Biostratigraphy of Middle Miocene (Sarmatian) wetland systems in an Eastern Alpine intramontane basin (Gratkorn Basin, Austria): the terrestrial gastropod approach

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Abstract: A rare late Sarmatian terrestrial gastropod fauna is described from the Gratkorn Basin. This intramontane basin developed during the Miocene at the junction between the Eastern Alps and the Pannonian Basin System. During the mid-Sarmatian, a considerable drop of the relative sea level, probably coinciding with uplift in the Eastern Alps, caused the Paratethys Sea to retreat from marginal basins and embayments. An alluvial plain developed in the Gratkorn Basin, indicated by fluvial gravel and paleosol formation. A moderately diverse gastropod fauna of 17 species inhabited this alluvial plain. The composition corresponds to Sarmatian faunas from southern Germany and the North-Alpine Foreland Basin. Taxonomically, it can clearly be distinguished from superficially similar and ecologically equivalent faunas of the Pannonian. Thus, we document the value of terrestrial gastropods as a biostratigraphic tool to date the lithologically often very similar freshwater systems in Miocene intramontane basins. The clausiliid *Pseudidyla martingrossi* Harzhauser & Binder and the camaenid *Pleurodonte michalkovaci* Binder & Harzhauser are introduced as new gastropod species.

Key words: Middle Miocene, Austria, Eastern Alps, Styrian Basin, Gratkorn Basin, biostratigraphy, terrestrial gastropods.

Introduction

The high-frequency oscillations of the Central Paratethys Sea have recently been revealed by well-log analysis and integrated stratigraphy (Harzhauser & Piller 2004; Piller & Harzhauser 2005). Within that system, a major 4th order drop of the relative sea-level at ca. 12 Ma was recognized, being reflected by the progradation of gravels far into the Vienna and Styrian Basins. No coeval non-marine depositional environments in marginal settings of the Eastern Alps have been described until now. This lack of information is mainly based on the difficulties in dating the limnic-fluvial sediments in the various small basins, such as the Gratkorn Basin. Tectonics and poor outcrop conditions render even a small-scale lithostratigraphic correlation uncertain. Terrestrial mollusc faunas might thus be the only biostratigraphic tool available. However, the Miocene terrestrial mollusc fauna is still poorly analysed in terms of stratigraphy.

Late Middle Miocene terrestrial mollusc faunas from the circum-Paratethyan hinterland are rare. Early Sarmatian assemblages are recorded from two Lower Austrian localities in the North-Alpine Foreland Basin (Reisperbachtal — Papp 1952; Hollabrunn — Schütt 1967). A late Sarmatian wetland fauna is known from the Austrian Eisenstadt-Sopron Basin (Harzhauser & Kowalke 2002). Papp (1958) recorded an allochthonous fauna (not determinable at species level) from upper Sarmatian strata of the central Styrian Basin in south-eastern Austria. In addition, Szalai (1928), Boda (1959) and Kókay (2006) described species from various Hungarian localities in the Bakony region

and the Bükk Mountains. Răcăştie (formerly Rákosd) in the Deva region in Romania is another important Sarmatian locality described in detail by Gaál (1911) and Szalai (1928). Partly coeval assemblages are also documented from the Steinheim Basin in southern Germany (Finger 1997 and references). All so-called Sarmatian localities in the Eastern Paratethyan region that yield terrestrial gastropods, such as Chisinau in Romania (Simionescu & Barbu 1940), actually represent Bessarabian and/or Khersonian faunas, which are already of Late Miocene age. In contrast, the Late Miocene development around Lake Pannon is much better resolved on the basis of numerous and rich localities (see Lueger 1981 and Harzhauser & Binder 2004 for localities and references). Due to the few records and the difficulties in identifying terrestrial gastropods, many earth-scientists neglect this group of molluscs. The stratigraphic and paleoecological value of terrestrial gastropods, although generally accepted for the Pleistocene, is thus still underestimated for the European Miocene. This study therefore emphasizes the applicability of terrestrial gastropods for Miocene stratigraphy if they fit into an integrated stratigraphic context.

Geologic frame

The investigated gastropod fauna originates from the clay pit St. Stefan in the Gratkorn Basin, a small satellite basin, approximately 7 km long and 3 km wide, beyond the north-western margin of the Styrian Basin (Fig. 1). Paleozoic rocks (mainly carbonates and phyllites) roughly

encircle the Gratkorn Basin. It opens to embayments of the Styrian Basin only in the south-west. Our knowledge about the basin filling is restricted to rare outcrops and shallow drillings north-east of Gratkorn.

In general, the lowermost part of the exposed, approximately 190-m-thick rock column consists of very coarse- to medium-grained, polymictic gravels/conglomerates with some rounded, outsized gneiss boulders ($>1\,m^3$). These coarse gravels extend from the Gratkorn Basin to the south-east into the transition to the Styrian Basin (Clar 1938; Winkler-Hermaden 1957; own data). There, they are underlain by marine lower Sarmatian marls (*Elphidium reginum* to *Elphidium hauerinum* Zone; see Clar 1938; Flügel 1958, 1959; own data; Figs. 1 and 2).

In the Gratkorn Basin, the basal clastics are overlain by up to 20-m-thick, occasionally plant-bearing pelites. Alternations of gravels/conglomerates, sands and pelites follow above. In the adjacent transition to the Styrian Basin, cm-thick intercalations of oolites are documented from that level (own data). The topmost strata are formed by medium- to fine-grained, mainly quartz-rich gravels/conglomerates with minor sandy and pelitic intercalations of Pannonian age. Matrix-supported breccias and red earth occur attached to the Paleozoic basement and are interpreted as heterochronous Miocene talus deposits (see Clar 1933; Flügel 1975 and own mapping; Fig. 1).

Lithology and fossil content

The clay pit St. Stefan is situated 0.7 km east of Gratkorn (10 km northwest of Graz; 15°20′55″ E/47°08′15″ N; Fig. 3). Poorly sorted silts with numerous disarticulated skeletons, isolated bones and teeth of amphibians, reptiles and mammals, calcareous endocarps of *Celtis* (hackberry) and the herein discussed gastropod fauna are exposed at the base of the pit. This mottled layer is intensively bioturbated. Root traces and ferruginous concretions are common, indicating the development of a paleosol. In the northern part of the pit, this layer is overlain by more than 1.5-m-thick, matrix-supported, polymictic debris flow gravels, which taper off to the South. Gravels and paleosol are superimposed by more than 15-m-thick pelites with several intercalated lignitic layers, especially in the lower part of the section. Tree stumps several meters in height occur sporadically. While the leaf flora of the pelites is rather poor, more than 30 fruit and seed taxa, alongside 11 freshwater ostracod species (Meller & Gross 2006; Gross in print), are recorded. Gastropod operculi (*Bithynia*) and fish fragments (cyprinids) are abundant in these fine clastics. Some layers contain mass occurrences of the fossil legume *Podocarpium podocarpum*. Two beds in particular yielded well-preserved specimens of freshwater crabs (*Potamon proavitum*; Gross & Klaus 2005). The ostracod
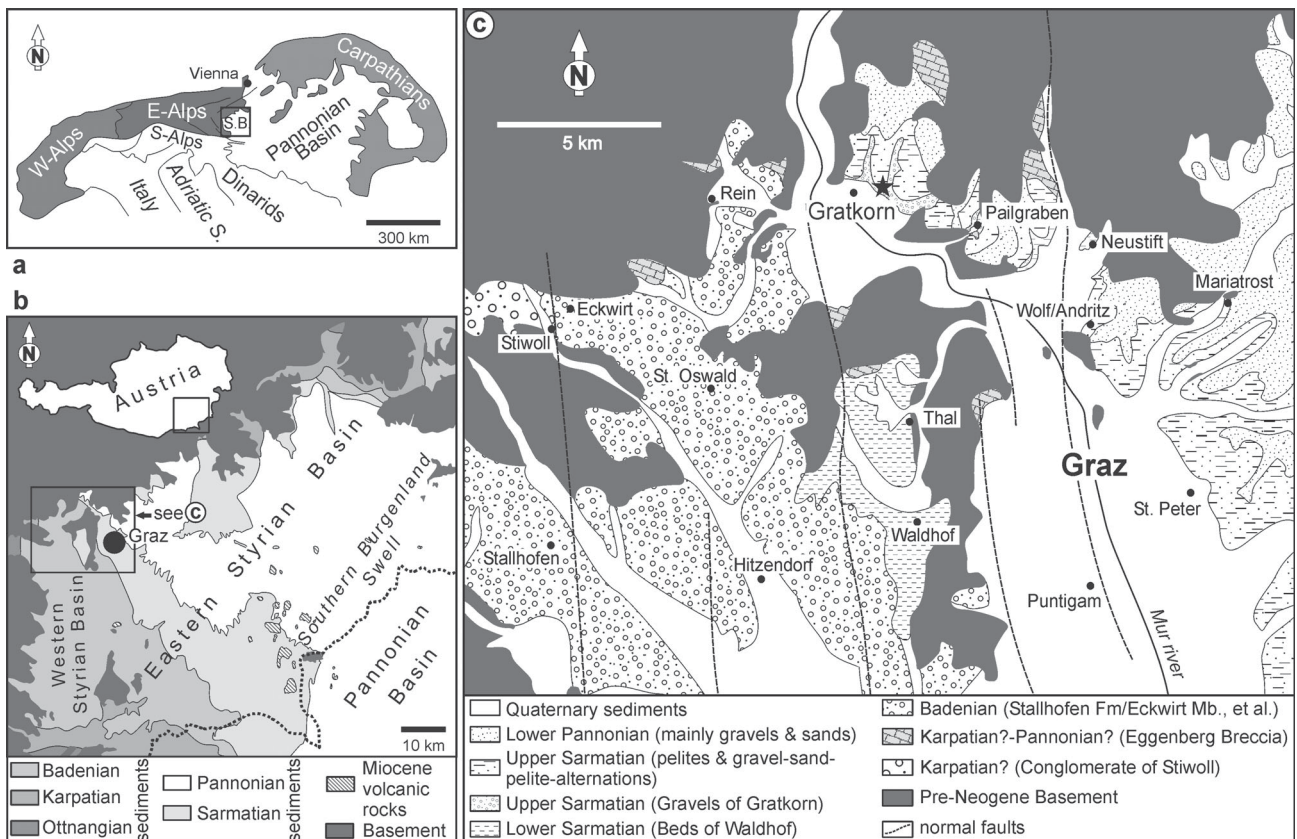

Fig. 1. a — Position of the Styrian Basin (S.B.) within the Pannonian Basin System. **b** — Geological sketch of the Styrian Basin. **c** — Simplified geological map of the north-western margin of the Styrian Basin (based on Kollmann 1965; Ebner 1983; Flügel & Neubauer 1984; Riepler 1988; Kröll et al. 1988; Gross et al. 2007 and own data).
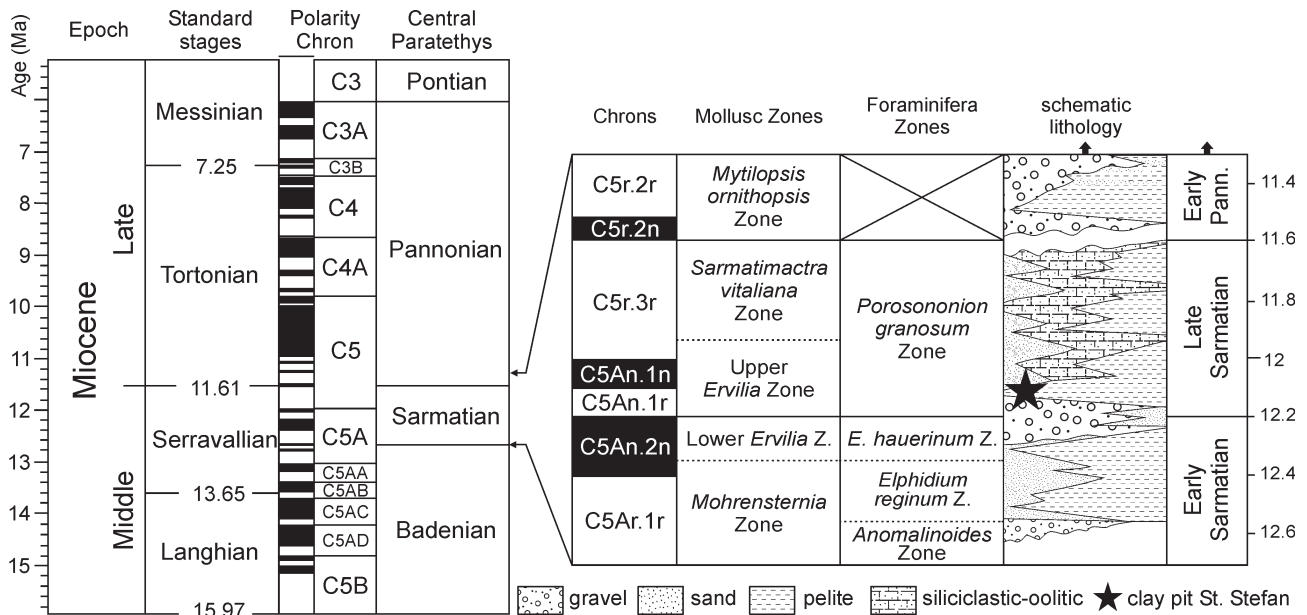
Fig. 2. Stratigraphy of the late Middle and Late Miocene (especially of the Sarmatian and early Pannonian; Styrian Basin) and stratigraphic position of the investigated clay pit St. Stefan (based on Harzhauser & Piller 2004 and Lourens et al. 2004).

assemblages of these fine clastics — as well as the potamonid crabs — indicate the formation of a shallow, sometimes richly vegetated, freshwater lake within a warm, perhaps subtropical climate.

Paleobotanic investigations and studies of the vertebrate fauna are ongoing (G. Daxner-Höck, Vienna and B. Meller, Vienna). Unpublished paleomagnetic analyses recorded normal polarity for the pelites of St. Stefan (Moser 1997). Very coarse gravels are developed below the base of this outcrop, as indicated by own geological mapping of the surroundings as well as by shallow borings at the nearby motorway and within the pit (unpublished logs and Peer 1998). Coarse gravels have been previously reported from the top of the clay pit but are no longer visible (Flügel 1995).

The problem of dating intramontane freshwater deposits

Despite the proximity of the Gratkorn Basin to the Styrian Basin, any biota typical for the marine Parathethys or the brackish Lake Pannon — such as molluscs, foraminifers and ostracods — are missing. Geochronologically dateable tuffitic layers, like in the adjacent Stallhofen embayment (Ebner et al. 1998, 2000), are absent too. Earlier conclusions based on lithological correlations were often contradictory and assigned these strata to the Early, Middle or Late Miocene (see Hilber 1893; Clar 1938; Winkler-Hermaden 1957; Ebner 1983; Flügel 1997; Moser 1997). The proposed stratigraphic position as indicated above (Geologic frame) is based solely on lithostratigraphic correlations with adjacent outcrops of the Styrian Basin and cannot exclude errors due to fault zones obscured by the vegetation. Recently, a vague dating of the Gratkorn Basin fill as Middle Miocene was based upon the occurrence of

Podocarpium, which seems to vanish in the Pannonian Basin realm at the end of the Sarmatian (Hably 1992; Meller & Gross 2006). Similarly, the preliminary investigations of the mammal fauna from the basal beds of the clay pit point to a Sarmatian or early Pannonian age (personal communication, G. Daxner-Höck, Vienna). The present contribution tries to solve this problem by focusing on the terrestrial gastropod assemblage of the paleosol.

Material and sample preparation

The gastropods were obtained by washing approximately 30 kg of dried sediment from the basal layer of the clay pit St. Stefan (sieves: 250/500/1000/2000 μm). Diluted hydrogen superoxide was used for a better disintegration of the bulk sample. The preservation of the shells is excellent, showing even delicate micro-sculpture. Fragmentation seems to have occurred mainly during the washing procedure. The predominance of small-sized shells is thus at least partly artificial. Large-sized shells such as *Pleurodonte michalkovaci* nov. sp. are deformed due to diagenesis and are only available if collected separately in the field. The described material is stored in the collection of the Natural History Museum in Vienna (NHMW 2006z0236/0001-0005) and the Landesmuseum Joanneum in Graz (Inv. No. 203458).

Systematic Paleontology

The authorship of all species-level taxa is also indicated in the references; higher taxonomic categories follow Falkner et al. (2001) and Bank et al. (2001).
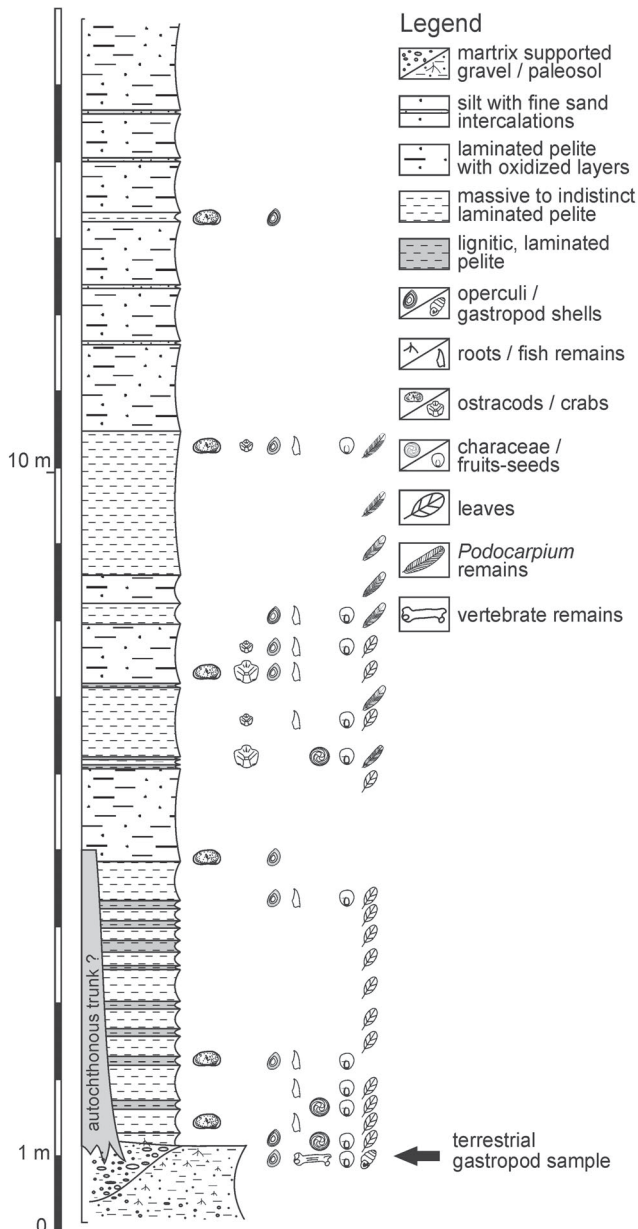
Fig. 3. Schematic profile of the clay pit St. Stefan (paleobotanic contents based on unpublished data of B. Meller, Vienna).

Class: **Gastropoda** Cuvier, 1795
Order: **Architaenioglossa** Haller, 1890
Family: **Aciculidae** Gray, 1850
Genus: *Platyla* Moquin-Tandon, 1856

Platyla callosiuscula (Andreae, 1904)
(Fig. 4.1–2)

1904 *Acme callosiuscula* — Andreae: 14, fig. 13
1976 *Acicula (Platyla) callosiuscula* — Schlickum: 3, pl. 1, fig. 4

Description: Only fragments of the last whorls are available. These are characterized by a conspicuous, broad varix-like lip-callus terminating the aperture. This callus is more or less rectangular in cross-section with a slight concavity on the back. This concavity was also stressed by Andreae (1904), who described the callus as duplicate. Whorls are moderately high with smooth shell surface and narrow, slant adsutural band.

Remarks: *Platyla callosiuscula* appears during the Middle Miocene, being recorded from Opole in Poland (Andreae 1904). During the Sarmatian it is widespread in the North-Alpine Foreland Basin and southern Germany (Schütt 1967; Schlickum 1976). No Late Miocene record of this conspicuous species is known to the authors.

Order: **Neotaenioglossa** Haller, 1892
Family: **Bithyniidae** Troschel, 1857
Genus: *Bithynia* Leach, 1818

Bithynia sp.

Remarks: A single fragment of a calcified operculum was found. Its outline does not differ from that of the Late Miocene *Bithynia jurinaci* (Brusina, 1884); no clear identification, however, is possible. The scarceness of the aquatic bithyniids indicates that these gastropods were only rare elements in the assemblage.

Order: **Pulmonata** Cuvier in Blainville, 1814
Family: **Planorbidae** Rafinesque, 1815
Genus: *Gyraulus* Charpentier, 1837

Gyraulus vermicularis (Stoliczka, 1862)
(Fig. 4.3–3a)

1862 *Planorbis vermicularis* — Stoliczka: 5, pl. 17, fig. 1
2002 *Gyraulus vermicularis* — Harzhauser & Kowalke: 75, pl. 2, fig. 14

Description: Tiny, planispiral, moderately involute shell fragment with inflated, round whorls, without angulation, increasing rapidly in width. Protoconch ornamented by indistinct spiral cords which are connected with small transverse bows. Teleoconch sculpture consisting of a dense pattern of strongly prosocyrt growth lines of irregular strength.

Remarks: The fragment is reminiscent of the endemic *Gyraulus steinheimensis* (Hilgendorf, 1867) and displays an identical protoconch sculpture (see Nützel & Bandel 1993). Differences are the larger size of the Steinheim species, its more numerous whorls and the less increasing width of the early whorls.

Gyraulus vermicularis is known so far only from late Sarmatian deposits of the Styrian Basin and the Eisenstadt-Sopron Basin (Stoliczka 1862; Harzhauser & Kowalke 2002).

Order: **Stylommatophora** Schmidt, 1855
Family: **Valloniidae** Morse, 1864
Genus: *Vallonia* Risso, 1826

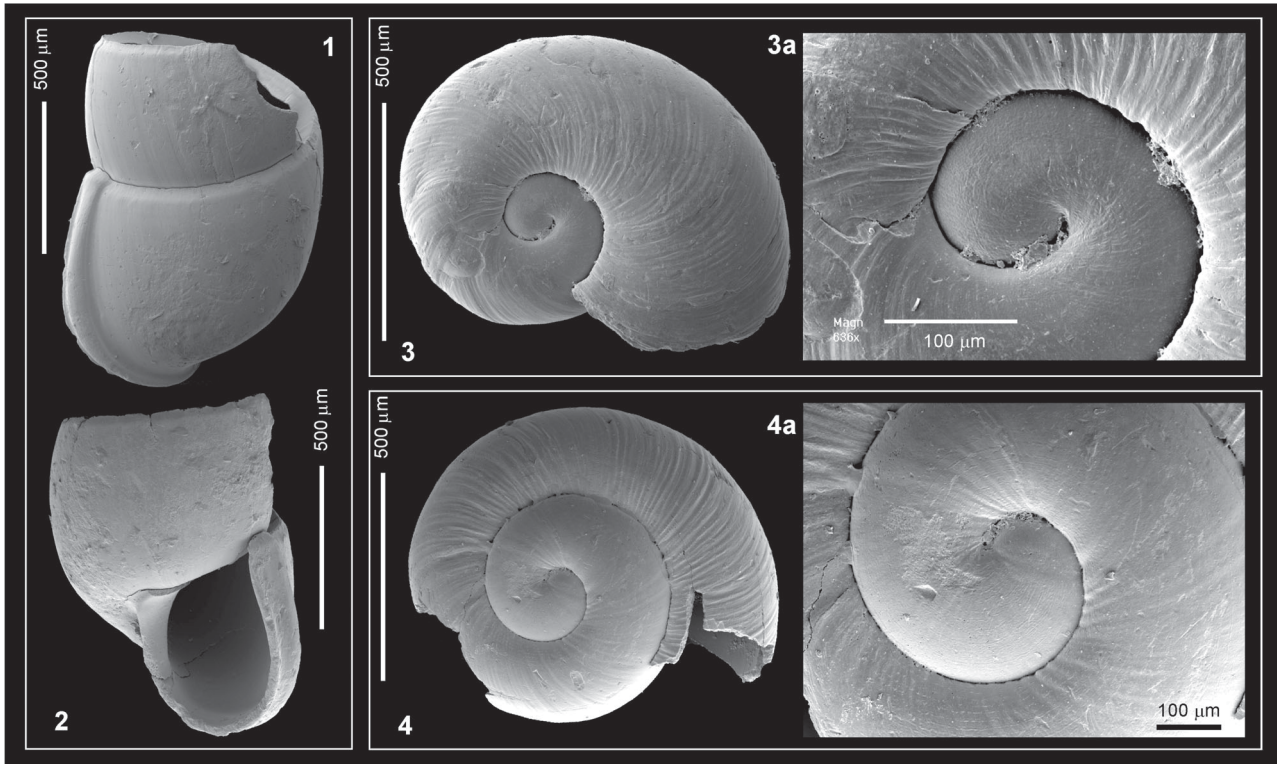*Vallonia subpulchella* (Sandberger, 1874)
(Fig. 4.4–4a)

Fig. 4. **1–2** — *Platyla callosiuscula* (Andreae, 1904); **3–3a** — *Gyraulus vermicularis* (Stoliczka, 1862); **4–4a** — *Vallonia subpulchella* (Sandberger, 1874).

1874 *Helix (Vallonia) subpulchella* — Sandberger: 544, pl. 29, figs. 3a–c
2002 *Vallonia subpulchella* — Harzhauser & Kowalke: 76, pl. 10, figs. 1–2
2004 *Vallonia subpulchella* — Harzhauser & Binder: 16, pl. 6, figs. 5–6

Remarks: The fragmentary specimen displays the protoconch and parts of the first teleoconch whorl. Size and sculpture corresponds fully to equivalent parts of Middle and Late Miocene shells of *Vallonia subpulchella* as described by Harzhauser & Kowalke (2002) and Harzhauser & Binder (2004). Due to the perfect preservation of the protoconch surface, a delicate sculpture of disconnected spiral cords is visible. This sculpture was undescribed up to now because specimens from the upper Sarmatian of the Eisenstadt-Sopron Basin in Harzhauser & Kowalke (2002) bear only faint remnants of these spirals due to abrasion.

Family: **Pupillidae** Turton, 1831
Genus: *Pupilla* Fleming, 1828

Pupilla iratiana (Dupuy, 1850)
(Fig. 5.1–3)

1850 *Pupa Iratiana* — Dupuy: 310, pl. 15, fig. 7
1997 *Pupilla iratiana* — Finger: 18, pl. 12, figs. A–B

Description: Stout, cylindrical shell of 5 convex teleoconch whorls with a coarse sculpture of oblique ribs formed by growth lines. Protoconch consisting of about 1.3 whorls; initial cap with vague honeycomb pattern passing into a hammered surface on the following part. Demarcation between protoconch and teleoconch abrupt, coinciding with the onset of a prominent axial ribbing. The last whorl develops a weak concavity along the middle line and terminates in a wide aperture with a thin parietal tooth and a slightly adapically decentred, swollen columellar fold. A small palatal denticle appears deep inside the aperture. Umbilicus wide and deep.

Remarks: Isolated early teleoconch whorls are abundant; due to their trochoid outline they might be mistaken for a *Discus*, *Janulus* or *Strobilops*. These taxa, however, lack the hammered sculpture of the protoconch. The coarse sculpture and the stout outline distinguish *Pupilla iratiana* from the syntopic *Truncatellina lentilii* (Miller, 1900). *Pupilla iratiana* is a Middle Miocene species known from Sansan in France (Fischer 2000), Várpalota in Hungary (Kókay 2006) and Steinheim in Germany (Finger 1997).

Family: **Vertiginidae** Fitzinger, 1833
Genus: *Truncatellina* Lowe, 1852

Truncatellina lentilii (Miller, 1900)
(Fig. 5.5–6)

1900 *Pupa (Isthmia) Lentilii* — Miller: 406
1967 *Truncatellina lentilii* — Schütt: 206, fig. 7

Description: Elongate, cylindrical shell with 4–5 moderately convex teleoconch whorls. Depressed trochoid protoconch with coarsely hammered sculpture on the initial part. This sculpture weakens distinctly within the first protoconch whorl. Dense and prominent growth lines on the first teleoconch whorl, decreasing rapidly in strength. High last whorl terminating in a flap-like aperture with almost straight outer lip. A small but distinct parietal tooth appears deep inside the aperture. Columella swollen; umbilicus wide.

Remarks: Similar to *Pupilla iratiana*, the isolated protoconchs of *Truncatellina lentilii* are common in the samples, being superficially reminiscent of a *Strobilops* (see above).

The Late Miocene *Truncatellina suprapontica* Wenz & Edlauer, 1942 differs considerably in its coarser sculpture and the more pointed and narrower protoconch (see Harzhauser & Binder 2004). *Truncatellina lentilii* is virtually restricted to the Middle Miocene, occurring at Undorf (Germany), in the Steinheim Basin (Finger 1997) and the North-Alpine Foreland Basin (Schütt 1967).

Genus: *Negulus* Boettger, 1889

Negulus gracilis Gottschick & Wenz, 1919
(Fig. 5.4)

1919 *Negulus suturalis gracilis* — Gottschick & Wenz: 9, pl. 1, figs. 12–13
2004 *Negulus gracilis* — Harzhauser & Binder: 126, pl. 6, figs. 9–10

Description: Despite the fragmentary preservation, identification is possible due to the characteristic sculpture, which does not differ at all from conspecific specimens from the Late Miocene of the Vienna Basin (coll. NHM; Harzhauser & Binder 2004). It consists of delicate, thin, widely spaced, prominent prosocline axial ribs and much weaker, densely spaced secondary ribs in the interspaces. The height of the body whorl corresponds to that of the Late Miocene material and suggests a total height of about 2 mm.

Remarks: The species appears in the late Middle Miocene, when it is also known from the Sarmatian of the Austrian North-Alpine Foreland Basin (Schütt 1967), the Bakony Mountains in Hungary (Kókay 2006) and the Steinheim Basin in Germany. It persists into the Late Miocene, being a common element in terrestrial deposits of the Pannonian (Lueger 1981; Harzhauser & Binder 2004).

Genus: *Vertigo* Müller, 1773

Vertigo angulifera Boettger, 1884
(Fig. 5.7–8)

1884 *Vertigo (Alaea) angulifera* — Boettger: 271, pl. 4, fig. 10
1919 *Vertigo (Alaea) angulifera* — Gottschick & Wenz: 18, pl. 1, figs. 36–37
1967 *Vertigo (Vertilla) angulifera angulifera* — Schütt: 207, fig. 9

Description: Stout, small-sized shells with 5 strongly convex whorls. Early protoconch displays a very weakly
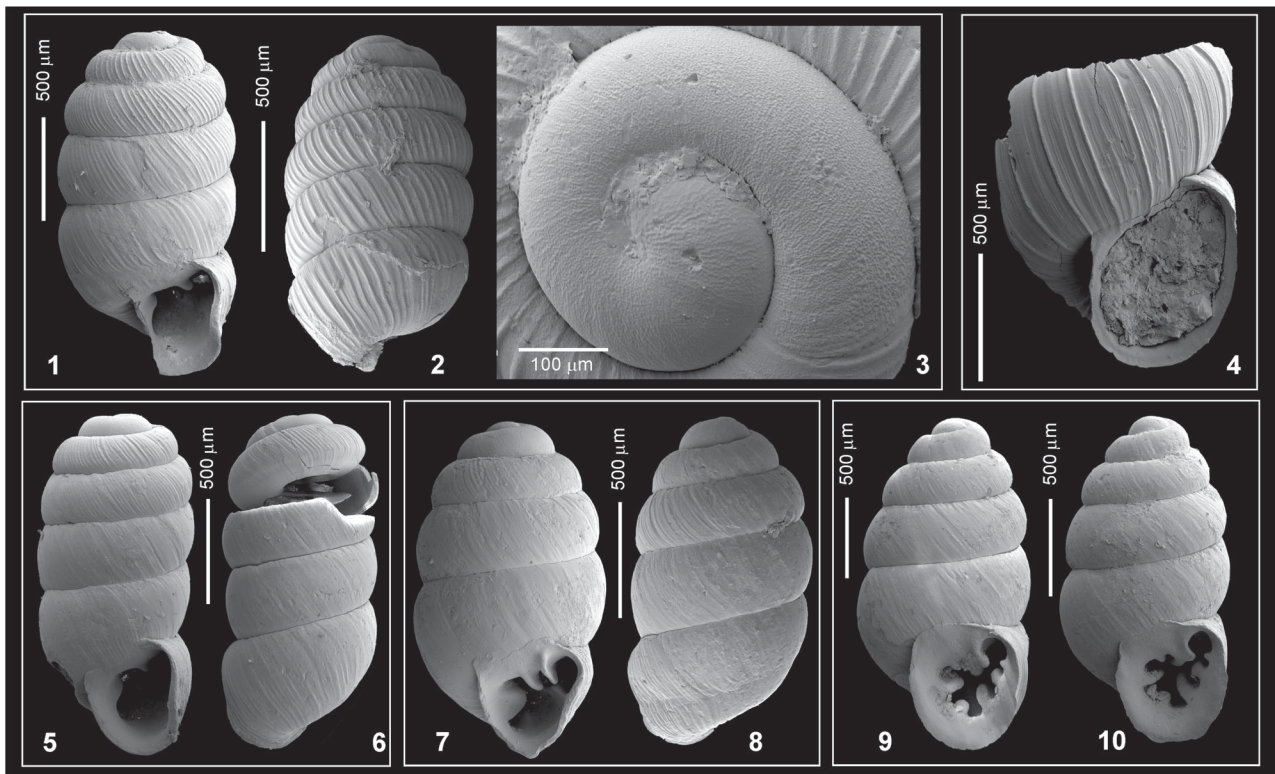

Fig. 5. 1–3 — *Pupilla iratiana* (Dupuy, 1850); **4** — *Negulus gracilis* Gottschick & Wenz, 1919; **5–6** — *Truncatellina lentilii* (Miller, 1900); **7–8** — *Vertigo angulifera* Boettger, 1884; **9–10** — *Gastrocopta (Sinalbinula) sandbergeri* Stworzewicz & Prisyazhnuk, 2006.

hammered surface which is lost on the later parts of the protoconch. Transition to the teleoconch marked by an indistinct rim. An irregular, dense sculpture of oblique growth lines is usually developed on the first two teleoconch whorls and close to the aperture; along the middle parts of the shell the sculpture is indistinct. A deep furrow is developed on the body whorl, causing a shallow concavity in the outline of the aperture. Deep umbilicus. The sub-trigonal aperture bears two prominent but rather thin parietal teeth and a blunt columellaris. A large palatal tooth reaches far into the aperture, almost touching the posterior parietal tooth.

Remarks: The species is a common element in the Middle Miocene of Central Europe. It is reported from the Badenian (MN6) of Hungary (Gál et al. 2000) and from the Sarmatian of the Steinheim Basin (Finger 1997) and the North-Alpine Foreland Basin (Schütt 1967). The Middle to Late Miocene *Vertigo callosa* (Reuss, 1852) differs clearly in its stout ovoid outline, the less incised sutures and the broader parietal teeth. *Vertigo angulifera* might thus be a stratigraphically important species, which — at least in the Central Paratethys area — allows a distinction between Sarmatian and Pannonian deposits.

Family: **Gastrocoptidae** Pilsbry, 1918
Genus: *Gastrocopta* Wollaston, 1878
Genus: *Sinalbinula* Pilsbry, 1916

Gastrocopta (Sinalbinula) sandbergeri
Stworzewicz & Prisyazhnyuk, 2006
(Fig. 5.9–10)

1875 *Pupa (Vertigo) suevica* — Sandberger: 654
2006 *Gastrocopta (Sinalbinula) sandbergeri* — Stworzewicz & Prisyazhnyuk: 167, figs. 1, 2A–E

Description: Moderately slender shell of 5 convex whorls, pointed apex and weak sculpture of growth lines. Expanded aperture with extended columellar lip covering the lower third of the last whorl's base. Strong apertural sculpture consisting of a large, protruding, biplicated parietal tooth accompanied by a weaker infrapalatalis, a prominent, slightly adapically inclined columellar fold followed by a basalis of almost same strength. Outer lip structured by a protruding inferior palatal tooth, a slightly weaker superior palatalis and a small suprapalatalis (following the terminology of Lueger 1981).

Remarks: Stworzewicz & Prisyazhnyuk (2006) introduced *Gastrocopta sandbergeri* as a new name for the nomen nudum *Pupa suevica* of Sandberger (1875). This species already appears during the early Middle Miocene in Poland (Stworzewicz & Prisyazhnyuk 2006) and is a common species in the Sarmatian of Steinheim (Finger 1997). The early Sarmatian shell described by Schütt (1967) from the North-Alpine Foreland Basin as *Gastrocopta suevica* differs considerably in its elongate outline and the weak aperture structures. *Gastrocopta sandbergeri* seems to be restricted to the Middle Miocene; superficially similar shells from the Late Miocene (partly described as *G.*

suevica, e.g. Schlickum 1976) represent *Gastrocopta nouletiana* (Dupuy, 1850) or *Gastrocopta serotina* (Ložek, 1964) (see Lueger 1981; Harzhauser & Binder 2004).

Family: **Clausiliidae** Gray, 1855
Genus: *Pseudidyla* Boettger, 1877

Pseudidyla martingrossi Harzhauser & Binder nov. sp.
(Fig. 6.1–3)

Material: 5 specimens from Gratkorn in Styria/Austria.
Holotype: Fig. 6.3, NHMW 2006z0236/0005, height: 1.9 mm.
Paratype: Fig. 6.1, NHMW 2006z0236/0002, height: 3.8 mm.
Paratype: Fig. 6.2, NHMW 2006z0236/0004, height: 3.1 mm.
Type locality: Gratkorn, Austria; 15°20′55″ E/ 47°08′15″ N.
Type stratum: Paleosol close to the top of the "Gravels of Gratkorn".
Age: Middle Miocene, late Sarmatian (= late Serravallian).
Name: In honour of Martin Gross — paleontologist at the Landesmuseum Joanneum in Graz, who discovered this new species.
Description: Small-sized clausiliid; protoconch high trochospiral consisting of 2 bulbous, smooth whorls, which are slightly wider than the first teleoconch whorl. The first three teleoconch whorls are turreted with almost sub-parallel flanks. Later whorls increase in width. Entire teleoconch covered by coarse and densely spaced axial ribs, partly dichotomizing. Last whorl with neck and distinct neck furrow. Depressed fig-like aperture with wide sinulus and basal furrow. Superior lamella narrow, long and slightly curved; followed by 2 very weak peristome folds on the interlamellar. A prominent inferior lamella is divided in two branches which terminate shortly before the margin of the aperture. The surface of the anterior lamella displays a pattern of tiny nodes, being elongated parallel to the axis (Fig. 6.2a). The subcolumellar fold curves down obliquely and terminates in a weak denticle. The basal furrow is delimitated by this fold on the right and by an indistinct swelling on the left. A thin, continuous, upper palatal fold and a short middle one are developed (visible in fractured specimens Fig. 6.2). A knoblike thickening follows below on the palatal. Anterior margin everted and forming a thickened lip in adult specimens.
Remarks: Only a few *Pseudidyla* species are described from the Miocene of Europe (see Nordsieck 1981). *Pseudidyla schultzi* Binder, 2004 from the Early Miocene of Oberdorf (Styria, Austria) differs by its folds on the interlamellar and by additional folds below the inferior lamella and the palatal plicae. *Pseudidyla polyptyx* Boettger, 1877 from the early Middle Miocene of Hrušovany (Czech Republic) and late Early Miocene of Teiritzberg (Austria) is larger and displays a much weaker axial sculpture. Further, it differs by the interlamellar folds, the presence of a lower palatal-fold and the absence of a palatal-

swelling (see Binder 2002). *Pseudidyla polyptyx supragonypteryx* (Schütt, 1967), an early Sarmatian subspecies redescribed by Nordsieck (1981), is clearly distinguished by the smaller protoconch, consisting of a single whorl, the broad early teleoconch, the wide aperture, the shorter superior lamella, the smaller inferior lamella and the finer axial sculpture of the last whorl. *Pseudidyla moesingensis* Sandberger, 1875 differs by its divided subcollumelar lamella and 1–2 folds on the left basal mouth-edge. *Pseudidyla boettgeri* Nordsieck, 1981, from the Middle Miocene of Opole in Poland, is highly reminiscent of the new species but develops a narrower aperture, a deeper basal furrow and a correspondingly more pronounced keel. *Pseudidyla moersingensis hollabrunnensis* Schütt, 1967 differs by the absence of the two branches of the inferior lamella. Another similar species is the Late Miocene to Pliocene *Clausilia strauchiana* Nordsieck, 1972, which differs in its slender teleoconch and shorter superior lamella.

Family: **Punctidae** Morse, 1864
Genus: *Punctum* Morse, 1864

Punctum parvulum Gottschick, 1920
(Fig. 6.6–6a)

1920 *Punctum propygmaeum parvulum* — Gottschick: 39
1997 *Punctum propygmaeum parvulum* — Finger: 18, pl. 10, figs. G–I

Description: Small-sized, depressed to almost flat trochoid shell of 1.4 protoconch whorls and only 2 teleo-

conch whorls. Protoconch ornamented by weak spiral threads covering the flanks and top of the whorls. In the anterior third of the whorls, a very delicately hammered surface sculpture appears, being most prominent on the initial cap. A dense pattern of sigmoidal growth lines, crossed by weak spiral threads, forms the sculpture of the teleoconch.

Remarks: This species was usually treated as a subspecies of *Punctum propygmaeum* (Andreae, 1904) or as a synonym of that Middle to Late Miocene species (e.g. Lueger 1981). The protoconch and early teleoconch of *Punctum parvulum* from Steinheim (in Finger 1997) and from Gratkorn differ from that of *Punctum propygmaeum* as illustrated by Lueger (1981) from the Late Miocene of the Vienna Basin. The Sarmatian species develops a more prominent sculpture of spiral threads and the radial sculpture of the early teleoconch is accentuated by spiral threads. Moreover, the Late Miocene shells develop an additional teleoconch whorl.

Family: **Patulidae** Tyron, 1866
Genus: *Discus* Fitzinger, 1833

Discus euglyphoides (Sandberger, 1874)
(Fig. 6.4)

1874 *Patula (Charopa) euglyphoides* — Sandberger: 583, pl. 29, fig. 1
2006 *Discus euglyphoides* — Kókay: 74, pl. 28, figs. 1–2

Description: All available specimens are fragmented or subadult, consisting of only 2–3 strongly convex teleo-
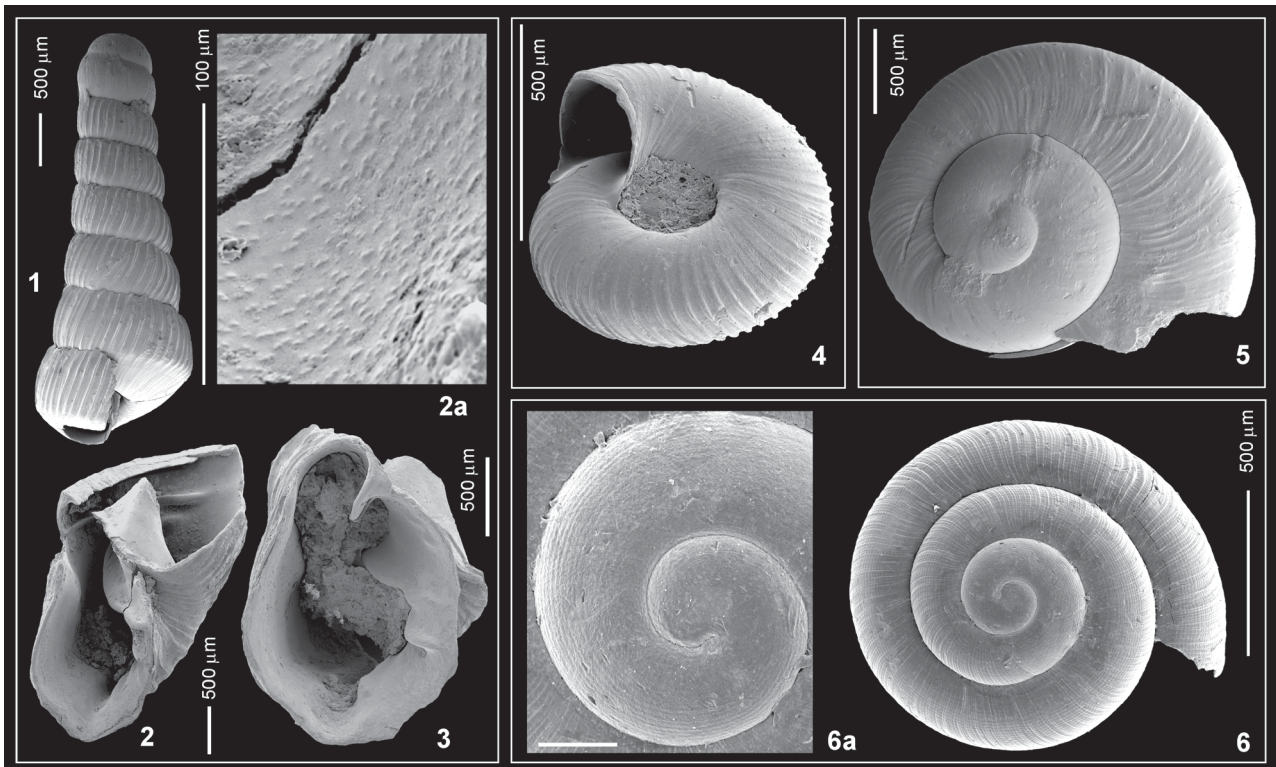

Fig. 6. 1–3 — *Pseudidyla martingrossi* Harzhauser & Binder nov. sp., (3 holotype); **4** —*Discus euglyphoides* (Sandberger, 1874); **5** — *Nesovitrea boettgeriana* (Clessin, 1877); **6–6a** — *Punctum parvulum* Gottschick, 1920.

conch whorls. Outline depressed conical. Adult shell ornamented with prominent, dense, regular, prosocline axial ribs which continue on the base, reaching into the wide, perspectivic umbilicus. Protoconch consisting of 1¼ convex whorls with deep sutures and weak, hammered, wrinkled surface sculpture.

Remarks: *Discus euglyphoides* is known from the Sarmatian of the Styrian Basin and from the Middle Miocene of Zwiefaltendorf (Schlickum 1976). A further occurrence in the Sarmatian of the North-Alpine Foreland Basin is reported by Schütt (1967), who identified his specimen as *Discus pleuradrus* (Bourguignat, 1881). The Badenian to Pannonian *Discus pleuradrus* lacks the strong radial ribs on the base and is less conical. Its protoconch is less inflated and bears some adsutural axial wrinkles (see Harzhauser & Binder 2004). *Discus costatus* (Gottschick, 1920), which is considered to be a synonym of *Discus pleuradrus* by Lueger (1981), differs in its slightly keeled body whorl and the narrower umbilicus. *Discus euglyphoides* was probably frequently intermingled with *Discus pleuradrus* (Bourguignat, 1881), obscuring its range and geographical distribution.

<div align="center">

Family: **Oxychilidae** Hesse, 1927
Genus: *Nesovitrea* Cooke, 1921

Nesovitrea boettgeriana (Clessin, 1877)
(Fig. 6.5)

</div>

1877 *Hyalinia boettgeriana* — Clessin: 35
1976 *Nesovitrea (Perpolita) boettgeriana* — Kókay: 76, pl. 28, figs. 13–15

Description: A very small depressed trochoid shell of 2.2 mm diameter. The low protoconch hardly emerges; its surface is almost smooth except for very delicate spiral threads close to the suture. The only available specimen displays a marked rim and constriction separating a totally smooth part of the protoconch (0.75 whorls) from the weakly ornamented rest (0.5 whorls). The sculpture on the teleoconch consists of somewhat irregular growth lines. The base is not accessible.

Remarks: The shell is reminiscent of the Late Miocene *Nesovitrea disciformis* (Lueger, 1981). That species differs only in its larger size, weaker sculpture and an even less convex protoconch. Moreover, the conspicuous constriction is not developed within the protoconch but at the transition to the teleoconch (see *Nesovitrea disciformis* in Harzhauser & Binder 2004, pl. 11, fig. 14).

Nesovitrea boettgeriana is an Early to Middle Miocene species, being reported up to now only from southern Germany and Hungary (Clessin 1877; Gál et al. 1999; Kókay 2006).

<div align="center">

Family: **Vitrinidae** Fitzinger, 1833
Genus: *Oligolimax* Fischer, 1878

Oligolimax sp. (cf. *suevica* (Sandberger, 1874))
(Fig. 7.4)

</div>

Description: A single protoconch of 0.9 mm diameter is available. The initial part is rather flat and only weakly emerging from the following whorl, which becomes increasingly convex. The ornamentation consists of a conspicuous spiral pattern of small pits. The spiral rows are rather irregular and 10 to 20 µm apart. The poor regularity of the spiral patterns becomes even less distinct towards the teleoconch.

Remarks: Protoconch information on *Oligolimax* is available for the Greek *Oligolimax cerigottana* (Gittenberger) and *Oligolimax cepahalonica* (Rähle) illustrated in Gittenberger (1992). Both species differ from the herein described protoconch in the much more regular arrangement of the spirals. Distinctly more similar is the protoconch sculpture of the Italian *Oligolimax annularis* (Studer, 1820) as illustrated in Manganelli & Giusti (2004), which differs only in its rugolose growth lines.

A similar protoconch, probably of the same species, is illustrated as "*Vitrina* sp." in Finger (1997) from Steinheim in Germany. These protoconchs therefore probably represent *Oligolimax suevica* (Sandberger, 1874), which is widespread in Sarmatian deposits (e.g. Schütt 1967).

<div align="center">

Family: **Limacidae** Lamarck, 1801
Genus: *Limax* Linnaeus, 1758

Limax sp.
(Fig. 7.1)

</div>

Remarks: Thin limacid shells with parallel margins. Specimens from the Steinheim Basin described by Finger (1997) might be conspecific. *Limax* sp. in Harzhauser & Kowalke (2002) from the upper Sarmatian of the Eisenstadt-Sopron Basin in Austria is more elongate. *Limax excavatus* Andreae, 1904 from the lower Sarmatian of the North-Alpine Foreland Basin (Schütt 1967) lacks the parallel margins but is elliptical in outline.

<div align="center">

Family: **Testacellidae** Gray, 1840
Genus: *Testacella* Draparnaud, 1801

Testacella schuetti Schlickum, 1967
(Fig. 7.2–3)

</div>

1967 *Testacella schuetti* — Schlickum: 63, fig. 1
1967 *Testacella (Testacella) schuetti* — Schütt: 218, fig. 19

Description: Small-sized, ear-shaped, robust shells of elongated ovoid outline. The apex is only weakly protruding and knob-like. Early shell covered with a weak, dense ornament of tiny, shallow pits which form a faint radial striation. This radial sculpture is gradually replaced by wrinkled axial grooves culminating in distinct growth lines in adult shells. Aperture elongated, wide with strongly thickened columella and a low parietal swelling. Muscle scar deep, strongly curved and sickle shaped.

Remarks: Only a few *Testacella* species are described from the Middle and Late Miocene of Europe. Most of them, such as *Testacella zelli* Klein, 1853 from the *Silva-*

na beds in Germany (e.g. Schlickum 1976), differ by the pointed apex. An unidentified *Testacella* shell from the Pannonian of Leobersdorf in the Vienna Basin (Lueger 1981) differs by its less elongated outline and the absence of sculpture. Hence, *Testacella schuetti* is only known from Sarmatian deposits of the North-Alpine Foreland Basin and the Styrian Basin. The abundance of the otherwise rarely documented species indicates that *Testacella schuetti* might have preferred moist settings in wetland habitats. Correspondingly, the second known occurrence in the Sarmatian of Lower Austria (Schlickum 1967) was found in shoreface sands and is one of the most frequent species there (Schütt 1967).

Family: **Camaenidae** Pilsbry, 1895
Genus: *Pleurodonta* Fischer von Waldheim, 1807

Pleurodonte michalkovaci Binder & Harzhauser nov. sp.
(Fig. 7.5a–d)

Material: 1 specimen from Gratkorn in Styria/Austria.
Holotype: Fig. 6.5, Joanneum Inv. No. 203458, diameter: 1.9 mm.
Type locality: Gratkorn, Austria; 15°20′55″E/ 47°08′15″N.
Type stratum: Paleosol close to the top of the "Gravels of Gratkorn".
Age: Middle Miocene, late Sarmatian (= late Serravallian).

Name: In honour of Michal Kováč, an earth scientist at the Comenius University, who is a specialist on the geodynamics of the Pannonian realm.
Description: Depressed and flattened shell with four regularly increasing whorls. The smooth earliest part of the protoconch is followed by a sculptured part comprising delicate, curved ribs with tiny knobs. The first teleoconch whorl bears delicate, sickle-shaped axial ribs, whereas the following whorls display slightly irregular and less delicate primary and secondary ribs. Immediately before the aperture, the last whorl abruptly turns down (60°). The thickened and reflected mouth-edge forms a lip. The ovoid peristome covers large parts of the umbilicus. The micro-sculpture consists of little knobs arranged in rows and forming wavelike sculpture.
Remarks: The fossil specimen is partly fractured and depressed by compaction. Nevertheless, the large protoconch with delicate ribs and knobs, the shell outline and the lip morphology allow an affiliation with the Camaenidae. This gastropod family is widespread in the tropics and occurs in South America, the Caribbean islands and in eastern Asia and Australasia (Richardson 1985). The fossil representatives of this group indicate a much wider distribution during the Cenozoic Era (compare Andreae 1904; Binder 2004) and reveal this group as an interesting climate proxy. In Central Europe, the Sarmatian *Pleurodonte michalkovaci* is among the last representatives of this family aside from a last range expansion during the middle Pannonian.
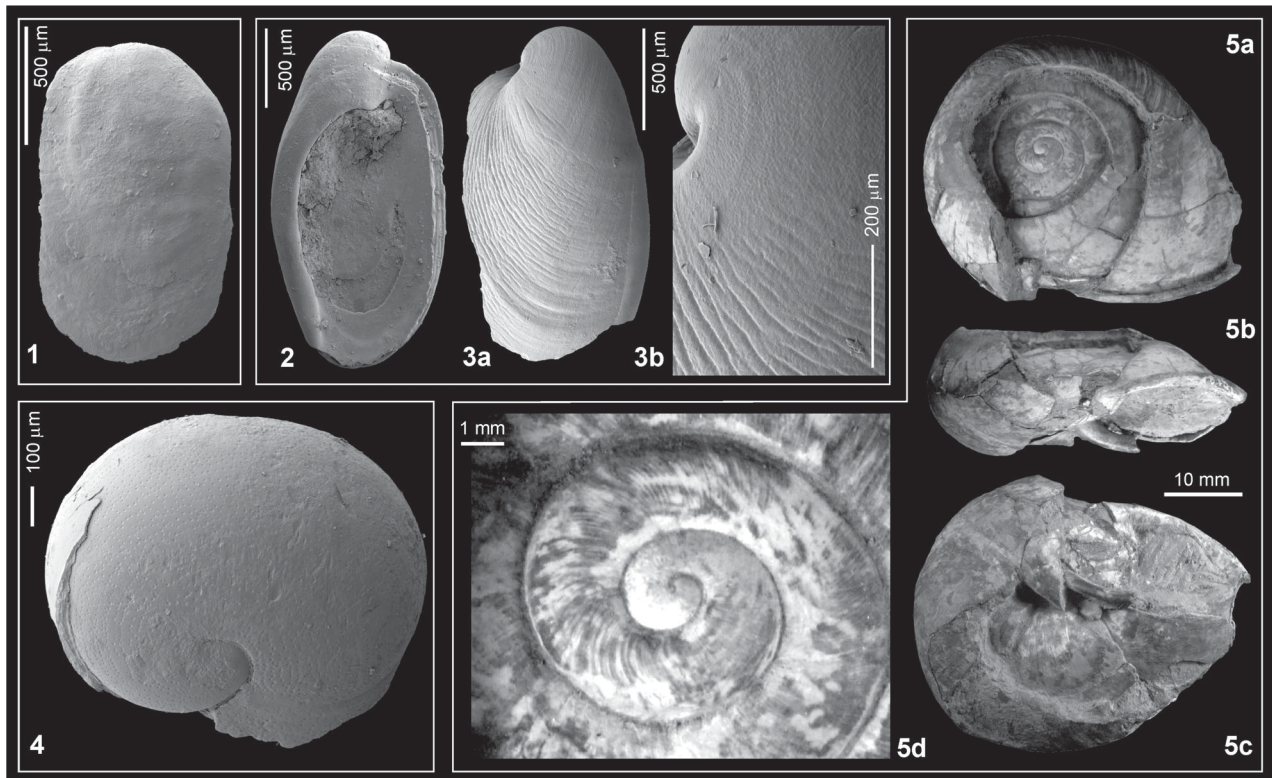

Fig. 7. 1 — *Limax* sp.; **2–3** — *Testacella schuetti* Schlickum, 1967; **4** — *Oligolimax* sp. (cf. *suevica* (Sandberger, 1874)); **5a–d** — *Pleurodonte michalkovaci* Binder & Harzhauser nov. sp. (holotype).

The only comparable species is *Galactochilus sarmaticus* (Gáal, 1911) from the Sarmatian of Răcăştie in Romania. It differs from *Pleurodonte michalkovaci* by its larger protoconch and by its almost fully covered umbilicus.

Results and discussion

A total of 17 gastropod species are recorded. This low to moderately diverse assemblage is strongly dominated by very few taxa. The most frequent species are terrestrial taxa such as *Testacella schuetti* Schlickum, 1967, *Gastrocopta (Sinalbinula) sandbergeri* Stworzewicz & Prisyazhnyuk, 2006, *Vertigo angulifera* Boettger, 1884, *Pupilla iratiana* (Dupuy, 1850) and *Truncatellina lentilii* (Miller, 1900). All other species are rare and have been documented by 1–5 specimens only. Especially the aquatic gastropods are almost absent. A single fragment of a *Bithynia*-operculum and a solitary *Gyraulus vermicularis* (Stoliczka, 1862) represent the entire aquatic gastropod fauna. This composition is not surprising, considering the terrestrial depositional environment (paleosol). The absence of typical inhabitants of moist habitats such as carychiids is highly unusual.

Biostratigraphy

The main problem of the Gratkorn Basin project was to separate Middle Miocene from Upper Miocene deposits. The lack of marine taxa typical for Sarmatian deposits and endemic Lake Pannon molluscs — indicative for the Late Miocene (Pannonian) — complicated the biostratigraphic evaluation. The mainly terrestrial gastropod fauna, however, turned out to be highly significant for the Middle Miocene (Table 1). Only 2 species are also known from Pannonian (Late Miocene) faunas (*Vallonia subpulchella*, *Negulus gracilis*), whilst most taxa are restricted to the Middle Miocene. Moreover, only 4 taxa already appear in the early Middle Miocene (Badenian) and persist into the Sarmatian (*Platyla callosiuscula*, *Vertigo angulifera*, *Gastrocopta (Sinalbinula) sandbergeri*, *Nesovitrea boettgeriana*). At least 4 species, namely: *Pupilla iratiana*, *Truncatellina lentilii*, *Punctum parvulum*, and *Discus euglyphoide* occur during the late Middle Miocene (late Badenian and Sarmatian). Finally, *Testacella schuetti* and *Gyraulus vermicularis* are restricted to the Sarmatian. The total assemblage is therefore indicative for the Sarmatian stage.

Biogeography

The still rather punctiform knowledge of the Miocene terrestrial mollusc fauna and the usually rather vague stratigraphic correlation hampers the biogeographic analysis. The discrimination of biogeographic from stratigraphic differences among the Central European assemblages is often difficult. Nevertheless, the small fauna displays only a negligible percentage of endemism. Among the terrestrial taxa, only *Pseudidyla martingrossi* nov. sp. and *Pleurodonte michalkovaci* nov. sp. are unknown from other localities. *Testacella schuetti* had a restricted distribution, being known so far from the North-Alpine Foreland Basin and the Styrian Basin. Similarly, the aquatic *Gyraulus vermicularis* is recorded only from the Styrian Basin and the Eisenstadt-Sopron Basin. All other taxa are widespread in Central Europe during the Middle Miocene. The closest relation exists with the assemblages from the Steinheim Basin in southern Germany, as described by Finger (1997), and with the early Sarmatian assemblage from Hollabrunn in the Austrian part of the North-Alpine Foreland Basin (Schütt 1967). A good correlation is also evident with the Middle Miocene *Silvana* beds of southern Germany (e.g. Zwiefaltendorf & Schlickum 1976). This pattern indicates that the Gratkorn Basin was settled by a typical Central European terrestrial fauna. The western extension of the Paratethys Sea into the North-Alpine Foreland Basin had already retreated to the Vienna Basin, allowing a southward migration of the Central European terrestrial gastropod faunas. Nevertheless, the Eastern Alps already formed a considerable elevation and might have acted as a barrier for migration. The connection of the "southern" fauna with those in the North was therefore probably only given along the narrow lowland fringe bordering the Eastern Alps along the Vienna Basin and the Styrian Basin.

Paleoecology

The paleoecological interpretation of the terrestrial assemblage is also difficult. Most of the represented genera have modern congeners, which together cover a broad range of environmental requirements. The low percentage

Table 1: Stratigraphic distribution of the Gratkorn Basin mollusc fauna (Sar. = Sarmatian).

Stratigraphy / Taxa	MIOCENE		
	MIDDLE		LATE
	Badenian	Sar.	Pannonian
Platyla callosiuscula	– –		
Bithynia sp.	—		
Gyraulus vermicularis		—	
Vallonia subpulchella	———————	—	————
Pupilla iratiana	——		
Truncatellina lentilii	——		
Negulus gracilis	– – – –	– –	———
Vertigo angulifera	——		
Gastrocopta (S.) sandbergeri	——		
Pseudidyla martingrossi		—	
Punctum parvulum	——		
Discus euglyphoides	– –		
Nesovitrea boettgeriana	——		
Oligolimax sp. [cf. *suevica*]	——		
Limax sp.	——		
Testacella schuetti		—	
Pleurodonte michalkovaci		—	

of aquatic taxa supports the interpretation of a paleosol for the basal layer. The most abundant species is the slug *Testacella schuetti*. Modern *Testacella* species live mainly underground as earthworm predators. This implies an at least moderately moist sol cover on an alluvial plain. Rotting wood and plant-litter in swampy environments or wet grassland are preferred by modern *Nesovitrea*, *Discus* and some vertiginids. Extant *Platyla* species inhabit leaf-litter in moist woodland but may, as the calciphile *Platyla gracilis*, also occur in screes. Leaf-litter is the typical habitat of the snaggletooth *Gastrocopta* and for *Punctum*. These genera and *Vertigo*, however, may also spread into open and drier habitats similar to *Vallonia*, which is frequent in open and dry grassland. Many European vertiginids and valloniids are calciphile species. Modern congeners of the frequent *Truncatellina lentilii* (Miller, 1900) and *Pupilla iratiana* (Dupuy, 1850) are xerophile and thermophile species, which rely on calcium-rich substrates in open landscapes. For data on extant species see Ložek (1964), Kerney et al. (1979), Fechter & Falkner (1989), Wiese (1991) and references therein. The absence of terrestrial taxa, which are usually frequent along the shores of lakes, such as *Carychium,* is enigmatic.

In conclusion, woodland with moist sol offered habitats for abundant ear-shell slugs, gastrocoptids and vertiginids along with rarer representatives of *Discus* and *Nesovitrea*. The frequency of *Truncatellina lentilii* and *Pupilla iratiana* suggest that nearby limestone-screes and sun-exposed open areas were present as well.

Conclusions

The terrestrial gastropod fauna from the basal beds of the limnic basin fill of the Gratkorn Basin indicates a Sarmatian (late Middle Miocene) age of the sediments. The depositional environment was a vegetated alluvial plain with a moist sol cover, some sun-exposed open areas and nearby limestone-screes. The overlying pelites of the clay pit St. Stefan are interpreted by Gross et al. (2007) to reflect the transgression at the beginning of the late Sarmatian. While in the open Styrian Basin marine depositional sediments predominated, a limnic environment developed in the Gratkorn Basin. The hydrological and geographical frame for the development of lentic freshwater systems in intramontane Alpine satellite basins of the Pannonian Basin complex originated geodynamically during mid-Sarmatian times. This phase coincided with a period of intense regression at the end of the early Sarmatian. Up to 100 m of sand and gravel were deposited in the Styrian and Vienna Basins, and the Alpine embayments fell dry. Erosion and basinward progradation of alluvial-fluvial/deltaic systems occurred (Harzhauser & Piller 2004; see Strauss et al. 2006). This drop in relative sea level is widely recognized in the Eastern Alpine realm and was correlated by several authors with a pronounced uplift of the basement (e.g. Winkler-Hermaden 1951, 1957; Harzhauser & Piller 2004). The paleosol at the base of the clay pit St. Stefan documents a short period of landscape stability on the alluvial plain. In a more distal position (about 40 km to the SE), Papp (1958) similarly recorded, close to the top of the mid-Sarmatian gravels, a small, poorly preserved, allochthonous terrestrial gastropod fauna. In contrast to the marginal setting of the Gratkorn Basin, these deposits comprise marine foraminifers and molluscs of the lower *Porosononion granosum* Zone (see Kollmann 1965). The subsequent late Sarmatian transgression caused the sedimentation of marine marls in the deeper parts of the Styrian Basin, while in the proximal Gratkorn and northwesternmost Styrian Basin (Graz area) limnic conditions prevailed. The recorded normal polarity for the pelites of St. Stefan (pers. comm. R. Scholger) is in good correspondence with the Chron C5An.1n around 12 Ma. Several mixed siliciclastic-oolitic parasequences follow in the adjacent Styrian Basin in the upper Sarmatian (Friebe 1994; Kosi et al. 2003; Harzhauser & Piller 2004). For a very brief period, one of these oolite shoals even extended into the limnic systems at Mariatrost close to the Gratkorn Basin (Fig. 1, own mapping M.G.), but did not enter this intramontane basin.

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