

Life in the fluvial hinterland of the late Sarmatian Sea (middle Miocene): a rare terrestrial fossil site in the Styrian Basin (Austria)

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(Manuscript received April 11, 2017; accepted in revised form December 12, 2017)

Abstract: This paper describes the section and fossil content of a former gravel pit in the Eastern Styrian Basin (SE Austria), which exposes sediments of a fluvial system, ranging from within channel to overbank environments. A predominately terrestrial gastropod fauna of 15 species so far, was recovered from a palaeosol formed in a moist and vegetated, floodplain or abandoned channel. Up-section, a shallow freshwater pond/lake developed within the floodplain, settled by fishes, molluscs and ostracods. By integrating regional geological and biostratigraphical data derived from the terrestrial gastropod fauna as well as from the other recovered biota, these strata are of late middle Miocene (late Sarmatian s.str.) age. Hence, this fossil site provides a rare insight into the terrestrial habitats in the hinterland of the Sarmatian Sea and their biota, which are otherwise barely known in Central Europe.

Keywords: Middle Miocene, Sarmatian s.str, gastropoda, Styria/Austria, terrestrial environments.

Introduction

Outcrops, exposing terrestrial sediments of late Sarmatian (late Serravallian) age are rare in Austria and the Central Paratethys as well due to a major hiatus at the middle–late Miocene transition (e.g., Kováč et al. 2004; Schreilechner & Sachsenhofer 2007; Harzhauser et al. 2008; Gross et al. 2011a; Stworzewicz et al. 2013; Neubauer et al. 2015a, 2017; Fig. 1). While the marine system of the Sarmatian Sea is well investigated and a lot of data have been gathered about palaeobiological and geological changes (e.g., Papp et al. 1974a; Harzhauser & Piller 2004; Piller & Harzhauser 2005; Piller et al. 2007), information on the surrounding continental environments is still fragmentary.

An abandoned gravel pit (Badenbrunn), situated in the Eastern Styrian Basin (46°53'51.1" N, 15°46'21.3" E; 32 km SE Graz, 5 km NW Gnas; 320 m a.s.l., Fig. 2A,B), is treated here. It exposes a palaeosol, rich in terrestrial gastropods. Additional fossil findings, which include plants, ostracods, fish remains and mammals, are quite diverse. Hence, this locality promises a further insight into the so far poorly studied hinterland of the Paratethyan aquatic system during late middle Miocene times. The present study focuses on the taxonomic evaluation of the found gastropods and their palaeoenvironmental and stratigraphic indication, supplemented by sedimentological and additional palaeontological information.

The geological context

The Badenbrunn gravel pit is located in the Eastern Styrian Basin, more precisely in the Gnas Subbasin (Kröll et al. 1988; Gross et al. 2007; Fig. 2A). According to detailed geological mappings by Kollmann (1965) the outcrop exposes upper Sarmatian sediments (Gleisdorf Formation; Fig. 2B). Close by exploration drillings of the crude oil mining company RAG (= Rohöl-Aufsuchungs AG; e.g., F 883 and F 884; ~1000 m SE, ~298 m a.s.l.; Fig. 2B) penetrated at a depth of about 9 m clays and marls with abundant "*Pirenella picta*" [= *Granulolabium bicinctum* (Brocchi, 1814)] shells, which is a marine batillariid gastropod (unpublished report RAG, 1954). In a regional context, these gastropods and the nearby (around the town of Gnas) occurring oolitic limestones are typical for the marine upper Sarmatian deposits of the Central Paratethys (Kollmann 1965; Piller et al. 2007). About 1400 m to the west (~370 m a.s.l.; "Kratzlwirt", see Fig. 2B), *Mytilopsis ornithopsis* (Brusina, 1892) findings are mentioned by Winkler (1927) and Kollmann (1965). They are indicative for the early Pannonian ("Zone B" sensu Papp 1951). Drilling F 868 reached at the same sea level, about 500 m towards the W, beds with abundant dreissenid bivalve fragments ("*Congeria* sp."), which most probable refer to the early Pannonian (early Tortonian) as well. Accordingly, the section of Badenbrunn is bracketed by sediments of the late Sarmatian Sea in the foot-wall and by deposits of brackish Lake Pannon (e.g., Magyar et al. 1999; Gross et al. 2011b) in the hanging wall.

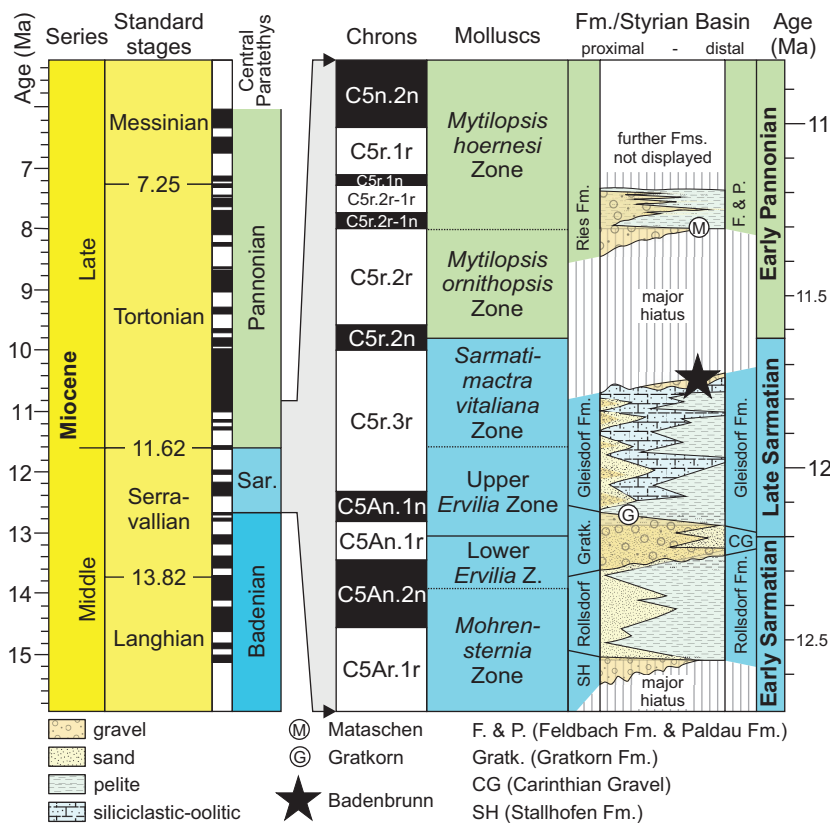


Fig. 1. Stratigraphic position of the Badenbrunn outcrop (modified after Gross et al. 2014; international and regional stratigraphic scheme based on Neubauer et al. 2015a).

Material and sample preparation

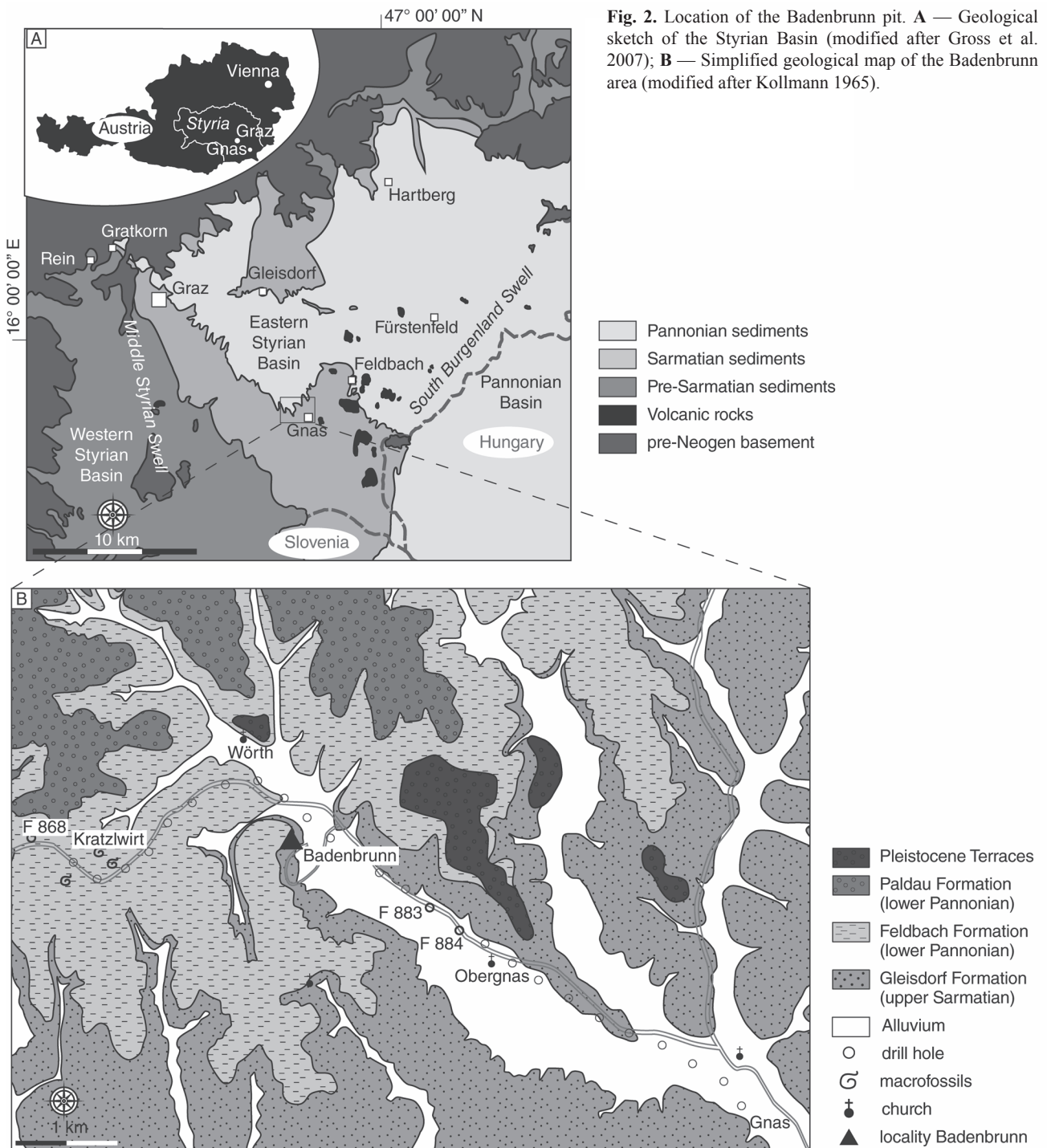
The outcrop was vertically logged by visual inspection of the lithofacies (thickness, colour, grain size, bedding planes, sedimentary structures, macrofossil content); lithofacies coding follows the scheme of Miall (1996). Samples were taken from bed 4 and 5 for more detailed palaeontological analyses (Fig. 3). About 10 kg from layer 4b were repeatedly soaked in water and dried over 4 weeks and washed through standard sieves (250/500 μm). Both fractions were picked out completely. About 400 g of layers 5a and 5b were disintegrated by using diluted hydrogen peroxide ($\text{H}_2\text{O}_2:\text{H}_2\text{O}=1:4$) and sieved (standard sieves: 63/125/250/500 μm). Sieve residuals were picked out completely. Inspections of microfossils were done through an optical microscope (Leica M205 C; camera: Leica DFC290; software: Leica Application Suite) and/or using a scanning electron microscope (JEOL JSM-6610LV).

The Badenbrunn section

The lowermost 1.50 m (bed 1) of the outcrop is formed by orange to yellow, trough cross-bedded, clast-supported, sandy coarse-medium gravel (Gt) and dm-thick, cross-bedded sand interlayers (St; Fig. 3). A general fining upward trend is visible. The uppermost 0.20 m consists of partly carbonatic

cemented fine gravel including irregular, lateritic encrustations. Above (bed 2), 0.70 m thick grey, trough cross-bedded medium sand (St) with partly ripple bedded fine sand layers (Sr) is developed. Scattered pebbles and clay intraclasts are embedded. From section metres 2.20 to 2.90 (bed 3), the sediments consist of grey and orange, parallel bedded, badly sorted sandy silt and silty clay alternations (cm-scale; Fl) with cm-thick concretionary layers; the bedding planes are inclined (250/30). Up-section (layer 4a), 1.10 m yellow, indistinctly parallel bedded silt and silty fine sand alternations (Fl; partly convolute bedded) follow; the bedding planes are inclined (30–0°) with about the same dip as bed 3. In the uppermost 0.10 m rare gastropods are present. The transition upwards to layer 4b is gradual. Layer 4b is 0.15 m thick and comprises orange-yellow to olive-grey mottled, massive silt (Fr). It contains abundant gastropods and oxidized root traces (reaching down into layer 4a) as well as a few characean gyrogonites and rare vertebrate remains. This stratum is conformably overlain by bed 5 (Fm), which is divided into 0.12 m brown grey, discontinuously laminated fine sandy silt,

containing abundant leaves and other plant fragments as well as rare bivalves and ostracods (layer 5a), and 0.13 m grey or light yellow, laminated clay (layer 5b) with bivalves (unionids), plant fragments (i.e., *Glyptostrobus* cones and twigs; gyrogonites), fish remains, ostracods and rare gastropods (i.e., *Ferrissia*). A cm-thick layer of light grey, thin laminated clay forms the boundary with bed 6. 1.00 m of light grey to orange-brown, horizontal bedded silt and sand alternations follow above (bed 6; Fl). In the lower 0.15 m abundant plant fragments (i.e., *Trapa* nuts) are incorporated. About 0.50 m from the base, a grey, cm-thick, massive clay layer is intercalated. Close to the upper boundary a ripple-bedded fine sand lens (Sr), up to 40 cm thick, is developed. The upper boundary is formed by 50 mm thick, dark-light grey, laminated silty clay (Fm), containing fragments of plants, mostly leaves. Above (bed 7), 0.55 m of reddish brown, laminated alterations of silty clay without plant fragments and silt with plant fragments (leaves, wood) are recorded (Fl). A thin layer of white, calcic nodules marks the beginning of bed (8): 0.25 m greyish brown, horizontal bedded fine to medium sand (Sh). Bed 9 is internally differentiated by layers of white calcic nodules and its sedimentary structures: 9a consists of 0.20 m of grey-orange ripple-bedded sand (Sr). Above (layer 9b), 0.80 m of grey-orange, low-angle cross-bedded medium sand (Sl) is developed. A 10 mm thick layer of white, calcic nodules separates it from the topmost, >2.00 m thick part of the section (layer 9c),



which consists of dm-thick sets of grey–orange, ripple- and horizontal bedded medium sand (Sr, Sh) with cm-thick layers of calcic nodules.

Systematic palaeontology

The fossil material is stored in the collection of the Universalmuseum Joanneum, Department for Geology &

Palaeontology, Graz (UMJGP). Chronostratigraphic correlations are based on Neubauer et al. (2015b).

Molluscs

The systematic arrangement follows Bouchet et al. (2005), Jörger et al. (2010) and Welter-Schultes (2012). Names in the synonymy lists are reproduced strictly as originally provided by the authors.

Class: Gastropoda Cuvier, 1795
 Subclass: Caenogastropoda Cox, 1960
 Order: Littorinimorpha Golikov & Starobogatov, 1975
 Superfamily: Truncatelloidea Gray, 1840
 Family: *Bithyniidae* Troschel, 1857
 Genus: *Bithynia* Leach, 1818

Material: layer 4b: 3 opercula (UMJGP 211.480).
Dimensions: largest specimen: height: 2.6 mm, diameter: 1.8 mm.

Remarks: The drop-shaped outline is characteristic for *Bithynia*. Identification on the species level, however, is difficult without the shells.

Palaeoecology: Recent *Bithynia* species live in vegetated slow moving or standing freshwater (Welter-Schultes 2012).

Bithynia sp.
 Fig. 4A–B

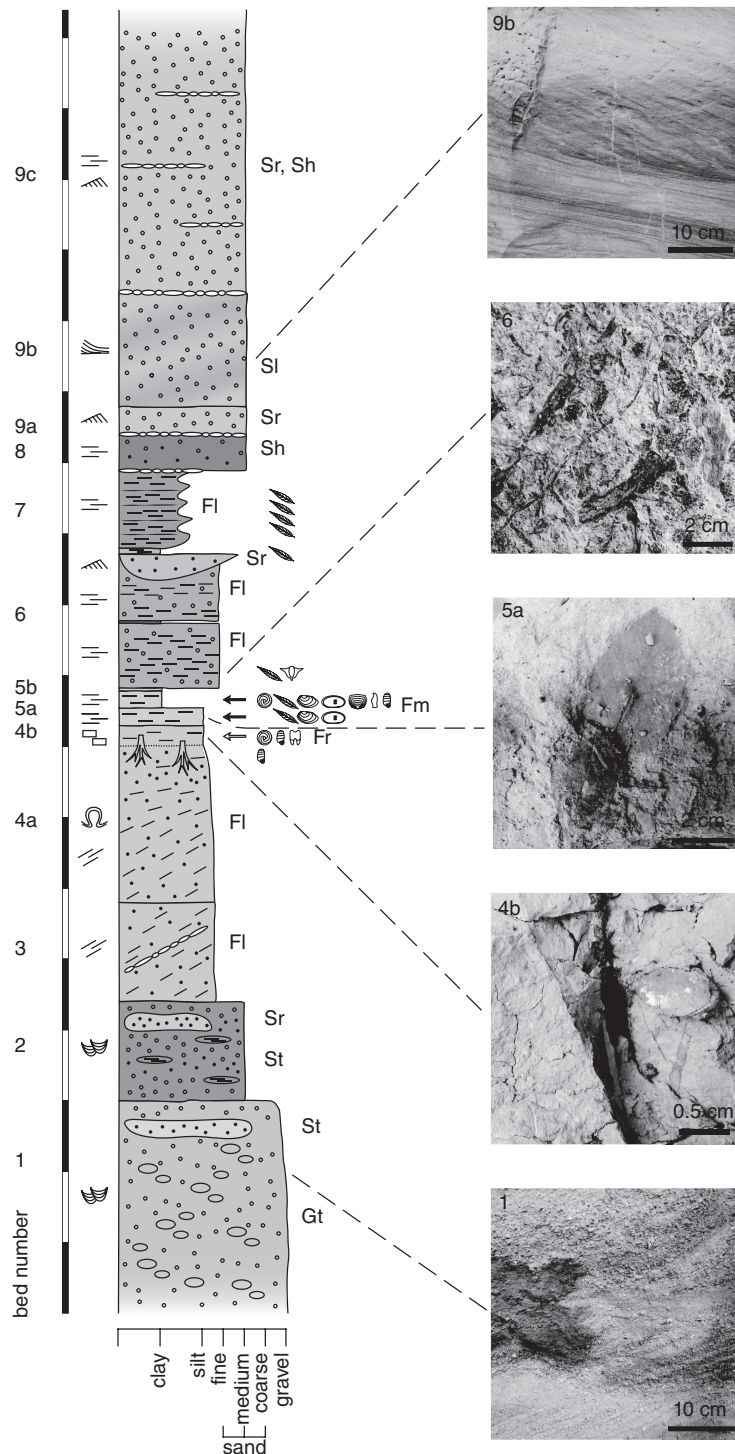
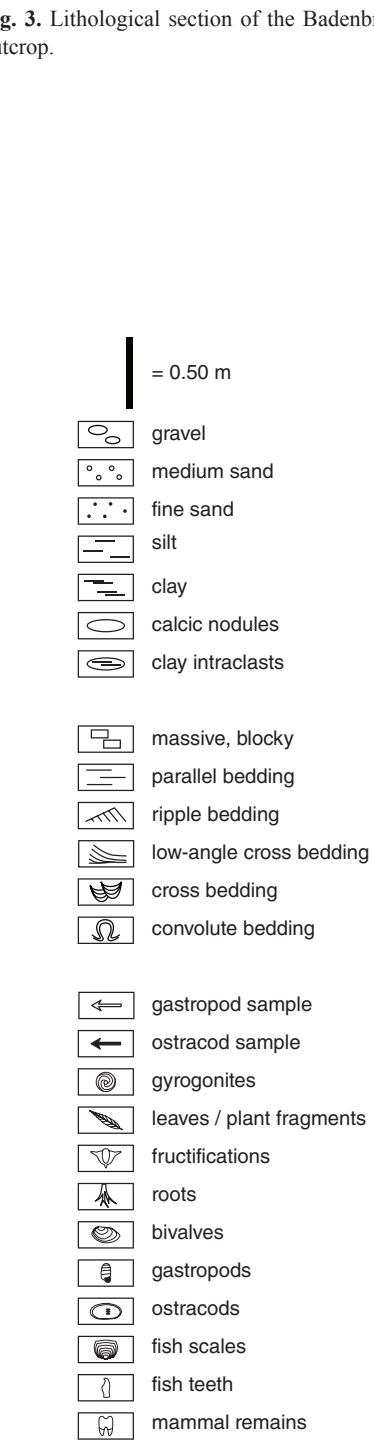


Fig. 3. Lithological section of the Badenbrunn outcrop.



Subclass: Heterobranchia Burmeister, 1837
 Clade: Panpulmonata Jörger, Stöger, Kano, Fukuda,
 Kneibelsberger & Schrödl, 2010
 Order: Hygrophila Férussac, 1822
 Superfamily: Planorboidea Rafinesque, 1815
 Family: Planorbidae Rafinesque, 1815
 Subfamily: Ancylinae Rafinesque, 1815
 Genus: *Ferrissia* Walker, 1903

***Ferrissia cf. wittmanni* (Schlickum, 1964)**

Fig. 4C

cf. 1964 *Ancylus wittmanni* n. sp. – Schlickum, p. 15, pl. 2, figs. 36–38.

cf. 2014 *Ferrissia wittmanni* (Schlickum, 1964) – Harzhauser et al., p. 18, pl. 5, figs. 3–4, 13 [cum syn.].

Material: layer 5b: 1 specimen (UMJGP 211.481).

Dimensions: length: 0.60 mm.

Remarks: A single fragment of a *Ferrissia* is available showing a blunt apex with smooth initial part and broad collar of prominent radial ribs as described for *F. wittmanni* by Kowalke & Reichenbacher (2005) and Harzhauser et al. (2014). This sculpture allows a separation from the widespread middle Miocene *Ferrissia deperdita* (Desmarest, 1814), which has faint radial threads (see Harzhauser et al. 2014; Salvador & Rasser 2014; Salvador et al. 2016; Neubauer et al. 2017).

Distribution: *F. wittmanni* was originally described from the Ottnangian (early Miocene) of Bavaria (Schlickum 1964) but was subsequently also documented from middle Miocene strata of Hungary and Austria (Kókay 2006; Harzhauser et al. 2014).

Palaeoecology: *Ferrissia* species are freshwater inhabitants (Welter-Schulte 2012).

Superorder: Eupulmonata Haszprunar & Huber, 1990
 Infraorder: Acteophila Dall, 1885
 Superfamily: Ellobioidea Adams & Adams, 1855
 Family: Carychiidae Jeffreys, 1830
 Genus: *Carychium* Müller, 1773

***Carychium sandbergeri* Handmann, 1887**

Fig. 5A–F

- * 1887 *Carychium Sandbergeri* Handm. – Handmann, p. 46.
- 1923 *Carychium sandbergeri* Handmann – Wenz, p. 1199.
- 1942 *Carychium sandbergeri* Handmann – Wenz & Edlauer, p. 84, pl. 4, fig. 4.
- 1977 *Carychium (Saraphia) sandbergeri* Handmann – Strauch, p. 167, pl. 16, figs. 36, 38.
- 1974b *Carychium sandbergeri* Handmann – Papp, p. 381, pl. 17, fig. 2.
- 1978 *Carychium (Saraphia) sandbergeri* Handmann – Schlickum, p. 248, fig. 1.
- 1981 *Carychium (Saraphia) pachychilus* Sandberger – Lueger, p. 14, pl. 1, figs. 5–8, 9–10.
- 2004 *Carychium sandbergeri* Handmann – Harzhauser & Binder, p. 14, pl. 6, figs. 1–2, 11, 14.

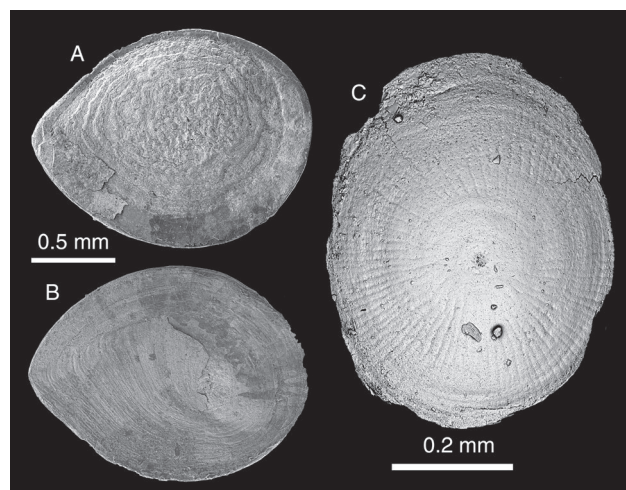


Fig. 4. A, B: *Bithynia* sp.; C: *Ferrissia cf. wittmanni* (Schlickum, 1964).

Material: layer 4b: 5 specimens and fragments (UMJGP 211.482).

Dimensions: height: 1.80 mm, diameter: 0.75 mm.

Description: Fusiform, slender shells with 4 convex spire whorls. Bulbous protoconch of 0.3 mm diameter with inflated initial part and faintly pitted surface. Early teleoconch with faint spiral threads close to the lower and upper sutures. Later teleoconch whorls with prominent, prosocline growth lines. Last whorl high, subcylindric. Aperture with strongly thickened peristome, well-rounded basal lip and broad, reflected inner lip. Three prominent lamellae comprising a slender and large parietal lamella, a slightly weaker and lower columellar lamella and a knob-like palatal lamella. Parietal lip well demarcated from base with straight margin, forming a distinct angulation with the weakly rounded inner lip.

Remarks: As only a few complete specimens were available, and they turned out to be very fragile, the columellar area was not opened for closer inspection, although it is suggested in Strauch (1977) and Stworzewicz (1999a) to be essential for identification. The Badenbrunn specimens agree with shells of *C. sandbergeri* from the Pannonian of the Vienna Basin (e.g., Harzhauser & Binder 2004) in sculpture and apertural features. Extremely slender morphotypes as described by Strauch (1977) and Stworzewicz (1999a), however, are missing at Badenbrunn.

Distribution: Middle to late Miocene in the Carpathian Foredeep, Pannonian Basin and Vienna Basin (late Badenian: Oppeln (Poland); Sarmatian: Rákosd, Várpalota (Hungary); middle–late Pannonian: Richardhof, Eichkogel (Austria), Öcs (Hungary); Wenz & Edlauer 1942; Schütt 1967; Harzhauser & Binder 2004; Kókay 2006).

Palaeoecology: Most probably riparian areas and very moist habitats, as well as woodlands (Schütt 1967; Harzhauser & Binder 2004).

***Carychium nouleti* Bourguignat, 1857**

Fig. 5G–I

- *1857 *Carychium nouleti* Bourguignat, p. 226.
 1923 *Carychium nouleti nouleti* Bourguignat – Wenz, p. 1195.
 1977 *Carychium (Saraphia) nouleti* Bourguignat – Strauch, p. 162, pl. 15, figs. 24–27, pl. 18, fig. 61, pl. 20, fig. 83.
 1999a *Carychium nouleti* Bourguignat – Stworzewicz, p. 269, figs. 19–22.
 2004 *Carychium nouleti* Bourguignat – Binder, p. 194, pl. 3, fig. 2.
 2016 *Carychium (Saraphia) nouleti* Bourguignat – Salvador et al., p. 136, fig. 2U.
 2017 *Carychium nouleti* Bourguignat, 1857 s.l. – Neubauer et al., p. 740, fig. 4 A–E, J, O.

Material: layer 4b: 2 specimens (UMJGP 211.483).

Dimensions: height: 1.65 mm, diameter: 0.75 mm.

Description: Stout shell of 4.5 whorls with conical spire and deep sutures. Spire whorls strongly convex; last whorl very high. Bulbous protoconch 2.5 mm in diameter with weakly convex initial part and faintly pitted surface, persisting on the first teleoconch whorl, which bears faint spiral threads. Sculpture of teleoconch consisting of moderately prominent, densely spaced, prosocline growth lines. Ovoid aperture with moderately thickened peristome and weakly reflected inner lip; columellar lamella broad and low, parietal lamella large and slender, palatal lamella broad, knob-like.

Remarks: The identification remains tentative without information on the internal columellar apparatus. At first glance, the shells might be identified as stout specimens of *C. sandbergeri* from which they differ in the much weaker sculpture, broader aperture and much higher last whorl. In addition, the parietal lamella is weaker and has a more adapical position compared to *C. sandbergeri*. In overall outline, the shells are reminiscent of the late Miocene *Carychiopsis berthae* (Halaváts, 1903), as described by Strauch (1977), Harzhauser & Binder (2004) and Katona et al. (2015) from Austria and Hungary. A clear difference, however, is the much weaker axial sculpture and the absence of the second parietal lamella.

Distribution: *C. nouleti* appears during the early Miocene in France, Austria and Poland and is widespread during the middle Miocene with records from Austria, Germany and France (Wenz 1923; Stworzewicz 1999a; Binder 2004; Salvador et al. 2016). The youngest reliable records are mentioned from the late Miocene mammal zone MN9 by Stworzewicz (1999a) from Poland.

Palaeoecology: Most probably riparian areas and very moist habitats, as well as woodlands (Schütt 1967).

Infraorder: Stylommatophora Schmidt, 1855
 Non-achatinoïd clade: sensu Wade et al., 2006
 Unassigned “subclade”: Orthuretha Pilsbry, 1900
 Superfamily: Pupilloidea Turton, 1831
 Family: Vertiginidae Fitzinger, 1833
 Subfamily: Gastrocoptinae Pilsbry, 1916
 Genus: *Gastrocopta* Wollaston, 1878

***Gastrocopta fissidens* (Sandberger, 1863)**

Fig. 5J–O

- * 1863 *Pupa fissidens* sp. nov. – Sandberger, p. 57, pl. 5, figs. 16a–c.
 1914 *Leucochilus fissidens* (Sandberger) – Fischer & Wenz, p. 97, pl. 6, fig. 19.
 1999b *Gastrocopta* cf. *ferdinandi* (Andreae 1902) – Stworzewicz, p. 165, fig. 63.
 2013 *Gastrocopta fissidens* (Sandberger, 1863) – Stworzewicz et al., p. 188, fig. 4D.

Material: layer 4b: 13 specimens, many fragments (UMJGP 211.484).

Dimensions: largest specimen: height: 1.80 mm, diameter: 0.91 mm.

Description: Small, ovate-turreted shell with 3.5 strongly convex teleoconch whorls separated by deeply incised sutures. Protoconch consisting of 1.2 convex whorls of 0.4 mm diameter with wrinkled microsculpture. Shell surface covered by prominent, prosocline growth lines. Last whorl moderately high, convex, terminating in subcircular aperture. Peristome continuous, broad, weakly reflexed, well detached from base. Umbilicus narrow, largely covered by inner lip. Parieto-angular tooth strongly divided into two bent teeth. A weak infraparietal tooth may be largely reduced in some specimens; columellar lamella large, subhorizontal; knob-shaped basal lamella appears deeper in aperture. Three long parietal lamellae, becoming successively smaller adapically.

Remarks: The species is characterized by its strongly convex whorls and the bifid parieto-angular tooth. Both features allow a separation from the similar middle and late Miocene *Gastrocopta ferdinandii* (Andreae, 1902) and *G. serotina* sensu Stworzewicz et al. (2013). Wenz (1923, p. 930) doubted, that the Sarmatian specimens from Poland are conspecific with the Oligocene and early Miocene *G. fissidens* and suggested a relation with *G. obstructa* (Sandberger, 1875), which however is higher and more cylindrical.

Distribution: The oldest records of *G. fissidens* derive from the Oligocene of Germany, where it is also frequently recorded from lower Miocene sites (Wenz 1923). In Poland, this species is recorded from the latest early to middle Miocene (mammal zones MN5 to MN7/8) by Stworzewicz (1999b) and Stworzewicz et al. (2013). A smaller morphotype was described as *Gastrocopta fissidens infrapontica* by Wenz (1927) from the late Miocene (early Pannonian) of the Vienna Basin.

Palaeoecology: Recent *Gastrocopta* are found in mesophytic and swamp forests (Stworzewicz et al. 2013).

Family: Vertiginidae Fitzinger, 1833
 Subfamily: Nesopupinae Steenberg, 1925
 Genus: *Negulopsis* Nordsieck, 2014

***Negulopsis suturalis* (Sandberger, 1858)**

Fig. 5P–R

- * 1858 *Pupa suturalis* A. Braun – Sandberger, p. 54, Pl. 6, figs. 2–2a.



Fig. 5. A–F: *Carychium sandbergeri* Handmann, 1887; G–I: *Carychium nouleti* Bourguignat, 1857; J–O: *Gastrocopta fissidens* (Sandberger, 1863); P–R: *Negulopsis suturalis* (Sandberger, 1868).

- 1919 *Negulus suturalis gracilis* n. var. – Gottschick & Wenz, p. 9, pl. 1, figs. 11–13.
 1981 *Negulus suturalis gracilis* Gottschick u. Wenz – Lueger, p. 18, pl. 2, figs. 2a–b.
 2004 *Negulus gracilis* Gottschick & Wenz – Harzhauser & Binder, p. 18, pl. 6, figs. 9–10.
 2008 *Negulus gracilis* Gottschick & Wenz – Harzhauser et al., p. 50, fig. 5.4.
 2013 *Negulus suturalis* (Sandberger, 1858) – Stworzewicz et al., p. 191, fig. 4L.
 2014 *Negulus suturalis* (Sandberger, 1858) – Harzhauser et al., p. 854, figs. 8K–N.
 2015 *Negulopsis suturalis* (Sandberger, 1858) – Harzhauser et al., p. 29, pl. 5, figs. 5–6.

Material: layer 4b: 1 specimen, 1 aperture fragment (UMJGP 211.485).

Dimensions: height: 1.70 mm, diameter: 0.80 mm.

Remarks: This widespread species was described and discussed in detail recently by Stworzewicz et al. (2013) and Harzhauser et al. (2014, 2015). We follow these authors and especially Stworzewicz (1999b) who treat the late Miocene

Negulopsis gracilis (Gottschick & Wenz, 1919) as a subjective junior synonym of *N. suturalis*. The alleged morphological features characterizing *N. gracilis* (smaller size and slender shape) are also observed in various early and middle Miocene populations of *N. suturalis*.

Distribution: *N. suturalis* is known from the Oligocene of Germany, the early Miocene of Germany, Czech Republic, Poland, Austria, Hungary and the middle Miocene of Poland, Hungary and Austria (Stworzewicz 1999b; Kókay 2006; Harzhauser et al. 2014). During the late Miocene, it is widespread in Austria, Hungary and Slovakia (Harzhauser & Binder 2004). The last occurrence is documented from the Messinian of the Po Basin in Italy (Harzhauser et al. 2015).

Palaeoecology: *N. suturalis* seems to have preferred moist habitats in riparian areas.

Unassigned “subclade”

Superfamily: Clausilioidea Gray, 1855

Family: Filholiidae Wenz 1923

Genus: *Triptychia* Sandberger, 1875

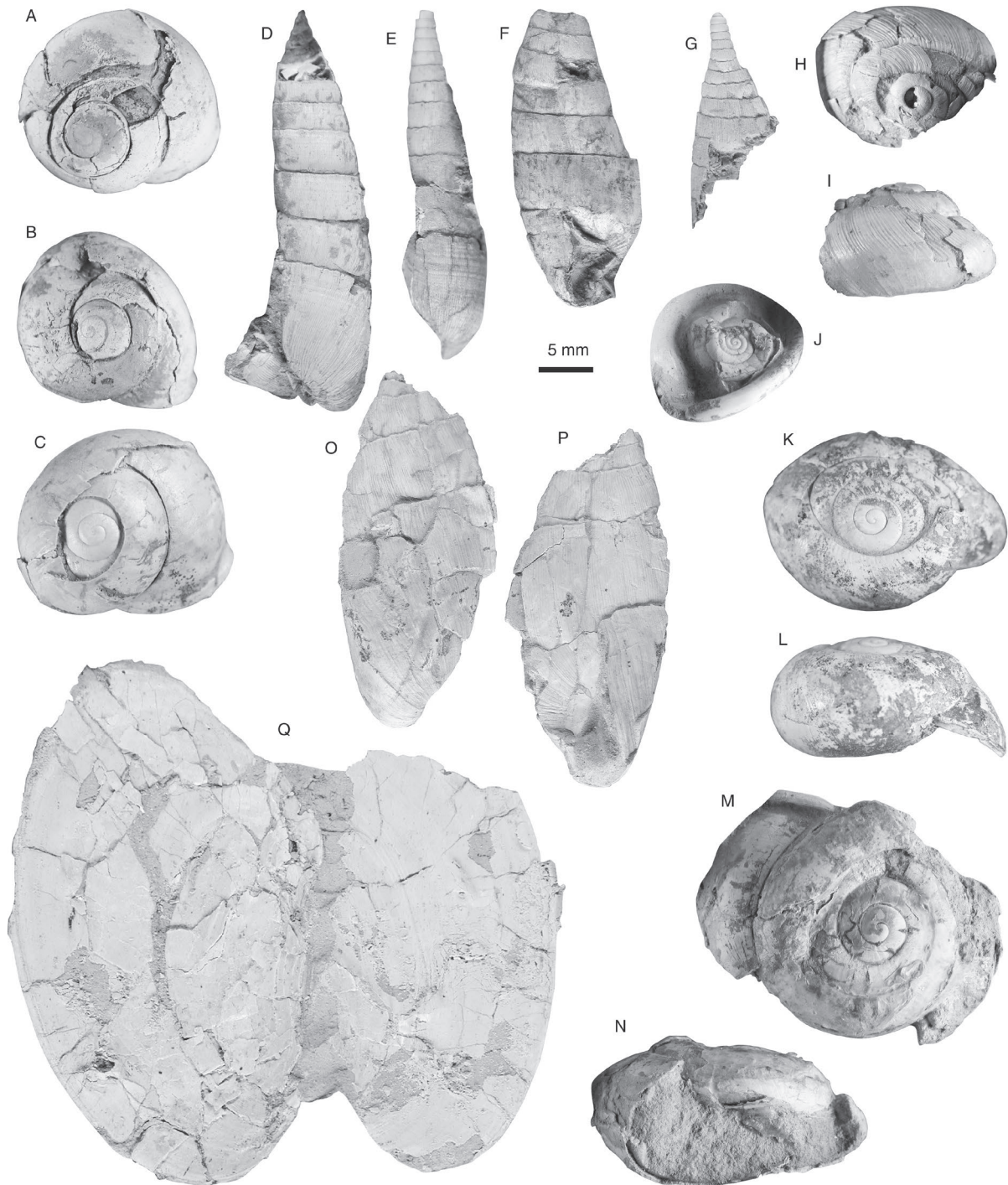


Fig. 6. A–C: *Palaeotachea sylvestrina* (Schlotheim, 1820); D–G: *Triptychia sarmatica* Kókay, 2006; H–I: *Archaeozonites costatus* Sandberger, 1875; J: *Klikia giengensis* Klein, 1846; K–N: *Pseudochloritis gigas* (Pfeffer, 1930); O–P: *Pseudoleacina* sp.; Q: *Anodonta* cf. *carinthiaca* Modell, 1957.

***Triptychia sarmatica* Kókay, 2006**

Fig. 6D–G

2006 *Triptychia leobersdorfensis sarmatica* nov. ssp. – Kókay, p. 82, pl. 31, figs. 5–7, pl. 41, figs. 6–7.

2006 *Triptychia* (*Triptychia*) *leobersdorfensis sarmatica* Kókay, 2006 – Schnabel, p. 153, pl. 4, figs. 53–54.

Material: layer 4b: 11 specimens (UMJGP 211.354, 211.355, 211.357, 211.361, 211.367, 211.370, 211.372, 211.382, 211.404, 211.405a, 211.405b).

Dimensions: largest specimen (without initial spire whorls): height: 42 mm, diameter: 11 mm.

Description: Moderately large, slender shell consisting of >12 teleoconch whorls (due to sediment compaction most

specimens appear very broad); earliest spire whorls turreted, weakly convex; later spire whorls widening, nearly flat. Early spire whorls with very prominent, regular and densely spaced axial ribs, which become weaker, thinner and slightly wavy on later spire whorls and continue on last whorl. Weak, narrow spiral incisions may appear in the upper half of the last whorl. Adapical tips of the axial ribs produce a weakly crenulate, slightly wavy suture. Aperture not wide, drop-shaped; two columellar lamellae with a slightly more prominent upper lamella; parietal lamella larger; none of the lamellae reach the peristome. Sinulus long, narrow, acute. Columellar lip and parietal lip well detached from base.

Remarks: This species is frequently found at Badenbrunn. Despite the moderate preservation, its size, characteristic axial sculpture and the long, narrow and acute sinulus correspond well with *T. sarmatica* from the Sarmatian of Várpálotá in Hungary. The late Miocene *Triptychia leobersdorfensis* (Troll, 1907) has a shorter and wider sinulus and its axial sculpture is less prominent.

Palaeoecology: *Triptychia* species are considered as indicators for moist and warm forests (Binder 2002, 2008; Schnabel 2007).

Unassigned “subclade”: Limacoidea
Superfamily: Limacoidea Lamarck, 1801
Family: Limacidae Lamarck, 1801

Limacidae gen. et sp. indet.

Fig. 7A

Material: layer 4b: 4 specimens and fragments (UMJGP 211.486).

Dimensions: largest specimen: width: 2 mm, length: 3 mm.

Remarks: The elongate ovoid outline of the calcitic plates and their projecting, asymmetrical nucleus support their placement in the Limacidae. For the same reasons as for the Milacidae, the authors refrain from identification on species or genus level.

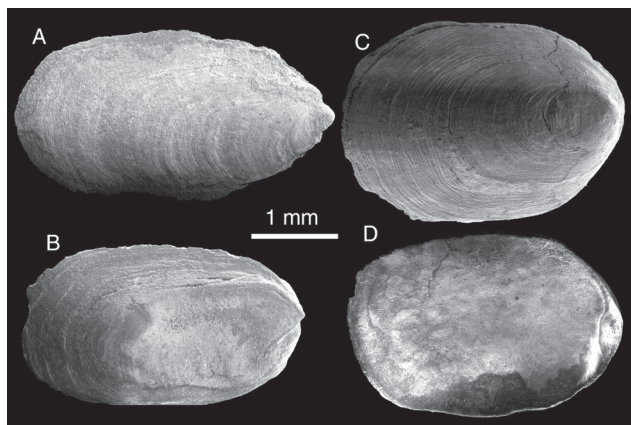


Fig. 7. A: Limacidae gen. et sp. indet.; **B:** Agriolimacidae gen. et sp. indet.; **C–D:** Milacidae gen. sp. indet.

Family: Agriolimacidae Wagner, 1935

Agriolimacidae gen. et sp. indet.

Fig. 7B

Material: layer 4b: 1 specimen (UMJGP 211.487).

Dimensions: width: 1.9 mm, length: 3.2 mm.

Remarks: Based on the outline with the subparallel margins and the only moderately displaced nucleus, this single specimen is placed here in the Agriolimacidae as described by Reuse (1983) and Frank (2006). As for all slugs, a more detailed identification is impossible.

Superfamily: Zonitoidea Mörch, 1864

Family: Zonitidae Mörch, 1864

Genus: *Archaeozonites* Sandberger, 1875

Archaeozonites costatus Sandberger, 1875

Fig. 6H–I

* 1875 *Archaeozonites costatus* Sandberger – Sandberger, p. 604.

1916 *Zonites (Aegopsis) costatus* (Sandberger) – Gottschick & Wenz, p. 21, pl. 1, figs. 1a–c.

1976 *Archaeozonites costatus* Sandberger – Schlickum, p. 18, pl. 5, fig. 66.

2002 *Miozonites costatus* (Sandberger) – Binder, p. 168, pl. 1, figs. 14–16, pl. 3, fig. 8, pl. 7, fig. 3, pl. 8, fig. 4.

2013 *Miozonites costatus* (Sandberger, 1874) – Stworzewicz et al., p. 194, fig. 5L.

2014 *Miozonites costatus* (Sandberger) – Harzhauser et al., p. 33, pl. 10, figs. 13–19.

2015a *Archaeozonites costatus* Sandberger – Salvador et al., p. 259, figs. 3Q–R.

2015b *Archaeozonites costatus* Sandberger, 1875 – Salvador et al., p. 206, figs. 20–P.

2016 *Archaeozonites costatus* Sandberger, 1875 – Salvador & Rasser, p. 49, fig. 2Z.

Material: layer 4b: 2 specimens (UMJGP 211.383, 211.396).

Dimensions: Both specimens are deformed, which makes precise measurements difficult. 211.383 is vertically compressed: height: 12 mm, diameter: 22 mm. 211.396 shows horizontal compression: height: 4 mm, diameter: 15 mm.

Description: Medium sized shells consisting of at least 4 teleoconch whorls; spire whorls moderately convex with deep sutures. Last whorl with weak angulation at mid-whorl, coinciding with the maximum diameter. Sculpture consisting of densely spaced and slightly irregular prosocline ribs on spire whorls; ribs become slightly sigmoidal on last whorl and fade out below angulation. Umbilicus moderately wide and deep. Aperture destroyed.

Remarks: The fragmented (or subadult) specimens are rather high spired and have a very strong axial sculpture. In these features, they correspond well to the shells described by Binder (2004) from the late early Miocene of the Korneuburg Basin in Austria. The sculpture is also identical to specimens from the early middle Miocene of Styria described by

Harzhauser et al. (2014) supporting the identification of the poorly preserved material.

Distribution: A widespread species, which appears during the late early Miocene and becomes ubiquitous in the middle Miocene. Occurrences are documented from Switzerland, southern Germany, the North Alpine Foreland Basin (Germany, Austria), the Korneuburg Basin (Austria) and the Rein Basin (Austria; Wenz 1923; Binder 2002, 2004; Harzhauser et al. 2014; Salvador & Rasser 2014, 2016; Salvador et al. 2015a). The northernmost distribution was described by Stworzewicz et al. (2013) from the Sarmatian of Poland. Middle Miocene specimens from drillings in Hungary, described by Kókay (2006) as “*Aegopsis costatus*” might rather represent another species.

Palaeoecology: Moist woodland (Binder 2002; Harzhauser et al. 2014).

Superfamily: Parmacelloidea Fischer, 1856
Family: Milacidae Ellis, 1926

Milacidae gen. et sp. indet.

Fig. 7C–D

Material: layer 4b: 7 specimens and fragments (UMJGP 211.488).

Dimensions: largest specimen: width: 3 mm, length: 5 mm.

Remarks: Based on their symmetrical, calcitic, broad ovoid plates with nearly straight sides and a peripheral, convex nucleus, we place these specimens in the Milacidae. The identification of Milacidae species or genera based solely on plates is nearly impossible, because diagnostic features of slugs are mostly related to soft body anatomy (Wiktor & Likharev 1979).

Unassigned “subclade”

Superfamily: Helicoidea Rafinesque, 1815
Family: Eloniidae Gittenberger, 1979
Genus: *Klikia* Pilsbry, 1895

***Klikia giengensis* (Klein, 1846)**

Fig. 6J

- * 1846 *Helix giengensis* – Klein, p. 69, pl. 1, fig. 9.
- 1911 *Klikia giengensis* Krauss – Wenz, p. 85, pl. 4, figs. 6–10.
- 1916 *Klikia (Klikia) giengensis* (Klein) – Gottschick & Wenz, p. 56.
- 1923 *Klikia (Klikia) giengensis giengensis* (Klein) – Wenz, p. 539.
- 1976 *Klikia (Klikia) giengensis* (Klein) – Schlickum, p. 16, pl. 4, fig. 58.
- 2006 *Klikia (Klikia) giengensis* (Klein) – Kókay, p. 91, pl. 25, fig. 9.
- 2013 *Klikia giengensis* (Klein) – Stworzewicz et al., p. 195, fig. 6A.
- 2014 *Klikia giengensis* (Klein) – Harzhauser et al., p. 33, pl. 11, figs. 9–11, 22.

Material: layer 4b: 1 fragmentary specimen (UMJGP 211.348b).

Dimensions: about 10 mm diameter.

Description: A single fragment is available comprising 5 densely coiled spire whorls with flat spire. Microsculpture

consisting of a dense pattern of tiny papillae on entire spire. Base and aperture are destroyed or covered by sediment.

Remarks: Despite the fragmentary preservation, the flat spire, the tightly coiled spire whorls and the dense pattern of papillae are very characteristic for *K. giengensis* and allow a separation from all other species of the genus.

Distribution: This species appears already during the early Miocene (Binder 2004) and occurs around the early/middle Miocene boundary in France and southern Germany. In the Styrian Basin, it is recorded from lower Badenian strata (Harzhauser et al. 2014) and is frequently mentioned from the middle Miocene Silvana-beds in Germany (Mörsingen, Hohenmemmingen, Zwiefaltendorf) (Schlickum 1976). Sarmatian occurrences are documented from Várpálot in Hungary (Kókay 2006).

Palaeoecology: This species seems to have preferred moist woodlands (Harzhauser et al. 2014).

Family: Helicidae Rafinesque, 1815
Genus: *Palaeotachea* Jooss, 1912

***Palaeotachea sylvestrina* (Schlotheim, 1820)**

Fig. 6A–C

- * 1820 *Helicites sylvestrinus* – Schlotheim, p. 99.
- 1923 *Cepaea sylvestrina sylvestrina* (Schlotheim) – Wenz, p. 690.
- 1974b *Cepaea sylvestrina* (Schlotheim) – Papp, p. 391, pl. 19, figs. 1–5.
- 2016 *Palaeotachea sylvestrina* (Schlotheim, 1820) – Höltke & Rasser, p. 245, figs. 5.6–5.9, 6.5.

Material: layer 4b: 8 specimens (UMJGP 211.408, 211.409a, 211.409b, 211.410, 211.411a, 211.412, 211.416, 211.418).

Dimensions: largest specimen: height: 15 mm, diameter: 21 mm.

Description: Ovoid-conical shells comprising 3.5 teleoconch whorls and 1.25 smooth and weakly convex protoconch whorls. Spire whorls moderately convex with distinct growth lines on early whorls and deep sutures; last whorl high, strongly convex. Peristome reflexed, distinctly prosocline in lateral view. Surface smooth except for growth lines. Colour pattern in UV-light consisting of three spiral bands on last whorl; the uppermost spiral band occurs slightly above the position of the maximum diameter followed by a second one slightly below and a third one on the base.

Remarks: All specimens are deformed by sediment compaction and the apertures are filled by sediment. Therefore, the identification is tentative. Nevertheless, the high spire and deep suture allow a separation from the similar *Palaeotachea silvana* (Klein, 1853) (see Höltke & Rasser 2016) and the colour pattern agrees with typical *P. sylvestrina* from the Sarmatian of Austria and Hungary (Papp 1974b).

Distribution: Middle Miocene in the North Alpine Foreland Basin, Southern Germany and the Vienna Basin spanning mammal zones MN6 to MN7/8 (Papp 1974b; Höltke & Rasser 2016). Early Miocene occurrences, mentioned as *Cepaea* cf.

sylvestrina by Salvador (2013) need confirmation and are not listed under this species by Höltnke & Rasser (2016). Late Miocene occurrences might rather represent *P. etelkae* (Halaváts, 1923) (Lueger 1981).

Palaeoecology: The ecological requirements of this extant genus are unknown. Like the recent species of *Cepaea*, the *Palaeotachea* species seem to have settled a broad range of habitats (see Welter-Schultes 2012 for *Cepaea* ecology).

Genus: *Pseudochloritis* Boettger, 1909

***Pseudochloritis gigas* (Pfeffer, 1930)**

Fig. 6K–N

- * 1930 *Tropidomphalus* (*Pseudochloritis*) *gigas* – Pfeffer, p. 76.
- 1957 *Tropidomphalus* (*Pseudochloritis*) *gigas* Pfeffer – Papp, p. 86.
- 1967 *Tropidomphalus* (*Pseudochloritis*) *gigas* Pfeffer – Schütt, p. 219, fig. 23.
- 1974b *Tropidomphalus* (*Pseudochloritis*) *gigas* Pfeffer – Papp, p. 389, pl. 18, figs. 2a–c.
- 1981 *Tropidomphalus* (*Pseudochloritis*) *gigas* Papp – Lueger, p. 58, pl. 12, fig. 4, pl. 13, fig. 4, pl. 16, fig. 5.
- 2008 *Pseudochloritis gigas* (Pfeffer) – Binder, p. 174, pl. 2, figs. 4a–c.

Material: layer 4b: 10 specimens (UMJGP 211.340, 211.346, 211.347, 211.348a, 211.380, 211.381, 211.413, 211.415, 211.417a, 211.417b).

Dimensions: largest specimen: height: 26 mm, diameter: 33 mm.

Description: Large helicoid shells with depressed spire; protoconch comprising 1.5 feebly convex whorls with delicate ribs and tiny papillae. Teleoconch consisting of 3.5 whorls with incised suture and wide, high and regularly convex last whorl; sculpture consisting of weak prosocline growth lines, being typically most prominent close to the upper suture. Terminal last whorl bends down abruptly close to the aperture; peristome thickened with strongly reflexed lip and slight constriction right before aperture. Deep, moderately wide umbilicus partly covered by inner lip. No colour pattern visible in UV-light.

Remarks: This is the largest gastropod species at Badenbrunn and can be recognized easily by its depressed spire, strongly reflexed peristome and only partly covered umbilicus. The Pannonian *Pseudochloritis depressus* (Wenz, 1927) is smaller and the spire whorls are less tightly coiled; *P. richarzi* (Schlosser, 1907) is much smaller and has a higher spire (see Lueger 1981).

Distribution: *P. gigas* is widespread during the Sarmatian in the North Alpine Foreland Basin, the Vienna Basin, the Lavanttal Basin and the Bakony Mountains (Lueger 1981; Kókay 2006; Binder 2008). The youngest records derive from the early Pannonian of the Vienna Basin (Lueger 1981).

Palaeoecology: Lueger (1981) proposed vegetated areas near creeks or ponds as the habitat of this species; Binder (2008) and Höltnke & Rasser (2015) discussed moist habitats.

Achatinoid clade: sensu Wade et al., 2006
Superfamily: Testacelloidea Gray, 1840
Family: Oleacinidae H. & A. Adams, 1855
Genus: *Pseudoleacina* Wenz, 1914

***Pseudoleacina* sp.**

Fig. 6O–P

- 2006 *Palaeoglandina gracilis porrecta* (Gobanz) 1854 – Kókay, p. 85, pl. 32, fig. 8 [non *Paleoglandina porrecta* (Gobanz, 1854)].
- 2006 *Poiretia* ex. aff. *taurinensis* (Sacco) 1886 – Kókay, p. 86, pl. 32, fig. 11 [non *Palaeoglandina taurinensis* (Sacco, 1886)].

Material: layer 4b: 1 compressed specimen (UMJGP 211.358), 2 fragments (UMJGP 211.369, 211.375).

Dimensions: UMJGP 211.358 height of fragment: 36 mm, diameter (compressed): 15 mm.

Description: The available specimens show an elongated ovoid shell, with high, nearly straight-sided spire whorls and moderately high, subcylindric last whorl, attaining about 1/3 of the total height. Suture narrow but deeply incised. Sculpture consisting of prominent, densely spaced, slightly irregular, weakly prosocline axial ribs. The axial ribs are united in an indistinct narrow adsutural cord along the upper suture. Peristome thin; aperture drop-shaped; columella slightly twisted, anteriorly truncated. Inner lip forming a distinct callus attached to the base.

Remarks: Kókay (2006) documented this species under two names from Sarmatian deposits of Várpalota in Hungary. All his specimens are fragmentary and derive from drillings. One specimen was identified by Kókay (2006) as *Palaeoglandina gracilis porrecta* (Gobanz, 1854), which differs in its inflated last whorl and much shorter spire (see Harzhauser et al. 2014 for discussion on this species). The same features allow a clear separation from the Miocene *Palaeoglandina gracilis* (von Zieten, 1832) (see Harzhauser et al. 2014 and Salvador et al. 2015a). Another specimen was identified by Kókay (2006) as *Poiretia* ex. aff. *taurinensis* (Sacco, 1886) from which it differs clearly in its fusiform outline and much stronger sculpture (see Ferrero-Mortara et al. 1984 for the syntype of the early Miocene Italian *Glandina taurinensis* Sacco, 1886). *Pseudoleacina eburnea* (Klein, 1853), from the middle and late Miocene of Germany and Austria, is much smaller and has much more delicate sculpture (see Harzhauser & Binder 2004; Salvador et al. 2015a). *Pseudoleacina rakosdensis* (Gaál, 1911), from the Sarmatian of Hungary, differs in its slender outline and the axial ribs, which fade out below the shoulder. *Pseudoleacina kleiniana* (Pilsbry, 1909), from the middle Miocene of southern Germany, differs in its fusiform last whorl (see Schlickum 1976).

The specimen from Badenbrunn and the coeval specimens from Hungary seem to represent a new, undescribed species. Unfortunately, the preservation of the available material is not suitable to serve as type specimens to formally establish a new species.

Distribution: This species is known so far only from the Sarmatian of Várpalota in Hungary and Badenbrunn in Styria.

Class: Bivalvia Linnaeus, 1758
 Subclass: Palaeoheterodonta Newell, 1965
 Superfamily: Unionoidea Rafinesque, 1820
 Family: Unionidae Rafinesque, 1820
 Genus: *Anodonta* Lamarck, 1799

***Anodonta* cf. *carinthiaca* Modell, 1957**

Fig. 6Q

cf. 1957 *Anodonta splendens carinthiaca* n. ssp. – Modell, p. 98, figs. 3–4.

cf. 2001 *Anodonta (Anodonta) splendens carinthiaca* Modell, 1957 – Schultz, p. 379, figs. 8a–b.

Material: layer 5b: 1 specimen and several fragments (UMJGP 211.489).

Dimensions: length: 54.9 mm, height: 32.8 mm.

Description: An articulated specimen with moderately fragile valves is available; hinge and umbonal area are destroyed. Dorsal margin straight, passing into evenly rounded anterior margin. Ventral margin rounded; posterior margin subangulate with long, nearly straight posterodorsal area. Maximum height in posterior third.

Remarks: Based on the characteristic outline and the rather thin shell, the specimen seems to represent an *Anodonta carinthiaca*, which was described by Modell (1957) from the Sarmatian of Slovenia. This species was separated by Modell (1957) from the mainly early Miocene *Anodonta splendens* (Goldfuss, 1837) because of stratigraphic reasons. A systematic revision of this group, however, is beyond the scope of this paper.

Palaeoecology: *Anodonta* species prefer calm freshwater in lakes, and oxbow lakes with muddy or sandy substrate and rarely appear in running waters (Welter-Schultes 2012).

Ostracods

Suprageneric classification and terminology of valve characters follow Meisch (2000) and Sames (2011), respectively. Abbreviations: L=left valve, R=right valve; f=female, j=juvenile, A-1, ...=juvenile stages; l=length, h=height (both in millimetres).

Class: Ostracoda Latreille, 1802
 Order: Podocopida Sars, 1866
 Superfamily: Cypridoidea Baird, 1845
 Family: Candonidae Kaufmann, 1900
 Subfamily: Candoninae Kaufmann, 1900
 Genus: *Fabaeformiscandona* Krstić, 1972

***Fabaeformiscandona* cf. *balatonica* (Daday, 1894)**

Fig. 8. A–C

Material: layer 5b: 4 valves, 28 fragments (UMJGP 211.490).

Dimensions: Rf: l=0.98–1.01 mm, h=0.52–0.54 mm; Lf: l=1.02 mm, h=0.52–0.63 mm.

Remarks: At Badenbrunn only few, fragmented female valves have been found. They are very similar to *F. balatonica* – at least in a wider sense (e.g., Absolon 1970; Janz 1997; Meisch 2000; Pipík 2001; Gross 2004; Fuhrmann & Goth 2011; Witt 2011; Fuhrmann 2012). The early Karpatian–middle Badenian (Central Paratethyan distribution) species *Fabaeformiscandona pokorny* (Kheil, 1964), which could be the ancestor of *F. balatonica*, differs by its more pointed posteroventral end (e.g., Witt 1998, 2000; Gross 2006; Reischenbacher et al. 2007). Due to the limited material and the still unresolved variability of this species(-group), an assured determination is not possible (Janz 1997; Meisch 2000).

Distribution: (of *F. balatonica* s.l.): middle Miocene (Badenian) to recent (Pipík 2001; Witt 2011).

Palaeoecology: Extant *F. balatonica* favours shallow ephemeral pools and swampy marginal lake settings but also occurs in the littoral of lakes, in rivers and densely vegetated rivulets. Potentially, it is able to cope with slightly elevated (oligohaline) salinity (Meisch 2000; Pipík 2001; Gross 2004).

***Fabaeformiscandona* sp. 1**

Fig. 8E–H

Material: layer 5a: 2 valves, 6 fragments; layer 5b: 112 juvenile valves, 14 fragments (UMJGP 211.491).

Dimensions: Lj: l=0.61–0.65 mm, h=0.31–0.33 mm; Rj: l=0.61–0.62 mm, h=0.31–0.32 mm.

Remarks: These juvenile (?A-2) candoninae shells are the most frequent ostracod remains occurring at the Badenbrunn locality. Perhaps, these valves represent larval stages of *F. cf. balatonica* (see Gross 2004).

Palaeoecology: See *F. cf. balatonica*.

***Fabaeformiscandona* sp. 2**

Fig. 8I

Material: layer 5a: 1 R fragment (UMJGP 211.492).

Dimensions: l=? mm, h=0.42 mm.

Remarks: This specimen displays some similarity with *Fabaeformiscandona fabaeformis* (Fischer, 1851), which is, however, more elongated (Janz 1997; Fuhrmann 2012). By neglecting its significantly larger size, *Fabaeformiscandona hyalina* (Brady & Robertson, 1870) match very well solely based on the outline (see Fuhrmann 2012). As the posterior end of the shell is missing and only one fragment is available, specific identification is unfeasible.

Palaeoecology: See *F. cf. balatonica*.

Genus: *Pseudocandona* Kaufmann, 1900

***Pseudocandona* cf. *praecox* (Straub, 1952)**

Fig. 8J

Material: layer 5a: 1 Lj, 1 Rj; layer 5b: 1 Rj, 1 fragment (UMJGP 211.493).

Dimensions: Rj: l=0.63 mm, h=0.32 mm.



Fig. 8. A–C: *Fabaeformiscandona* cf. *balatonica* (Daday, 1894) (A: L; B: R; C: R, central muscle scars); **D:** *Ilyocypris* ?ex gr. *gibba* (Ramdohr, 1808), R; **E–H:** *Fabaeformiscandona* sp. 1 (E: L; F: L; G: R; H: R); **I:** *Fabaeformiscandona* sp. 2, R; **J:** *Pseudocandona* cf. *praecox* (Straub, 1952), R; **K–L:** *Paralimnocythere rostrata* (Straub, 1952) (K: L; L: L).

Remarks: These valves probably represent the A-2 stage of a *Pseudocandona* species and resemble juveniles of *P. praecox* (e.g., Witt 1998; Schäfer 2005), which is suggested to be a junior synonym (Janz 1992, 1997; Witt 2000) or not (Schäfer 2005, 2011) of *Pseudocandona steinheimensis* (Sieber, 1905). The material available at present does not enable a more precise identification as well as a decision about this possible synonymy (see Janz & Matzke-Karasz 2001; Gross 2004).

Distribution: (of *P. praecox*): lower Oligocene to late middle Miocene (Sarmatian) in the Swiss Molasse Basin, North Alpine Foreland Basin and Třeboň Basin (see Witt 1998, 2000; Schäfer 2005, 2011).

Palaeoecology: Presumably a dweller in stagnant freshwaters (ponds and lakes; see Janz 1997).

Family: Ilyocyprididae Kaufmann, 1900
Subfamily: Ilyocypridinae Kaufmann, 1900
Genus: *Ilyocypris* Brady & Norman, 1889

***Ilyocypris* ?ex gr. *gibba* (Ramdohr, 1808)**

Fig. 8D

Material: layer 5b: 3 R, 1 fragment (UMJGP 211.494).

Dimensions: R: l=0.75mm, h=0.44 mm.

Remarks: Only few, to some degree fragmented *Ilyocypris* valves are available. This hampers a closer determination by considering the variability of *Ilyocypris*' shell characters (e.g., nodes). Partly species-specific "inner marginal ripples" are not preserved in the current specimens (Janz 1994; Meisch 2000; Mazzini et al. 2014).

Among Central European Miocene *Ilyocypris* species, *I. gibba* of Witt (2000; although somewhat more elongated and larger) and the valve fragment (*Ilyocypris* sp.) of Gross (2004) are most similar. Equally, extant *I. gibba* (e.g., Triebel 1941; Fuhrmann 2012) resembles the present specimens. Due to the lack of knowledge about marginal ripples neither species identification nor a profound allocation to the "*gibba*"-group are possible (Witt 2002).

Distribution: (*I. gibba* of Witt 2000 and *Ilyocypris* sp. of Gross 2004): early (Ottangian) to late Miocene (early Pannonian) in the North Alpine Foreland Basin and Styrian Basin.

Palaeoecology: *Ilyocypris* occurs in shallow, fresh to slightly saline (oligohaline) water bodies (ponds, lakes, springs, rivers; e.g., Morkhoven 1963; Meisch 2000; Karanovic 2012).

Superfamily: Cytheroidea Baird, 1850
Family: Limnocytheridae Klie, 1938
Subfamily: Limnocytherinae Klie, 1938
Genus: *Paralimnocythere* Carbonnel, 1965

***Paralimnocythere rostrata* (Straub, 1952)**

Fig. 8K–L

* 1952 *Limnocythere rostrata* n. sp. – Straub, p. 499–500, pl. C, figs. 55–56, text-fig. 23.

1965 *Limnocythere rostrata* Straub 1952 – Lutz, p. 310–311, text-fig. 26.

1989 *Limnocythere rostrata* Straub 1952 – Reichenbacher, pl. 3, fig. 13.

2000 *Paralimnocythere rostrata* (Straub 1952) – Witt, p. 119, pl. 1, fig. 3.

2011 *Paralimnocythere rostrata* (Straub 1952) – Pirkenseer & Berger, p. 32–33, pl. 3, figs. 4a–b.

Material: layer 5a: 1 Lf; layer 5b: 1 Lf, 3 fragments (UMJGP 211.495).

Dimensions: Lf: l=0.56–0.58 mm, h=0.31 mm.

Remarks: These very fragile, female valves match well with *P. rostrata* in Pirkenseer & Berger (2011). In the latter, however, the reticulum forms low, oblique ridges in the anteroventral area, which are not developed in the specimens of Badenbrunn. Given the variation in ornamentation of this species (fide synonyms included by Pirkenseer & Berger 2011), this slight difference is suggested to represent intraspecific variability. Potentially, *Paralimnocythere* sp. of Pipík (1998: Danube Basin; middle Pannonian) also belongs to *P. rostrata* but the provided (tilted) illustration does not allow a detailed comparison. The late Miocene (Tortonian) species *Paralimnocythere bouleigensis* Carbonnel, 1965 is similar (compare figures of paratypes in Martens 1992) but diverges by its more pronounced ventrolateral swelling and pitted surface (see also Carbonnel 1969). *Paralimnocythere tenera* Sokač, 1972 from the Pannonian of Croatia is similar but its anterior and posterior parts are finely punctuated. Sokač (1972) has not mentioned a reticulum, which is clearly visible in our specimens. Unfortunately, the illustrations of this author do not allow a detailed examination and a reinvestigation of *P. tenera* is needed to clarify its relation to *P. rostrata*.

Distribution: (fide Pirkenseer & Berger 2011): Oligocene to middle Miocene (Badenian) in the Upper Rhine Graben, Swiss Molasse Basin, Aquitaine Basin, North Alpine Foreland Basin and North Croatian Basin (see Witt 2000; Hajek-Tadesse et al. 2009).

Palaeoecology: *P. rostrata* probably inhabits shallow freshwater environments, like ponds, lakes and rivers (see Pirkenseer & Berger 2011 and ecological demands summarized for extant *Paralimnocythere* species in Meisch 2000).

Vertebrates

The taxonomy used here follows Böhme (2010: fishes), Prieto et al. (2010: rodents) and Aiglstorfer et al. (2014: proboscideans).

Class: Actinopterygii Cope, 1887
Order: Cypriniformes Bleeker, 1859
Family: Cyprinidae Bonaparte, 1832
Subfamily: Cyprininae Bonaparte, 1840
Genus: *Palaeocarassius* Obrhelová 1970

***Palaeocarassius* sp.**

Fig. 9A–C

Material: layer 5b: 2 posterior teeth, 1 pharyngeal tooth (UMJGP 211.496; provisional determination M. Böhme).

Distribution: Early Miocene to late Miocene (late Pannonian) in the Central Paratethys (Böhme & Ilg 2003; Böhme 2010 and personal comment M. Böhme, 2015).

Palaeoecology: An inhabitant of lacustrine environments (Böhme 1999, 2010).

Subfamily: Leuciscinae Howes, 1991
Genus: *Palaeoleuciscus* Obrhelová 1969

***Palaeoleuciscus* sp.**

Fig. 9D–E

Material: layer 5b: 7 pharyngeal teeth (UMJGP 211.497; provisional determination M. Böhme).

Remarks: Four teeth have a pointed terminal hook, the other three show marks of usage or are fragments. The teeth show a wide tooth crown, narrowing towards the shaft.

Distribution: Early Miocene to late Miocene (middle Pannonian) in the Central Paratethys (Böhme & Ilg 2003 and personal comment M. Böhme, 2015).

Palaeoecology: Probably an inhabitant of rivers and associated backwaters (Böhme 2002).

Class: Mammalia Linne, 1758
Order: Rodentia Bowdich, 1821
Family: Muridae Illiger, 1811
Subfamily: Copemyinae Jacobs & Lindsay, 1984
Genus: *Democricetodon* Fahlbusch, 1964

***Democricetodon* sp. nov. (sensu Kálin & Engesser, 2001)**

Fig. 9F

Material: layer 4b: one isolated m1 (UMJGP 211.498; provisional determination J. Prieto).

Remarks: *Democricetodon* sp. nov. (sensu Kálin & Engesser, 2001) is a small hamster. The anterocone of the m1 is round to ovaloid, the long mesolophid reaches the edge of the tooth. The molar has two roots (see Prieto et al. 2010).

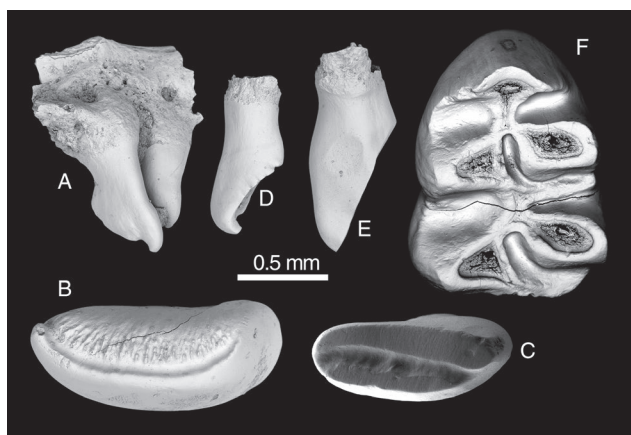


Fig. 9. A–C: *Palaeocarassius* sp. (A: pharyngeal tooth; B–C: posterior teeth); D–E: *Palaeoleuciscus* sp., pharyngeal teeth; F: *Democricetodon* sp. nov. (sensu Kálin & Engesser, 2001), m1.

Distribution: in Central Europe: late middle Miocene (Sarmatian) to late Miocene (middle Pannonian; Gross et al. 2011a).

Palaeo-ecology: A wet and wooded habitat has been suggested for *Democricetodon* sp. nov. (sensu Kálin & Engesser, 2001) (Wessels & Reumer 2009; Prieto et al. 2014).

Order: Proboscidea Illiger, 1811
Family: Deinotheriidae Bonaparte, 1845
Genus: *Deinotherium* Kaup, 1829

***Deinotherium levius* Jourdan, 1861**

Remarks: Mottl (1958) described a tusk, which previously was found at Badenbrunn (UMJGP 54.563). She identified it as *Deinotherium levius* Jourdan, 1861 and suggested a late Sarmatian age for the specimen. Nevertheless, Mottl (1958) mentioned that *Deinotherium* species identifications, solely based on tusks, are difficult and are not conclusive for stratigraphic purposes (see Aiglstorfer et al. 2014).

Discussion

Sedimentology

Due to poor outcrop conditions, observations are confined to vertical section analysis, which renders an interpretation difficult (Bridge 1993). Our tentative facies interpretation is based on Miall (1996) and Einsele (2000). More detailed sedimentological investigations are needed, but this is beyond our possibilities.

The basal (bed 1), cross-bedded gravels (Gt) with some cross-bedded sand lenses (St) indicate sedimentation from unidirectional currents and are interpreted as channel-fill or transverse bar deposits and remnants of 3-D dunes of a fluvial system. Up-section (bed 2), trough cross- and subordinately ripple-bedded sands (St, Sr) refer to the development of 3-D dunes/ripples. Bed 2 is overlain by silt-fine sand alternations (beds 3–4a; Fl), which display obliquely (~30°) oriented bedding planes. Towards the hanging wall (top of layer 4a), the bedding gradually converts into subhorizontal stratification (layer 4b). The lithofacies of these beds implies deposition from suspension and low velocity currents, for example, in overbank areas or abandoned channels. Due to the upward decrease in the dip of bedding planes, deposition by lateral accretion (point bar) can be suspected. The massive, blocky structured layer 4b (Fr) is rich in terrestrial gastropods and notably affected by roots, penetrating up to ~0.8 m into layer 4a. This indicates incipient pedogenic overprint of suspension load deposits in an overbank environment or abandoned channel. Bed 4b is topped by pelitic sediments (bed 5; Fm), containing aquatic biota (molluscs, ostracods, fishes). These characteristics refer to deposition from suspension in standing waters like in floodplain ponds or oxbow lakes.

Above (beds 6–9), the sediments coarsen upwards pointing to increased influx of the trunk river. Partly plant-rich

sand–silt alternations (beds 6–7; Fl), indicative for interchanges of weak traction current and suspension sedimentation, might be deposited during floodwaters (distal crevasse splays?) in a vegetated floodplain. Upper plane bed conditions are indicated by the horizontal bedded fine–medium sand (Sh) of bed 8, possibly formed during the initial stage of a crevasse splay and followed by ripple-bedded sand deposition (layer 9a; Sr) as the flow diminished. The outcrop-wide, approximately uniformly low-angle bedded (Sl) layer 9b could represent a sandy channel fill (crevasse channel?). Cm-thick calcic layers of nodules in the ripple- and horizontal bedded layer 9c, possibly mark further individual sheet flooding/crevasse splay events.

Palaeoecology

In total, 15 gastropod and 1 bivalve species were found at the Badenbrunn section. Terrestrial taxa derive mainly from the palaeosol-layer 4b, where aquatic gastropods (only 3 *Bithynia*-opercula) are almost absent. As discussed in the taxonomic descriptions, most taxa indicate humid woodland, which is especially supported by the high number of *Triptychia* specimens. The presence of two *Carychium* species suggests moist bottom conditions, for example, with leaf litter. Therefore, the gastropod assemblage points to a vegetated, moist environment with nearby water bodies (e.g., poorly drained floodplain or abandoned channel). A rather moist forest habitat has been assumed for the late Sarmatian *Democricetodon* species (Prieto et al. 2010, 2014). However, a single tooth is certainly not significant for palaeo-environmental reconstructions.

The ostracod fauna of the overlying bed 5 gives a clear indication for a freshwater environment, most probably of a shallow pond or lake. No indications of any marine influx — for example, of ostracods, typical for the Sarmatian Sea — have been found. In accordance, the recovered fish remains and molluscs (*Anodonta*, *Ferrissia*) point to a limnic setting. Although more detailed sampling and taxonomic works are necessary concerning the plant material, abundant *Glyptostrobus* remains in layer 5b hint at a swampy, very shallow environment (Averyanov et al. 2009). Shallow, nutrient-rich lentic waters are indicated by the presence of plentiful occurrences of *Trapa* nuts (Kovar-Eder et al. 2002, Meller & Hofmann 2004).

With the gradual return to a more proximal setting in respect to the trunk river (beds 6–7), only plant fragments of the riparian forest (e.g., *Alnus*, *Salix*) can be found.

Biostratigraphy

The mollusc assemblage indicates a middle Miocene age. Taxa, such as *Ferrissia* cf. *wittmanni*, *Triptychia sarmatica*, *Klikia giengensis*, *Archaeozonites costatus* and *Palaeotachea sylvestrina*, are unknown from the late Miocene (Fig. 10). The frequent *Pseudochloritis gigas* persisted into the early Pannonian but is most widespread during the Sarmatian. Therefore, the stratigraphic ranges of the taxa exclude a Pannonian age (late Miocene) and point to a Sarmatian (late middle Miocene) age. A Badenian age can be excluded due to the presence of *P. gigas*.

The ostracod fauna found in layer 5, overlying the palaeosol (4b), is quite poor both in abundance and in diversity. Specimens are largely fragmented and juvenile valves are common. Due to these limitations, the biostratigraphic value of the ostracod fauna is restricted. However, there are some implications, arguing for a middle Miocene, possibly Sarmatian age: Fairly speculatively, *Fabaeformiscandona balatonica* s.l. appears in middle Badenian times as a descendant of *Fabaeformiscandona pokorny* and may, hence, hint at an age not older than the middle Badenian.

Stratigraphy Taxa	MIOCENE			
	LOWER	MIDDLE		UPPER
	Karpatian	Badenian	Sarmatian	Pannonian
<i>Bithynia</i> sp.				
<i>Anodonta</i> cf. <i>carinthiaca</i>	— —	— —	— —	
<i>Archaeozonites costatus</i>		— —	— —	
<i>Carychium sandbergeri</i>		— —	— —	
<i>Carychium nouleti</i>			— —	— —
<i>Ferrissia</i> cf. <i>wittmanni</i>			— —	
<i>Gastrocopta fissidens</i>				— —
<i>Klikia giengensis</i>		— —	— —	
<i>Limacidae</i> gen. et sp. indet.				
<i>Milacidae</i> gen. et sp. indet.				
<i>Negulopsis suturalis</i>				
<i>Palaeotachea sylvestrina</i>	— —	— —	— —	
<i>Pseudochloritis gigas</i>			— —	— —
<i>Pseudoleacina</i> sp.			— —	
<i>Triptychia sarmatica</i>			— —	

Fig. 10. Stratigraphic distribution of the Badenbrunn gastropod fauna.

Fabaeformiscandona sp. 1 (possibly juveniles of *F. cf. balatonica*) and *Fabaeformiscandona* sp. 2 do not offer a biostratigraphic implication to date. *Pseudocandona praecox* would point to an age not younger than Sarmatian times, however, this claim remains tentative due to ambiguous taxonomic identification of the current material. Due to similarities with Ottnangian–early Pannonian *Ilyocypris* species, *Ilyocypris* ?ex. gr. *gibba* vaguely refers to this time range. Despite some similarities with Pannonian *Paralimnocythere* species, *Paralimnocythere rostrata* is reported until now only from the Oligocene to the middle Miocene.

The isolated tooth of *Democricetodon* sp. nov. (sensu Kälin & Engesser, 2001) provides only a rough biostratigraphic indication. This species is found in Central Europe during the late Sarmatian to the middle Pannonian times.

Palaeocarassius and *Palaeoleuciscus* teeth have been found co-occurring in layer 5b. Both are reported separately throughout the Miocene, up to the Pannonian. However, coexisting records of both are unknown from the late Miocene so far (personal comment, M. Böhme, 2015).

In consideration of the hitherto available palaeontological indications and the available geologic information, a late middle Miocene (late Sarmatian) age is plausible for the Badenbrunn locality.

Conclusions

The Badenbrunn pit exposes fluvial sediments ranging from thalweg to point bar and overbank deposits (e.g., poorly drained floodplain, floodplain pond or abandoned channel, crevasse splay/channel).

A moderately diverse terrestrial gastropod fauna settling a moist and vegetated floodplain or abandoned channel has been found. Subsequently, this fauna was replaced by an aquatic (freshwater) assemblage due to floodplain pond or oxbow lake development.

The recovered mollusc assemblage points to a Sarmatian age (late middle Miocene). Ostracod, fish and rodent remains support this dating. Based on the geological background (marine upper Sarmatian sediments in the footwall; brackish lower Pannonian sediments in the hangingwall), a late Sarmatian age of this site is most plausible.

Terrestrial deposits, close to the Sarmatian/Pannonian boundary in age are virtually undescribed from the Styrian Basin and rare in the Central Paratethyan realm as well. For example, the localities of Gratkorn (~42 km NW) and Mataschen (~14 km E) are slightly older or younger respectively (Fig. 1). Both sites differ notably in their faunal composition (Gross 2008; Gross et al. 2011a, b, 2014; Harzhauser et al. 2008).

Our study contributes to a better understanding of the palaeobiological and palaeoecological characteristics of the Paratethyan hinterland around the middle–late Miocene transition, which is, however, a period of critical turnovers in

aquatic and continental ecosystems of Central Europe (e.g., Piller & Harzhauser 2005, Böhme et al. 2008, 2011).

Acknowledgements: We thank Madelaine Böhme (Tübingen) and Jérôme Prieto (Munich) for determination of the fish and rodent material. Thanks go to Norbert Winkler (UMJ, Graz) for his assistance during fieldwork and sample preparation. For access to the pit, we are grateful to Rupert Niederl (Badenbrunn). We are thankful to two anonymous reviewers for their helpful comments.

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