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Vienna Basin Excursion

Mathias Harzhauser
Natural History Museum Vienna
Geological-Paleontological Department
Burgring 7
A-1010 Wien, Austria
mathias.harzhauser@nhm-wien.ac.at

Michael Wagreich
University of Vienna
Institut für Geologische Wissenschaften
UZA II – Althanstrasse 14
1090 Wien, Austria
michael.wagreich@univie.ac.at

Werner E. Piller
University of Graz
Institute for Geology and Paleontology
Heinrichstrasse 26
A-8010 Graz, Austria
werner.piller@uni-graz.at

Vienna Basin

Geography

The Vienna Basin covers large parts of eastern Austria (Lower Austria, Vienna, and Burgenland) and reaches into the territories of the Czech Republic in the north and the Slovak Republic in the east. It is about 200 km long and 55 km wide, striking roughly southwest-northeast from Gloggnitz (Lower Austria) in the SSW to Napajedla (Czech Republic) in the NNE. As classical Neogene Basin it was the target of hundreds of geoscientific studies since the early 19th century.

Tectonic setting and development

The Vienna Basin is a rhombic Neogene pull-apart basin. Its south-western border is formed topographically by the Eastern Alps and to the north-west by the Waschberg and Ždánice Units. In the east it is bordered by the hills of the Rosalia, Leitha, Hainburg and the Male Karpaty Mountains, all four hill ranges are part of the Alpine-Carpathian Central Zone. The Pieniny Klippen Belt represents an internal boundary of the Outer Carpathian Flysch Belt; sediments of the Magura unit create the northern margin of the basin. The basement of the basin is formed by those Alpine-Carpathian nappes bordering the basin also on the surface. The maximum thickness of the Neogene basin fill attains 5500 m. Since the basin is subdivided by a morphological high structure, the Spannberg ridge, into a northern and a southern part, marine sedimentation was restricted to the north (north of the Danube) during the Early Miocene and extended into the south only during the Middle and Late Miocene. Due to the complex fault system the basin was internally highly structured into horst and graben systems. At the borders of the basin, relatively uplifted blocks occur; these are separated from the deep depressions along major faults (e.g., Mistelbach block along the Steinberg fault, Moravian central depression along the Bulhary fault in the northern basin, Mödling block along the Leopoldsdorf fault in the southern basin; Láb-Malacky elevation along the Leitha and Láb fault system).
The development of the present Vienna Basin, situated at a junction between the Alpine and the Carpathian orogen, as well as its superposition on the Cenozoic accretionary wedge of the Rheno-Danubian and the Outer Western Carpathian Flysch belts, and on the units of the Northern Calcareous Alps, Central Eastern Alps and the Central Western Carpathians, is reflected in a very complex tectonic evolution. A detailed overview including all relevant literature used in the present text was presented by Kovac et al. (2004).

1. The formation of the Vienna Basin started in the Early Miocene as E-W trending piggyback basin on top of the Alpine thrust belt. It was initiated during the Eggenburgian and was active until the Early Karpatian.

2. In the late Early Miocene (Late Karpatian) thrusting was replaced by lateral extrusion of the West Carpathian lithospheric fragment from the Alpine realm and depocenters originated by pull-apart mechanism. During the Karpatian, mostly NE-SW oriented deep sinistral strike-slips have been activated along the eastern margin of the basin (Leitha Fault System), together with N-S oriented normal faults. In the Early Badenian, an activity of NE-SW oriented faults reaching the platform basement of the Bohemian Massif has been registered at the western margin of the basin as well (Steinberg, Schrattenberg and Bulhary faults).

3. The Middle Miocene subsidence of the synrift stage of the Vienna Basin was controlled by a paleostress field with NE-SW oriented compression (NW – SE extension). The Badenian basin formation influenced above all the NE-SW oriented normal faults. The second phase of more rapid tectonic subsidence during the Early Sarmatian is related to ENE-WSW sinistral strike-slips and NE-SW oriented normal faults. These faults induced subsidence of the Zistersdorf–Moravian Central Depression. The synrift stage extension in the northern part of the Vienna Basin was enhanced by active elongation of the Western Carpathian orogen during the Sarmatian due to subduction pull in front of the Eastern Carpathians.

4. The Late Miocene sedimentation represents a crustal relaxation of the post-rift stage in basin evolution during the Pannonian. In the late Pannonian and Pliocene, the Vienna Basin reached a stage of tectonic basin inversion. After this change the pull-apart kinematic was no longer active and only minor amounts of sediment were deposited. Fault-controlled subsidence in grabens at the eastern margin

of the basin (Zohor-Plavecký Mikuláš and Mitterndorf grabens) documents a sinistral transtensional regime of this zone, lasting up to the recent time, accompanied by seismic activity.

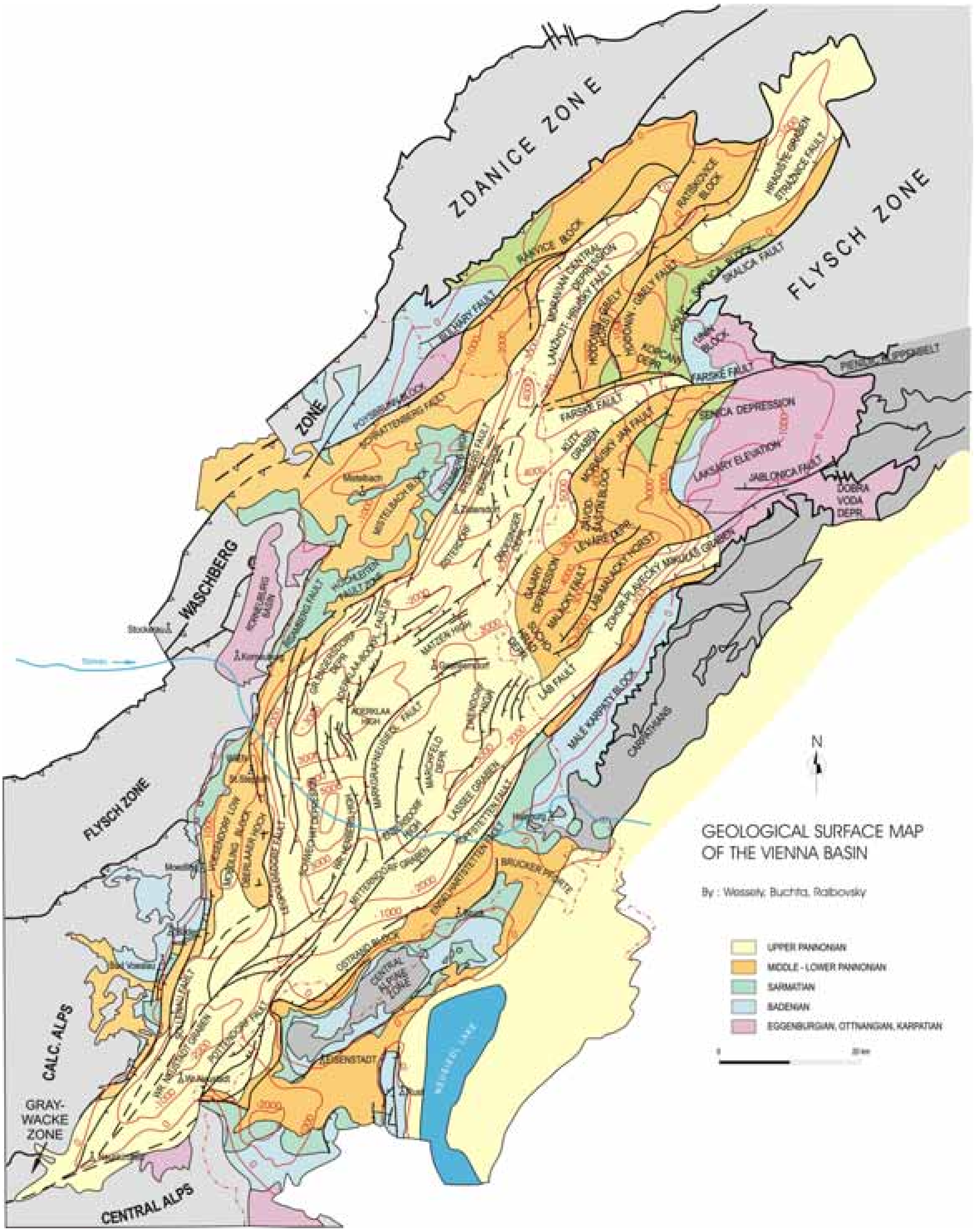


Figure 1
The Vienna Basin, bounding zones and tectonic lineaments (Wessely, Geological Survey, in press)

Northern Vienna Basin and Mistelbach Subbasin

Stop 1

A Sarmatian Flood-Tidal Delta and its Internal Structure on a Middle Miocene Oolite-Shoal

Stop "Nexing Muschelgrube", Sarmatian Scalica Formation, ~12.2 my (excerpt from Harzhauser and Piller in press)

Nexing is a small village in Lower Austria about 7 km SE of Mistelbach and about 40 km NE of Vienna. The locality is known to earth-scientists as the designated holostratotype of the Sarmatian Stage (Senes, 1974). Although this holostratotype is not representative for the Sarmatian due to its unique sedimentological and paleontological characters, it is the stratotype for this Paratethys stage. The largely biogenic sediments of the pit Nexing have been exploited up to recent years as lime-addition for bird feed.

The deposits at section Nexing are part of the Miocene sediment-cover of the Mistelbach tectonic block in the Vienna Basin. This tectonic unit represents a marginal block of about 60 km length and 18 km width that is separated from the deeper Vienna Basin by the Steinberg fault zone (Kröll & Wessely, 1993). The surface distribution of the Sarmatian in the area was excellently mapped by Grill (1968). Generally, most of the Sarmatian deposits are covered by Upper Miocene (Pannonian) fluvial and limnic sediments, obscuring the facies relations of the Sarmatian.

Figure 2
Outcrop Nexing (so-called Muschelgrube) in Lower Austria.

Chronostratigraphy and Biostratigraphy: The mid to upper Sarmatian deposits are dated as Upper *Ervilia* Zone and lowermost *Sarmatimactra* Zone in terms of mollusc zonation and as lower *Porosononion granosum* Zone of the benthic foraminifera zonation. The boundary between the Upper *Ervilia* Zone and the *Sarmatimactra* Zone is situated at the base of unit 3. The dating is based on the occurrence of the cardiid *Plicatiforma latisulca* (Münster) and the evolutionary levels of the gastropod *Duplicata duplicata* (Sowerby) and of the bivalves *Ervilia dissita podolica* (Eichwald), *Venerupis gregarius* (Partsch), and *Sarmatimactra eichwaldi* Laskarev.

Lithologies and Lithofacies: All logs can be correlated by a characteristic marker bed and may be divided into 4 main units which are described in the following:

Unit 1: The base of the deposits consitst of green silt with scattered plant debris. These pelites display a dip of 15°-16° in north-western direction. Macrofauna is virtually missing, but a poor microfauna with the foraminifera *Porosononion granosum* and various elphidiids occurs.

Unit 2: The silty sediment of unit 1 is overlain by about 14 m of steeply inclined planar bedded foresets of coarse mollusc shell-sand. The sediment represents a solely bioclast-supported, polytaxic skeletal concentration The carbonate content of the sediment ranges from 78-81% w/w. This content may decrease to 60 % in poorly sorted layers with high amounts of siliciclastics. Aside from the predominance of biogenic components, the poorly sorted sediment consists of middle to coarse quartz sand with intermingled ooids, scattered flysch pebbles and rare reworked oolite-clasts. These coquinas are very poorly sorted because the bioclasts are generally larger than the bulk of the siliciclastic components, whilst the pebbles and oolite-clasts surpass the bioclasts in size.

The thickness of the foresets ranges from 80 to 280 cm (measured perpendicular to the bedding planes), being separated by fine to medium sand intercalations of 1-30 cm thickness. Occasionally, this intercalating layer is missing, but is often preserved as reworked clasts in the overlying shell bed. Towards the top the sets are divided by shallow and broad channel-like structures with thick silt-fine sand drapes of up to 40 cm thickness. The foresets dip at angles ranging from 21° to 36° in western to north-western direction. A general steepening from base to top is observed, with angles from 21°-28° in the lower part of the unit and 30°-36° in the upper portion. However, the dip-angles distinctly decrease in the uppermost parts of the shell-sand foresets, where values of 15°-25° are measured.

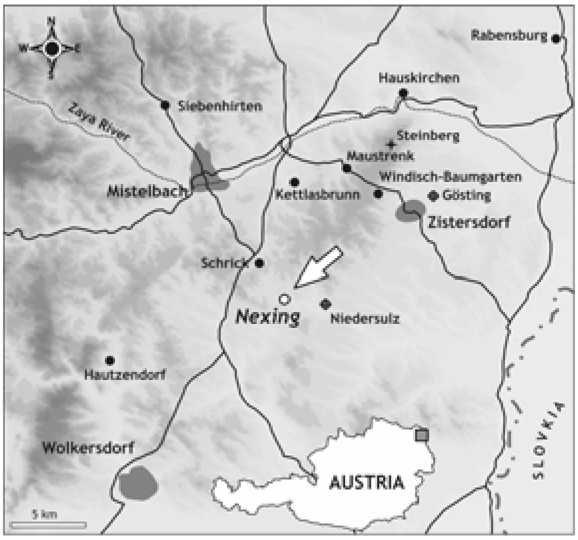


Figure 3
Geographic position of Nexing.

Unit 3: This unit represents a marker horizon allowing a correlation across the outcrop area. At section Nexing 4 it consists of a 20-180 cm thick layer of silty fine sand bearing well-rounded flysch pebbles, oolite pebbles and mud clasts of up to 5 cm diameter. Large-sized molluscs are floating within these deposits. Laterally, the amount of pebbles decreases and

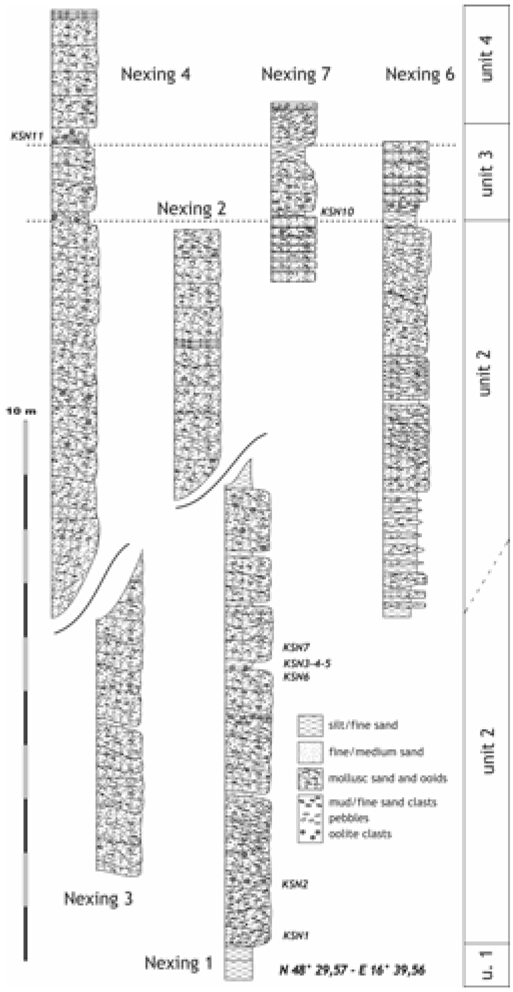


Figure 4
Lithologic logs of the pit.

10-30 cm of silt and fine sand with well-developed small-scale ripples occur. It is overlain by 100-150 cm inclined planar bedded mollusc shell sand with sand intercalations and frequent pebbles and concretions. The latter are irregular, tube-like, glossy brown structures reminiscent of abraded bones, but turned out to consist of calcite and can be allied with reworked root-horizons. The dip angle of this bed ranges from 15° to 4°. At Nexing 7, another layer of 30-50 cm of silt and fine sand with small-scale ripples follows; the dip angle is around 4°. Again, this layer of well-sorted sediment changes within 150 m towards the northwest and is replaced by fine sand with well-rounded oolite pebbles and flysch pebbles at section Nexing 4.

Unit 4: Above, with a sharp boundary, 2-3 m of steeply inclined, planar bedded shell-sand follow. It hardly differs from unit 2 but displays dip angles between 12° and 25°. This Miocene unit grades into various silty, sandy and gravelly layers with shell hash which are interpreted as Pleistocene reworking. This interpretation is supported by the relation of the deposits to the adjoining Pleistocene loess.

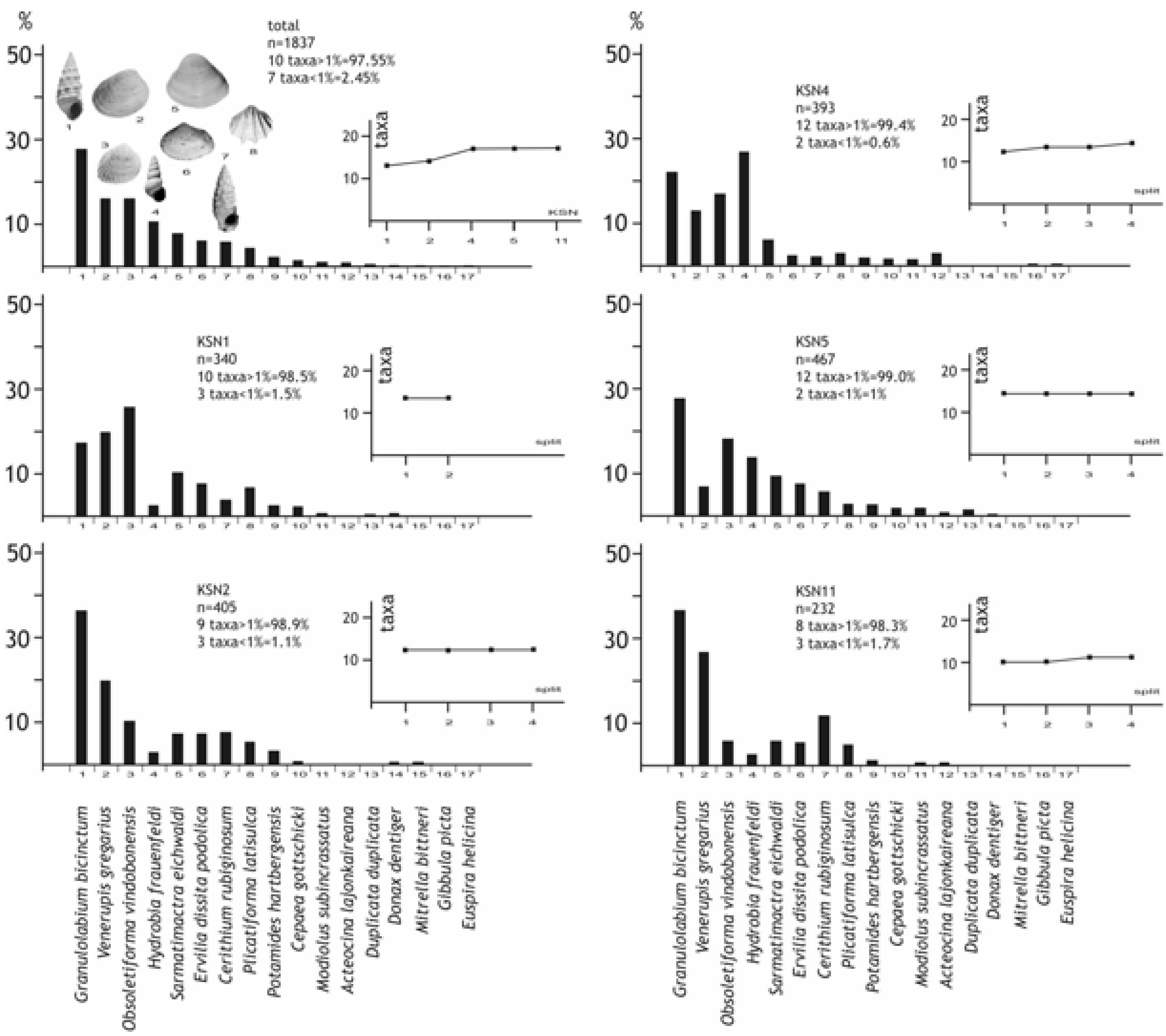
Fauna: Up to 81% of the deposits are made up of biogenes derived nearly exclusively from molluscs. Based on the collections of the NHMW, 21 gastropod species and 11 bivalve species are recorded from the current outcrop. This low diversity is typical for Sarmatian mollusc assemblages that have passed a crises at the Badenian/Sarmatian boundary. This event is reflected in the extinction of most stenohaline marina taxa and a remarkable evolution of the remaining survivors (Papp, 1956; Svagrovský, 1971).

The collections of the NHMW and various private collections also contain several vertebrate remnants from Nexing. Aside from the frequent teeth of sea-breams, the dolphins *Acrodelphis* and *Pachyacanthus* and the seal *Phoca vindobonensis* represent the aquatic vertebrates of the shoal. Terrestrial vertebrates, although randomly found throughout the section, are most abundant in units 3 and 4, probably as a result of lag formation and subsequent reworking. The most common genera are the turtle *Testudo*, the antilope *Protragocerus*, the giraffid-related *Palaeomeryx,* the rhinoceratid *Aceratherium* and the elephant *Deinotherium.*

Figure 5

Taxonomic composition and percentage abundance of mollusc species in five standardized bulk samples. The eight quantitatively most important taxa are illustrated. Bivalves are based on hinges and umbos, whereas fragments are not included.

Species-sampling curves for each sample (KSN 1, 2, 4, 5, 11) and for all samples (total) are drawn, documenting a well-balanced sampling quality and quantity.



Paleoecology and Dynamics: The current outcrop situation offers insight into parts of the longitudinal and transversal extension of the sedimentary bodies. The foresets in the lower part of unit 2 display more or less straight "crests" and planar down slopes. The length of the down slopes based on outcrop observations can be estimated to attain at least 30-40 m. Taking the calculated dip angle of 20° into consideration, a height of about 10-13 m can be predicted for that structure. This rough estimation fits well with the situation outcropped along the wall at section Nexing 1. There, the base of the foresets is exposed. Consequently, the lowest dip angles, observed at the base of the unit, correspond to very distal parts of the slipfaces, indicating early progradation.
At the first glance the overall geometry is therefore strongly reminiscent of giant 2-D dunes and resembles the *class IIIA* category of tidal dunes of Allen (1980). Steep foresets with down slope angles of 20° develop beneath a large-scale separated flow. During phases of substantial slackening of currents the foresets became separated by thick mud drapes. Interpreting the foresets as slipfaces of giant dunes, however, would result in problematic inferences with paleogeography, namely with the depositional depth.
Although there is considerable doubt about a straightforward correlation between (inertial) dune height and flow depth, several authors such as Mosher & Thomson (2000) discuss a vague correlation between dune height and total water depth. Following the various rules of thumb presented by the mentioned authors, a total water depth ranging from 40-90 m would have to be calculated for the 10-13 m high structures of Nexing. Based on the topographic altitude of the correlative deposits of the shallower oolite shoal, this depth estimation turns out to be much too deep. Especially the marker horizon in unit 3 – suggesting a phase of emersion of the entire shoal – allows a good correlation of the deposits throughout the Mistelbach block. Hence, a maximum water depth of 10-20 m is most plausible and an interpretation as a dune field is rejected. Nevertheless, bioclastic sand dunes from Ackers Shoal (Torres Strait, NE Australia) reach a height between 3-8 m in a moderate water depth of around 20 m (Keene & Harris, 1995), and therefore an interpretation as "mega"dunes cannot be ruled out completely.

A second possibility is to discuss these structures as washover deposits that formed along the seaward fringe of the shoal. This, however, conflicts with the internal architecture of the shell dunes and ripples, which points to regular short-term high-energy conditions rather than to random events. Furthermore, the steep-angled foresets differ distinctly from the subhorizontal to low-angle planar stratification as described by Schwartz (1982) from washover fan deltas.

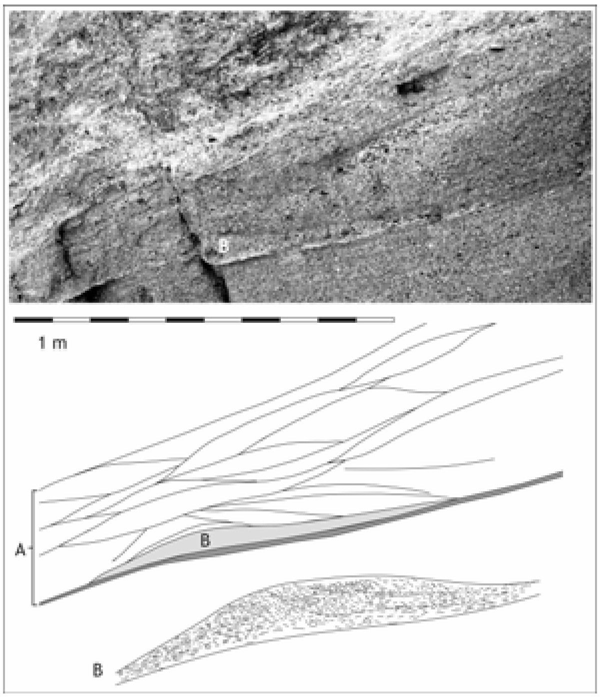


Figure 6
Outcrop photo showing cross-section through a shell dune (A) with mud-drape at the base. The graph below illustrates the internal structure formed by stacked shell ripples. The orientation of shells and fragments of one ripple (termed B) is depicted. Steepest angles and maximum imbrication is achieved in the middle part of the ripple overlying a basal layer of more or less planar bedded shell hash. A further subdivision of the ripple as indicated by the dashed lines seems to be likely. The paleocurrent is suggested to come from the right.

We therefore interrpret the huge foresets as tidal delta foresets. Due to the paleogeographic situation, only the flood current can be responsible for their formation. and the structure is therefore supposed to represent a flood-tidal delta which followed a channel or inlet into the lagoonal part of the shoal.

During the subsequent westward migration of the delta, the steep foresets gradually buried the preceding ones. At that time, the relative sea level in the Vienna Basin was quite stable and a coinciding loss of accommodation space can therefore be predicted. This assumption is supported by the changing geometry of the foresets. Towards the top of unit 2 the regular foreset pattern becomes replaced by a more wavy and partly channel-like bedding. These structures might either represent large lobate foresets or longitudinal tidal bars. Their internal structure, however, is identical with that of the planar bedded foresets. This morphological shift is interpreted to be caused by a shallowing upward trend. Consequently, current velocity probably increased, being reflected in succession from lower-speed bedforms towards higher-speed bedforms.

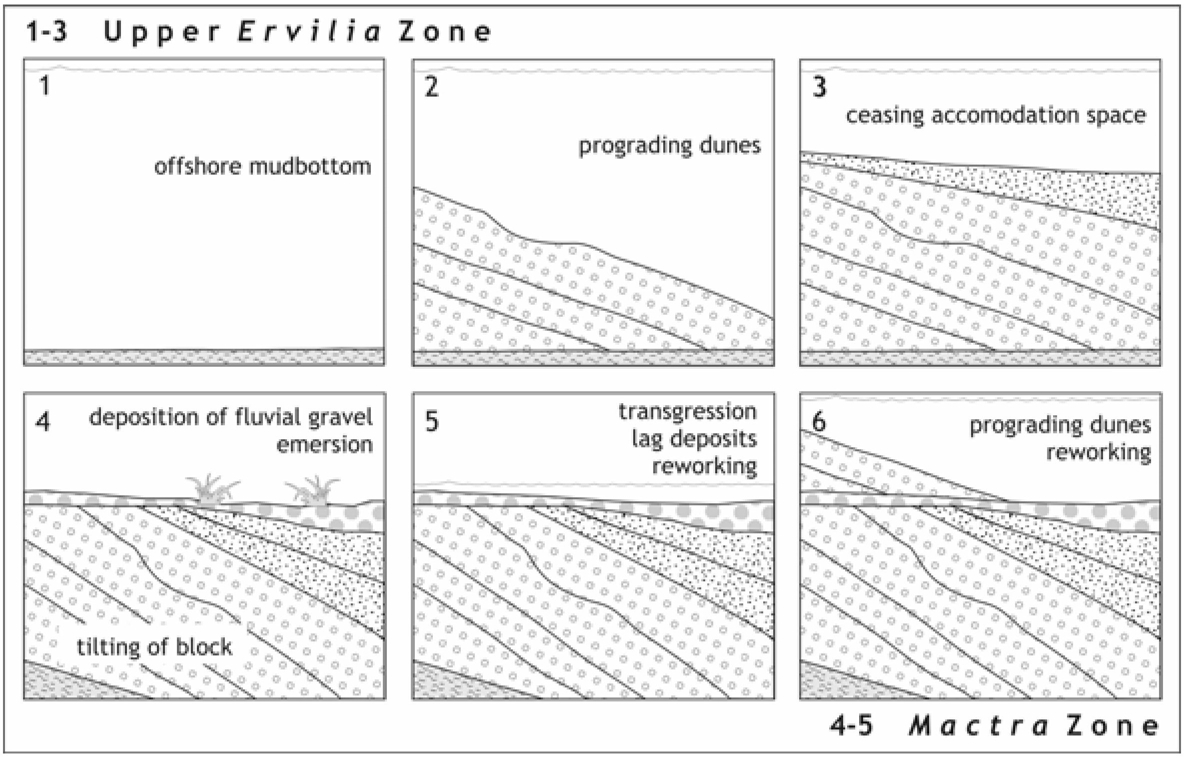


Figure 7
Simplified evolution of the shoal on the marginal block of the Vienna Basin during the Late Sarmatian.
1-3: The migration of the flood-tidal delta started during the late *Ervilia* Zone, gradually prograding in western direction into the shoal across shallow marine clays. Due to the rather stable relative sea level, a drop in the accommodation space alters foreset geometry.
4-6: An emersion phase of the delta, also evident in other parts of the shoal, enabled the development of vegetation. Fluvial deposits spread over the dry shoal. The renewed transgression during the *Mactra* Zone led to a reworking of these deposits and also allowed the re-establishment of a second flood-tidal delta.

Paleogeographic setting of the flood-tidal delta: The paleogeographic situation shows that the deposits formed at the sea-side margin of a shoal. In the northwest, the Steinberg elevation acted as island during that time, whereas in the west, the mainland formed the coast. The island situation is proved by rocky littoral deposits such as the so-called “Riesenkonglomerat” along the basinward side of the Steinberg elevation (Grill, 1968). Due to the current pattern, inferred from the dip directions of the foresets, most of the terrigenous material involved in the shell dune formation cannot be derived from the mainland at the time of deposition. Its origin is rather related to reactivation and reworking of deposits that accumulated along the Steinberg elevation during the earliest Sarmatian. The source for those deposits was the Molasse Basin and the Waschberg Zone. After the retreat of the Badenian Sea from the Molasse Basin, incised valleys developed due to the subsequent 3rd order lowstand systems tract that occurred at the Badenian/Sarmatian boundary (Harzhauser & Piller, 2004b). Drainage from the Molasse Basin via the modern Zaya Valley developed and transported fluvial gravel and various siliciclastics onto the Mistelbach block (gravel of that river is exposed at Siebenhirten near Mistelbach). During the following early Sarmatian transgressive systems tract, the sea entered the valley and replaced the fluvial system and the fluvial input ceased. A further source for redeposition in the flood-tidal delta is siliciclastics that accumulated on the Mistelbach block earlier in the Badenian.

The shoals surrounding the Steinberg elevation – settled by enormous masses of shallow marine molluscs – are thought to have supplied the flood-tidal delta with the striking amount of shells and shell hash. These shell masses, as well as the reworked oolites, may have been transported by SSW-directed shoal-parallel currents to the tidal inlet where they were deposited in a flood-tidal delta. A hint on the extension and origin of the delta in the direction of that hypothetical current is also offered by the well Niedersulz 9 (OMV company), about 2 km ESE of Nexing. There, equivalent shell accumulations have been reported in an internal report (Note that the well Niedersulz 9 is already on an *en echelon* block at the margin of the Vienna Basin. Thus the shelly beds and overlying lignites which formed during the emersion of the shoal are now in a topographically deeper position). Thus, the WNW orientation of the downslopes of the foresets and shell dunes is interpreted to result from a dominant flood current entering the shoal via the broad tidal inlet in the area of Nexing. In that inlet, the foresets probably migrated within a large tidal channel because the paleocurrents exhibit little variance. Similar tidal channels with flow-transverse bedforms occur on modern oolite sand shoals of the Bahamas (Hine, 1977) and the Persian Gulf (Evans, et al. 1973).

That channel might have been initiated during the lowstand in the earliest Sarmatian by the above-mentioned fluvial system that structured the Mistelbach block prior to the Sarmatian flooding.

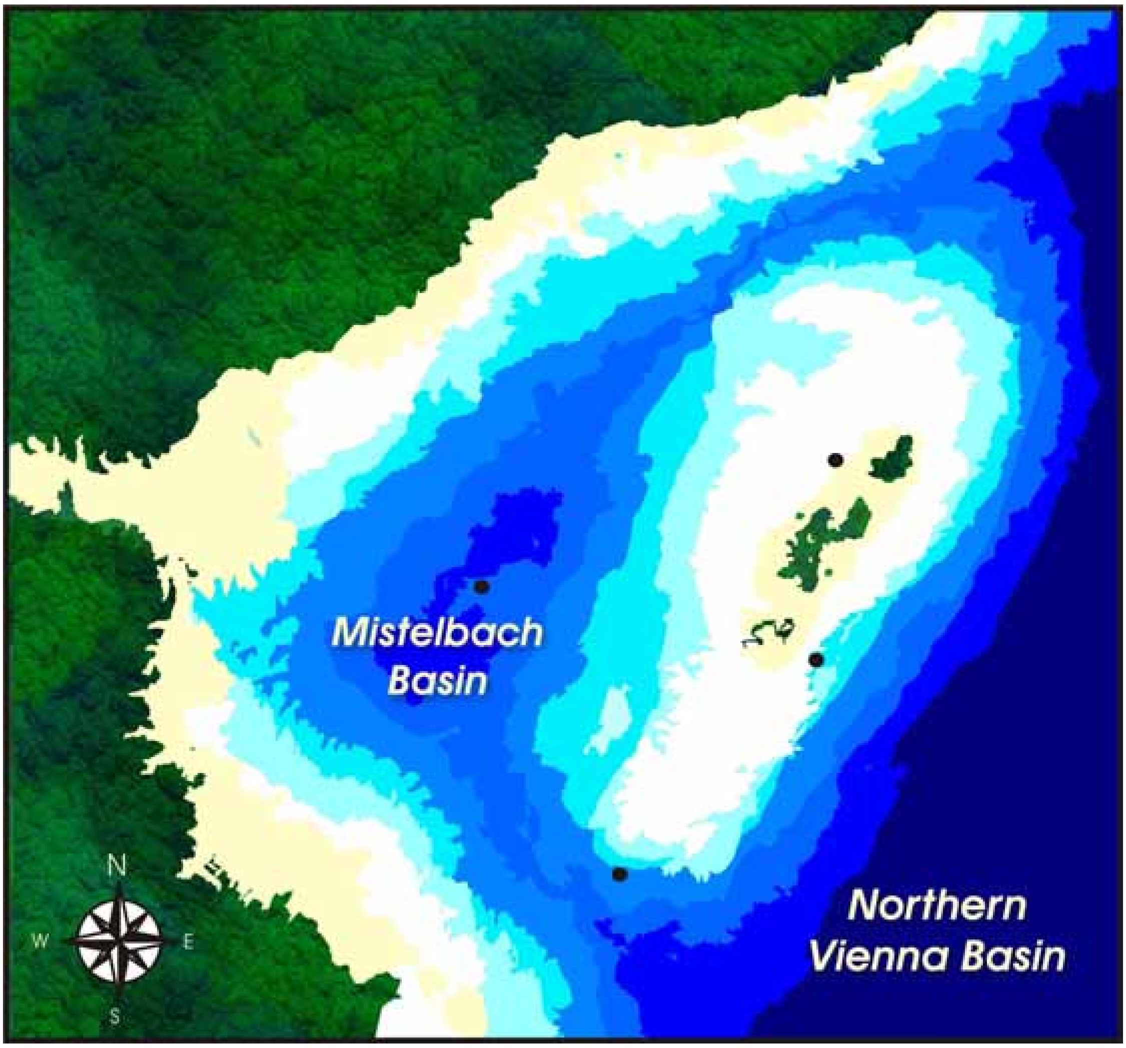


Figure 8
Paleogeography of the Mistelbach Subbasin during the Sarmatian; the southernmost black dot indicates the position of Nexing within a tidal channel.

Stop 2

Sarmatian Bryozoan-Algal pools and Oolite shoals

Stop Maustrenk, Holic Formation, Scalica Formation, Lower and Upper Sarmatian, 12.7-11.6 my (excerpt from Piller and Harzhauser in prep.)

At Maustrenk unique bryozoan-algal-thrombolite bioherms of up to 50 cm size occur in Lower Sarmatian carbonate sediments of high-energy conditions. The build-ups are overlain and partly truncated by cross-bedded oolites. Build-up growth starts with a *Cryptosula/Hydroides* (bryozoa/serpulid) pioneer community, followed by massive *Schizoporella* (bryozoa) colonies overgrown by coralline algae and calcareous filaments (eukaryote algae?). The latter are main constituents of a thrombolite which, together with Schizoporella and coralline algae, forms a framestone fabric. Generally, a high water energy regime is responsible for the bioherm growth in combination with high Ca-concentration of sea-water. This setting roughly parallels that on the Exuma Cays, Bahamas. The ecological succession within the bioherms reflects increasing nutrification and decrease in water quality.

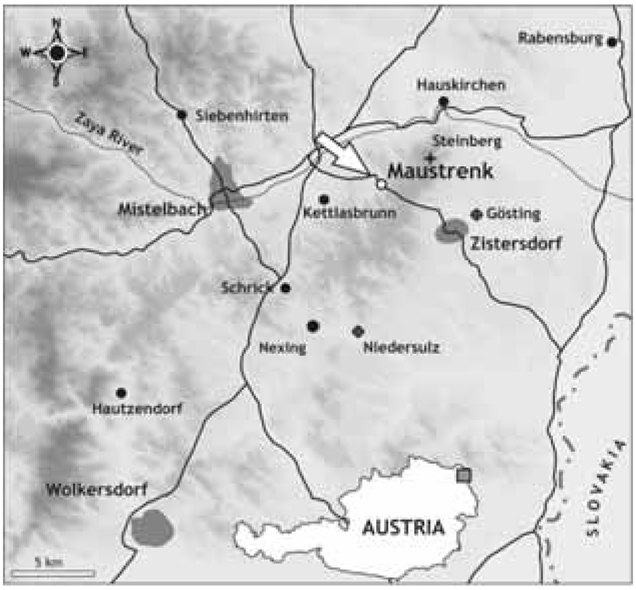


Figure 9
Geographic position of Maustrenk

Chronostratigraphy and Biostratigraphy: Based on the occurrence of *Elphidium reginum* and Mohrensternia, the age of the lower part of the section is correlated with the Early Sarmatian. The overlying oolites bear a mollusc fauna which is indicative for the Upper Sarmatian *Ervilia* Zone.

Lithology: The sedimentary sequence in which these build-ups occur is about 7 m high. It starts with an emersion horizon of Middle Miocene (Badenian) Leitha Limestone made up predominantly by coralline algal fragments and larger foraminifera. During subaerial exposure and after transgression of the Sarmatian these limestone became eroded and reworked forming coarse, well rounded, detrital carbonate sands arranged in large, cross-bedded sets representing subtidal sand dunes oriented in SSW-NNE direction. These bodies of sand dunes are overlain by sand sheets with large ripples exhibiting roughly the same orientation. On top of many ripples individual carbonate build-ups grow. The space between the build-ups is filled by cross-bedded oolite sand and the overlying bed is also a cross-bedded sand made up predominantly of multi-layered, radial oolites. The build-ups and surrounding sediments are truncated and/or eroded prior to sedimentation of oolite sands.

Build-ups: The build-ups are globular, lense-like or columnar in shape and reach more than 50 cm in height and width. Their internal organisation shows a clear ecological succession: the basal part is constructed by crustose bryozoan colonies of the genus Cryptosula building up several centimeters of skeletal carbonate by forming repeated crusts. The serpulid Hydroides is frequently intergrown with Cryptosula and the bryozoan crusts are overlain by single-layered thalli of coralline algae (Lithoporella). This Cryptosula-bindstone is overgrown by and provides substrate to globular to hemispherical colonies of the bryozoan genus Schizoporella, which makes up the bulk of the build-up, forming a rigid framestone. The individual bryozoan colonies reach up 5 cm and more and are also frequently inter- and overgrown by Hydroides. Usually this Schizoporella framestone is overgrown by coralline algae (Lithoporella), which are encrusting but forming columnar protrusions up to several centimeters thickness. This Schizoporella/coralline algal framestone which occurs in repeated sequences is embedded into a microbial carbonate of dusty appearance. Within the framestone vagile benthic biota are made up of gastropods, bivalves, foraminifera (mainly miliolids) and ostracods. The zooecia of the bryozoa are frequently settled by filamentous, dichotomously branching structures. These are most abundant in the peripheral zooecia and decrease inwards. Finally the framestone is covered by a cap dominated by bifurcating filaments (2 size categories in diameter: 15-20 µm; 30-40 µm) in a clotted, micritic matrix which is best described as thrombolite. In some places serpulids, particularly “spirorbids”, may be abundant and also Cryptosula appears again. Voids, in particular those within bryozoan zooecia, are frequently rimmed by a first isopachous fibrous cement generation. The thrombolite is usually terminated by an erosional surface, which, however, may even cut down into the bryozoan/coralline algal framestone. Therefore, the outermost “crust” is frequently missing. This erosional surface is covered by an oolite. Space between the frame within the build-ups is frequently filled with oolites, proofing the still open framework of the build-ups.

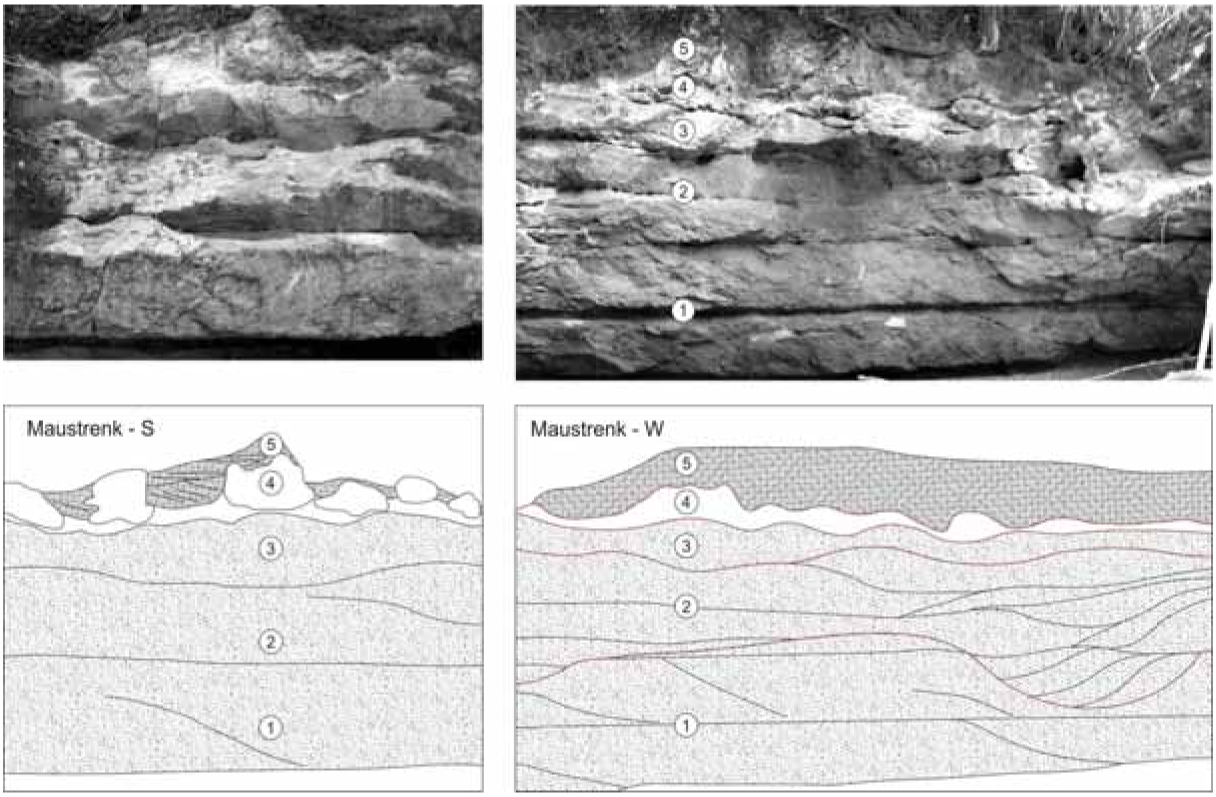


Figure 10
Outcrop wall at Maustrenk (Austria). At the very base the Badenian Leitha Limestone is truncated by a disconformity. Sarmatian sediments start with cross-bedded, channelized coarse-grained carbonate sands and detrital carbonate sand dunes (1 – 2) which are topped by a bed with ripples (3). The ripples are settled by bryozoan-algal-thrombolite build-ups. After an erosional surface, space between build-ups is filled by cross-bedded oolites (4) which also form the top bed (5). Height of outcrop: approx. 7 m.

Discussion: The basal sedimentary sequence of the studied succession exhibits a deepening of the environment after flooding of the emersion horizon during the Early Sarmatian. This forced the formation of sand dunes reflecting high hydrodynamic conditions. Upsection the magnitude of sand dunes decreases and they are finally overlain by sand with more symmetrical wave-ripples. The sequence clearly points to a shallowing upward trend from a few meters water depth at the base to very shallow subtidal conditions. The rippled sand must have been stable and firm enough to be settled by the crustose bryozoan *Cryptosula* and the serpulid worm tubes of *Hydroides*. This pioneer community was succeeded by the massive bryozoan colonies of Schizoporella forming a rigid skeletal frame frequently overgrown by crustose coralline algae of columnar growth form. These are finally overgrown by a thrombolite. The frame of this is made up of calcareous filaments which may be interpreted either as cyanobacteria or as eukaryotic algae embedded in clotted micrite. The cyanobacterial assignment would match modern as well as fossil examples (e.g., Pentecost and Riding, 1986; Riding et al., 1991b). The modern *Schizothrix* filaments and mats as being reported to be the main constituents of the modern Bahamian stromatolites are, however, not calcified (e.g., Reid et al. 1995; Feldmann and McKenzie, 1998). In fact, the filaments fit much better those structures assigned to the green alga *Ostreobium* (e.g., Kobluk and Risk, 1977) which is considered to be the most important frame-builder in the Bahamian thrombolites by Feldmann and McKenzie (1998).

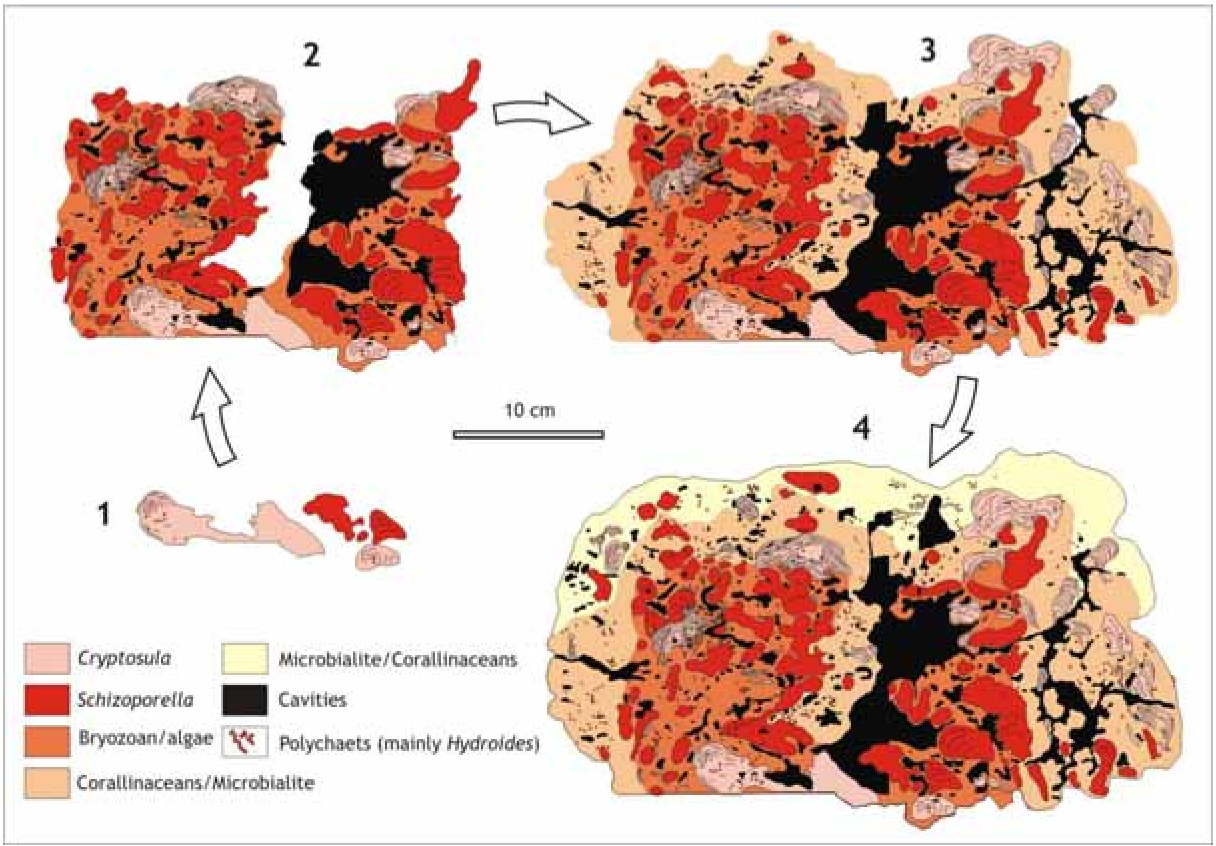


Figure 11
Individual bryozoan-algal-thrombolite build-up. Various growth stages may be deciphered pointing to a complex environmental history.

This described ecological succession clearly reflects a change in environmental conditions.

- At the very base of the build-ups basically the Cryptosula/Hydroides pioneer community reflects colonization of the sediment surface by highly opportunistic organisms. The community is frequently overgrown by a first coralline algal crust, followed or accompanied by microbial carbonate. This succession may point to a slight nutrification.
- The next step with the growth of large *Schizoporella* colonies first proofs stable substrate on which these taxa may thrive. Again an overgrowth by crustose coralline algae occurs, in these cases frequently in columnar growth form. Again, an increase in nutrients might be indicated.
- However, the overlying "thicket" of eukaryotic (?) filaments and related clotted and pelleted sediments (thrombolite) implies a further increase in nutrient supply as does the final community of Cryptosula and spirorbid serpulids. The thrombolite can be considered to have been formed in a subtidal environment under normal marine conditions (Feldmann and McKenzie, 1997).
- The growth is terminated by erosion eventually during subaerial exposure of the build-ups. The next flooding event was coupled with a renewal of the water during transgression and allowed the production of thick oolite bars which are a widespread general feature of this transgression at the beginning of the Late Sarmatian. These migrating sand bars additionally truncated and asymmetrically eroded the build-ups.

Co-occurrences of microbial carbonate build-ups and thick oolites are not only reported from the extant Bahamas but in similar way also from the Upper Miocene of Spain (e.g., Riding et al., 1991a). Similar to the modern microbial build-ups for the Miocene examples sediment and water-energy stress is considered to be the main agent to deter competitors for destroying the microbial mats. Similar successions, however, starting with corals, particularly *Porites*, instead of bryozoa have been described from the Upper Miocene (Messinian) of Spain (Riding et al., 1991b; Feldmann and McKenzie, 1997) and from southern Italy (Bosellini et al., 2001) where the coral communities were terminated by microbial carbonate. In the latter example the final community of the build-ups is made up by vermetid-microbial trottoirs. The construction of the thrombolites by filamentous structures as described from SE Spain (Feldmann and McKenzie, 1997) is very similar to those described herein, the diameter of the structures is, however, much greater in the Spanish examples (100 µm) as in ours (15-20 µm; 30-40 µm).

Conclusions: The ecological succession is interpreted to reflect a general increase in nutrients and decrease in water quality. After an erosional phase a renewed water body entered the area of deposition and the build-ups became covered and eroded by high energy cross-bedded oolites. The reasons for the origin of this type of build-ups are manifold. One is the specific paleoceanographic and paleogeographic configuration during the late Middle Miocene of the Central Paratethys, prohibiting re-immigration of other euryhaline reef-building organisms, as for example corals. Another reason are environmental parameters reflecting high energy conditions and supersaturation of the sea water in respect to calciumcarbonate. Although organism groups are different, the environmental parameter are similar to those which favour modern subtidal "stromatolite" growth, as for example in the Exuma Cays, Bahamas.

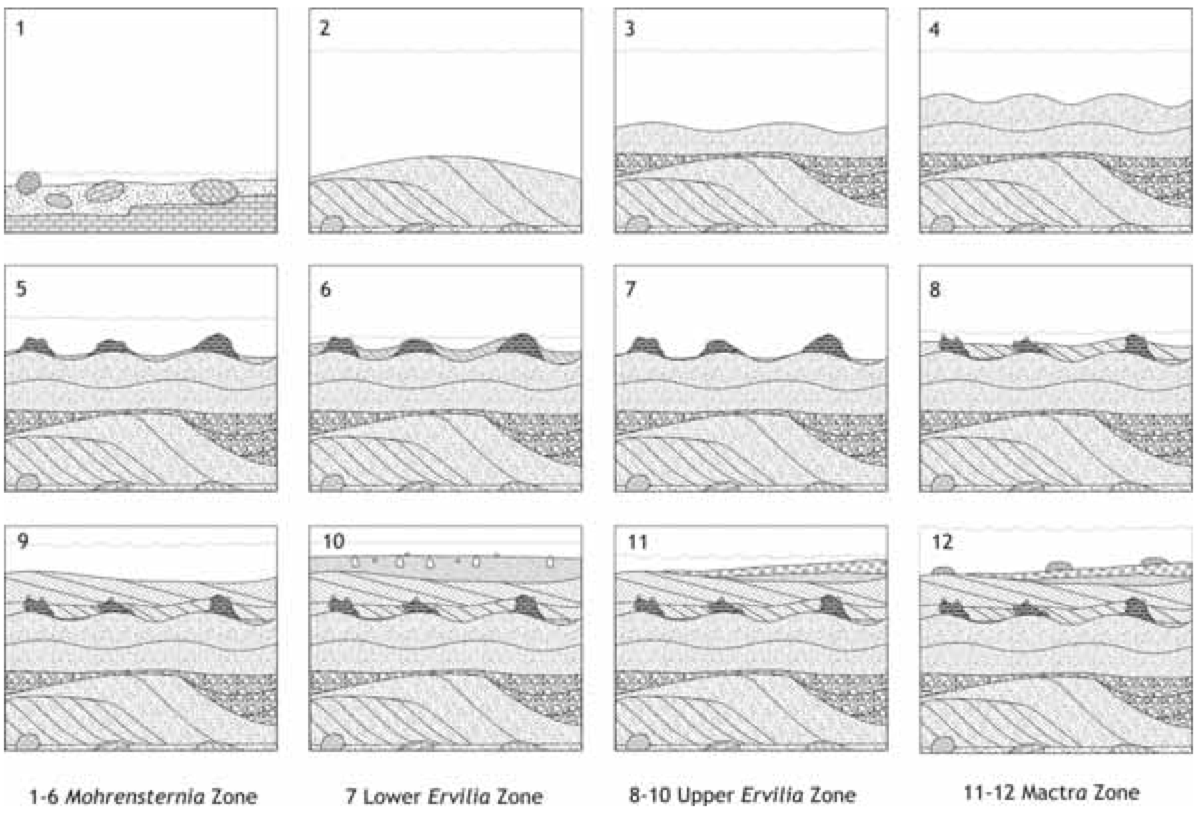


Figure 12

Simplified reconstruction of the depositional history in the lagoon of Maustrenk. 1-6 shows the Early Sarmatian transgression which coincides with a gradual decrease in accommodation space and the growth of build-ups in its late phase. Emersion and erosion took place during the mid-Sarmatian until a renewed transgression reached the area. An agitated oolite shoal developed. A third latest Sarmatian transgression is indicated by the growth of small build-ups consisting of nubeculariid forams.