



**Shell Accumulations
of the Nautilidae *Aturia (Aturia) aturi* (BAST.)
in the Lower Miocene Paratethys (Lower Austria)**

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5 Text-Figures and 1 Plate

*Lower Austria
Miocene
Paratethys
Nautilidae
Shell Accumulation*

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**Schalenanhäufungen
des Nautiliden *Aturia (Aturia) aturi* (BAST.)
in der untermiozänen Paratethys (Niederösterreich)**

Zusammenfassung

Sedimentologische und palökologische Untersuchungen wurden an zwei Aufschlüssen in Niederösterreich (Obermarkersdorf und Unternalb) durchgeführt. Zwei signifikante Schalenanhäufungen des Nautiliden *Aturia (Aturia) aturi* konnten dabei beobachtet werden. Die beiden allochthonen Vorkommen gehören der Retz-Formation an (Unteres Miozän; Eggenburgium). Die ungewöhnlich hohe Zahl an Gehäusen des nektonischen Nautiliden in einer littoralen bis flach sublittoralen Molluskenfauna deutet auf strömungsbedingte, postmortale Verdriftung des ansonsten eher seltenen Cephalopoden hin.

Abstract

Sedimentological and palaeoecological studies were carried out in two sections in Lower Austria (Obermarkersdorf and Unternalb). Two significant shell accumulations of the extinct nautilid *Aturia (Aturia) aturi* are documented. Each of these allochthonous occurrences is situated in the Retz Formation (Lower Miocene; Eggenburgian). The striking abundance of nektonic nautilid shells within a littoral to shallow sublittoral mollusc fauna reflects current-induced, post-mortem drifts of the otherwise rather rare cephalopod.

1. Introduction

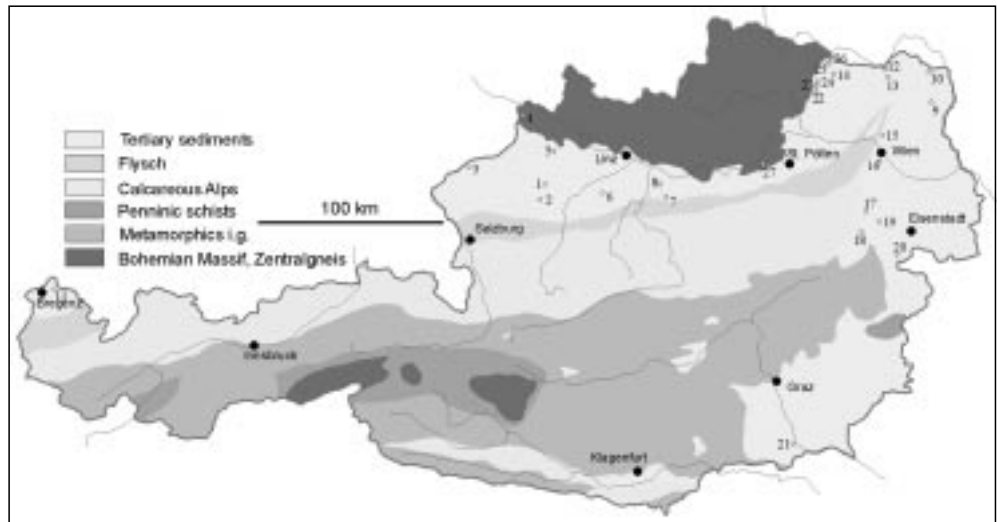
Two unexpected occurrences of the nautilid *Aturia aturi* (BASTEROT, 1825) were found during 1998/99 in the Lower Miocene (Eggenburgian) Retz Formation at the villages Unternalb and Obermarkersdorf in Lower Austria. This cosmopolitan species is documented from the Paratethys Sea from the Lower Miocene Eggenburgian stage (STEI-

NINGER et al., 1971) to the Middle Miocene Badenian stage (FRITZ & HIDEN, 1994/95) (Text-Fig. 1). According to SCHULTZ (1976) most of the other Austrian occurrences cited as *Aturia aturi* are rather doubtful. As SCHULTZ states, none of these specimens can be clearly identified with respect to the strict diagnostic features as proposed by

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Text-Fig. 1.
Neogene (Eggenburgian to Badenian) occurrences of *Aturia aturi* and *Aturia* cf. *aturi* in Austria.
1–24 and 27: after SCHULTZ 1976;
21: after FRITZ & HIDEN 1994/95; 25 and 26: this work.

1 = Vöcklabruck (Upper Austria); 2 = between Timelkam and Vöcklabruck (U. A.); 3 = Eisenhub near Braunau (U. A.); 4 = Brunnenthal near Scharding/Inn (U. A.); 5 = Neumarkt-Kallham (U. A.); 6 = Kremsmünster (U. A.); 7 = St. Peter (Lower Austria); 8 = Haag (L. A.); 9 = Steinberg area near Zistersdorf (L. A.); 10 = Lichtenwarth I near Schratzenberg (L. A.); 11 = Wirtatobel near Bregenz (Vorarlberg); 12 = Laa a. d. Thaya (L. A.); 13 = Enzersdorf near Laa a. d. Thaya (L. A.); 14 = Platt near Retz (L. A.); 15 = Teiritzberg near Korneuburg (L. A.); 16 = Pötzleinsdorf near Vienna; 17 = Vöslau (L. A.); 18 = Wöllersdorf (L. A.); 19 = Southern Vienna Basin (L. A.); 20 = Walbersdorf near Mattersburg (Burgenland); 21 = Retznei (Styria); 22 = Burgschleinitz near Eggenburg (L. A.); 23 = Eggenburg (L. A.); 24 = Gauderndorf near Eggenburg (L. A.); 25 = Unternalb (L. A.); 26 = Obermarkersdorf (L. A.); 27 = Mauer near Melk (L. A.).



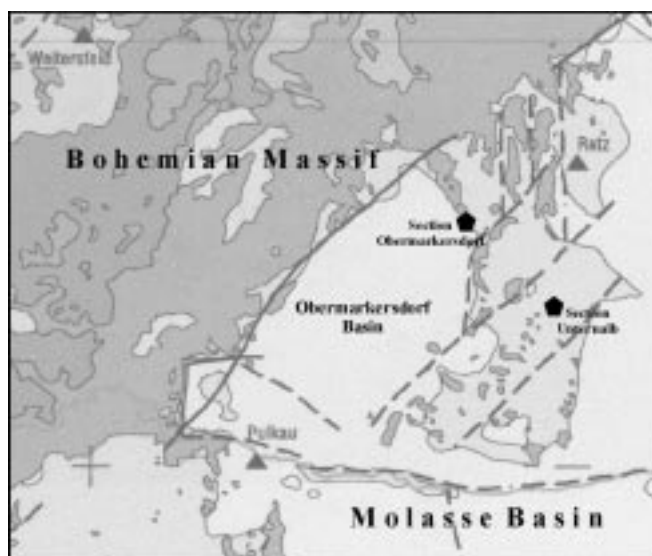
STURANI (1958, 1959) and JUNG (1966). However, the good preservation and the large number of individuals of the herein described nautilids supply further evidence of *Aturia aturi* s.s. for the Central Paratethys.

The unusual co-occurrence of neotonic nautilids within a littoral to shallow sublittoral mollusc fauna is a clear indication of current-induced, post-mortem drifts of the *Aturia* shells. Comparable shell accumulations of the modern *Nautilus pompilius*, along the shores of Thailand (TORIYAMA et al., 1964) suggest similar floating conditions of both nautilid genera.

2. Geological Setting

2.1. Section Obermarkersdorf

It is situated about 2.2 km NE from the village Obermarkersdorf (Austrian Map 1 : 50.000, sheet 9, Text-Fig. 2). There, sediments of the Retz Formation occur along a small crystalline crest, which corresponds to one of the numerous small islands, characterising the coastal line along the Bohemian Massif in the area around Retz during



Text-Fig. 2.
Position of sections Obermarkersdorf and Unternalb, 1 : 100.000.
Map after ROETZEL, MANDIC & STEININGER 1999, modified.

the Upper Eggenburgian. Tectonically, this crystalline crest forms the north-eastern border of the Obermarkersdorf Basin (ROETZEL & HEINRICH, 1999). The dating of the Retz Formation into the Eggenburgian is based on ostracods (ZORN, 1999); the mollusc fauna allows an even more exact dating into the upper Eggenburgian (MANDIC & HARZHAUSER, 1999). Yellow, fine to middle sands cover the flanks of this crest, while the crystalline core forms the top. The loose, micaceous sands contain no shelly fauna but bear grey, calcitically cemented quartz-sandstone concretions of fine to middle grained sand. These concretions, attaining up to 40 cm in diameter, exhibit a diverse mollusc-balanid fauna of the littoral and the shallow sublittoral environment. Aragonitic shells are completely dissolved but the remaining moulds exhibit well-preserved shell sculptures. Artificial plastic casts of the cavities therefore enabled the identification at the species level and the reconstruction of the fauna.

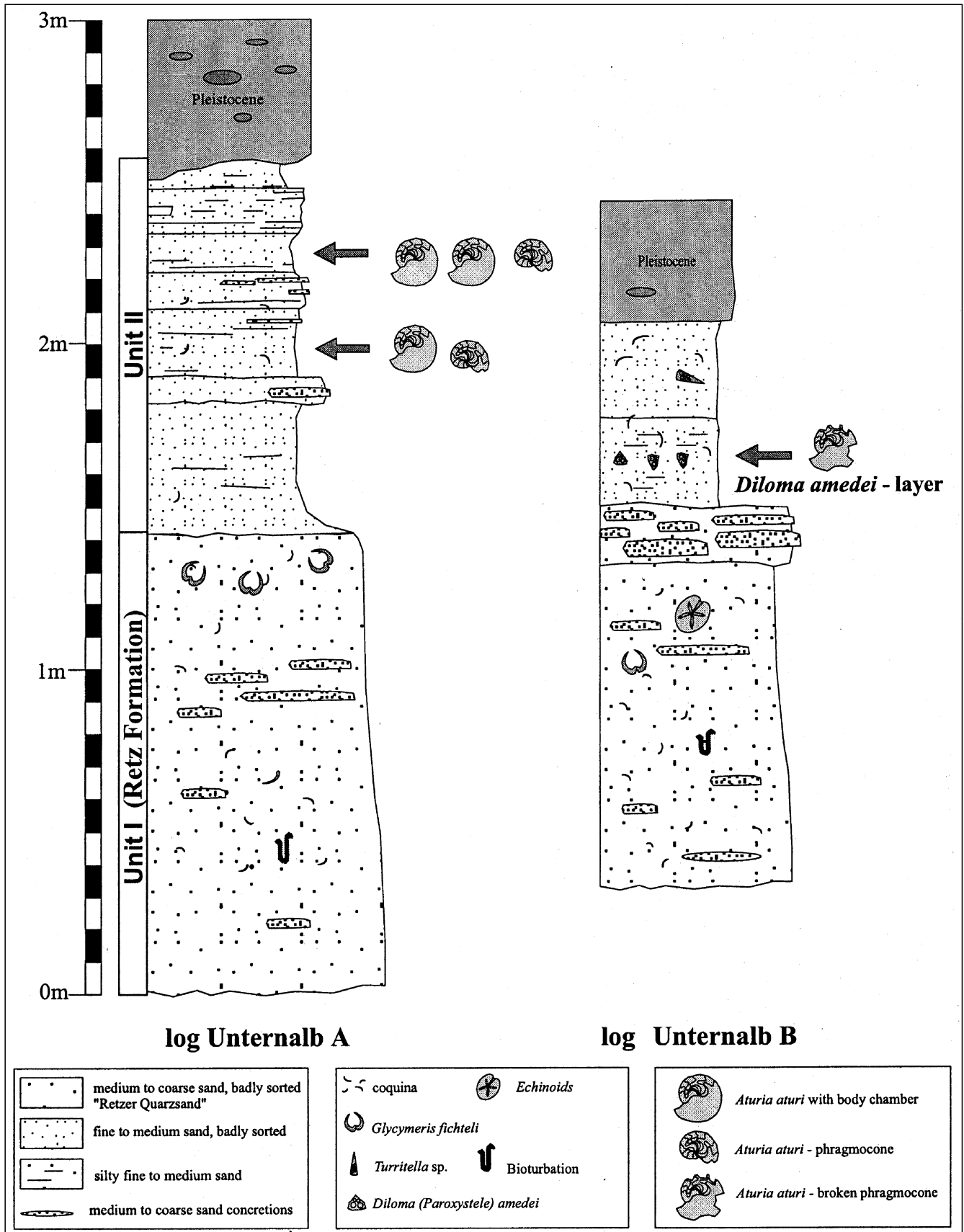
Gastropods predominate the taphocoenosis with abundant and large-sized *Diloma (Paroxystele) amedei*, *Babylonina eburnoides* and *Ficopsis (Fulguroficus) burdigalensis*. These prevailing species are accompanied by scattered *Naticarius tigrinus*, *Latirus (Latirus) valenciennesi*, *Turritella doublieri*, and *Trigonostoma* sp. The gastropods are hardly fragmented, and even the fragile siphos are usually preserved. Mytilidae prevail among the bivalves, accompanied by *Acanthocardia moeschani* and rare *Glycymeris fichteli*, both of which were embedded with partly articulated, gaping shells (HARZHAUSER et al., 1999). Balanids are also abundant but are largely disarticulated.

The fauna indicates a parautochthonous occurrence of rocky littoral species mixed with subordinate infaunal molluscs from the adjacent sandy littoral to sublittoral.

The most remarkable allochthonous component of the fauna is the Nautilidae *Aturia (Aturia) aturi* (BASTEROT). With at least 15 specimens of the cephalopod within one concretion, the species represents one of the most abundant elements at the section.

2.2. Sections Unternalb A & B

They are situated in two abandoned sand pits SSW of Unternalb (ÖK 1 : 50.000 sheet 22, Text-Figs. 2 and 3). During the Eggenburgian the area was part of a shallow embayment ("Nalber Buch" [BERNHAUSER, 1955]; "Nalb



Text-Fig. 3.
 Logs A and B at the outcrop near Unterhalb.
 Arrows indicate position of *Aturia (Aturia) aturi*-bearing beds; Retz Formation – Late Eggenburgian (Lower Miocene).

Bay" [KROH & HARZHAUSER, 1999]). It was formed as a result of several NNW–SSE directed crystalline crests, projecting as numerous small offshore islands and subma-

rine highs approximately 6 km into the Molasse Basin. Two sedimentary units can still be logged at the sections; the underlying unit I consists of a few meters of whitish to

yellowish, poorly sorted and poorly rounded, immature, coarse quartzsands deriving from the Thayabatholith-granite which formed the coast and adjacent hinterland of Nalb Bay. Hanging wall unit II consists of up to 3 m thick, yellowish to greyish, immature fine to medium sand displaying a rapidly changing, patchy bio- and lithofacies. The log Unternalb A represents a proximal section, whereas Unternalb B is separated from the former by a small crystalline ridge and is in a more distal, basinward position. Unit I can be traced in all sections and displays similar lithological and biotic features. The most abundant macrofossils are pectinids such as *Pecten hornensis* and *Aquiptecten praescabruscula* (MANDIC & HARZHAUSER, 1999). Calcitic bivalves such as *Anomia ephippium* and various ostreids also appear in fair numbers. Venerids and lucinids may also occur, but due to the unfavourable preservation no specific identification is possible. Among the gastropods, *Turritella doublieri* and the medium-sized *Conus* cf. *mercati* prevail. Rare terebratulid bivalves, casts of a large *Xenophora* and remains of the nautilid *Aturia aturi* complete the list of common molluscs. These mollusc associations are accompanied by a rich echinoderm fauna consisting of at least three irregular echinoids: *Spatangus austriacus*, *Maretia? perornata* and *Echinolampas laurillardii* (HARZHAUSER & KROH, 1999).

In contrast, the sedimentology and bio-content of unit II are quite different in log B and A. Thus, unit II of log A bears accumulations of balanids, bryozoans, asteroids, regular echinoids, mytilids and glycymerids. The rich mollusc fauna consists of partly articulated shells of *Acanthocardium moeschani*, *Pholadomya alpina* and *Glycymeris fichteli*, whereas *Babylonia eburnoides*, *Tudicla rusticula* and *Ficopsis (Fulguroficus) burdigalensis* dominate the gastropod fauna, accompanied by two naticids and the very rare muricid *Typhis horridus*. More than 15 specimens of *Aturia aturi* were found in this unit, deriving from an area of about 5 m². In contrast only a single *Aturia* fragment was found, in the poorly sorted, muddy fine to coarse sands of the distal log B. The mollusc fauna of this unit consists mainly of aequipectinids, turritellids, scaphopods and several species of infaunal bivalves such as *Panopea menardi*.

3. Material

15 specimens from section Obermarkersdorf, 8 specimens from section Unternalb A, and 1 specimen from section Unternalb B (Text-Fig. 4) are documented. In addition, several fragments and casts were found at section Unternalb A. The poor preservation of the latter specimens allows no specific identification. Nonetheless it seems likely that these fragments derive from *Aturia aturi* as well.

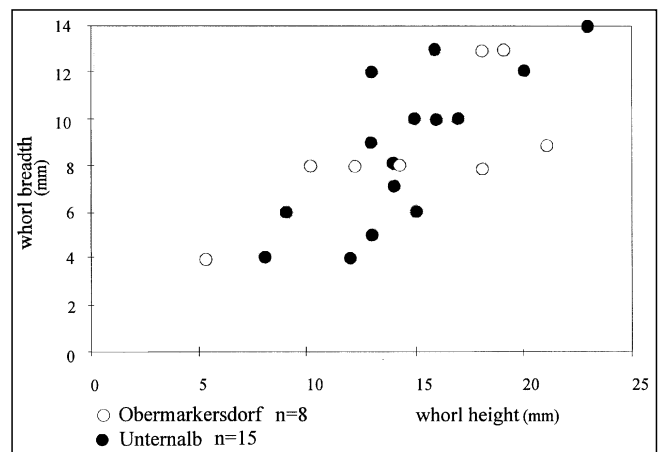
Classis: Cephalopoda CUVIER, 1795
Subclassis: Nautiloidea AGASSIZ, 1847
Ordo: Nautilida AGASSIZ, 1847
Superfamilia: Nautilaceae BLAINVILLE, 1825
Familia: Nautilidae BLAINVILLE, 1825
Genus: *Aturia* BRONN, 1838

The genus *Aturia* is characterized by involute, non-umbilicated, disk-shaped, smooth shells with a siphuncle close to the dorsum and a - within the nautiloids - complex suture line. One remarkable feature in the siphuncle of *Aturia* is the great length of the septal necks (WARD, 1987).

Aturia (Aturia) aturi (BASTEROT, 1825)

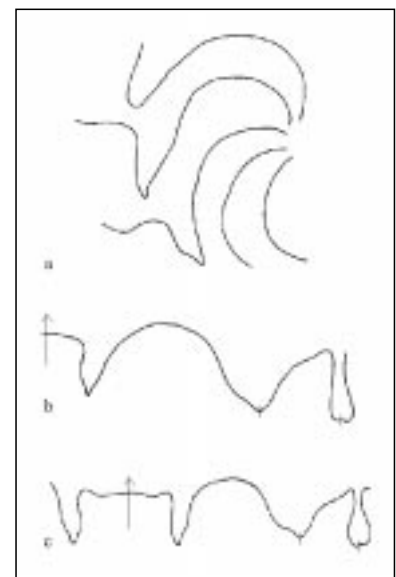
- 1825 *Nautilus Aturi* Nob. BASTEROT, p. 17.
 ?1912 *Aturia aturi* BAST. SCHAFFER, p. 52.
 ?1925 *Aturia aturi* BAST.? VREDENBURG, p. 9, 10.
 1958 *Aturia aturi* (BAST.) STURANI, p. 366, Pl. 18, Fig. 1, Pl. 19, Figs. 1-2, Pl. 20, Fig. 4.
 1959 *Aturia aturi* (BAST.) STURANI, p. 175, Pl. 6-7.
 1966 *Aturia aturi* (BAST.) JUNG, p. 487-489, Pl. 1, Fig. 1, Pl. 2, Fig. 1.
 1976 *Aturia (Aturia) cf. aturi* (BAST.) SCHULTZ, p. 16, Fig. 11, part.
 1994/95 *Aturia aturi* (BAST.) FRITZ & HIDEN, p. 14, Figs. 1-4.

Compressed to flattened discoid shell. The aperture is subtriangular and much higher than wide. The flanks converge ventrally with an angle about 20°. The flanks are highly compressed and flattened (Text-Fig. 4). The greatest width of the whorls is in the umbilical region (umbilicus closed). Septae are narrow-spaced, strongly curved, and attain a number of about thirteen in the last whorl. The umbilicus is situated more or less in the middle of the shell. The point of maximal curvature of the lateral saddle is in close position to the lateral lobus (Text-Fig. 5). The siphuncle aperture is well rounded and very small. Lyrae seem to be absent on the outer wall of the casts.



Text-Fig. 4. Compared dimensions of specimens from Unternalb and Obermarkersdorf (whorl height against whorl breadth).

Text-Fig. 5. Suture lines. a = specimen from section Unternalb A (Pl. 1, Fig. 10); b = specimen from section Obermarkersdorf (Pl. 1, Fig. 1); c = *Aturia (Aturia) aturi* (BASTEROT), after STURANI 1959 (Abb. 9D).



The shells are mainly broken and fragmented - partly due to preparation - only two steinkerns still bear an intact body chamber. The largest complete specimen has a diameter of 31 mm, while single chamber-casts suggest a size about 40 mm. Since the shells are dissolved, only steinkerns and moulds are present, but the excellent preservation of sutures and siphonal structures allows a dis-

tinct identification. Only a single specimen from section Unternalb B bears some fragments of the aragonitic shell. In addition, some of the plaster-moulds from Obermarkersdorf exhibit the shell surface and bear even delicate, close-set growth lines.

4. Distribution and Palaeobiology

Aturia evolved at the end of the Cretaceous, and became the most diverse nautiloid genus of the Cenozoic (WARD, 1987). Fossil *Aturia* can be found from Cenozoic marine deposits on most continents. *Aturia*, though in most cases rarely common, is worldwide distributed in the Miocene of both hemispheres and is known from remote places such as New Zealand (BEU & MAXWELL, 1990) and West Antarctica (TEICHERT & MATSUMOTO, 1987). The genus persisted to the end of Miocene (TEICHERT & MATSUMOTO, 1987).

Due to the delicate and usually obscured features required to differentiate of *Aturia aturi* (BASTEROT) from related species such as *Aturia cubaensis* (LEA), one can seldom rely on occurrence-data of *Aturia aturi* from the literature. Undoubtedly, warmwater species were distributed during the Lower and Middle Miocene in the Mediterranean and Paratethyan bioprovinces and displayed amphiatlantic distribution. Additionally it is clearly recorded from various Miocene localities in the Indo-West Pacific and the Eastern Pacific regions (JUNG, 1966).

Generally, the Cenozoic nautilids display a higher proportion of rather compressed shell shapes compared to the Jurassic and Cretaceous nautilid record (WARD, 1987). Correspondingly, the genus *Aturia* develops highly compressed shells. The evolution of the *Aturia* and Aturoidea group in many ways mimics the initial radiation of the ammonoids in the Devonian Period of the Palaeozoic (WARD, 1987). In both of these groups the evolution of highly compressed shell shapes was accompanied by the formation of more complex septal sutures. *Aturia* and Aturoidea have septa quite similar in form to mid-Palaeozoic goniatites (WARD, 1987) such as *Imitoceras* and also similar to the clymeniids such as *Cymaclymenia* (MILLER et al., 1957).

Both groups evolved shells with flattened flanks, which are inherently weaker than globular shells of equal shell thickness. This "stability problem" was solved convergently in both the Palaeozoic goniatites and the Tertiary nautiloids by emphasizing the role of the septae in buttressing the shell to strengthen the compressed flank areas. By increasing sinuosity of the septa at their contact with the outer shell wall, the buttressing effect was increased without increasing septal thickness. In both the Palaeozoic and the Cenozoic cases, the parallelism in sutural form coincides with the evolution of strongly compressed shells (WARD, 1980). Even under consideration of these changes within the Tertiary nautiloids, the entire suite of post-Triassic nautiloids remain a very homogeneous and morphologically conservative group. All had shell shapes with short body chambers (generally from a third to, at most, half a whorl; *Aturia* ca. 156°).

In contrast to the centrally located siphuncle in most nautiloids, the siphuncle in *Aturia* is in a dorsal position on the whorl, or placed against the inside shell wall. It shares this feature with the clymeniid ammonoids of the Palaeozoic, the endoceratid nautiloids of the Palaeozoic, and modern *Spirula*. In live position, the last chamber of *Aturia* was probably oriented much like that of modern *Nautilus*, with the connecting rings of the siphuncle oriented vertically.

Similarly, *Aturia* displays rather analogous decoupling adaptations to that of *Spirula*. The long septal necks of *Aturia* would effectively produce decoupling at even lower percent emptying volumes than in *Nautilus* (WARD 1980). Thus, *Aturia* may have been among the most active and deeply living nautiloids, judging from the shell's large size, excellent streamlining, and siphuncle configuration (WARD, 1980, 1987).

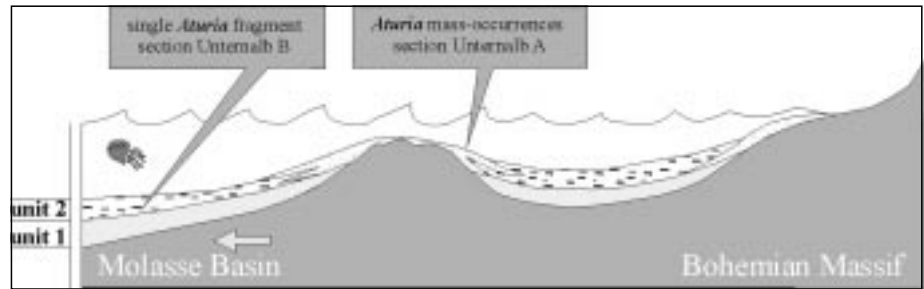
5. Conclusions

According to WARD (1987) nautiloids are never abundant in Cenozoic strata but are not rare either. However, the Lower Austrian occurrences furnish evidence that specimens of *Aturia* can be abundant in special cases and even may form shell concentrations in environments distinctly different from the habitat of the animals.

The described shell accumulations are bound to littoral to shallow sublittoral environments along the coast of the Eggenburgian Paratethys Sea. Since the rocky shores and shallow embayments cannot be expected to have been a suitable habitat for a nectonic, deep-water dwelling cephalopod, the shell accumulations are clearly linked to current-induced, post-mortem drifts of *Aturia* shells. HAMADA (1964) and TORIYAMA et al. (1964) report comparable shell concentrations for modern *Nautilus*. Despite REYMENT'S (1958) doubts, that empty shells of fossil cephalopods floated like those of *Spirula spirula* and the modern *Nautilus*, we favour the "surface-drift-theory" for the post-mortem drifts of *Aturia* shells. The studies of HAMADA (1964) and TORIYAMA et al. (1964) on the necroplanktonic features of recent *Nautilus*-shells provide evidence for postmortal driftings of 3000 km and floats of more than one year, which are reflected in bioerosion and epifaunal settlement. Similarly, SAUNDERS & SPINOSA (1979) recorded a post-mortem drift of a *Nautilus* shell over a distance of 1000 km (between Palau and Mindanao) in a maximum of 138 days, an average of approximately 7 km per day. The record is held by a floating specimen that drifted ashore after 11 years (ISHII, 1981). These open sea surface drift-routes are strongly associated with currents, whereas nearshore drifts are mainly induced by wind directions. Although the actualistic ecological comparison of *Nautilus* with the fossil *Aturia* is complicated by differences in shell outline and suture lines (see above), which may reflect adaptation to different habits, the general drift-behaviour is considered to be identical. This hypothesis is also strongly supported by the observations of KOBAYASHI (1954), who relates the various Cenozoic, nearshore occurrences of *Aturia* in Japan with the proto-Kuroshio current. As demonstrated by KOBAYASHI (1954) by bottle-float experiments, it is hardly possible to reconstruct the necroplanktonic history of shells in detail. During one of his experiments one bottle arrived after ten months whereas a second bottle reached the same locality after two months. This difference is explained by the complicated interplay of oceanic currents and counter-currents, tidal currents and winds. Correspondingly, the unknown interplay of these factors resulting in the formation of the fossil shell accumulations prevent any detailed reconstruction of palaeo-flumenology or drift routes.

Similar to the Lower Austrian shell accumulations, most of the Japanese findings are classified by KOBAYASHI as embayment type occurrences, representing necroplanktonic floats. He also states that the animals did not inhabit these embayments but on the other hand concludes that

Text-Fig. 6.
Suggested relation between the two *Aturia* occurrences of section Unternalb at one of the submarine highs.



the natural habitat of the population was probably not very far from the localities. This might also be stated for the Eggenburgian *Aturia aturi*. The usually excellent preservation of the shell surfaces (as seen on plaster moulds) indicates a short period of floating. Epifauna as described by HAMADA (1964) on *Nautilus* shells and by SEILACHER (1960) on ammonoid shells, being characteristic for long floatings, is completely missing on the material from Obermarkersdorf and Unternalb. Similarly heavy exfoliation or abrasion can be excluded since even delicate growth lines are well preserved. Therefore the shells are interpreted to have been transported over a rather short distance from the adjacent Molasse Basin. According to TEICHERT & MATSUMOTO (1987) the endogastric position of the siphon in the genus *Aturia* indicates adaptations to deep-water rather than shallow-water environments. Thus the deep Late Eggenburgian Molasse Basin was probably the natural habitat of the *Aturia* population. In contrast, the shallow embayments along the coast acted only as traps for post-mortem drifts.

The transgression which affected the coasts in that region during the Late Eggenburgian and Early Ottungian (ROETZEL, MANDIC & STEININGER, 1999) resulted in a rapid sediment covering of the *Aturia*-bearing strata, and probably explains the preservation of the littoral to sublittoral taphocoenoses. Moreover the slightly heterochronous deposition of the two shell accumulations seems to be linked to this transgression (section Obermarkersdorf is topographically higher and in a somewhat more landward position than Unternalb).

Hence the herein reported mass-occurrences of *Aturia aturi* are always bound to littoral environments, whereas the sublittoral fauna of the distal log Unternalb B bears

only a single specimen. This specimen consists only of the early parts of the phragmocone and displays some breakage of the shell surface. As demonstrated by TORIYAMA et al. (1964), recent *Nautilus* floats easily if the camerate portion of the shell is in a good state of preservation, even when the body chamber is broken. On the other hand, during the floating experiments the *Nautilus* shells sank rather abruptly if the phragmocone is broken. The single, fragmented *Aturia* from Unternalb B therefore had little capacity for drifting. This *Aturia*-occurrence coincides with a thin coquina of the archaeogastropod *Diloma (Paroxystele) amedei*. KROH & HARZHAUSER (1999) interpret this layer to represent an allochthonous occurrence of shells which were transported into the shallow basin from an adjoining littoral environment in the course of a storm. This particular nautilid shell was probably damaged during this high-energy event and then transported from the coast to the outer bay (Text-Fig. 6). The energetic conditions along the coast of the investigated area of the Bohemian Massif resulted in a fair percentage of breakage of the body chambers. On the other hand the good preservation of the shell surfaces clearly shows that the fragmentation usually did not affect the phragmocones.

Acknowledgements

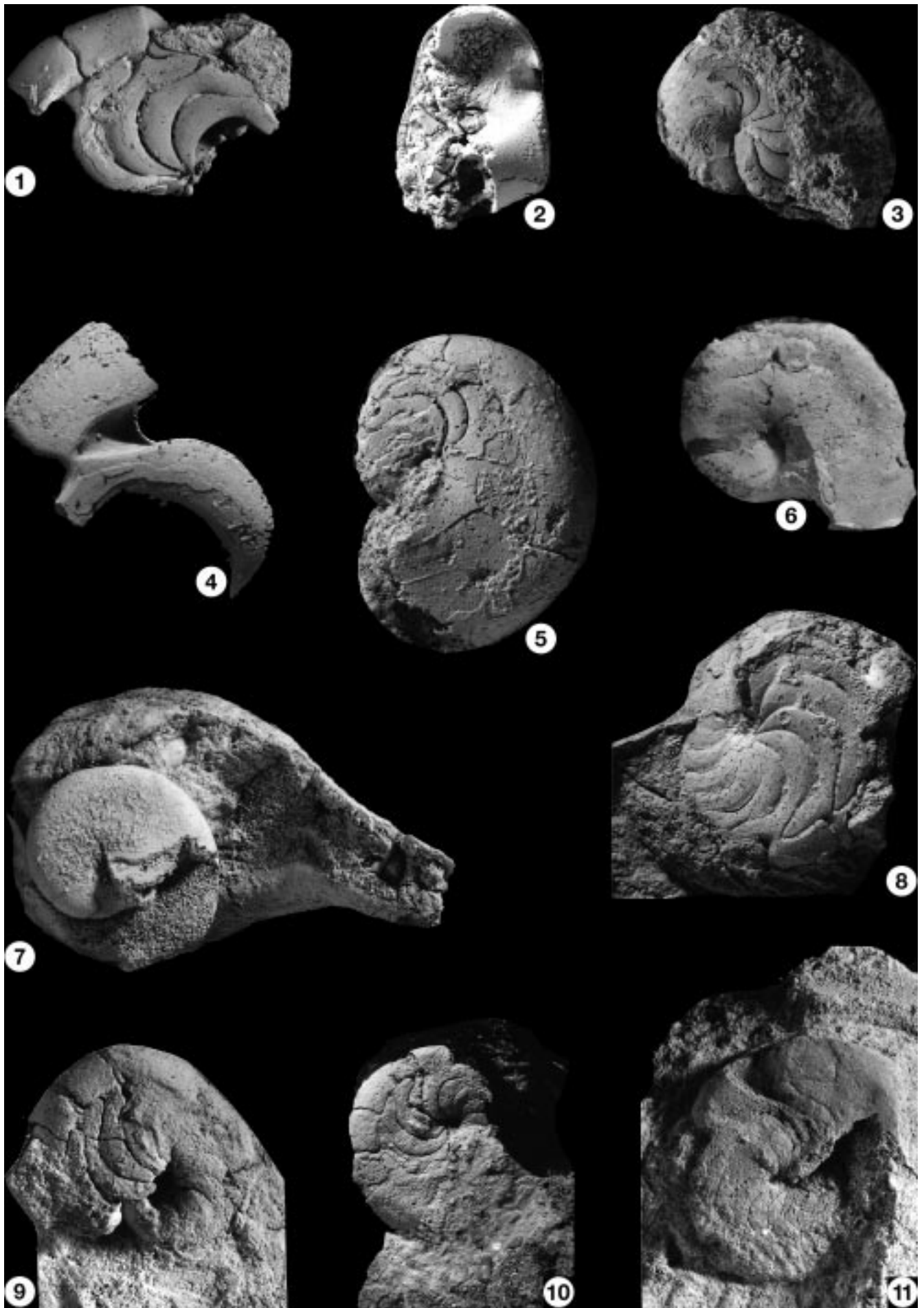
Thanks are due to Dr. Kathleen HISTON (Geological Survey, Vienna), Dr. Herbert SUMMESBERGER and Dr. Ortwin SCHULTZ (Museum of Natural History, Vienna) and Ao. Prof. Dr. Leopold KRYSYTN (Institute of Palaeontology, Vienna) for their valuable, constructive comments and their help. The study was supported by the FWF (P 13745 Bio and P 13641 Geo).

Plate 1 *Aturia (Aturia) aturi* (BASTEROT)

- Fig. 1: Part of the phragmocone with suture lines. Obermarkersdorf; 2.5 ×.
- Fig. 2: Same specimen; dorsal position of the siphuncle. Obermarkersdorf; 2.5 ×.
- Fig. 3: Lateral view. Unternalb; 3 ×.
- Fig. 4: Lateral view of one chamber. Unternalb; 2.5 ×.
- Fig. 5: Lateral view of a specimen with body chamber. Obermarkersdorf; 2 ×.
- Fig. 6: Lateral view of plastic cast with body chamber. Obermarkersdorf. 2 ×.
- Fig. 7: Plastic cast on a *Ficopsis burdigalensis*. Obermarkersdorf; 2 ×.

- Fig. 8: Lateral view of a phragmocone. Obermarkersdorf; 2 ×.
- Fig. 9: Lateral view of a phragmocone. Unternalb; 2 ×.
- Fig. 10: Lateral view of a phragmocone with parts of the body chamber. Unternalb; 1 ×.
- Fig. 11: Lateral view of a phragmocone with parts of the body chamber. Unternalb. 2 ×.

All specimens are stored in the collection of the Museum of Natural History, Vienna.



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