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NEW ICHTHYOFAUNA FROM THE HOLEŠICE AND LIBKOVICE MEMBERS IN THE WESTERN PART OF MOST BASIN (EARLY MIOCENE), THE CZECH REPUBLIC

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Abstract: New material of fish fossils from the west part of Most Basin is described here. Disarticulated and articulated fish remains were discovered in several layers in the Holešice and Libkovice members. Fossil fish occurrence, their taxonomic structure and taphonomy were evaluated in the context of the sediments. The data indicate that conditions in the lake, which formed when the coal swamp was flooded, were variable. Most of the time, the water was well oxygenated; occasionally the oxygen saturation was reduced to hypoxia and even anoxia. Conditions subsequently changed, and the lake became well oxygenated. Especially in the Libkovice Member, the fish-containing layers appear to be characterized by relatively quick sedimentation.

Key words: teleost fishes, stratigraphy, taphonomy, palaeoecology, lake system, Neogene, Early Miocene, Most Basin

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Introduction

Fish fauna from the Northern Bohemian Miocene have been known and studied since the end of the 18th century (for details regarding Cenozoic fish research in Bohemia see Obrhelová and Obrhel 1987), but a modern systematic approach and detailed comparative analysis were first applied to these specimens by Obrhelová (1961). Her detailed osteological studies were presented in several monographies focused mainly (but not only) on the family Cyprinidae (especially Obrhelová 1966, 1967, 1969, 1970a, b, 1971). Aside from the systematic studies, she also did significant and detailed work focused on stratigraphy and palaeoecology from the ichthyological point of view within the Cheb and Sokolov basins (Obrhelová 1979, 1982, 1986, 1990, Obrhelová and Obrhel 1983). Obrhelová (1994) also summarized systematic and palaeoecological data of Most Basin ichthyofauna, but data available to her at the time was relatively poor, mostly from the Holešice Member (Břešťany clays). It is also necessary to mention clarification of some systematic and ecological points during subsequent years, especially those published by Gaudant (1993, 1996) and Böhme (in Kvaček et al. 2004). Later, the east part of Most Basin opened by Bílina Mine afforded both articulated and disarticulated fish specimens (recently deposited in the collection of National Museum in Prague; Ekrt et al. 2018). The fossil fish record in the western part of the Most Basin opened by Merkur and Libouš mines was very poor in the past. In recent years, fish skeletons have been acquired from the Libouš Mine (land Registry Spořice and Březno): many disarticulated, some semi-articulated and a few articulated. The sites and collected material are important in numerous aspects, but mainly because they represent the stratigraphically youngest and unique fossil fish record of Holešice and Libkovice members in context of the entire Most Basin.

Material and methods

The coal seam in the west part of Most Basin has been continuously excavated since the 19th century. Both small quarries and deep mines were opened here, and after the 1950s, large quarries were opened (Prunéřov mine, Merkur Mine, Libouš Mine – all three later merged into one "Nástup Tušimice" Mine). The layers above the coal seam afforded fish fossils. Fossils were collected dominantly in the Merkur Mine. Data from the collections of the National Museum indicate that various collectors were active in various eras: N. Obrhelová in the 1960s–1980s; Č. Bůžek, Z. Kvaček and O. Fejfar in the 1980s; P. Coufal, O. Janeček and Z. Dvořák since the 1990s. In recent years, T. Novotný discovered

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several layers with plants, and he also mentioned fauna (Prokop et. al. 2016, Novotný et al. 2021). Recently, authors of the paper together with collaborators collected fish fossils in the Libouš Mine, and selected relevant specimens from the National Museum's collections that had been gathered in other neighboring mines, to form a compilation of material appropriate for the present study. All material studied here is deposited in the collection of Department of Palaeontology, National Museum, Prague, the Czech Republic.

From past collecting, most specimens come from beds about 0–2 m above the top of the coal seam. In the higher units, only rare fish fossils in quarry and in core-drilling were discovered during the 1960s–1980s. Their recorded stratigraphic setting is questionable. Discovery of crandallite layers (Coufal and Mejstříková 1996, Mach et al. 2021) and the newest research about geochemistry, mineralogical composition, palaeomagnetic dating and correlations in Most Basin (Matys Grygar et al. 2017, 2021), helped to identify the stratigraphic position of new specimens collected in recent years, especially in units located higher stratigraphically. This fact induced our interest in collecting and researching the lithostratigraphic beds – Holešice and Libkovice members.

The claystone rocks with fossils were dried very slowly, to eliminate cracking caused by volume changes. After that, some specimens, especially in the carbon rich claystones, were infused and glued with consolidant Paraloid B-72. Despite the care, some larger rocks cracked or deformed.

It is also necessary to mention that our understanding of North Bohemian Cenozoic fish fauna is far from complete. Some questions were answered satisfactorily, like diversity and the true nature of the genus *Palaeoleuciscus* by Gaudant (1993). But others, like Gaudant (2002) suggesting possibly synonymizing some species traditionally considered as separate taxa remain unresolved. Therefore, this brief overview should not be considered the final step to complete understanding of a less-known stratigraphic sequence, but an addition to existing knowledge, which may well be subject to further modifications.

The listed taxa are ordered following Nelson et al. (2016). For each layer, at least one specimen of each taxon (determined to the genus or species level) was given an inventory number. Specimens determined only to the family level are not listed in the following parts of the text (every family is represented by at least one specimen determined to the genus or species level).

Geologic setting of western part of Most Basin and fish fossil content

The basement of the western part of Most Basin is represented by crystalline rocks of the Krušné hory Mountains, Cretaceous sediments and Paleogene volcaniclastics and sediments of the Střezov Formation (Eocene, Oligocene). This last-mentioned unit provided meager fish remains in brownish grey muscovitic silty claystones of an ancient maar lake. The maar is known only from core-drilling, and fossils are distributed in three layers of silty claystones (Brus and Hurník 1984, Obrhelová and Obrhel 1987, Obrhelová 1990). N. Obrhelová described the fish remains as *Bilinia* (*Bilinia uraschista* known from the Eocene fossil site Kučlín was synonymized by Gaudant (2000) with *Properca prisca*) and *Amia* (relevant specimens now classified within genus *Cyclurus*; Gaudant 1987), known for example from the Eocene Kučlín site. These fish taxa differ significantly from the younger (Miocene) specimens collected in the Most Formation.

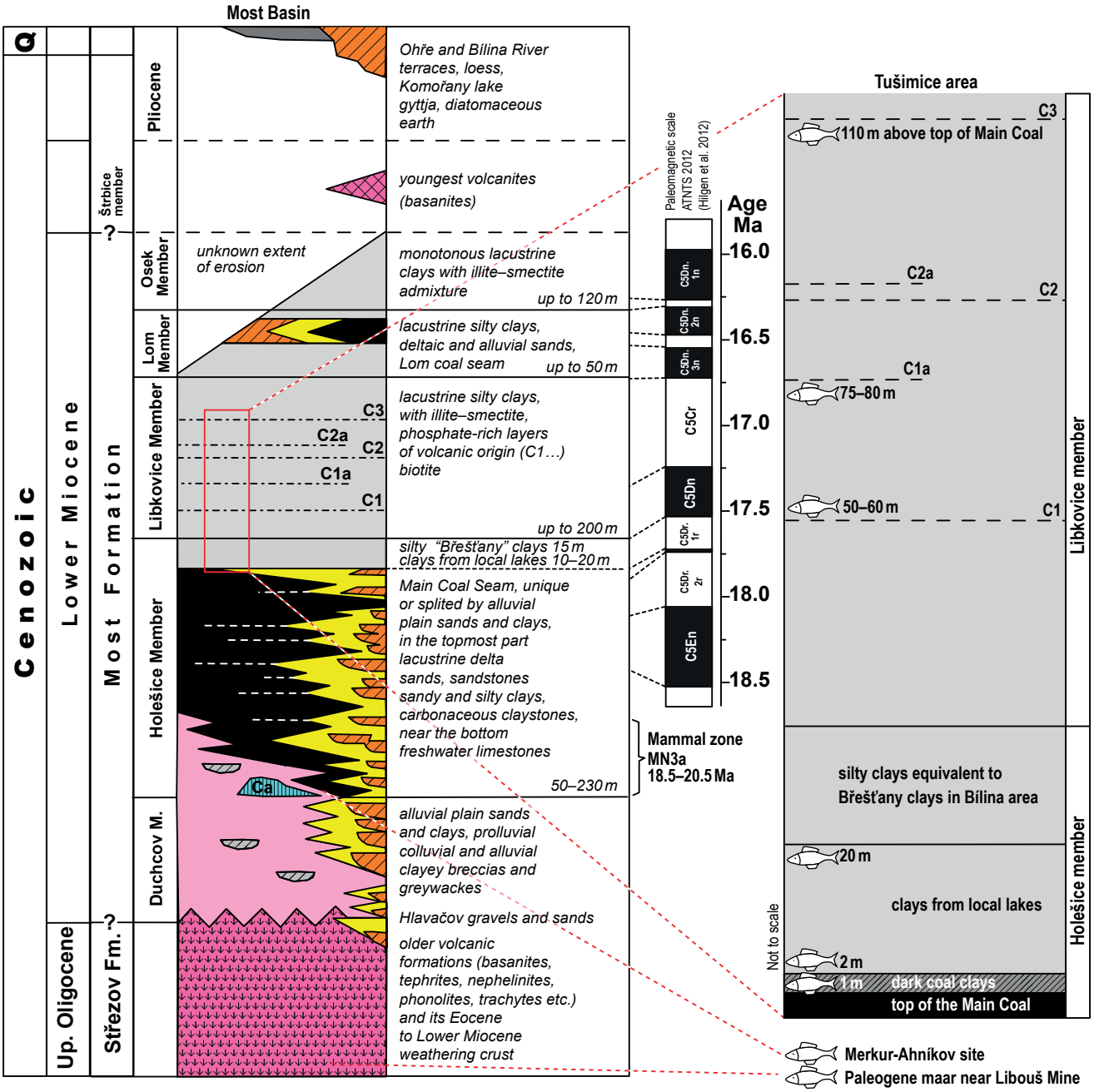
The Most Formation (Lower Miocene) lies discordantly on a volcanic background and is subdivided into a few units (Text-fig. 1). The basal Duchcov Member comprises an alluvial plain, proluvial sediments and colluvial sediments; none of them yielded any fish remains. Above that, coaly clays and coal comprise the Holešice Member; in the Merkur-Ahníkov area, close to the Duchcov/Holešice members border, we find abundant vertebrate terrestrial fauna of MN 3 age (Fejfar 1990, Fejfar and Kvaček 1993, Fejfar et al. 2003, Heissig and Fejfar 2013, Mach et al. 2017), with a minimal amount of fossil fish. Clastic and organic sedimentation was strongly influenced by carbonate-rich water from local thermal springs, which allowed preservation of all kinds of Miocene faunas. Fish remnants consist of several isolated bones among terrestrial fauna preserved in coal-rich silty clays. One determinable pharyngeal bone probably belongs to the species *Palaeoleuciscus chartaceus*.

Above that, still in the Holešice Member, there is an enormous coal seam, as result of massive organic swamp sedimentation. However, the coal seam is split into various levels by clastic sediments from the nearby extensive alluvial system, the so-called Žatec delta (Novotný and Mach 2016). Coal production eventually ended, because the swamp with trees was flooded, but sedimentation continued, with lacustrine clays overlying the coal seam. These oldest lacustrine sediments above the main coal seam still belong to the Holešice Member, with thicknesses 15–30 m.

Above this are deposited very similar clays of the Libkovice Member, intercalated by at least 3 thin layers of phosphate sediment. These are called "crandallite bearing horizons", and each layer has volcanogenic material at its base (Mach et al. 2021). These horizons help with stratigraphic ranking in the Libkovice Member. The difference between the Libkovice and Holešice overlying clays is based on the mineralogical composition of the clays (Matys Grygar et al. 2017, 2021). Almost all thickness of overlying clay sediment is bioturbated by invertebrate fauna. This bioturbation has been named *Planolites montanus* (Mikuláš et al. 2006); it completely disrupted the original lamination. The fossil record in the upper part of the Holešice Member (clay layers above the coal seam) and the Libkovice Member in the western part of Most Basin is generally very poor, apart from a few layers described by Novotný et al. (2021). These layers also contain the fish fauna described here. Dating of these clays overlying the coal in the area addressed in this paper to 16.7–17.7 Ma is based on palaeomagnetic indications (Matys Grygar et al. 2017).

Above the coal seam, fish remains (see Pl. 1 for representative specimens) occurred in the following six layers (Text-fig. 1):

- 0–1 m – dark brown carbonaceous silty clay of Holešice Member, locally called coaly shale, with abundant remains of reptiles and frog fossils mentioned by Špinar (1972). Here are abundant fish fossils, often articulated



Text-fig. 1. Lithostratigraphic scheme for Most Basin (edited according to Kvaček et al. 2019 and Hilgen et al. 2012) with fossiliferous horizons of Holešice and Libkovice members in its west part. Stratigraphic position of fish remnants is highlighted.

or semi-articulated, sometimes even with preserved soft body tissues, and even when the skeletons are partly or completely disarticulated, the bones often remain associated.

This layer yielded ca. 200 specimens, 150 of them taxonomically identifiable (at least to the family level). **Cyprinidae**: *Palaeotinca* sp. (NM-Pv 10055), *Palaeoleuciscus chartaceus* (NM-Pv 10063), ?*Chalcalburnus* (NM-Pv 10064), **Umbridae**: *Umbra* sp. (NM-Pv 10056).

- 2 m – light brownish-grey silty clay. Disarticulated isolated fish remains.

  This layer yielded ca. 50 specimens, 20 of them taxonomically identifiable (at least to the family level). **Cyprinidae**: *Palaeotinca* sp. (NM-Pc 2551–2552), *Aspius* sp. (NM-Pc 2560–2561), *Barbus* sp. (NM-Pc 2554–2555), ?*Chalcalburnus* sp. (NM-Pc 2562–2563, NM-Pc 2553).
- 20 m – light brownish-grey silty clay. Disarticulated but associated fish in core-drilling.

  This layer yielded 2 specimens, 1 of them taxonomically identifiable. **Cyprinidae**: *Palaeoleuciscus* sp. (NM-Pv 10057).
- 50–60 m – light beige-gray silty clay. Disarticulated but associated fish remains.

  This layer yielded ca. 35 specimens, 6 of them taxonomically identifiable (at least to the family level). **Cyprinidae**: *Palaeoleuciscus chartaceus* (NM-Pv 10058), *Palaeotinca* sp. (NM-Pv 10065); **Esocidae**: *Esox* sp. (NM-Pv 10066).

- 75–80 m – light brownish-beige silty clay. Disarticulated but associated fish remains.
  This layer yielded 15 specimens, 9 of them taxonomically identifiable (at least to the family level). **Cyprinidae**: *Aspius* sp. (NM-Pv 10067), *Barbus* sp. (NM-Pc 2657–2660, core drilling); **Esocidae**: *Esox* sp. (NM-Pv 10060).
- 110 m – light grey and greyish-beige silty clay. Disarticulated but associated fish remains.
  This layer yielded ca. 30 specimens, 10 of them taxonomically identifiable (at least to the family level). **Cyprinidae**: *Palaeotinca* sp. (NM-Pv 10061), *Palaeoleuciscus chartaceus* (NM-Pv 10068), *Chalcalburnus steindachneri* (NM-Pv 10062), *Barbus bohemicus* (NM-Pv 10069), ?*Aspius* sp. (NM-Pv 10070); **Esocidae**: *Esox* sp. (NM-Pv 10071).

Palaeoecological and taphonomic interpretations

The origin of isolated fish bones found close below the coal seam base (Merkur-Ahníkov fossil site) is not fully understood. The environment was a mixed mesophytic forest, with streams and temporary pools. Although the fish remains could be autochthonous, it seems more probable that they are allochthonous, from pellets cast by birds of prey. This conjecture is supported by both the great diversity of discovered bones, from small mammals, amphibians and reptiles, and also the concentration of such remains in relatively small, isolated patches, presumably accumulated under birds' nesting sites. The fish *Palaeoleuciscus* identified in this layer, presumed to have similar habitat requirements to the recent *Leuciscus*, would have preferred well-oxygenated water. Nevertheless, the complex mosaic of habitats on the Ahníkov site make interpretation difficult.

The semi- and fully articulated ichthyofauna from the carbonaceous clays just above the coal seam (0–1 m) indicate a hypoxic to anoxic environment, which limited microbial decay. Extensive taxonomic diversity and the presence of genera inhabiting the benthopelagic part of the water column (such as *Umbra* sp.), together with taxa sensitive to a decrease in oxygen in the water suggest that the water was well oxygenated most of the time. However, the abundance of articulated fish skeletons with preserved soft body tissue, as well as remains of frog tadpoles in these layers both indicate that oxygen depletion occasionally occurred across the entire water column. We consider the presence of *Palaeotinca* (that was most probably able to tolerate reduced oxygen in the water) not palaeoenvironmentally significant. The absence of *Esox* is quite interesting. These predators, well known from recent, require well oxygenated water, and deeper lake or/and natural shelters for ambush hunting. Other fish remains show the oxygen conditions should have been sufficient for *Esox* as well. The lowest beds above the coal seam contain fallen tree trunks, branches, and stumps standing in situ, which could have afforded shelter for *Esox*. The higher parts contain smaller plant detritus, but not bigger tree parts. The absence of the predator in this lowest layer could be explained by the environment being cluttered with flora fragments and too shallow for such a large predator.

Isolated fish bones collected about 1 m higher (2 m above the top of the coal seam) indicate a change in environment. No associated bone groups from one fish specimen were recorded. The dead fish bodies were completely dismantled, with their bones were widely spread and buried by sediment. It seems the oxygen content in water was now sufficient for the activity of scavengers. The oxygen condition in the water and sediment seems to have become more uniform, as opposed to the previous stratification.

In term of taphonomy, the four subsequent fossil-fish-bearing layers (20, 50–60, 75–80, 110 m above the top of the coal seam) seem to be roughly uniform. The findings are rarely semi-articulated. More often they are disarticulated, but associated in bone groups from one fish specimen. The taphonomy indicates some limit on post-mortem physical dismantling. Low oxygen levels in the water are a possibility, but the absence of Fe-sulfides and carbon in the sediments argues against it. Quick sedimentation seems more likely. The fish fossils occur in beds with abundant plant leaves. It is not clear whether the plant occurrences are a result of occasional higher sedimentation speed in the foreland of the delta body, or related to a lack of bioturbation (Novotný et al. 2021). Except for the fossil-rich beds, sediments in the Libkovice Member are substantially affected by bioturbation of *Planolites montanus* type (Mikuláš et al. 2006). The bioturbated beds afforded very few fossil leaves and fish remains – there are almost no conspicuous fish remains like articulated and semiarticulated specimens, or even bone associations. It seems the fish bodies were disarticulated and widely spread before being buried in sediment.

The uppermost three layers document the presence of a well-diversified fish assemblage inhabiting all parts of the water column (benthopelagic *Barbus* and demersal *Palaeotinca*, *Palaeoleuciscus* in the upper part), and include *Esox* sp., pelagic top predator of the fish assemblage (accompanied by *Aspius* in the two upper-most layers).

Conclusions

The fish species discovered in different beds in Holešice and Libkovice members and their taphonomy contribute to the understanding of conditions and palaeoenvironment in this section of Most Basin.

The paucity of determinable fish fossils recovered from the bottom part of the Holešice Member (Merkur-Ahníkov site) currently prevents reliable palaeoenvironmental evaluation. Moreover, the taphonomic history is apparently influenced by birds of prey. In the future, data about fish fauna from the site may be substantially enlarged, because a great number of diverse small-vertebrate bones are waiting for studying in detail.

The fish and juvenile amphibian record from dark brown carbonaceous beds just above the top of the coal seam (0–1 m) shows occasional reductions in oxygen saturation, to hypoxia and even anoxia, particularly near the bottom. The absence of the large predator *Esox* could be coherent with big plant remains in the sediment. Both of these suggest organic barriers in the emerging lake. Later, when the tree parts disappeared, perhaps the water was still too shallow for the existence of a big predator with such a specific hunting strategy.

The taphonomy of fish fragments in the layer about 2 m above the coal seam reveals intensive activity of decomposers on the lake bottom. It is most likely related to oxygen stabilization to uniform values across the entire water column.

All four fossiliferous layers, 20 m, 50–60 m, 75–80 m and 110 m above the top of the coal seam appear to be similar. The association of fish fossils with the large predator *Esox* indicate stable conditions in a deep and well-ventilated lake. The common high abundance of fauna and flora and absence of *Planolites* bioturbation in the same beds could be explained solely by quicker sedimentation, since the higher sedimentation speed was certainly accompanied by more extensive import of plant particles into the basin.

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Explanations of the plate

PLATE 1

Selected fossil fishes from different layers of Holešice and Libkovice members

1. Semiarticulated skeleton, *Palaeotinca* sp. (NM-Pv 10055); 0–1 m above coal seam.
2. Isolated scale, *Umbra* sp. (NM-Pv 10056); 0–1 m above coal seam.
3. Pharyngeal bone, *Aspius* sp. (NM-Pc 2561); Prunéřov, 1–2 m above coal seam.
4. Pharyngeal bone, *Palaeoleuciscus* sp. (NM-Pv 10057); Černovice-borehole CV 104, 20 m above coal seam.
5. Partly disarticulated incomplete skull, *Palaeotinca* sp. (NM-Pv 10058); 50–60 m above coal seam.
6. Articulated, rather crumpled skeleton, Cyprinidae indet. (NM-Pv 10059); 50–60 m above coal seam.
7. Disarticulated cranial bones, *Barbus* sp. (NM-Pc 2658–2660, glued together); Černovice-borehole CV 65, 80 m above coal seam.
8. Articulated incomplete skull, *Esox* sp. (NM-Pv 10060); Spořice, 75–80 m above coal seam.
9. Opercular bone, *Palaeotinca* sp. (NM-Pv 10061); Spořice, 110 m above coal seam.
10. Pharyngeal bone, *Chalcalburnus steindachneri* (NM-Pv 10062); Spořice, 110 m above coal seam.

PLATE 1