Reconstruction of Vegetation and Landscape Development During Volcanic Activity in the České Středohoří Mountains

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ABSTRACT. Volcanogenic strata of Upper Eocene age formed in the early stages of surface volcanic activity in the České středohoří Mountains are documented by ancient fish fauna, palynology and macropalaeobotany as well as radiometric dating at Kučlín, Kostomlaty, and Lbín. A volcanogenic lake system apparently existed in the southern part of the České středohoří Mts. at that time, and was drained by rivers and basin systems (Staré Sedlo Fm.) across Bohemia and Saxony towards the North Sea, as suggested by the marine fish element (Morone). Volcanogenic sites reveal mainly Mesophytic forest vegetation reflecting paratropical – subtropical seasonal climate, while the plant assemblages of the Staré Sedlo Fm. correspond to subtropical gallery and riverine forests along riverbanks. The Late Eocene landscape of northern Bohemia was apparently an uneven peneplain with lowland rivers, lakes, maars and moderate volcanic uplands. At the Eocene/Oligocene boundary, the drainage system towards Saxony was interrupted. As the rift continued its deepening, separate shallow coal basins and lakes covered most of the České středohoří Mts., its periphery and the adjacent Most Basin. Sedimentation was often disturbed by volcanic activity, when lava flows entered basin waters. According to the changing fish faunas and vegetation, four levels can be recognised within the Ústí and Děčín formations: Roudníky – Větruše with ammiids and Juniperus; Kundratice – Seifhennersdorf with the Gobius–Thaumaturus fish assemblage and taxads; Jedlka, Suletice, Markvartice with Calocedrus and a combination of Thaumaturus and Paleorutilus; and Matrý – Lužice/ Žichov with pines and Palaeorutilus. At first, vegetation was dominated by mixed Mesophytic and deciduous forests, reflecting a climatic deterioration at the Eocene/Oligocene boundary. Warming trends can be noticed higher up in the stratal succession. The youngest phase of the České středohoří Mts. (Dobrná Fm.) is not accompanied by plant and animal fossils. Information about the ecosystems (Cunninghamia, Taiwania, Fagus and Palaerutilus), climate and environment is provided only by the maar fill at Kleinsaubernitz in Saxony, which preceded this last period of landscape development, when a new river system (Hlavačov Gravel and Sand) originated in central Bohemia.

KEY WORDS: mid-Tertiary, ecosystems, landscapes, northern Bohemia, palaeobotany.

Introduction

The area of northern Bohemia and Saxony offers a rare opportunity to follow the development of landscape and ecosystems for a longer period back to the geological history. Today, the landscape of the České středohoří Mountains presents a picturesque upland formed by neovolcanic bodies, mostly stocks, dykes and lava sheets, and steep slopes with landslides. However, the pronounced relief originated quite recently due to erosion processes during the latest Cenozoic. The preserved fossil record provides information from the Eocene times onwards for an attempt to reconstruct ancient vegetation, climate and environment in this part of central Europe.

This paper presents ideas about the landscape development, based on the macroscopic plant and animal fossil record. The study area extends from northern Bohemia to Saxony across the České středohoří Mountains and its wider periphery (Fig. 1). The Tertiary landscape can be reconstructed only partly, like making a puzzle, because geological data for such a reconstruction are fragmentary. On the other hand, we are fairly well informed about the fossil flora and vegetation, less completely about the fauna except for fish communities.

The facies diversity of the deposits and the fossil record they contain served as a basis for a reconstruction of the environment and the landscape development from the Late Eocene to the Oligocene/Miocene boundary. Different kinds of vegetation require different living conditions, thus reflecting changing habitats; for instance, water plant communities, riparian forests or mesophytic forests. And the composition of vegetation and its physiognomy may bring more precise information also about palaeoclimatic conditions.

Since the pioneer studies carried out by Reuss, Ettingshausen, Deichmüller and others, which brought the first incomplete data about the deposits of the North Bohemian Tertiary and the fossil record, our knowledge has greatly expanded thanks to the detailed geological and palaeontological research in the few last decades. The following palaeontological studies were used as additional sources for the topic briefly discussed here: e.g., Bůžek et al. (1976, 1978), Obrhelová and Obrhel (1987), Bellon et al. (1998), Kvaček and Walther (1995, 1998, 2001), Walther (1996, 1999), Radoň (2001), Radoň et al. in press, Kvaček (2002a, b, c).

Results

The Tertiary of the České středohoří Mountains has been traditionally divided into two lithostratigraphic units: the Staré Sedlo Formation, comprising mostly quartzite sandstone of Upper Eocene age and the České středohoří Complex composed of alkaline volcanics and intravolcanic deposits, such as diatomites, marls and volcaniclastics, ranging in age from Upper Eocene to Lower Miocene. In a recent study, Cajz (2000) attempted to divide this volcanic complex into three lithostratigraphic units on the basis of magma differentiation, namely into the Ústí, Děčín and Dobrná formations. Ulrych et al. (2001) modified the scheme, defining more informal units. Based on the fossil

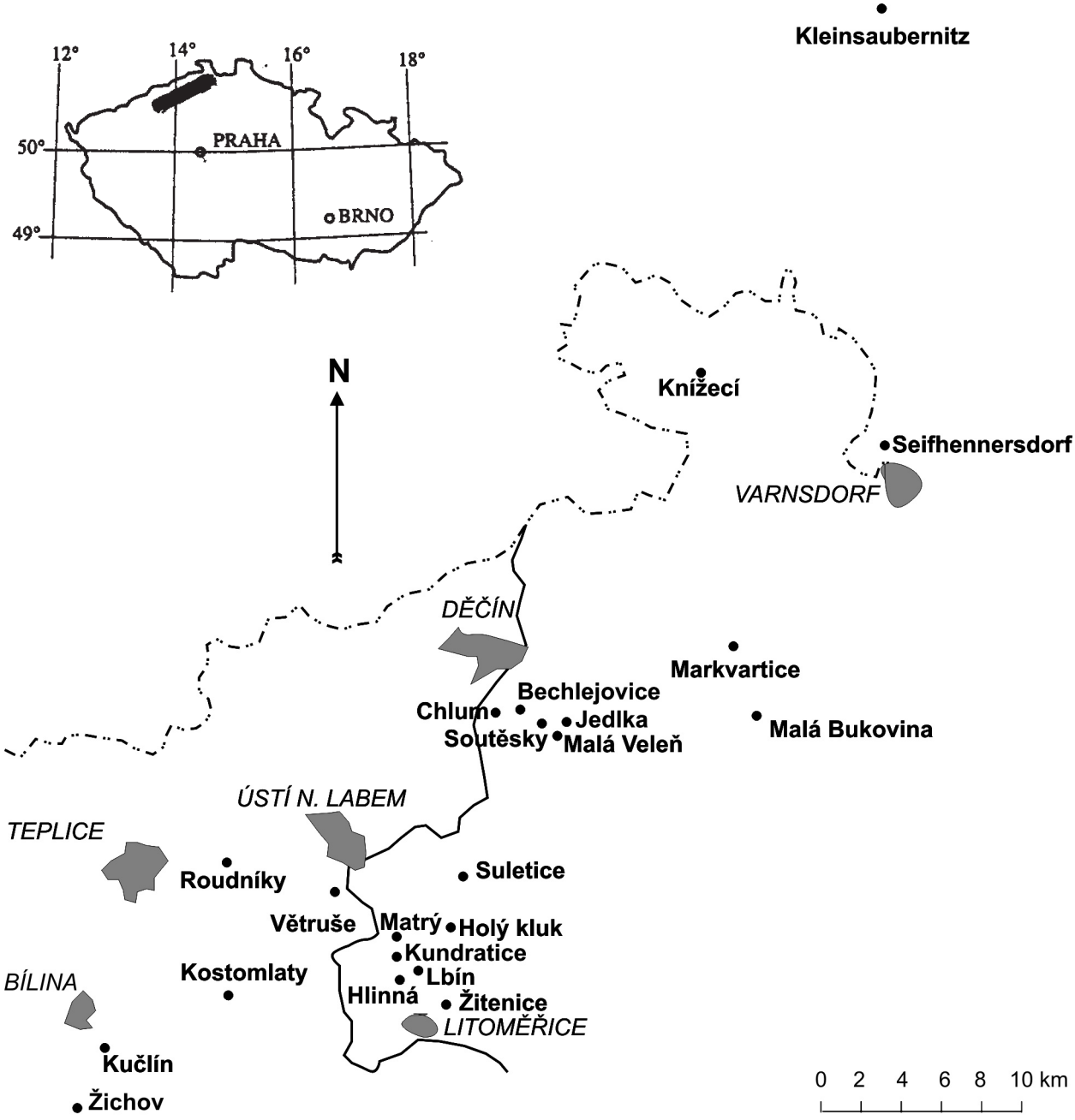

Fig. 1. A map of the sites studied.

record, the present paper subdivides this scheme into six levels reflecting the changing ecosystems (Fig. 2).

Similarities of the land flora and the fish fauna as well as radiometric data suggest that the deposits at several localities lying on the southern periphery of the České středohoří Mountains were formed during the initial surface volcanic phase in Late Eocene times (Konzalová 1981, Bellon et al. 1998, Kvaček 2002a). The sites of lacustrine deposits at Kučlín, Kostomlaty and wider surroundings of Lbín share, as index fossils, *Doliostrobus* (Kvaček 2002c), Eocene pollen flora (Konzalová 1981) and ancient fish fauna comprising four fish genera at Kučlín (Micklich and Böhme 1997, Gaudant in Bellon et al. 1998): freshwater *Bilinia*, *Thaumaturus*, *Cyclurus* (~ *Amia*) and marine *Morone.* The occurrence of the latter element recovered by Micklich and Böhme (1997) corroborates that an extensive volcanogenic lake system must have existed at that time stretching from Bílina to Litoměřice, as Obrhelová and Obrhel (1987) suggested many years ago. Micklich and Böhme (l.c.) expect a connection with the North Sea via rivers and basin systems, which drained the lake across northern Bohemia towards the north. Indeed, the basal part of the Ústí Formation overlaps in time with the fluvial deposits of the Staré Sedlo Formation. These two lithostratigraphic units partly represent two heteropic facies of the same age, closely adjoined, locally with no hiatus (Kvaček 2002a). Starting with the peneplain of the Eocene landscape, we must expect a flat

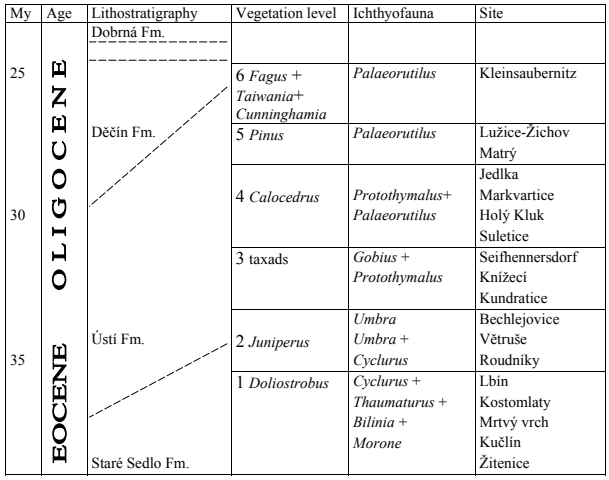

Fig. 2. Stratigraphical scheme of the České středohoří Mountains with fossil records.

weathered surface with some uneven relief due to river and freshwater systems, which can be recognized only in places. At this time, already small centres of volcanic activity existed, causing the first upland relief structures. Volcanic activity induced the formation of small sedimentary settings, like maar lakes, crater lakes or small tectonic basins.

A similar configuration of landscape can be seen today in several volcanic areas, like in the Yellowstone National Park in Wyoming. Deposits of the large Yellowstone Lake correspond to those of the Kučlín lake, the monumental Mammoth Hot Springs with limestone cascades resemble once active sites at Kostomlaty, and the valley of the Yellowstone River corresponds to the Staré Sedlo sandstone. Although the floras of the two facies differ in some respect, this is due to synecology of vegetation and environmental differences. Aquatic to upland communities on fertile volcanogenic soils differed from riparian forests along rivers on oligotrophic sandy soils. The Kučlín diatomite, the limestone at Kostomlaty and volcaniclastics at the base of the Ústí Formation near Lbín reveal mainly mesophytic forest vegetation, suggesting very warm, paratropical to subtropical seasonal climate without frosts and with a short period of slight deficient precipitation. The warm climate is corroborated by the occurrence of crocodiles (*Diplocynodon*). Plant assemblages of the Staré Sedlo Formation (Knobloch et al. 1996) reflect riverine gallery forests along riverbanks, well supplied with groundwater, and growing on alluvial soils. These forests were also subtropical, but dominated by evergreen Fagaceae (mainly *Eotrigonobalanus furcinervis* ssp. *furcinervis*). These ecological differences in the Late Eocene vegetation types in general inevitably lead to an assumption that the two Floral Assemblages ("Florenkomplexe") *sensu* Mai (1995) – the Hordle–Zeitz and Bembridge–Spechbach also overlap in time.

After this stage of landscape development, the basinal and river systems largely withdrew from northern Bohemia towards the west and north. This palaeogeographic change was also connected with the withdrawal of very thermophilic vegetation. Climatic deterioration known also from other parts of Europe as the "Grange Coupure" of Stehlin generally occurred at the Eocene/Oligocene boundary. It was connected with large-scale changes of vertebrate fauna and immigration of deciduous trees, known as modern Arcto-Tertiary (or Turgai) elements coming from Central Asia to Europe. In the České středohoří Mountains, this turnover is dated radiometrically to 36.3–34.5 Ma at the level of fossiliferous volcaniclastics of old basalts in the area of Roudníky at Ústí nad Labem (Bellon et al. 1998). This dating is surprising because it falls largely to the Upper Eocene. Another locality, situated about 5 km to the east in the Labe River valley, is Větruše. It yielded similar plant assemblages with additional *Engelhardia*. Fish fauna of this level still includes a representative of amiids, surviving from the Kučlín level, and a new immigrant, *Umbra*. The plant assemblages at the sites of Roudníky and Větruše reflect vegetation of warm–temperate climatic zone, where only some rare thermophilic elements (*Engelhardia*, *Tetraclinis*) survived. At this level, a newly recognized conifer, *Juniperus pauli* (Kvaček 2002b), the oldest record of junipers in the world, corroborates interconnection of the lake deposits at Roudníky and Větruše. Other elements noteworthy of this level are roses and tulip tree. Besides fish fauna, teeth of a crocodile *Diplocynodon darwinii* occur in larger quantity (Radoň 2001) and suggest that the climate could not be very cold at that time.

A similar assemblage of *Diplocynodon* and *Umbra* is connected with Bechlejovice, a famous site of fossil frogs (Špinar 1972). According to many common elements of this flora (Knobloch 1997, Kvaček & Walther in preparation) and that of Roudníky, the fossil record preserved in this banded diatomite documents further development of the Early Oligocene ecosystems within the old basalt phase of the Ústí Formation. Several rare plants are noteworthy – the oldest sweet fern (Kvaček 2001), extinct linden (Hably et al. 2000) and mahonia, which were found in association with other plant elements, frogs, fish, crocodiles and a small crayfish (Houša 1957).

The next level, situated in the upper part of the Ústí Formation, falls roughly to late Early Oligocene times younger than 32 Ma. It is characterized by new fish fauna with dominant *Gobius* (= *Pirskenius* Obrhelová) and *Prototymalus* Laube (= *Varhostychtis* Obrhelová – see Gaudant 1996). This level is rich in palaeontological sites, like the Jesuit Valley at Kundratice (Kvaček and Walther 1998), Seifhennersdorf in Saxony (Walther 1996), Hrazený Hill at Knížecí (as Pirskenberg in Knobloch 1961) and many other sites scattered over the northern part of the České středohoří Mountains. Most of them represent smaller volcanic lakes filled with diatomite and oil shale. The exact network of water reservoirs is not known but this level may have passed to the basinal coal-bearing sedimentation outside volcanic areas in Saxony, namely the Haselbach level (Haselbach and Kundratice–Seifhennersdorf floral assemblages sensu Kvaček & Walther 2001). Many accessory plant elements are shared by the Haselbach and Kundratice floras. Vegetation, contrary to the preceding level, shows a higher proportion of evergreen and thermophilic plants, conifers also include representatives of taxads (*Taxus engelhardtii*, *Torreya bilinica*, *Cephalotaxus parvifolia*). Later on, warming trends are more and more noticeable, obviously on account of

the Rupelian transgression (e.g., Malá Veleň with palms of the *Phoenicites*-type – Radoň 2001).

The Děčín Formation, mostly Upper Oligocene in age, is connected with the trachybasalt volcanism. At this time, a large stratovolcano was formed (Cajz 2000). In its large irregular calderas, various kinds of volcaniclastics were deposited, including lahars but also thin coal seams and diatomite beds. At several sites, e.g., Suletice (Kvaček and Walther 1995), Holý Kluk (Radoň et al. in press), Markvartice (Bůžek et al. 1976), warming trends were reflected by the vegetation. Alder leaves dominate the lahar deposits at Jedlka and Velká Bukovina (Radoň 2001), suggesting the existence of riparian habitats. Weathering profiles elsewhere and thermophilic plant elements, including palms, indicate warm climatic conditions. Besides taxads, a noteworthy conifer was *Calocedrus suleticensis* (Brabenec) Z. Kvaček (1999), whose near relatives grow today in southern China and Taiwan. As for fish fauna, *Protothymalus* survived and was partly associated with a new immigrant, *Palaeorutilus* (at Markvartice – see Böhme 1996), although its documentation is incomplete. This level correlates with the Floral Assemblage Nerchau–Flörsheim in Saxony (Kvaček and Walther 2001).

Higher up in the Děčín Formation, another turnover of ecosystems was registered. It represents the youngest level with documented palaeontological finds in the České středohoří Mts. The sites are connected with volcaniclastics at Matrý Hill and with the silicified diatomite at Žichov and Lužice (Radoň 2001). The change is marked by fish fauna – a small species of *Palaeorutilus* Gaudant (= *Leuciscus luzicensis* Obrhelová – see Gaudant 1996, Böhme 1996) as well as by flora – younger immigrants spreading mostly in the Miocene, such as *Ulmus pyramidalis* and *Acer tricuspidatum* f. *crenatifolium*. Remains of *Pinus* are common (Radoň 2001). Rocks of this level have not been radiometrically dated yet.

Younger basalts, pertaining to the Dobrná Formation, are not connected with fossiliferous deposits. A single site of the floral level preceding this period lies at Kleinsaubernitz in Saxony, near the boundary with northern Bohemia. It is a maar fill (Suhr 1999) containing rich flora (Walther 1999). It is fairly well known that this assemblage represents a mixture of Oligocene and Miocene elements including the index leaf fossil of beech *Fagus saxonica*, associated with conifers typical of Late Oligocene (*Cunninghamia*) and Miocene (*Taiwania*). This period in the Eochattian was characterized by the new Kleinsaubernitz Floral Assemblage (Walther 1999).

After this period, the landscape development changed again and river deposits appeared in central Bohemia. A large river was formed in central Bohemia and drained into the Most Basin. It left a valley filled with the Hlavačov Gravel and Sand, which is correlatable with the Thierbach Floral Assemblage (Mai and Walther 1991, Teodoridis 2001). Dating of these deposits is not sure, but we know from the Paratethys and Boreal marine sediments that this level may fall before or within the Oligocene/Miocene boundary (Kvaček and Walther 2001). By this time, the volcanic activity of the České středohoří Mountains almost ceased. No fossil-bearing deposits are available directly from the study area to yield data about ecosystems and palaeoenvironment.

Conclusions

The development of landscape, climate and ecosystems in the time interval from the Late Eocene to the Oligocene/Miocene boundary was newly interpreted. Six vegetation levels were recognized in connection with changes of vegetation, ichthyofauna and climatic oscillations. Boundaries of the lithostatigraphic units – Staré Sedlo Fm. of fluvial quartzitic sandstone on one hand, and volcanic rocks, diatomites, limestones and pyroclastics of the Ústí, Děčín and Dobrná formations (the former České středohoří Complex) do not coincide with the floral levels and are obviously diachronous. It was possible to correlate the herein presented system with floral assemblages ("Florenkomplexe") based on lowland basin plant record in the Weisselster Basin in Saxony. Comparing assemblages from different lithofacies, vegetation changes can be traced in more detail and accuracy. The combination of volcanological and palaeontological data proved highly effective in assessing the landscape and ecosystem development of the České středohoří Mountains during mid-Tertiary times.

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