15

Earth's Future Climate

Understanding the past allows one to better understand the future. As demonstrated earlier, one can use the historic Earth's atmosphere composition and pressure (Figure 5.3) as well as the adiabatic theory (Eq. 2.25) for the determination of the temperature parameters for the past, current and future Earth's temperatures. The calculated values of temperature from these equations (Eq. 2.25) are presented in Figure 15.1.

Figure 15.1 displays data illustrating that after the Archaean time, the Earth's surface temperature has been continuously declining despite the increase of the Sun's luminosity (*Curve 4*). After the accumulation of water on the Earth's surface, forming the ocean and emergence in the Early Proterozoic time of the oceanic crust, Earth's temperature decline has occurred due to bonding of carbon dioxide in carbonate rocks. Later, during the Proterozoic and Phanerozoic times, this process continued through the life-sustaining activity of nitrogen-consuming bacteria, which resulted in cooling down of the Earth's surface.

The effect of the nitrogen-consuming bacteria and thunderstorm activity on the Earth's climatic evolution played a positive role in creating a favorable environment for the evolution of life on the Earth. Had these

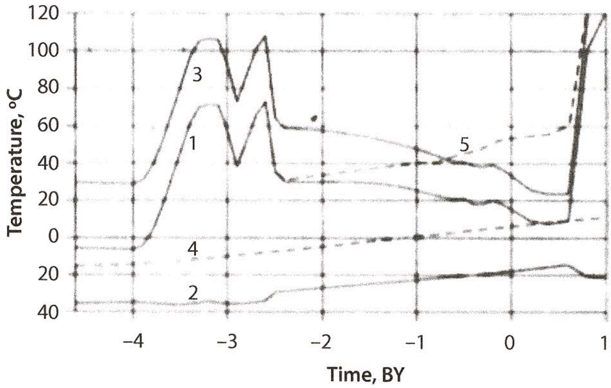

Figure 15.1 Averaged evolution of Earth's climates at: constant Earth's precession angle $\psi = 24°$. *Curve 1* – Average for Earth surface temperature at the sea level estimated using Eq. 2.25. *Curve 2* – Effective Earth's temperature using Eq. 2.23. *Curve 3* – Earth's atmosphere greenhouse effect using Eq. 2.6. *Curve 4* – The absolute black body temperature using Eq. 2.3. using the distance of the Earth-from-the-Sun, (d) describing the increase with time of the Sun's luminosity, *S*. *Curve 5* – Average Earth's temperature on the assumption that there was no nitrogen consumption by bacteria.

bacteria and thunderstorms not existed, the current atmospheric pressure would be ≈2 atm. and Earth's average surface temperature would be over 50 °C (rather than today's 15 °C) and would exceed 70 °C at the equator. This would exceed the coagulation temperature of some vitally important proteins required for life. The conditions appropriate for life could then only be preserved on mountain summits at high latitudes. However, under conditions so extreme, the oxygen necessary for life would not be able to accumulate in sufficient amounts. In fact, should nitrogen have not been continually removed from the Earth's atmosphere, today, as in Archaean time, the Earth would be populated only by thermophilic bacteria and, maybe, primitive multicellulars.

To check the propriety of the reviewed theoretical constructions, the authors combined in Figure 15.2 (at an appropriate scale) the theoretical curve of the Earth's climate evolution and empirical curve of sea flint isotopic temperature (sea flints were deposited on the ocean floor and describe the temperature of the ocean near-bottom water (see Figure 1.3). As shown in Figure 15.2, theoretical constructions quite nicely approximate empirical data (with the accuracy of temperature determination from the sea flints and theoretical estimates). Thus, the Earth's climatic paradox is defined by a continuous decline of the atmospheric pressure. First, it occurred at the expense of bonding the carbon dioxide of the Archaean atmosphere in the carbonates of Earth sediment cover. Later, after Archaean time, it was due

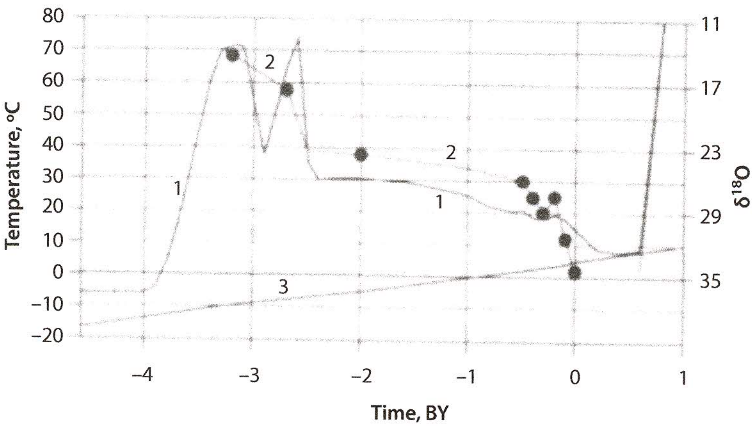

Figure 15.2 Superposition of isotopic temperature for sea flints on a theoretical curve of Earth's climate evolution: *Curve 1* – Theoretical curve of average Earth's temperature evolution on the oceanic surface (see Figure 15.1). *Curve 2* – Oxygen $\delta^{18}O$ isotope shifts in sea flints (solid black dots are estimate temperature of benthic water where the sea flints were deposited) (After Schopf, 1982). *Curve 3* – Temperature of absolutely black body at the Earth–Sun distance describing Sun luminosity (see Figure 15-3).

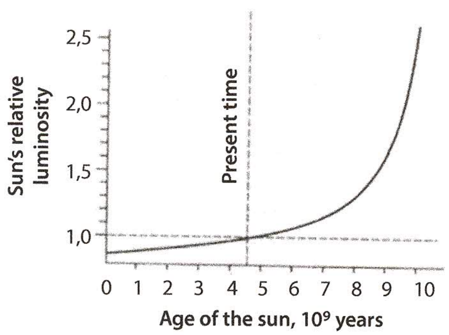

Figure 15.3 The Sun luminosity vs. time. (After Aller, 1976.)

to life-sustaining activity of the nitrogen-consuming bacteria bonding the atmospheric nitrogen in organic compounds, which then were buried with Earth's sedimentary sequences. Most of these sedimentary sequences were deposited on the global ocean floor and again pulled into the mantel through the oceanic plate subduction zones under the island arcs and continents.

Based on the oxygen $\delta^{18}O$ isotope shifts in sea flints, a substantial temperature decline in the ocean near-bottom water had already begun by the end of Proterozoic and drastically increased in Phanerozoic time. It happened exactly at the time when the first glaciations occurred on the Earth, which spread over the high-latitude areas of the World Ocean. The local benthic temperature maximum (≈200 MY ago) exactly corresponds with a warm climate epoch in the second half of Mesozoic, during the formation of the supercontinent Pangea and the total absence of traces of glaciation.

The current cooling of the Earth will not last forever because 50 to 100 MY in the future, the equilibrium between temperature decline due to (1) the bacterial removal of nitrogen from the atmosphere and (2) the temperature increases due to increasing Sun luminosity. This state of balance will likely occur ≈600 MY in the future and will be drastically disrupted by degassing of the abiogenic oxygen released at generation within the mantle of the core matter under reaction of Eq. 12.2. After that generation of the free oxygen will begin in the mantle at a rate 2.1×10^{16} g/year or 21 billion tons/ year. Should this entire supply of oxygen enter the atmosphere, its partial pressure would increase at a rate approximately 4 atm per million years. The oxygen degassing rate will be lower, but still will reach 0.02 atm per million years. This means that after 200 MY, after the beginning of oxygen degassing from the mantle, its partial pressure will have reached almost 4 atm. Earth's average surface temperature will rise to ≈76 °C due to the greenhouse effect. After another 200 MY (i.e., a billion years in the future), the oxygen pressure will have exceeded 14 atm and Earth's near-surface temperature will have risen to 110 °C.

After the beginning of endogenic oxygen degassing, life on land could not survive. Because of the low dissolved oxygen solubility in water, only in the oceans will higher life forms be able to exist. A continued warming of the surface of the Earth will result in the boiling of the ocean water (≈1.5 BY in the future) and an irreversible *greenhouse effect* will emerge with an Earth temperature ≈550 °C. Thus, even most primitive thermophilic prokaryotes will not be able to survive.

The analysis of the future Earth's climate by the authors shows that the geodynamic conditions favorable for life are not limitless. Most likely, the total duration of life on Earth is ≈4.6 BY (starting 4 BY ago and ending at ≈600 MY in the future). For the evolution of highly organized life, there is even less time. Life in the ocean has a maximum of 1.3 BY (600 MY in the past to 700 MY in the future) and on land no longer than 1 BY (400 MY in the past to 600 MY in the future).