Stop A2/3

TYPE LOCALITY OF THE ADELHOLZEN BEDS (PRIMUSQUELLE BOTTLING PLANT) AN EOCENE (LUTETIAN, PRIABONIAN) DEEPENING SEQUENCE

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Topics:

Lithology, biostratigraphy (planktic foraminifera, calcareous nannoplankton, nummulitids), stable isotope stratigraphy, changing paleoenvironments, paleoproductivity.

Tectonic unit:

North Helvetic Unit.

Lithostratigraphic units:

Adelholzener Schichten (Adelholzen Beds), Stockletten.

Chronostratigraphic units:

Lutetian, Priabonian

Biostratigraphic units:

Planktonic foraminiferal zones P10-P115/16 (E8-E14/15), calcareous nannofossil zones NP15a-NP20 (CP13-CP15b), shallow benthic foraminifera zones SBZ 13-15.

Location:

Primusquelle bottling plant southwest of Adelholzen, Siegsdorf, Bavaria.

1. Introduction

The section at Adelholzen is situated at the southwestern tip of the "Adelholzener Mineralwasser" bottling plant (Primusquelle, Fig. A2.12). The outcrop became accessible after excavations for the new plant. The steep slopes became overgrown and will be completely covered with grass and bushes in the near future. In 1996, the complete section was sampled with high resolution (20 cm-intervals).

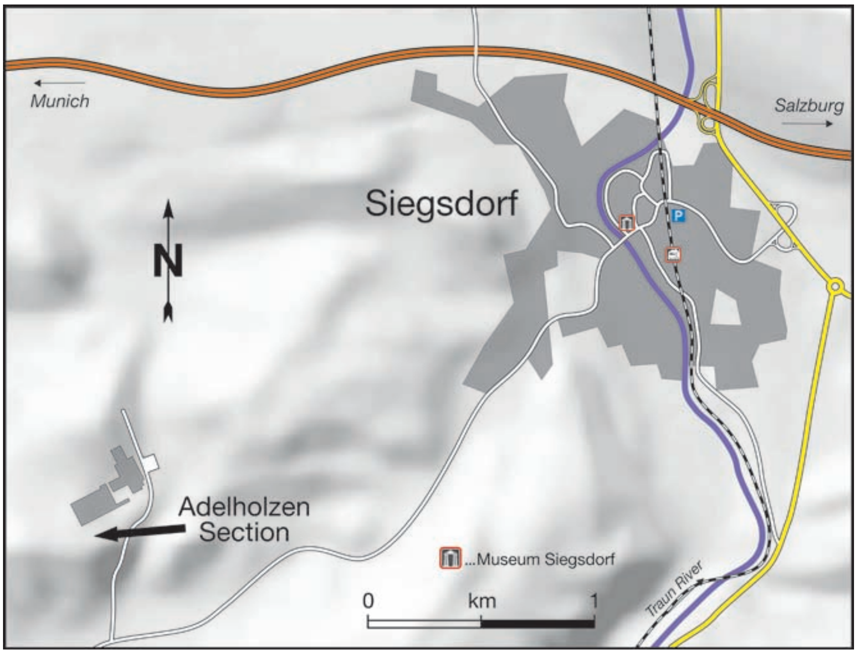


Figure A2.12 ▲
Outcrop of Adelholzener Schichten

Figure A2.13 shows the upper portion of the exposed rocks. The section covers the entire Lutetian and large parts of the Priabonian. It is part of the Helvetic (tectonic) Unit and represents the sedimentary processes that took place on the southern shelf to upper bathyal of the European platform at that time. The nummulitic marls and sand

Figure A2.13 ▲
Outcrop of Adelholzener Schichten and Stockletten (“Globigerina”-Marls) behind the new bottling plant

of the area around Siegsdorf are famous for their high numbers of very large sized *Nummulites* and *Assilina*. Also in the Adelholzen Section, large specimens of these genera can be found in high numbers (Fig. A2.14).

2. Lithology

Six lithologic units occur in the Adelholzen-Section (Fig. A2.15). These lithologic units are, from base to top, 1) marly, glauconitic sands with predominantly *Assilina* (thickness exposed c. 4 m), 2) marly bioclastic sands with predominantly *Nummulites* (c. 4.5 m), 3) glauconitic sands (c. 0.6 m), 4) marls with *Discocyclina* (c. 4.2 m), and 5) marly brown sand (c. 1.1 m). The brown color of the latter unit results from its high content of sub-mm sized iron-hydroxide nodules. These units were combined as “Adelholzener Schichten” (Hagn et al., 1981) with unit 1 as “Untere Adelholzener Schichten” (lower Adelholzen Beds), unit 2 as “Mittlere Adelholzener Schichten” (middle Adelholzen Beds), and units 3 to 5 as “Obere Adelholzener Schichten” (upper Adelholzen Beds). For the sixth unit, Stockletten, no formal name has been established so far and the traditional name is still in use. Lateral equivalents in the west are called “Globigerina-Marls” (Hagn et al., 1981). The local name Stockletten refers to the sticky character of this marls (Letten = claystones, marls). The total thickness of all units exposed is about 18 m.

3. Biostratigraphy

The Adelholzen-Section is rich in planktonic foraminifera. Reworked specimens from older deposits commonly occur, whereas many zonal markers were not found within the investigated samples; other potential index species show a rather sporadic occurrence instead of a continuous record. Consequently, our age model is based mainly on calcareous nannofossils and nummulitids and one zonal boundary only is based on planktic foraminifera. Contrary to foraminifera, the nannoplankton samples are characterized by low percentages of reworked taxa. Nummulitids form the base for the biostratigraphic classification of the lower and middle Adelholzen Beds (units 1 and 2). Lack of first and last occurrences, evidence of stratigraphic gaps, and reworked planktonic foraminifera specimens complicate

Figure A2.14 ▲
Close up of the basal nummulitic (Assilina, Nummulites) marlstone.

the construction of a consistent biostratigraphic framework. As reported from other sections elsewhere, planktic foraminifera, calcareous nannoplankton and larger benthic zonations did not always correlate well with established zonal schemes.

3.1 Planktonic foraminifera

Planktonic foraminifera form up to 80 % of the total foraminiferal assemblages in the Stockletten, but also the basal nummulitic marls contain about 20 % of planktonic species (see below). We dry sieved the total washed residue over a 0.250 mm sieve in order to concentrate the stratigraphically important species. Based on the occurring species we were able to recognize the planktonic foraminiferal zones P10 to P12 (according to Berggren et al., 1995) or E8 to E11 (according to Berggren and Pearson, 2005), and zones P15/16 (or E14/15) as shown in Figure 4. All species identified from the > 0.250 mm fractions are shown in Figures A2.16 and A2.17.

The almost permanent occurrence of *Guembelitroides nuttalli* (Fig. A2.16/21, 22) characterizes Zone P10 (or E8) up to the E10-E11 boundary (within P12). Its disappearance indicates this boundary. *Globigerinatheka kugleri* (Fig. A2.16/31, 32) appears somewhat earlier and indicates the base of Zone P11 (E9). *Globigerinatheka index* (Fig. A2.16/27, 28) occurs first within the *Discocyclina*-marls and continues until the topmost sample. Its first occurrence, together with the first occurrence of *Turborotalia pomeroli* Fig. A2.17/28 – 30) points to the transition from Zone P11 (E9) to P12 (E10). Presence of *G. index* in the topmost sample indicates an age older than P17 (E16) for this sample. First occurrences of *Turborotalia cerroazulensis* (Fig. A2.17/31 – 33) point to the upper portion of zone P12.

The nannoplankton assemblages clearly indicate a long stratigraphic gap of at least 3 Ma (NP 17 is completely missing) within the lower portion of the Stockletten (Fig. A2.15). Consequently, indicators for P13 and 14 (E12, 13) cannot be found. This assumption is supported by the almost complete disappearance of acarinids in the overlying strata, pointing to a strong change in paleoceanography. Presence of *Turborotalia increbescens* (Fig. A2.17/34 – 36), supported by a few *Subbotina gortanii* (Fig. A2.17/14) is indicative for an interval covering P15 to 16 (E14-15). One found specimen of *Orbulinoides beckmanni* (Fig. A2.16/18, indicative of P13/E12) in sample AH-132 has apparently been reworked from eroded sediments.

In addition to these index species, the distribution of other occurring species has been considered. This includes several species of *Globigerinatheka, Turborotalia*, *Acarinina,* and *Morozovelloides*. However, because of the relatively shallow paleo-water depths, occurrences of species are not always continuous with respect to their total ranges. Conspicuous are the lack of *Acarinina* in the middle and upper parts of the Stockletten, its replacement by *Globigerinatheka*, and the almost complete absence of *Hantkenina* in the entire section.

The basal layers, and, but to a much lesser extent, the overlaying rock units, contain a considerable amount of displaced planktic individuals, in particular from Zone P9. Many of them are in a good state of preservation and cannot be distinguished by this attribute alone from the autochthonous assemblage. Particularly frequent are: *Acarinina pentacamerata, A. quetra, Morozovella aequa, M. lensiformis*, and *M. subbotinae*.

3.2 Calcareous nannofossils

All investigated sediments contain very rich and well preserved calcareous nannoplankton assemblages, dominated by small reticulofenestrids (Fig. A2.18/28b), normal sized reticulofenestrids (Fig. A2.18/25, 26), and *Cyclicargolithus floridanus* (Fig. A2.18/27). Calcareous nannoplankton reworked

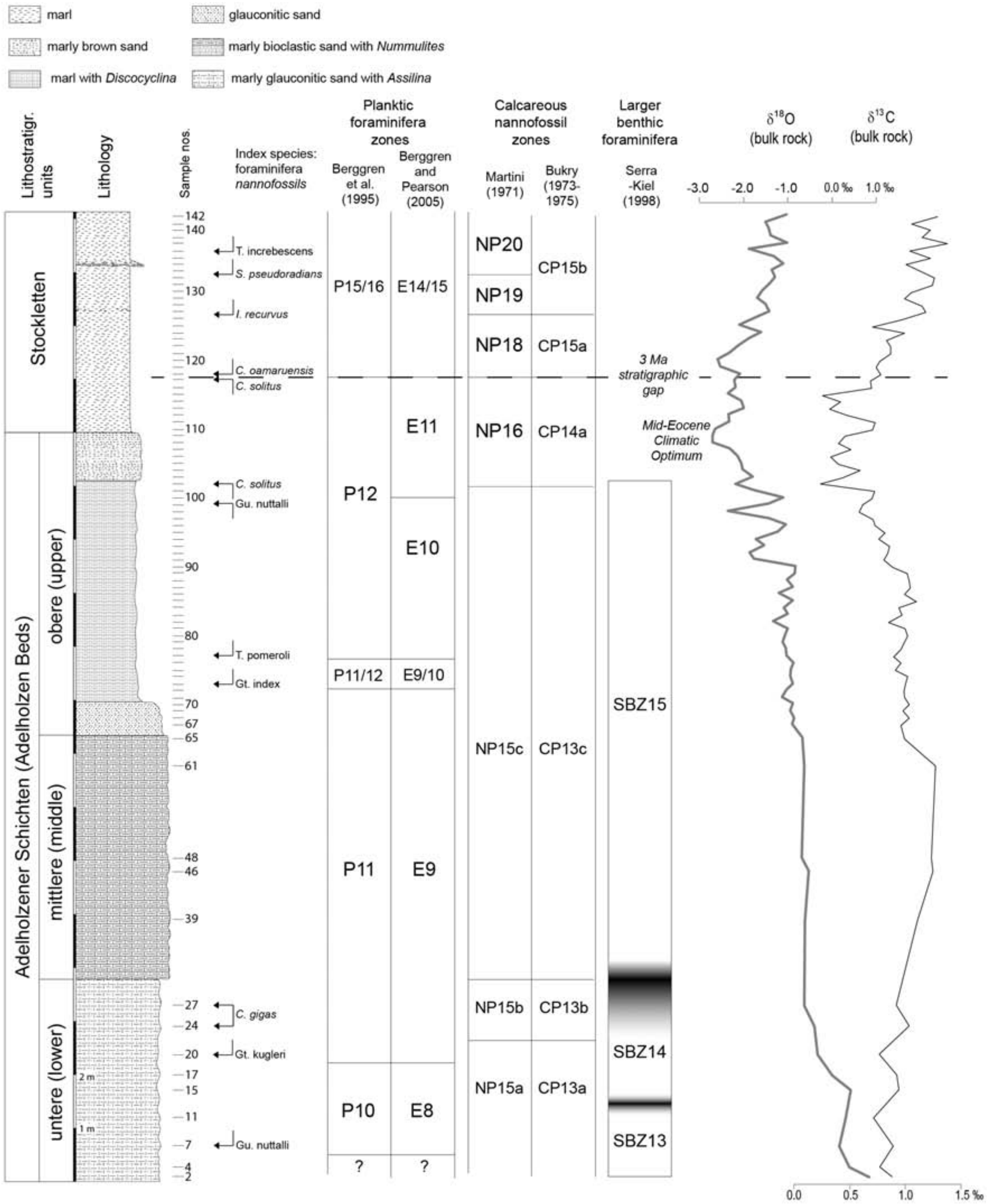
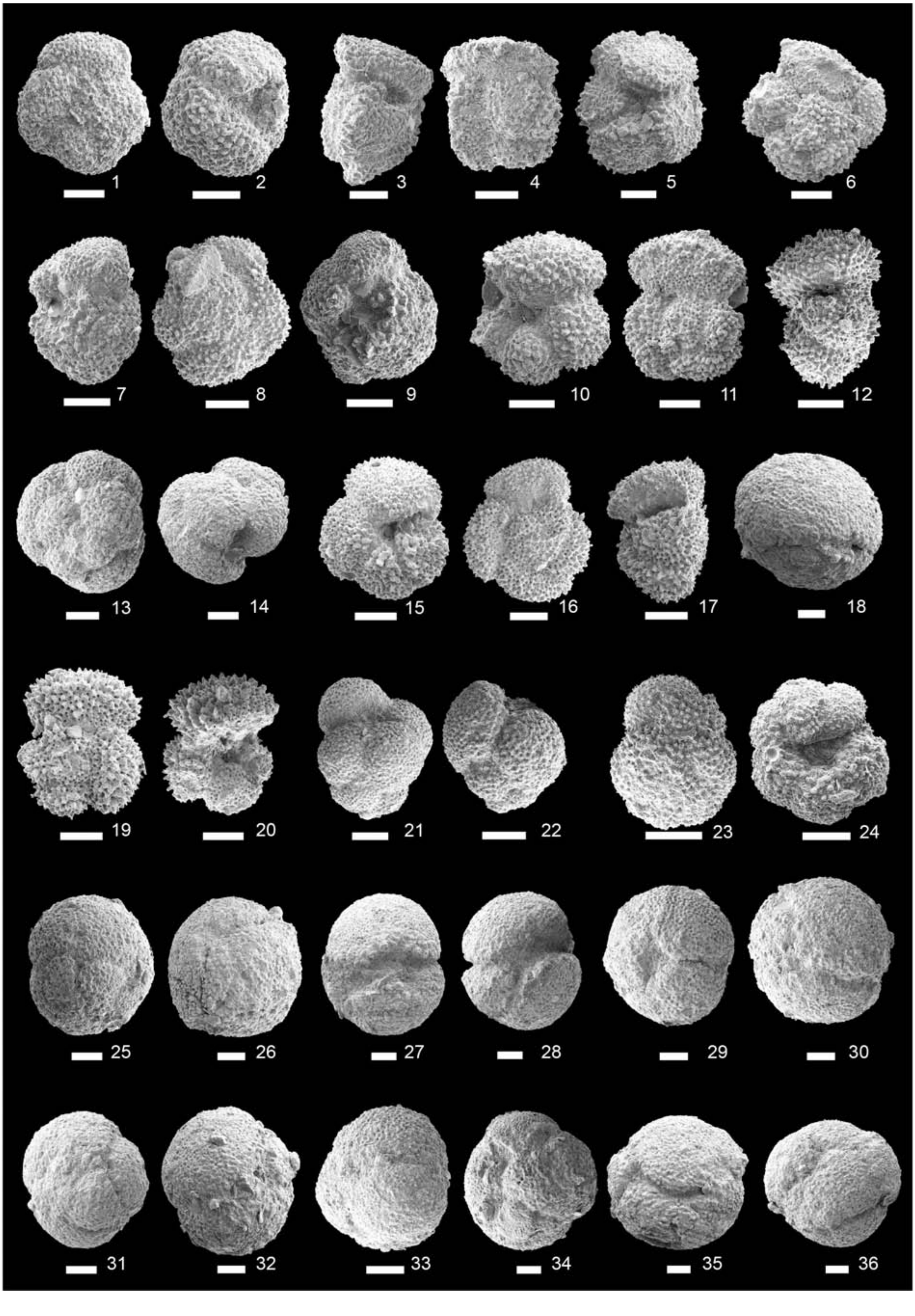


Figure A2.15 ▲
Lithologic section of the section investigated, biostratigraphic zonation and δ13C-isotope curve.

Figure A2.16 ►
Stratigraphically important planktic foraminiferal species from the >0.250 mm-fraction. **1, 2.** *Acarinina boudreauxi* (1 sample AH-95, 2 sample AH-99). **3 – 5.** *Acarinina bullbrooki* (sample AH-101). **6.** *Acarinina rohri* (sample AH-117). **7 – 9.** *Acarinina collactea* (7, 9 sample AH-97, 8 sample 101). **10 – 12.** *Acarinina praetopilensis* (10, 11 sample AH-101, 12 sample AH-115). **13, 14.** *Acarinina pseudosubsphaerica* (sample AH-77). **15-17.** *Acarinina punctocarinata* (sample AH-116). **18.** *Orbulinoides beckmanni* (reworked specimen, sample AH-132). **19, 20.** *Acarinina topilensis* (sample AH-116). **21, 22.** *Guembelitroides nuttalli* (21 sample AH-77, 22 sample AH-99). **23, 24.** *Igorina broedermanni* (sample AH-95). **25, 26.** *Globigerinatheka euganea* (25 sample AH-133, 26 sample AH-132). **27, 28.** *Globigerinatheka index* (sample AH-129). **29, 30.** *Globigerinatheka korotkovi* (sample AH-129). **31, 32.** *Globigerinatheka kugleri* (sample AH-127). **33, 34.** *Globigerinatheka luterbacheri* (33 sample AH-139, 34 sample 133). **35, 36.** *Globigerinatheka subconglobata* (sample AH-129). Length of scale bars: 0.1 mm.

from older strata occurs with very low percentages. Nannoplankton zonations established by Martini (1971) and by Okada & Bukry (1980) were used for biostratigraphical subdivision of the section. Qualitatively investigations on sediments allow us the subdivision of the section into five standard nanno-



plankton Zones (NP15-NP20) and three subzones (NP15a-c) as defined by Martini (1971), as well as three zones (CP13-CP15) with subzones (CP13a-c, and CP15a,b) as defined by Okada & Bukry (1980).

Sediments of the Adelholzen beds can be attributed to Nannoplankton Zone NP15 (*Nannotetrina fulgens* Zone) and the lower part of NP16. *Blackites inflatus*, its last occurrence (LO) marks the NP14/NP15 boundary, was not found in the sediments analysed. The zonal marker for NP15 *Nannotetrina fulgens* (Fig. A2.18/22) is present but very scarce, whereas *Blackites gladius* occurs continuously throughout this part of the section. Some additional zonal markers as *Lophodolithus rotundus* (Fig. A2.18/1) and *L. acutus* (Fig. A2.18/2) observed in this part of the section confirm this stratigraphic attribution. *Chiasmolithus gigas* (Fig. A2.18/43, 44) with its short stratigraphic range defines the limits of Nannoplankton Zone NP15b (CP13b) and was observed in samples AH-24 and AH-27. Thus, the marly glauconitic sand with *Assilina* ("Lower Adelholzen beds"), can be assigned to subzones NP15a (CP13a) and NP15b (CP13b). The "Middle Adelholzen beds" can be completely attributed to the lower part of NP15c (CP13c). The "Upper Adelhozen beds" belong stratigraphically to the upper NP15c (CP13c) and the lowermost part of *Discoaster tanii nodifer* Zone NP16. The NP15/NP16 boundary, defined by the LO of *Blackites gladius* (sample AH-102), can be placed within marly brown sand layer of the "Upper Adelholzen beds". The first occurrence (FO) of *Reticulofenestra umbilicus* (Fig. A2.18/23) defines the lower boundary of CP14a. Rare specimens of *R. umbilicus* were observed below the NP15/16 bundary. Continuous occurrences of this large reticulofenestrids were observed from above the CP13c/CP14a boundary.

The Stockletten comprises nannoplankton zones upper NP16, NP18, NP19 and NP20 (CP14b – CP15b). Zone NP17 (*Discoaster saipanensis* Zone) which is defined as the period between LO of *Chiasmolithus solitus* (Fig. A2.18/36) and FO of *Chiasmolithus oamurensis* (Fig. A2.18/45, 46) could not be documented in the Adelholzen section. The LO of *Chiasmolithus solitus* was observed in sample AH-117, whereas next sample AH-118 already contains *Chiasmolithus oamaruensis*. This long sedimentation gap within the lower part of the Stockletten is placed between samples AH-117 and AH-118. The NP18/19 (CP15a/CP15b) boundary is marked by the first occurrence of the easily recognizable *Isthmolithus recurvus* (Fig. A2.18/10, 11). This form with its LO in the lower Oligocene continuously occurs from sample AH-127 throughout the upper part of the profile. Due to restricted occurrences of *S. pseudoradians* and taxonomic difficulties, the nannoplankton zones NP19 (*Isthmolithus recurvus* Zone) and NP20 (*Sphenolithus pseudoradians* Zone) usually cannot be distinguished. Nevertheless, the FO of *S. pseudoradians* was observed in sample AH-135 and therefore the NP19/NP20 boundary was tentatively placed below this sample within the uppermost portion of the Stockletten.

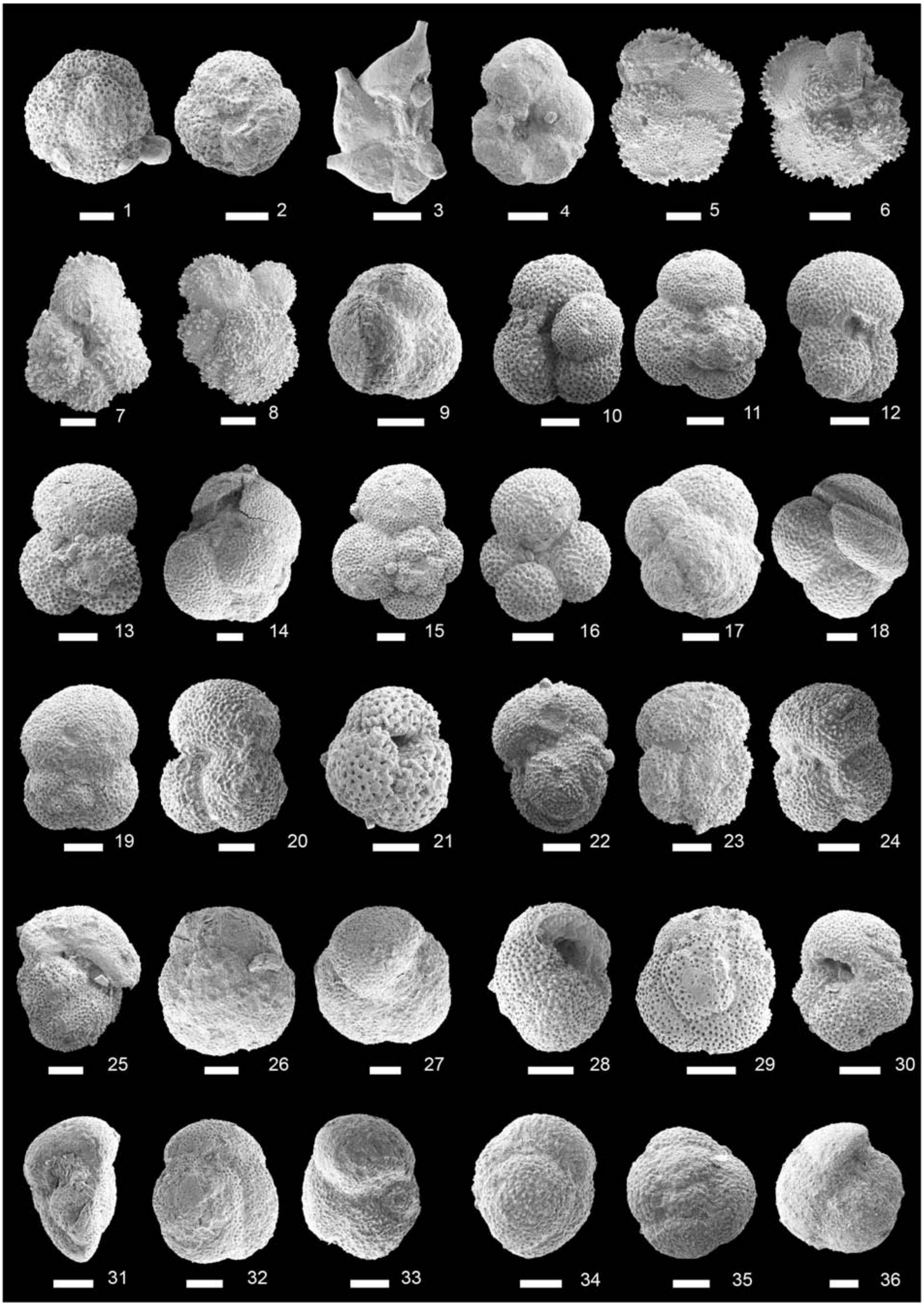
3.3. Nummulitids

The lower part of the presented profile is rich in Larger Benthic Foraminifera (LBF). The abundant fauna is mainly composed by the genera *Assilina*, *Nummulites* and *Discocyclina* (Fig. A2.19). Taxa belonging to the lineage of *Assilina exponens*, the most abundant within the sediment, allow the biostratigraphic determination of the shallow benthic zones (SBZ) from SBZ 13 to SBZ 15 (*sensu* Serra-Kiel et al., 1998) along the profile.

The limits between these Oppel-zones have have been observed by biometric determination of the investigated taxa. Specimens of *Assilina tenuimarginata*, abundant in both A and B forms in the lowest part of the profile indicate lowermost Lutetian with probably some reworked specimens (*A. cuvillieri)* from the uppermost SBZ12 (uppermost Ypresian). *A. tenuimarginata* is further above replaced by *A. ex-*

Figure A2.17 ►
Stratigraphically important planktic foraminiferal species from the > 0.250 mm-fraction (continuation). **1, 2.** *Catapsydrax unicavus* (sample AH-75). **3.** *Hantkenina liebusi* (sample AH-93). **4.** *Pseudohastigerina wilcoxensis* (sample AH-101). **5, 6.** *Morozovelloides coronatus* (5 sample AH-77, 6 sample AH-101). **7, 8.** *Morozovelloides lehneri* (7 sample AH-79, 8 sample AH-89). **9.** *Subbotina angiporoides* (sample AH-139). **10, 11.** *Subbotina corpulenta* (sample AH-101). **12.** *Subbotina cruciapertura* (sample AH-97). **13.** *Subbotina eocaena* (sample AH-115). **14.** *Subbotina gortanii* (sample AH-142). **15, 16.** *Subbotina hagni* (15 sample AH-115, 16 sample AH-116). **17, 18.** *Subbotina jacksonensis* (17 sample AH-141, 18 sample AH-137). **19, 20.** *Subbotina linaperta* (19 sample AH-139, 20 sample AH-101). **21.** *Subbotina senni* (sample AH-2). **22 – 24.** *Turborotalia frontosa* (22, 24 sample AH-97, 23 sample AH-101). **25 – 27.** *Turborotalia possagnoensis* (25 sample AH-113, 26, 27 sample AH-129). **28 – 30.** *Turborotalia pomeroli* (sample AH-116). **31 – 33.** *Turborotalia cerroazulensis* (sample AH-135). **34 – 36.** *Turborotalia increbescens* (34, 35 sample AH-139, 36 sample AH-137). Length of scale bars: 0.1 mm.

ponens, which remains abundant within the sediments of all the lower part of the presented profile and indicates middle to late Lutetian and Bartonian age (SBZ 14-17). With the samples AH24 and 27 some larger specimens belonging to *A. exponens* have been found. They are up to 15 mm large in diameter for



8 or 9 whorls in A forms; no B forms have been found. Multispiral growth is evident as well as opposite growth direction.

Specimens belonging to the genus Nummulites are lower in abundance along the profile. All the investigated specimens belong to the phylum of *N. distans - millecaput* (*sensu* Schaub, 1981). In the lower part of the profile (samples 4 – 17) *N*. cf. *kaufmanni* and *N. alponensis* are present. The proloculus diameter, very small in size, measured on the investigated specimens is a clear indication for the species preceding *N. millecaput* and later on *N. maximus*. In fact, *N. millecaput* starts to be present from sample 24 and later became abundant indicating SBZ 15 (upper, but not uppermost, Lutetian). The species *N. millecaput* is present as A and B forms until the sample 61, which is the last sample where LBF have been investigated. The largest B forms belonging to *N. millecaput* are 6 cm in diameters for more than 45 whorls. Other specimens have a radius of 20 – 24 mm for 34 – 42 whorls. Specimens from the last nummulitid-bearing sample (101, top *Discocyclina*-marls) are not younger than SBZ 15.

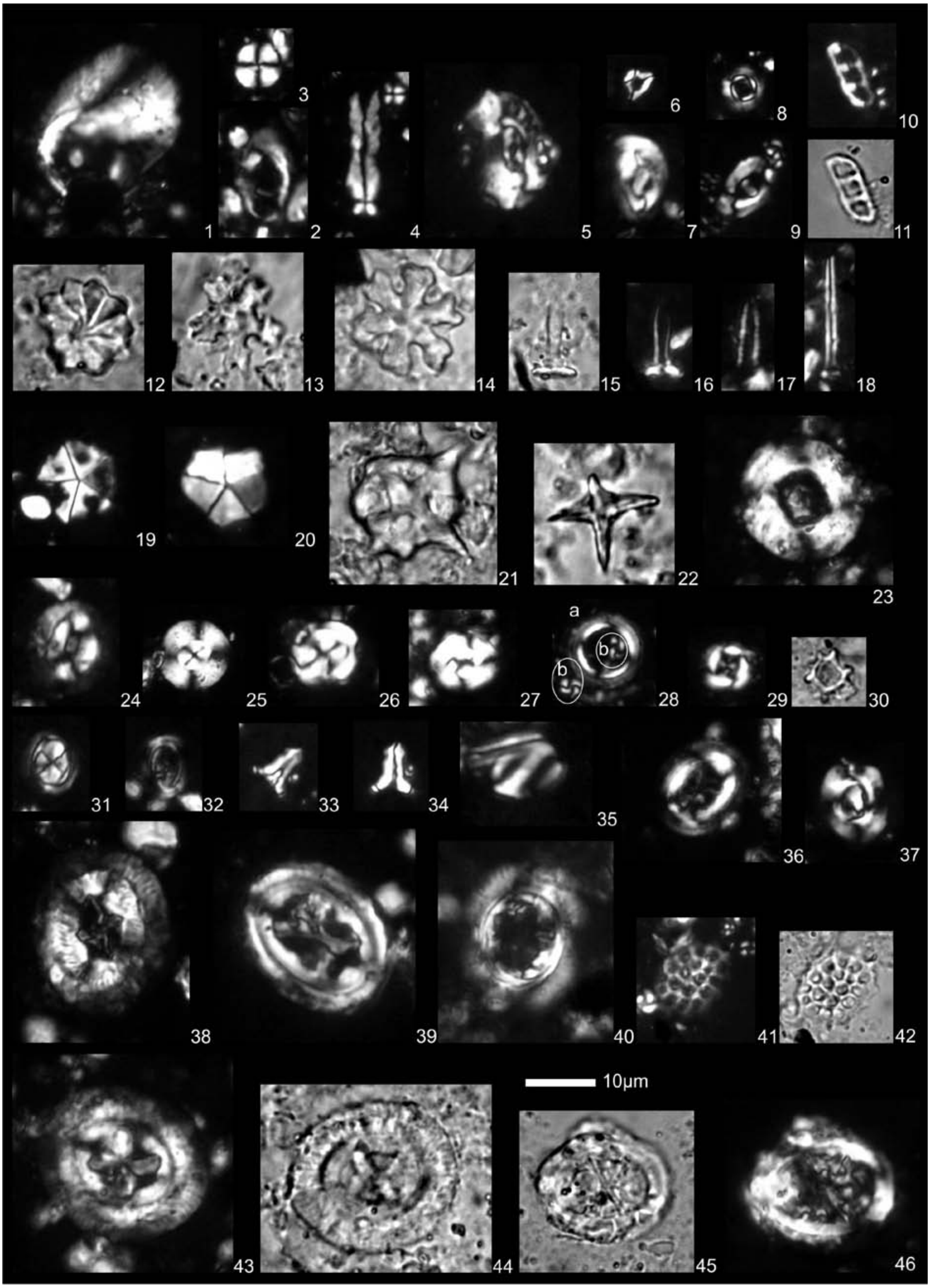
Bioturbation (microborings?) occurred abundantly and mainly on discocyclinids. More than 50 specimens have been sectioned on the equatorial plane revealing a completely bioturbated embryonic apparatus. Therefore a consistent taxonomy on such forms has not been provided.

4. Stable O and C-isotope stratigraphy, age model and sedimentation record

In order to refine the stratigraphic resolution of the Adelholzen Section, we measured bulk rock stable isotope ratios ($\delta^{13}C$, $\delta^{18}O$). The resulting curves are shown in Figure A2.15. We then subdivided the $\delta^{13}C$- and $\delta^{18}O$ curves into five subsequences according to the nannoplankton and planktic foraminiferal zones and correlated these units with characteristic curve patterns of a global stack published in Hancock & Dickens (2005). The zonal boundaries used are P11/P12, E10/E11, NP16/NP18, and NP19/NP20. Despite the prominent (at least) 3 Ma years long stratigraphic gap represented by the completely missing nannoplankton zone NP17 within the lower Stockletten, another stratigraphic gap of c. 0.4 Ma within the upper zone P11 (i.e., within the glauconitic sands, base of “obere Adelholzener Schichten”) appears plausible as additional peaks show up in the $\delta^{13}C$ reference record.

Figure A2.18 ►
Stratigraphically important calcareous nannofossils. **1.** *Lophodolithus rotundus* Bukry & Percival, 1971; Sample AH-2; NP15a. **2.** *Lophodolithus acutus* Bukry & Percival, 1971; Sample AH-2; NP15a. **3.** *Cyclicargolithus luminis* (Sullivan, 1965) Bukry, 1971; Sample AH-2; NP15a. **4.** *Sphenolithus furcatolithoides* Locker, 1967; Sample AH-7; NP15a. **5.** *Helicosphaera lophota* Bramlette & Sullivan, 1961; Sample AH-27; NP15b. **6.** *Lanternithus minutus* Stradner, 1962; Sample AH-140; NP20. **7.** *Helicosphaera bramlettei* Müller, 1970; Sample AH-108; NP16. **8.** *Calcidiscus*? *protoannulus* (Gartner, 1971) Loeblich & Tappan, 1978; Sample AH-80; NP15c. **9.** *Helicosphaera seminulum* Bramlette & Sullivan, 1961; Sample AH-2; NP15a. **10, 11.** *Isthmolithus recurvus* Deflandre, 1954; Sample AH-130; NP19. **12.** *Discoaster barbadiensis* Tan, 1927; Sample AH-2; NP15a. **13.** *Discoaster distinctus* Martini, 1958; Sample AH-108; NP16. **14.** *Discoaster deflandrei* Bramlette & Riedel, 1954; Sample AH-27; NP15b. **15, 16.** *Blackites gladius* (Locker, 1967) Varol, 1989; Sample AH-7; NP15a. **17.** *Blackites virgatus* Bown, 2005; Sample AH-27; NP15b. **18.** *Blackites spinosus* (Deflandre & Fert, 1954) Hay & Towe, 1962; Sample AH-108; NP16. **19.** *Pemma basquensis* (Martini, 1959) Báldi-Beke, 1971; Sample AH-80; NP15c. **20.** *Braarudosphaera bigelowii* (Gran & Braarud, 1935) Deflandre, 1947; Sample AH-117; NP16. **21.***Nannotetrina cristata* (Martini, 1958) Perch-Nielsen, 1971; Sample AH-77; NP15c. **22.** *Nannotetrina fulgens* (Stradner, 1960) Achuthan & Stradner, 1969; Sample AH-27; NP15b. **23.** *Reticulofenestra umbilicus* (Levin, 1965) Martini & Ritzkowski, 1968; Sample AH-108; NP16. **24.** *Coccolithus cachaoi* Bown, 2005; Sample AH-27; NP15b. **25.** *Reticulofenestra bisecta* (Hay, Mohler & Wade, 1966) Roth, 1970; Sample AH-135; NP20. **26.** *Reticulofenestra scrippsae* (Bukry & Percival, 1971) Roth, 1973; Sample AH-135; NP20. **27.** *Cyclicargolithus floridanus* (Roth & Hay, 1967) Bukry, 1971; Sample AH-80; NP15c. **28.** a) *Coronocyclus bramlettei* (Hay & Towe, 1962) Bown, 2005; b) *Reticulofenestra minuta* Roth, 1970; Sample AH-115; NP16. **29.** *Cribrocentrum reticulatum* (Gartner & Smith, 1967) Perch-Nielsen, 1971; Sample-AH 110; NP16. **30.** *Corannulus germanicus* Stradner, 1962; Sample AH-108; NP16. **31.** *Clausicoccus fenestratus* (Deflandre & Fert, 1954) Prins, 1979; Sample AH-75; NP15c. **32.** *Campylosphaera dela* (Bramlette & Sullivan, 1961) Hay & Mohler, 1967; Sample-AH 90; NP15. **33, 34.** *Zygrhablithus bijugatus* (Deflandre, 1954) Deflandre, 1959; Sample AH-80; NP15c. **35.** *Pontosphaera exilis* (Bramlette & Sullivan, 1961) Romein, 1979; Sample AH-27; NP15b. **36.** *Chiasmolithus solitus* (Bramlette & Sullivan, 1961) Locker, 1968; Sample AH-117; NP16. **37.** *Reticulofenestra dictyoda* (Deflandre, 1954) Stradner, 1968; Sample AH-140; NP20. **38.** *Coccolithus mutatus* (Perch-Nielsen, 1971) Bown, 2005; Sample AH-27; NP15b. **39.** *Chiasmolithus grandis* (Bramlette & Riedel, 1954) Radomski, 1968; Sample AH-27; NP15b. **40.** *Pontosphaera formosa* (Bukry & Bramlette, 1969) Romein, 1979; Sample AH-108; NP16. **41, 42.** *Clathrolithus ellipticus* Deflandre, 1954; Sample AH-110; NP16. **43, 44.** *Chiasmolithus gigas* (Bramlette & Sullivan, 1961) Radomski, 1968; Sample AH-27; NP15b. **45, 46.** *Chiasmolithus oamaruensis* (Deflandre, 1954) Hay, Mohler & Wade, 1966; Sample AH-140; NP20.

The correlation of the Adelholzen record to the reference curve suggests a largely complete and even sedimentation without larger stratigraphic gaps in addition to the gaps indicated above. This appears to be particularly valid for the “obere Adelholzener Schichten” and the Stockletten.



Both the $\delta^{13}C$- and $\delta^{18}O$ curves show the characteristic peak successions of the reference curve. Consequently, we were able to identify prominent isotopic and climatic events such as the Middle Eocene Climatic Optimum (MECO), which is positioned within the marly brown sand (E11, NP16). However, diagenetic overprint lead to exceptional low $\delta^{13}C$-values, in particular in the marly nummulitic sands up to the basal Stockletten. Diagenetic overprint is even more prominent in the $\delta^{18}O$-curve. Values down to -3‰ during MECO are far beyond any temperature signal. However, peak positions correspond perfectly to those in the reference curve.

The overall sediment-accumulation rate was about 1.8 mm per 1000 years. However, sedimentation rates were much higher during deposition, in particular for the nummulitid-sands and *Discocyclina*-marls in the lower part of the Adelholzen Section.

5. Macrofossils

Despite the larger foraminifera *Nummulites* and *Assilina* in the lower and middle Adelholzen Beds, a number of other macro-faunal elements has been found at Adelholzen. The lower Adelholzen Beds contain articulated large oysters (*Pycnodonte gigantica*), spondylids with preserved spines, sea urchin remains, and occasionally internal molds of bivalves. The middle Adelholzen beds contain only a few serpulids grown on *Nummulites* and some sea urchin remains. In the three units of the upper Adelholzen Beds, various macrofossils were found. Glauconitic sands: free serpulids, oysters (*Pycnodonte* sp.), large but rare crabs; marls with *Discocyclina*:sea urchins (*Conoclypeus* sp.), spines of *Spondylus* sp., crabs with preserved limbs, free serpulids, and nodular bryozoan colonies; marly brown sand: crabs, partly with limb preservation, spondylids, shark teeth, rare amber, and lumachelles at the very top of this unit. The Stockletten are almost free of macrofossils, only at its base a few tiny bivalves can be found.

6. Changing water depths

The ratio of planktic to benthic foraminifera (P/B-ratio or percent planktic foraminifera) is proportional to water depth in modern oligotrophic open marine settings (e.g., van der Zwaan et al., 1990). It is considered to be a good estimator also for paleo-water depth estimations at least during the Cenozoic. The percentage of planktic foraminifera in the assemblages is displayed in Figure 9 together with rough absolute water depth estimates. Our absolute estimates are based on the P/B-ratio and range from 50 m (inner shelf) at the base of the section to a maximum of c. 600 m (upper bathyal) in the Stockletten. Nummulitids and macrofossil assemblages (oysters, spondylids, sea urchins, serpulids, crabs, bryozoans, shark teeth) however point to shallower paleo-water depths, in particular for the basal and middle lithologic units.

The P/B-ratio shows several distinct increases in paleo-water depth (transgressive phases). The corresponding lowstands (Lu2-4, Pr2) fit well with global sequence boundaries (Luterbacher et al., 2004).

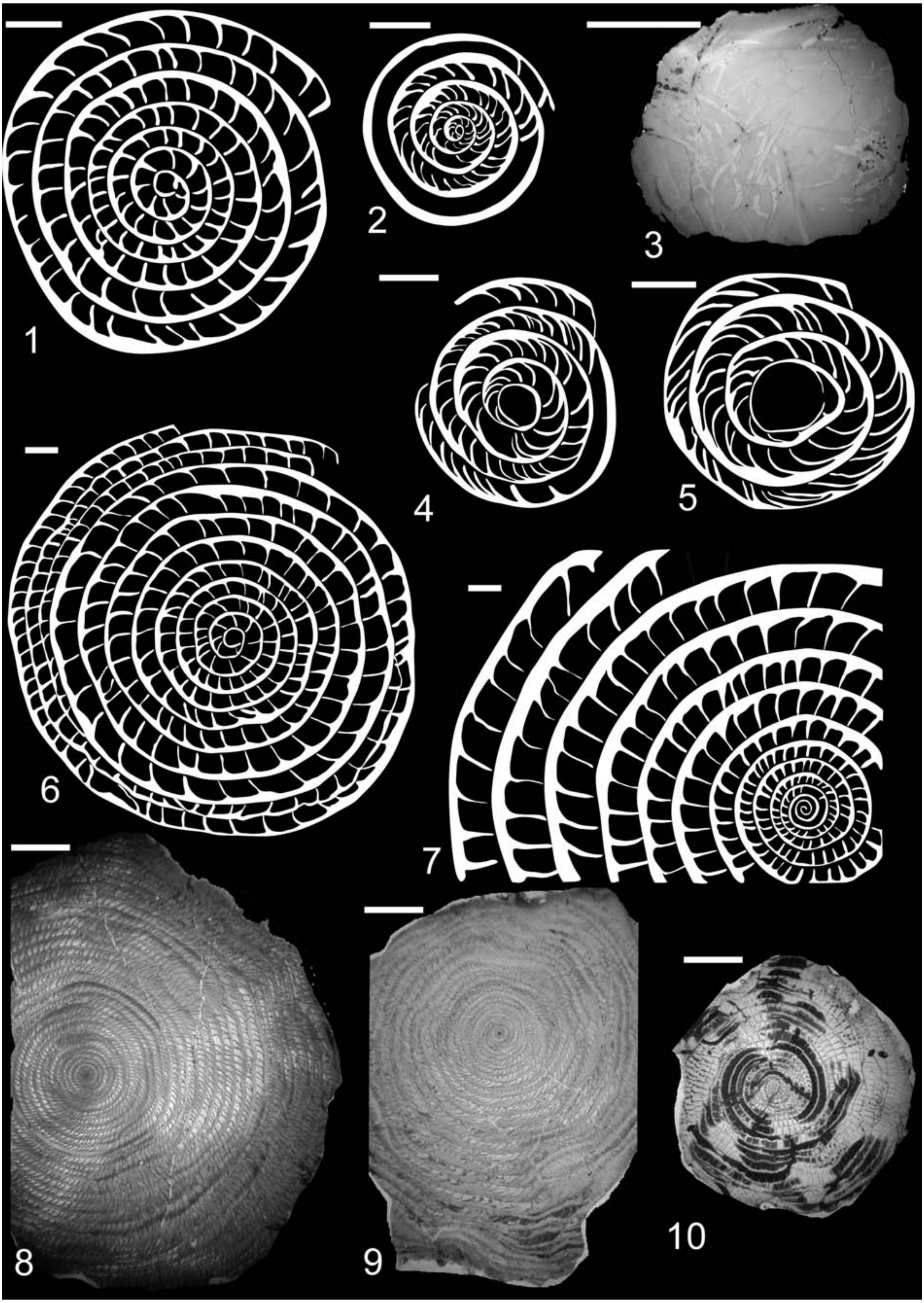
7. Changing paleo-productivity

The number of heterotrophic planktic and benthic foraminifera is largely coupled to primary surface productivity as these groups either feed directly on diatoms, coccolithophores or other algae (planktic foraminifera, e.g., Hemleben et al, 1989) or depend on the organic rain that reaches the seafloor (benthic foraminifera, e.g., Gooday, 2003). Foraminiferal abundance is therefore a good estimator for paleo-productivity of ancient eco-systems. Figure 9 shows rather parallel curves for planktic and benthic foraminiferal abundance, pointing to at several transgressive phases that resulted in increased nutrient

Figure A2.19 ►
Stratigraphically important nummulitids. **1.** *Assilina cuvillieri*, A-form, scale bar; 1 mm (sample AH-2). **2.** *Nummulites alponensis*, A-form, scale bar; 1 mm (sample AH-15). **3.** *Discocyclina* sp. with bioturbation, scale bar; 10 mm (sample AH-11). **4.** *Nummulites millecaput* A-form, scale bar; 1 mm (sample AH-27). **5.** *Nummulites millecaput* A-form, scale bar; 1 mm (sample AH-61). **6.** *Assilina exponens* (larger specimen), A-form, scale bar; 1 mm (sample AH-24). **7**. *Assilina tenuimarginata*, B-form, scale bar; 1 mm (sample AH-7). **8.** *Nummulites millecaput*, B-form, scale bar; 5 mm (sample AH-39). **9.** *Nummulites millecaput*, B-form, scale bar; 5 mm (sample AH-65). **10.** *Assilina exponens*, B-form, scale bar; 5 mm (sample AH-65).

mobilization and subsequent increased numbers of foraminifera. The highest foraminiferal abundance (planktic as well as benthic) was reached shortly after the MECO-event.

The benthic assemblages are dominated by rather large planoconvex or lenticular species (*Cibici-*



doides, Planulina, Lenticulina etc.). Dominance of these genera points to oxic conditions at the seafloor (Kaiho, 1999).

All samples from the section contain very rich calcareous nannoplankton with the dominance of small reticulofenestrids, *Reticulofenestra dictyoda* and *Cyclicargolithus floridanus.* Small reticulofenestrids generally dominate nannoplankton assemblages along continental margins. High amounts of *Reticulofenestra minuta* can be interpreted as indicator of a warm, well stratified water column. Low percentages of *Coccolithus pelagicus* point to oligotrophic paleoenvironments and are in good agreement with the foraminiferal interpretations.

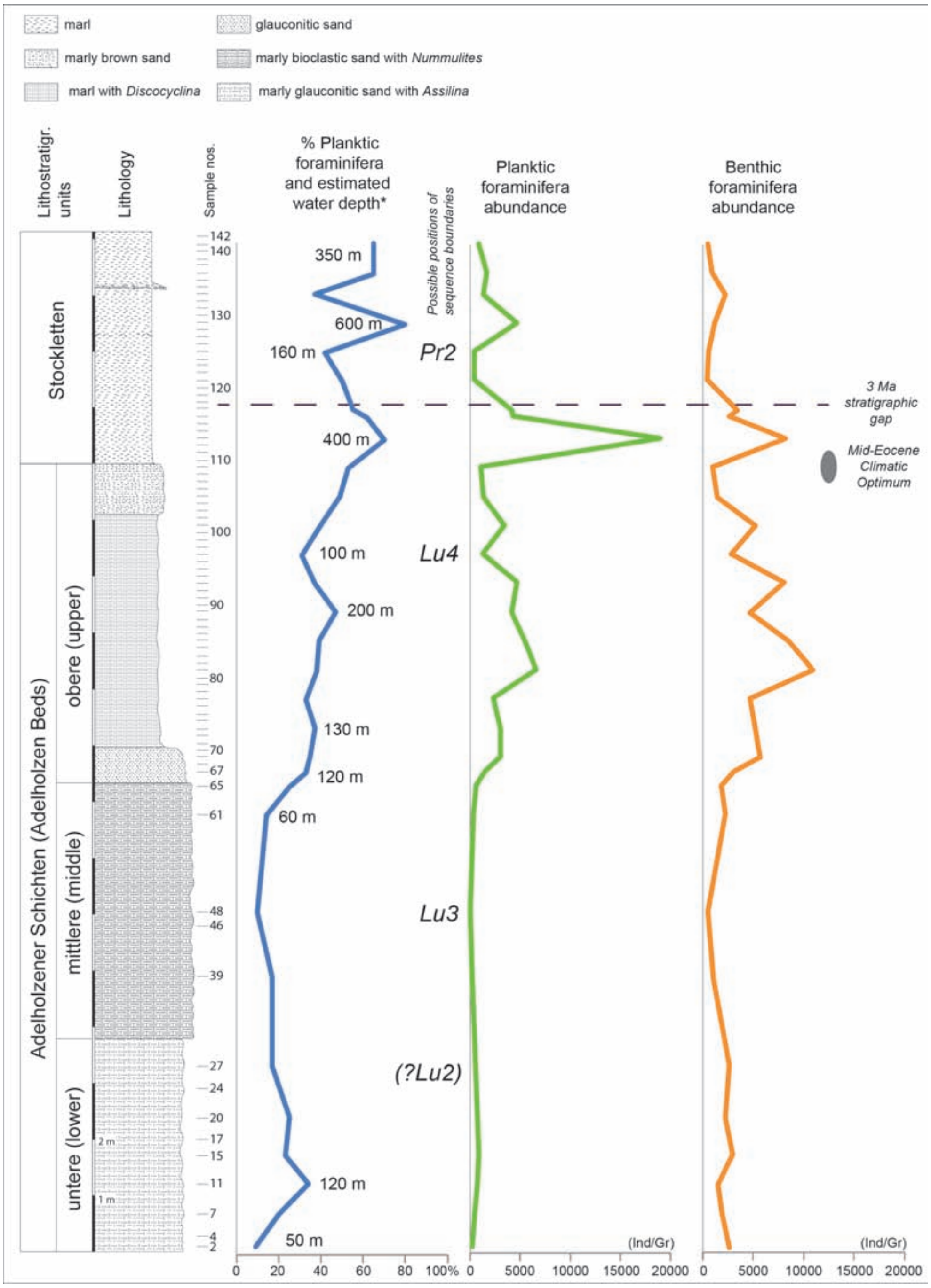


Figure A2.20 ▲
Water depths estimations according to percent planktic foraminifera and frequency of planktic and benthic Foraminifera (individuals per gram dry sediment). Percentage peaks in planktic foraminifera may represent transgressive cycles (*Lu,Pr*) as indicated. *) Estimates appear to be too high with respect to macrofauna, see text for further details.