# LESSON 13

## THE OCEAN'S MEMORY OF THE ICE AGES

### The Endless Cycles of Climate Change

1 Of fjords and reefs and pioneers
2 Discovery of the Great Ice Age
3 Multiple ice ages and astronomy
4 The enchanting world of microfossils
5 Discovery of the ice-age cycles
6 A time scale and orbital pacing
7 On the origin of the 100-kyr cycle
8 The last ice age and how it ended

Fig. 13.01. A glacier calving into a fjord in Svalbard, Norway. We live in the warm phase of an ice age that began 3 million years ago, when Greenland acquired an ice cap (1).

We live in an ice age, geologically speaking. Some considerable portion of the water on this planet is locked up in ice, at high latitudes (Fig. 13.01) (1). More precisely, we live in a warm period within a long series of ice-age fluctuations.

Over the last million years, the sealevel was about 200 feet (60 m) lower than today, on average. It was higher than today only for a few percent of this time span. The reason the sealevel was normally much lower, was the presence of large ice sheets that covered much of Canada and Scandinavia, and of thickened ice on Greenland, as well as increases in ice volume elsewhere. During times of maximum ice volume on land (*glacial maxima*) ice fields covered the region of the Great Lakes in North America, and the Baltic Sea in northern Europe. Besides, many elevated regions in temperate to high latitudes had substantial mountain glaciers: the Rocky Mountains, the High Sierras, the Alps and the Himalayas all had enormous ice fields. In the northern hemisphere, much of the glacial ice disappeared between 16,000 and 8,000 years ago; but not from the Antarctic continent, which has been in a glacial condition for more than 15 million years (Fig. 13.02). Ice-age climate fluctuations are prominently a matter of the northern hemisphere, the southern hemisphere's climate being stabilized by the permanent ice cap on Antarctica.

Modern landscapes – just about all of them, including coastal landscapes – carry a legacy from the last glacial period, and cannot be understood when only present-day processes are considered. By the same token, neither the present distribution of plants on the surface of Earth, nor that of coral reefs and atolls can be understood without reference to ice age history. Furthermore, the same is true for the zoogeography of the sea, inasmuch as the evolution of marine birds and mammals is involved. The evolution of present-day warm-blooded vertebrates, obviously, was closely linked to the history of ice ages and the associated changes in the ocean environment, for the last three million years.

The climate future of the planet hinges largely on the response of ice on Greenland and in Antarctica to ongoing warming. As the Egyptian priest told the Greek traveler Solon – if you don't think on a time scale of many thousands of years, your knowledge and understanding remains that of a child (2). The priest had a point, but his time scale (the last 10,000 years) fell short. It is the last million years that we need to consider. And perhaps more.

Fig. 13.02. Glaciers at sealevel on the Antarctic Peninsula, Bransfield Strait. The Antarctic has been in an ice age for some 15 million years. The sea surface is ice free in summer, during the present warm period.

**Notes and references**

**1.** The ice on Antarctica is equivalent to a change in sealevel of roughly 70 m (230 feet) and that on Greenland of roughly 7 m. The fact that we have open waters in summer around Svalbard (near 80ºN, Fig. 13.01) confirms that we are in a warm phase of the present ice age.

**2.** According to Plato, the priest told Solon that the Greeks do not value knowledge that is ancient, but are caught up in current affairs. Thus their knowledge is very limited. [Platon (427-327 B.C.) Timaios. (Steph. 22c).]

## Images

Fig. 13.03. A fjord in western Norway, filling an ancient glacial valley. The seawater penetrates deeply into the land, bringing heat (and tourist ships).

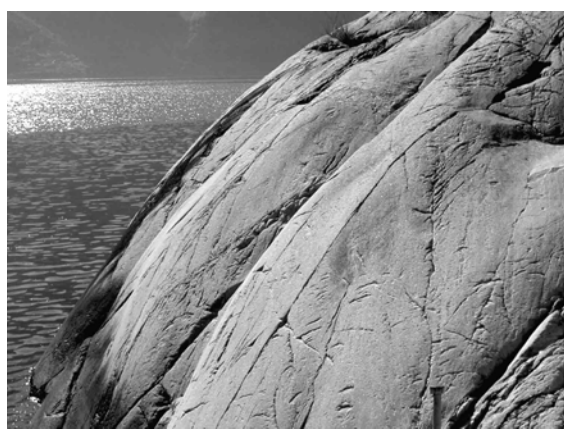

Fig. 13.04. Polished rocks in the fjords of Norway bear testimony to the former presence of enormous glaciers.

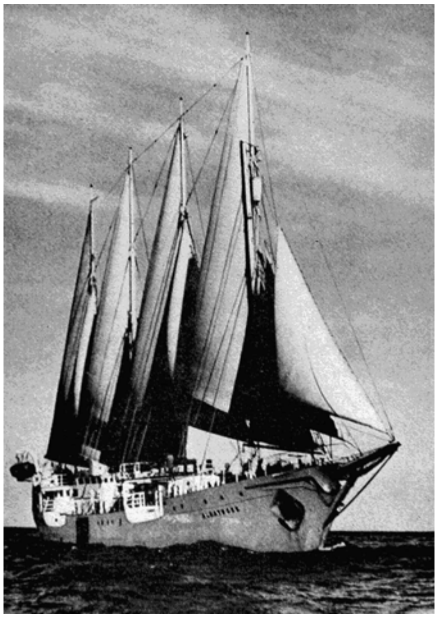

Fig. 13.05. The *Albatross*, of the Swedish Deep-Sea Expedition (1947-49), the first ship that took long cores for retrieving the ocean's memory of the ice ages.

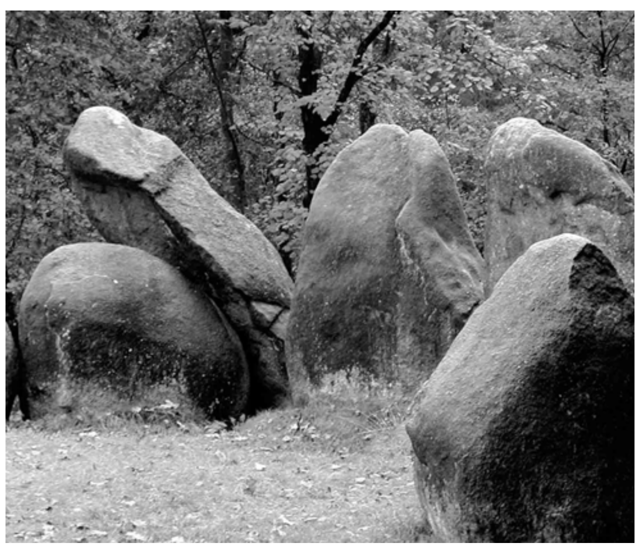

Fig. 13.06. Erratics in a forest south of Bremen, remnants of an ancient grave mound.

Fig. 13.07. The discovery of a climatic condition, not so long ago, involving enormous expansion of ice (background) was initiated by research on the remains of mammoth and other extinct large mammals.

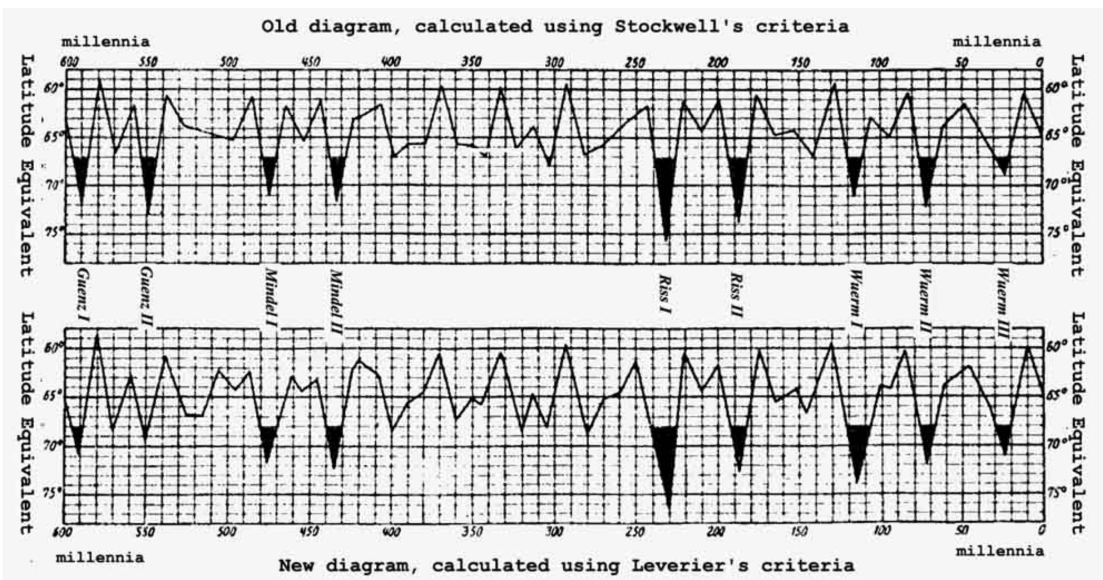


Fig. 13.08. Milankovitch diagrams, made in the 1920s, showing ups and downs of summer insolation, from 600,000 years to present, based on two different astronomical data sets. Proposed times of northern ice buildup (cool summers) shown in black. (Lettering translated and replaced.)

Fig. 13.09. Ice and snow reflect sunlight, while open water and snow-free land absorb it, being dark. Old ice appears gray. Reflectivity (“albedo”) determines uptake of sunlight and conversion to heat. Clouds play a more complex role: they reflect sunlight but they also radiate heat downward, acting as a blanket. (Hinlopen Strait, Svalbard, July 2007.)

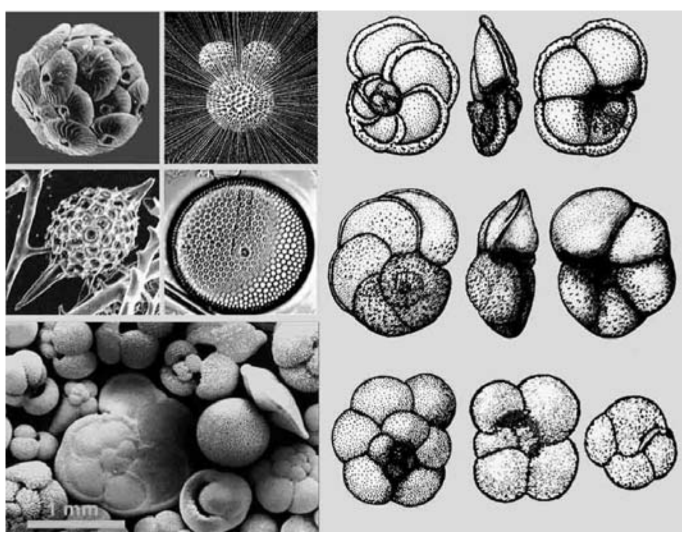


Fig. 13.10. Microfossils. Upper left: coccoliths, spined foraminifer, radiolarian, diatom. Lower left: planktonic foraminifers, SEM image of washed sediment. Right: drawings of planktonic foraminifers.

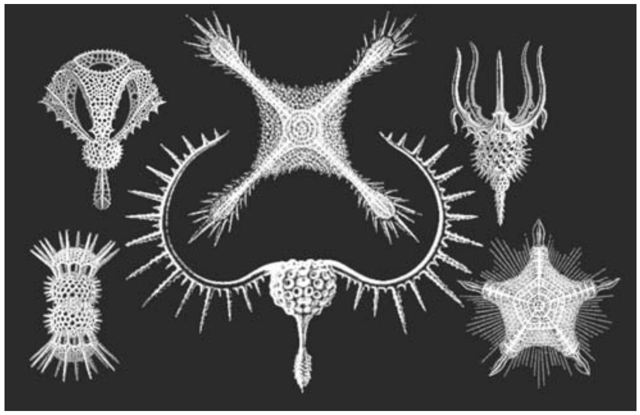

Fig. 13.11. Radiolarian microfossils from deepsea sediments, drawn by E. Haeckel.

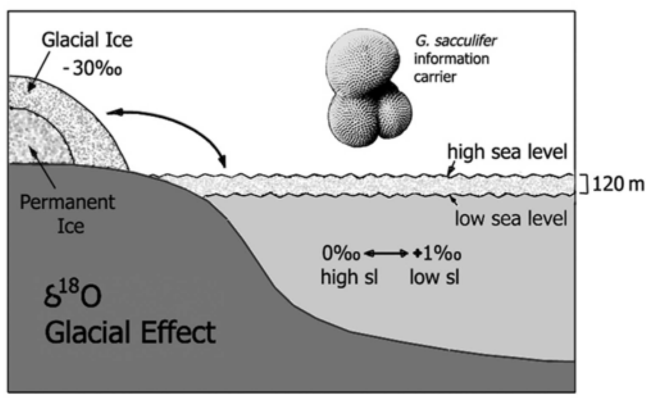


Fig. 13.12. The isotopic composition of the foraminifer *G. sacculifer* changes with the amount of water extracted from the sea to make ice caps. A drop of sealevel of 120 m (full-size ice cap) engenders a change of isotopic composition of the water by approximately 1 permil.

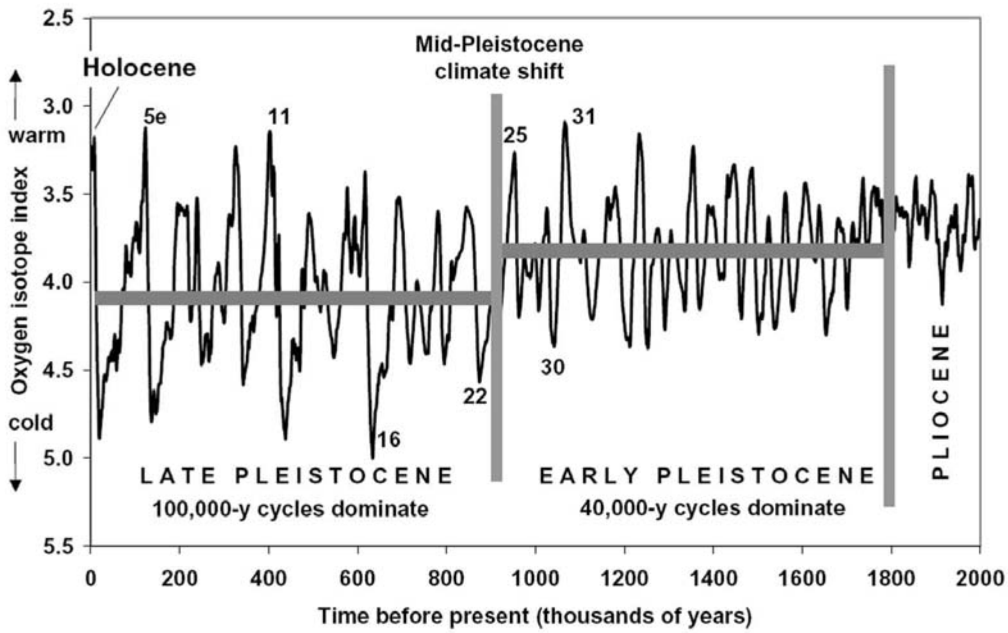


Fig. 13.13. Isotopic variations in benthic foraminifers for the last 2 million years, comprising the "Pleistocene" (1.8 m.y. ago to 0.01 m.y. ago) and the "Holocene," (the last 11,000 years). Note the shift in mean position of sea level at 0.9 m.y. ago, and the predominance of large cycles after this Mid-Pleistocene climate event.

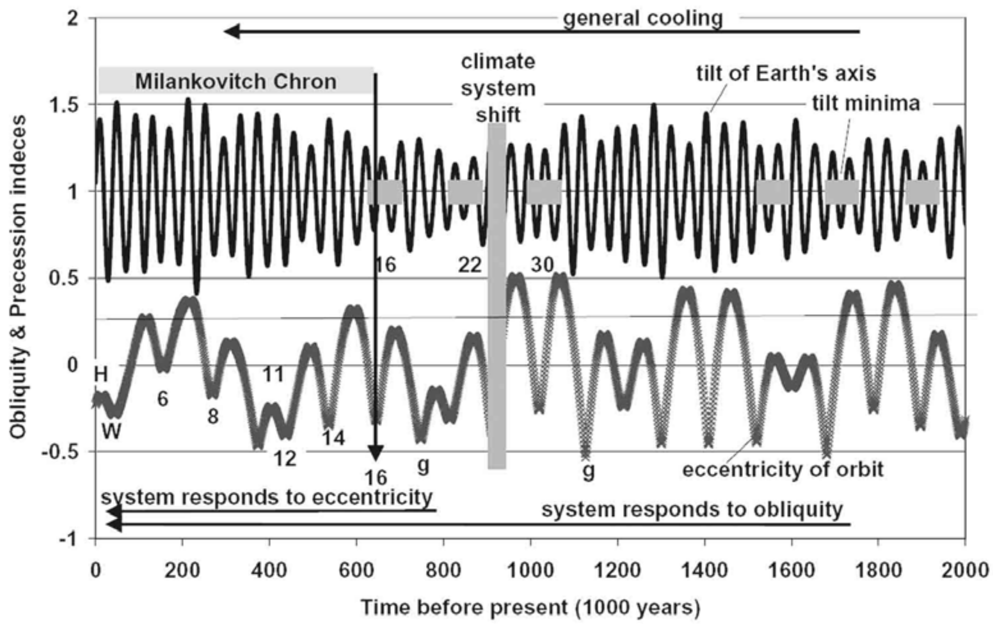


Fig. 13.14. Astronomical forcing and the response of the Earth's climate system for the last two million years. Shown are the variations in tilt (or *obliquity*) of Earth's axis and the variations of eccentricity (deviation of orbit from a circle) through time. Even numbers denote major ice-age stages. They are common only after the climate shift, and tend to occur during periods of reduced eccentricity. However, Stage 11, a major warm period, occurs during a time of low eccentricity, as does the Holocene (**H**), contrary to expectations from Milankovitch theory. This suggests that the external forcing does not determine climate directly, but modifies climate oscillations inherent to the system. The system listens to those elements of the forcing that agree with its own preferences.
"Milankovitch Chron," the period studied by Milankovitch. "g", a modest glaciation; "H", Holocene (last 11,000 years); W, last glaciation ("Wuerm" in Europe, "Wisconsin" in North America).

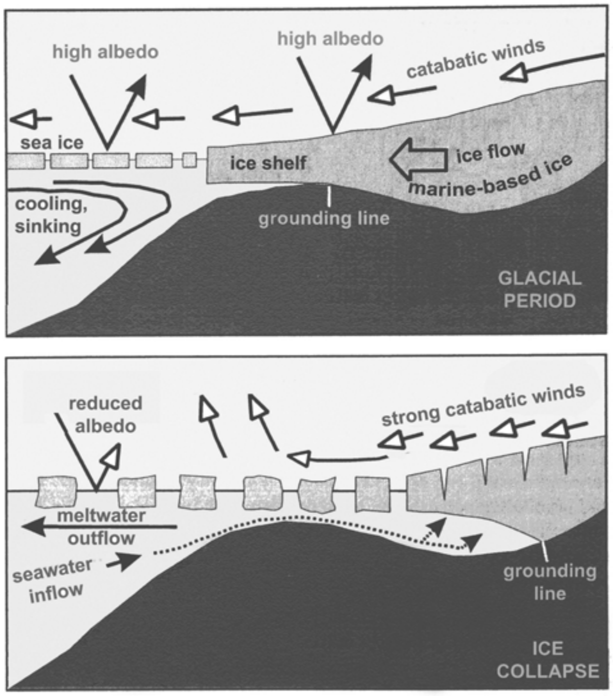


Fig. 13.15. Hypothesis of collapse of marine-based ice sheets, triggered by a rise in sea level.

Fig. 13.16. The polar bear (*Ursus maritimus*) is one large predator that did not succumb to the wave of extinction at the end of the last glacial. Its food is provided by the sea, and human enemies are rare in the high Arctic. (Hinlopen Strait, Svalbard, July 2007.)

Fig. 13.17. The high mountains of California were shaped by glacial ice. (Yosemite Park.)

**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, orig.; 2, orig.; 3, orig.; 4, orig.; 5, Pettersson 1953; 6, orig.; 7, J. Imbrie and K. Imbrie (background) and Zoological Institute and Museum Hamburg (orig.); 8, M. Milankovitch 1930; 9, orig.; 10, Geo Bremen, Thomson in Krűmmel 1907, Seibold and Berger 1993 (see Ch. 4 for reference), M. Yasuda (SEM, foraminifers), F.L. Parker 1962; 11, E. Haeckel (see Ch. 1 for reference); 12, Seibold and Berger 1993; 13, orig., data J. Zachos et al., 2001; 14, orig., data A. Berger and M. Loutre, 1991; 15, Berger and Eystein 1995; 16, orig.; 17, orig. **References**: H. Pettersson, 1953. *Westward Ho with the Albatross*. E.P. Dutton, New York, 218pp.; J. Imbrie and K.P. Imbrie, 1979, *Ice Ages, Solving the Mystery*. Enslow, Hillside, N.J., 224pp.; M. Milankovitch (1930) *Mathematische Klimalehre und astronomische Theorie der Klimaschwankungen.* Handbuch der Klimatologie, Bd 1, Teil A. Bornträger, Berlin, 176pp.; Wyville Thomson in O. Krűmmel, 1907, *Handbuch der Ozeanographie*, Bd. 1, J. Engelhorn, Stuttgart, 526pp.; F.L. Parker, 1962, *Planktonic foraminiferal species in Pacific sediments*. Micropaleontology 8 (2) 219-254; J. Zachos, M. Pagani, L. Sloan, E. Thomas, K. Billups, 2001. *Trends, rhythms, and aberrations in global climate 65 Ma to present.* Science, 292, 686-693; A. Berger, A., and M.F. Loutre, 1991, *Insolation values for the climate of the last 10 million years.* Quat. Sci. Rev., 10: 297-317; W.H. Berger and E. Jansen, 1995. Younger Dryas episode: Ice collapse and super-fjord heat pump. In: S.R. Troelstra, J.E. van Hinte, G.M. Ganssen (eds.) The Younger Dryas, North-Holland, Amsterdam, pp. 61-105.