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Chapter 15
The Uplift of the Himalaya-Tibetan Plateau and Human Evolution: An Overview on the Connection Among the Tectonics, Eco-Climate System and Human Evolution During the Neogene Through the Quaternary Period

Tetsuzo Yasunari

Abstract This paper reviews the recent studies on the uplift of the Tibet-Himalaya mountains (TH) and its association with the human origin and evolution through the climate and ecosystem changes in Afro-Eurasian continents.

The uplift of TH since the late Tertiary Era gradually formed the Asian monsoon system and dry climate in southwest Asia through North Africa. Meanwhile, during 5–10 Ma the formation of the Rift valley of east Africa brought about drier climate and grassland in the equatorial east Africa, which has an important implication to the early hominid evolution. The uplift of TH also caused and/or enhanced decrease of atmospheric CO_2 content through chemical weathering of mountain slopes, which has induced colder climate through the late Tertiary to the Quaternary Era. The lowering of CO_2 content caused expansion of grassland of the C4-plant and associated evolution of Ungulata (e.g., antelope), which may have also affected the early hominid evolution.

The Quaternary period was characterized with glacial cycles of 40–100k year periods. The ice/snow albedo feedback of Tibetan Plateau may have played as an amplifier of the climate change of this Era. Large temporal and spatial variability of wet/dry zones in east Africa affected by the glacial cycles is very likely to induce further evolution and diffusion, including the migration to Eurasia. During this period, the cold climate and weakened Asian monsoon formed a broad zone of steppe and grassland in central Asia through Europe, and enabled large variety of herbivorous mammals there. The codependent relation between these mammals and the hominid species was essential for the evolution of the later hominid species (Homo erectus) to the modern hominid (Homo sapiens).

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Under the warm and stable climate of the Holocene since 10 ka the modern hominid heuristically started agriculture and civilization, which has, however, been a new epoch called "the Anthropocene" when the human beings are changing the earth system itself.

15.1 Introduction

Recent research into the origins and evolution of humans is making great progress with the addition of new methods such as the molecular clock and DNA analysis. It is thought that seven million years ago during the latter half of the Neogene period of the present Cenozoic Era Hominia, the direct ancestors of humankind, branched off from subhuman primates in equatorial Africa. The Quaternary period (since approximately 2.6 million years ago up to present) is defined as the period when humans started to become active. Due to recent progress in geosciences including stable isotope analysis and numerical experiments using climate models, we are coming to realize that, during the time from the latter half of the Neogene period to the Quaternary period when humans originated and evolved, an uplift of the Tibetan and Himalayan massif and tectonic changes in the African region started, leading to enormous changes in the climate and environment of the Afro-Eurasian continent.

This paper attempts a comprehensive view on the global-scale tectonic changes centering on the uplift of the Himalayan mountains and the Tibetan Plateau (hereafter called HTP) and how the resultant changes in climate and the biosphere regulated or encouraged the origins and evolution of humankind, by reviewing the recent results of research in geoscience, paleoclimatology and paleoecology, and anthropology.

15.2 The Origin and Evolution of Humans and Environmental Change – Why Africa?

It was Molnar, famous for his research in the tectonics of Tibet and the Himalayas, who first pointed out the possible connection between the uplift of the HTP from the Neogene period to the Quaternary period and the origin and evolution of humans (Molnar 1990). Figure 15.1 shows the average height evolution of the HTP from the start of the Eocene epoch (60Ma: 60 Million Years Ago) to the present and the changes in human brain size since the Miocene epoch (40 Ma) (from the ape-man Australopithecus to the modern man Homo sapiens). Molnar suggested that both these figures show a sudden increase toward modernity, particularly after the Late Neogene period, and that rather than mere coincidence, the global scale tectonic

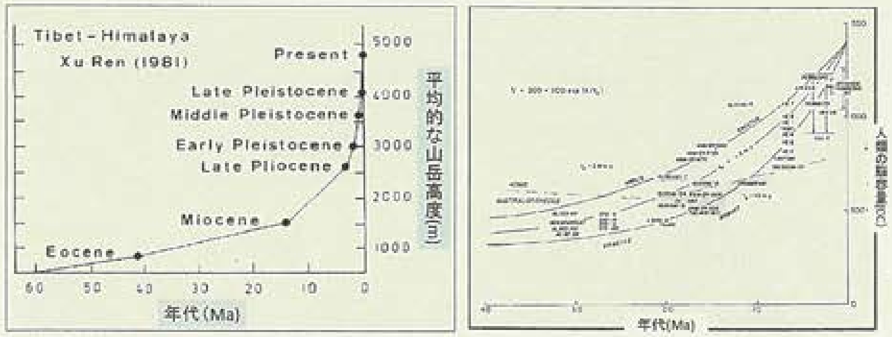

Fig. 15.1 Left: The average altitude of the Tibetan and Himalayan massif from the second half of the Quaternary (60 Ma) and (right) changes in the capacity of human brains since the end of the Late Tertiary (4 Ma). The continuous line shows changes based on various inferences, and the broken line divides the Australopithecus and Homo genus. (Modified the figure by Molnar 1990)

changes typified by the uplift of the HTP and human evolution may have a close relationship. Of course, the latest findings of both geoscience and anthropology indicate, as we shall see later, that the relationship between the Earth's tectonic changes and the associated climatic and environmental changes and human evolution is not that simple.

The ancestors of humans branched off from the apes several million years ago as ape-men (Australopithecus) (DeMenocal 2004). From this start, there emerged primitive man, paleanthropic man (Neanderthals), and over a hundred thousand years ago, our direct ancestor, modern man (Homo sapiens). Recent anthropology has reconsidered these distinctions, but this paper will avoid getting into these questions, using designations like primitive man and modern man as they are. Rather, what I want to consider here is why Africa was the stage where ape-man emerged and evolved through primitive man to modern man. If humans evolved from the relatives of apes inhabiting tropical rain forests, then humans should have originated from South America or Southeast Asia. Here, the distribution of continents and oceans in the Eocene (50 ma) and the Miocene (20 Ma) when the mountains started to rise (Fig. 15.2). At the start of the Eocene, there were already tropical rain forests on all the continents around the equator, where primates would have inhabited. However, the continent of South America was still separated from the North American continent, and the African continent was also separated from the Eurasian continent by the Tethys Sea (the ancient Mediterranean). The tropical and subtropical forests were extended over a wide area from the equator to the subtropical zone of Southeast Asia due to the monsoon climate that already existed along the Southeast and East Asian coast. During the Miocene era, the Tethys Sea closed, and the African continent were joined to the Eurasian continent, and a subtropical arid or semi-arid area were

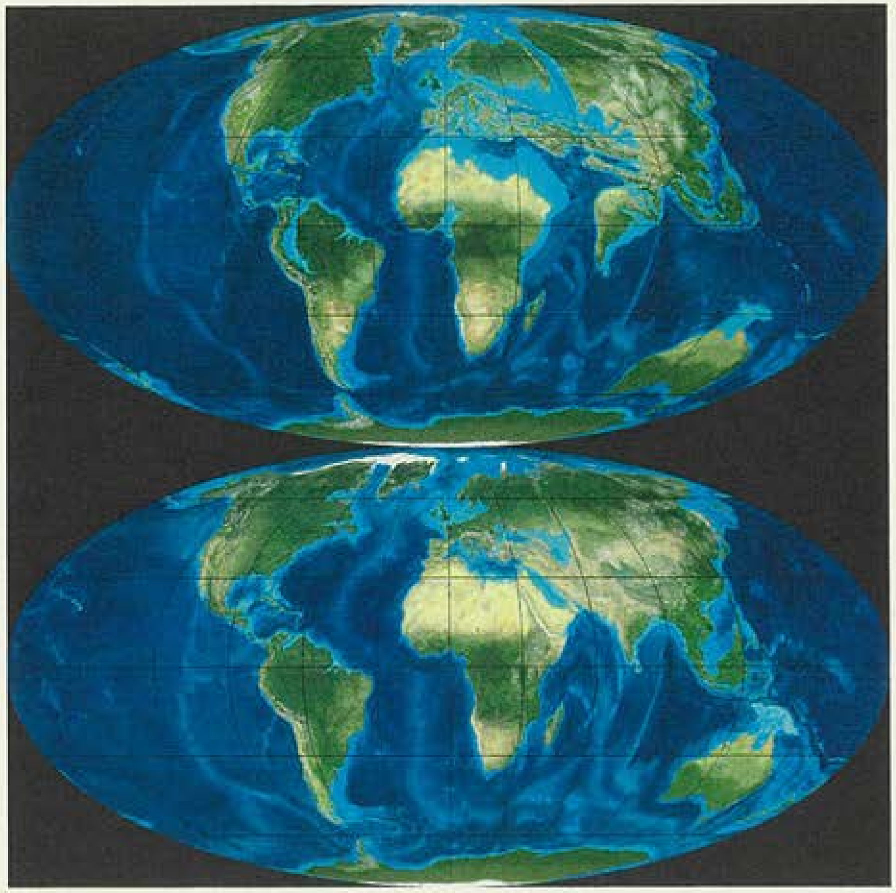

Fig. 15.2 Distribution of sea and land around the Paleogene Eocene (50 Ma) and the Neogene Miocene (20 Ma). http://en.wikipedia.org/wiki/File:Neogene-MioceneGlobal.jpg

gradually expanding between both continents. This geographical contrast of climate and ecosystem in the Southeast Asia through African tropics may be very important for the issue of human evolution. In the late Neogene era, the uplift of the HTP became more pronounced. As will be discussed in the next, the differences in climate and ecosystems between the African and Southeast Asian tropics was further reinforced. It is likely that these differences have a profound implication for the environmental conditions that enabled the origin and evolution of humans on the African continent.

15.3 Uplift of the HTP and Global Climate Change in the Neogene Period

15.3.1 When Did the Uplift of the HTP Occur?

After the Indian subcontinent (the Indian Plate) collided with the Eurasian continent at 50 Ma, the uplift of the HTP began, and by 20 Ma, mountains of a certain height had already formed (Fig. 15.2). At this time, the Tethys Sea had already disappeared, and the African continent and Eurasian continent were largely joined. Not only the HTP but also the world's main mountains existing today such as the Rockies, the Andes, and the Alps, started their upheaval at almost the same time.

In the past few decades there has been much discussion on the tectonics of the Himalayan uplift and the formation of the Tibetan plateau. Some recent research has suggested that uplift proceeded after 50 Ma when the Indian subcontinent (plate) collided with the Eurasian continent, and the mountains were already quite high in the Neogene period (from 23 Ma). For example, based on tectonic dynamics and structural geological research, Molnar et al. (1993) assume that by up to 8 Ma, they had reached heights of around 1000–2500 m on average. Other geological surveys estimated that a significant portion of the plateau had already reached its current height around 11–14 Ma (Sakai 2005; Sakai et al. 2006). From isotopic analysis of water in lakes on the Tibetan plateau, Rowley and Currie (2006) estimated that the area from the Himalayas to the southern part of the plateau had already reached its current height around 35 Ma, and gradually expanded northward. Wang et al. (2008) assumed that although the central part of the plateau was already at its current height in the period before 30 Ma, the uplift of the northern part of the plateau and the southernmost part of the Himalayas was more recent, from 10 Ma onwards. On the other hand, from analysis of the teeth of herbivorous animals that inhabited the plateau around 7 Ma, Wang et al. (2006),for example, assume that they were eating carbon fixing plants (described below) that prefer a warmer climate, so it was at most about 3000 m high, and after 7 Ma, it rose considerably to today's height. For this reason, much discussion continues today concerning the characteristics of the vast Himalayan region, such as when and how high it reached, and conclusive results have yet to emerge. However, when we consider the impact of this massif on the global climate, average elevation is an only one of the important indices. To evaluate moisture transportation to the plateau and the influence on the atmosphere, it is also important whether the Tibetan plateau was widely covered with vegetation, and the height of the Himalayas, which act as a barrier of moisture transport to the Tibetan plateau.

15.3.2 *Reduction of CO_2 Concentration and Cooling of the Climate in the Cenozoic Era*

Here, we discuss the temperature trend of the Earth as a whole in the whole Cenozoic Era. Figure 15.3 shows the change global deep ocean temperature estimated from changes in the oxygen isotope ratio ($\delta^{18}O$) (Zachos et al. 2001) from 60 Ma to the present. This figure clearly shows global cooling trend after a warm peak around 50 Ma. The change in temperature from around 40 Ma to 10 Ma appears to be associated with the formation of the Antarctic ice sheet, its melting and re-expansion, linked to the separation of Antarctica. Then from 10 Ma (Mid Miocene) through the Quaternary period, there was significant cooling up to the present, and we are now coming to realize that the uplift of the HTP made a significant contribution.

The remarkable uplift of the HTP between subtropical and tropical areas simultaneously caused intense weathering and erosion of its slopes by rain and river water. As we will explain next, the uplift of this massif strengthened the monsoon, and heavy rain intensified the weathering and erosion of its slopes. Silicate, a principal constituent of rock, captures atmospheric CO_2 in the process of chemical weathering, generating calcium carbonate and silicic acid, which are washed away by the water. Through this weathering and erosion, the uplift of the mountains works to reduce the CO_2 concentration in the global atmosphere. The overall global cooling from the second half of the Tertiary (around 10 Ma) to the Quaternary period seen in Fig. 15.3 is basically due to the reduction in atmospheric CO_2 concentration from the active weathering and erosion of the HTP, and associated weakening of the greenhouse effect (Molnar and England 1990; Raymo and Ruddiman 1992). What is notable here is that, as shown in Fig. 15.4, C_3 and C_4 plants that have different photosynthesis and physiological characteristics predominate, according to the atmospheric CO_2 concentration and growing season temperature. C_3 plants are those with conventional photosynthetic characteristics. C_4 plants incorporate a cycle called the C_4 pathway for further concentrating CO_2, for more efficient photosynthesis (CO_2 absorption) than C_3 plants. In addition, C_4 plants photosynthesize more efficiently than C_3 plants in arid climates with harsh moisture conditions, and as Fig. 15.4 shows, they are highly adaptable to a low-CO_2 atmosphere. In particular, around 6–8 Ma, there was a change in grasslands in arid areas in all parts of the world from C_3 plants that prefer high concentrations of CO_2 to C_4 plants that are adapted to low CO_2 concentrations. It is inferred that at this time, concentrations of atmospheric CO_2 were declining on a global level due to weathering and erosion (Cerling et al. 1993, 1997). The cooling of the climate due to a decline in CO_2 levels through the weathering process as a result of the uplift of the HTP is an important condition for the emergence of glacial cycles as explained in Fig. 15.4. However, the fact that humans evolved at the same time as this cooling of the climate has interesting implications considering current global environmental issues.

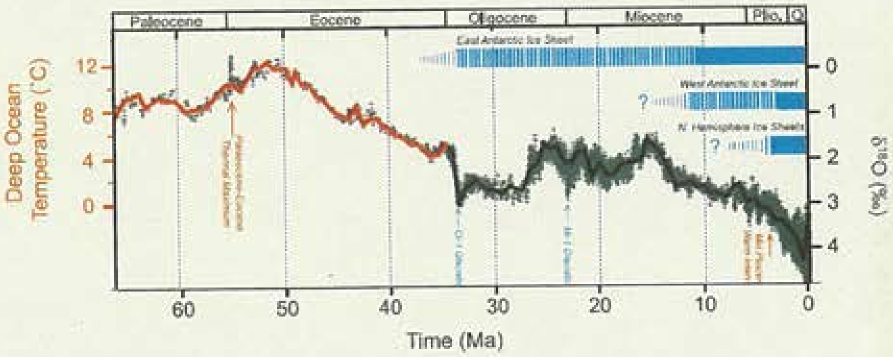

Fig. 15.3 Changes in the global sea temperature in the past 65 million years from the Tertiary to the Quaternary period (today) based on oxygen isotope ratios (Delta-O18) of marine sediment cores. Particularly rapid cooling from around the Late Tertiary (5 Ma) is noticeable. (Some changes made to the figure by Zachos et al. (2001) found in the report by the IPCC (2007))

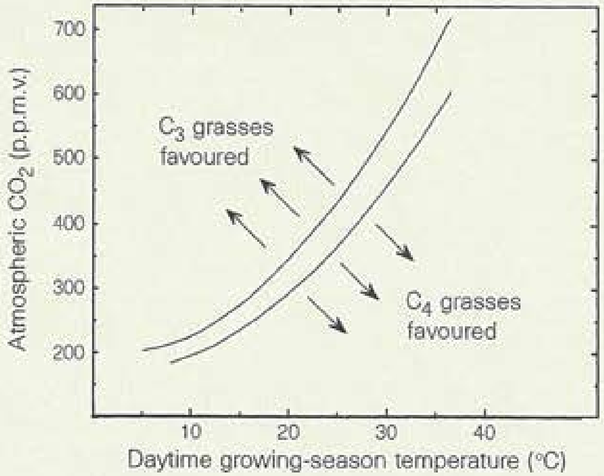

Fig. 15.4 Prevalence of herbaceous C_3 and C_4 plants with temperature (daytime temperature in the growth phase) and atmospheric CO_2 concentration as functions (Cerling et al. 1997)

15.3.3 *The Emergence of the Asian Monsoon and an Arid Climate*

Since the 1970s, numerical simulations by General Circulation Models (GCMs) have already demonstrated that the vast mountain massif of the HTP located in the relatively low latitude subtropics generates a vast monsoon climate over a broad area of the Eurasian continent from the south to the east of the HTP, and an arid climate on its west and northwest side, due to the thermal and dynamical effects induced by the orography of the HTP (Hahn and Manabe 1975; Manabe and Broccoli 1990; Ruddiman 1997). The author's group conducted more quantitative research through numerical simulation with a Coupled General Circulation Model (CGCM), to determine how different (mean) heights of the HTP affect climate formation, including the interactive processes how change of atmospheric circulation affect ocean circulation through atmosphere-ocean interaction, and its feed back to the atmosphere (Abe et al. 2003, 2004, 2005). As shown in Fig. 15.5, the results of these numerical simulations indicate that the Asian monsoon becomes pronounced when the average height of the HTP is about 60% of their current elevation, and the arid land extending to the west of the Tibetan plateau also appears in tandem with the occurrence of the Asian monsoon, at largely the same time. By combining these results by the climate model studies with those inferred from the paleoclimatology and paleoecology of the Asian and African regions (e.g., An et al. 2001), we can approximately estimate the chronology of tectonic evolution (uplift) of the HTP and relevant climate formation. These studies show that as the climate of this region, about 7–10 Ma, a monsoon close to today's Indian monsoon (South Asia) was formed, and almost simultaneously, the arid areas of North Africa, Southwest and Central Asia also appeared (Sakai 2005). Some paleo-ecological studies also show that flora and fauna indicating an arid climate emerged in significant numbers in this region from approximately 10 Ma (Cerling et al. 1993; Amer and Kumazawa 2005). Through these results we can estimate that at this time, the Tibetan plateau had reached about 60% of its average height.

On the other hand, in largely tropical East Africa, around the time when the Great Rift Valley stretching 7000 km north to south formed (5–10 Ma), a long plateau with a total height of 1000–2000 m was formed, with a 5000 m volcano at its western tip and deep gorges. Increased uplift of the East African plateau since ~15–10 Ma might be connected to climate change in East Africa and human evolution. The uplifting East African plateau intercepted those winds and contributed to the increased aridification of East Africa (Ring 2018). The results of the numerical simulation of the authors using the CGCM climate model (Abe et al. 2003) indicated that this East African plateau forms a barrier to the damp easterlies over the equatorial Indian Ocean, and causes the aridification of equatorial East Africa, playing a significant role in the formation of today's savanna climate as shown in Fig. 15.6.

It is noteworthy to state that the formation of this East African plateau (and the Great Rift Valley) and the remarkable uplift of the Himalayas and Tibetan plateau inferred from the speed of weathering and erosion (with the associated change in CO_2 concentration) are likely to have occurred nearly simultaneously. These huge tectonic event in Afro-Eurasian continents may have caused enhanced South Asian summer monsoon, desert climate in central to west Asia (An et al. 2001), and the appearance of expansive arid Savanna climate of East Africa (savanna) at almost the same time, around 5–10 Ma.

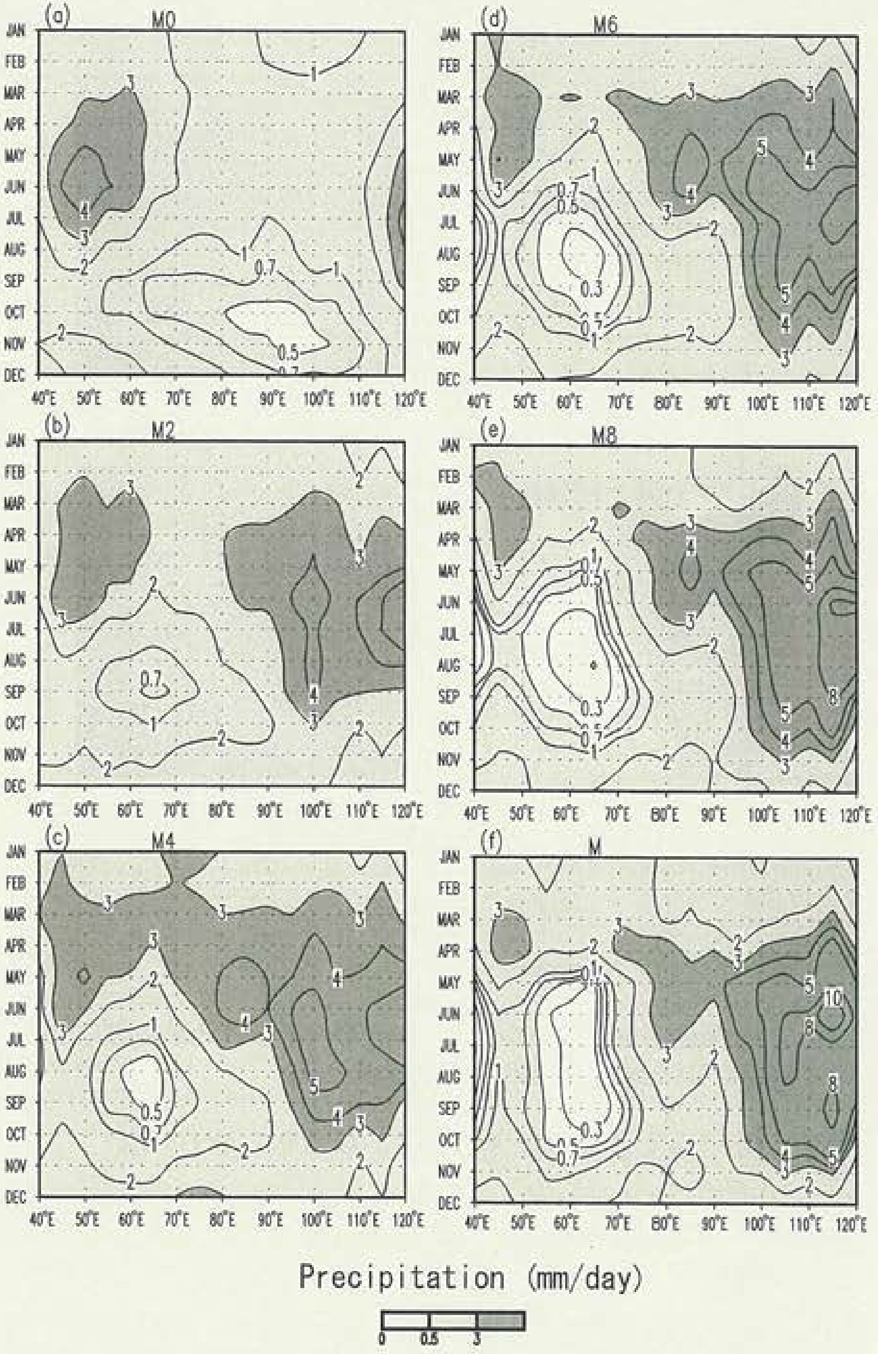

Fig. 15.5 Changes in the summer monsoon (June to August) precipitation along Northern latitude 30–45 N when the average height of the Himalayas and Tibetan plateau is changed. When average altitude of the massif is (**a**) 0% of today (M0 no mountains), (**b**) 20% (M2), (**c**) 40% (M4), (**d**) 60% (M6), (**e**) 80% (M8), (**f**) 100% (current M altitude) (Abe et al. 2005). The unit is mm/day. Dark hatching shows regions with 3 mm/day or more, and white space shows regions with 0.5 mm/day or less. (Abe et al. 2005)

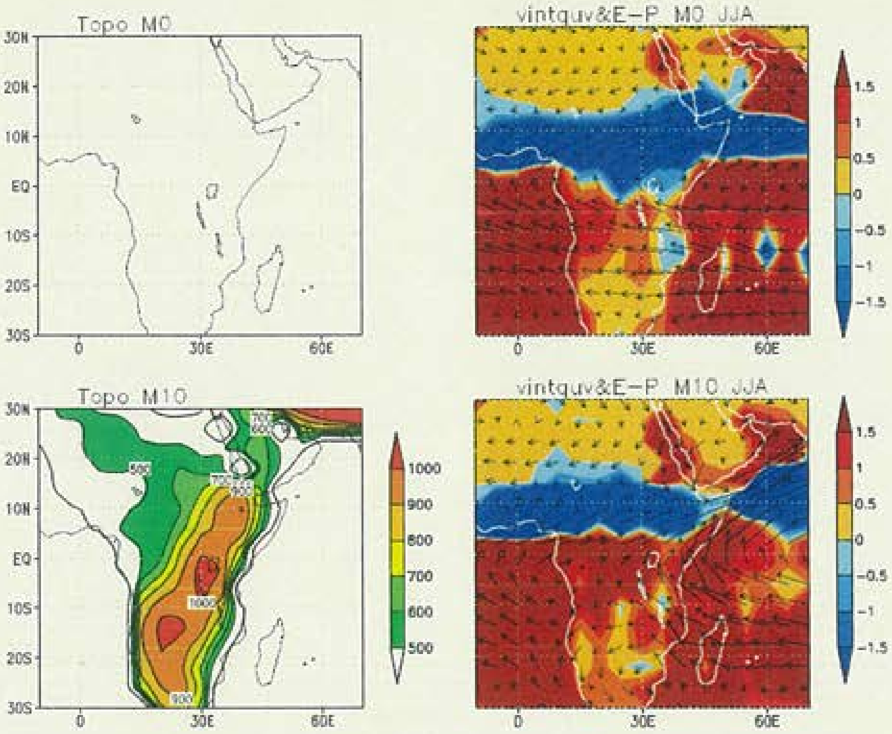

Fig. 15.6 Changes in Northern Hemisphere summer (JJA) precipitation in the CGCM when there was no East African plateau (top right) and today (M10) (bottom right). Blue is the real precipitation (P-E). The arrows show the lower atmosphere wind vectors. The left is the terrain elevation used for numerical modeling. (Drawn with the simulated data from Abe et al. (2003))

15.4 The Quaternary Period Glacial Cycle and the Role of the Himalayas and Tibetan plateau

15.4.1 The Start of the Ice Age and a 40,000-Year Glacial Cycle

The Quaternary period is defined as the newest epoch in the history of the Earth, including the present, when humans appeared and started their explosive evolution. Its start has recently been revised from 1.8 Ma to 2.6 Ma (Gibbard et al. 2009). At almost the same time, the climate of the entire globe cooled, and in the northern hemisphere, ice sheets and glaciers repeatedly expanded and contracted in an ice age. The timing of human evolution and the ice age correspond, but as we noted earlier, rather than mere coincidence, they have a necessary relationship.

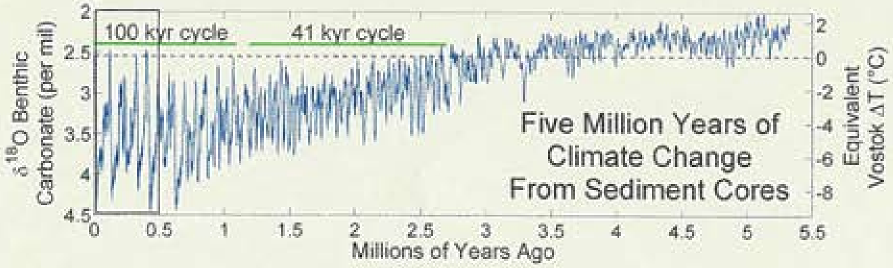

Fig. 15.7 Global temperature change for the past 5.5 million years. Dashed lines show the average temperature of today's Earth. (Lisiecki and Raymo 2005)

Figure 15.7 shows the global temperature changes since 5.5 Ma (Lisiecki and Raymo 2005). It shows that from around 2.5 to 3 Ma, the trend in declining temperature strengthened, and variations also became larger. In the first half of the period from 5.5 to 2.5 Ma, the cycles ranged from 20,000 to 30,000 years with small amplitude, but in the first half of the Quaternary period from 2.5 to 1 Ma, 40,000-year cycles, and from 1 Ma to the present, 100,000-year cycles become prominent, with very large amplitude.

The mechanism behind the modulation of these ice age climate cycles occured is still widely debated, but the basic mechanism for this modulation is thought to be attributed to long-term seasonal changes in the flux of solar radiation on the Earth's surface and the complex variation in latitude distribution resulting from a combination of the periodic movement of eccentricity, axial tilt, precession that make up the Earth's orbital elements (the elements that determine the characteristics of its revolutionary movement), caused by the nonlinear interaction of the attraction of the Earth, Sun and other planets in the solar system. This variation is called the Milankovitch cycle, after Milankovitch who first identified the mechanism. Orbital eccentricity has a cycle of about 100,000 years and about 400,000 years, axial tilt about 41,000 years, and precession about 20,000 years (Milankovitch 1941). Recent studies have suggested that the flux of solar radiation due to the Milankovitch cycle has a complex non-linear relationships between the climate, the continental ice sheets and the lithosphere–asthenosphere system, combined with changes in atmospheric greenhouse gas composition (e.g., CO_2), which are thought to cause these changes and modulations (Lisiecki and Raymo 2005; Abe-Ouchi 2013).

What, then, caused initiation of the cold glacial period in the Quaternary period? As we explained in Sect. 15.3.2, the decrease in atmospheric CO_2 concentration (weakening of the greenhouse effect) due to weathering and erosion accompanying the uplift of the Himalayas and Tibetan plateau and the cooling trend should have been important conditions, but no conclusive answers have been found for the emergence of glacial cycles. Currently the Earth's tilt is 23.5 °, but it moves in a range from 22.5 ° to 24.5 °. In the first half of the Quaternary period (2.6 to 1 Ma), a glacial cycle continued, corresponding to variations in axial tilt on an approximately

40,000-year cycle. In periods when the tilt is small, latitudes with enormous insolation come to the low latitude side, so there is a possibility that the south-north temperature gradient increases. However, a change in some sort of mechanism within the climate system that reduces south-north heat transport efficiency (the strength of heat transport) is necessary for the polar regions to become colder. Tectonic changes that occurred at this time (around 3 Ma) included the formation of the Isthmus of Panama (the separation of the Atlantic and Pacific oceans), and the northern edge of the Australia-New Guinea continent reached the equator. The former reinforced the upwelling in the equatorial eastern Pacific Ocean (and increased the east-west water temperature difference), establishing the east-west circulation system (Walker circulation) connecting the atmosphere and ocean in the tropics (Maslin and Christensen 2007). The latter changed the Indonesian throughflow flowing from the Pacific Ocean to the Indian Ocean from the warm seawater originating in the southern Pacific Ocean to the cold seawater originating in the northern Pacific Ocean, reducing the water temperature of the whole equatorial Indian Ocean (Cane and Molnar 2001). These changes are thought to be linked to the start of the glacial period with the 40,000 year period.

In the equatorial Africa, climate change was characterized by a decline in rainfall and aridification in eastern Africa caused by the lower water temperature of the equatorial Indian Ocean (particularly the western Indian Ocean) (Hastenrath et al. 1993; Goddard and Graham 1999). In the tropical Pacific Ocean, it is inferred that the Walker circulation was strengthened about 1.7 Ma, and heat transport to high latitudes was weakened, contributing to cooling and expanded glaciers in polar regions (Molnar and Cane 2002). In the current climate system, dominant fluctuations of the Walker circulation system are reprented as the ENSO (El Niño Southern Oscillation) phenomenon itself, which causes extreme climate events such as drought and heavy rain in the tropics including the African region. This implies that the ENSO cycle may have started in this period, suggesting that the range of interannual variability of the climate in the tropics increased.

On the other hand, it has been proved that the Walker circulation system spanning the Pacific and Indian oceans has a close connection with the Asian monsoon, tending to appear the La Niña (El Niño) phenomenon with strong (weak) Asian monsoons (Yasunari 1990, 1991). Through the simulation using CGCM conducted by the authors (Abe et al. 2003), this coupling of the ENSO and monsoon is shown to be strongly apparent at the time when the mean height of the HTP is about 80% or more of today's height. It can be inferred from recent tectonics research that the HTP had already reached this height level in this period (from 3 Ma). However, as we explain in the next Sect. (15.4.2), the Asian monsoon was generally weak in the glacial period, as indicated both in the paleoclimate data and in climate models. That being the case, how can we interpret the combination of a strong Walker circulation and a weak Asian monsoon in the glacial period, unlike today? As noted above, the east-west gradient of the ocean surface temperature along the equator was maintained, possibly by a mechanism that differs from that today. This issue remains for the future study.

15.4.2 *Dynamics of the 100,000-Year Glacial Cycle and Possible Role of the HTP*

Cooling progressed further in the Quaternary period, and about 1 Ma, a glacial cycle of about 100,000 years prevailed, with very significant expansion of ice sheets and glaciers in the cold periods. The fluctuations of this time scale are well understood in considerable detail based on ocean sediment cores and ice cores from Antarctica and Greenland. Figure 15.8 shows global temperature fluctuations over the past 800,000 years revealed in ice cores from Antarctica (Jouzel et al. 2007). It is known that not only temperature but also mass of snow and ice (ice sheets, glaciers and snowfall) worldwide, seawater temperature, the concentration of CO_2 and CH_4 greenhouse gases in the atmosphere, and so on fluctuated in ways that explain climate warming and cooling. In other words, in this 100,000-year cycle, all elements

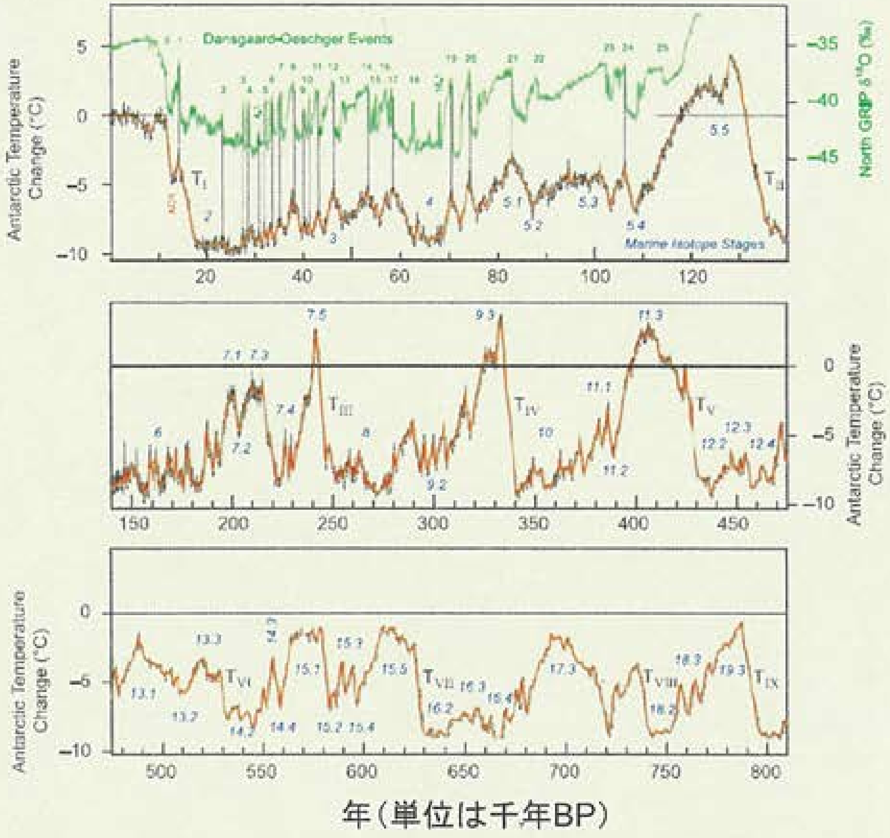

Fig. 15.8 Average temperature of the Earth in the past 810 Kyr reconstructed from Antarctic ice sheet Dome C ice cores. From 120 Kyr, the temperature deviation reconstructed from Greenland ice cores is shown (Jouzel.et al. 2007)

of the global climate including the deep-ocean thermohaline circulation have been involved in the climate system from the polar regions to the tropics. The fluctuations of this cycle have been thought to harmonize with the 100,000-year cycle of the Earth's orbital element (change in eccentricity).

The dynamics of this 100,000 year glacial cycles is still one of the big mysteries in the glaciation of the Quaternary Period. However, numerous studies have pointed to the importance of the modulatory timing by which insolation of summer in the Northern Hemisphere fluctuates significantly due to the nonlinear interaction of the 40,000-year cycle (axial tilt) and/or 20,000-year cycle (precession), which have significant amplitudes. A recent climate model study including ice-sheet dynamics (Abe-Ouchi et al. 2013) has proved that the viscoelastic response of the earth's crust to the continental ice-sheet is essential for producing the 100,000 year cycle. This study also shows that the fluctuations in summer insolation in the Northern Hemisphere plays a key role as a pacemaker of snow-ice sheet cover on the Eurasian and North American continents. The extent of the area covered by snow in summer on the Eurasian and North American continents, which constitute the greater part of the land, significantly affects global-scale surface heat balance, by controlling insolation through the albedo (reflection rate of solar radiation) effect of snow. In current summers, accumulated snow largely disappears from the continents. However, if it were to remain over a fairly wide area even in the summer, it would trigger climate cooling on a global scale, with the expansion of ice sheets and glaciers at high latitudes. This particular study (Abe-Ouchi et al. 2013) emphasizes the effect of stagnant snow cover in summer on the North American continent, where quasi-stationary cold trough can easily be formed due to the orographic effect of the Rockies.

However, our previous study by using a GCM (Yasunari et al. 1991) showed that a remarkable atmospheric teleconnection pattern over the north Pacific through the North American continent is likely to be induced by the anomalous snow cover over the Tibetan Plateau and East Asia during spring through late summer. These circulation patterns with anomalous cold trough over Canada are responsible for the considerable decrease of surface temperature particularly over the northeastern part of North America. These results are partly supported by the observed circulation anomalies associated with the weak Asian monsoon condition (Yasunari and Seki 1992). These evidences suggest the possible role of the anomalous snow cover over Eurasia on the initiation of the glacial period of the 100,000 year cycle. The authors also carried out a numerical simulation using the CGCM to investigate the possibility that the extent of snow on the Tibetan plateau 115 ka when insolation was at its lowest in the Northern Hemisphere summer after rapid cooling from the peak of the interglacial period about 120 ka shown in Fig. 15.8 may have contributed to global scale cooling. The results showed that from 120 ka to 115 ka, the change in solar radiation in summer reduced summer temperatures on the continents of the Northern Hemisphere by 5–8 °C, the presence of snow on the plateau reduced temperatures particularly at mid and low latitudes by a further several degrees, and the extent of snow around the North Pole expanded, which persisted from year to year (Yasunari et al. 2006). These studies suggest that the albedo effect of the sufficiently high Tibetan plateau at relatively low latitudes effectively may effectively reduce the absorption of solar radiation at the Earth's surface, and further promoted a temperature drop on a hemispheric scale, representing an important element causing glacial-interglacial cycles.

Under the current climate, the area of snow cover over the Tibetan plateau in summer is very small, with the majority bare ground without snow. This absorbs large amounts of solar radiation, becoming a strong heat source for the atmosphere, as explained in Sect. 15.3.3. However, if snow remained over the entire plateau throughout the summer, it might weaken the Asian monsoon, as well as cooling the atmosphere of the whole Northern Hemisphere, changing atmospheric circulation significantly, even in the north America through the atmospheric teleconnection (Yasunari et al. 1991).

15.5 Changes in the Climatic and Environmental Conditions Related to the ORIGIN and evolution of Humans

15.5.1 Climatic and Ecological Changes Prompting the Origin of Humans (Ape-Men)

The definition of an ape-man, considered as the ancestor of humans, is upright bipedal walking, and degeneration (reduction) of the canine teeth (Mitsui 2005). According to this definition, ape-men are said to have emerged 5–7 Ma, in equatorial East Africa. Around that time, as described in Sect. 15.3.2, the formation of the Great Rift Valley in East Africa stretching for several thousand kilometers from Ethiopia to South Africa caused the aridification of the regional climate. The shift from forests to grasslands caused the primates of the area to start walking on two feet, becoming ape-men. This is the so-called "East Side Story". But when an older ape-man (Sahelanthropus tchadensis) was discovered near Lake Chad in the Sahel region of West Africa, this theory came into doubt. However, the East-West contrast between the humid Asian monsoon in the East, and the dry climate in the West was intensified at this time due to the rise of the HTP, and it is possible that the whole North African region including Lake Chad entered an arid period.

What needs to be clarified is what necessity for survival drove the first humans to walk upright due to the change in climate and ecosystem from forest to grassland. In both East Africa and around Lake Chad, there was probably a long period during which gradual aridification changed the ecosystem from forest to mixed grasslands and lakes. The aridification at this time (6–8 Ma) probably lead to the sudden spread of grasslands of C_4 plants suited to low CO_2 concentrations (Cerling et al. 1993), promoting the evolution of today's herbivorous fauna (and carnivorous animal groups as their predators). In this kind of ecological environment, if we assume that it became necessary to switch from simply collecting nuts and berries from trees in the forest to feeding on the grassland animals, then we can assume that the need to hold sticks required walking on two legs. Bipedalism was probably a strategy for survival among the herbivores living in the grasslands and the carnivores that fed on them.

15.5.2 *The Evolution of Primitive Man and Climatic and Ecological Changes from the Late Neogene to the First Half of the Quaternary Period*

The evolution from ape-man to primitive man who actively used tools such as stone tools began around 3 Ma with Australopithecus, followed by Homo habilis and Homo erectus. Evolution continued with the appearance of modern man, Homo sapiens, around 0.1–0.2 Ma. We will not review the study of human evolution any further here. Figure 15.9 shows the evolution from primitive man from 3 to 4 Ma to modern man, with climate change on a global scale and in Africa, and the change in vegetation in East Africa on the same timeline, prepared by DeMenocal (2004).

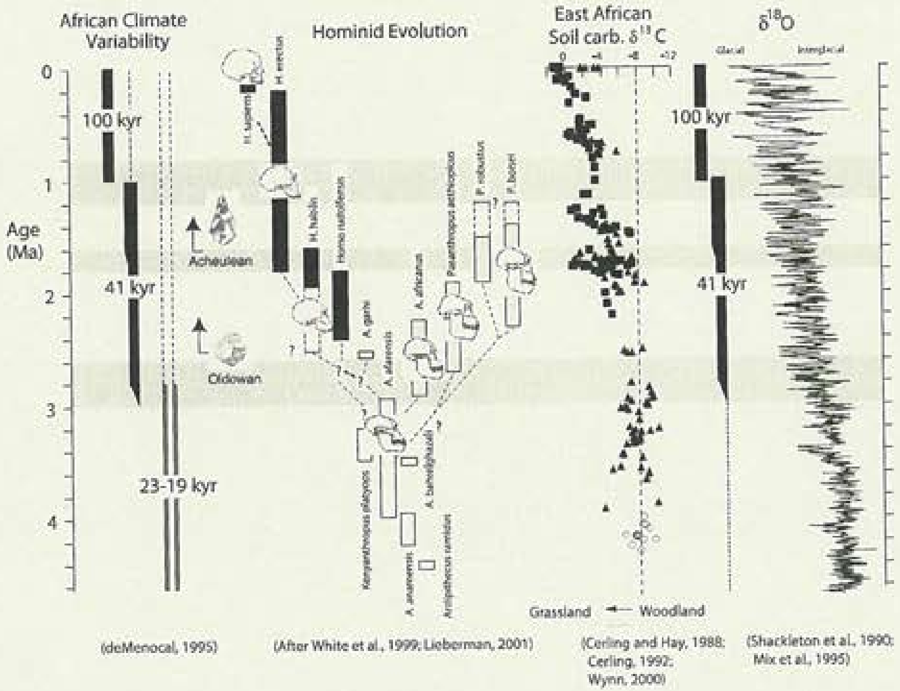

Fig. 15.9 The evolutionary process from hominins to modern man from the Late Tertiary (4.6 Ma) to the present. It also shows variations in the global climate ($\delta^{18}O$) and the process of evolution of East African grassland vegetation ($\delta^{13}C$) at the same time. (DeMenocal 2004)

As this figure makes clear at a glance, from the late Pliocene (5 to 3 Ma) to the first half of the Quaternary period (3 to 1 Ma), various species of Australopithecus emerged, one of which evolved into modern man via Homo habilis and Homo erectus. Paranthropus, with its strong jaw adapted for eating hard nuts and the like diverged at this time, becoming extinct before 1 Ma. This was a time of dramatic differentiation and selection for primitive man. As the figure shows, in this period global cooling occurred, with a 40,000-year glacial cycle becoming prominent (see Sect. 15.4.1). We know that aridification in East Africa progressed around 2.8 Ma, around 1.7 Ma and around 1.0 Ma, gradually changing from forest to grassland. The Quaternary period glacial period began 2.8 Ma when global cooling began. 1.0 Ma roughly corresponds to the period when the 100,000-year glacial cycle began. Around 1.7 Ma, cooling of the western Indian Ocean proceeded due to tropical East-West circulation (due to upwelling), and aridification in East Africa made further advances. This figure strongly suggests that differentiation proceeded in response to these gradual changes in climate and ecosystem, where primitive man evolved into modern man (Homo) including evolution of the use of stone tools, while hominins such as Paranthropus went extinct.

One of the keys to determining the relationship between the aridification of the climate and the evolution (differentiation) of primitive man is the evolution of herbivores such as antelope (the generic name of bovine ungulates including gazelles, impala etc.) in response to changes in the ecosystem (Vrba 1995; DeMenocal 2004). With the shrinking of the forests and expansion of grasslands, these herbivores speciated explosively in periods corresponding roughly to the three stages mentioned above. This probably encouraged the evolution of stone tools and primitive man who hunted them with such tools, while on the other hand, hominins who relied on the forests for food declined. The primitive man Homo erectus, who shifted his focus to hunting, left Africa at this time, and moved to Central Asia, Europe, and East Asia. The background to this was no doubt the deteriorating conditions for hunting and gathering due to changes in flora and fauna resulting from the increasing aridification of the East African climate. In a vast area from North Africa to the Levant region of the Middle East to Central Asia, a dry climate prevailed due to the presence of the HTP (see Sect. 15.3.2). It was already a cold glacial period, and the Asian monsoon was weak and the dry climate in the west was also weakened, resulting in an expansive steppe grassland bordering the desert regions, forming a vast corridor between Southwestern Asia and Central Asia. The northern half of Europe was already covered in ice sheets, while the southern regions were grassland. You can imagine primitive men gradually making their way north in pursuit of the herds on the steppe corridor, or pushing to the East and West. Some primitive men such as Peking Man, discovered at Zhoukoudian in the suburbs of Beijing, are thought to have reached East Asia. Peking Man is said to have used fire, but he was probably unable to withstand the cold climate of the glacial period and died out. Much further south, Java Man is believed to have reached the island of Java in Indonesia. In the glacial period, the level of the South China Sea decreased, and so-called Sundaland emerged. Java Man is thought to have moved south to Java at that time.

15.5.3 *The Emergence of Homo sapiens and the Glacial Cycle of the Late Quaternary Period*

As mentioned in Sect. 15.4.2, the global climate from about 1 Ma became very cold, and as far as it has been ascertained to date, from 0.8 Ma, a pronounced 100,000-year glacial-interglacial cycle has prevailed. The past 10,000 years until now is known as the postglacial age, but this cycle is still continuing, and we should note that we are living in a short interglacial period in the middle of a long, ongoing cold glacial period.

The direct ancestor of today's humans, Homo sapiens, is said to have appeared in Africa from 150 to 200 ka based on mitochondrial DNA analysis (Cann et al. 1987). As Fig. 15.8 shows, this period was cooling after two previous inter-glacials (around 200 ka) towards a glacial period on a 100,000-year cycle. From this time, our ancestors from Africa were moving or dispersing to the Eurasian continent, evolving into the present human species, Homo sapiens. During this time, basically a cold glacial climate prevailed in the whole globe, though it was interrupted by a short interglacial period. A question may be, then, why humans did evolve into modern man in this particular period?

Typical savanna grasslands where C_4 plants predominate, found in the current East African tropics (such as the Serengeti National Park), finally emerged around 1 Ma (Cerling 1992). At the same time, animals such as ungulates that are linked to today's fauna, which are adapted to grasslands, speciated actively (Vrba 1995). From tropical and subtropical East Africa to the Arabian Peninsula and Southwest and Central Asia, the glacial period was, if anything, paired with a weakening of the Asian monsoon. It is highly likely that the dry climate of this region weakened, becoming more humid than today's, and grassland formed an almost unbroken corridor. Alternatively, it is highly likely that repeated North-South displacements of dry and humid climate zones due to glacial cycles caused North-South displacement or expansion and contraction of the grasslands. For example, in numerical simulations reproducing the climate model combined with a vegetation model for the climate and vegetation of the last glacial periods (21 ka, 16 ka), as Fig. 15.10 shows, it is inferred that the Arabian Peninsula, which is a completely desert region today, was covered with grassland vegetation in the glacial periods (Kutzbach et al. 1998). Considering these climatic and ecological environmental conditions, as when primitive man left Africa, some modern men would have pursued the ungulates that proliferated on the grasslands, encouraged by the expansion and contraction of the grassland, gradually moving to the Eurasian continent. While pursuing a hunting lifestyle, these people would gradually have tamed the grassland ungulates such as wild cows and sheep, leading to domestication and nomadism (Imanishi 1995).

Although we have developed our thesis based on the currently prevailing African single origin hypothesis for Homo sapiens, there are naturally arguments against this theory, and the inferences made in this paper are not definitive. However, it can be said that as with the origin and evolution of primitive man, our direct ancestor modern man evolved in a cold climate during a glacial period, in a region with a relatively dry climate and ecosystem formed due to the presence of the HTP. When considering the formation of the Mongoloids of East Asia, the geographical dispersion of modern man from Africa as shown in Fig. 15.11 is an interesting problem. This figure shows possible main routes by which modern man entered Southeast Asia via the Indian subcontinent south of the Himalayas. A question may how he could pass through the dense tropical and subtropical forests of the Yunnan and Assam regions with their monsoon climate. There is rather, a high possibility that his main route was via the steppe grassland between the southern rim of the giant Siberian lake (Mangerud et al. 2004) formed in the West Siberian lowland, and the Tibetan plateau. Alternatively, the distinctive Mongoloid features may have resulted from mixing of the human races that took both routes.

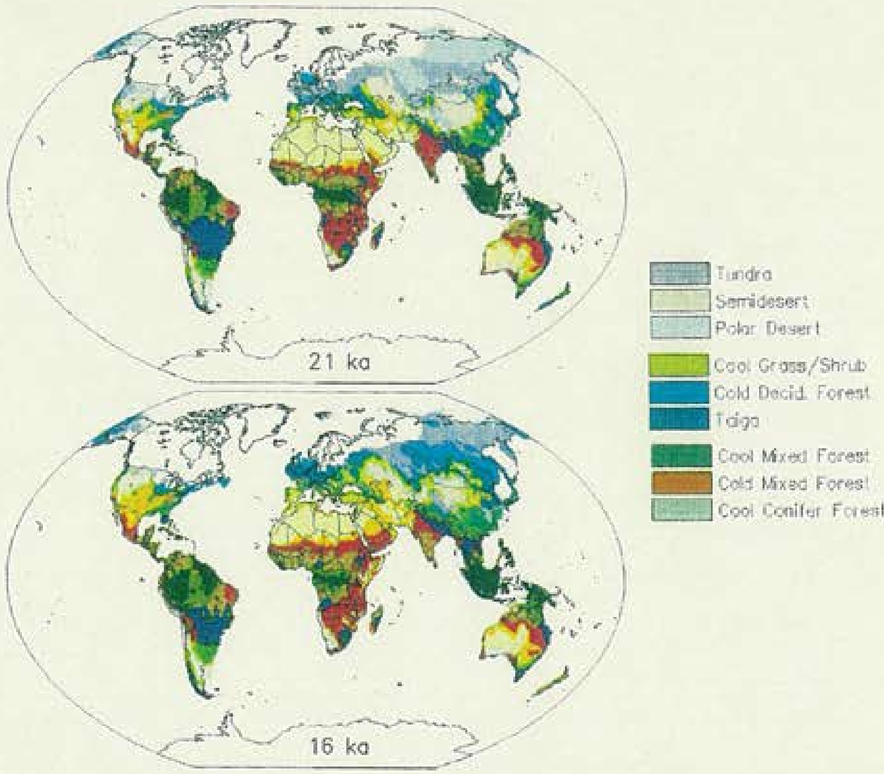

Fig. 15.10 The distribution of vegetation in the interglacial (21 Ka) and glacial period (16 Ka) estimated using a vegetation model and temperature, precipitation and insolation based on a climate model (Kutzbach et al. 1998)

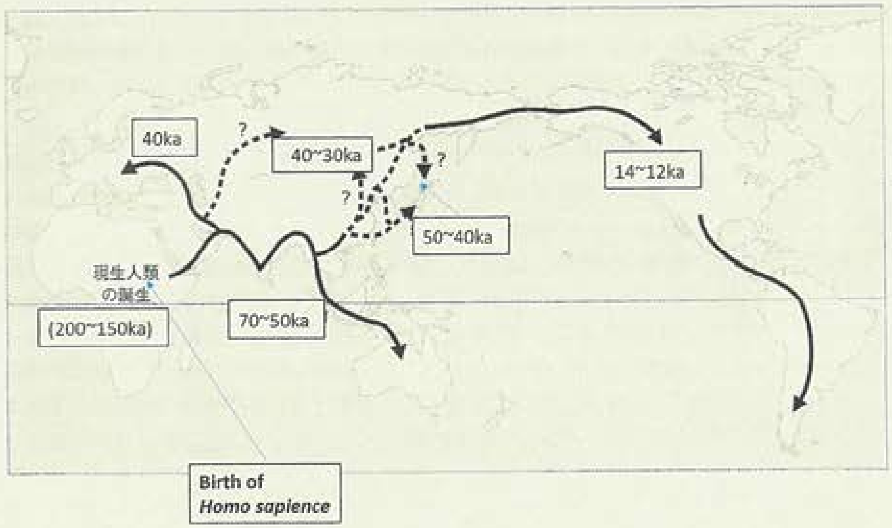

Fig. 15.11 Global dispersion of modern man (the period is estimated) (after from Mitsui 2005)

15.5.4 *Human Development in Monsoon Asia and Discovery of Paddy Rice Farming on Alluvial Plains*

Around 10 ka, the Earth's most recent glacial period ended, followed temporarily by the Younger Dryas period (13 to 12 ka), a short period of recurrence of cold climate. After the Younger Dryas period, the Earth entered a postglacial age (interglacial period), with a relatively warm and stable climate. This period has continued until now (or very recently), which is named as the Holocene period as a geological classification as shown in Fig. 15.12 (Rockstrom et al. 2009; Alley 2000). The peak of warming occurred 8000 to 6000 years ago. In the Holocene, humans, who evolved on the grasslands under a dry climate in the glacial period, along with the C_4 plants and ungulates unique to Quaternary period arid lands, entered the humid forest valleys and wetlands of the mountains under a monsoon climate, where malaria was rampant and which they had hitherto avoided as the haunt of evil spirits.

However, in this particular humid region called monsoon Asia, humans invented (or discovered) paddy-field rice farming. With the uplift of the HTP, the complex mountain folds have been created by the rivers that flowed east, southeast and south of the HTP. Under these tectonic and climatic situations, numerous deep valleys and alluvial plains have been formed due to active erosion and earth/sand deposition along the valleys and near the river mouths. These valleys and alluvial plains were the habitat of the grasses that were to become rice plants (Sato 1996). Many arguments on the origin place of rice have been made (e.g., Yunnan Province of China or delta area of Yangtze river). Whichever it was, the existence of complex valleys and alluvial plains formed in the periphery zone of the HTP in southern China and Southeast Asia or India is thought to be a necessary geographical condition for the start of rice farming. Thereafter, for thousands of years rice farming in monsoon Asia made big developments so that today, 60% of the world's population is engaged in it. This humid monsoon Asia produced diverse traditional cultures based on rice paddy farming, and became one of the centers for world civilization.

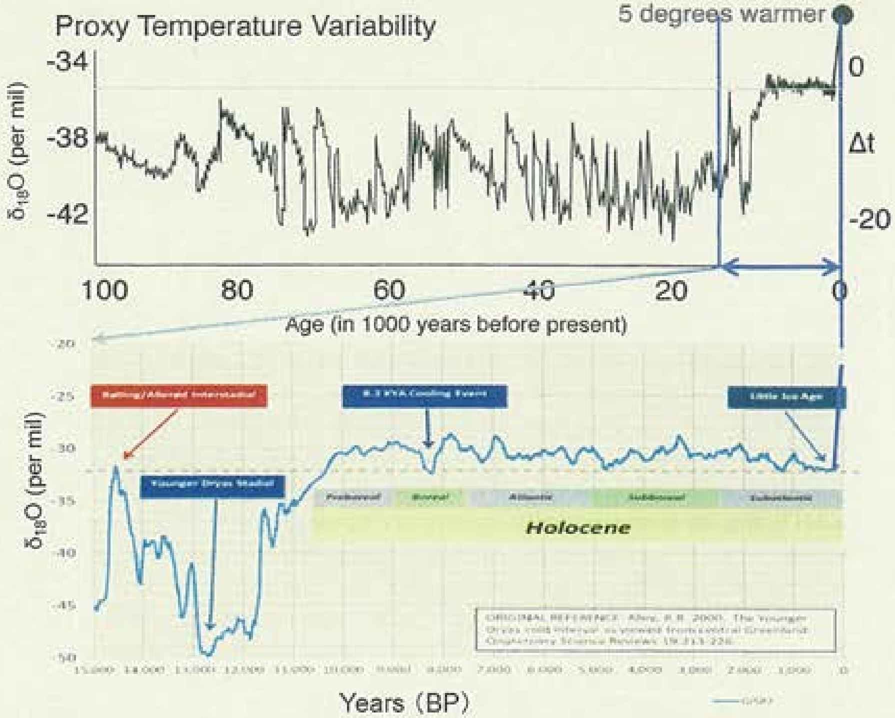

Fig. 15.12 (Top) Changes in the Earth's average temperature from 100,000 years ago to the present, estimated from Greenland ice cores, etc. It also shows temperatures rising rapidly in the late twentieth century. (Original figure: Rockstrom et al. 2009 original drawing) (Bottom) Expanded view of the changes in the period from the end of the glacial period from 15,000 years ago to the Holocene. (Original figure: Alley 2000) It also shows temperatures rising based on observation since 1950. Note that the vertical axis is shown as $\delta^{18}O$ ratio, and the standards for temperature conversion differ between top and bottom

Incidentally, the progenitor of wheat, another of the three major crops, was found under the dry climate in Southwest Asia. Here, the formation of a wetland ecosystem along the humid valleys arising from the extensive snow melt from the Zagros Mountains can be considered important for the formation of many agricultural progenitors. Wheat farming also started in this region about 12,000 years ago in the postglacial age, becoming the basis of the Mesopotamian civilization. However, the drying of the climate during the Holocene, presumably associated with enhanced Asian monsoon climate to the east (refer to Sect. 15.3.3), prompted the development of irrigation agriculture, which finally had caused the salinization of soils and loss of sustainability, ultimately leading to the demise of the Mesopotamian civilization.

15.6 Summary and Remarks

The association and implication of the uplift of the Himalaya and Tibetan Plateau (HTP) during the Neogene period through the Quaternary period to the evolution of humans are comprehensively overviewed and discussed, based on the recent scientific results in earth science, paleoclimatology, paleoecology, and anthropology. We have focused the earth history in the Neogene (20 Ma ~) to present, when the height of the HTP can be thought to have become a pronounced influence on the Earth's climate. There is almost no doubt that aridification of climate and the change of ecosystem in East Africa from a forest to a grassland ecosystem, are due to the uplift of the HTP, and the terrestrial uplift accompanying the formation of the Great Rift Valley that occurred at roughly the same time (around 5–10 Ma), had a major significance in the origin of primitive man. Formation of the arid climate was coupled with the establishment of the Asian monsoon. The increase in monsoon rainfall on the uplifted HTP caused a reduction in CO_2 concentration in the atmosphere through weathering and erosion along slopes of the HTP, which should have enhanced global colder climate from the Neogene to the Quaternary period. In addition, the lower CO_2 concentration caused expansion of grassland comprising C_4 plants, promoting the evolution of diverse ungulates. These factors were important for the evolution of hominins.

From the Quaternary period (since 2.6 Ma), the Earth entered a period of climate change with expanding and contracting of ice sheets on 20,000- or 40,000- to 100,000-year glacial cycles. A definitive answer to the role played by the HTP in these glacial cycles has yet to be fully understood. However, research using climate models suggests the possibility of the albedo effect of snow and ice as an amplifier of climate change. Hominid evolution advanced in this glacial cycle. During this period, along with these glacial cycles, the climate of East Africa repeatedly varied between humid and dry climate, associated with wax and vane in the Asian monsoon, which probably should have been important opportunities prompting the evolution of hominins.

In the region from East Africa to the Arabian Peninsula, a humid–dry–humid climate and ecosystem was distributed south to north. In the glacial and interglacial periods, this distribution was characterized by displacement and variation in the strength of the contrast. These variations represented an evolutionary pressure on primitive and modern man, and they also became the opportunity for moving to Eurasia. In addition, during the Quaternary period, the cold glacial periods of the climate change cycles were also long compared to the warmer interglacial periods, which in turn could be a demanding climate for the humans even after their migration to the Eurasian continent. Nevertheless, Central and Southwest Asia was, unlike today's desert, a vast grassland steppe, and was inhabited by diverse herbivorous animals, providing a main stage for the co-evolution of humans and herbivorous animals.

In the warm, relatively stable Holocene climate starting after the end of the last glacial period about 10 K, humans developed agriculture cultivating rice and wheat to the East and West of the HTP respectively. This new settled life-style for humankind induced a new era of civilization. It should be noted that based upon the agriculture and civilization including urbanization the humans achieved the industrial revolution started in Europe in the eighteenth century. Since the industrial revolution, human activities have significantly been changing the Earth's surface including the atmosphere, the hydrosphere and the biosphere, and this human impact has become so enormous particularly since the middle of the twentieth century. The recent global warming of climate may be one of the tangible evidences (IPCC 2013). It is said that the Holocene is over and we are now entering a new era called the Anthropocene (Crutzen 2002).

The uplift of the HTP is still continuing due to tectonic mechanisms, and the basic mechanism of the glacial cycle can also be operated even today. However, there is a big question how the current global warming will change the glacial cycle of the Quaternary period. Considering the complex, nonlinear earth (climate) system, it is not easy for us to prognose the future state of the earth's climate.

On the other hand, the changing climate in the Anthropocene is causing serious rapid changes of the environment of the HTP region, including the overall retreat of glaciers, which are threatening human society of this region. We should not forget that traditional human-nature system in various regions of the world have been formed and maintained under the relatively stable Holocene climate and ecosystem. What should the relationship between the natural environment and humans be like in the Anthropocene? This question is also a pressing issue in the HTP region.

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