, München, 141–143.

Piller, W. E., Egger, H., Erhart, C.W., Gross, M., Harzhauser, M., Hubmann, B., Van Husen, D., Krenmayr, H.G., Krystyn, L., Lein, R., Lukeneder, A., Mandl, G.W., Rögl, F., Roetzel, R., Rupp, C., Schnabel, W., Schönlaub, H.P., Summesberger, H., Wagreich, M., Wessely, G., 2004. Die stratigraphische Tabelle von Österreich 2004 sedimentäre Schichtfolgen. Poster, Österreichische Stratigraphische Kommission; Österreichische Akademie der Wissenschaften, Kommission für die paläontologische und stratigraphische Erforschung Österreichs.

Pippérr, M., Reichenbacher, B., Kirscher, U., Sant, K. and Hanebeck, H., 2018. The middle Burdigalian in the North Alpine Foreland Basin (Bavaria, SE Germany) – a lithostratigraphic, biostratigraphic and magnetostratigraphic re-evaluation. Newsletters on Stratigraphy, 51/3, 285–309.

Raffi, I., Backman, J., Fornaciari, E., Pälike, H., Rio, D., Lourens, L., Hilgen, F., 2006. A review of calcareous nannofossil astrobiochronology encompassing the past 25 million years. Quaternary Science Reviews, 25/23–24, 3113–3137. https://doi.org/10.1016/j.quascirev.2006.07.007

Reuss, A.E., 1847. Die fossilen Polyparien des Wiener Tertiärbeckens. Ein monographischer Versuch. Naturwissenschaftliche Abhandlungen (ed. Haidinger, W.), 2,1-109.

Riegl, B., Piller, W.E., 2000. Biostromal Coral Facies: a Miocene Example from the Leitha Limestone (Austria) and its actualistic Interpretation. Palaios, 15, 399–413. https://doi.org/10.1669/0883-1351(2000)015<0399:BCFAME>2.0.CO;2

Roetzel, R., 2009. Erläuterungen zu Blatt 23 Hadres. Geologische Karte der Republik Österreich 1 : 50000. Geologische Bundesanstalt, Wien, 150 pp.

Roetzel, R., De Leeuw, A., Mandic, O., Márton, E., Nehyba, S., Kuiper, K.F., Scholger, R., Wimmer-Frey, I., 2014. Lower Miocene (upper Burdigalian, Karpatian) volcanic ash-fall at the south-eastern margin of the Bohemian Massif in Austria – New evidence from 40Ar/39Ar-dating, palaeomagnetic, geochemical and mineralogical investigations. Austrian Journal of Earth Sciences, 107, 2–22.

Rögl, F., Müller, C., 1976. Das Mittelmiozän und die Baden-Sarmat Grenze in Walbersdorf (Burgenland). Annalen des Naturhistorischen Musuems in Wien, 80, 221–232.

Rögl, F., Ćorić, S., Hohenegger, J., Pervesler, P., Roetzel, R., Scholger, R., Spezzaferri, S., Stingl, K. 2007. The Styrian Tectonic Phase – A Series of Events at the Early/Middle Miocene Boundary Revised and Stratified (Styrian Basin, Central Paratethys). Joannea Geolgie, Paläontologie, 9, 89–91.

Rögl, F., Ćorić, S., Harzhauser, M., Jimenez-Moreno, G., Kroh, A., Schultz, O., Wessely, G., Zorn, I., 2008. The

Middle Miocene Badenian stratotype at Baden-Sooss, Lower Austria. Geologica Carpathica, 59, 367–374. http://www.geologicacarpathica.com/browse-journal/volumes/59-5/article-452/

Royden, L.H., 1985. The Vienna Basin: a thin-skinned pull-apart basin. In: Biddle, K.T. and Christie-Blick, N. (Eds.), SEPM Special Publications 37, pp 319–338.

Rybár, S., Šarinová, K., Sant, K., Kuiper, K.F., Kováčová, M., Vojtko, R., Reiser, M.K., Fordinál, K., Teodoridis, V., Nováková, P., Vlček, T., 2019. New 40Ar/39Ar, fission track and sedimentological data on a middle Miocene tuff occurring in the Vienna Basin: Implications for the north-western Central Paratethys region. Geologica Carpathica, 70/5, 386–404. https://doi.org/10.2478/geoca-2019-0022

Salvador, A., 1994. The International Stratigraphic Guide: A guide to stratigraphic classification terminology, and procedure. John Wiley, New York, 214 pp.

Sant, K., Kuiper, K.F., Rybár, S., Grunert, P., Harzhauser, M., Mandic, O., Jamrich, M., Šarinová, K., Hudáčková, N., Krijgsman, W., 2020. 40Ar/39Ar geochronology using high sensitivity mass spectrometry: Examples from middle Miocene horizons of the Central Paratethys. Geologica Carpathica, 71/ 2, 166–182. https://doi.org/10.31577/GeolCarp.71.2.5

Sauer, R., Seifert, P., Wessely, G., 1992. Guidebook to excursions in the Vienna Basin and the adjacent Alpine-Carpathian thrustbelt in Austria. Mitteilungen der Geologischen Gesellschaft, 85, 264 pp.

Schmid, H.P., Harzhauser, M., Kroh, A. 2001. Hypoxic Events on a Middle Miocene Carbonate Platform of the Central Paratethys Austria, Badenian, 14 Ma. Annalen des Naturhistorischen Museums in Wien, 102A, 1–50.

Schmieder, M., Kennedy, T., Jourdan, F., Buchner, E., Reimold, W.U., 2018. A high-precision 40Ar/39Ar age for the Nördlinger Ries impact crater, Germany, and implications for the accurate dating of terrestrial impact events. Geochimica et Cosmochimica Acta, 220, 146–157. https://doi.org/10.1016/j.gca.2017.09.036

Schultz, O., 2005. Bivalvia neogenica Solenoidea – Clavagelloidea. Catalogus Fossilium Austriae, Österreichische Akademie der Wissenschaften, Wien, 1/3, pp. 691–1212.

Schultz, O., Brzobohatý, R., Kroupa., O., 2010. Fish teeth from the Middle Miocene of Kienberg at Mikulov, Czech Republic, Vienna Basin. Annalen des Naturhistorischen Museums in Wien, 112, 489–506.

Špička, V., 1966. Palaeogeografie a tektonogeneze Vídeňské pánve a příspěvek k její naftově-geologické problematice. Rozpravy Československé Akademie Věd, Řada matematickýchpřírodopisných Věd, 76, 12, 3–118.

Špička V., Zapletalova I., 1964. Nástin korelace karpatu v československé části vídeňské pánve. Sborník geologických ved, Geologie, 8, 125–160.

Steininger, F., Papp, A., 1978. 9. Faziostratotypus: Gross Höflein NNW, Steinbruch "Fenk", Burgenland, Österreich. In: Papp, A., Cicha, I., Senes, J. and Steininger, F., (eds.), M4 Badenien (Moravien, Wielicien, Kosovien). Chronostratigraphie und Neostratotypen: Miozän der zentralen

Paratethys. Verlag der Slowakischen Akademie der Wissenschaften, Bratislava, 6, pp. 194–203.

Steininger, F.F., Piller, W.E., 1999. Empfehlungen (Richtlinien) zur Handhabung der stratigraphischen Nomenklatur. Courierier des Forschungs-Institutes Senckenberg, 209, 1–19.

Stenzel, H.B., 1971. Oysters. Treatise on Invertebrate Paleontology, N/3, pp. 953–1224.

Stille, H. 1924. Grundfragen vergleichender Tektonik. Borntraeger, Berlin, 1–443.

Strauss, P., Harzhauser, M., Hinsch, R., Wagreich, M., 2006. Sequence stratigraphy in a classic pull-apart basin Neogene, Vienna Basin. A 3D seismic based integrated approach. Geologica Carpathica, 57/3, 185–197.

Studencki, W., 1988. Facies and sedimentary environment of the Pinczow Limestones (Middle Miocene; Holy Cross Mountains, Central Poland. Facies, 18, 1–26.

Talman, S.G., Keough, M.J., 2001. Impact of an exotic clam, Corbula gibba, on the commercial scallop, Pecten fumatus, in Port Phillip Bay, south-east Australia: evidence of resource-restricted growth in a subtidal environment. Marine Ecology Progress Series, 221, 135–143. https://doi.org/10.3354/meps221135

Tollmann, A., 1955. Das Neogen am Nordwestrand der Eisenstädter Bucht. Wissenschaftliche Arbeiten aus dem Burgenland, 10, 75 pp.

Tollmann, A., 1985. Geologie von Österreich. Band II. Außerzentralalpiner Anteil. Deuticke, Wien, 710 pp.

Vass, D., 2002. Litostratigrafia Západných Karpát: neogén a budínsky paleogén. Štátny geologický ústav D. Štúra, Bratislava, 202 pp.

Vass, D., Nagy, A., Kohút, M., Kraus, I., 1988. Devínskonovoveské vrstvy: Hruboklastické sedimenty na juhovýchodnom okraji Viedenskej panvy. Minerlia Slovaka, 20/2, 109–122.

Wagreich, M., Pervesler, P., Khatun, M., Wimmer-Frey, I., Scholger, R., 2008. Probing the underground at the Badenian type locality: geology and sedimentology of the Baden-Sooss section (Middle Miocene, Vienna Basin, Austria). Geologica Carpathica, 59, 375–394.

Weber, K., Zuschin, M., 2013. Delta-associated molluscan life and death assemblages in the northern Adriatic Sea: implications for paleoecology, regional diversity and conservation. Palaeogeography, Palaeoclimatology, Palaeoecology, 370, 77–91. https://doi.org/10.1016/j.palaeo.2012.11.021

Weissenbäck, M., 1995. Ein Sedimentationsmodell für das Unter- bis Mittelmiozän Karpatien-Badenien des zentralen Wiener Beckens. Dissertation am Geologischen Institut der Universität Wien, 154 pp.

Weissenbäck, M., 1996. Lower to Middle Miocene sedimentation model of the central Vienna Basin. In: Wessely, G. and Liebl, W. (Eds.), Oil and Gas in alpidic thrustbelts and basins of Central and Eastern Europe. European Association of Geoscientists and Engineers EAGE, Special Publications 5, pp. 355–363.

Wessely, G., 1983. Zur Geologie und Hydrodynamik im südlichen Wiener Becken und seiner Randzone:

Mitteilungen der Österreichischen Geologischen Gesellschaft, 76, 27–68.

Wessely, G., 2000. Sedimente des Wiener Beckens und seiner alpinen und subalpinen Unterlagerung. Mitteilungen der Gesellschaft für Geologie und Bergbaustudenten Österreichs, 44, 191–214.

Wessely, G., 2006. Niederösterreich. Geologie der Österreichischen Bundesländer. Geologische Bundesanstalt Wien, 416 pp.

Wessely, G., Ćorić, S., Rögl, F., Zorn, I., 2007a. Stratigraphy of the Thermal Water Area Baden - Bad Vöslau at the Western Border of the Southern Vienna Basin. Scripta Facultatis Scientiarum Naturalium Universitatis Masarykianae Brunensis, Geology, 36, 39–44.

Wessely, G., Ćorić, S., Rögl, F., Draxler, I., Zorn, I., 2007b. Geologie und Paläontologie von Bad Vöslau (Niederösterreich). Jahrbuch der Geologischen Bundesanstalt, 147, 419–448.

Wiedl, T., Harzhauser, M., Piller, W.E., 2012. Facies and synsedimentary tectonics on a Badenian carbonate platform in the southern Vienna Basin Austria, Central Paratethys. Facies, 58, 523–548. https://doi.org/10.1007/s10347-011-0290-0

Wiedl, T., Harzhauser, M., Kroh, A., Ćorić, S., Piller, W.E., 2013. Ecospace variability along a carbonate platform at the northern boundary of the Miocene reef belt Upper Langhian, Austria Palaeogeography, Palaeoclimatology, Palaeoecology, 370, 232–246, http://dx.doi.org/10.1016/j.palaeo.2012.12.015

Wiedl, T., Harzhauser, M., Kroh, A., Ćorić, S., Piller, W.E., 2014. From biologically to hydrodynamically controlled carbonate production by tectonically induced palaeogeographic rearrangement Middle Miocene, Pannonian Basin. Facies, 60, 865–881. https://doi.org/10.1007/s10347-014-0408-2

Zuschin, M., Harzhauser, M., Mandic, O., 2007. The stratigraphic and sedimentologic framework of fine-scale faunal replacements in the Middle Miocene of the Vienna Basin Austria. Palaios, 22, 285–295. https://doi.org/10.2110/palo.2005.p05-023r

Zuschin, M., Harzhauser, M., Hengst, B., Mandic, O., Roetzel, R., 2014. Long-term ecosystem stability in an Early Miocene estuary. Geology, 42, 1–4. https://doi.org/10.1130/G34761.1

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