LESSON 14

ABYSSAL MEMORIES

A Thousand Holes in the Bottom of the Sea

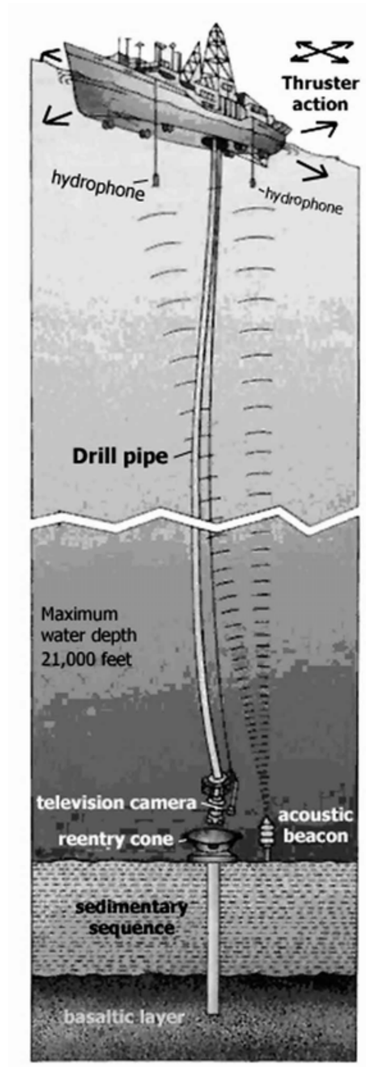

Fig. 14.01. The recovery of the memories in the deep seafloor requires modern drilling technology.

The deep ocean has memories going back 100 million years, and more. Ramming a steel tube into the seafloor is fine for getting samples for the last one percent of that, but to get the whole story one needs to use a floating drilling platform, a ship with a huge derrick over a hole in the center of the vessel, to handle a string of pipes armed with a drill bit that eats its way deep into the bottom (Fig.14.01). Sending a steel tube through the central hole of the bit, we can then sample the sediment well below the seafloor. The memories of the ocean are stored within fossil-bearing deposits dominated by calcareous forms: nannofossils and foraminifers. In many places, one also finds siliceous fossils: radiolarians and diatoms. Both planktonic and benthic fossils are represented, and they tell the stories of climate-driven changes in surface waters and in the waters in contact with the bottom.

There are four great themes that emerge from the study of deposits on land and on the seafloor, as follows. Furthest back there is the ancient warm ocean, whose oxygen content was low and whose climatic fluctuations were subdued. Shallow seas were widespread on the continents. In North America, for example, an enormous seaway reached from the Gulf of Mexico into the Arctic. Great marine reptiles dominated the scene in these seas – ichthyosaurs, plesiosaurs, mosasaurs, turtles and crocodiles. Mollusks were represented by the usual assortment of clams and snails, as well as a rich variety of ammonites and belemnites, with some bivalves building substantial reefs. Then suddenly, about 65 million years ago, came death from the heavens, in the shape of an "asteroids," an enormous chunk of rock on an erratic path in the solar system. Instead of falling into the Sun (the most common fate of such rocks) or into Jupiter's atmosphere (the second most common), it hit Earth, setting off calamitous consequences. Devastation was abrupt, global, and thorough. After this horrifying scene came a period of recovery, lasting many millions of years. Again the ocean was warm, even unusually warm in one brief period. Finally there arrived the time of the great cooling, starting 40 million years ago. The shelf seas retreated. Ice started building up at the South Pole. Deep waters became cold. The Drake Passage opened and strong winds circling the Antarctic drove a great ring of cold water around it as in a merry-go-round. Productivity of the sea responded, and life flourished in the southern ring current. Continued cooling generated strong trade winds and coastal upwelling where these winds blew along the shores. Marine mammals and birds responded with bursts of diversification. Finally, the cooling brought ice to the northern landmasses that surround the Arctic sea, beginning seven million years ago. Being so far from the pole, however, this ice buildup was highly unstable, and its coming and going helped generate enormous climate fluctuations. The great cooling from 40 million years ago to the ice ages with their waxing and waning northern ice shields: that is the central theme of the "Cenozoic" (Fig. 14.02). It is the period referred to as the "Age of Mammals," and it produced the largest organisms on the planet, the "great whales."

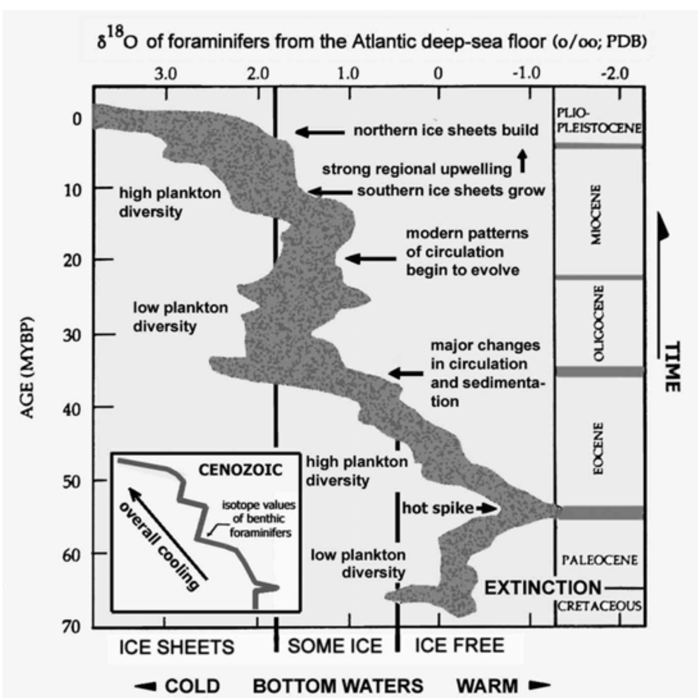

Fig. 14.02. The great cooling of the Cenozoic as seen in the trend and the steps of the oxygen isotope history of benthic foraminifers on the deep-sea floor (as compiled by Ken Miller in the mid-1980s) based on results of deep-sea drilling.

Images

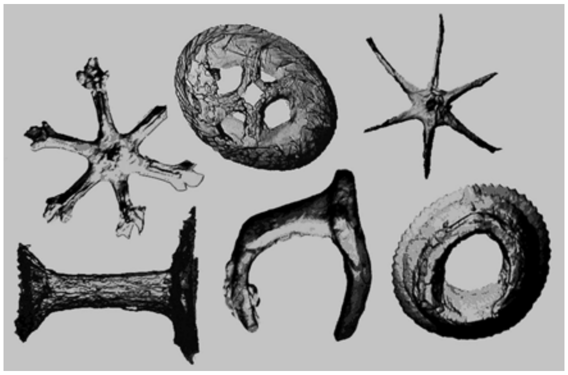

Fig. 14.03. Nannofossils (remains of calcareous nannoplankton) from sediment samples recovered by Leg 1 of the Deep Sea Drilling Project. Nannofossils are among the most important information carriers in deep-sea deposits. Typical scale: 10 µm.

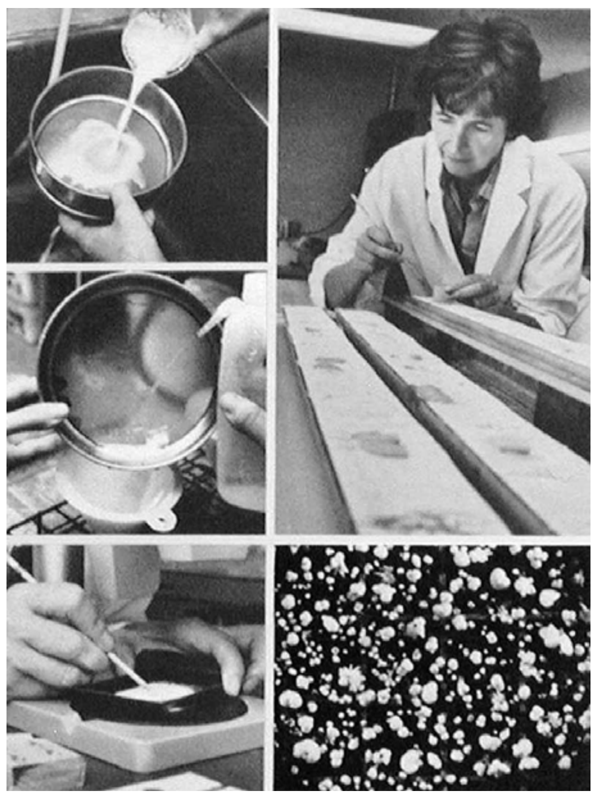

Fig. 14.04. Processing foraminifers: sampling the core, sieving of the wet slurry, inspecting hundreds of fossils under the microscope.

Fig. 14.05. Handling the massive drill collar at the rotary table of the drilling vessel requires skill, brawn and caution.

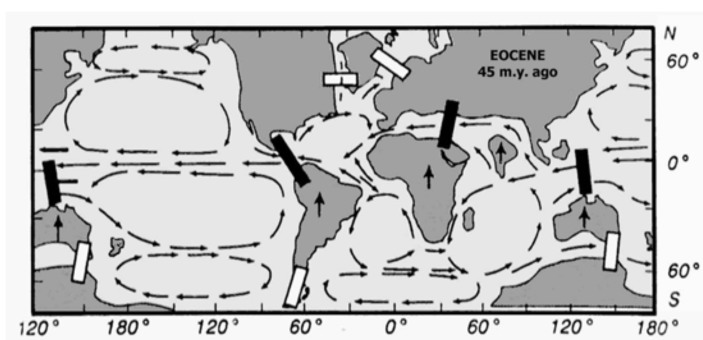

Fig. 14.06. Seaways opening (white markers) and seaways closing (black markers) changed the circulation of the ocean in the Cenozoic. The straits at Tasmania and Drake Passage (arrows) are crucial in the history of the silica budget, which is dominated by extraction in the circumpolar current.

Fig. 14.07. Diatom debris in the ooze around Antarctica. Such deposits greatly increased after 40 million years ago, depriving the rest of the ocean of silicate and changing the global patterns of productivity.

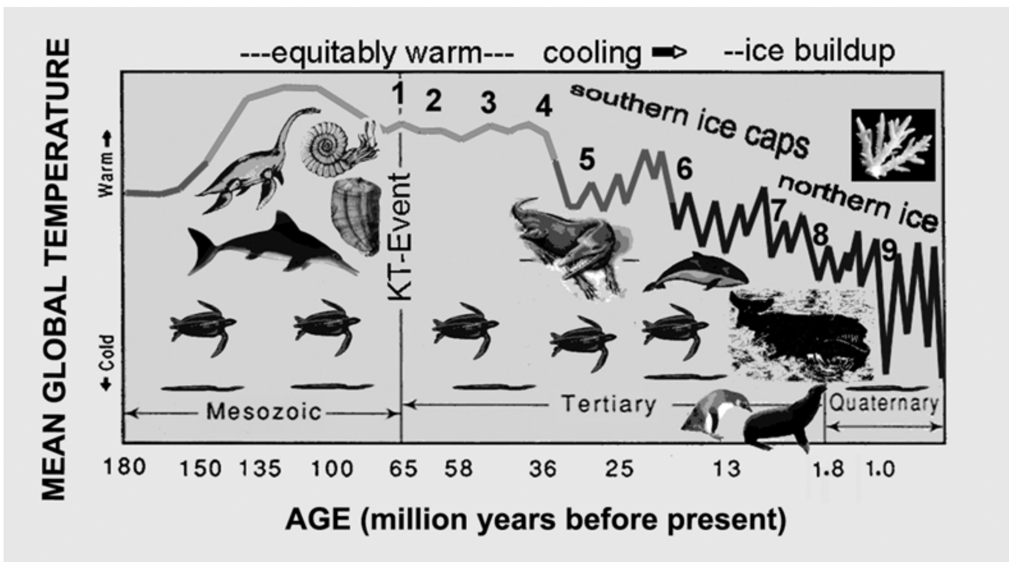

Fig. 14.08. Generalized scheme of ocean history since the Jurassic (middle Mesozoic). The Mesozoic seas bore warm-water creatures (plesiosaurs, ichthyosaurs, ammonites, rudist) that went extinct at the KT-Event (1), and others that did not (turtles, eels) but entered the earliest Tertiary (2). The onset of cooling in the Eocene (3), with a sudden temperature drop at its end (4) led to the buildup of ice (medium gray, 5). Twenty million years later (6) large ice sheets started to dominate Antarctica, and another 17 million years later (7) such ice sheets expanded in Greenland and (sporadically) in Canada and Scandinavia. The evolution of whales, seabirds and seals is closely tied to this history of cooling steps. In the Quaternary, corals evolved fast-growing forms that can cope with large and repeated change of sealevel. Note the expansion of the time scale toward the right (that is, the present).

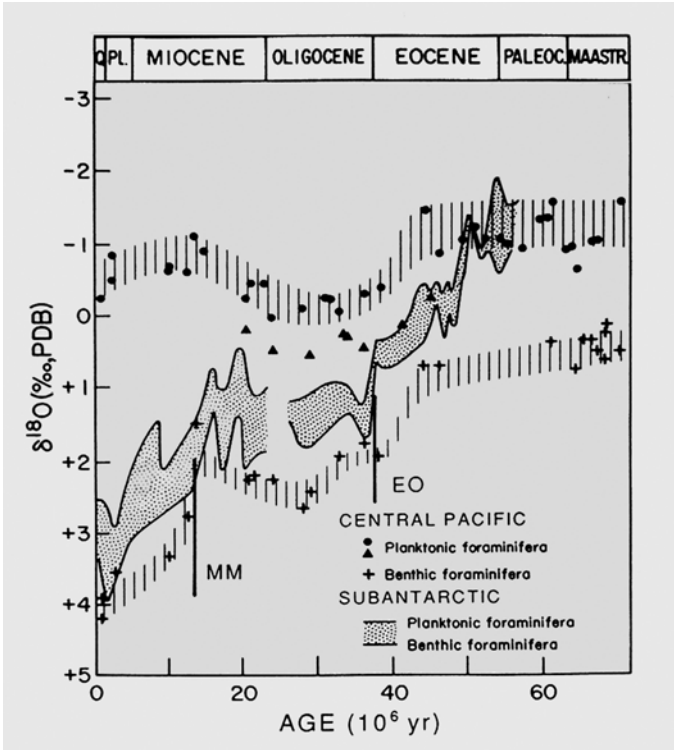

Fig. 14.09. Inventory of climate change in the Tertiary ocean, in 1975, by R. Douglas and S. Savin (central Pacific) and by J. Kennett and N. Shackleton (sub-Antarctic), based on oxygen isotopes in foraminifers. Note overlap of plankton values in high and low latitudes in the early Eocene, and separation upon cooling in high latitudes.

Fig. 14.10. Penguins depend on highly productive waters in the southern hemisphere. Their evolution is linked to a cooling planet, with upwelling around an ice-covered Antarctic continent.

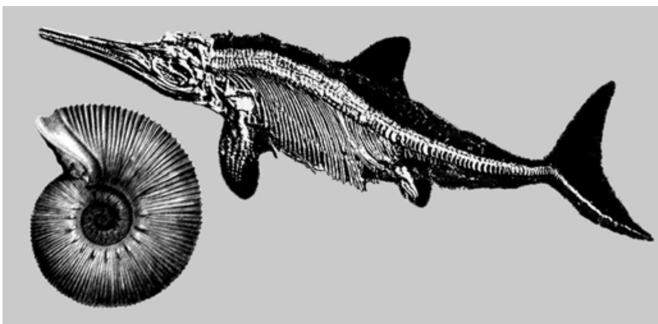

Fig. 14.11. Two well-known types of fossils from the Mesozoic: ammonite and ichthyosaur. Both types of organisms thrived in shallow warm seas for millions of years. (Not to scale.)

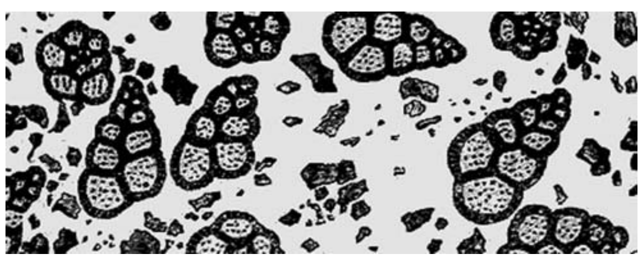

Fig. 14.12. Microscopic fossils in Cretaceous chalk contain information about climatic conditions at the time.

Fig. 14.13. Typical marine deposits of Cretaceous age, exposed on land: (a) finely bedded sandy mudstones from an uplifted offshore basin (La Jolla, California), (b) muddy silt- and sandstones from shelf seas in the great central North American seaway (Mesa Verde, Colorado), (c) limestone layers, from shallow seas in uppermost Cretaceous and lowermost Tertiary (Denmark), (d) finely laminated black shale, from oxygen-deprived shallow seas (southeastern France).

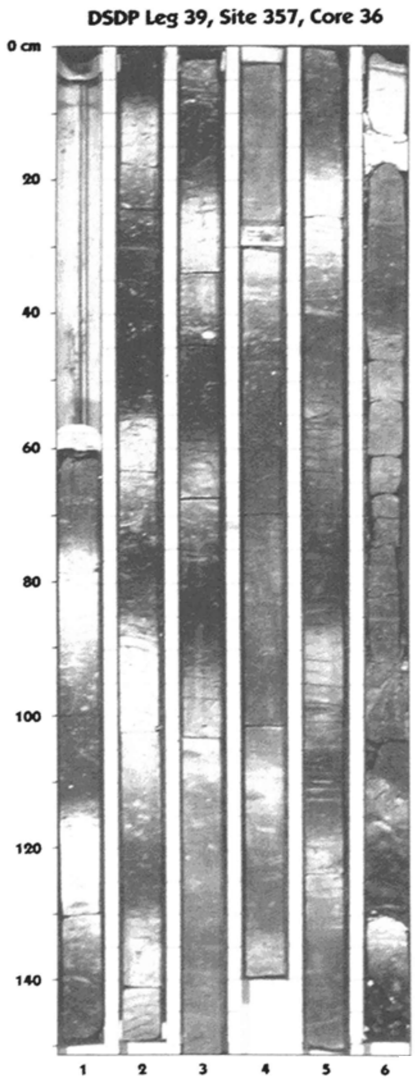

Fig. 14.14. Cyclic changes in calcareous deepsea sediments: evidence that subtle changes in seasonality (tied to the eccentricity of the orbit) produced cycles in deepwater production and ocean productivity in the Late Cretaceous.

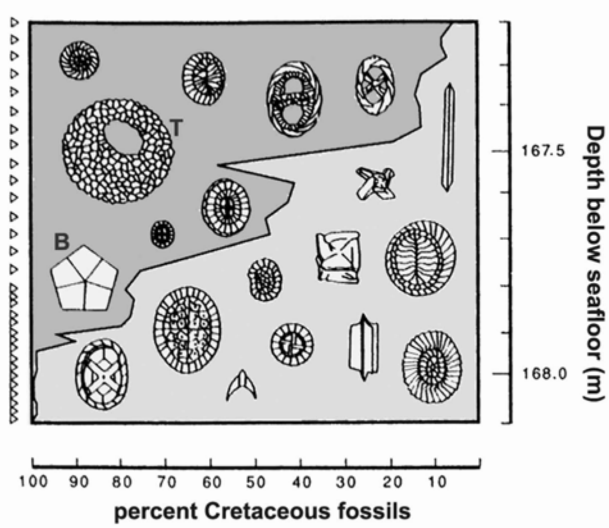

Fig. 14.15. The abrupt change of nannofossil flora at the end of the Cretaceous, as documented by H. Thierstein and H. Okada, in Site 384 of the Deep Sea Drilling Project, in 1979. Sample spacing to the left. B, *Braarudosphaera*, a stress-tolerant nannofossil; T, *Thoracosphaera*, a dinoflagellate cyst.

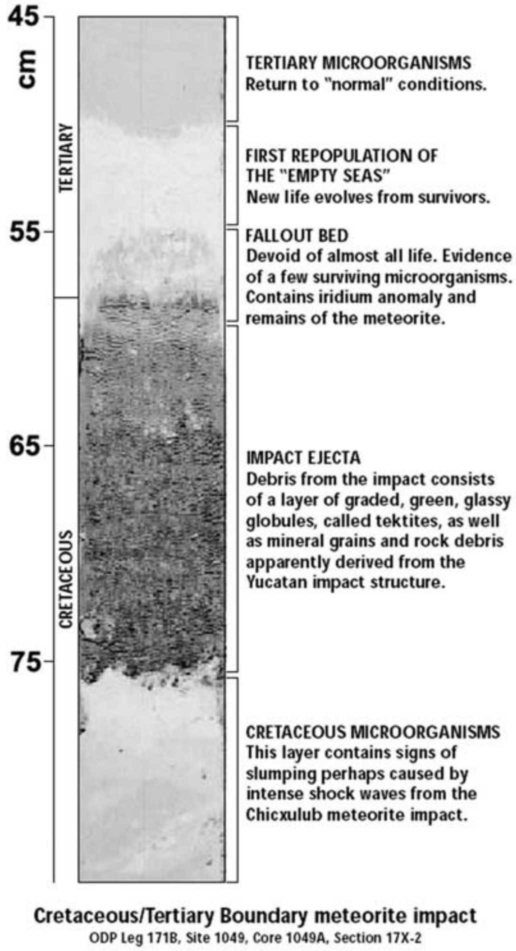

Fig. 14.16. Details of the K/T transition in a core taken by the Ocean Drilling Project, off NE Florida.

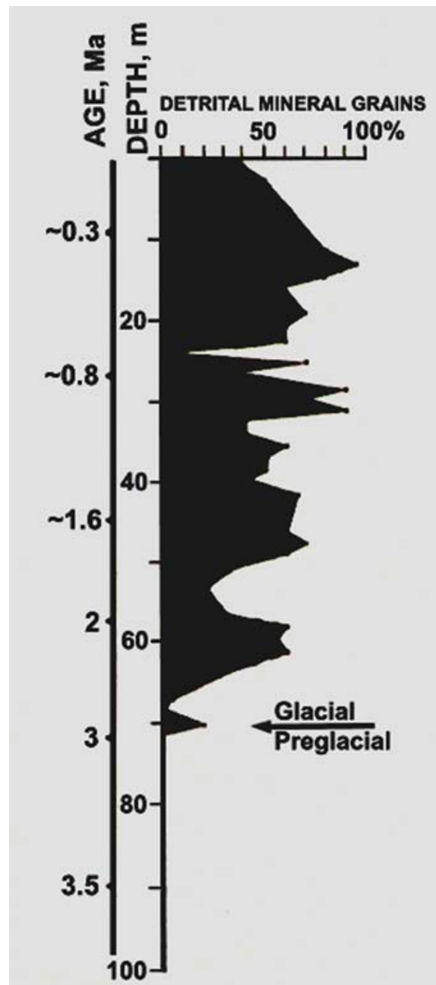

Fig. 14.17. The onset of deposition of mineral grains in DSDP Site 116, NW Atlantic, marks the arrival of glacial conditions in North America, according to W. Berggren, 1972.

Fig. 14.18. The climate history of the Antarctic and the ice-bearing sea around it provides a crucial element in tracing the evolution of the ocean toward modern conditions.

Figure sources (where based on sources in the literature, on the web or in museum exhibits: figures are considerably modified and adapted for present purposes, using Adobe Photoshop; drawings and photographs by the author are marked "orig."): 1, ODP; 2, Miller et al. 1987; 3, Bukry and Bramlette, 1969; 4, SIO Annual Report 1983 (E. Vincent); 5, ODP; 6, Haq 1981; 7, C. Chun in O. Krűmmel 1907; 8, orig., background graph J. Thiede et al., AWI; 9, Berger, Vincent, Thierstein, 1981; 10, orig.; 11, Hauff Palaeontological Museum (ichthyosaur), and Neumayr 1895; 12, Neumayr 1895; 13, orig.; 14, DSDP (T. Herbert); 15, Thierstein and Okada 1979; 16, ODP (R. Norris and Leg 171B Scientific Party, tektite: B. Huber, Smithsonian Institute); 17, Berggren 1972; 18, orig. **References**: Ocean Drilling Program, Texas A&M, College Station; K.G. Miller, R.G., Fairbanks, G.S., Mountain, 1987, Tertiary oxygen isotope synthesis, sea level history, and continental margin erosion. Paleoceanography 2, 1-19; D. Bukry and M.N. Bramlette, 1969, *Coccolith age determinations – Leg 1, Deep Sea Drilling Project,* Initial Rpts. Deep Sea Drilling Project, 1, 369-387; B.U. Haq 1981, cited in E. Seibold and W.H. Berger, 1993 (see Ch. 4 for reference). O. Krűmmel, 1907, Handbuch der Ozeanographie, Band I. J. Engelhorn, Stuttgart, 526pp.; J. Thiede et al. 1992, cited in E. Seibold and W.H. Berger, 1993 (*ibid.*); W.H. Berger et al. 1981 (data R.G. Douglas and S.M. Savin, 1975, and N.J. Shackleton and J. Kennett, 1975) cited in E. Seibold and W.H. Berger, 1993 (*ibid.*); M. Neumayr, 1895, *Erdgeschichte*, Bd. 2, *Beschreibende Geologie*, 2nd ed., Bibliographisches Institut, Leipzig und Wien, 700pp.; T.D. Herbert and S.L. D'Hondt, 1990, *Precessional climate cyclicity in late Cretaceous-early Tertiary marine sediments: A high resolution chronometer of Cretaceous-Tertiary boundary events.* Earth and Planetary Science Letters, 99, 263-275; H.R. Thierstein and H. Okada, 1979, cited in E. Seibold and W.H. Berger, 1993 (*ibid.*); W.A. Berggren, 1972, cited in E. Seibold and W.H. Berger, 1993 (*ibid.*).