14

Climatalogical Effect of Continental Drift

Continental Drift's Effect on the Earth's Precession Angle

Continental drift is an explanation of how the Earth's continental crust shifts its position over time. This concept set forth in 1912 by Alfred Wegener, a geophysicist and meteorologist, was an attempt to explain why similar mineral, animal and plant fossils are found on different continents with separations of oceans, mountains, etc. Wegener proposed that all the continents were once joined together in a gigantic continent, called an *Urkontinent,* before breaking up into large bodies of land and drifting to their current positions (Figure 14.1). At the time of his announcement, geologists denounced Wegener's theory of continental drift. He published the details of his ideas in 1915, in a book entitled *The Origin of Continents and Oceans*. Today, this concept, that continents can and do shift position on the surface of the Earth, known as the plate tectonics, is widely accepted.

This shifting of the continent's position on the Earth's surface alters the Earth's spherical symmetry and center-of-mass. As a result of these

Before After

Figure 14.1 Earth before and after the land masses (continents) were broken and redistributed over the Earth's surface. (After Live Science, 2015.)

changes in continental position, there is a change of the Earth's precession angle. As discussed in Chapter 2, a change in the precession angle directly affects the planet's temperature regime as shown by Eq. 2.26:

$$T_t = b^{\alpha}\left[\frac{S(1-A)}{\sigma\left\{4\left(\frac{\frac{\pi}{2}-\psi}{\frac{\pi}{2}}\right)+2\left(\frac{\psi}{\frac{\pi}{2}}\right)\left(\frac{2}{1+\cos\psi}\right)\right\}}\right]^{\frac{1}{4}}\left(\frac{p_t}{p_o}\right)^{\alpha}. \qquad \text{(Eq. 2.25)}$$

The influence of this change can be expressed mathematically, even though one may not fully recognize all the topographical density anomalies in the mantle and the Earth's crust. Today, the effect upon the precession angle, due to the current continental positions on the surface of the Earth, is relatively small, due to their current distribution, the moment of force, $\Delta M_{\text{cont+m}} \approx 0.2$ to 0.6×10^{29} cm$^2 \cdot$ g/s^2. However, at the time of the formation of the supercontinents, the positioning of the land mass was often located at lower latitudes and distributed in only one area on the Earth's surface. At the time of the supercontinents, the Earth's center of mass would have been different than today's, as would the moment of force $\Delta M_{\text{cont+m}}$. Figure 14.2 estimates many of the recognized continental positions on Earth's surface over the past 2.6 BY.

Chumakov (2004) determined surface temperatures of the Sargasso Sea from ocean sediments. ≈100-MY ago in the tropical belt, approximately at 20° North latitude where temperatures ranged between 25° to 30 °C. The maximum equatorial temperature, T_{eq}, likely reached 28 to 32 °C, whereas

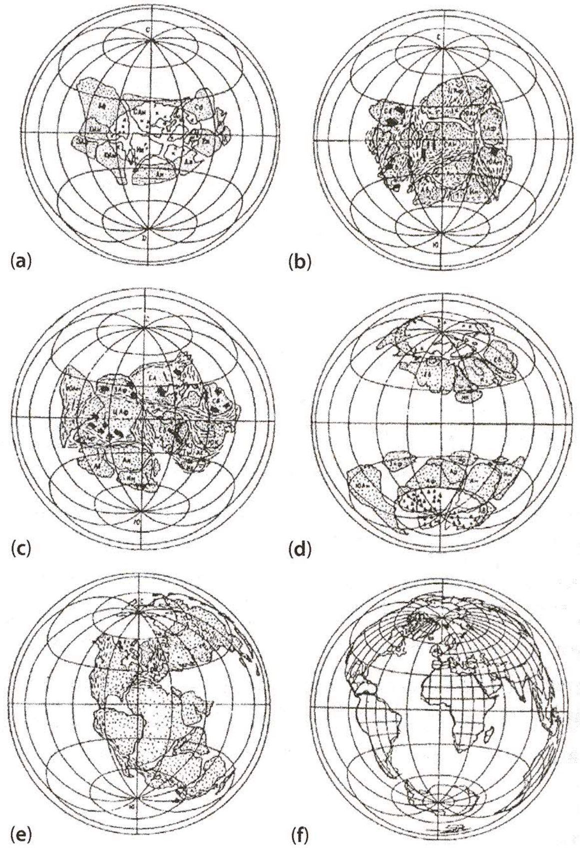

Figure 14.2 Paleo-reconstruction of the positions of the continents and oceans over the past 2.6 BY according to Lambert: (a) Monogaea, 2.6 BY ago. White areas on the continents indicate glaciers, whereas crosses indicate tillites and tilloids (Chumakov, 1978). (b) Megagaea by Sttille, l.8 BY ago. Wavy shading indicates folding belts and blackened areas show Redbed Formations (Anatolieva, 1978). (c) Mezogaea, 1 BY ago. (d) Disintegration of Mezogaea and formations of Laurasia and Gondwana, 750 MY ago. White areas on the continents indicate glaciers, whereas small triangles show location of tillites and tillotds (Chumakov, 1978). (e) Pangaea of Wegener, 200 MY ago, and (f) Present-day position of continents and oceans. (After Sorokhtin *et al.*, 2009, figure 1.41, p. 79.)

the Earth's poles were dominated by positive temperatures, T_{pl}. Recognizing the temperature relationships:

$$T_{eq} = T_s + 0.036\ \Delta T \text{ and } T_{pl} = T_s + 0.64\ \Delta T, \qquad \text{(Eq. 14.1)}$$

and

$$\Delta T \approx \frac{\Delta T_o}{p_s} \qquad \text{(Eq. 14.2)}$$

where the present-day difference between the temperatures at the equator and poles of the Earth, ΔT_o, is about 30 °C. Also, regarding the moment of force (ΔM_m):

$$\Delta M_m + M_s = \Delta M_{cont+m}. \qquad \text{(Eq. 14.3)}$$

One can estimate the equatorial temperature at ($T_{eq} \approx 32$ °C) and the positive polar temperatures (T_{pl}) are compatible with a precession angle of $\psi = 34°$. Beside the Cretaceous paleotemperature, determination for the precession angle in the past geologic epochs, this calculation is supported by data from the glaciation-distribution era in the Earth's history.

The stationary precession angle at the time of the Pangaea formation on the surface of the Earth, ≈100 MY ago, approached 34°. Judging from the reconstruction of other super continents and their different configurations with smaller individual masses (see Figure 14.2), the estimates of precession angles at the time of their formation (Figure 14.3) are somewhat lower (Sorokhtin and Ushakov, 2002). During the time intervals between the

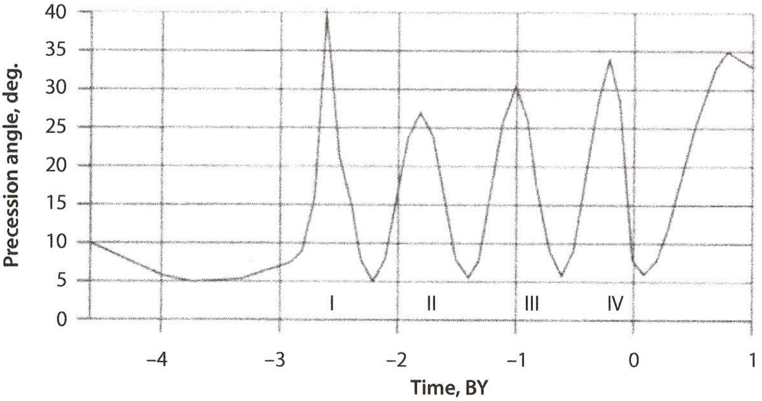

Figure 14.3 Probable values of the precession angle of the Earth at the time of the supercontinents: (I) Monogaea, (II) Megagaea, (III) Mezogaea (Rodinia); and (IV) Pangaea. The tremendous masses of the supercontinents of Monogaea, Megagaea, and Mezogaea were 0.7, 0.8, and 0.9 of the mass of Pangaea, respectively. It was also assumed that a future supercontinent Hypergaea would form in 800 MY due to the Earth's weakening tectonic activity.

formation of the supercontinents, the writers estimated that the precession angle was close to a minimum of 6° to 8° C.

Using the Earth's precession angle in (Figures 14.3 and 14.4), one can estimate the Earth's average surface temperature. In addition, one can use the same model and acknowledging the changes in surface temperatures for the oceans and continents, at Earth's equator and poles, an estimate of the Earth's surface temperature may be determined.

During periods of supercontinent formation, as shown in Figures 14.3 and 14.4, were accompanied by a corresponding increase in the Earth's near-surface temperature. For example, during the formation of the supercontinent, Monogenea, ≈2.6 BY ago, the Earth's average temperature exceeded 70 °C at sea level. Such elevated temperatures during the Archean time were largely determined by the presence of a dense atmosphere and increasing precession angle during formation of a second supercontinent, ≈1,8 BY ago, the surface temperature of the oceans and continents were about 32 °C and 22 °C, respectively. The Earth's temperature had decreased to 26 °C, whereas the average temperature of the continents increased to 25 °C, due to the lowering continental height. Finally, during the formation of the supercontinent Pangaea, ≈200 MY ago, the temperature was 23 °C and lower. During the intervals between the formation of the supercontinents, the average temperatures at sea level and continents decreased by 7° to 10 °C.

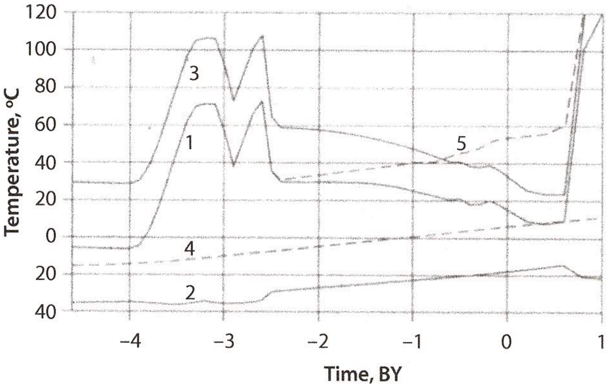

Figure 14.4 Evolution of Earth's temperature (climates) assuming a constant Earth's precession angle (current) of y = 24°. *Curve 1* – an average for Earth's surface temperature at sea level calculated using Eq. 2-25. *Curve 2* – the effective Earth's temperature using Eq. 2.23. *Curve 3* – Earth's atmospheric 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.

There was a drastic increase in the Earth's precession angle at the time of formation of the supercontinent Monogaea. This supercontinent formation was simultaneously associated with descending mantle flow, while on the opposite side of the equatorial zone, the matter from the former primordial Earth's kernel was ascending, being displaced by the Earth's core emergence (Sorokhtin, 2004; Sorokhtin and Ushakov, 2002). This ascendance of matter from depth would have created a substantial "bulge" of the mantle, substantially distorting the Earth's spherical symmetry and altering the Earth's center of gravity and, thus, its precession angle.

The formation of supercontinents results in changes other than just the physical structure. Because of the alteration of the location for the center of mass, it also alters the Earth's precession angle and, thus, the climatic conditions of the Earth. When these major climate changes occur, they can often be correlated with the beginning or closure of a geologic period. The correlation of the precession angle with the geologic event for supercontinent formation can be seen in the physical changes of the direction and intensity of oceanic currents, gyres, etc. Through geologic history, there have been several major climatic changes that can be attributed to changes in the precession angle. Today, the physical blockage of the equatorial oceans current system appears to coincide with icehouse events (Gerhard *et al.*, 2001). ***The conclusion is that pronounced global climatic changes are caused primarily by changes in insolation and those Earth's tectonics that affect the precession angle.*** Changes in insolation are often the result of a change in the precession angle between the Earth and Sun.

Latitudinal Temperature Contrast on Earth's Surface

To determine the latitudinal contrast for the Earth's climate, one can compare the planet Earth to Venus. Table 2.2 was prepared utilizing the known temperature measurements of Venus's atmosphere for low (0° to 30°) and high (75°) latitudes for different elevations, i.e., at different pressures. These Venus observations indicate that climatic contrast, as defined by temperature difference, for different latitudes is approximately proportional with the atmospheric pressure. Utilizing this relationship, it is possible to calculate the latitudinal variations of the temperature distribution within the Earth's atmosphere, dependent on its pressure. This enables the determination of not only the average Earth's temperature, but also the temperature at its poles and equator. Utilizing this correlation and the Earth's precession angle variation model, one can estimate the average temperature of the World's Ocean, and the temperature at the Earth's equator and poles (see Figure 14.4 and Eq. 2.26).

During the Phanerozoic time, because of the increased oxygen partial pressure in the atmosphere, the phyto- and zooplankton productivity increased. The phyto- and zooplankton subsequently served as a source for hydrocarbon generation. Sea plankton productivity likely increased even greater during the warm Mesozoic time interval, especially in Cretaceous. This process was certainly facilitated by a vast Late Cretaceous sea transgression that flooded about a third of the continental lowland areas. At the same time the deposition of organic matter and the deposition rate, significantly increased in the newly formed and heated epicontinental seas. In the open ocean, the deposition rate drastically declined. It is possible that a well-known Mesozoic (especially Cretaceous) burst of the oil generation was associated with this warming climate and the extensive marine transgression over the dry land. The nature of this Late Cretaceous transgression and its influence on the oceanic biota has been reviewed in greater detail by Sorokhtin and Ushakov (2002).

The equation for the determination of the temperature evolution on ancient continents is:

$$\text{Grad } T = \frac{g}{c_p} \qquad \text{(Eq. 14.4)}$$

This equation enables the calculation of the average tropospheric temperatures at various elevations as a function of the atmospheric heat absorbing capacity, $c_{p,}$ and gravity acceleration g. It provides the opportunity to determine the atmospheric temperature at any elevation up to $p \approx 0.2$ atm. The atmospheric heat conductivity may be determined by:

$$\alpha = \frac{\mathrm{R}}{\mu(c_p + C_w + C_r)}, \qquad \text{(Eq. 14.5)}$$

and

$$c_p = \frac{\left[\left\{p_{N_2} c_{p(N_2)}\right\} + \left\{p_{O_2} c_{p(O_2)}\right\} + \left\{p_{CO_2} c_{p(CO_2)}\right\} + \left\{p_{Ar} c_{p(Ar)}\right\}\right]}{p}. \qquad \text{(Eq. 14.6)}$$

Sorokhtin and Ushakov (2002) used these equations to estimate the continental standing height above sea level (see Figure 14.4). The average temperature fluctuations at Earth's equator and poles can be estimated using Eqs. 2.26 and 14.3 (see Figure 14.6).

Each supercontinent formation epoch was accompanied by increasing near-surface temperatures (see Figures 14.4 & 14.5). At the time of the supercontinent Monogaea's emergence, ≈2.6 BY ago, the average temperature at the ocean level exceeded 70 °C, whereas on continents it only reached 30 °C. The elevated temperature at the end of Archaean time was substantially determined by: (1) a dense layer of atmosphere; (2) an increase in the Earth's precession angle during the formation of the Earth's core; and (3) the formation of the supercontinent Monogaea. During the formation of the supercontinent Megagaea (Stille's) (≈1,8 BY ago) the average oceanic and continental temperatures approached 22° and 32 °C, repectively. During the formation of the supercontinent of Mezogaea (Rodinia) (≈1 BY ago), the average oceanic temperature declined to 28 °C, whereas average temperature on the continents, due to their lower standing level increased to 25 °C. During the formation of Wegener's Pangaea supercontinent (≈200 MY ago) the temperatures declined, respectively, to 23 °C and 19 °C. In-between supercontinent formation periods, the average temperatures at sea level and on the continents declined by 7° to 10 °C.

At the beginning of the oldest glaciation era (Archean, ≈3.9 to 3.7 BY ago), a young sea basin and embryonic future continental shield emerged and was positioned within a relatively narrow equatorial belt. As a result,

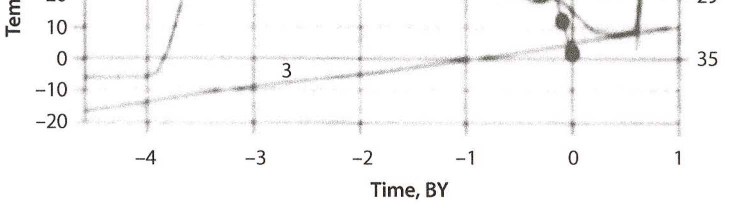

Figure 14.5 Isotopic temperature for ocean flints superposed on a theoretical curve of Earth's climate evolution. *Curve 1* – average theoretical curve of the Earth's temperature evolution at the oceanic surface (see Figure 14.5, curve 1); *Curve 2* – Oxygen δ^{18}O isotope shifts found in sea flints (see Figure 1.3, solid black dots, after Schopf, 1982) and estimated temperature of the depth of benthic water where the sea flints were deposited; *Curve 3* – Temperature of an absolutely black body at the Earth-Sun distance describing Sun luminosity (see Figure 1.10).

the sea basins of that time were warm, with temperatures ranging from (3° to 5 °C) to 20 °C (see Figure 14.4). The altitude of these young continental mountains may have reached an altitude of 3 to 4 km (Figure 14.5). Being on the equator and despite the general warming of the temperature of the Earth, the mountain temperatures were likely negative. The evidence of glaciations which did emerge in these elevated formations is local in nature; however, these glaciers are limited because it appears that there was very little liquid water present on the Earth. The authors suggest this may be an explanation of why there are no traces of early Archaean glaciation.

The Middle Archaean glaciation occurred, ≈2.9 BY ago (Figure 14.6), as the Earth's tectonic activity and the atmospheric pressure decreased (see Figures 4.4 and 5.3). The glaciation might have been developing in high and moderate latitudes, as the Earth's tectonic activity had broadened to latitudes in the range of ±40° to 50°. The young continental shields at the latitudes could have also drifted. At the same time, their standing height increased to 5.5 to 6 km (Figure 14.5). In the Middle Archaean time, the amount of water in the ocean basins significantly increased (see Figure 5.12). The temperature increased by 30° to 40 °C, increasing the evaporation. Therefore, the high-mountain glaciation in the Middle Archaean time most likely could have been accompanied by the formation of small ice sheets, which have left their footprint in the Earth's geologic record.

Sorokhtin (2004) noted that genuine oceans, although not very deep (only up to 1 km), emerged in the Early Proterozoic time. The continental stand remained rather high, ranging from 2 to 4 or 5 km (Figure 14.5).

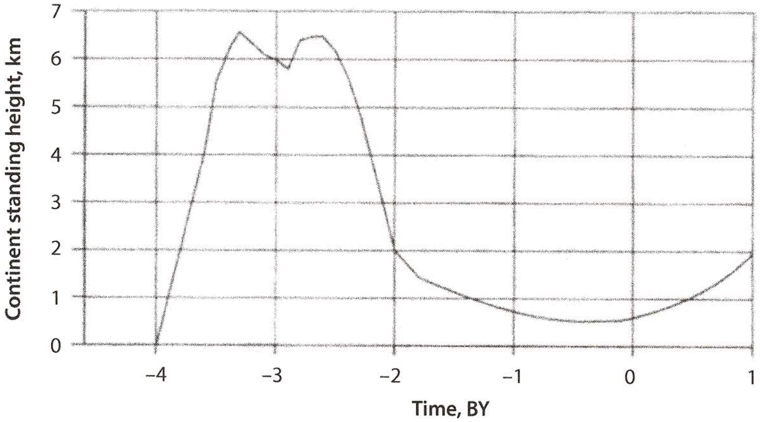

Figure 14.6 The standing height of continents versus time.

In the beginning of the third identified glaciation era (Huron glaciation, group III in Figure 14.6) glaciation sheets developed in all latitudes.

By the end of the third glaciation era, the first in the Earth's history, supercontinent Monogaea disintegrated. Its fragments, which had stood high above the sea level, had been scattered over all the Earth's surface. After this disintegration of the supercontinent, in the middle of the third glaciation era, 2.4 to 2.1 BY ago, the ice sheets probably formed on all continental massifs regardless of their latitude. Glacial deposits of this age testify to the nature of glaciations now found on today's continents. This includes several locations: in North America, the North American Huron formation; in Europe, the Baltic Shield; in South Africa, formations of Transvaal and Griqualand; and in Western Australia, Turi formation. In each of these regions, the glaciation age is almost identical, 2.4 to 2.2 BY ago.

During the time interval of 2 to 1 BY ago as shown in Figure 14.6, negative average annual temperatures did not exist on the Earth. Therefore, continental glaciation should not have occurred. Chumakov (2004) showed that there were no traces of glaciation existing in the horizons of Lower Proterozoic, Early Riphean, and most of the Middle Riphean. This was an extended glacier-free period in the Earth's evolution.

In the Late Riphean and Paleozoic, a new era of continental glaciation began. This period was associated with a notable cooling of the Earth's climate (see group IV in Figure 14.6). Vast snow-covered territories at the poles with a high albedo (around 0.7) resulted in substantially lower temperatures.

Despite rather severe continental glaciations, there were no stable marine glaciations (similar to those of the present-day, e.g., Arctic Ocean) either in the Late Riphean or in Paleozoic. That was because the circumpolar areas of the oceans and seas, at that time, had only a slightly negative average annual temperature. For that reason, melting occurred during the interglacial periods (see Figure 14.4).

The last and fifth glaciation period began in the middle of Cenozoic (≈40 MY ago), which was the most extensive in the Earth's history. The fifth glaciation era continues today. This is the last one in the Earth's history (group V, Figure 14.3). The first sea glaciations in the Earth's history occurred in the Oligocene and Miocene, in the Arctic Ocean and in portions of the Southern Ocean (shelf glacier covers in the Ross and Weddell seas). As a result, there was a substantial temperature decline of the near-bottom ocean water (16 °C to today's 2 °C) between the Paleocene and Eocene period.

Climate cooling existed during the Pleistocene on those continents positioned close to the poles. This resulted in negative average annual

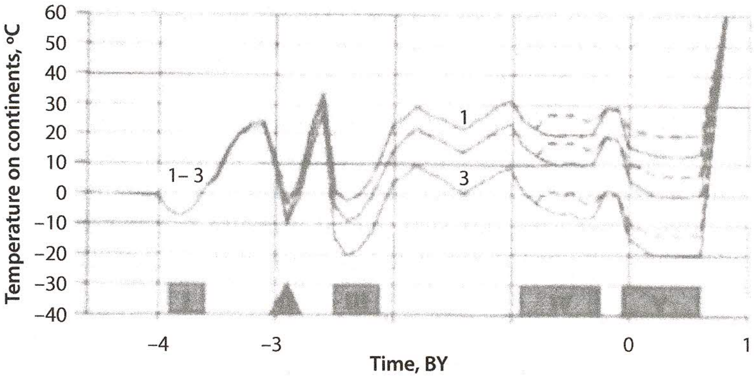

Figure 14.7 Evolution of the Earth's surface temperature for the continents caused by the mutual influence of: *Curve 1* – evolution of Earth's atmosphere; *Curve 2* – standing height of continents (see Figure 14.6); and Curve 3 – variation in the angle of precession (Figure 14.3). Temperatures calculated at: *Curve 1* – temperature at the Earth's equator of the continents; *Curve 2* – average temperature of continents; and *Curve 3* – temperature at the continental poles. Dashed line indicates temperatures during the interglacial periods I to VI: Periods of glaciation on high mountains. (After Chumakov, 2004.)

temperatures. As a result, the ice-sheets had to emerge on the continents. If the areal extent of these ice sheets had been significant, the albedo of the ice-sheet snow cover rendered an impact. Depending on the elevation of the glacial cover, the average temperatures above them dropped to −40 °C and at times, even −60 °C.

Verification of the theoretical estimates for the average temperatures on the surface of the ice sheets were obtained by comparing the estimates to the experimental data. Wells were drilled to obtain ice cores to determine the annual average temperatures $\overline{T}$ in the central areas of the Antarctic where possible the sea cyclones do not reach. Kotlyavov (2000) measured temperatures at Dome-C, ≈3.24 km above the sea level, $\overline{T} = -53$ °C, and the Komsomolskaya and Vostok station, elevation 3.5 km above sea level, at a temperature, $\overline{T} = -55$ °C and −55.5 °C. O. G. Sorokhtin and A.P. Kapitsa measured a temperature of $\overline{T} = -60$ °C on the summit of the main Antarctic dome, at an elevation of 4 km above sea level. The theoretical temperature values for the same elevations are, respectively, −54.6°, −55.7° and −62.3 °C, which are close to the measured data.

The question arises as to why there was a warm climatic interval between two severe glacial periods at the end of the Mesozoic: between the Riphean-Paleozoic and the late Cenozoic era. The origin of this warm period was associated with two factors: (1) the formation of the supercontinent Pangaea, and (2) increased generation of biogenic oxygen.

The climate evolution theory expounded here indicates a substantial role of living organisms in the formation of the Earth's climates. The nitrogen-consuming bacteria have especially affected the global Earth's climate in the Late Proterozoic and Phanerozoic time. Their life-sustaining activity has more than halved the nitrogen partial pressure in the Earth's atmosphere. This lowering of the pressure has resulted in a significant cooling and emergence of glaciations in high and moderate latitudes of the continental Proterozoic and Phanerozoic. Generation of biogenic oxygen by phytoplankton and land vegetation during the Phanerozoic time gave rise to the blossoming of highly organized life on the Earth and partly compensated for the decline in partial pressure of nitrogen. That was the reason for a notable climate warming period occurred at the end of Mesozoic. However, after reaching by oxygen the maximum (equilibrium) pressure level of about 0.231 atm, a new atmospheric pressure decline and, thus, a new cooling era, with the succession of glacial epochs had begun.

Thus, the primary causes of the Earth's climate change have been a: (1) gradual decline in the atmospheric pressure due to life-sustaining activity of nitrogen-consuming bacteria; (2) variations in the precession angle; and (3) variations of the Sun activity.