3.2 Tertiary Climates of Central Europe

Unlike the subsequent period of the Quaternary, climatic conditions of the Tertiary were greatly different than those of today and led to the origin of different landform assemblages that can be identified in the landscape of the Czech Republic even nowadays. Sediments that fill basin structures of the Czech Republic, namely organogenic sediments of the rank of coal (e.g. in Mostecká pánev Basin), are other important evidence of different climatic conditions of the Tertiary. From the point of view of paleogeography, very important sediments are Miocene formations of the Carpathian Foredeep.

Tertiary climate was characterised by the alternation of warmer and colder oscillations with a tendency towards gradual cooling (Chlupáč et al. 2002). Climate has been reconstructed in the Wiess Elster Basin in the vicinity of the border between Bohemia and Germany. Paleobotanical analyses show that climate in Central Europe in the period from the Middle Eocene to Lower Oligocene was tropical, with mean annual temperature ranging from 23 to 25 °C, mean annual precipitation from 1,000 mm to 1,600 mm and coldest month mean (CMM) from 17 to 21 °C (Mosbrugger et al. 2005). Lower temperatures were associated with a majority of the Oligocene period with CMM around 5 °C, while the latest Chattian was marked by a temperature peak which was recorded by Mosbrugger et al. (2005) from the Lower Rhine Basin. This peak corresponds to the Late Oligocene Warming known from isotope records (Zachos et al. 2001). The warmest period of the Neogene was the Miocene (Chlupáč et al. 2002) in which the trend of warming continued up to the Middle Miocene. This warming seems to be rather stepwise, while the curves show several short-term variations. In the Weisselster Basin record there is evidence of short-term cooling at the base of the Aquitanian (Mosbrugger et al. 2005). The Middle Miocene temperature peak in Central Europe corresponds to the Middle Miocene Climatic Optimum that is observed globally. After Mosbrugger et al. (2005), the Miocene cooling seems to be between 14 and 13 Ma when considering all different records and analysed climate variables. In the Molasse Basin, CMM decreased more rapidly than in both other regions, and, at the end of the Middle Miocene, CMM dropped below 4 °C. The transition between the Miocene and the Pliocene shows a gradual trend in climate cooling. During the Late Pliocene the cooling intensified and CMM fell below the freezing point (Mosbrugger et al. 2005).

3.3 Quaternary Climatic Cycle

Quaternary evolution in Central Europe is connected with fundamental changes in environmental conditions and essential paleogeographic changes that were related to the transgression of the continental ice sheets, temperature drop and changes in morphogenesis.

A comprehensive overview of landscape evolution is brought by Quaternary climate and sediment model compiled by Ložek (1973, 1999a, b, 2007). The author characterises the evolution using four phases (Fig. 3.1): early glacial period, pleniglacial period, late glacial and interglacial. It is evident that global trends of the climate system oscillation were reflected in regional cycles. On the basis of an extensive set of data about Quaternary sediments Ložek (1999a, b) was able to derive a rather general model that characterises not only climate parameters but also points to the conditions of the evolution of soils and vegetation and the processes of weathering and material deposition. The four phases of Ložek's model are described below.

The phase of early glacial is characterised by the onset of cold climate. Mean annual temperatures range between +3 and −1 °C, depending on the location. Cooling brings a distinct decline in precipitation (mean annual precipitation totals are estimated to 200–400 mm). The landscape undergoes gradual aridization, which becomes evident in pedogenesis and vegetation composition. Interglacial forests are divided into smaller units whose species composition changes towards a boreal forest (taiga). Conifers start to appear, while the species of Central European temperate forest are in recession. Very dry periods bring forth chernozem steppes. The transformation of ecosystems gradually gives rise to cold continental steppes in which grasses and chernozems prevail. Temperatures and precipitation totals continue to decrease, while the cycle passes into the phase of the so-called pleniglacial.

Pleniglacial phase is characterised by the transgression of the continental glacier and conditions of periglacial climate in a great part of the territory. Glaciers start to appear in the topmost areas of mountain ranges and the ice sheet expands into the northernmost parts of the recent Czech Republic territory. Mean annual temperatures drop to −3 to −5 °C, which leads to the occurrence of permafrost. Tree vegetation recedes considerably, while groups of trees only survive in protected areas or vanish totally. The development of vegetation is limited by very low precipitation totals, ranging between 100 and 200 mm/year. Cold and dry climate is

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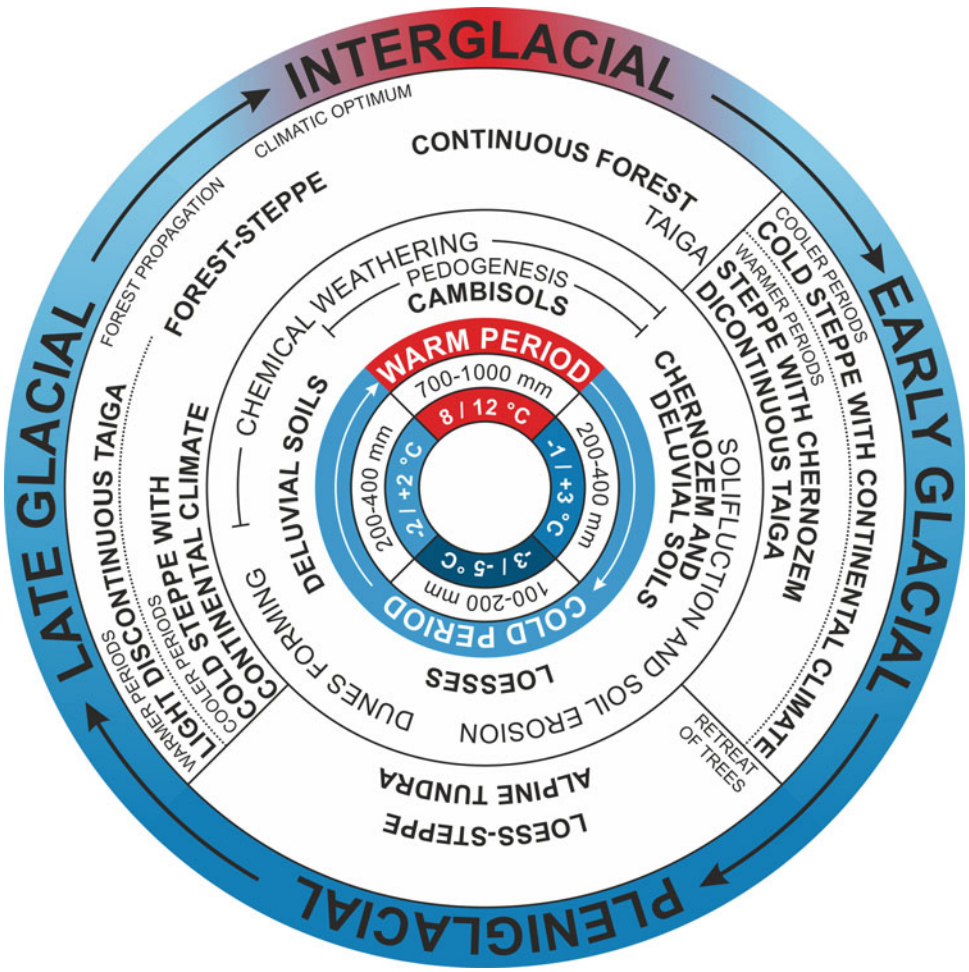


Fig. 3.1 Simplified Quaternary climate and sediment model compiled by Ložek (2007)

marked by strong atmospheric flow and loess deposition. This leads to the formation of cold loess steppes. However, the foreground of the ice sheet and higher locations witness the formation of tundra or sub-alpine ecosystems with cryogenic soils. Soil-forming substrates are very rich in salts and calcium carbonate, which leads to the spreading of halophile and calciphile species. The character of non-glaciated parts of the landscape is significantly affected by intensive congelifraction, presence of permafrost and gelifluction. The period of low temperature is replaced by gradual warming of climate, which leads to temperature oscillation. The landscape starts to enter the period of late glacial.

Mean annual temperatures in *late glacial phase* are still relatively low, ranging between –2 and +2 °C, however, the warming trend and increasing humidity are evident (200–400 mm). The climate is characterised by significant instability, which is reflected by the fact that cold continental steppes are preserved at many places, while the onset of thermophilic vegetation is very slow. Degradation of permafrost makes itself felt both by the increase in the thickness of its active layer and gradual decomposition of continuous permafrost areas into isolated permafrost patches. The retreat of the continental ice sheet along with the deglaciation of the highest mountain ranges brings fundamental changes in environmental conditions. Periods of warm oscillations make conditions for light discontinuous taiga with birch, pine and sea-buckthorn. Colder phases still witness the occurrence of cold continental steppe. Large accumulations of material weathered during cold periods start to be influenced by chemical weathering. Towards the end of the late glacial, forest species start to appear and the area covered by forests gradually extends.

Interglacial phase is a phase of warm climate. Annual temperature means increase greatly (8–12 °C) and the climate becomes more humid (700–1000 mm/year). The landscape changes fundamentally. With the onset of climatic optimum the open landscape is gradually closed by the Central European forest that replaces forest-steppe communities. Soils rich in calcium enable intensive spreading of basophilic species and high temperatures predetermine the spreading of xerophilic communities. Intensive chemical weathering and leaching alkali out of soil gradually gives rise to cambisols. Forest formations change regarding the species and gradual acidification of the surroundings

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facilitates the spreading of acidophilic species. The continuous forest reaches the phase of climax. However, the climatic system undergoes further development and enters the phase of cooling, which involves the spreading of cold-loving species, acidification intensifies and taiga spreads in the landscape.

3.4 Quaternary Climate in Central Europe

Climate cooling at the end of the Tertiary led to the Pleistocene, characterised by the alternation of cold (glacials) and warm (interglacials) periods. Using marine isotope stages (MIS) as a framework, it is possible to identify 104 stages of cool (52) or warm (52) climate periods during the whole Quaternary (and 103 MIS within the Pleistocene). Early Pleistocene was characterised by the mean annual temperature below 0 °C; however, this very old period in Central Europe is not covered well by precise data. On the basis of geomorphological proxy data, Czudek (2005) estimates that during cold phases of the Early Pleistocene mean annual temperatures dropped to −3 to −4 °C. The formation of cryogenic structures in the southern Moravia can indicate mean monthly temperatures of the coldest month to –20 °C, which would point to the occurrence of continuous permafrost (Vandenberghe 2001b). With respect to the climate of our territory, there is relatively little information on the Middle Pleistocene. Our conclusions are again drawn from proxy data (e.g. ice wedges and a range of pseudomorphoses). Mean annual temperature is estimated for −5 °C. Temperatures of the coldest months were on average around −20 °C or even lower. The Late Pleistocene was characterised by the peak in periglacial landform-shaping processes in the territory of the recent Czech Republic (Czudek 2005). In the Eemian interglacial period mean annual temperatures were around 13 °C and the climate was very humid (Czudek 2005). Subsequent cooling in the Weichsellian glacial period again brought mean annual temperatures below the freezing point (−2 and −5 °C). The greatest drop in temperatures came in the pleniglacial (73–13 ka BP) when in the phase of the Last Glacial Maximum (LGM) mean annual temperatures were −6 to −8 °C; mean January temperatures ranged between −18 and −20 °C. The warmest summer months reached temperatures between 5 and 6 °C (2005). Ložek (1999a) states that climate had continental character, with long and cold winters, short springs, but relatively warm summers. He further mentioned that annual precipitation totals ranged between 100 and 200 mm and they occurred particularly in the warm part of the year. An interesting approach in the reconstruction of environmental conditions during the LGM is brought by the study of Alvaradoa et al. (2011) in which a drop in temperatures by 5–7 °C was confirmed by the analysis of dissolved noble gases in groundwater of the Bohemian Cretaceous Basin. The end of the Pleistocene (Late Pleistocene) was characterised by a distinct increase in temperatures; however, with considerable oscillation between interstadials (Bölling and Alleröd) and stadials (Older and Younger Dryas). Mean annual temperatures in interstadials ranged between 2 and 5 °C, while during stadials they were around −2 to −3 °C (Czudek 2005).

Warming at the end of the Younger Dryas brought radical changes to the environment. Considerable retreat of the glaciers led to the onset of the Holocene interglacial. Climate warming was accompanied by increased precipitation that accelerated vegetation growth and changes in the pedogenetic conditions, weathering and relief evolution. Individual chronozones of the Holocene landscape evolution are shown in Fig. 3.2 including reconstructed temperatures and precipitation totals after Ložek (2007) and Starkel (1990a). In the Preboreal (10,300–9,300 BP) mean annual temperature was by c. 3 °C lower than nowadays. Continuing continental climate was warmed in the course of the Preboreal (9300–8400 BP); mean annual temperature was by 2–3 °C higher than nowadays (Czudek 2005).

Climatic optimum was reached in the Atlantic (8400–5100 BP) in which the mean annual temperature was up to 3 °C higher than today (Czudek, 2005). An important characteristic of the Atlantic climate was significantly higher precipitation, namely by 100 %, if compared with nowadays (Ložek 1999c). The beginnings of the Subboreal (5100–2400 BP) were by 1 °C warmer than the present-day mean. The main feature of the Subboreal period was ambivalence and drier periods alternating with more humid ones and warmer periods alternating with colder ones (Czudek 2005). The period of the Subatlantic (2400 BP—the present day) brought cooling and, at the same time, increased precipitation (Ložek 1999c). Humid climatic phases are reflected in the landslide activity phases in the Carpathian part of the Czech Republic (Pánek et al. 2010) that also correspond with the Polish landslide activity chronology (Fig. 3.2).

The latest pollen data proxies and the relationship of pollen and the climate changes during Holocene are brought by the research of Veron et al. (2014) from the peat bog of Boží Dar (Krušné hory Mts). The authors confirm very cold Late Glacial dominated by *Cyperaceae* grass land (12.5–11.0 kyr BP), the Early Holocene warming and the onset of *Pinus* (11.0–9.0 kyr BP). During the Boreal the temperature increased with an increase in the shade-intolerant *Corylus* and a concurrent decrease in *Pinus* (9.0–8.1 kyr BP). The Atlantic chronozone is classified as the warmest and wettest period of the Holocene characterised by the species of *Alnus* and *Fraxinus* (8.1–4.3 kyr BP). The following Subboreal chronozone was detected as drier and possibly colder and characterised by the decline in temperature-sensitive species (< 4.3 kyr BP). Similar results of temperature trends were

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