Taphonomy and sequence stratigraphy of spectacular shell accumulations from the type stratum of the Central Paratethys stage Eggenburgian (Lower Miocene, NE Austria)

With 12 figs, 2 tabs

Oleg Mandic, Mathias Harzhauser & Reinhard Roetzel

Abstract

The mollusc faunas of the Lower Miocene Eggenburgian stage are known to science for nearly 200 years. However, the first detailed taphonomic and paleoecologic analysis of the famous coquinas from the strato-type area of that stage is presented in the current paper. An extremely accurate documentation of the shell accumulations at Nonndorf in Lower Austria allowed the separation of 7 coquina types which are discussed in terms of taphonomy, paleoecology and sedimentology. One of these types represents a typical storm wave concentration which later acted as barrier for subsequent populations of burrowing glycymerids. These bivalves are preserved with articulated valves within the slightly older death-assemblage forming a very conspicuous coquina. Hence, the term *"forced within-habitat concentration"* is proposed for this rare type of multi-phased coquina formation.

Based on the paleoecology of the pectinid *Oopecten gigas* and granulometric data, a two-stepped transgression can be documented for the investigation area. This new approach allows a further division of the 3rd order Bur-1 cycle which comprises the Lower Eggenburgian deposits.

Key words: Lower Miocene, Taphonomy, Molluscs, Paleoecology, "forced" within-habitat concentration, sequence stratigraphy

Zusammenfassung

Seit beinahe 200 Jahren werden die diversen Molluskenfaunen des Eggenburgium (Untermiozän) gesammelt und beschrieben. In der vorliegenden Arbeit wird nun erstmals eine ausführliche taphonomische und paläoökologische Analyse der auffälligen Schille vorgestellt. Eine überaus detaillierte Dokumentation der verschiedenen Schalenakkumulationen bei Nonndorf in Niederösterreich ermöglicht eine Unterscheidung von 7 Schill-Typen, die hinsichtlich ihrer taphonomischen, paläoökologischen und sedimentologischen Eigenschaften diskutiert werden. Ein Schill-Typus entspricht einer typischen Konzentration durch Sturm-ereignisse. Dieser Schill fungierte später als sedimentäre Barriere für die grabende Bivalve *Glycymeris fichteli*. Die Glycymeriden sind doppelklappig innerhalb des etwas älteren Tempestites erhalten und bilden somit einen bemerkenswerten, mehrphasigen Schilltypus für den der Terminus *"forced within-habitat concentration"* vorgeschlagen wird.

Basierend auf der Paläoökologie des Pectiniden *Oopecten gigas* und unter Berücksichtigung der granulometrischen Daten werden zwei transgressive Parasequenzen im frühen Eggenburgium unterschieden. Diese verbesserte Auflösung der Sedimentationgeschichte ermöglicht eine Zweigliederung des bereits beschriebenen Zyklus dritter Ordnung (Bur-1), dem die Sedimente des Unteren Eggenburgium zugeordnet werden.

Schlüsselworte: Unter-Miozän, Taphonomie, Mollusken, Paläoökologie, „forced within-habitat concentration", Sequenz-Stratigraphie

Authors' addresses: Oleg Mandic, Department of Paleontology, University of Vienna, Geozentrum, Althanstrasse 14, A-1090 Vienna, Austria, <oleg.mandic@univie.ac.at.>; Mathias Harzhauser, Museum of Natural History Vienna, Geological-Paleontological Department, Burgring 7, A-1014 Vienna, Austria, <mathias.harzhauser@nhm-wien.ac.at>; Reinhard Roetzel, Geological Survey of Austria, Department of Sedimentary Geology, Rasumofskygasse 23, A-1031 Vienna, Austria, <rroetzel@cc.geolba.ac.at>

Introduction

The Eggenburgian is a regional Lower Miocene stage of the Central Paratethys. Its historical type region is in the NE of Austria some 60 km NW from Vienna (Steininger 1971). The biostratigraphic frame of this stage is based largely on its characteristic mollusc fauna (Steininger & Senes 1971). Exceptional Eggenburgian mollusc fossil Lagerstätten were first noted at the beginning of the 19th century (Stütz 1807). During the 19th century they were already systematically collected, and those specimens, still stored in collections of the Museum of Natural History in Vienna, served as base for the illustrations in the famous monograph on Central Paratethys bivalves by Hörnes (1856, 1870).

Although the mollusc taxonomy was elaborated through subsequent works of Schaffer (1910, 1912), Sieber (1955, 1958), Steininger (1963) and Steininger et al. (1971) environmental analyses based on those data remained scanty.

Hence, the major goal of the present study is to document and interpret for the first time the taphonomic features of the famous mollusc coquinas in the historical type region of the Eggenburgian in the Horn Basin. The shell-layers form conspicuous beds within a sedimentary succession that developed during a marine flooding into an active fluvial system. A paleoenvironmental analysis of that complex system based on sedimentological and paleoecological data is provided; further, the succession is also discussed in terms of sequence stratigraphy.

Paleogeography and Chronostratigraphy

The Paratethys as a northern satellite sea of the Western Tethys (= Proto-Mediterranean) formed in the early Oligocene by the raising Alpine island chain which acted as geographic barrier (Rögl & Steininger 1983, Rögl 1998). Subsequently, it was portioned into two large geotectonic units which underwent different environmental histories due to differently timed geotectonic events, infill of Molasse sediments, and global sea level fluctuation controlling marine and non-marine phases. The studied sediments belong to the smaller, western unit termed "Central Paratethys", which included also the "Western Paratethys" s.s. during the Oligocene and Early Miocene (Rögl 1998). The Eggenburgian stage corresponds to the Lower Burdigalian stage of the chronostratigraphic standard scale (fig. 1) (Steininger & Wessely 2000).
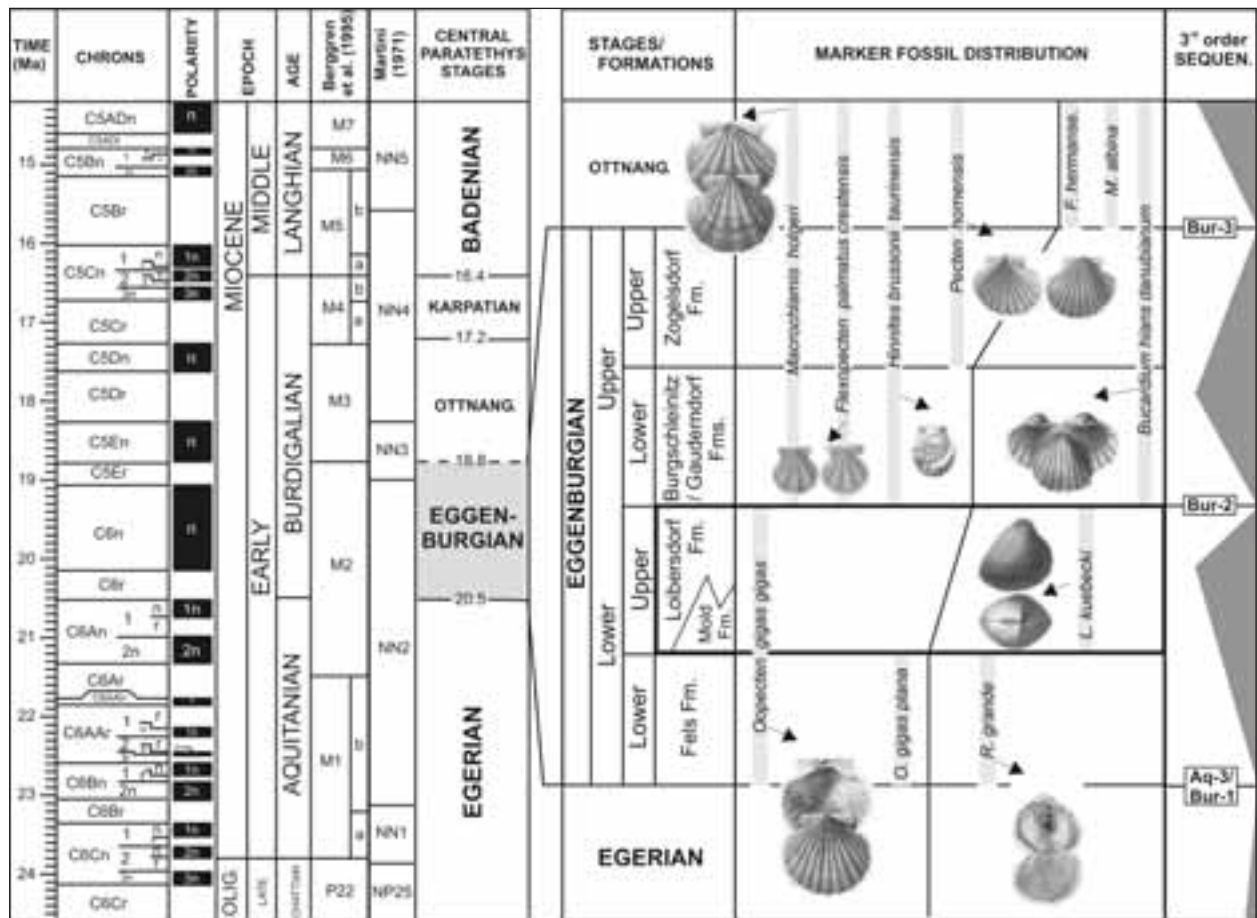

Fig. 1: Chronostratigraphic, geochronologic, magnetostratigraphic and biostratigraphic correlation of the Eggenburgian stage (modified after Mandic & Steininger 2003). Position of the Loibersdorf Formation is marked by bold lines. Sequences modified after Vakarcs et al. (1998).

Geological Setting

Lower Eggenburgian successions reflect a stepwise landward shift of the paleo-shoreline (MANDIC & STEININGER 2003). The marine sediments onlapped either directly on a relief formed by crystalline rocks of the SE Bohemian Massif or prograded into an estuarine-fluvial system coming from NW (ROETZEL et al. 1999) into the Horn Basin. The latter formed an "L"-shaped (E-W and N-S striking), asymmetric (E tilted), tectonically induced valley in the Bohemian Massif (fig. 2). During the Oligocene and Early Miocene a large river entered the sea in southern direction via this valley, depositing fluvial gravels and sands of the St. Marein-Freischling Formation. During a first transgressive impulse a narrow estuarine system established in the Horn Basin. Clays, marls and sands with scattered lignites of the Mold Formation were deposited. Mudflats with dense populations of batillariid and potamidid gastropods and oyster bioherms fringed the coasts of the Horn Basin. Melanopsids, neritids and theodoxids indicate a still active fluvial influx.

Finally, the transgrading sea flooded the alluvial plane of the river completely. The brackish-estuarine biotopes of the Mold Formation were gradually replaced and fully marine conditions became installed forming the sandy Loibersdorf Formation. The sands of the Loibersdorf Formation include the historical "holostratotype" of the Eggenburgian stage at Loibersdorf (STEININGER 1971) as well as the section Nonndorf, described in this paper.

Biostratigraphy

The dating of the section Nonndorf into the Early Eggenburgian is based on the mollusc fauna and on the genetic relation to the close-by holostratotype Loibersdorf (STEININGER 1971; MANDIC & STEININGER 2003).

Hence, the occurrence of *Oopecten gigas* (SCHLOTHEIM) in those sections implies their Early Eggenburgian age. The species is the marker fossil from which the name of the *Oopecten gigas* Zone derives, as proposed by BALDI & SENES (1975). As shown by MANDIC in ROETZEL et al. (1999), the *Oopecten gigas* Zone is divided in the studied region into two subzones based on the evolutionary shift from *Oopecten gigas* planus (SCHAFFER) towards *Oopecten gigas* gigas (SCHLOTHEIM). This biozonation correlates well with the lithostratigraphy of the area: the older Fels Formation covers the *O. gigas planus* Subzone, whilst the Loibersdorf Formation yields faunas of the *O. gigas gigas* Subzone.

Furthermore, the mollusc fauna of the sections Loibersdorf and Nonndorf are characterized by the occurrence of *Laevicardium? kuebecki* (HAUER). Although being commonly represented in respective sediments throughout the Paratethys, within the Eggenburg Group it is restricted to the Loibersdorf Formation. Aside from these marker species the entire mollusc assemblage allows a positioning

of the Loibersdorf Formation between the Fels Formation and the Upper Eggenburgian formations. This was demonstrated recently by MANDIC & STEININGER (2003) using computer based hierarchical classification techniques.

The *Oopecten gigas* Zone is correlated with the upper part of the nannoplankton zone NN2, the middle part of the plankton zone M2 and with the upper part of the mammal zone MN 2. An indirect correlation with the chron C6n is most likely (see also chapter "sequence stratigraphy").

Materials and methods

Several excavation campaigns of the University of Vienna, Department of Paleontology and the Krahuletz-Museum in Eggenburg focused on the fauna of the marine transgression into the Horn Basin. The material is stored at those institutions and at the Museum of Natural History of Vienna and the private collection of Gerhard Putzgruber in Straß im Straßertal (Lower Austria). Especially the extremely rich shell accumulations at the base of the Loibersdorf Formation were studied in detail. Those spectacular coquinas were found to be auspiciously developed at the forest margin outcrop east of Nonndorf at the eastern margin of the Horn Basin (fig. 3). To improve the poor outcrop conditions artificial outcrops were made, exposing favorably the transition from the estuarine-brackish pelites of the Mold Formation into the fully marine sands of the Loibersdorf Formation. Additional excavations on the westward following parcels, topographically below the above-mentioned outcrop, exposed sands below the Mold Formation representing presumably the underlying fluvial facies of the St. Marein-Freischling Formation.

Several quadrants of up to 2 m² have been excavated in the various shell-beds of the section. Each quadrant was exposed by preparation with air pressure and mechanical devices. During these efforts the surface following the paleo-relief of each coquina was tried to expose. The taphonomy and taxonomic composition of the coquinas was documented in vertical sections as well as in expansive horizontal sections (figs 4–10). The exact position of fossils and pebbles was transferred to a transparent plastic sheet. Numbers of specimens were counted in quadrants and taphonomic features of each shell were documented in detail (fig. 11, tables 1–2). Additionally, a series of granulometric data were achieved for the investigated layers (fig. 12).

Description of the Nonndorf-forest margin section
(N 48°36'04'' – E 15°43'17'')

The artificial outcrop exposed a 7 m thick succession of predominantly sandy to muddy siliciclastic sediments (fig. 4). Four lithological main-units have been dis-
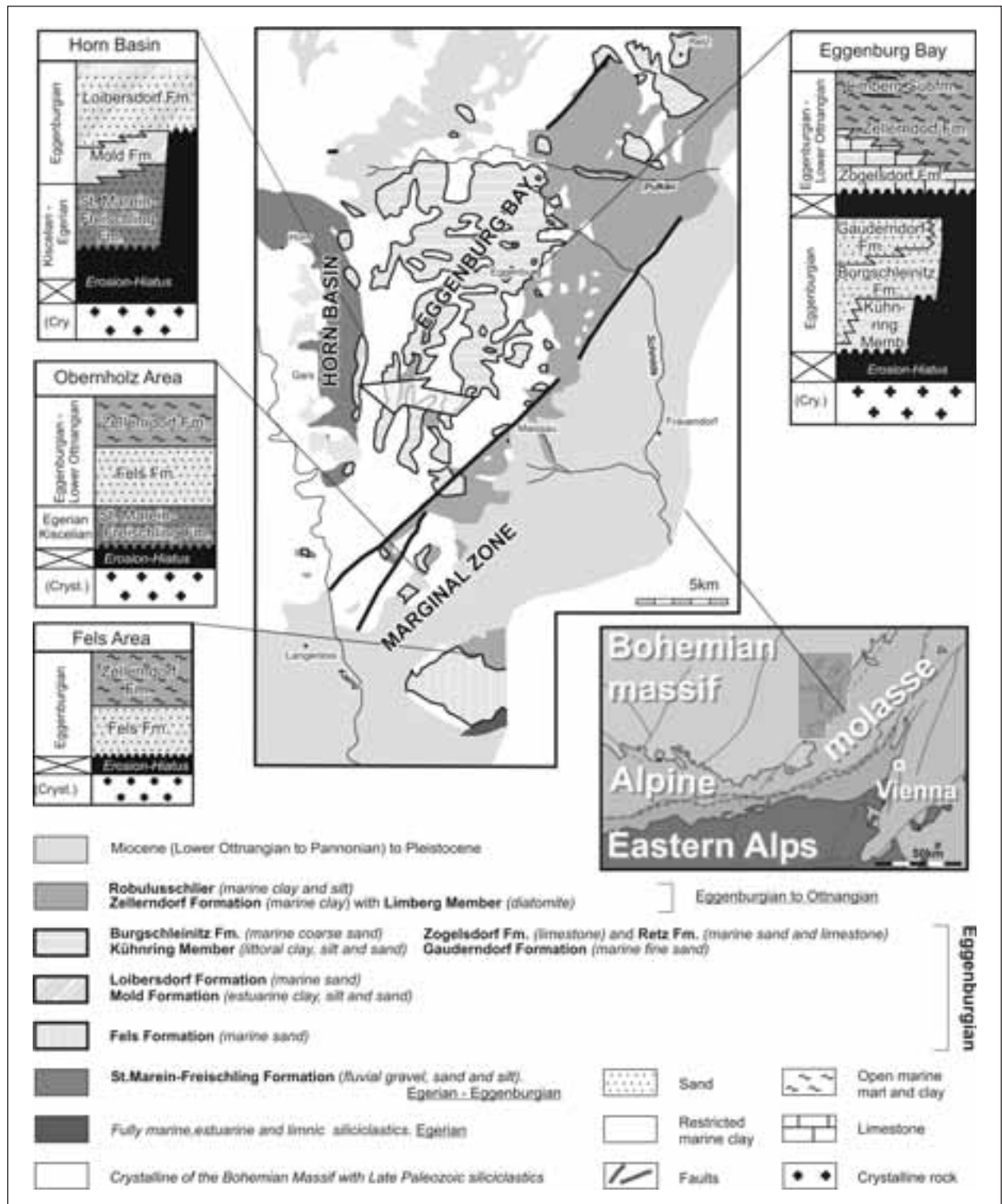
Fig. 2: Regional geologic and lithostratigraphic overview of the studied area (modified after ROETZEL et al. 1999 and MANDIC & STEININGER, 2003). The studied section (marked by the white arrow) is placed on the eastern margin of the Horn Basin, representing a longitudinal, small scale tectonically induced basin within the SE Bohemian Massif. The basal filling of the basin comprises the fluvial St. Marein-Freischling Formation. The Early Eggenburgian (Early Miocene) flooding installed initially estuarine conditions (Mold Formation). The fully marine environment was established with the Loibersdorf Formation. Due to their different paleotopography, the adjoining areas experienced a slightly different development. Thus, the open sea-exposed, marginal zone comprised the oldest parts of the Eggenburgian transgression. Therein, the Fels Formation was in the basal Eggenburgian already barren of any fluvial influence. The Eggenburg Bay, an Early Eggenburgian paleotopographic high, did not get flooded by the sea before the Late Eggenburgian. Hence its marine successions are stratigraphically younger than the youngest marine deposits of the Horn Basin (see text for more details).

Fig. 3: Overview of the studied site at Nonndorf-forest margin. Its topographic position E from Gars am Kamp and E from Non-ndorf bei Gars is indicated on the map (modified Austrian topographic map 1:200.000). Additionally the position of the type section ("holostratotype") of the Eggenburgian stage at Loibersdorf is given. The large photograph shows the studied outcrop. The position of characteristic coquinas and layers is indicated. The pit in front of the main wall outcrops the partial section underlying the *Ophiomorpha*-Layer (unit 1, see fig. 3). The horizontal plane between the pit and the wall is in the level of the *Oopecten gigas*-Coquina (see fig. 3 and 7). It represents the base of unit 3 (the main shell bed). The plane within the upper right part of the wall provided the horizontal view into the Upper *Glycymeris fichteli*-Coquina and is illustrated on fig. 3 and Fig. 9. The fossil block, on the upper, right side of the illustration, gives a 3D overview of the main shell bed top. Note the non-fragmented, large sized, thick-shelled bivalves dominating the structure. Note the articulated *Glycymeris fichteli* shells restricted to the uppermost level of the block (preparation by Gerhard Putzgruber, Straß im Straßertal, Lower Austria; on display in the Earth Science gallery of the Krahuletz-Museum, Eggenburg, Lower Austria).

tinguished. The lower part is made up of pelitic sediments (1) passing upwards into bioturbated sands (2). A thick coquina follows embedded in pebble-bearing sand (3), passing finally upwards into a well-sorted sandy unit (4). In terms of lithostratigraphy unit 1 and the lower parte of unit 2 belong to the Mold Formation, whereas the upper part of unit 2 and unit 3 to 4 represent the basal Loibersdorf Formation.

1. The pelitic unit begins with a spotted greenish-gray to brownish marly clay and silty clay with grayish flaser bedding (50 cm). Above follow about 10 cm of calcareous sandy clay with frequently nests and lenses with *Mytilopsis basteroti* (DESHAYES) and hydrobiid gastropods; additionally, thin shelled *Cerastoderma sp., Granulolabium plicatum* (BRUGUIÈRE) and *Polymesoda subarata sowerbii* (BASTEROT). A clayey layer on its top (5 cm) includes thin but dense monospecific coquinas of articulated or convex-side-up positioned *Mytilopsis basteroti* or *Granulolabium plicatum. Agapilia picta* is additionally represented therein. A badly sorted 30 cm thick sandy to silty clay follows containing numerous mollusc fragments. Finally, the top of the pelitic unit is formed by 50 cm dark, grayish silty clay yielding frequent coaly and limonitic lenses. Scattered terrestrial gastropods occur.

2. This unit begins with an intercalation of brownish and grayish clayey silt (10 cm) bearing a *Polymesoda*-coquina in its basal part. Flaser bedding occurs. Sandy to clayey silt follows (15 cm) bearing lenses with well-sorted grayish fine sand. It passes upwards into flaser-bedded clayey silt (10 cm) reminiscent of the basal layer of the unit. In the following layer the sandy components start to predominate the lithology. Its lower part consists of intercalated yellowish and grayish silty fine sands (30 cm) passing toward the top into yellowish silty fine sands (15 cm). The top layer (120 cm) finally is an intercalation of grayish and yellowish fine to medium sand with frequent trace fossils of *Ophiomorpha* up to 2 cm in diameter and scattered pebbles. Sands are moderately well to well-sorted with subangular to subrounded grains dominated by quartz and mica. Except of the basal coquina the unit 2 is barren of molluscs.

3. The main shell-bed (fig. 5) is significantly less sorted and much coarser. It contains pebbles and coquina layers of different types. It overlays the previous unit with a sharp lithological boundary showing a distinct relief up to 15 cm. Bioturbation reaches from the base into the underlying horizon. Thus, coarse grains are dragged down up to the 30 cm into the sands below. The shell-bed shows two main parts. The lower one (100 cm) bears more frequent pebbles and contains less dense packed shell material. The upper part (20 cm) represents a densely packed coquina dominated by large- and thick-shelled bivalve shells.

The lower subunit starts with a pebble-bearing coquina embedded into a fining upward matrix of coarse to fine sand (15–20 cm). Large, convex-side-up shells of *Oopecten gigas* (SCHLOTHEIM) dominate the spectrum, including also large mytilid bivalves *[Crenomytilus? aquitanicus* (MAYER)] and trochid *[Paroxystele amedei* (BRONGNIART)] and batillariid *[Granulolabium plicatum* (BRUGUIÈRE)] gastropods. The presence of balanid remains is moreover conspicuous. The overlying bed of coarse to fine sand (30 cm) is reminiscent of the previous layer but the large-sized pectinid-shells are absent and the pebbles occur only scattered. Upsection a second but rather subordinate "large pectinid – pebble layer" of 10 cm thickness follows. The small, disarticulated shells of *Acanthocardia moeschana* (HÖRNES) dominate the accumulation. The distribution of pebbles and shells differs laterally significantly. Shells are commonly abraded, the predominantly gneiss lithoclasts are up to 10 cm in diameter.

It passes upwards into a coquina (30 cm) in the same fine to coarse sandy matrix only with rare pebbles and without pectinids. Again the frequency of pebbles increases within the following coquina (40 cm). It is twofold with a lower part of 15 cm thickness with more frequent pebbles and larger-sized and more densely packed mollusc shells. Fragmentation gets stronger towards the top. The upper subunit is a dense coquina in a fine to coarse sandy matrix, contributed mainly by large bivalve shells. Large gneiss pebbles are frequent only in its lower part (fig. 6).

4. Finally the top unit is made up by a 2 m exposed bed of fine sand. In its lower part (20 cm) mollusc shells – mainly articulated and disarticulated bivalves – are distributed in the matrix. In the overlying sediments no molluscs are visible except of one thin coquina (10 cm) exposed 140 m above the base of the unit (fig. 7). This coquina is a single horizon of disarticulated, well-preserved, large bivalve shells, reminiscent of those distributed at the units base.

Taphonomy and Paleoecology of Mollusc Layers

Unit 1

Mytilopsis basteroti/Granulolabium plicatum-Coquinas

Taphonomy: The *Mytilopsis* and *Granulolabium* coquinas are primarily the consequence of biogenic processes and the result of opportunistic strategies. They mark short events of optimal environmental conditions preferred by these opportunistic taxa. As soon as those conditions become established, extremely individual rich populations develop immediately. Subsequently, when environmental conditions change the often short-lived populations col-
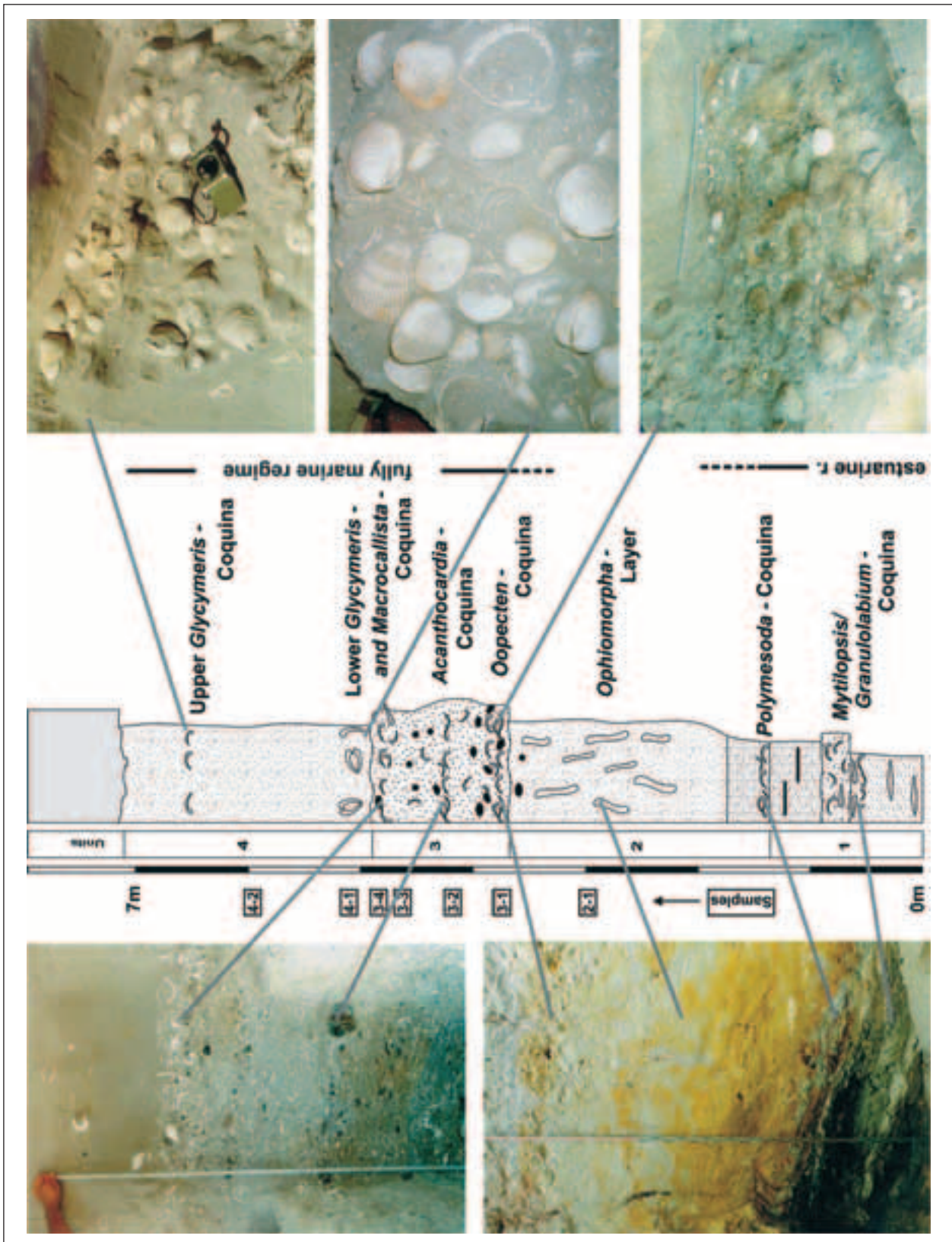
Fig. 4: Illustration shows the investigated section. Photographs on its left side represent the nature of the vertical section. The correlation of some characteristic layers is indicated. Photographs on the right side show the horizontal view into three most conspicuous coquinas. The lower one corresponds with fig. 7A; the middle one shows a detail of the fig. 8A, the upper one is the SE view into the quadrant illustrated in fig. 9. Additionally, the environmental regime witnessed by mollusc paleoecology is indicated. The 2 m thick layer dominated by *Ophiomorpha*-burrows is barren of any other fossils.
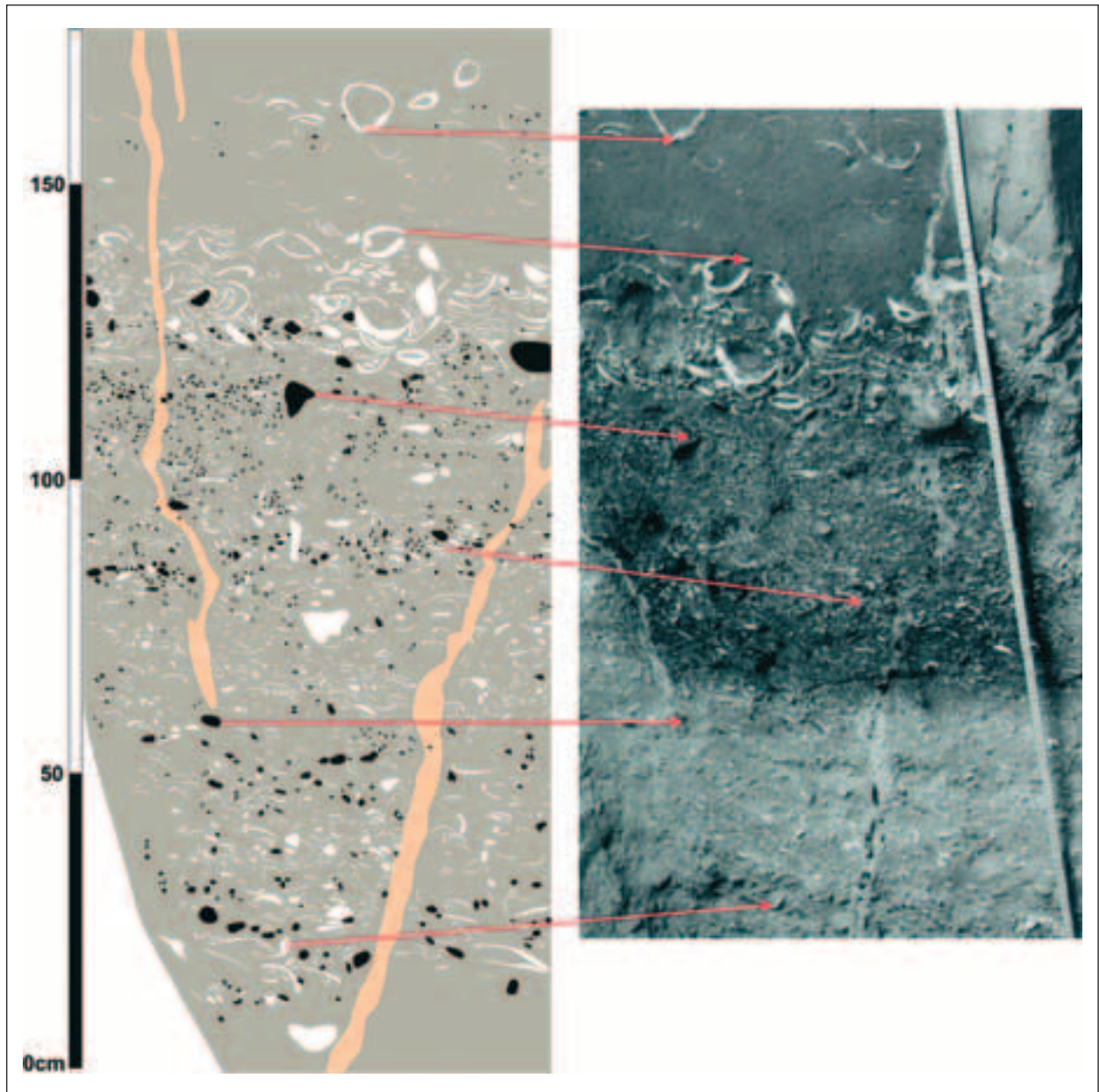
Fig. 5: Detailed overview of the main shell bed (unit 3). On the left side the reproduction of the original transparent sheet drawing is given, on the right side the photograph of the corresponding partial section is provided. Their correlation is indicated by arrows. White color represent biogenes, black color the pebbles and granules, the orange one indicates the secondary distortion by roots. Note the elongated, horizontally oriented shells of *Oopecten gigas* in the basal part of the main shell bed. The upper part of the shell bed is sealed by a homogeneous bed of densely-packed, large and thick-walled bivalves. The thick articulated shells in its upper part and in the layer above it, marked by the arrows belong to *Glycymeris fichteli*.

Fig. 6: The reproduction of the transparent sheet giving the lateral striking of the main lithologic boundaries within the main shell bed in unit 3. The distribution of pebbles and granules is indicated in black. The light colored lens-horizon topping the bed comprises the secondarily disturbed coarse sand horizon, which presumably resulted from the activity by burrowing organisms. The other boundaries, except for the basal one show likely very irregular striking. The burrowing structures crossing the latter boundary are also present (compare with text).
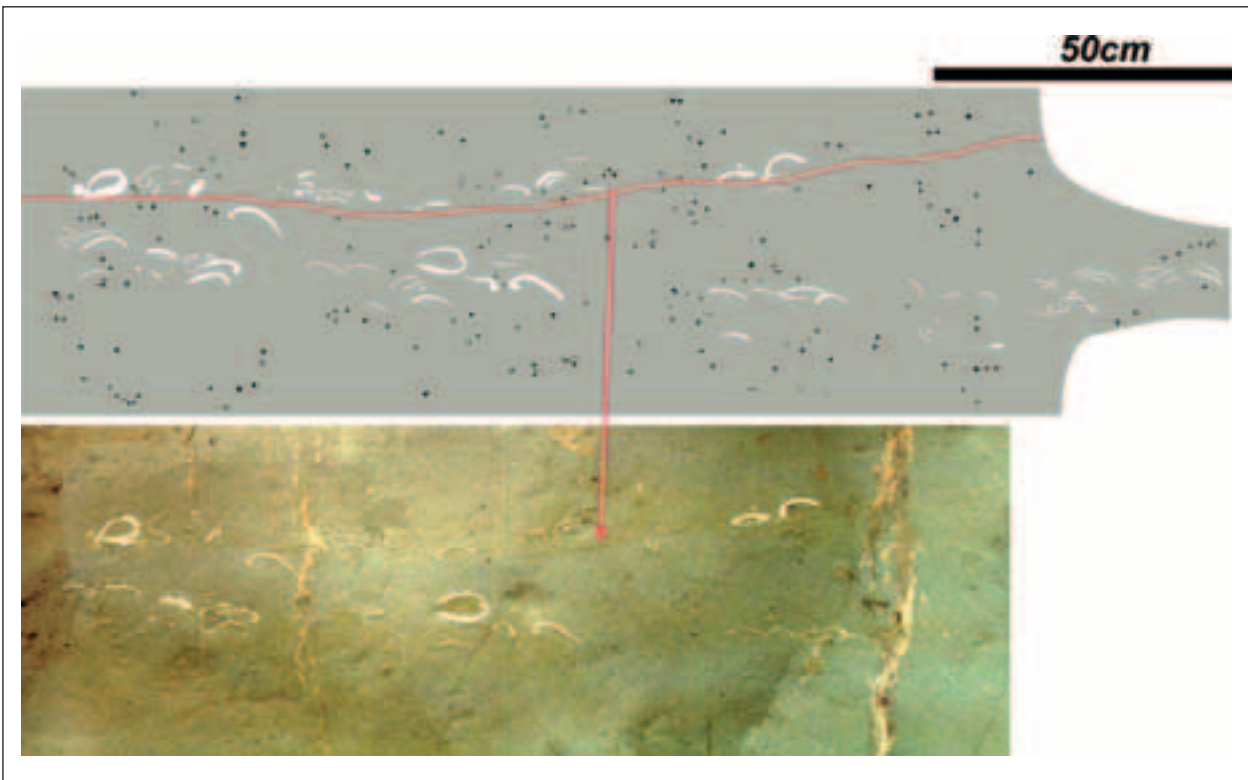

Fig. 7: The Upper *Glycymeris fichteli*-Coquina of unit 4 presented as a transparent sheet drawing (the upper illustration) and a photograph (the lower illustration). Shells are white, granules are black colored. The red line marks the micromylonit of a small-scale reverse fault. The coquinas above and below the fault belong to the same horizon. Note the preferred convex up position of the bivalve shells, horizontal orientation of articulated shells *(Glycymeris fichteli)* and telescoping of valves pointing to a transport by the submarine current.

lapse (HARZHAUSER & MANDIC 2004). Such accumulations can be classified as within-habitat census assemblage sensu KIDWELL & BOSENCE (1991).

Paleoecology: The genus *Mytilopsis* developing during the Eocene from the polyhaline Corbiculidae comprises up to recent days primarily brackish water taxa (NUTTALL 1990). These byssate, highly effective filter feeders, feeding on various kinds of seston, are typical opportunistic species characterized by mass occurrences and high abundances, so soon as preferred environmental conditions get reached. The modern representatives are inhabitants of

mangrove swamps of Western Africa and do not tolerate salinities exceeding the 25 ‰ mark (Archambault-Guezou 1976). The Miocene *Mytilopsis basteroti*, thriving always in estuarine embayments, has never been found primarily in open marine environments. Hence, the coquina dominated by that species points to a phase of enhanced fluvial influence within the Horn Basin estuary.

The lenses of shell accumulations of hydrobiids, *Granulolabium plicatum* and rare *Tympanotonos margaritaceus* reflect various close-by habitats of intertidal mudflats and muddy coasts of an estuary or lagoon. The extant *Granulolabium diemenensis* (Quoy & Gaimard) is reported by Lozouet et al. (2001) to prefer littoral environments with more or less continuous water flow, whereas *Hydrobia* is documented to settle the higher intertidal area as well (Willmann 1989). *Agapilia picta*, too, is a well-known constituent of estuarine-lagoonal settings of the Oligocene and Lower Miocene. The associated fauna as documented by Baldi (1973) and Harzhauser & Kowalke (2001) suggests that this neritid favored mudflats, mangroves and estuaries within a broad range of salinities, but did not extend into fluvial freshwater environments.

Somewhat reminiscent assemblages have been described by Harzhauser et al. (2002) from the Karpatian (upper Lower Miocene) of the Korneuburg Basin and by Harzhauser & Mandic (2001) from the Egerian (Upper Oligocene) of the Molasse Basin. Especially the Oligocene assemblage is more or less identical whereas the Karpatian one differs by the absence of *Polymesoda*, which at that time has already vanished from the Central Paratethys. These Oligocene assemblages settled muddy coastal flats and lagoons along the eastern margin of the Bohemian Massif.

or less monospecific composition of the coquina points to a habitat which was optimal for *Polymesoda subarata* but unfavorable for other molluscs. Similar *Polymesoda*-dominated taphocoenoses are widespread in the Oligocene and the Lower Miocene in the Central Paratethys (Hölzl 1957, Baldi 1973, Barthelt 1989, Harzhauser & Mandic 2001) and the Mediterranean area (Harzhauser & Kowalke 2001).

Modern *Polymesoda* species are restricted to the temperate to tropical Atlantic and Pacific Northern to Central America (Morton 1983). Like its Indo-Pacific relative *Geloina* the genus is a typical brackish water dweller, although fresh water occurrences and one species in hypersaline water are recorded. According to Baldi (1973) its water salinity requirement ranges from 3 to 10 ‰ and between 2–20 ‰ according to Popov et al. (1993). These data fit well to the observation of Morton (1983) who described salinity ranges from 0 to 10 ‰ for *Polymesoda carolianiana* (in Florida), which may stand increased values of up to 26.3 ‰ for short periods. However, this species spawns especially during rainy seasons and its spat seem to prefer fresh water. Generally, the animals are adversely affected by prolonged salinities above 18–20 ‰. *Polymesoda* needs water temperatures between 18 and 32°C and is most frequent on intertidal flats of estuaries, estuarine bays, oxbow lakes and especially in mangrove swamps. It expands also into shallow subtidal zones but maximally down to 10 m water depth (Morton 1983).

The absence of other species might be explained by strongly lowered salinities, which made the estuary unlivable even for mytilids and oysters.

Unit 2

Polymesoda subarata sowerbii-Coquina

Taphonomy: The formation of the coquina is classified as a within-habitat time-averaged shell lag assemblage (Kidwell & Bosence 1991). Tidal currents might have removed the fine fraction of the sediment, producing shell lags along the shores of the estuary. Similar shell beds contributed by intertidal bivalves such as *Marcia flammea* (Gmelin) develop in mangrove tidal channels along the Persian Gulf (own observation M.H.). The fact that *Polymesoda* shells are preserved suggests that the highly acidic swamp conditions in which those bivalves presumably dwelled were gradually replaced by more balanced marine conditions. Otherwise, the acid environment would have caused rapid chemical dissolution of the mollusc shells (Barthelt 1989).

Paleoecology: The fauna as well as the paleogeographic situation clearly indicate estuarine conditions. Thousands of suspension feeding *Polymesoda subarata sowerbii* flourished along the muddy coasts of the embayment. The more

Unit 3

Oopecten gigas-Coquina

Taphonomy: The 1.5 m² surface (figs 4, 8A) allowed the identification of 45 individuals on the species level (fig. 11, table 2). From 7 species level taxa, 6 were bivalves. The surface was densely covered by 30 large-sized (up to 15 cm in diameter), disarticulated *Oopecten gigas* shells. Therefore, this species contributes more than 68 % to the coquina's taxonomic structure. The predominantly convex-side-up oriented valves indicate a stable position, pointing to a possible influence by currents.

The position of the coquina within the base of the sequence comprising presumably beach deposits is contradicted by the preferred offshore habitat of modern and fossil pectinid accumulations and opposes a (sub)autochthonous origin (see below). Indeed, reworking of *Oopecten gigas* shells is already confirmed by radiometric methods from the Lower Ottnangian sediments in Upper Austria (Roetzel et al. 1999). Hence, the coquina comprises a multi-habitat time-averaged assemblage sensu Kidwell & Bosence (1991).
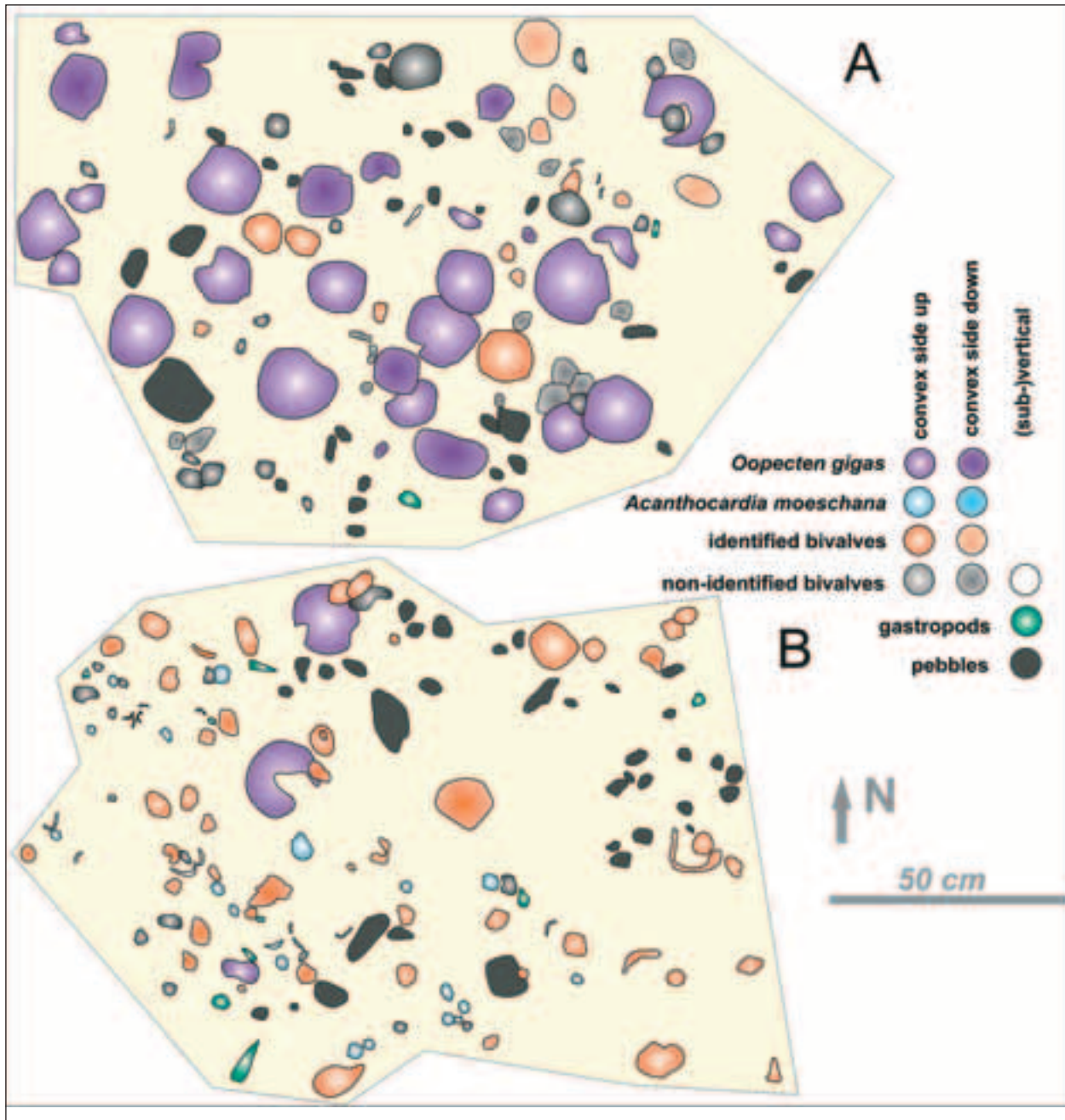
Fig. 8: Horizontal transparent sheet records for the *Oopecten gigas*-Coquina (A) and the *Acanthocardia moeschana*-Coquina (B). The latter coquina comprises the pebble layer of the central part of the main shell bed, comprising likely the large *Oopecten gigas* valves. Note the density of *Oopecten gigas* shells in the basal coquina. The large pebbles are predominantly flattened fragments of Bittesch Gneiss, a formation partly still marking the eastern boundary of the Horn Basin (see fig. 1). For the taphonomic characterization of the coquinas see Fig. 10 and tab. 2.

Paleoecology: The coquina is contributed by two different ecological guilds. The trochid *Paroxystele amedei* and balanids are typical elements of the rocky littoral. Especially *Paroxystele amedei* is frequently documented from agitated, near-shore settings along the Bohemian Massif during the Eggenburgian (KROH & HARZHAUSER 1999, LUKENEDER & HARZHAUSER 2002). Close-by littoral environments are also indicated by the occurrence of the batillariid *Granulolabium plicatum*.

The second ecological guild, represented by the large-sized *Oopecten gigas*, contradicts the foregoing interpretation. Extant pectinid aggregations, being dense enough for purposes of commercial fishery occur in modern seas always below 10 m water-depth (BRAND 1991). For example, *Pecten maximus* colonies occur typically between 20–45 m depth. A coquina dominated by articulated *Oopecten gigas* shells is known also from the slightly older Fels Formation. In the section Fels-Dornergraben,

it comprises the position between a shallow sublittoral sandy unit and an overlying fine sandy, deeper sublittoral to neritic unit (STEININGER 1963).

Acanthocardia moeschana-Coquina

Taphonomy: This coquina represents the middle part of the main shell bed of unit 3 (fig. 4). It marks a level of renewed accumulation of large pebble material. Correspondingly, *Oopecten gigas* shells contribute to the accumulation, although rather scattered in comparison with the basal bed. The taxonomic diversity is the highest within the section, contributed by 25 mollusc taxa (7 gastropods). On the about 1.5 m² large surface 77 individuals (8 gastropods) could be identified (fig. 11, table 2). Convex-side-up valves are less dominating than in the previous layer (63%); articulated valves are absent. Except for some larger fragments, the shells are rather small-sized and randomly distributed (fig. 8B); accordingly, the fragmentation is high. The rather high diversity in combination with fragmentation points to a time averaged shell bed and a multi-habitat time-averaged assemblage sensu KIDWELL & BOSENCE (1991), respectively. Its position in the sequence close above the basal gravel bed supports its interpretation as a beach deposit.

Paleoecology: Although dominated by shells of *Acanthocardia moeschana*, there are numerous additional coquina constituents. These have a wide range of preferred habitats from giant, estuarine *Crassostrea gryphoides* to offshore dwelling venerids and pectinids. Hence, the typical foreshore to offshore bivalve representatives, such as *Glycymeris fichteli, Macrocallista lilacinoides, Paphia benoisti* and *Laevicardium? kuebecki* are the characteristic elements therein. The gastropods are most diverse within this horizon. Typical shoreface representatives such as *Granulolabium* are mixed with fully marine, foreshore/offshore dwellers such as the carnivores *Conus* and *Natica* or various suspension feeders, such as *Turritella eryna rotundata* and *Protoma cathedralis*.

Macrocallista lilacinoides-Coquina

Taphonomy: The coquina is composed of densely packed, conspicuously large-sized mollusc remains, predominantly bivalves (figs 4, 9). The exposed quadrant of 2 m² allowed the identification of 202 individuals on the species level, representing the maximal identification rate per horizon within the section (fig. 11, table 2). Despite that, the taxonomic richness (10 bivalve, 5 gastropod species) lies distinctly beyond the previous horizon. This implies a shorter time averaging and a nearly absent habitat mixing. The homogenous appearance and low fragmentation rate suggest a rather short exposure on the marine bottom. Possibly, the coquina was generated by one or several high-energy events, during that most of the sediment was removed, causing an amalgamation of shells into a dense

package. This process occurred most likely within a sublittoral environment - which is also indicated by the major part of the fauna - and above the storm weather wave base allowing periodically enhanced energy levels. No transportation is indicated. In fact, the highest rate of convex-down oriented bivalves implies the absence of exposure to submarine currents and suggests a sudden embedding as dominating generic mechanism. In terms of the shell bed classification of FÜRSICH & OSCHMANN (1993), such a pattern refers to a typical storm wave concentration.

Paleoecology: The taxonomic composition of the coquina is almost identical with the following two shell beds of unit 4. The differences derive almost exclusively from typical taphonomic features, such as valve orientation, articulation or thickness and package.

The bed consists mainly of disarticulated but well-preserved shells of *Macrocallista lilacinoides* and *Glycymeris*

Fig. 9: Horizontal transparent sheet records of the uppermost unit 3 *(Macrocallista lilacinoides-*Coquina) (B) and the lowermost unit 4 (lower *Glycymeris fichteli-Coquina)* (A). Note the difference in density of shell remains between the two layers. The identified molluscs of the illustration A are predominantly articulated individuals of *Glycymeris fichteli* (compare data in tab. 2). Consequently, this bed is termed as the Lower *Glycymeris fichteli-*Coquina. Note, in contrast to previous figure the almost complete absence of pebbles.

fichteli. As pointed out by KONDO (1998), the large venerids are siphonate, shallow, moderately rapid burrowers and typical "all-rounders" well adapted to environments of varying physical instability, except for disoxic and shifting substrates. *Glycymeris fichteli* is a non-siphonate, sluggish burrower well adopted to high energy environments. KONDO (1998) referred *Glycymeris* from channel bottoms and from all current-swept environments unaffected by

rapid sedimentation. The latter author described similar abundant glycymerids from a shell-gravel facies of the Pleistocene in Japan. Hence, the presence of those two taxa in combination with other, thick-shelled, shallow burrowers like *Laevicardium? kuebecki* points clearly to a foreshore to offshore position above the storm weather wave base (compare Upper *Glycymeris fichteli*-Coquina of unit 4).
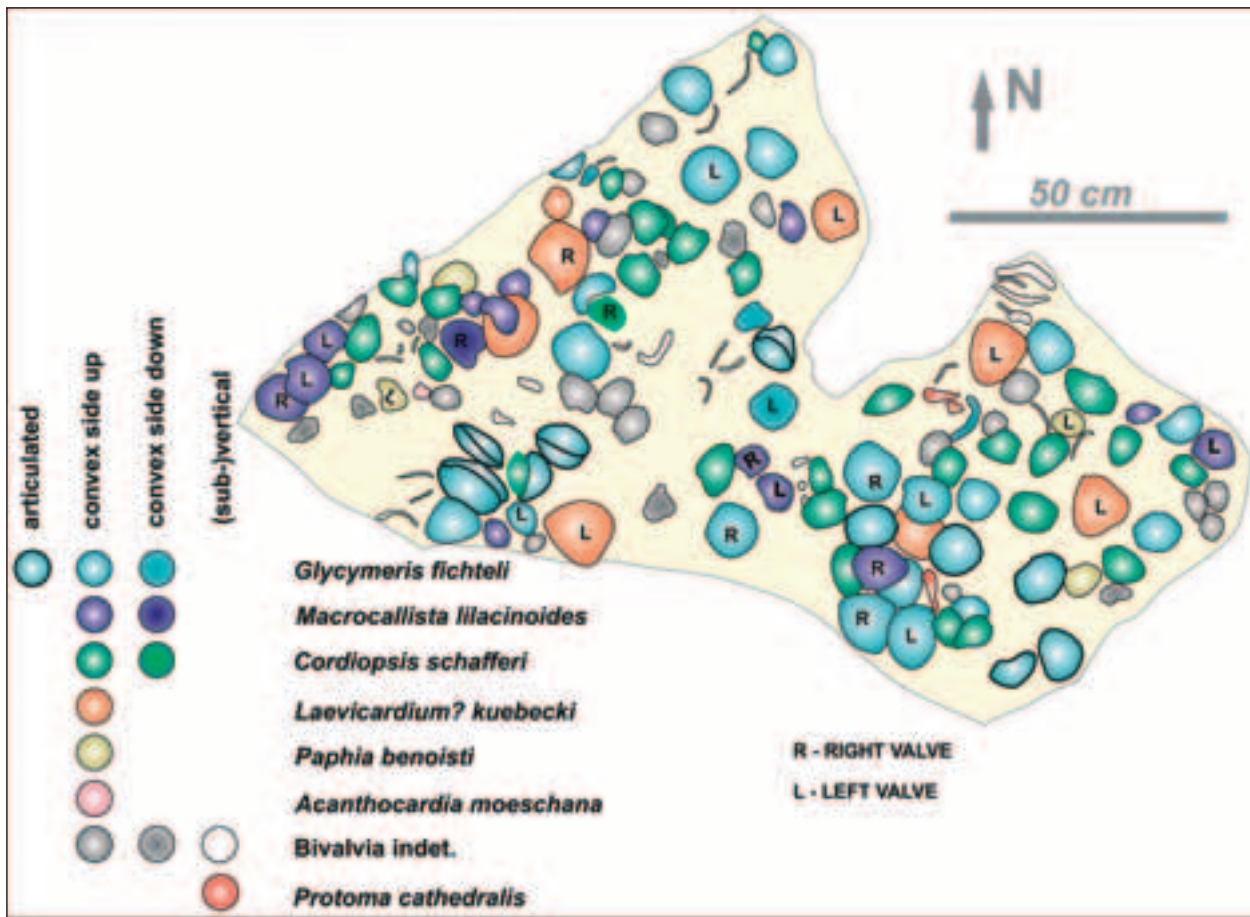

Fig. 10: Horizontal transparent sheet log of the Upper *Glycymeris fichteli*-Coquina (see also figs 2, 3 and 6). Note the articulated shells represented exclusively by *Glycymeris fichteli*. Moreover the dominance of convex-side-up valves is obvious (compare table 2 for details).

Unit 4

Lower Glycymeris fichteli-Coquina

Taphonomy: The Lower *Glycymeris fichteli*-Coquina (figs 4, 8A) interferes partly with the previous coquina. The sequence represents the natural habitat of the large-sized glycymerids ranging upsection from the point of colonization to their disappearance due to the gradual decrease of water turbulence in consequence of water deepening. A surface of about 2 m^2 was logged in detail; 92 specimens were detected but only 10 species-level-taxa (1 gastropod) could be identified (fig. 11, table 2). The highest number

of articulated individuals within the entire section is observed within this coquina. These articulated specimens are contributed by 23 individuals of *Glycymeris fichteli*, 2 *Macrocallista lilacinoides* and 1 each of *Cordiopsis schafferi* and *Laevicardium? kuebecki*. The dominating convex-side-down shells point to repeated in-place habitat disturbing by occasional storm events. The classification of this conspicuous construction in terms of taphonomic nomenclature requires a separate discussion (see discussion chapter).

Paleoecology: As indicated by the dominance of articulated *Glycymeris fichteli* shells the environment was the

preferred habitat of that species. As stated above, this was within the subtidal zone above the storm weather wave base.

Upper *Glycymeris fichteli*-Coquina

Taphonomy: The coquina was investigated on a 1.5 m² large horizontal surface (figs 4, 9). 95 mollusc remains were identified to the species level but the species richness level remained among the lowest in the section (7 species) (fig. 11, table 2). The dominance of convex-side-up valves, as well as the presence of the typical telescoping packing feature (fig. 7) point to transport by submarine currents (see KIDWELL 1991). The low thickness as well as the internal organization of the coquina point to a single event. The number of articulated valves is again low (10); all articulated shells belong to *Glycymeris fichteli*. In terms of the shell bed classification of FÜRSICH & OSCHMANN (1993), such a pattern refers to a typical proximal tempestitic concentration.

Paleoecology: The taphonomic features indicate transportation of shells deriving originally from the Lower *Glycymeris fichteli*-Coquina into a deeper, calmer habitat positioned below the storm weather wave base.

Discussion

The Mold Formation is characterized by 2 coquina types which point to lagoonal, estuarine conditions. Hence, in contrast to coquinas of the Loibersdorf Formation no evidence of high energy events can be observed. Consequently, both accumulations represent within-habitat accumulations, differing by the winnowing mechanism. Thus, the lower *Mytilopsis basteroti/Granulolabium plicatum*-Coquina is a mono-specific census assemblage produced by the mode of life of those gregarious, opportunistic mollusc species. By contrast, the *Polymesoda subarata sowerbii*-Coquina is a product of physical winnowing processes. The pavement was formed by the activity of waves and/or tidal currents (cf. FÜRSICH 1995).

The 5 shell accumulation horizons of the basal Loibersdorf Formation can be aligned with at least 4 different mechanisms and environmental regimes, respectively. The two lowermost coquinas *(Oopecten gigas*-Coquina, *Acanthocardia moeschana*-Coquina) in the basal part of the Loibersdorf Formation are regarded as multi-habitat time-averaged assemblages. They both bear abundant shells of *Oopecten gigas*, a stratigraphic index fossil of the Lower Eggenburgian. Pebbles and poorly sorted sand
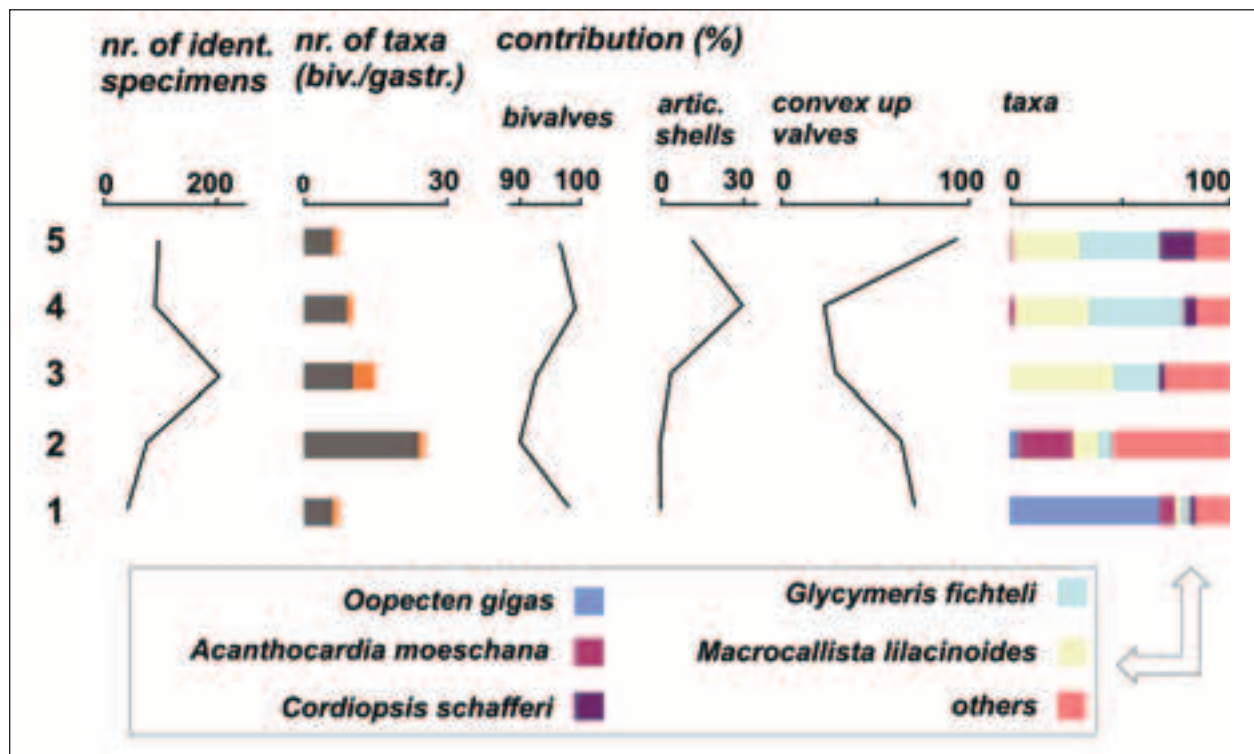

Fig. 11: The illustration shows the upsection distribution of recorded taphonomic parameter listed in tab. 2. The data are plotted from the base to the top as follows: 1. *Oopecten gigas*-Coquina, 2. *Acanthocardia moeschana*-Coquina, 3. *Macrocallista lilacinoides*-Coquina, 4. Lower *Glycymeris fichteli*-Coquina and 5. Upper *Glycymeris fichteli*-Coquina. Layers 1 to 3 correspond to unit 3; layers 4 and 5 to unit 4. Note the conspicuous peak of taxonomic diversity within layer 2. The overlying layer although comprising much more identified specimens has apparently lower species richness. Furthermore convex-side-up valves are characteristic for layers 1, 2 and 5 but not for the layers 3 and 4 pointing to generic differences related to the hydraulic regime. The enhanced number of articulated shells *(Glycymeris fichteli)* are a characteristic feature unique for layer 4 and the basal unit 4, respectively.

Table 1: List of mollusc taxa occurring in the studied section of Nonndorf. Unit 2 is barren of molluscs, except for the basal *Polymesoda*-coquina (Units 1-2: Mold Formation; Units 3-4: Loibersdorf Formation).

No. Taxa	Units 1-2	3-4	No. Taxa	Units 1-2	3-4
GASTROPODS			**BIVALVES**		
1 Nerita plutonis (Basterot)	-	x	1 Anadara (Anadara) fichteli grandis (Schaffer)	-	x
2 Agapilia picta (Férussac)	-	x	2 Glycymeris (Glycymeris) fichteli (Deshayes)	-	x
3 Paroxystele amedei (Brongniart)	-	x	3 Glycymeris (Glycymeris) latiradiatus (Sandberger in Gümbel)	-	x
4 Granulolabium plicatum (Bruguière)	x	x	4 Mytilus sp.	-	x
5 Tympanotonos margaritaceus (Brocchi)	x	-	5 Oopecten gigas (Schlotheim)	-	x
6 Protoma cathedralis (Brongniart)	-	x	6 Aequipecten opercularis miotransversa (Schaffer)	-	x
7 Turritella eryna rotundata Schaffer	-	x	7 Anomia (Anomia) ephippium costata Brocchi	-	x
8 Turritella terebralis Lamarck	-	x	8 Ostrea (Ostrea) edulis adriatica Lamarck	-	x
9 Turritella sp.	-	x	9 Crassostrea gryphoides (Schlotheim)	-	x
10 Petaloconchus intortus (Lamarck)	-	x	10 Chama sp.	-	x
11 Capulus sp.	-	x	11 Lucinidae gen. et sp. indet.	-	x
12 Hydrobia sp.	x	-	12 Diplodonta (Diplodonta) rotundata rotundata (Montagu)	-	x
13 Jousseaumea diluviana (Gray)	-	x	13 Acanthocardia (A.) moeschana (Hörnes)	-	x
14 Euspira helicina (Brocchi)	-	x	14 Bucardium burdigalinum grande (Schaffer)	-	x
15 Natica tigrina Defrance	-	x	15 Bucardium hoernesianum (Hörnes)	-	x
16 Natica epiglottina moldensis Schaffer	-	x	16 Laevicardium? kuebecki (Hauer)	-	x
17 Neverita josephinia manhartensis (Schaffer)	-	x	17 Divalinga ornata (Agassiz)	-	x
18 Trigonostoma sp.	-	x	18 Lutraria (Lutraria) sanna Basterot	-	x
19 Babylonia eburnoides (Matheron)	-	x	19 Gari (Gobraeus) labordei major (Schaffer)	-	x
20 Euthriofusus burdigalensis (Defrance)	-	x	20 Mytilopsis basteroti (Deshayes)	x	-
21 Conus sp.1	-	x	21 Polymesoda subarata sowerbii (Basterot)	x	-
22 Conus sp.2	-	x	22 Dosinia (Pectunculus) exoleta (Linnaeus)	-	x
			23 Dosinia (Asa) lupinus (Linnaeus)	-	x
			24 Paphia (Callistotapes) benoisti praecedens Kautsky	-	x
			25 Paphia (Callistotapes) subcarinata (Schaffer)	-	x
			26 Callista italica (Defrance)	-	x
			27 Macrocallista lilacinoides (Schaffer)	-	x
			28 Pelecyora (Cordiopsis) schafferi Kautsky	-	x
			29 Panopea (Panopea) menardi (Deshayes)	-	x
			30 Thracia (Thracia) pubescens (Pulteney)	-	x

Table 2: Distribution of taphonomic parameter extracted for the investigated coquinas of the Loibersdorf Formation. The categories "species" and "individuals" comprise numbers; the category "contributions" comprises percentages. Fig. 11 provides the graphic overview on that data.

Parameter			Coquina				
			O. gigas	A. moeschana	M. lilacinoides	G. fichteli 1	G. fichteli 2
species	gastropods		6	7	5	1	1
	bivalves		1	18	10	9	6
	molluscs		7	25	15	10	7
individuals	molluscs		45	77	202	92	95
	gastropods		1	8	15	1	3
	bivalves		44	69	187	91	92
		articulated	0	0	6	27	10
		disarticulated	44	43	181	64	85
		convex up	21	48	50	14	79
		convex down	9	28	131	50	6
contributions	bivalves		97.78	89.61	92.57	98.91	96.84
		articulated	0.00	0.00	3.21	29.67	10.53
		convex up	70.00	63.16	27.62	21.88	92.94
	taxa	Oopecten gigas	68.18	4.35	0.53	0.00	0.00
		Acanthocardia moeschana	6.82	27.54	0.00	2.20	1.09
		Glycymeris fichteli	4.55	7.25	22.46	43.96	38.04
		Cordiopsis schafferi	2.27	0.00	2.67	5.49	16.30
		Macrocallista lilacinoides	2.27	13.04	50.27	34.07	31.52
		others	15.91	47.83	24.06	14.29	13.04

indicate very shallow marine conditions in a well-agitated coastal environment. The close position to the shoreline is also indicated by shells of the batilariid *Granulolabium plicatum* (BRUGUIÈRE) and the trochid *Paroxystele amedei* (BRONGNIART). Littoral environments are also favored by the mytilid *Crenomytilus? aquitanicus* (MAYER) and balanids, which are abundant elements in the basal coquina.

The overlaying coquinas, which are embedded in a medium sand, differs distinctly in its composition and displays a much higher diversity (59 species). It is predominated by infaunal bivalves such as *Macrocallista lilacinoides* (SCHAFFER), *Laevicardium? kuebecki* (HAUER) and *Glycymeris fichteli* (DESHAYES). Among the gastropods, *Protoma cathedralis* (BRONGNIART), *Babylonia eburnoides* (MATHERON), and *Paroxystele amedei* (BRONGNIART) are most important along with several naticids such as "*Natica epiglottina moldensis* SCHAFFER".

In one of the quadrants 168 bivalve shells could be identified on the species level. From these only 23 specimens are represented by articulated valves, whereas the other 145 specimens are disarticulated. The articulated valves could be attributed exclusively to *Macrocallista lilacinoides* and *Glycymeris fichteli*. Articulated valves are documented for 35% of the glycymerids but only for 2% of the *Macrocallista lilacinoides* specimens. This points to a two-stepped story of coquina formation. The *Macrocallista lilacinoides*-coquina probably formed as result of heavy agitation during a storm event and could thus be classified as a storm bed. Later the fine sand that buried the shell bed was settled by shallow burrowing glycymerids. During a subsequent high energy event the sediment was swapped away. Consequently, the glycymerids became trapped within the remaining thin sediment cover above the *Macrocallista lilacinoides*-coquina. Hence, the shell bed acted as unconformity impassable for the large-sized, robust *Glycymeris fichteli* individuals. The specimens searched for or actively produced niches in the top of the shell bed. This resulted in a secondary amalgamation of articulated glycymerid shells within the death assemblage – actually being an inappropriate habitat for such large burrowing bivalves. Thus, for such kind of shell accumulation a new term of the taphonomic nomenclature is proposed, designated as "forced within-habitat concentration". Later on, during the deepening of the depositional environment, the glycymerids remained the dominating element within the lower part of unit 4. However, they disappeared in the upper part of unit 4 when less agitated subtidal depths established. This in-situ occurrence of glycymerids and rare specimens of *Panopea menardi* DESHAYES in the overlying sand strongly supports the presented interpretation. Indeed, the upper *Glycymeris fichteli*-Coquina which is a single thin bed intercalated within the fine sand body comprises the typical features of a current driven proximal tempestite (FÜRSICH & OSCHMANN 1993).

Granulometric analysis

A granulometric analysis was carried out to characterize the sediments embedding the studied coquinas in detail. Thus, the granulometric data for several typical horizons within and surrounding the main shell beds (units 2 to 4) are available (fig. 12).

The sample 2-1 of unit 2 is positioned 80 cm below the base of unit 3 and represents a fine to medium sand with Ophiomorpha. The samples from unit 3 are 3-1 *(Oopecten gigas*-Coquina: gravelly medium to fine sand), 3-2 (directly below the *Acanthocardia moeschana*-Coquina: medium to fine sand), 3-3 and 3-4 (20 cm below and within the *Macrocallista lilacinoides*-Coquina: coarse to fine sand and gravelly fine to medium sand). The samples from unit 4 are 4-1 representing the lower *Glycymeris fichteli*-Coquina and 4-2 taken 60 cm below the upper *G. fichteli*-Coquina, both fine-grained sands (fig.4).

The grain size distribution in phi values, presented in log-probability plots (fig. 12) all show distinctly separated log-normal populations allocated to the transport by rolling, saltation and suspension. All log-probability plots from the investigated samples correspond to those from nearshore settings (VISHER 1969, GLAISTER & NELSON 1974).

Aside from a poorly sorted rolling population, the sample of unit 2 (2-1) shows a very well sorted saltation population between 1.25 and 3 phi and a relatively high amount of suspension material. The plot is corresponding to marine sands from the wave zone (VISHER 1969) whereas the high amount of fine clastics might derive from the nearby river entering the sea.

All samples from unit 3 (3-1 to 3-4) show three to four populations with two saltation populations with breaks between 1.5 and 2 phi. The latter break is indicative for the deposition on the foreshore of a beach (VISHER 1969). Sorting of the two saltation populations is much worse than in unit 2, but due to swash and backwash activity the amount of fine grained material is much lesser.

In the samples of unit 4 (4-1, 4-2) a saltation break at 2.5 phi still exists, but the saltation population is better sorted and the rolling population is much lesser than in unit 3. Hence, the influence of the "swash" is still active but the transport energy and the hydrodynamic level already decrease.

Therefore, a shift from the inner shoreface to the inner foreshore and than to the outer foreshore could be deduced from the grain size distributions in units 2 to 4.

Additional information can be extracted from the plot of skewness against standard deviation, calculated after FOLK & WARD (1957). Those data (fig. 12) clearly support the genetic independence of the defined lithological units. Hence, the sorting improves upsection within the better-sorted matrix of the lower *Glycymeris fichteli*-Coquina (unit 4), whereas units 2 and 3 are apparently poorly sorted. Subsequently, the nearly symmetrical (3-2) to negative (coarse) (3-4) skewed main shell bed (unit 3) opposes the positive (fine to very fine) skewed underlying and overlying units. This implies
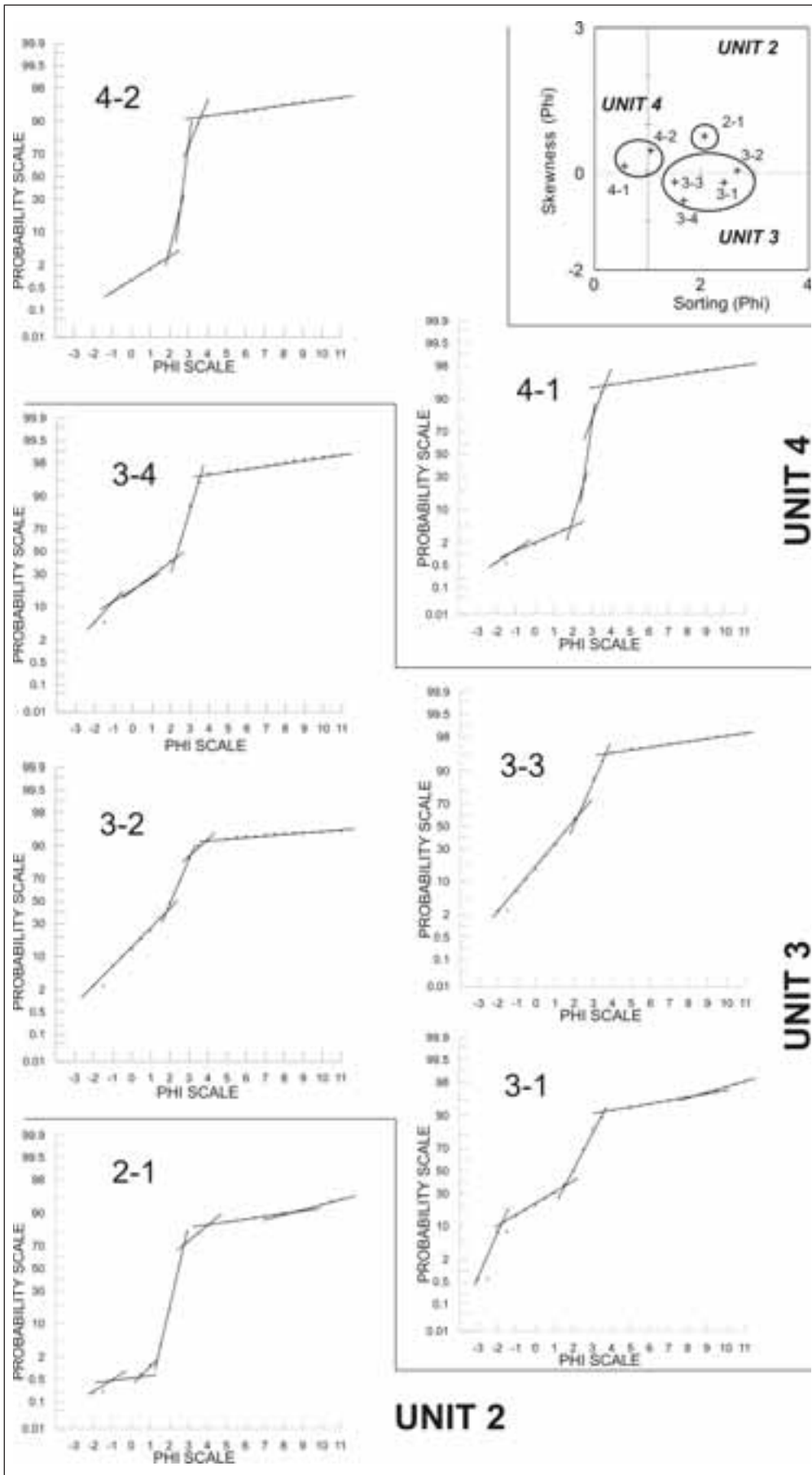
Fig. 12: Illustration shows granulometric data for 7 samples of units 2 to 4. The exact position of samples is given in fig. 3 and in the text. The grain size distribution in phi values is presented in log-probability plots. They show distinct separated log-normal populations allocated to transportation processes by rolling, saltation and suspension (VISHER 1969). Right above is shown a plot of skewness against standard deviation calculated after FOLK & WARD (1957). The plots support well the genetic independence of the defined lithological units. Unit 2 is badly sorted and fine skewed, unit 3 is badly sorted and coarse skewed and unit 4 is principally better sorted and fine skewed.

that the sediment of unit 2 is principally bad sorted but fine skewed; unit 3 is principally bad sorted and coarse skewed and unit 4 is principally better sorted and fine skewed.

Implications for Sequence Stratigraphy

Few concepts of a high order Eggenburgian sequence stratigraphy are currently available. VAKARCS et al. (1998) were among the first to apply the terminology and models of VAIL et al. (1977), POSAMENTIER & VAIL (1988) and others to the Eggenburgian depositional systems. By focusing on the Pannonian Basin, VAKARCS et al. (1998) proposed two cycles for the Eggenburgian which they introduced as Bur-1 and Bur-2 cycles (fig. 1). These are bounded by the Aq-3/Bur-1 sequence boundary, corresponding tentatively to the Egerian/Eggenburgian chronostratigraphic boundary, and the Bur-2/Bur-3 sequence boundary which is correlated with the Eggenburgian/Ottnangian boundary. The mid-Eggenburgian sequence boundary separating the Bur-1 from the Bur-2 cycle is calibrated with the middle part of chron C6n. Consequently, the herein investigated deposits of Nonndorf as well as the *Oopecten gigas* Zone have to be placed into the lower part of the Bur-1 cycle of VAKARCS et al. (1998) and HARDENBOL et al. (1998).

The following Bur-2 cycle is also excellently reflected in the area by the mollusc fauna, which suffers a drastic change in composition and displays a wave of Mediterranean immigrants during the transgression of the Bur-2 cycle (MANDIC & STEININGER 2003). This cycle, however, is not preserved in the discussed succession.

The low stand systems tract of the Bur-1 cycle might be represented by the fluvial gravels and sands of the St. Marein-Freischling Formation, which fills the tectonically induced valley of the Horn Basin during the Oligocene and Early Miocene. The initial transgression seems to be reflected by the formation of the lowermost Eggenburgian Fels Formation on the margin of the Bohemian Massif.

During the ongoing TST (transgressive systems tract) the sea intruded into the marginal drainage valleys of the Bohemian Massif and estuarine-lagoonal settings established. These are well reflected by pelites, coaly clays and lignite of the Mold Formation and are represented already within the investigated section (units 1 and lower part of unit 2).

However, an even finer tuning of relative sea-level changes for the TST of the Bur-1 cycle can be extracted for the section Nonndorf. Based on sedimentological and paleoecological data at least two low-order "cycles" or parasequences are proposed herein.

The first parasequence is very clearly developed and corresponds to the middle transgressive systems tract of the Bur-1 cycle. It comprises the lithologically defined units 1 and 2 of the section Nonndorf and reflects the shift from estuarine towards shallow marine environments. The first climax of flooding is indicated by the sand of the upper part of unit 2, representing probably a lower shoreface facies with abundant crustacean burrows (*Ophiomorpha*).

The top of that transgressive parasequence with its related flooding surface is not preserved. However, it is still recognizable in the basal part of the following parasequence. There, the occurrence of *Oopecten gigas*, which is known to form monospecific populations in about 30 m water-depth, contrasts the otherwise littoral fauna of the coquinas with balanids, batillariids and mytilids. This paleoecological inhomogeneity is interpreted to be deriving from reworking of an *Oopecten* layer during the second parasequence. This *Oopecten* layer is thus part of the "deep" top of the first parasequence, which became truncated by the second one. Consequently, shallow sublittoral marine conditions and a water-depth of about 30 m established during the first parasequence.

The second "cycle", comprising units 3 and 4 is again distinctly transgressive and is tentatively correlated with the late TST of the Bur-1 cycle of VAKARCS et al. (1998). The transgression is well reflected by a shift from shallow marine tempestitic shelly beds – that obviously formed above the wave base – towards a less agitated and sublittoral environment of unit 4. From a paleoecological point of view, the deepening of the environment is excellently proofed by the succession of littoral elements at the base (except for the reworked *Oopecten*), via shoreface towards shallow sublittoral faunas with deep burrowing *Panopea* at the top.

A minor relative sea-level drop caused the boundary between either "cycles" (or parasequences). This drop of relative sea-level might have been triggered by the local tectonic evolution at this sensitive and highly active margin of the Bohemian Massif (STEININGER et al. 1991). Therefore, it is doubtful if these parasequences have counterparts in other depositional areas of the Central Paratethys. However, due to the quite inconspicuous and tricky character of that boundary it might have been overlooked easily in other studies.

Pure autocyclic shifts due to alternations within the fluvial system as trigger for that development can be excluded as the top of the first parasequence as well as the entire second parasequence are already fully marine. At that time, the influence of the river that supplied the estuary of the Mold Formation already completely diminished. One could speculate that the back-stepping of the marine shore towards the north and sediment accumulation could produce a transverse barrier displacing the river course towards the northern Eggenburg Bay. This might have caused the deposition of the Kühnring Member next to the new river mouth. In the Eggenburg Bay the marine succession started in the Late Eggenburgian, distinctly later than in the Horn Basin. At its base indeed the swamp environment of the Kühnring Member is bearing gavials and primitive hippopotami (cf. DAXNER-HÖCK 1971; ROETZEL & STEININGER 1999).

Conclusion

In the section Nonndorf the transgression of the Eggenburgian Sea is documented by a two-stepped fining and deepen-

ing upward sequence. In contrast to earlier interpretations, the flooding of the Horn Basin occurred in two phases. During the first one, the fluvial system was pushed back and estuarine environments established. These gradually became replaced by marine sublittoral ones. Surprisingly, the climax of this first phase is completely truncated by the following parasequence. Its maximum depth can only be indirectly deduced from the occurrence of a reworked *Oopecten gigas* coquina in the base of the overlying parasequence. This pectinid is interpreted to have settled sublittoral environments in about 20–40 m water depth, contradicting the littoral character of its associated fauna in the basal part of the second parasequence. Therefore, the pectinid shells have to be reworked from the non-preserved first parasequence. During the subsequent landward shift of the coast, shallow water environments became installed, settled mainly by infaunal bivalves. Sporadic storm events triggered the accumulation of shells in several tempestitic layers. These conspicuous shell beds acted as unconformity for large-sized glycymerids, which settled the sediment thereafter. This resulted in a secondary amalgamation of articulated glycymerid shells within a slightly older death assemblage. Later on, during the deepening of the depositional environment, only glycymerids and rare specimens of *Panopea menardi* settled the less agitated subtidal habitat.

During these transgressions at least 7 types of coquinas developed. The mechanisms which caused these shell accumulations, however, are manifold and tricky. Due to the very detailed analysis, the accumulations can be classified as within-habitat census assemblages *(Mytilopsis basteroti/Granulolabium plicatum*-Coquinas), as within-habitat time-averaged shell lag assemblage *(Polymesoda subarata sowerbii*-Coquina), as multi-habitat time-averaged assemblages *(Oopecten gigas*-Coquina, *Acanthocardia moeschana*-Coquina) and as storm wave concentrations *(Macrocallista lilacinoides*-Coquina, lower *Glycymeris fichteli*-Coquina). The upper *Glycymeris fichteli-Coquina* is considered as current driven proximal tempestite. The strange and conspicuous accumulation of articulated *Glycymeris fichteli* within the death assemblage of the *Macrocallista lilacinoides*-Coquina is a very rare example of a "forced" within-habitat concentration due to the lack of suitable substrate.

Acknowledgments

References

ARCHAMBAULT-GUEZOU, J. (1976): Etude de Dreissenidae du Neogene europeen et revue stratigraphique des niveaux correspondants de la Paratethys. Travaux du Laboratoire de Paleontologie, Universite de Paris, Faculte des Sciences d'Orsay, pp. 1-359.

BALDI, T. (1973): Mollusc fauna of the Hungarian Upper Oligocene (Egerian). – 1-511; Budapest (Akadémiai Kiadó).

BALDI, T. & SENES, J. (1975): Biozones in the late Tertiary of the Paratethys on the basis of pectinid faunas. – In: CICHA, I. (Ed.): Biozonal division of the Upper Tertiary basins of the Eastern Alps and West Carpathians. – International Union of Geol. Sciences, Proceedings of the VIth congress, Bratislava, September 1975, 41-44, Prague (Geol. Survey).

BARTHELT, D. (1989): Faziesanalyse und Untersuchungen der Sedimentationsmechanismen in der Unteren Brackwasser-Molasse Oberbayerns. – Münchner Geowissenschaftliche Abhandlungen, A, **17**: 1-118.

BRAND, A. R. (1991): Scallop Ecology: Distributions and behaviour. – In: S.E. SHUMWAY (Ed.): Scallops: Biology, Ecology and Aquaculture. – Developments in Aquaculture and Fisheries Science, **21**: 517-584.

DAXNER-HÖCK, G. (1971): Vertebrata (Excl. Pisces) der Eggenburger Schichtengruppe. – In: STEININGER, F. F. & SENES, J. (Eds): M1, Eggenburgien. Die Eggenburger Schichtengruppe und ihr Stratotypus. – Chronostratigraphie und Neostratotypen, **2**: 761-777; Bratislava (VEDA).

FOLK, R. L. & WARD, W. C. (1957): Brazos Rivers bar: A study in the significance of grain-size parameters. – Journal of Sedimentary Petrology, **27**: 3-26.

FÜRSICH, F. T. (1995): Shell concentrations. – Eclogae geologica Helvetica, **88**/3: 643-655.

FÜRSICH, F. T. & OSCHMANN, W. (1993): Shell beds as tool in facies analysis: The Jurassic of Kachchh, western India. – Journal of the Geological Society London, **150**: 169-185.

Gleister, R.P, & Nelson, H.W. (1974): Grain– size distribution, an aid in fact identification. – Bulletin of Canadian Petroleum Geology, **22**: 203-240.

HARDENBOL, J., JACQUIN, T., FARLEY, M., B., THIERRY, J., DE GRACIANSKY, P. C. & VAIL, P. R. (1998): Mesocoic and Cenozoic Sequence Chronostratigraphic chart. – In: DEGRACIANSKY, P. C., HARDENBOL, J., JACQUIN, T. & VAIL, P. R. (Eds): Mesozoic and Cenozoic Sequence Chronostratigraphic Framwork of European Basins. –Society of Economic Paleontologists and Mineralogists, Special Publications, **60**: 3-14.

HARZHAUSER, M. & KOWALKE, T. (2001): Early Miocene brackish-water Mollusca from the Eastern Mediterranean and from the Central Paratethys – a faunistic and ecological comparison by selected faunas. – Journal of the Czech Geological Society, **46**/3-4: 353-374.

HARZHAUSER, M. & MANDIC, O. (2001): Late Oligocene Gastropods and Bivalves from the Lower and Upper Austrian Molasse Basin. – In: PILLER, W. E. & RASSER, M. W. (Eds): Paleogene of the Eastern Alps. – Schriftenreihe der Erdwissenschaftlichen Kommissionen österreichischer Akademie der Wissenschaften, **14**: 671-774.

HARZHAUSER, M. & MANDIC, O. (2004, in press): The muddy bottom of Lake Pannon a challenge for Dreissenid settlement (Late Miocene; Bivalvia). – Palaeogeography, Palaeoclimatology, Palaeoecology.

HARZHAUSER, M., BÖHME, M., MANDIC, O. & HOFMANN, CH.-CH. (2002):

The Karpatian (Late Burdigalian) of the Korneuburg Basin – A Palaeoecological and Biostratigraphical Synthesis. – Beiträge zur Paläontologie, **27**: 441-456.

HÖLZL, O. (1957): Die Corbiculidae der oligozänen und miozänen Molasse Oberbayerns sowie Bemerkungen zu den oberbayerischen Cyrenenschichten nebst Beschreibung neuer Arten. – Geologica Bavarica, **29**: 1-84.

HÖRNES, M. (1856): Die fossilen Mollusken des Tertiär-Beckens von Wien. I. Univalven. – Abhandlungen der Kaiserlich-Königlichen Geologischen Reichsanstalt, Wien, **3**: 1-736.

HÖRNES, M. (1870): Die fossilen Mollusken des Tertiär-Beckens von Wien. II. Bivalven. – Abhandlungen der Kaiserlich-Königlichen Geologischen Reichsanstalt, Wien, **4**: 1-479.

KIDWELL, S. M. (1991): The stratigraphy of shell concentrations. – In: ALLISON, P. A. & BRIGGS, D. E. G., (Eds): Taphonomy. Releasing the data locked in the fossil record. – Topics in Geobiology, **9**: 211-290; New York (Plenum).

KIDWELL, S. M. & BOSENCE, D. W. J. (1991): Taphonomy and Time-Averaging in of Marine Shelly Faunas. – In: ALLISON, P. A. & BRIGGS, D. E. G. (Eds): Taphonomy – Releasing the Data Locked in the Fossil Record. – Topics in Geobiology, **9**: 15-209; New York (Plenum Press).

KONDO, Y. (1998): Adaptive Strategies of Suspension-Feeding, Soft-Bottom Infaunal Bivalves to Physical Disturbance: Evidence from Fossil Preservation. – In: JOHNSTON, P. AA. & HAGGART, J. W. (Eds): Bivalves: An Eon of Evolution – Paleobiological Studies Honoring Norman D. Newell. – 377-391; Calgary (University of Calgary Press).

KROH, A. & HARZHAUSER, M. (1999): An Echinoderm Fauna from the Lower Miocene of Austria: Paleoecology and Implications for Central Paratethys Paleobiogeography. – Annalen des Naturhistorischen Museums in Wien, **101A**: 145-191.

LOZOUET, P., LESPORT, J.-F. & RENARD, P. (2001): Révision des Gastropoda (Mollusca) du Stratotype de l'Aquitanien (Miocène inf.): site de Saucats "Lariey", Gironde, France. – Cossmanniana, h.s., **3**: 1-189.

LUKENEDER, A. & HARZHAUSER M. (2002): Shell Accumulations of the Nautilidae Aturia (Aturia) aturi in the Lower Miocene Paratethys. – Abhandlungen der Geologischen Bundesanstalt, **57**: 459-466.

MANDIC, O. & STEININGER, F. F. (2003): Computer-based mollusc stratigraphy – a case study from the Eggenburgian (Lower Miocene) type region (NE Austria). – Palaeogeography, Palaeoclimatology, Palaeoecology, **197**: 263-291.

MORTON, B. (1983): Mangrove Bivalves. – In: RUSSELL-HUNTER, W. D. (Ed.): The Mollusca, Vol. 6 Ecology. – 77-138; Orlando & others (Accademic Press).

NUTTALL, C. P: (1990) Review of the Caenozoic Heterodont Bivalve Superfamily Dreissenacea. – Palaeontology, **33/3**: 707-737.

POPOV, S. V., VORONINA, A. A. & GONCHAROVA, I. A. (1993): Oligocene-Lower Miocene Stratigraphy and Bivalves of the Eastern Paratethys. – Trudy Paleontologiceskogo Instituta, 256: 1-206. (in Russian)

POSAMENTIER, H. W. & VAIL, P. R. (1988): Eustatic controls on clastic deposition II. – Sequence and system trackt models. – In: WILGUS, C. K., HASTINGS, B. S., KENDALL, C. POSAMENTIER, H. W., ROSS, C. A. & VAN WAGONER, J. C. (Eds): Sea – level changes: an integrated approach. – Society of Economic Paleontologists and Mineralogists, Special Publications, **42**: 125–154.

ROETZEL, R. & STEININGER, F. F. (1999): Älteres Tertiär (Paleozän, Eozän und Oligozän: 65 bis 23,8 Millionen Jahre vor heute). – In: STEININGER, F. F. (Ed.): Erdgeschichte des Waldviertels. – Schriftenreihe des Waldviertler Heimatbundes, **38** (second edition): 75-78; (Horn).

ROETZEL, R., MANDIC, O. & STEININGER, F. F. (1999): Lithostratigraphie und Chronostratigraphie der tertiären Sedimente im westlichen Weinviertel und angrenzenden Waldviertel. – Arbeitstagung der Geologischen Bundesanstalt, 1999: 38–54.

RÖGL, F. (1998): Palaeogeographic considerations for Mediterranean and Paratethys Seaways (Oligocene to Miocene). – Annalen des Naturhistorischen Museums in Wien, **99**(A): 279-310.

RÖGL, F. & STEININGER, F. F. (1983): Vom Zerfall der Tethys zu Mediterran und Paratethys. Die neogene Paläogeographie und Palinspastik des zirkum-mediterranen Raumes. – Annalen des Naturhistorischen Museums in Wien, **85**(A): 135-163.

SCHAFFER, F. X. (1910): Die Bivalven der Miocänbildungen von Eggenburg.– Abhandlungen der Kaiserlich-Königlichen Geologischen Reichsanstalt, Wien, **22**(1): 5-112.

SCHAFFER, F. X. (1912): Die Gastropoden der Miocänbildungen von Eggenburg. Mit einem Anhang über Cephalopoden, Crinoiden, Echiniden und Brachiopoden. – Abhandlungen der Kaiserlich-Königlichen Geologischen Reichsanstalt, Wien, **22**(2): 127-193.

SIEBER, R. (1955): Systematische Übersicht der jungtertiären Bivalven des Wiener Beckens. – Annalen des Naturhistorischen Museums in Wien, **60**: 169–201.

SIEBER, R. (1958): Systematische Übersicht der jungtertiären Gastropoden des Wiener Beckens. – Annalen des Naturhistorischen Museums in Wien, **62**: 123-192.

STEININGER, F. F. (1963): Die Molluskenfauna aus dem Burdigal (Unter-Miozän) von Fels am Wagram in Niederösterreich. – Denkschriften, Mathematisch-Naturwissenschaftliche Klasse, Österreichische Akademie der Wissenschaften, 110(5): 1-88.

STEININGER, F. F. (1971): Holostratotypus und Faziostratotypen der Eggenburger Schichtengruppe im Raume von Eggenburg in Niederösterreich (Österreich). – In: STEININGER, F. F. & SENES, J. (Eds): M1 Eggenburgien. Die Eggenburger Schichtengruppe und ihr Stratotypus. – Chronostratigraphie und Neostratotypen, **2**: 104-166; Bratislava (VEDA).

STEININGER, F. F. & SENES, J. (1971): M1, Eggenburgien. Die Eggenburger Schichtengruppe und ihr Stratotypus. – Chronostratigraphie und Neostratotypen, **2**: 1-827; Bratislava (VEDA).

STEININGER, F. F. & WESSELY, G. (2000): From the Tethyan Ocean to the Paratethys Sea: Oligocene to Neogene Stratigraphy, Paleogeography and Paleobiogeography of the circum-Mediterranean region and the Oligocene to Neogene evolution in Austria. – Mitteilungen der Österreichischen Geologischen Gesellschaft, **92**: 95-116.

STEININGER, F. F., ROETZEL, R. & RÖGL, F. (1991): Geologische Grundlagen, Lithostratigraphie, Biostratigraphie und chronostratigraphische Korrelation und Paläogeographie der Molassesedimente am Ostrand der Böhmischen Masse. – In: Roetzel, R. & Nagel, D. (Eds): Exkursionen im Tertiär Österreichs. – 63-76, Wien (Österreichische Paläontologische Gesellschaft).

STEININGER, F. F., CTYROKÝ, P., ONDREJÍCKOVÁ, A. & SENES, J. (1971): Die Mollusken der Eggenburger Schichtengruppe. – In: STEININGER, F. F. & SENES, J. (Eds): M1, Eggenburgien. Die Eggenburger Schichtengruppe und ihr Stratotypus. – Chronostratigraphie und Neostratotypen, **2**: 356-591; Bratislava (VEDA).

STÜTZ, A. (1807): Mineralogisches Taschenbuch. Enthaltend eine Oryctographie von Unterösterreich zum Gebrauche reisender Mineralogen. – 1-394; Wien-Triest (J.G. Megerle v. Mühlfeld - Geistinger).

VAIL, P. R., MITCHUM, R. M. J., TODD, R. G., WIDMIER, J. M., THOMPSON, S. III., SANGREE, J. B., BUBB, J. N. & HATLELID, W. G. (1977): Seismic stratigraphy and global changes of sea level. – In: CLAYTON, C. E., (Ed.): Seismic stratigraphy - application to hydrocarbon exploration. – American Association of Petroleum Geologists, Memoir, **26**: 49-212.

VAKARCS, G., HARDENBOL, J., ABREU, V. S., VAIL, P. R., VÁRNAI, P. & TARI, G. (1998): Oligocene-Middle Miocene Depositional Sequences of the Central Paratethys and their Correlation with Regional Stages. – Society of Economic Paleontologists and Mineralogists, Special Publications, **60**: 209-231, Tulsa.

VISHER, G.S. (1969): Grain size distributions and depositional processes. – Journal of Sedimentary Petrology, **39**: 1074-1106.

WILLMANN, R. (1989): Muscheln und Schnecken der Nord- und Ostsee: NJN Naturführer. – 1-310; Fulda (Neumann-Neudamm Verlag).