Changing paleo-environments of the Lutetian to Priabonian beds of Adelholzen (Helvetic Unit, Bavaria, Germany)

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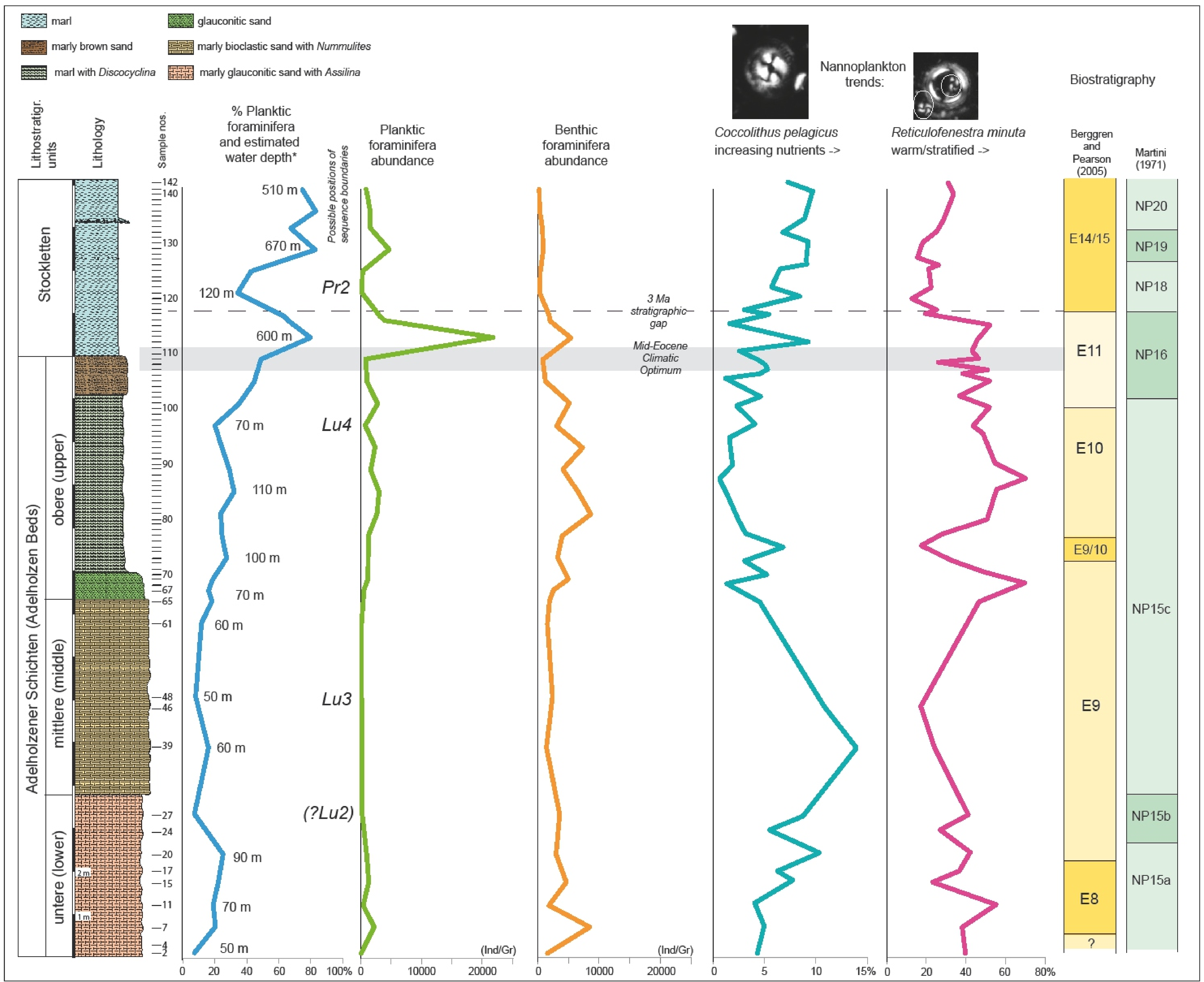
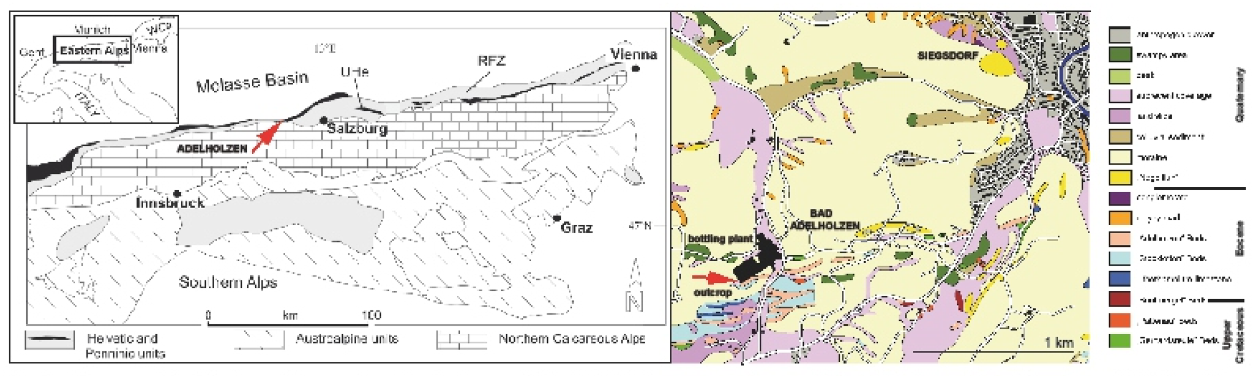




Tectonic map of the Eastern Alps and geological map of the Adelholzen area, changed after BIS (Bayerisches Landesamt für Umwelt).

The Adelholzen-Section is rich in planktic and benthic foraminifera. Planktic foraminifera form up to 80% of the total foraminiferal assemblages in the Stockletten, but also the basal nummulitic marls contain up to 20% of planktic species. The ratio of planktic to benthic foraminifera 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 points to depth ranges from 50 m (inner shelf) at the base of the section to a maximum of c. 650 m (upper bathyal) in the Stockletten. Nummulitids and macrofossil assemblages (oysters, spondylids, sea urchins, serpulids, crabs, bryozoans, shark teeth) point to shallower paleo-water depths for the basal and middle lithologic units.

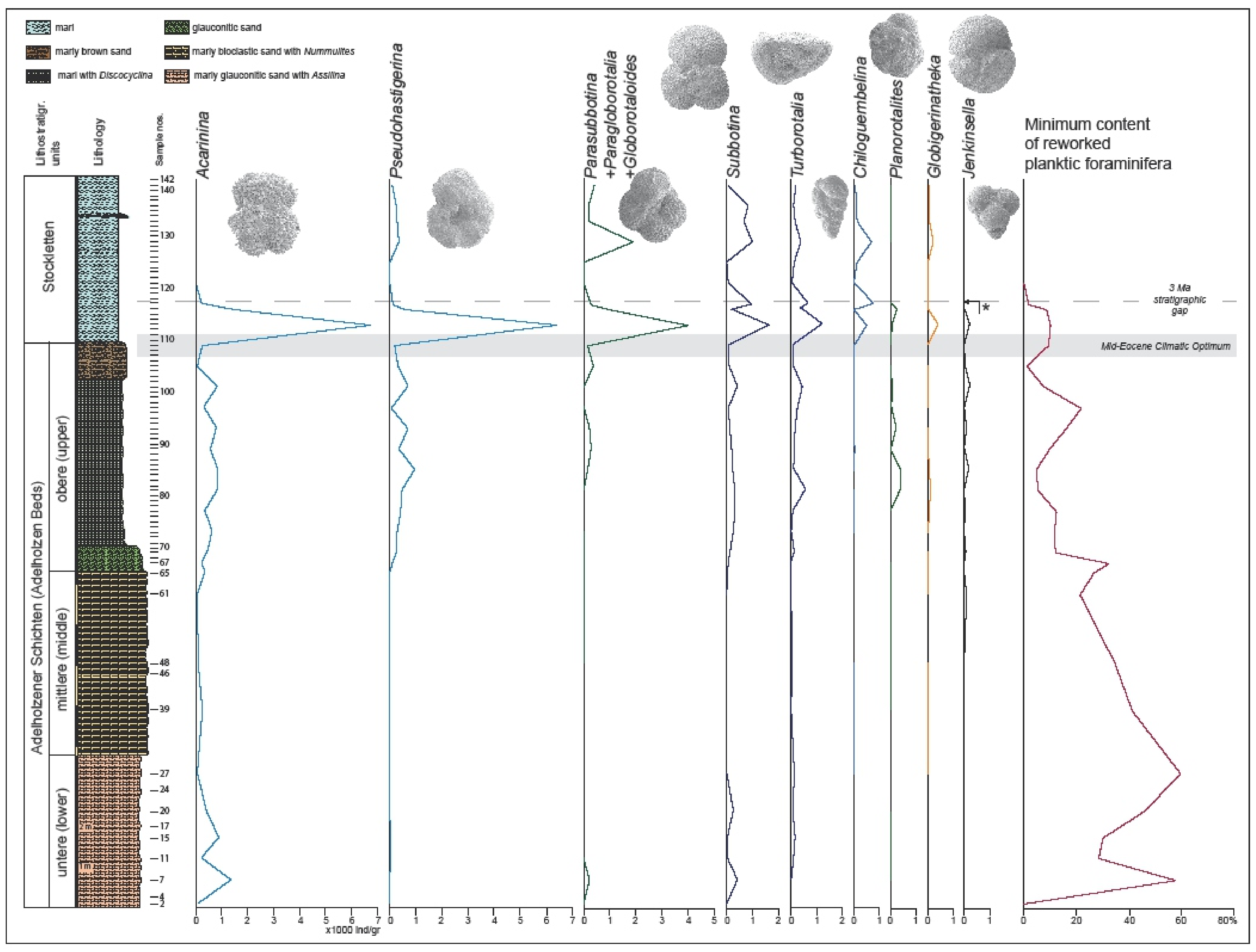
The succession shows four (or five) distinct increases in paleo-water depth (transgressive phases): within the *Assilina*-sands, possibly in the lower portion of the *Nummulites*-sands, during the *Discocyclina*-marl sedimentation and two incomplete cycle in the brown sand and the Stockletten.

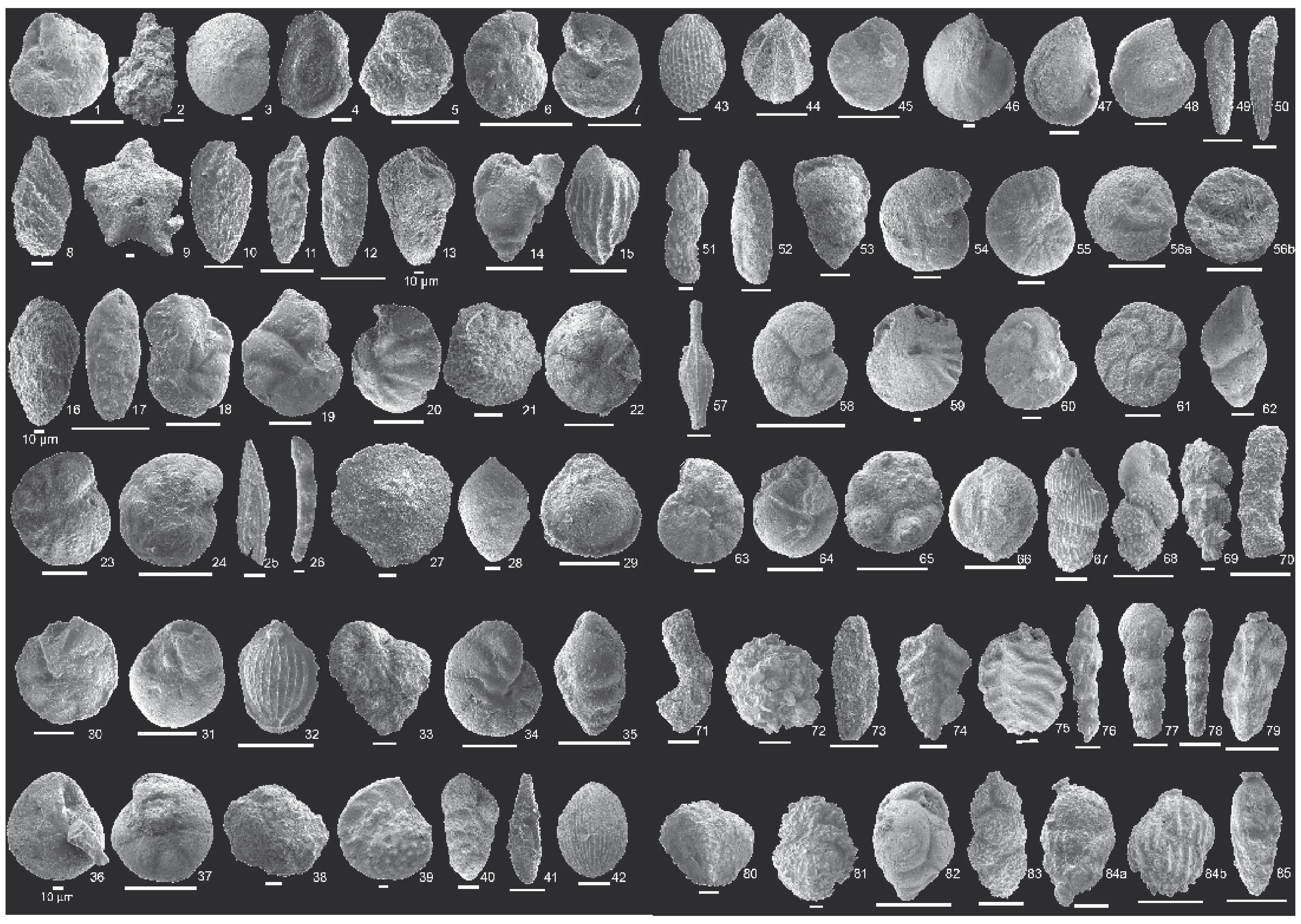
The number of heterotrophic planktic and benthic foraminifera is largely coupled to primary surface productivity as these groups either feed directly on diatoms, coccolithophores or other algae (planktic foraminifera) or depend on the organic rain that reaches the seafloor (benthic foraminifera). Foraminiferal abundance is therefore a good estimator for paleo-productivity of ancient eco-systems. The rather parallel curves for planktic and benthic foraminiferal abundance are both pointing to at least two major transgressive phases that resulted in increased nutrient mobilization and subsequent increased numbers of foraminifera. The second one coincides with a climatic optimum shortly before the Mid-Eocene Climatic Optimum (MECO). The benthic foraminiferal assemblages are dominated by rather large planoconvex or lenticular species (*Cibicidoides, Gavelinella, Lenticulina* etc.), pointing to oxic conditions at the seafloor.

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 margin. High amounts of *Reticulofenestra minuta* can be interpreted as indicator of warm, well stratified water column. Low percentages of *Coccoli-*

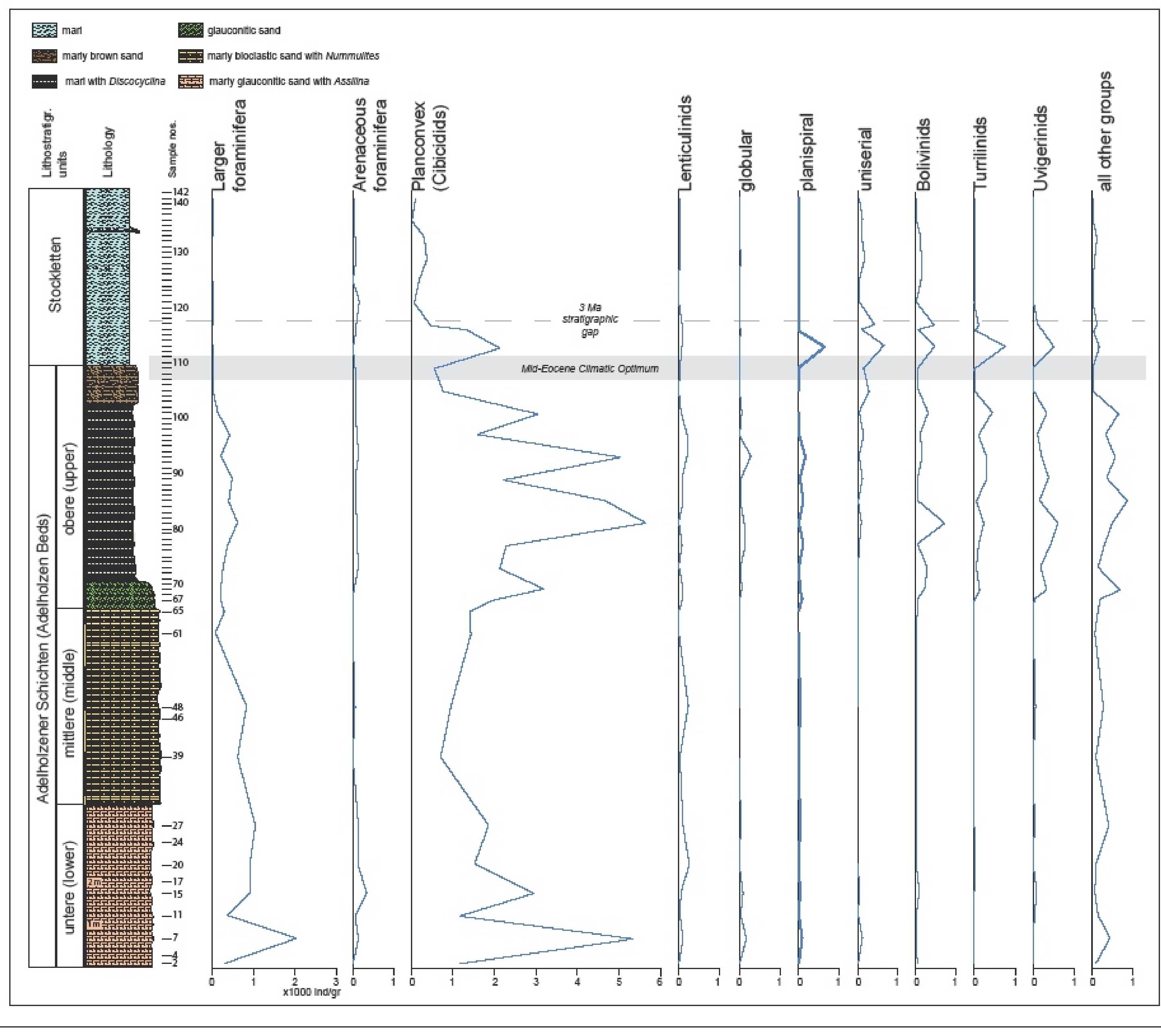
Paleo-water depth estimation, foraminiferal abundance, and nannoplankton trends:
Water depth estimates are based on the percentage of planktic foraminifera (relative to the total assemblage, formula of Van der Zwaan et al. 1990, Mar. Geol. 95, 1-16), and show generally increasing water depths from base to top of the investigated section. Several cycles are indicated by possible positions of sequence boundaries (*Lu, Pr*). Paleo-water depths range from inner shelf to upper bathyal environments. While in the Adelholzen Beds the benthic foraminifera form the majority of the assemblages, the planktic forms prevail in the Stockletten.
Very prominent peaks in water depth, planktic and benthic foraminiferal abundance after the MECO indicates abundance of food for foraminifera and possibly more oceanic conditions. These peaks are only slightly paralleled by a weak peak in *Coccolithus pelagicus*-percentage, a nutrient indicator, pointing to a moderate nutrient increase for this interval. Reduction of stratification of the water column was probablly reduced in the upper part of the Stockletten (higher numbers of cold-water/mesotrophic planktic foraminifera and *Coccolithus pelagicus*, lower numbers of *Reticulofenestra minuta*).

Abundances of planktic foraminifera genera (morphogroups):
The highest numbers show Acarinids, inhabiting the lower mixed layer. This symbiont bearing taxa prefer oligotrophic conditions. Increasing numbers of *Subbotina, Turborotalia*, and *Planorotalites* indicate the successive deepening at this site and the presence of cold waters and possibly higher nutrient levels. *Globigerinatheka* and *Jenkinsella* inhabit the shallow and warm surface waters. The prominent abundance peaks after the MECO in most planktic foraminifera (*Acarinia, Pseudohatigerina, Parasubbotina* etc.) indicate the presence of abundant food recources after a decrease during the MECO. However, eutrophic conditions were probably not reached (see also nannoplankton trends above).
Reworked species reach up to 60% of the planktic taxa. These are species restricted to the lower Eocene (mostly *Acarinina* and some *Morozovella*). The * indicates the extinction level of *Jenkinsella*.





Benthic foraminifera: **1**. *Alabamina dissonata* (Cushman & Renz, 1948), sample AH-27. **2**. *Ammobaculites* sp., sample AH-141. **3**. *Amphistegina* sp., sample AH-65. **4**. *Ammodiscus cretaceus* (Reuss, 1845), sample AH-129. **5**. *Anomalinoides capitatus* (Guembel, 1868), sample AH-141. **6**. *Anomalinoides darwini* (Hagn & Kuhn, 1989), sample AH-141. **7**. *Anomalinoides nobilis*, Brotzen, 1948, sample AH-07. **8**. *Astacolus crepidulus* (Fichtel & Moll, 1798), sample AH-101. **9**. *Asterocyclina* sp., sample AH-20. **10**. *Bolivina vaceki* subsp. *glabra*, Hagn, 1954, sample AH-97 **11**. *Bolivina* sp. 1, sample AH-77 **12**. *Bolivina* sp. 2, sample AH-77. **13**. *Bolivinoides oedumi*, Brotzen, 1948, sample AH-129. **14**. *Bulimina coprolithoides*, Andreae, 1884, sample AH-77. **15**. *Bulimina subtruncana*, Hagn, 1957, sample AH-141. **16**. *Bulimina tuxpamensis*, Cole, 1928, sample AH-85. **17**. ?*Cassidella* sp., sample AH-77. **18**. *Cibicides lobatulus* (Walker & Jacob, 1798), sample AH-93. **19**. *Cibicides ribbingi*, Brotzen, 1936, sample AH-65. **20**. *Cibicides simplex*, Brotzen, 1948, sample AH-85. **21**. *Cibicides subspirata* Nuttall, 1930, sample AH-07. **22**. *Cibicidoides grimsdalei* (Nuttall, 1930), sample AH-15. **23**. *Cibicidoides incrassatus* (Fichtel & Moll, 1798), sample AH-101. **24**. *Cibicidoides pachyderma* (Rzehak, 1886), sample AH-69. **25**. *Citarinella watersi* (Cushman, 1936), sample AH-101. **26**. *Dentalina consobrina*, d´Orbigny, 1884, sample AH-77. **27**. *Discocyclina* sp., sample AH-89. **28**. *Ellipsoglandulina labiata* (Schwager, 1866), sample AH-137. **29**. *Entosolenia crebra* (Matthes, 1939), sample AH-141. **30**. *Epistominella minuta* (Olsson, 1960), sample AH-077. **31**. *Epistominella vitrea*, Parker, 1953, sample AH-109. **32**. *Fissurina formosa* (Schwager, 1866), sample AH-101. **33**. *Gaudryina mcleani*, Hofker, 1955, sample AH-27. **34**. *Gavelinella* sp., sample AH-07. **35**. ?*Globobulimina* sp., sample AH-77. **36**. ?*Globocassidulina subglobosa* (Brady, 1881), sample AH-137. **37**. *Gyroidinoides* sp., sample AH-07. **38**. ?*Haplophragmoides* sp., sample AH-141. **39**. *Heterostegina costata* d´Orbigny, 1846, sample AH-85. **40**. *Karreriella subglabra* (Cushman, 1926), sample AH-137. **41**. *Lagena clavata* (d´Orbigny, 1846), sample AH-141. **42**. *Lagena gracilicosta*, Reuss, 1863, sample AH-101. **43**. *Lagena gracilicosta* var., Reuss, 1863, sample AH-101. **44**. Lagena sulcata (Walker & Jacob, 1798), sample AH-101. **45**. *Lenticulina inornata* (d´Orbigny , 1846), sample AH-69. **46**. *Lenticulina limbosa* (Reuss, 1863), sample AH-141. **47**. *Lenticulina* sp. 1, sample AH-137. **48**. *Lenticulina* sp. 2, sample AH-85. **49**. *Loxostoma plummerae*, Cushman, 1936, sample AH-93. **50**. *Loxostomoides applinae* (Plummer, 1927), sample AH-129. **51**. *Marginulina hirsuta* , d´Orbigny, 1826, sample AH-109. **52**. *Marginulina similis*, d´Orbigny, 1846, sample AH-141. **53**. *Marsonella oxycona* (Reus, 1860), sample AH-141. **54**. *Melonis affinis* (Reuss,1851), sample AH-27. **55**. *Melonis pompilioides* (Fichtel & Moll, 1798), sample AH-141. **56** a,b. *Neoconorbina ystadiensis* (Brotzen, 1948), sample AH-48. **57**. *Nodosaria* sp., sample AH-137. **58**. *Nonionella robusta*,Plummer, 1931, sample AH-85. **59**. *Nummulites* sp., sample AH-137. **60**. *Operculina* sp., sample AH-109. **61**. *Planulina austriaca* (d´Orbigny,1846), sample AH-69. **62**. *Pleurostomella incrassata*, Hantken, 1883, sample AH-137. **63**. *Porosononion* sp., sample AH-77. **64**. *Pullenia bulloides* (d´Orbigny, 1826), sample AH-137. **65**. *Pulvinulina velascoensis*, Cushman, 1925, sample AH-69. **66**. *Quinqueloculina brevidentata*, Le Calvez, 1947, sample AH-101. **67**. *Rectuvigerina multicostata* (Cushman & Jarvis, 1929), sample AH-11. **68**. *Rectuvigerina* sp., sample AH-116. **69**. *Reophax nodulosa* var. *brevior*, Lomnicki ,1900, sample AH-129. **70**. *Rhabdammina* sp., sample AH-141. **71**. *Rhizammina* sp., sample AH-141. **72**. *Saccammina globosa*, Crespin, 1963, sample AH-109. **73**. *Spiroloculina canaliculata* d´Orbigny , 1846, sample AH-129. **74**. *Spiroplectammina dentata* (Alth, 1850), sample AH-93. **75**. *Spiroplectammina* sp., sample AH-48. **76**. *Stilostomella adolphina* (d´Orbigny, 1846), sample AH-129. **77**. *Stilostomella paleocenica* (Cushman & Todd, 1946), sample AH-137. **78**. *Stilostomella plummerae* (Cushman, 1940), sample AH-141. **79**. *Trifarina bradyi* Cushman, 1923, sample AH-69. **80**. *Tristrix excavatus* (Reuss, 1863), sample AH-105. **81**. *Trochammina* sp., sample AH-105. **82**. *Turrilina brevispira*, ten Dam, 1944, sample AH-137. **83**. *Uvigerina hispida* Schwager, 1866, sample AH-77. **84**. *Uvigerina moravia* Boersma, 1984, a: sample AH-93, b: sample AH-85. **85**. *Uvigerina cf. semiornata* d´Orbigny, 1846, sample AH-069. Lengths of scale bars 0.1 mm, unless stated otherwise.



Abundances of benthic foraminifera morphogroups:
Deaceasing abundances of larger foraminifera within the < 1 mm-fraction indicate the increasing paleo-water depth. Most prominent are the high numbers of planoconvex morphotypes (*Alabamina, Anomalinoides, Cibicides, Cibicdoides, Gavelinella*....) within the marls with *Discocyclina*, pointing to well oxigenated bottom waters. High productivity indicators (Bolivinids, Turrilinids, Uvigerinids) occur always with moderate numbers. Increasing numbers of uniserial calcareous taxa (*Dentalina, Stilostomella*) reflect the decreasing water energy and indicate a general deepening.