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The Early Sarmatian – hidden seesaw changes

With 11 figs, 3 pls, 1 tab.

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Abstract

The Sarmatian stage is the deprived child of European stratigraphers, being usually simply referred to as the brackish transition from the "enthralling" Badenian with its diverse marine fauna towards the Pannonian with its exciting endemic freshwater species. In this paper we focus the attention on the swift fluctuations of the relative sea-level during the Early Sarmatian. These shifts are usually accompanied by changes in the faunal assemblages and are thus of regional rather than merely local importance.

Three sea-level fluctuations of different magnitude are proposed for the Early Sarmatian. They established as part of the LST and TST of a global 3rd order sequence. During the LST, gravel-filled incised valleys of the Molasse Basin and shallow marine environments became established in the Vienna Basin. The transgression coincides with pelitic sedimentation along the basins' margins. The maximum flooding might be indicated by the formation of thin diatomites and fish-bearing shales. Unique polychaete/bryozoan bioconstructions develop in the littoral zone during the Early Sarmatian. A minor regression caused the emergence of these carbonates, reflected by caliche, micro-stalactitic cements and *Microcodium*. A last transgressive impulse is well documented by the deposition of *Elphidium*-bearing sand above the erosional surface and by a very distinct transgressive shape of SP-logs in the Vienna Basin. The Lower Sarmatian is topped by a sudden ingression of alluvial gravel and other coarse siliciclastics in the Styrian Basin, the Eisenstadt-Sopron Basin and the Vienna Basin. This event is considered to have been triggered by regional tectonics, contradicting the general transgressive trend of the 3rd order cycle. However, the leap from Early Sarmatian siliciclastic depositional environments towards an oolithic-siliciclastic regime of the Late Sarmatian coincides with that regressive event. The accompanying change in the benthic faunas suggests that a more "pan-Paratethyan" aspect is involved.

Key words: Sarmatian, Middle Miocene, Central Paratethys, sea-level fluctuations, paleoecology, sequence stratigraphy

Zusammenfassung

Das Sarmatium ist das "ungeliebte Kind" der europäischen Stratigraphen. Es wird meist einfach als Übergang zwischen dem "spannenden" Badenium mit seiner diversen subtropisch-marinen Fauna und dem Pannonium mit einer bemerkenswerten endemischen Süßwasserfauna behandelt. In dieser Arbeit versuchen wir die Aufmerksamkeit auf die raschen Meeresspiegelschwankungen im frühen Sarmatium zu lenken. Diese Fluktuationen des Meeresspiegels sind meist mit drastischen Änderungen innerhalb der Faunen gekoppelt und dürften daher von überregionaler Bedeutung sein.

Drei deutliche Schwankungen des relativen Meeresspiegels können in dieser Studie für das frühe Sarmatium belegt werden. Diese können mit Teilen eines globalen Zyklus 3. Ordnung korreliert werden und entsprechen dessen LST und TST. Während des Tiefstandes wurden "incised valleys" des östlichen Molassebeckens mit fluviatilen Schottern gefüllt, während sich im Wiener Becken seicht-marine Bedingungen etablierten. Die folgende Transgression führte zu weitreichender pelitischer Sedimentation entlang der Beckenränder. Die maximale Überflutung (msf) könnte durch die Bildung von dünnen Diatomitlagen und "Fisch-Tonen" belegt sein.

Die einzigartigen Polychaeten-Bryozoen Biokonstruktionen des frühen Sarmatium entstanden zu dieser Zeit entlang der Küsten. Eine geringe Regression ließ die Karbonate auftauchen und es bildeten sich verschiedene pedogene Strukturen wie Caliche und *Microcodium* sowie mikrostalaktitische Zemente.

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Eine erneute Transgression plombierte die freiliegenden Karbonate bei Mannersdorf, wo Elphidium-Sande abgelagert wurden. In SP-logs des Wiener Beckens ist dieser transgressive Impuls sehr deutlich durch "fining upward" Kurven belegt. Diese transgressive Phase findet ein abruptes Ende durch plötzliche Schüttungen von fluviatilen Konglomeraten und groben Sanden im Steirischen, Eisenstädter und Wiener Becken. Dieses – wahrscheinlich tektonisch initiierte – Ereignis läuft dem generell transgressiven Trend des 3rd order TST zuwider.

Obwohl die Sequenzgrenze somit wahrscheinlich durch regionale Entwicklungen gesteuert wird, ist der Umschwung innerhalb der Ablagerungsregimes auffällig. Der Wechsel von siliziklastischen Systemen des tieferen Sarmatium zu gemischt siliziklastischen-oolithischen Ablagerungen des oberen Sarmatium wird durch diese Regression eingeleitet. Der damit einhergehende Faunenschnitt lässt vermuten, dass auch überregionale Mechanismen im Spiel sind.

Schlüsselworte: Sarmatium, mittleres Miozän, Zentrale Paratethys, Meerespiegel-Schwankungen, Paläoökologie, Sequenz Stratigraphie

Introduction

The re-evaluation of more than 40 outcrops and several well logs with focus on the rapidly changing litho- and biofacies revealed the Sarmatian of the western Central Paratethys as a rather tricky story. In this paper we concentrate on changes of the relative sea level during the Early Sarmatian.

Whilst the facies architecture of Badenian and Pannonian strata of the western Pannonian Basin system has been intensively analyzed during the last decades (e.g., Kreutzer 1990, Weissenbäck 1996, Kovác et al. 1998, Fuchs et al. 2001), little attention has been drawn on the Sarmatian deposits. Consequently, the Sarmatian is usually somewhat underrated as a single genetic sequence of the late Middle Miocene (Vakarcs et al. 1998, Baráth & Kovac 2000), without focus on its internal variability. Recently, in the Styrian Basin, the Upper Sarmatian Gleisdorf Formation and parts of the underlying coarse siliciclastics, termed the Carinthian Gravel, have been studied in more detail based on seismic data by Kosi et al. (2003). No modern data, however, are available on the sedimentary environments of the Early Sarmatian for either the Vienna Basin or the Styrian Basin.

A regressive pulse in the late Early Sarmatian was already recognized by Papp (1956), who interpreted this as a result of tectonic movements in the alpine hinterland. In fact, this phase corresponds to a major but still poorly documented erosional episode. In addition, at least two smaller regressive phases can be documented in nearshore deposits of the Lower Sarmatian.

These changes in relative sea level can be traced at 4 surface sections in three separate tectonic entities: the Styrian Basin: Klapping in Styria (South Burgenland Swell), the Eisenstadt Sopron Basin: St. Margarethen Hummel Quarry in Burgenland (Rust Mountains) and the Vienna Basin: Mannersdorf Baxa Quarry in Lower Austria (Leitha Mountains), Petronell (Hainburg Mountains). Geophysical borehole logs of well Niedersulz 9 (Vienna Basin) and well Paldau 1 (Styrian Basin) provide a correlation with offshore settings. Clearly, the proposed Early Sarmatian fluctuations are well traceable in the western Central Paratethys and are probably related to larger-scale patterns, resulting in a sequence stratigraphic model.

Stratigraphic frame

The term Sarmatian was introduced in 1866 by Eduard Suess. In his original definition, Suess focused on deposits of the Vienna Basin such as the "Hernalser Tegel" and the "Cerithien Sande". By definition, the term Sarmatian is thus restricted to deposits that formed in the Central Paratethys Sea. Subsequently, however, the term Sarmatian was also used for deposits of Eastern Europe and Asia, which formed in the so-called Eastern Paratethys Sea. In this area, the term Sarmatian has to be abandoned and must

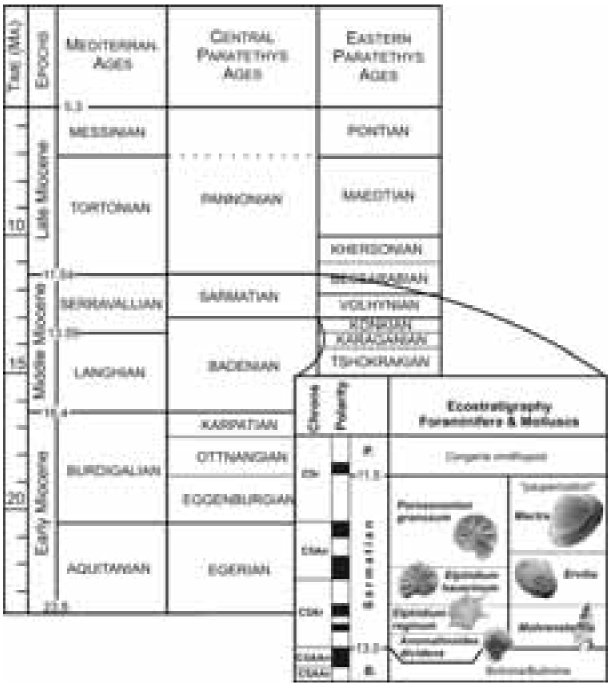


Fig. 1: Miocene chronostratigraphy of Europe modified after Rögl (1998) with ecostratigraphic zonation of the Sarmatian based on molluscs and benthic foraminifera.

be replaced by the regional stages Volhynian, Bessarabian, and Khersonian (fig. 1). According to Papp et al. (1974) and Popov (2001), the Sarmatian stage corresponds to the Volhynian and the Lower Bessarabian. Correspondingly, in this paper the term Lower/Early Sarmatian spans the *Mohrensternia* Zone and the lower part of the *Ervilia* Zone (mollusc zones) and the *Anomalinoides dividens* Zone, *Elphidium reginum* Zone, and *Elphidium hauerinum* Zone of the foram zonation. The Upper/Late Sarmatian comprises the upper part of the *Ervilia* Zone and the *Mactra Zone* of the mollusc zonation and the entire *Porosononion granosum* Zone of the foram zonation (see Papp et al. 1974 for discussion and references concerning this ecostratigraphic concept). A slightly different concept is offered by Görög (1992) and Bobrinskaya et al. (1998), who correlate the whole *Porosononion granosum* Zone with the Lower Bessarabian. This correlation, however, neglects the mollusc data that support the correlation as presented in fig. 1 (see Kojumdgieva et al. 1989 for further discussion).

Tectonic and geological setting

Sarmatian deposits are preserved in Austria in 4 main areas. These are the Vienna Basin with its subbasin the Eisenstadt-Sopron Basin (fig. 2), the Styrian Basin (fig. 3) and the Molasse Basin. We concentrate only on the Vienna Basin and the Styrian Basin.

1. *The Neogene Vienna Basin*, surrounded by the Eastern Alps, the West Carpathians and the western part of the Pannonian Basin, represents one of the best-studied pull-apart basins of the world (Royden 1985, Wessely 1988). It is rhombic, strikes roughly southwest-northeast, is 200 km long and nearly 60 km wide, and extends from Gloggnitz (Lower Austria) in the SSW to Napajedl (Czech Republic) in the NNE. The south-western border is formed topographically by the Eastern Alps and to the north-west by the Waschberg Zone. In the east it is bordered in the south by the hills of the Rosalia, Leitha and the Hainburg Mountains, and in the north-west by the Little Carpathian Mountains; all four hill ranges are part of the Alpine-Carpathian Central Zone. The Vienna Basin is connected with the Little Hungarian Basin via the "Hainburger Pforte" and with the Eisenstadt-Sopron Basin via the "Wiener Neustädter Pforte". The maximum thickness of the Neogene basin fill is 7000 m; the Sarmatian portion attains more than 1000 m in the central Vienna Basin (OMV data).

2. *The Eisenstadt-Sopron (Sub)Basin* is an asymmetrical subbasin of the Vienna Basin. It is more or less trigonal and measures about 20 x 20 km in width (Piller & Vavra 1991). In the north it is limited by the NE-SW trending Leitha Mountains and the associated SE dipping Eisenstadt fault (Fodor 1992). In the East, the basin is limited by the N-S trending Köhida fault system (Schmid et al. 2001). The Rust-Fertörakos Mountains separate the basin from the Danubian Basin in the East. A crystalline ridge, covered by Early Miocene gravel reaching from the Rosalia Mountains to the Brennberg, defines the southern margin. This topographical relief separates the Eisenstadt-Sopron Basin from the Styrian basin-complex tectonically and paleogeographically. The development of the Eisenstadt-Sopron Basin is closely linked with that of the Vienna Basin, although the thickness of the basin fill is much less (about 200 m in the marginal Mattersburg embayment according to Pascher 1991).

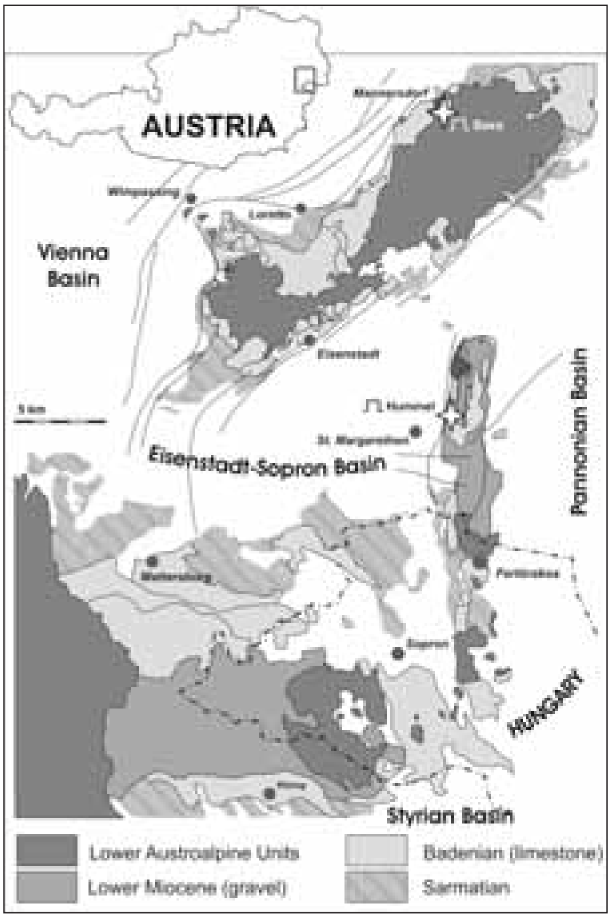


Fig. 2: Location map of the investigated sections in the Vienna Basin and the Eisenstadt-Sopron Basin.

3. *The Styrian Basin*, as a subbasin of the Pannonian Basin System, established during the Neogene at the eastern margin of the Eastern Alps. It is about 100 km long and about 60 km wide and contains about 4 km of Neogene sediments. It is divided into several small subbasins such as the Western Styrian Basin, the Mureck Basin, the Gnas Basin, and the Fürstenfeld Basin. It is separated from the Pannonian Basin by the South Burgenland Swell and is internally structured by the Middle Styrian Swell and the Auersbach Swell. An overview of the tectonic evolution of the Styrian Basin is given by Sachsenhofer (1996), and a detailed introduction into the surface distribution of the Sarmatian deposits is presented by Kollmann (1965). A composite section of the Sarmatian basin fill in the Styrian Basin suggests a thickness of up to 1050 m (Brix & Schultz 1993).

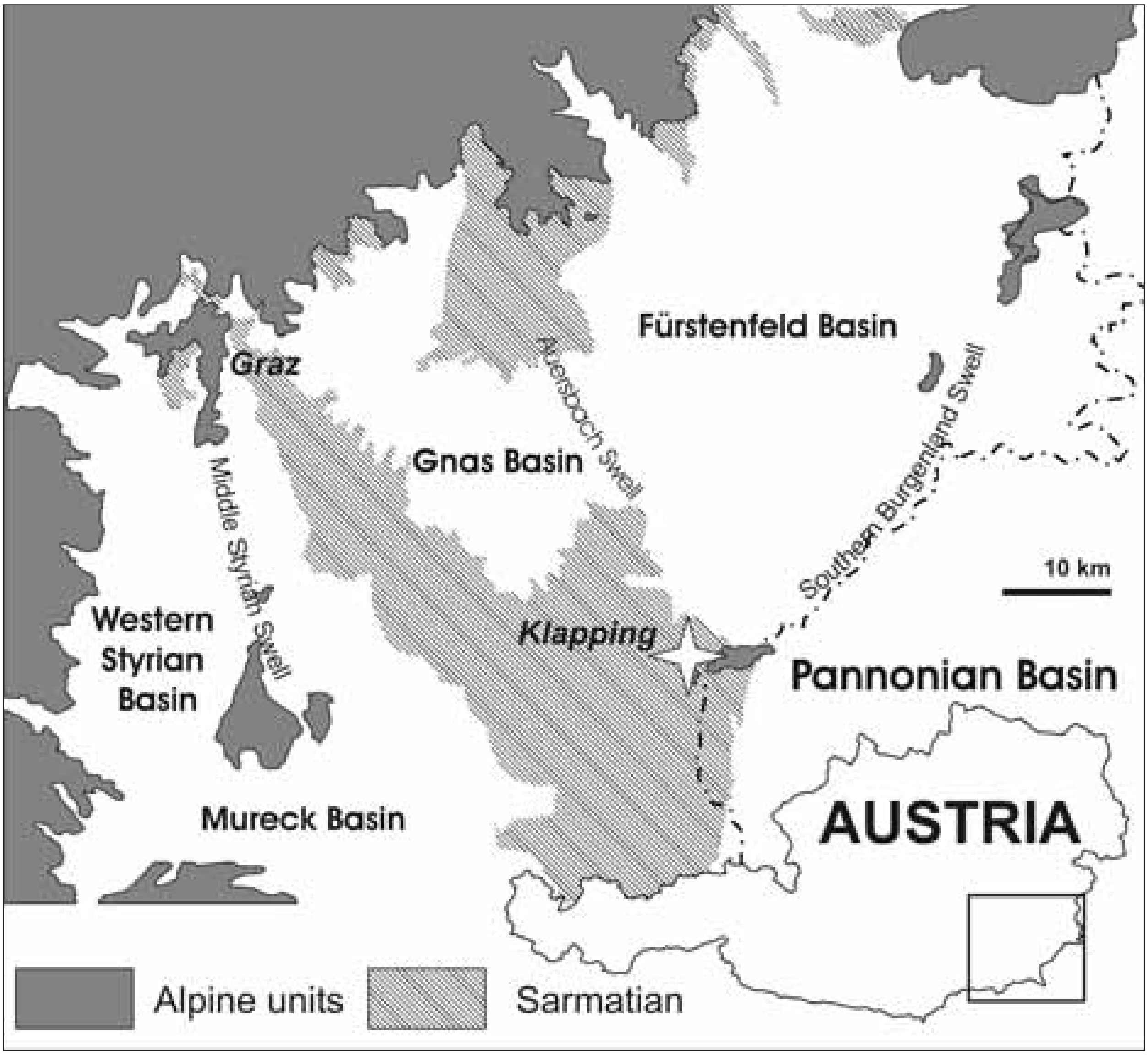


Fig. 3: Location map of the investigated sections in the Styrian Basin.

Investigated sections

1 *Vienna Basin*: Mannersdorf; Baxa Quarry

N 47° 57.78 / E 16° 35.65

The section is situated at the north-western wall at the entrance of the Baxa Quarry at Mannersdorf (Lower Austria). Its position at the foot of the Leitha Mountains points to a Sarmatian paleoenvironment along the SE coast of the Vienna Basin. The Sarmatian deposits yield limestones, marls and various mixed siliciclastic sediments of just under 7 m thickness. They are currently exposed along a pit wall of about 80 m width, overlying Triassic dolomite. Close by, Badenian corallinacean limestones form a thick cover on the Triassic carbonates in a higher topographic level starting ca. 10–20 m above the Sarmatian deposits. During the Sarmatian transgression, the Triassic dolomites formed a tectonically triggered erosional relief of up to 8 m height (see fig. 4). Especially section Baxa 2 typifies the steep walls which formed due to the roughly NNW-SSE striking faults.

Lithology

Five sections have been logged along the outcrop, exposing a rapidly changing and complex facies succession. Generally, two broad channel-shaped structures are preserved; they are separated by a dolomite ridge between section Baxa 3 and Baxa 2.

The lowermost part of the outcrop is made up by Triassic dolomite (unit 1) forming a tectonically induced and thereafter weathered paleorelief (pl. 1, fig. 1, 3a) overlain by a breccia (unit 2) containing mainly dolomite with scat-

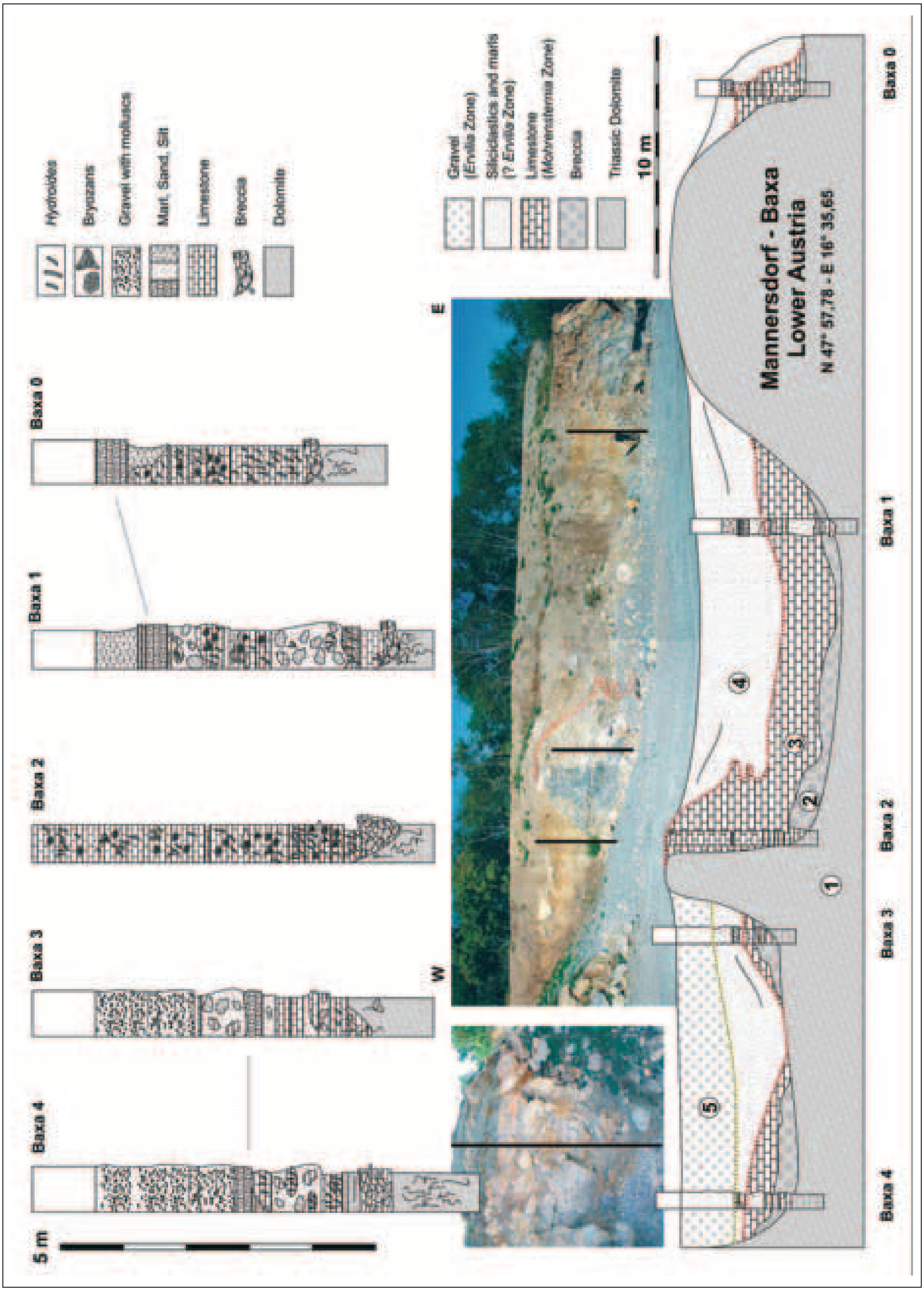


Fig. 4: Overview of the section Baxa in Mannersdorf (Lower Austria). The position of the investigated profiles (Baxa 0 – Baxa 4) within the outcrop is indicated.

tered limestone components. The latter bear tubes of the polychaete *Hydroides pectinata* (fig. 5, pl. 1, fig. 4b, pl. 2, fig. 1) and scattered molluscs that prove their Sarmatian age. The thickness of the breccia variies according to the relief but rarely exceeds 1 m. Pale, thick-bedded limestones (unit 3) follow, containing abundant colonies of *Hydroides* along with bryozoan bioherms composed of *Schizoporella* and celleporids. The thickness of this unit ranges from 5 m to 0 m due to erosion. Intercalations of siliciclastics, often bearing dolomite lithoclasts, are frequent. In-habitat reworking of already lithified Sarmatian limestones is also documented. Within intercalated layers of sandy marls, bioconstructions of *Hydroides* of up to 80 cm diameter and 40 cm height occur; they consist of cemented limestones in their core and grade laterally into marls with floating polychaete tubes (especially in sections Baxa 2 and 4).

The carbonatic unit (3) is overlain discordantly by a mainly sandy unit (4) of up to 3 m thickness. This starts with about 20-50 cm sand containing floating clasts of Sarmatian limestones and scattered dolomite pebbles.

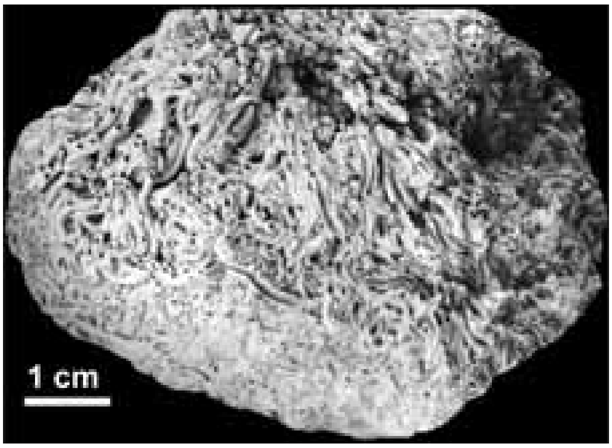


Fig. 5: A pebble of reworked Badenian corallinacean limestone which was settled by *Hydroides pectinata* during the Early Sarmatian. The specimen was found at Mannersdorf.

Additionally, a large lithoclast of Triassic dolomite (40 cm diameter) was found in section Baxa 1. This layer is followed by up to 50 cm calcareous marl with abundant plant debris. This bed allows a correlation of the sections Baxa 0 to 4. In the eastern channel (Baxa 0, 1, 2), poorly outcropped fine to medium sands with plant debris forms the top of the succession. The sand package is made up mainly of carbonate debris, elphidiid foraminifera and subordinate quartz (pl. 2, fig. 7). In the western channel the sandy unit is overlain by a 2.5 m thick layer of thick-bedded gravel with intercalations of corallinacean debris (5). The components are composed of dolomite pebbles and clasts of Badenian corallinacean limestone. Casts of reworked Badenian gastropods are common, whereas Sarmatian molluscs are represented only by rare casts of bivalves such as *Modiolus* and cardiids.

Biostratigraphy

The *Hydroides*/bryozoan limestones are typically developed during the Early Sarmatian. Equivalent deposits of the Styrian Basin and the Eisenstadt-Sopron Basin are dated into the *Mohrensternia* Zone (see biostratigraphy of the sections St. Margarethen and Klapping) based on the mollusc assemblage and the characteristic microfauna. At Mannersdorf the occurrence of *Mohrensternia* sp. in unit 3 of section Baxa 2 supports this dating. The complex lacks a significant microfauna and may thus correspond either to the *Anomalinoides dividens* Zone or to the *Elphidium reginum* Zone.

Unit 4 yields abundant, in some cases almost rock-forming elphidiids, which indicate the Early Sarmatian *Elphidium reginum* Zone. Typical taxa are *Elphidium reginum, Elphidium grilli*, *Elphidium aculeatum, Elphidium* cf. macellum, and *E. subumbilicatum* (determinations by F. Rögl, NHMW). The uppermost gravel lack any significant microfauna. Based on the poor mollusc fauna a range from Early to Late Sarmatian is possible.

Paleoecology and Dynamics

The basal breccia seems to have formed during an initial phase of transgression, which reworked the already tectonically altered and weathered dolomite basement. Sharp boulder edges indicate little transportation due to more or less autochthonous deposition. Attached to the dolomite rocks are crusts of microbial bindstones with large primary voids which are followed by cyanobacterial tufts (pl. 2, fig. 5) built by branched filaments (pl. 2, fig. 4). Peloidal microbial sediment fills the space partly between the tufts. The latter produce a digitate morphology of these basal encrustation (pl. 1, fig. 2, pl. 1, fig. 3b, pl. 2, fig. 5) and acted as base for the settlement of the polychaete *Hydroides pectinata* that formed numerous colonies. Laterally, these crusts often display alternate patterns of succession and facies alternation (pl. 1, figs 2–4b, pl. 2, figs 5–6). Frequently, the cyanobacterial crusts are followed by bryozoan and *Hydroides* dominated assemblages. The latter may be encrusted by nubeculariid foraminifera (pl. 2, fig. 6) and are overgrown by single-layered corallinacean algae (pl. 2, fig. 3), which are embedded into a microbial carbonate.

The preservation of the crusts along with the in-situ colonies of *Hydroides* indicate a rather calm and very shallow environment closely adjoining the dolomite ridges. Minor influx from the coast is documented by the occurrence of terrestrial gastropods (*Cepaea* sp.) within unit 3. The bedded limestones of unit 3 are best developed close to the dolomite ridge at Baxa 2. There, small cavities within the limestone can be observed, which are partly filled by a first generation of laminated fine sediments and a second generation of packstone with intraclasts (pl. 1, figs 5a-5b). These vugs seem to have formed within the well-cemented limestones due to vadose leaching. Microbial crusts, silt and asymmetrial cement rims (pl. 2, fig. 2) are characteristic features filling the cavities and point to a phase of emersion and partial erosion. This emersion phase is also well indicated by the discordant contact between unit 3 and 4. The unconformity is best exposed at section Baxa 0, where the sand of unit 4 cuts the limestone beds. Furthermore, at Baxa 2 the limestones of unit 3 formed a vertical relief filled by sand of unit 4.

Therefore, the overlaying beds are considered to represent a younger, but still Early Sarmatian, succession. The initial phase is indicated by the occurrence of dolomite pebbles and reworked Sarmatian limestone. This high-energy littoral environment is soon replaced by less agitated shallow marine settings which allowed the deposition of elphidiid sands and calcareous marls. The abundance and diversity of elphidiids suggest a deposition in a shallow sublittoral environment under more or less normal marine conditions, similar to modern elphidiid-dominated assemblages described by Murray (1991). Bioconstructers such as *Hydroides* or bryozoans are apparently missing.

Sarmatian *Hydroides*/bryozoan limestones are best preserved along the western parts of the channel-shaped structures, whereas this unit is strongly eroded along the eastern wings. The dolomite ridges clearly provided some shelter, allowing the carbonate to escape erosion in leeward position. This effect might be related to currents or wave directions. The same pattern apparently affected carbonate deposition prior to emersion. In both channels, unit 3 displays a succession of rather pure carbonates along the western flanks but yields siliciclastic intercalations with reworked limestones in the eastern part (compare log Baxa 2 with Baxa 1).

The Lower Sarmatian deposits of units 2 and 3 yield few reworked corallinacean limestones, whereas the units 4 and 5 bear abundant corallinacean fragments. Furthermore, the mollusc fauna of unit 5 comprises typical Badenian taxa such as *Astraea meynardi*, *Strombus* (*Lentigo) bonellii* and *Conus* sp. along with very rare Sarmatian species (*Musculus sarmaticus, Modiolus subincrassatus, Obsoletiforma* sp.). This points to intense reworking of Badenian deposits. The initial Sarmatian transgression during the *Mohrensternia* Zone therefore evidently did not reach the topographic level of the Badenian limestones along this part of the Leitha Mountains. In contrast, the second transgressive pulse, which developed still within the *Mohrensternia* Zone, rose to that level and formed the so-called "detrital Leitha limestone", which was exploited along the Leitha Mountains as Sarmatian building stone.

2 *Vienna Basin*: Petronell; abandoned undercut slope of the Danube

N 48° 07.33 / E 16° 52.99 – N 48° 07.23 / E 16° 52.92

The locality Petronell close to the village of Carnuntum in Lower Austria offers a composite section along a steep 20 m slope connecting the Pleistocene Petronell-Prellenkirchen terrace with the level of the modern Danube. The section was first investigated by Fuchs (1868), who correctly recognized the Sarmatian age of the succession and emphasized the occurrence of serpulids. Wessely (1961) assigned the section to the *Elphidium reginum* Zone and mentioned deposits with abundant *"Cibicides lobatulus"* outcropping in an underlying position

Lithology

The underlying Badenian deposits do not outcrop and the succession thus starts with about 3 m clay of Sarmatian

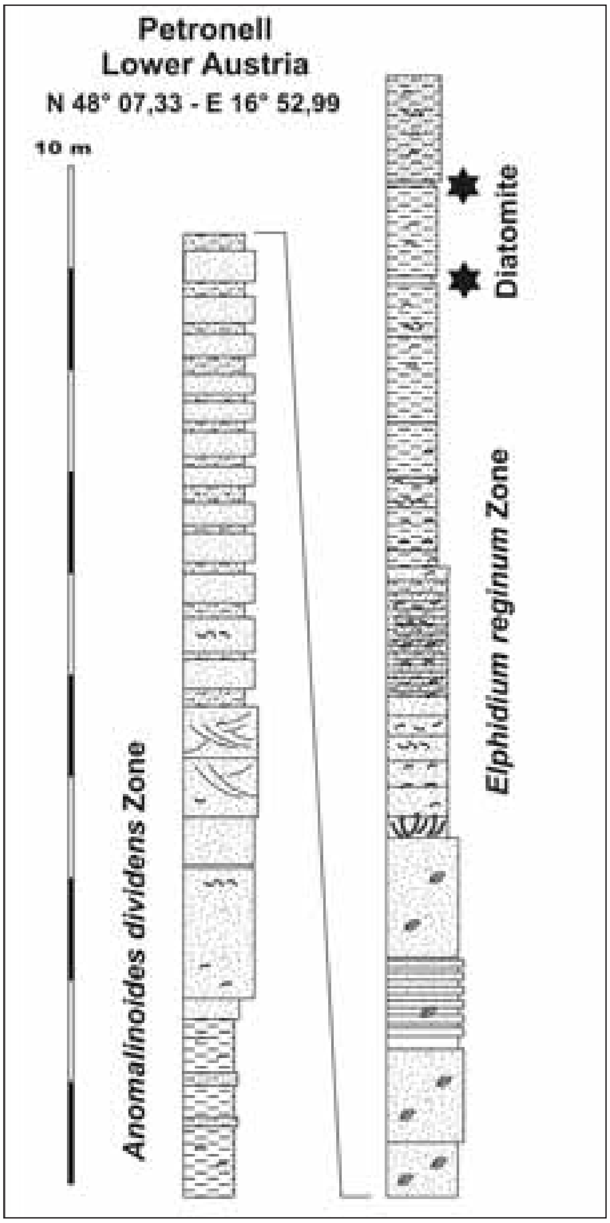


Fig. 6: Idealized log of the section Petronell. Note the fining upward trend in the top unit *(Elphidium reginum Zone)* and the coarsening upward cycle within the lower part which is dated as the *Anomalinoides dividens* Zone.

age. This clay passes into a 3 m thick unit of cross-bedded fine to medium sand with abundant, small-sized molluscs, forming loose covers on the top of the sets. This is followed by 4.5 m of sand interbedding with fine sands, medium sands and silty fine sands. The top of this sandy unit is formed by 3.5 m of thick-bedded fine to medium sand with numerous layers of plant debris and scattered fragments of lignite. The about 8 m thick silty-marly top unit displays a distinct fining upward trend. It starts with 3 m marly silt containing abundant tubes of the serpulid *Hydroides pectinata* along with masses of thin-shelled *Musculus sarmaticus* and *Modiolus subincrassatus*. A sandy layer of 10 cm thickness marks the transition to the following 5 m of marly clay and silt, which bears two thin beds of diatomite in the uppermost part. Two distinct beds of diatomite of 5–10 cm thickness, each consisting of few layers of diatomite with thin intercalations of clay, was detected. They are separated by an intercalation of 1 m of silty marl. Scattered fishes represent the sole macrofauna found within the diatomite. The mollusc fauna of the upper part is predominated by poorly preserved shells of *Ervilia, Abra* and *Mohrensternia*. Along this part of the section, small lenses of *Hydroides*-limestone are weathering from the outcrop. These consist exclusively of – usually unidirectionally orientated – tubes of *Hydroides pectinata* with marly matrix.

Pleistocene gravel of the Petronell-Prellenkirchen terrace truncate the Sarmatian succession.

Biostratigraphy

The mollusc fauna is highly indicative for the *Mohrensternia* Zone. A further subdivision can be recognized based on the foraminifera, indicating the *Anomalinoides dividens* Zone for the basal clay and the *Elphidium reginum* Zone for the fining upward unit in the top of the succession (pers. comm. F. Rögl, NHMW).

Paleoecology and Dynamics

The basal clays yield only cardiids but lack characteristic littoral molluscs of the Early Sarmatian. We suggest clay deposition in a shallow marine, calm environment off the coast for this part of the section. A shallowing is indicated by the coarsening upward cycle with cross-bedded sand. The mollusc fauna with abundant hydrobiids, *Mohrensternia, Ocenebra striata, Acteocina lajonkaireana, Donax lucidus*, and cardiids point to a deposition close to the shoreline. The faunal assemblage agrees fully with that of other Sarmatian shoreface environments as known from Hollabrunn in Lower Austria (Papp 1950). The shoaling finally culminates in coastal flats and ponds where leaves, axes and plant debris accumulated.

A renewed and more intense relative sea-level rise, indicated by the fining upward sequence in the top unit, replaced the littoral environment. In the initial phase, the silty sea-bottom was settled by masses of byssate *Musculus and Modiolus*. This assemblage switched to a mainly infaunal *Ervilia/Abra* assemblage towards the top, reflecting the deepening of the environment. Due to the lack of hardgrounds, the adherent *Hydroides* formed rather loose aggregates floating in the sediment. Small colonies could develop only close to the diatomitic level; they are represented as discontinuous lenses of limestone. The diatomite reflects a strongly reduced input of siliciclastics and documents a considerable bloom of algae. This and the position of the diatomite layers in the upper part of the succession within the "deep" *Ervilia/Abra* assemblage suggest that these layers correspond to the maximum flooding surface within this sequence.

3 *Eisenstadt-Sopron Basin*: St. Margarethen; Hummel Quarry "railway cut"

N 47° 48.14 / E 16° 37.89

The section Hummel is situated close to St. Margarethen in Burgenland. It represents an outcrop of up to 15 m height and more than 60 m length, which was originally built as an access for a private railway into the limestone quarry "Hummel". The so-called Leitha limestone, which is still exploited there as building stone, is of Badenian age and formed the paleorelief during the Sarmatian. Mainly Sarmatian deposits are outcropping within the W-E trending railway cut; they document a perfect cross section of a Sarmatian rocky coast (fig. 7).

Fuchs (1965) was the first to provide a sketch of the outcrop but assigned an incorrect age because he interpreted the entire succession as Late Sarmatian. In addition, he related the deposits with a single transgressive sequence.

As pointed out by Fuchs (1965), the area gives an impression of a steep rocky coast of the Sarmatian Sea, which was formed by already lithified Badenian corallinacean limestones. The N-S trending Köhida-fault zone controlled the paleomorpholgy and defines the eastern margin of the Eisenstadt-Sopron Basin (Schmid et al. 2001). The Rust Mountains, composed of metamorphics of the Austro Alpine unit, Early Miocene gravel and the Badenian limestones, seem to have acted as a small N-S trending island during the Early/Middle Miocene.

We produced high-resolution photo wallpaper to obtain a full dataset of the outcrop. Along a distance of 37 m, each clast was identified and categorized in the field or later by thin-sections according to its lithology and bio-content. Finally, based on the combined information, unconformities and "timelines" could be traced within the rather chaotic sedimentary complex. Both efforts are summarized in fig. 7.

Lithology

The outcrop offers a considerable range of lithologies. Aside from the corallinacean limestones, which occur as

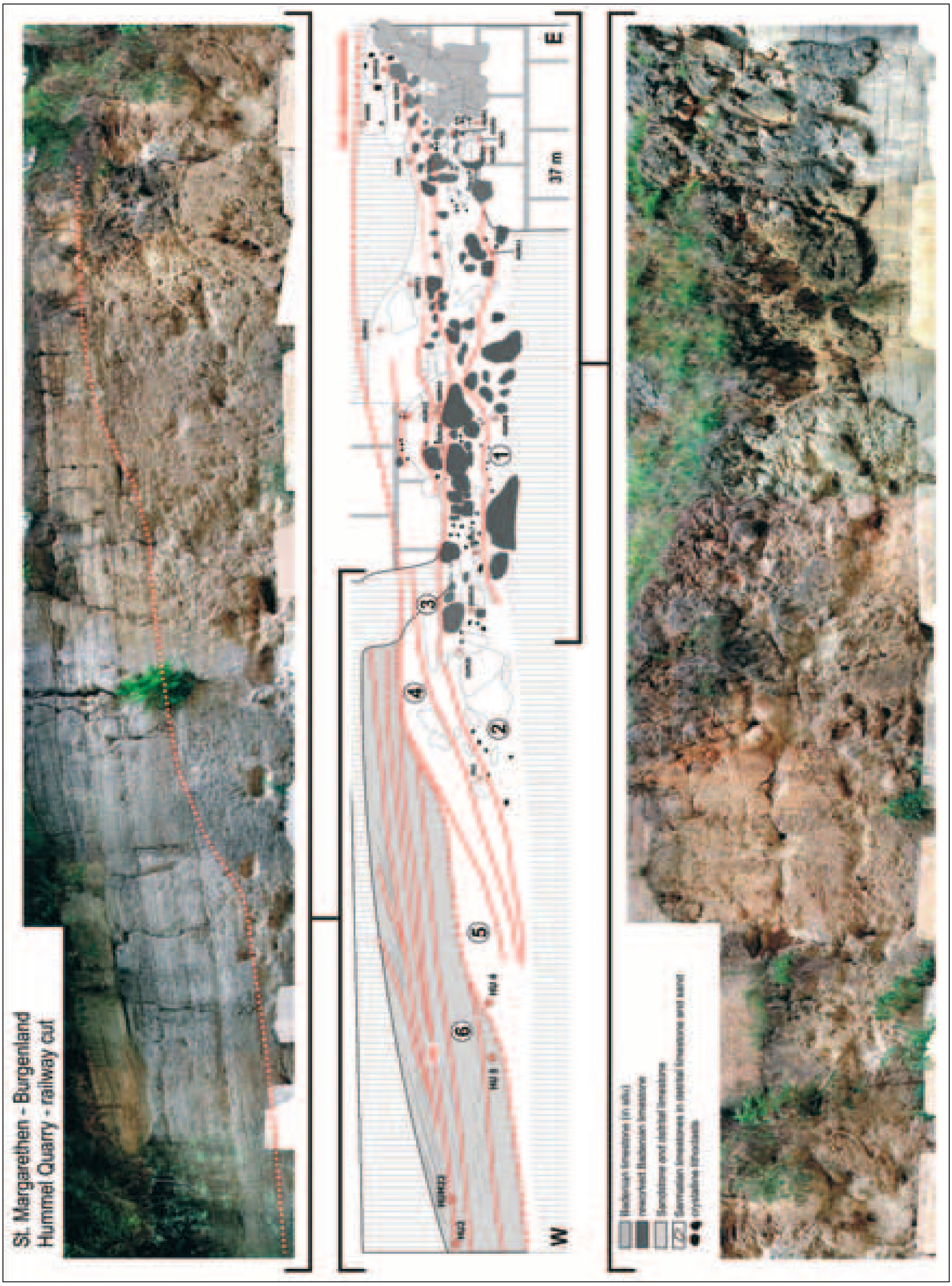


Fig. 7: Cross-section of the railway cut Hummel near St. Margarethen (Burgenland). Full red lines indicate parasequence boundaries. The dotted line marks the large hiatus between the deposits of the *Mohrensternia* Zone and the Upper *Ervilia* Zone and represents a type 1 sequence boundary.

boulders close to the paleocoast (note that these units 1–3 are not identical with those of section Baxa) and as crystalline lithoclasts of up to 30 cm diameter, various mixed siliciclastic/carbonatic sediments of different grainsizes (boulders, pebbles, sand, marl).

Micritic limestones showing a dense pattern of calcareous tubes of the polychaete *Hydroides pectinata* represent carbonates of Sarmatian age. Bryozoans such as Cryptosula and Schizoporella frequently contribute to these in various portions: the spectrum ranges from monospecific *Hydroides* aggregates (pl. 3, fig. 2) via various transitional stages to bryozoan limestones. Shells of the bivalves *Musculus* and *Modiolus* are occasionally abundant.

Less abundant are mixed siliciclastic marls and marly limestones containing coquinas of cardiids, *Musculus* and *Modiolus*. These sediments occur as autochthonous filling between boulders but are also frequently found as reworked clasts and slabs of up to 1 m diameter.

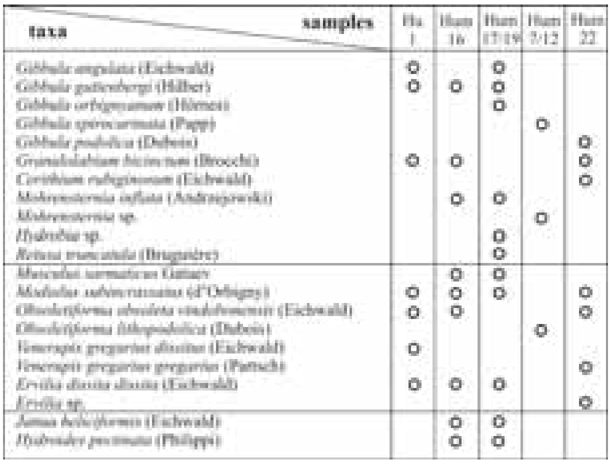
Laterally, towards the western entrance of the road outcrop, thin-bedded mixed siliciclastic marls and limestones appear. These sandy limestones, forming unit 6, are made up nearly exclusively of mollusc shells, shell hash and debris. Due to aragonite dissolution, the molluscs are only preserved as casts. The coquinas display little variation and consist of enormous amounts of the bivalves *Ervilia* sp., *Musculus subincrassatus* and poorly preserved cardiids. Among the gastropods, *Cerithium rubiginosum* predominates along with *Granulolabium bicinctum*.

Biostratigraphy

The careful examination of the outcrop reveals a twofold Sarmatian history. The first transgression already started during the Early Sarmatian as can be demonstrated by the mollusc fauna of the autochthonous sediment in the basal units 1–5 (e.g., sample HU 1). Occurrences of the gastropod *Mohrensternia inflata* in the samples HUM 16 and HUM 19 allow a very clear assignment to the *Mohrensternia* Zone in terms of mollusc zonation. Additionally, the occurrence of *Elphidium reginum*, mentioned by Fuchs (1965), indicates the corresponding *Elphidium reginum* Zone of the foram ecostratigraphy. Finally, the occurrence of the ostracod *Aurila mehesi* agrees with the inferred Early Sarmatian age (Cernajsek 1974). In the eastern part of the wall, samples HUM 7, 9, 12 still bear *Mohrensternia* together with the typical Early Sarmatian *Obsoletiforma lithopodolica*, representing the topmost part of the section which can be clearly assigned to the *Mohrensternia* Zone.

By contrast, the overlying unit 6 lacks *Mohrensternia*. In the basal part a well-preserved cast of a large, strongly sculptured *Gibbula podolica* and a mould of a large *Venerupis gregarius* were detected (HU 5). These taxa indicate the upper part of the *Ervilia* Zone sensu Papp (1975) and prove the hiatus between unit 5 and 6. The dating is also supported by the frequent occurrence of *Porosononion granosum* and *Aurila notata* in sample HUM 22, pointing to the Late Sarmatian.

Table 1: Molluscs and polychaetes in selected samples from section Hummel.



taxa \ samples	Hu 1	Hum 16	Hum 17/19	Hum 7/12	Hum 22
Gibbula angulata (Eichwald)	○		○		
Gibbula guttenbergi (Hilber)	○	○	○		
Gibbula orbignyanum (Hörnes)			○		
Gibbula spirocarinata (Papp)				○	
Gibbula podolica (Dubois)					○
Granulolabium bicinctum (Brocchi)	○	○			○
Cerithium rubiginosum (Eichwald)					○
Mohrensternia inflata (Andrzejowski)		○	○		
Mohrensternia sp.				○	
Hydrobia sp.			○		
Retusa truncatula (Bruguière)			○		
Musculus sarmaticus Gatuev		○	○		
Modiolus subincrassatus (d'Orbigny)	○	○	○		○
Obsoletiforma obsoleta vindobonensis (Eichwald)	○	○			○
Obsoletiforma lithopodolica (Dubois)				○	
Venerupis gregarius dissitus (Eichwald)	○				
Venerupis gregarius gregarius (Partsch)					○
Ervilia dissita dissita (Eichwald)	○	○	○		
Ervilia sp.					○
Janua heliciformis (Eichwald)		○	○		
Hydroides pectinata (Philippi)		○	○		

Paleoecology and Dynamics

The assemblages of units 1–3 from the sediment pockets between the rock boulders are strongly dominated by small-sized archaeogastropods such as *Gibbula guttenbergi* and *Gibbula angulata*. Among the bivalves, *Ervilia dissita dissita* is most abundant and is usually found with articulated valves. Similarly, *Modiolus subincrassatus* and *Obsoletiforma obsoleta vindobonensis* are often still articulated, excluding a major reworking of the shells. Aside from molluscs, the gregarious polychaete *Hydroides pectinata* and the spirorbid *Janua heliciformis* are ubiquitous in all samples. Especially, *Hydroides* formed dense aggregates preserved as well-cemented limestones.

Although most *Hydroides*/bryozoan colonies are typically represented as reworked clasts (e.g., samples HUM 17, HUM 19), autochthonous occurrences are also documented. Especially basal unit 1 yields Badenian boulders with in-situ overgrowth by Hydroides colonies (e.g., below sample HUM 17). These bioconstructions contain abundant archaeogastropods and large numbers of *Musculus sarmaticus* and *Modiolus subincrassatus*. Additionally, *Mohrensternia inflata* and the ostracod *Aurila mehesi* are common constituents of the assemblages. However, boulders of *Hydroides* limestones and chaotically arranged slabs of coquina limestones floating in units 2 and 3 document considerable erosion of already lithified, nearly synchronous deposits during the *Mohrensternia* Zone.

Within-habitat reworking seems to be linked with sea-level fluctuations during a stepwise transgression. This multi-phase process is documented by conformities separating units 1–4. Within these units the distribution of clasts shows a clear shift in composition and frequency. Thus, unit 1 has abundant lithoclasts of Badenian limestone and represents an initial phase of the transgression that heavily eroded the paleocoast. Within that unit the Early Sarmatian communities are preserved as calcareous coatings of *Hydroides pectinata* and bryozoans on the boulders (pl. 3, fig. 1).

The increase of crystalline lithoclasts in unit 2 points either to the erosion of the crystalline core of the Rust mountains during the next transgressive impulse or to the reworking of clasts from pre-Sarmatian sedimentary units. Furthermore, the proximally deposited, reworked Badenian boulders are laterally replaced by Sarmatian bioconstructions. These are predominated by *Hydroides pectinata* and the very abundant *Janua heliciformis*. The characteristic traces on the basal part of the latter indicate that the animals were usually attached to *Hydroides* tubes. *Ervilia dissita*, small-sized archaeogastropods such as *Gibbula guttenbergi* and *Musculus sarmaticus* are the typical molluscs associated with the serpulid thickets. The presence of algae is indicated by the abundance of herbivorous gastropods such as *Mohrensternia*, *Granulolabium* and *Gibbula*.

In the top of the Early Sarmatian succession (samples HUM 7, 9, 12) the abundance of *Hydroides* limestones decreases drastically. Instead, cardiid coquinas form densely packed shell beds of *Obsoletiforma lithopodolica* (fig. 8). *Mohrensternia* sp., *Gibbula spirocarinata* and rare *Ervilia dissita* are subordinate. Disarticulated shells frequently form the coquinas, although articulated specimens may occur. In-situ preservation, however, is absent. The change in the fauna indicates a shift from rocky littoral environments to shallow littoral flats on which cardiid coquinas formed due to wave energy or storms. High energy is also indicated by intercalations of shell hash that lack nearly any sediment.

The calcareous beds containing the cardiid coquinas fade out towards the top into very thin layers of unstructured micritic limestone. These were apparently formed by microbial activity and document a distinct change in the environment. The well-agitated setting was clearly replaced by calm littoral to supralittoral environments predominated by algae mats. The establishment of that facies might indicate the prelude of the Early Sarmatian regression.

The second sequence, comprising unit 6, lacks boulders, pebbles and in-situ colonies of bioconstructers. Thin-bedded layers of shell hash are composed of masses of the herbivorous gastropods *Granulolabium bicinctum* and *Cerithium rubiginosum*. The fauna indicates near-shore conditions. Modern relatives of these gastropods are frequently found in littoral settings such as mudflats (own observation). Infaunal elements such as cardiids and *Venerupis* are rare; hardground-dwelling species such as *Gibbula podolica* are also subordinate. This points to rather unstable sediment, which is unfavorable for infaunal taxa as well as for attachment by bioconstructers.

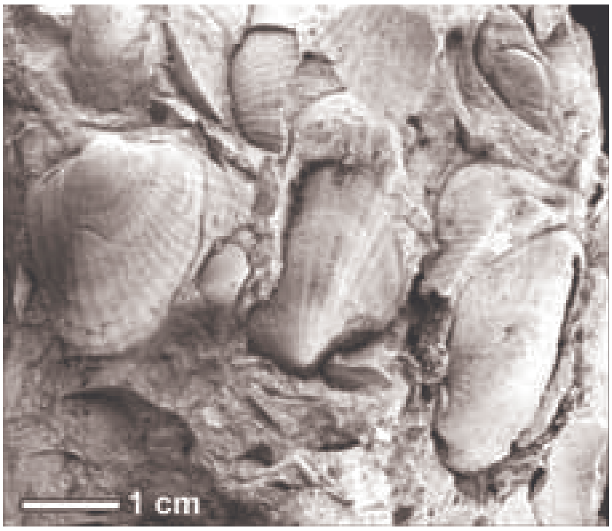


Fig. 8: A coquina composed mainly of shells of the cardiid *Obsoletiforma lithopodolica* forms the top of the Lower Sarmatian succession at the section Hummel.

In contrast to the lower sequence, the Badenian limestones no longer represent rocky coast. Instead, the more or less flat top of the Leitha limestone might have supported the establishment of extended, flat shoals during the Late Sarmatian, offering an optimal habitat for the ubiquitous batillariids and cerithiids. An in-situ colony of *Cryptosula* and *Schizoporella* to the left of HUM 4 marks the boundary between the Lower and Upper Sarmatian sequence.

Sequence stratigraphy: Units 1–3 of the Lower Sarmatian Sequence are clearly related to a transgressive systems tract. The shift from boulder deposits towards cardiid coquinas in unit 4 indicates the maximum transgression. However, the deposits reflecting the mfs and HST of this sequence have been eroded during the lowstand of the following sequence.

The base of the Upper Sarmatian sequence, represented by unit 6, is developed as onlap on the Lower Sarmatian deposits. These layers correspond to the transgressive systems tract, which culminates in a well-developed maximum flooding surface. The latter is evidenced by the formation of an about 15 cm thick layer of carbonatic silt and fine sand (samples HU 2, HUM 22). At that time, the paleorelief formed by the Lower Sarmatian units became flooded. The layers above the mfs display distinct downlap clinoforms, which seem to be linked to the late transgressive systems tract or the highstand systems tract of that sequence.

4 *Styrian Basin*: Klapping

N 46° 48.74 / E 15° 58.41

This section is located in an abandoned quarry in the forest close to Klapping south of St. Anna am Aigen in Styria. The outcrop was already mentioned by Kollmann (1965), who dated the deposits as Early Sarmatian. Its position at the southern tip of the Southern Burgenland Swell, separated from the mainland by the Styrian Basin, suggests little influx from the Alpine area during the Sarmatian.

Lithology

Similar to the section Hummel at St. Margarethen, Badenian corallinacean limestones form the base of the Sarmatian sequence. They form a humpy paleorelief which reaches up to 70 cm height but lacks sharp ridges. Immediately below this discontinuity, *Microcodium* is very abundant (pl. 3, fig. 3). Above this surface large boulders of the underlying limestone are absent and instead a thin layer of clay with lignite and scattered oysters marks the base of the Sarmatian transgression. Pebbles of 3–4 cm diameter indicate some reworking of the underlying Badenian limestones. Upsection follow about 3 m, thick-bedded, marly limestone consisting mainly of *Hydroides*, *Cryptosula*, *Schizoporella* and nodular bryozoans (celleporids?) (pl. 3, figs 4–5). This unit is subdivided by few, thin intercalations of clay and marl, which contain pebbles of reworked Sarmatian limestone and scattered, small-sized archaeogastropods (*Gibbula* ssp.). The tops of the limestone beds display a low relief. The carbonatic top bed of the unit is strongly altered, forming a characteristic layer of unstructured white grind. This is overlain by 20 cm clay that can be traced throughout the outcrop. A second, about 2 m thick unit of indistinctly bedded *Hydroides*/bryozoan limestone represents the top of the section. Two layers of weathered whitish layers of altered limestone divide this unit.

Within all limestone beds, *Hydroides*/bryozoan bioconstructions measuring up to 40 cm in diameter and 30 cm in height appear. The irregular growth and succession of such colonies and various small cavities and caverns yield a very bumpy surface, which obscures the bedding.

The succession is laterally bordered by Sarmatian gravel (Kollmann 1965), which indicates a regressive phase following the formation of the carbonates.

Biostratigraphy

In the basal unit overlying the Badenian corallinacean limestones, a thin layer of clay bears a biostratigraphically indicative mollusc fauna with *Mohrensternia sarmatica* and *Mohrensternia pseudoangulata* (fig. 10). The assignment to the Early Sarmatian *Mohrensternia* Zone agrees fully with the dating by Kollmann (1965), who documented the *Elphidium reginum* Zone based on the microfauna.

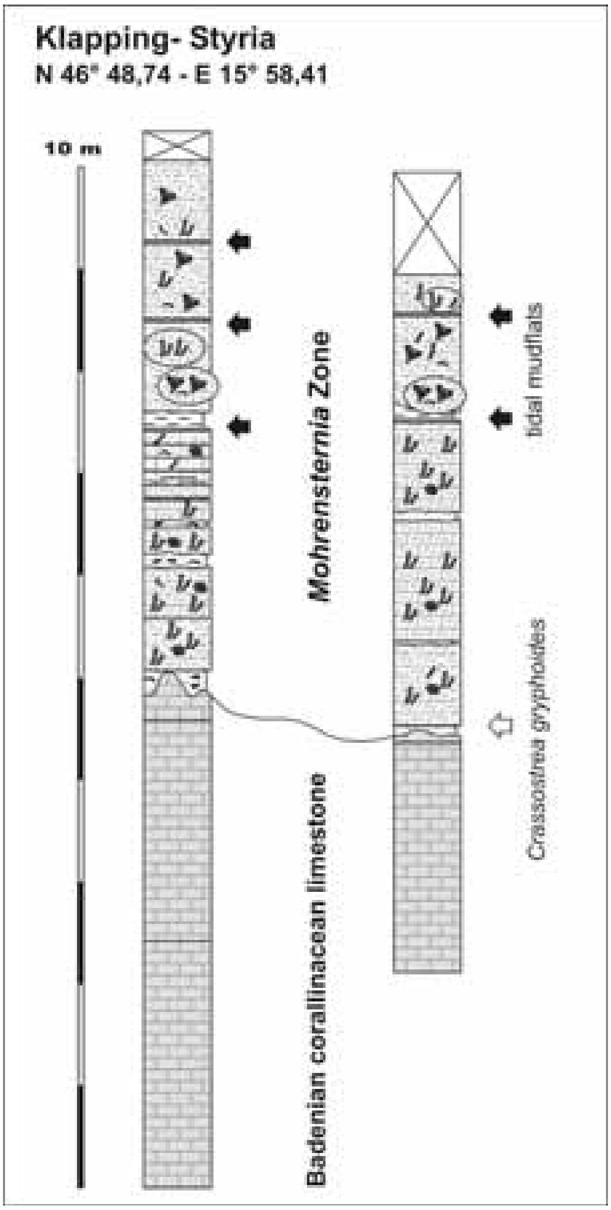


Fig. 9: Idealized log of section Klapping in Styria (see fig. 4 for legend).

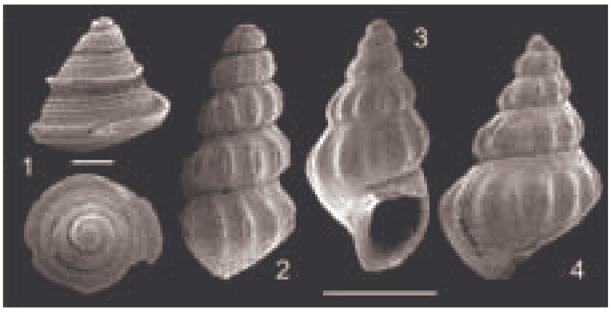


Fig. 10: Gastropods from the section Klapping which are restricted to the Lower Sarmatian *Mohrensternia* Zone. 1: *Calliostoma marginatum* (Eichwald), 2: *Mohrensternia pseudoangulata* Hilber, 3: *Rissoe turricula* (Eichwald), 4: *Mohrensternia sarmatica* (Friedberg) (scale bar: 1 mm).

Paleoecology and Dynamics

The paleorelief on top of the corallinacean limestones most probably formed during the LST at the Badenian/Sarmatian boundary. Subaerial exposure is indicated by the abundance of *Microcodium* which is interpreted as calcified roots (e.g., Klappa 1978, Tucker & Wright 1990). During the Early Sarmatian the sea transgraded onto this landscape. Clay, lignites and the minor reworking of the Badenian limestones document a low-energy coastal environment. A small colony of *Crassostrea gryphoides* accompanied by scarce *Terebralia bidendata* and numerous *Granulolabium bicinctum* point to the presence of a littoral mudflat. The relief, however, was sealed soon after by *Hydroides* and bryozoan bioconstructions. Bituminous exhalation of the sediment indicates a high content of organic matter contained by the highly porous framestone.

The following unit suggests a fluctuating coastline. Phases of flourishing *Hydroides*/bryozoan colonies of considerable size were interrupted at least 2–3 times by the formation of tidal mudflats (indicated by arrows in fig. 9). The low relief on the tops of the limestone beds and the scattered chips of weathered limestone in the base of the overlying beds document some erosion due to phases of emersion. The clay layer separating the lower unit from the top unit indicates a major interruption. The 3 strongly altered, unstructured crusts in the top bed of the lower unit and within the upper limestone unit are interpreted as caliche, which formed during phases of emersion. Thus, the Lower Sarmatian deposits at Klapping may represent at least 4–5 parasequences.

According to Kollmann (1965), the carbonates are laterally overlain by gravel. This contact is now obscured due to the vegetation. Kollmann (1965) emphasized that the stratigraphic position of that level is below the Carinthian Gravel and is therefore of Early Sarmatian age.

Implications from other outcrops

Two further outcrops document the considerable erosional phase between Lower and Upper Sarmatian deposits in basin margin positions. These are Maustrenk in Lower Austria and Grafenberg in Styria. Despite their different tectonic and paleogeographic setting – coast of the Alpine mainland in Grafenberg and island in the northern Vienna Basin for Maustrenk – both sections reflect a very similar development.

At both sections, *Hydroides*/bryozoan limestones developed during the Early Sarmatian *Elphidium reginum* Zone and became overlain by oolites during the Late Sarmatian. The discordance separating the oolites from the limestones at the Styrian section was already recognized by Brandl (1931) and Winkler von Hermaden (1952), who also discussed a phase of subaeral exposure. Later, Friebe (1994) ignored these data and erroneously considered the whole succession to reflect a single Upper Sarmatian sequence.

Reworked Sarmatian limestones with *Hydroides* tubes and bryozoans have been variously cited in the literature. One occurrence was described by Bobies (1924) from Kalch in the Styrian Basin. There, limestone pebbles with *Schizoporella* are found in sandy marls of the upper *Ervilia* Zone. The origin of these pebbles is clearly related to the erosive phase during the Sarmatian, which is documented herein.

Patches of Lower Sarmatian limestones, containing mainly *Hydroides* and *Cryptosula*, occur also as relics along the slopes of the Hainburg Mountains (Wessely 1961) and close to Bratislava. Both occurrences are apparently interfingering with Upper Sarmatian deposits. This situation was caused by the gradual transgression of the Upper Sarmatian, crossing the former coastline, as indicated by these limestone relics. This situation was repeatedly misinterpreted and accounts for the "Upper Sarmatian serpulite" in the Pannonian Basin system literature (e.g., serpulite in the top of the Upper Sarmatian Karlova Ves Member of Nagy et al. 1993).

However, not all occurrences of reworked Lower Sarmatian can be related to Sarmatian sea level fluctuations. Hörnes (1897) reported reworked Sarmatian limestone clasts with *Hydroides* from the section Wiesen (Burgenland). That well-known outcrop is famous for its Upper Sarmatian deposits (Papp 1974). The mentioned pebbles are redeposited in gravel of the Lower Pannonian on top of siliciclastics of the Sarmatian *Mactra* Zone.

Discussion

Three sea-level fluctuations within the Early Sarmatian can be discerned based on the presented data. The first relative sea-level fall occurred within the Early Sarmatian *Mohrensternia* Zone and divides the *Anomalinoides dividens* Zone from the *Elphidium reginum* Zone. At the section Petronell a distinct coarsening and shallowing upward trend indicates this phase. In the Styrian Basin, the same development is documented in the well Paldau 1, where the *Anomalinoides dividens* Zone shows a coarsening upward from marl towards sand and is topped by lignite. Correspondingly, the boundary between the *Anomalinoides dividens* Zone and *Elphidium reginum* Zone is marked by a gravely layer in the well Stiefingtal (Kollmann & Rögl 1978).

Unfortunately, oil companies treated this basal Sarmatian foram zone quite inhomogeneously. It was partly considered as the upper part of the Badenian or simply united within the *Elphidium reginum* Zone. Therefore, little reliable information can be obtained for this interval from well logs of the Vienna- and the Styrian Basin. In the northern part of the Vienna Basin, variegated limnic beds developed; they are termed "*Carychium* beds" after the predominating terrestrial gastropod (Jiricek & Senes 1974). At the same time, fluvial gravel was shed via a drainage system from the Molasse Basin into the north-western Vienna Basin (section Siebenhirten in Grill 1968).

The second retreat of the sea caused emergence and erosion at the top of many Sarmatian carbonate bodies, which had formed during the preceding transgression. These serpulid/bryozoan bioconstructions grew along the coasts of the mainland as well as along the shores of the islands, represented by the Hainburg Mountains, the Leitha Mountains, the Rust Mountains, and the South Burgenland Swell. An approximately N-SSW trending bow of islands and shoals established, which separated the Vienna Basin and the Styrian Basin from the open sea of the Danubian/Pannonian Basin.

Formerly emerged carbonates such as those at Mannersdorf/Baxa display vadose features like dissolution and microstalactitic cements.

A renewed transgressive pulse within the Early Sarmatian sealed the relief of the limestones at the section Mannersdorf Baxa and allowed the deposition of elphidiid sands and marls. In the Styrian Basin, basal gravel followed by sand and marl represent this phase, topping the older serpulid/bryozoan limestones at the section Klapping.

The last, yet major regression took place in the late Early Sarmatian (*Elphidium hauerinum* Zone, *Lower Ervilia* Zone). In the Styrian Basin it is reflected by the formation of an up to 100 m thick unit of coarse sand and gravel termed Carinthian Gravel (Kollmann 1965 and references therein). A similar development is observed in the Eisenstadt-Sopron Basin, where the so-called "Gravel of the Marzer Kogel" top the clays and marls of the *Elphidium hauerinum* Zone and forms the base of the *Porosononion granosum* Zone (Papp 1974a, Pascher 1991). In the Vienna Basin, the regression is also detected in well Niedersulz 9, where coarse sand and fine gravel are reported between 1750 m and 1800 m true vertical depth. During that phase, most nearshore deposits of the Early Sarmatian became exposed and eroded. Therefore the hiatus between Early Sarmatian and Late Sarmatian was rather dramatic along the margins of the herein studied basins. This hiatus is clearly visible at the section Hummel in St. Margarethen, where the gap spans parts of the *Elphidium hauerinum* Zone and – according to the rather evolved mollusc fauna – even lower parts of the *Porosononion granosum* Zone.

Conclusion

We consider the Sarmatian stage as a 3rd order cycle roughly corresponding to the TB 2.6 cycle of Haq et al. (1988). According to Sen et al. (1999) this cycle spans an interval between 12.5 and 11.3 Ma., which corresponds largely to the herein proposed duration of the Sarmatian stage. We therefore consider a correlation of the unconformities bounding the Sarmatian sequences with the Ser-3 (base) and Ser-4/Tor-1 (top) boundaries of Hardenbol et al. (1998). Within that cycle, the herein discussed deposits take up a rather basal position.

Therefore, in terms of sequence stratigraphy we interpret the first sequence – comprising the *Anomalinoides dividens* Zone – as part of a 3rd order LST (lowstand systems tract). During that time, gravel filled incised valleys of the Molasse Basin (section Siebenhirten) and shallow marine settings established in the less marginal areas as represented by the section Petronell (fig. 11).

The TST (transgressive systems tract) resulted in a flooding of the shoreface environments of the *Anomalinoides* Zone and the sea intruded onto the Molasse Basin. The rapid sea-level rise culminated in a mfs (maximum flooding surface), which is documented by layers of diatomites and fish-bearing shales in the upper *Elphidium reginum* Zone.

It is difficult to decide whether the *Hydroides*/bryozoan limestones formed already during the TST or if they are part of the HST (highstand systems tract). At Petronell, the first *Hydroides*-bioconstructions appear below the mfs, but these monospecific offshore-structures bear little in common with the littoral carbonates of St. Margarethen and Mannersdorf.

However, the erosional surface above the carbonates in Klapping, St. Margarethen and Mannersdorf is interpreted to be related to a low-order sea-level drop during the HST. Above, another transgressive impulse, as documented by the *Elphidium*-sand of Mannersdorf, marks the beginning of a rather transgressive episode within the HST. This phase includes the basal, marly parts of the *Elphidium hauerinum* Zone of the studied basins. It is abruptly interrupted by a major sea-level drop during the late *Elphidium hauerinum* Zone, which is discussed herein as the "third regression".

This quite brusque termination of a generally transgressive sequence seems to be linked to regional geodynamics rather than to global cycles. Some kind of a "forced regression" due to tectonic uplift of the alpine region, as emphasized already by Papp (1956), might best explain that feature. A regional trigger is also favored because the Volhynian/Bessarabian boundary – which is probably triggered by global events – cannot be claimed as a counterpart: it is distinctly younger than the discussed level.

Thus, the Lower Sarmatian deposits of the western Central Paratethys are interpreted as a 4th order sequence within the transgressive part of a global 3rd order sequence. Low-frequency shifts in the relative sea-level as documented in this study might represent regional 5th order cycles; these are developed in the Vienna Basin and the Styrian Basin. An even finer tuning is indicated by the parasequences of Klapping and St. Margarethen, but is obscured by the regional tectonics.

This interpretation is supported by the geophysical log data of the well Niedersulz 9 in the central Vienna Basin (kindly provided by the OMV, see Papp et al. 1974 for details). Here the basal *Anomalinoides dividens* Zone is not detected and the Sarmatian succession starts with the *Elphidium reginum* Zone. It displays a very clear fining up-

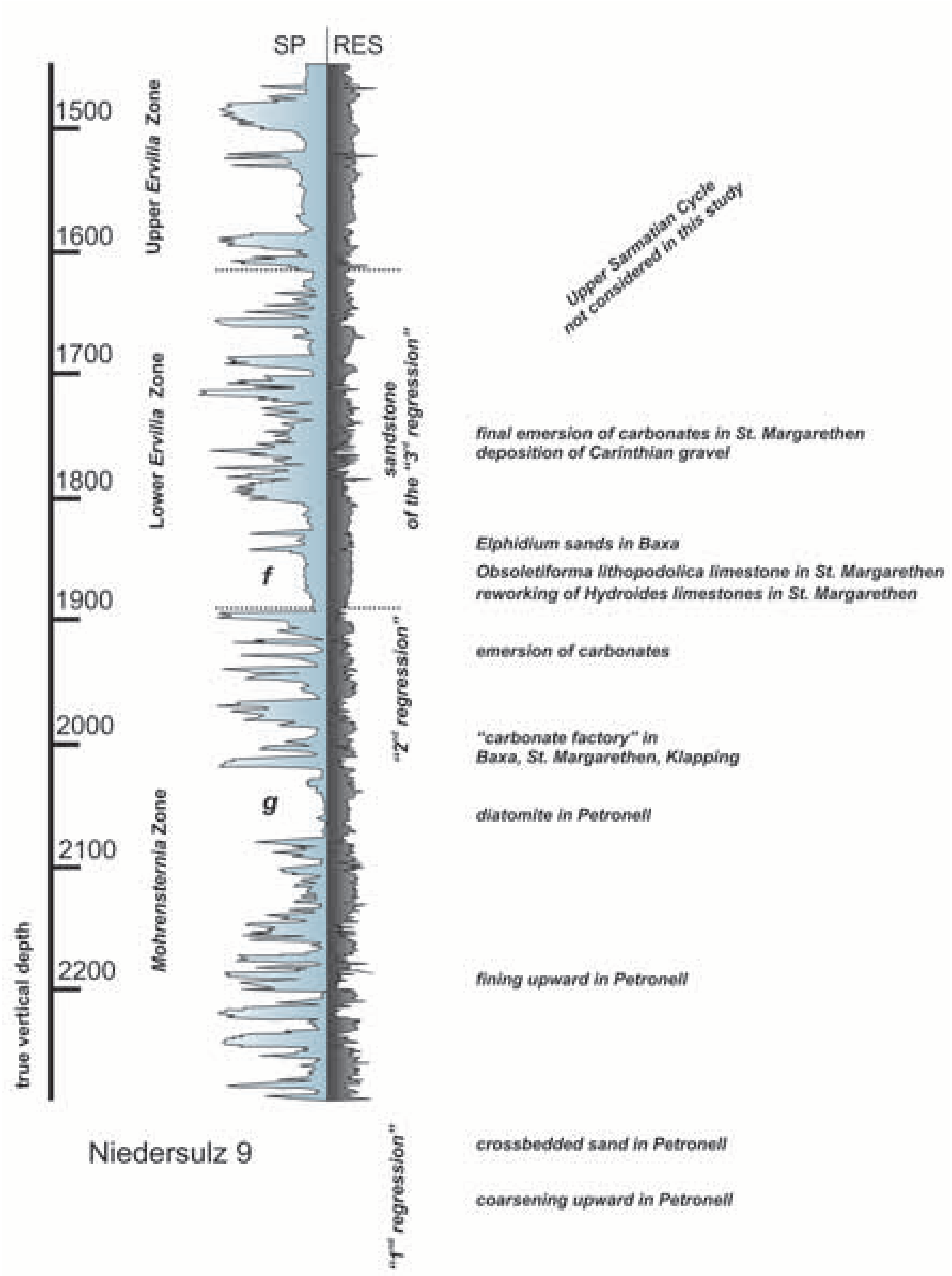


Fig. 11: SP- and Restivity log of the drilling Niedersulz 9 in the Central Vienna Basin. The cutout covers only the Lower and Middle Sarmatian. Data with kind permission of the OMV. The tentative correlation of some herein described lithological units and dynamics of the outcrops Mannersdorf/Baxa, St.Margarethen/Hummel, Klapping and Petronell is indicated.

ward trend which culminates in maximum flooding surface (indicated by "g" in fig. 11). Upsection, a unit with strongly serrated SP well log curve follows; it indicates a local HST development. The erosional surfaces observed on top of the Sarmatian carbonates at Mannersdorf and Klapping are correlated with this interval. A marked transgression follows, reflected by an inflection of the SP curve towards the shale line (labeled as „f" in fig. 11). The abrupt deflection above correlates with the deposition of coarse sand and corresponds to the 3rd – probably "forced" – regression discussed in this paper. The overlying Upper Sarmatian sequence differs considerably in its carbonate facies. Therefore, the separating regressive phase acted as major incision for the fauna and the depositional regimes.

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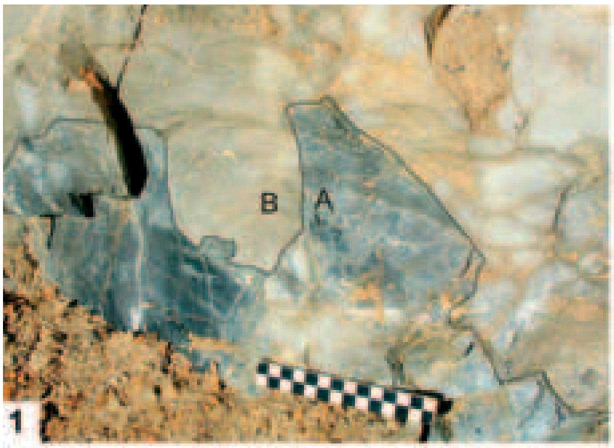
Plate 1

Closeups of the outcrop Baxa.

Fig. 1:	shows the relief of the Triassic dolomite (A = unit 1), which is filled by Sarmatian limestone (B = unit 3). In this position the otherwise typical layer of breccia (unit 2) is missing.
Fig. 2:	Detail showing the digitations of microbial mats that form the crust on the dolomite; laterally these crusts are replaced by *Hydroides* limestones.
Figs 3a–3b:	Microbial crusts and *Hydroides* limestones of unit 2 (B) attached to dolomite (A). Marly, thin-bedded *Elphidium*-sand of unit 3 (C) truncates the Lower Sarmatian limestone and touches the dolomite.
Figs 4a–4b:	Laterally, dense microbial crusts gradually pass into in-situ *Hydroides* thickets.
Figs 5a–5b:	A cavity within the Lower Sarmatian limestones of unit 3, documenting a multi-phased filling during the following transgression. The arrow in fig. 5b indicates a cavity which was only partly filled by carbonate mud.



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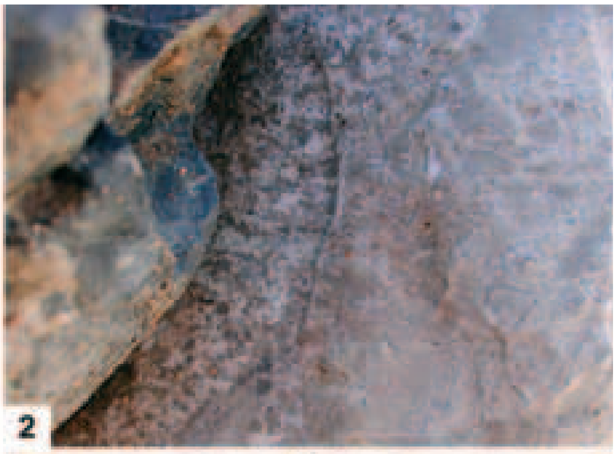

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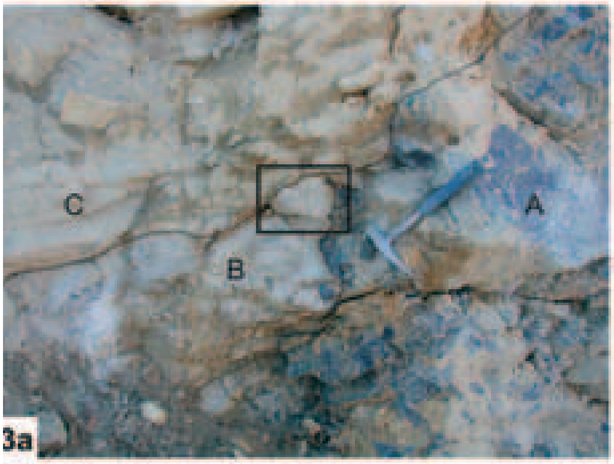

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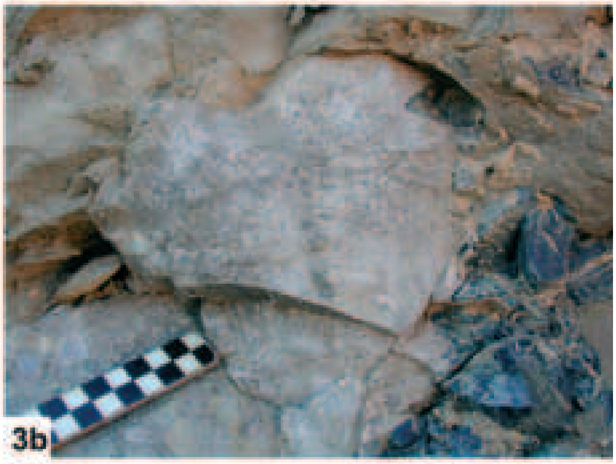

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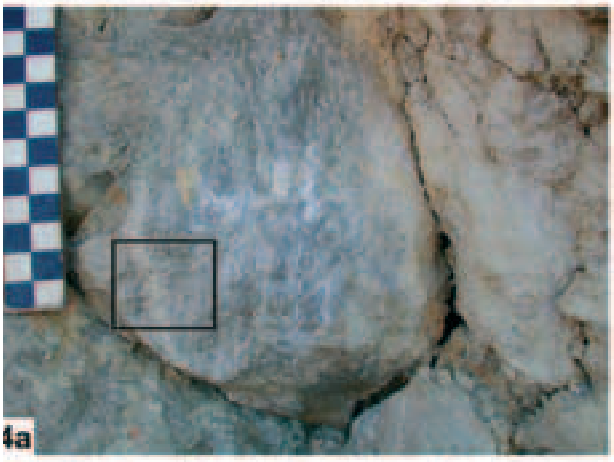

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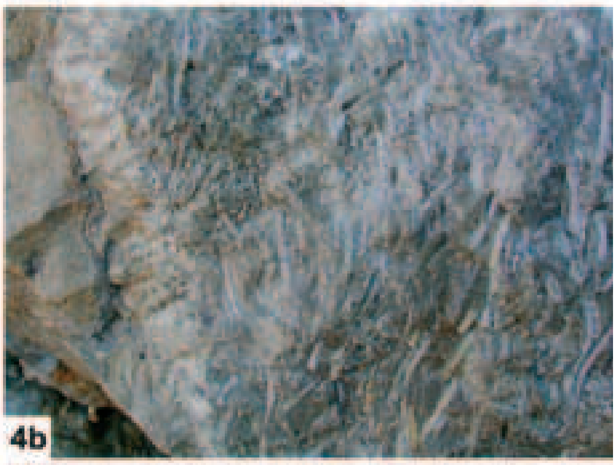

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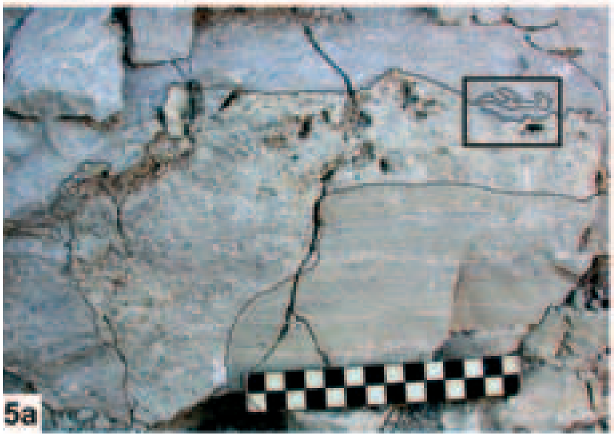

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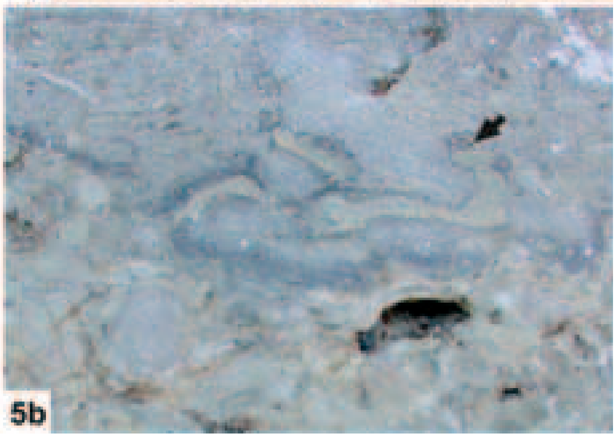

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Plate 2

Thin-sections from Mannersdorf Baxa in Lower Austria.

Fig. 1: cross sections through *Hydroides* tubes, which are geopetally filled with fine grained sediment. The remaining space and the large shelter pore below the tubes are lined by an isopachous, fibrous cement rim of marine origin. The remaining space is filled by blocky calcite. Parts of the *Hydroides* tubes are dissolved, probably due to meteoric-vadose leaching.

Fig. 2: *Hydroides* tubes in microbial bindestone. The remaining constructional pores within the bindstone exhibit microstalactictic (“dripstone”) cement proofing subaerial exposure of these rocks (arrow indicates dripstone).

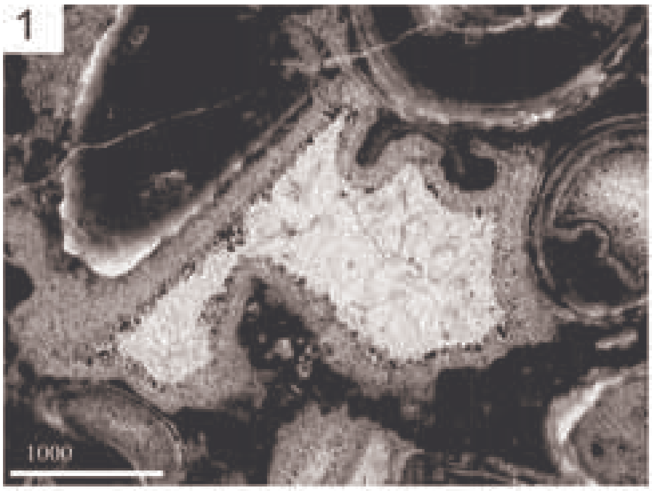
Fig. 3: Single-layered coralline algal thalli embedded in microbial carbonate with clotted structure.

Fig. 4: Cyanobacterial tufts built by dichotomously branched filaments.

Fig. 5: Growth succession starting on Triassic dolomite (T) with microbial bindstone (B) with primary vuggy pores. This boundstone is overlain by cyanobacterial tufts (C) producing a digitate morphology. The space between the cyanobacterial bushes is filled by peloidal sediment (P).

Fig. 6: Celleporid bryozoan colony and *Hydroides* tube overgrown by nubeculariid foraminifera.

Fig. 7: Foraminifera packstone contributed by various species of *Elphidium*.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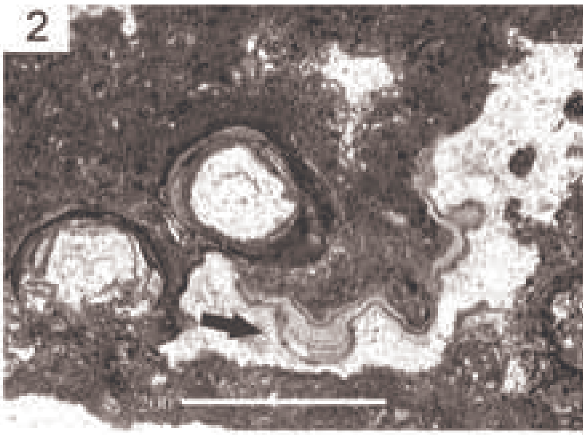
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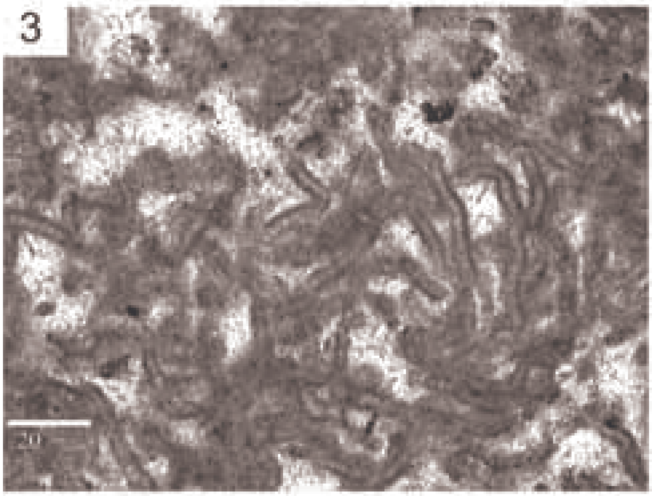
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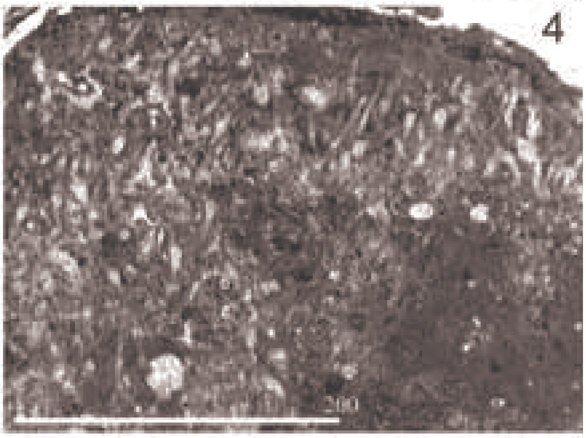
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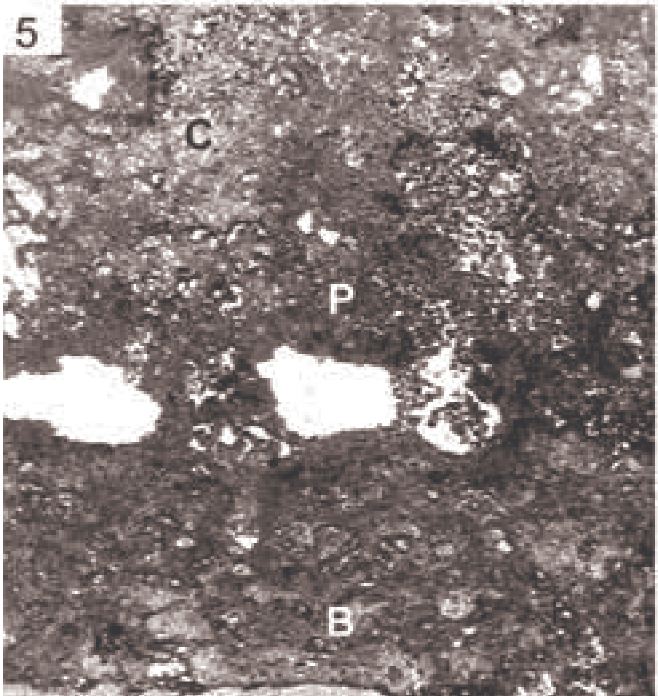
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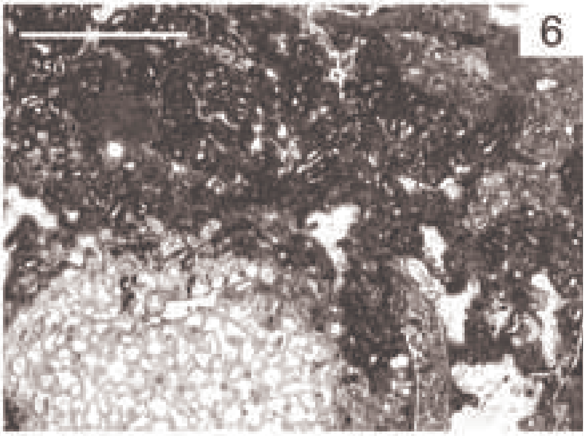
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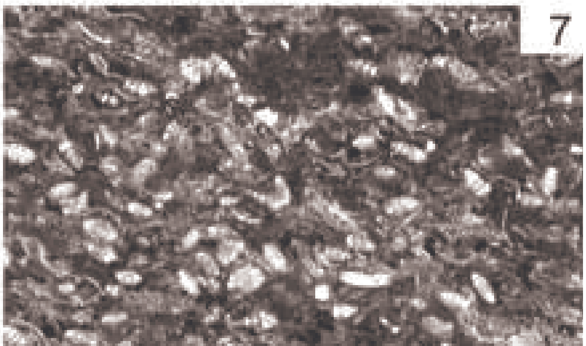
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Plate 3

Thinsections from section St. Margarethen “railway cut” in Burgenland (Austria).

Fig. 1: Sarmatian growth succession starting with crustose bryozoans (B) over foraminiferal rich sediment of Badenian age. The bryozoan crust is overgrown by cyanobacterial tufts in bushy aggregates which form a boundstone with many constructional voids.

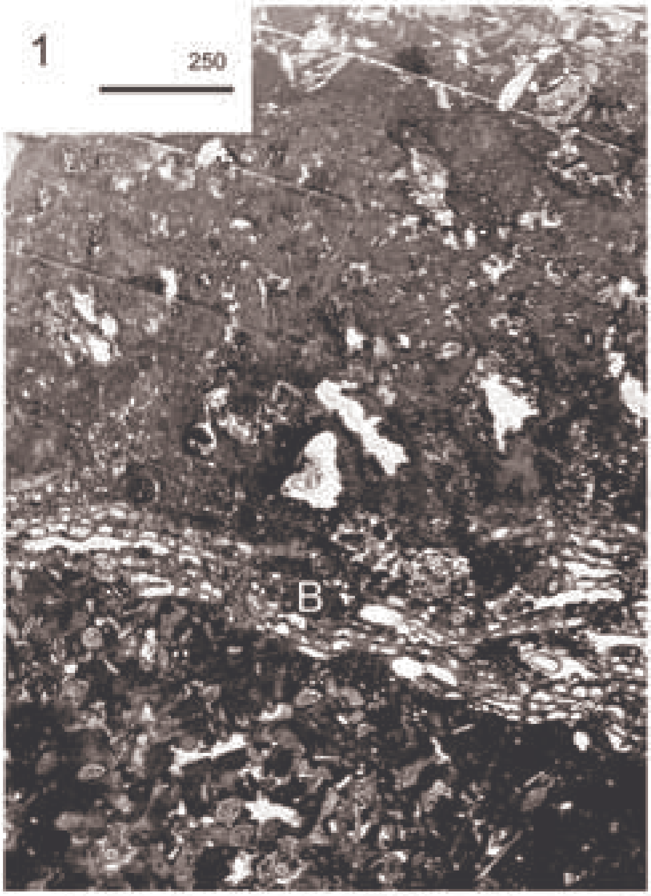
Fig. 2: monospecific *Hydroides* aggregate representing a more or less in-situ *Hydroides* thicket.

Thin-sections from section Klapping in Styria (Austria).

Fig. 3: *Microcodium* (calcified root cells) at the Badenian/Sarmatian boundary proof subaerial exposure and point to a semi-arid climate during formation.

Fig. 4: Limestones dominated by nodular bryozoans (celleporids?) with shell hash and tubes of *Hydroides*.

Fig. 5: *Hydroides-Cryptosula* limestone, being the most frequent lithology at the section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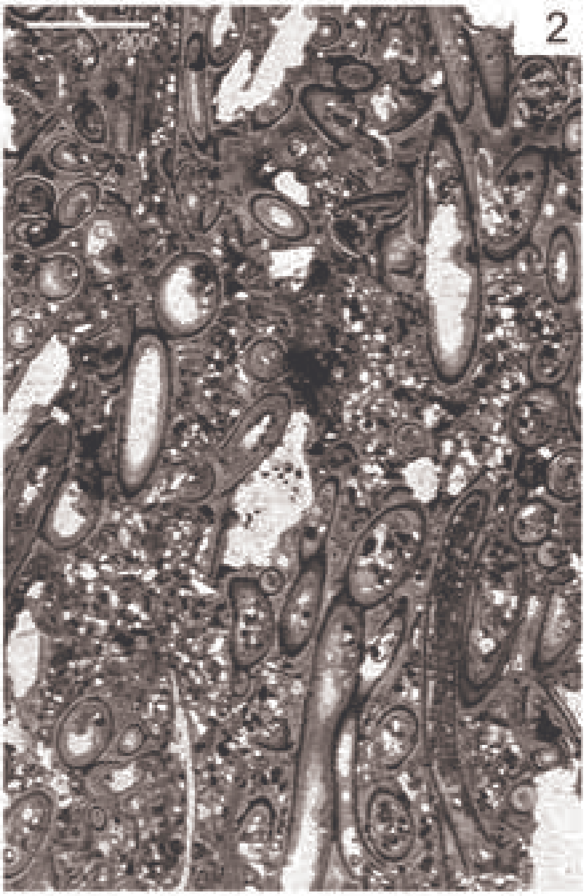
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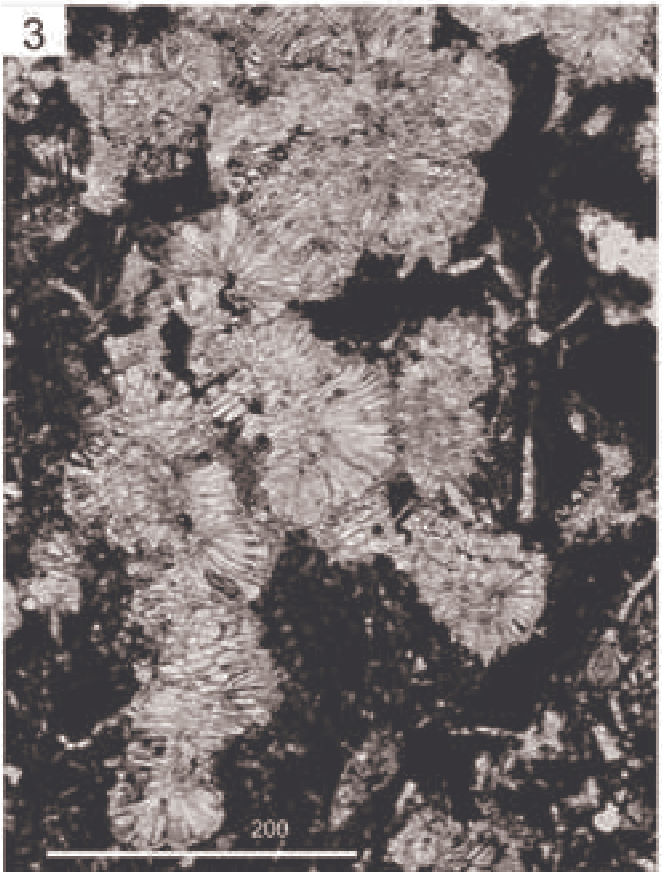
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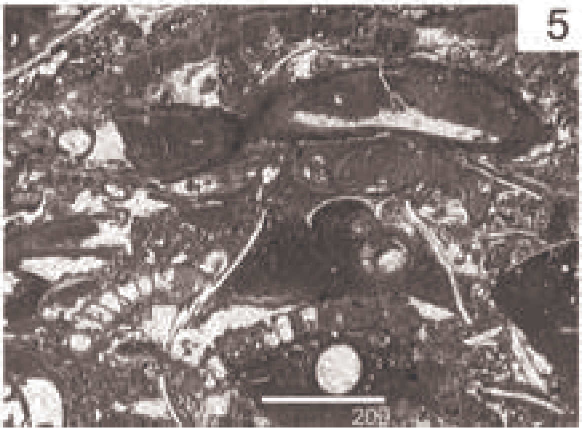
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