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Paleogeography of the Early Badenian connection between the Vienna Basin and the Carpathian Foredeep

Research article

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Abstract: The paleogeographic reconstruction for an early Badenian connection of the Vienna Basin and the Carpathian Foredeep in the Mikulov area (Mikulov Gate) based on paleontological (otoliths) and geological (regional geology, tectonics) data has been provided. The ecologically homogenous deep water associations of otoliths in the most NW tip of the Vienna Basin (Sedlec HJ-2 Borehole) links up bathymetrically with nearly adequate otolith assemblages in the southernmost Moravian part of the foredeep. Ten meso- and bathypelagic teleost species have been identified in the Vienna Basin for the first time. Geological analyses proved inversion processes of recurrent nature along old faults of the NW-SE direction in the Dyje (Thaya) Depression. In the early Badenian the Mikulov Gate resulted from the sagging block of the Waschberg Zone. This marine channel was relatively deep (> 200m, as indicated by otoliths) and in all probability flooded an entire front of the nappes in this area.

Keywords: Central Paratethys • South Moravia • Middle Miocene (Langhian) • otoliths • tectonics

1. Introduction

Research on fish otoliths in the lower Badenian of the Vienna Basin has been focused on outcrops representing first and foremost a marginal or shallow water sedimentary environment [1–3]. Borehole material has usually only brought individual otoliths, the number of which was not convenient for understanding individual fish assemblages on a stratigraphic level.

In the years 1975-6, the Sedlec HJ-2 core borehole was carried out near the Austria/Czech border (fig. 1) within the framework of regional hydrogeological research in the Mikulov-Valtice region [4]. It was situated about 1km E of Sedlec (Czech Republic, Southern Moravia, x = 594.772, 44; y = 1,207 323, 70; z = 175.6m a. S.). It drilled 300 m thick lower Badenian sediments dated biostratigraphically by Molčíková [5]. They contain rich otolith fauna (as much as forty specimen/1 kg of material) being unusually monotonous and stable in the drill hole interval 4.9-267.4m. A short Czech report about this fauna was previously published by Brzobohaty [6]. It's elaboration, representation and paleogeographic consequences are the aim of the article presented.

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2. Material and methods

Forty two otolith-bearing samples were taken in the interval between 3.8 - 267.5m of the Sedlec HJ-2 Borehole. The otoliths were obtained from the lower Badenian calcareous clays by washing through a 1 mm sieve and picked using a binocular microscope. A total of about 18 nominal teleostei species (six of them extant) have been identified. The paleobathymetrical evaluation of the otolith association was made on the basis of actualistic approach.

A list of all otolith-based taxa is given in fig. 3. The abbreviation "cf." in the binomina was used in the case of well-preserved material where specific identity could not be unequivocally determined. All figured specimens (pl. 1) can be found in the collections of the Department of Geological Sciences of the Masaryk University in Brno (collection of types and figured specimens, inventory numbers: O298-O314. For all general matter about otoliths and their morphological nomenclature, the reader is referred to Nolf [7].

The study focuses on the area of the southern Moravian part of the Carpathian Foredeep and the Vienna Basin as well as on parts of the Ždánice Unit. A longitudinal geologic section has been constructed for the southernmost part of the Ždánice Unit between Strachotín-2 and Nikolčice-2A wells to illustrate local tectonics causing the connection between both basins established during the early Badenian. General methods of induction and extrapolation were used for paleogeographic interpretations.

3. Geological setting

In the Lower Miocene the Vienna Basin, as a typical piggy-back structure on top of Alpine-Carpathian thrust belt units, constituted a more or less paleogeographically uniform depositional region together with the Carpathian Foredeep. The following pull-apart processes with NE-SW oriented sinistral strike-slip faults emphasized basin individualisation. These tectonics were associated with characteristic dipping of blocks on the W margin of the basin, e.g., a moving down at the marginal Schrattenberg Fault already began in the early Badenian and reached values of up to 500-700m [8]. The structure of the Ždánice Unit in this region is also segmented by cross faults [9].

The Sedlec HJ-2 Borehole was situated in the NW tip of the Vienna Basin (fig. 1) close to the boundary with the Flysch Belt Ždánice Unit and is represented morphologically by the Mikulov Highlands. It was positioned eastward from the Falkenstein-Mikulov Faults in the Sedlec Depression laying between the Mikulov Block and the Rakvice Block [10].

The lower Badenian Lanžhot Beds overlie the rocks of the Ždánice Unit and are predominantly represented by pelites about 300m thick laying sharp on the basal clastics [8]. Generally, these beds belong to the early Badenian transgressive system tract of the VB5 cycle in the Vienna Basin [11].

The Sedlec HJ-2 Borehole (fig. 2) primarily drilled through green-grey to light grey silty calcareous clays ("Tegels") of the Lanžhot Beds locally with small layers (cm) of fine grained sands and sporadic pebbles of sandstones and hornstones. Fragments of molluscs are concentrated around borehole depths of 20m and 133m [4]. The foraminiferal fauna was systematically analyzed from 16 samples of the borehole and quantitatively viewed in relative terms by Molčíková [5] - very often, often, common, rare, very rare. The following summary is based on this analysis.

The foraminiferal benthos is relatively rare and fragmentary with a prevalence of shallow-water species at the base of the borehole (300m-286m). In higher levels it is characterised by species as well as individual abundance of bolivinids, buliminids, globobuliminids, cassidulinids and occasionally also nonionids (95-97m, 124-126m). Some other groups are individually rare, but occur continuously - *Lenticulina* ssp. (abundant only at 124-126m and 151m), stilostomellids (124-126m), *Uvigerina* ssp., *Eponides* and *Sphaeroidina bulloides* d'Orb. From 200m to the top of the borehole the *Pullenia bulloides* (d'Orb.) occurs, common mainly in the middle part of the profile between 95m to 179m. The common *Melonis pompilioides* (F. et M.) also complements the sample at 124-126m. *Valvulineria complanta* (d'Orb.) occurs continuously in all samples, more frequently at 95-7m and 151m. *Trifarina angulosa* (Will.), species commonly associated with shelf-edge-upper-slope areas in the recent [12] is commonly located at 65-67m, 124-126m and 286m. Typically shallow-water groups such as *Ammonia*, *Pararotalia*, *Amphimorphina*, *Amphistegina* (one occurrence only, 33-35m), *Elphidium*, *Hanzawaia*, *Spiroloculina*, shallow water miliolids, etc. are rare or very rare in the profile and occur discontinuously. The portion of shallow water elements with bryzoans and the older re-deposited fauna is somewhat higher in the short episodes connected to small layers of fine grained sands and molluscs fragments (e.g. the interval from 20m to 36m).

These assemblages indicate lower-shelf to upper-bathyal depths of sedimetation with an inclination to dysoxic environment at the bottom [comp. 13,14]. Lower oxygen level could be documented by low oxygen-indicative groups

Fig. 1

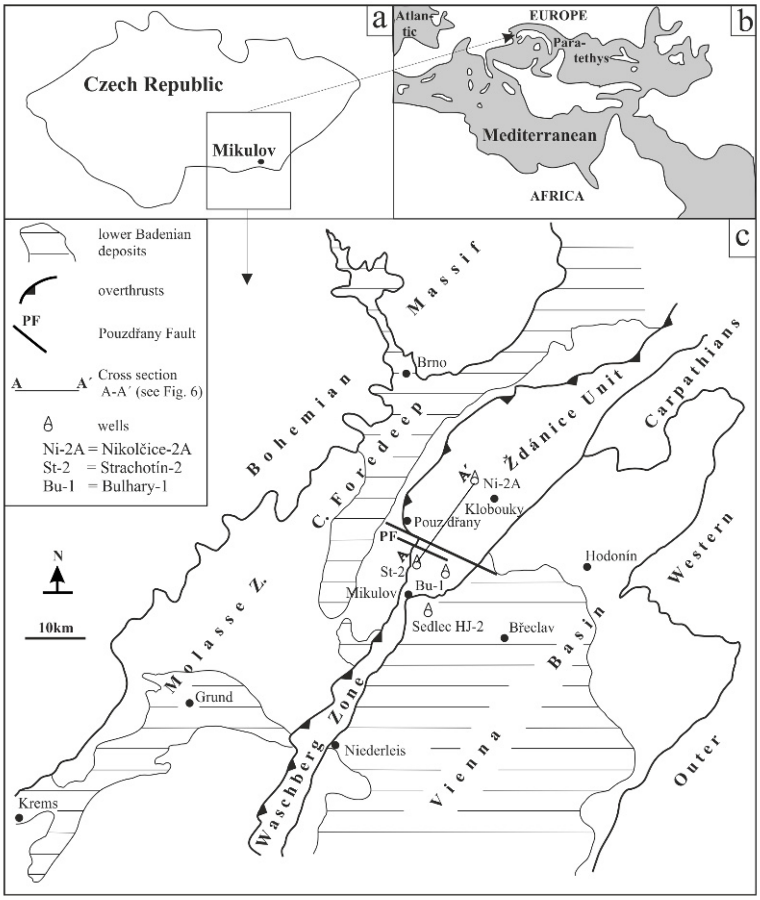

Figure 1. The geographical (a), paleogeographical (b), and geological (c) position of the studied area (b - after [52], c - after [38, 43], modified).

such as *Valvulineria complanata, Sphaeroidina bulloides, Pullenia bulloides, Lenticulina* gr., bolivinids, globobuliminids and stilostomellids. Oxic indicators such as *Cibicidoides* and *Heterolepa* are missing or very rare.

The foraminiferal plankton is often diversified (see fig. 2), individually abundant and supplemented by only sporadic radiolarians. It is represented mainly by species *Globigerina concinna* Rss., *G. tarchanensis* Subb. et Chuz., *G. praebulloides* Bl. and *Globigerinella obesa* (Bolli). The index species *Orbulina suturalis* Bronn. occurs only in the top of the profile (5-6m). Praeorbulinas and *Uvigerina macrocarinata*, the benthic index species of the Lower Lagenidae Zone [15, 16], were not found. In contrast, there is a relatively frequent occurrence (rare to common) of species *Paragloborotalia*? *mayeri* (Cush. et El.) and *Globorotalia bykovae* (Ais.) which together with a presence of benthic species *Vaginulina legumen* (Linn.) at 124-126m confirm the early Badenian age in the Western Carpathian basins [17, 18].

The foraminiferal assemblages of the lower section indicate the Lower Lagenidae Zone and from 124m up they indicate the Upper Lagenidae Zone in the context of the Vienna Basin regional ecostratigraphy [5]. This level is usually biostratigraphically correlated with the uppermost NN4 Zone and the lower part of the NN5 Zone and the lower Badenian (= Langhian) in the chronostratigraphic sense respectively [18, 19].

The stratigraphic position is also documented by otolith fauna. Species such as *Vinciguerria poweriae* (Cocco), *Benthosema fitchi* (Brz. et Sch.), *Hygophum hygomi* (Ltk.), *Lampadena gracile* (Schub.) and *L. speculigeroides* Brz. et N. are considered to be early Badenian immigrants in the Central Paratethys [20] and together with lack of the Karpatian index species such as *Lampanyctus carpaticus* (Brz.) and *Hygophum hygomi* (Brz.) indicate the cited age.

Fig. 3

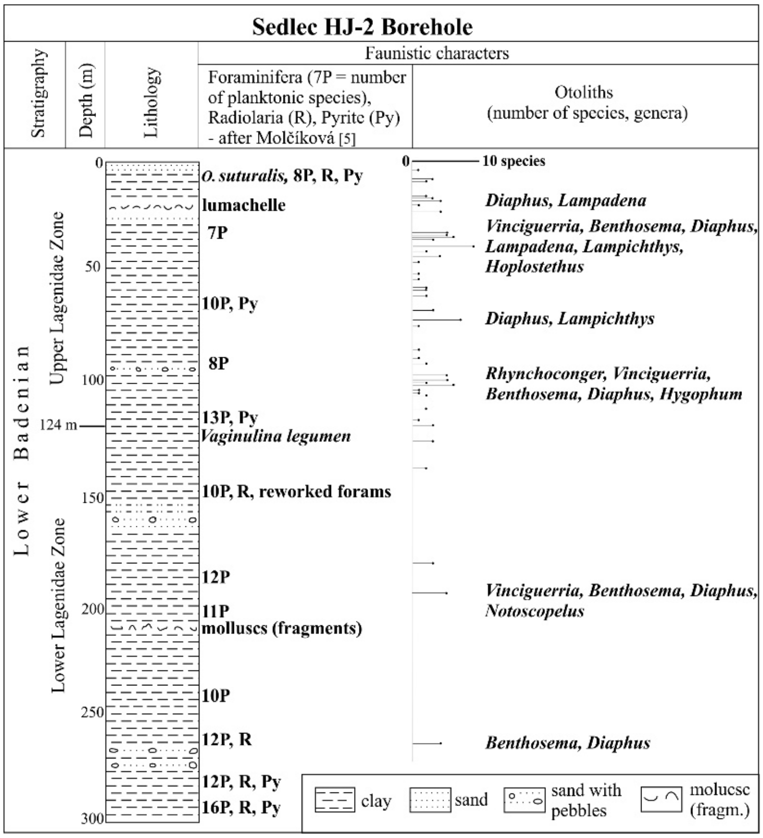

Figure 2. Stratigraphy [5], lithology [4] and paleontology of the lower Badenian deposits in the Sedlec HJ-2 Borehole.

4. Results

4.1. Otoliths

The otoliths occur from a depth of 267m to the top of the profile (fig. 2, fig. 3). There are intervals with nine species (~ forty specimens, unusually rich from the point of view of borehole probes). This provides evidence for a very diversified presence and individually abundant fish assemblages in the water column during the sedimentation of the studied clays. The association in the borehole contains otoliths of meso- bathypelagic fishes with a clear majority of myctophids apart from one juvenile non-identifiable specimen of shallow water gobiids at a borehole depth 106.5m. The ecological data of the extant species and the extant relatives of the fossil species are provided as follows [21–23].

Congridae. *Rhechias pantanellii* (Bassoli & Schubert, 1906) ranks among the most frequent representatives of conger eels in the wide Mediterranean Miocene otolith faunas (fig. 7/15). The only extant species of these genera, *Rhechias bertini* (Poll, 1953), lives bathydemersal along the uppermost continental slope (200-400m) in the Eastern Atlantic.

Phosichthyidae. Otoliths (fig. 7/16) of the extant and luminescent species *Vinciguerria poweriae* (Cocco, 1838) are a common component of the deep water associations of the lower Badenian in the Carpathian Foredeep [24]. They have been identified in the Vienna Basin for the first time. At present *V. poweriae* is circumglobal widespread in the bathypelagic assemblages, primarily found at 300-600m during the day and 50-350m at night. Along with *Cyclothone* the genus *Vinciguerria* has the greatest individual abundance of any vertebrate genera in the world [22].

Myctophidae. At present the family is represented by primary oceanodromous meso- to bathypelagic fishes with luminous organs. They mostly migrate between epi- (at night) and mesopelagial (during the day) and are cos-

Fig. 3

metres \ species	*Rhynchoconger pantanellii* (B. et Sch.)	*Vinciguerria poweriae* (Cocco)	*Vinciguerria* sp.	*Benthosema fitchi* (Brz. et Sch.)	*Diaphus acutirostrum* (Holec)	*Diaphus cahuzaci* Steurb.	*Diaphus debilis* (Kok.)	*Diaphus haereticus* (Brz. et Sch.)	*Diaphus kokeni* (Proch.)	*Diaphus regani* Taaning	*Diaphus taaningi* Norman	*Diaphus* div. sp. juv.	*Hygophum hygomi* (Ltk.)	*Lampadena gracile* (Schub.)	*Lampadena speculigeroides* Brz. et N.	*Lampadena* sp.	*Lampichthys schwarzhansi* (Brz.)	*Notoscopelus mediterraneus* (Kok.)	*Gadomus tejkali* (Brz. et Sch.)	*Gadiculus argenteus* Guich.	*Hoplostethus* cf. *mediterraneus* Cuv.	? Gobiidae indet. juv.
3.8m												+										
7.8m										+		+						+				
9.5m							+	+														
16.5m							+									+						
17.5m					+		+					+										
18.5m					+	+				+		+										
20.5m						+																
23.5m		+						+		+		+										
33.5m						+	+			+		+	+									
34.5m						+	+			+		+								+		
35.5m					+	+	+					+	+				+					
36.5m							+					+						+				
40.5m		+		+	+		+	+			+	+			+						+	
42.5m							+												+			
44.5m		+					+					+					+					
48.5m												+										
52.7m					+																	
54.5m												+										
58.1m										+		+										
59.2m					+		+															
61.5m						+						+										
66.5m									+			+		+								
70.5m					+	+	+	+		+		+					+					
72.5m																+						
92.5m												+										
95.5m												+										
98.5m				+								+										
99.5m				+						+		+		+				+				
100.5m				+	+					+												
101.5m							+					+										
102.5m			+	+	+			+			+	+										
104.5m												+										
105.5m	+											+										
106.5m												+										+
111.5m				+								+										
121.5m										+												
122.5m				+						+		+										
125.5m										+		+		+								
139.5m												+										
174.5m				+			+			+												
187.5m			+	+			+			+								+				
267.5m				+		+	+			+												

Figure 3. List of teleost species represented by otoliths in the Sedlec HJ-2 Borehole.

mopolite apart from e.g. *Notoscopelus mediterraneus* (Costa, 1844) in the western Mediterranean.

There are three extant species in the profile. *Diaphus regani* Taaning, 1932 (figs 7/3, 4) is a typical species of the mesopelagial in the Indo-West Pacific Region and occurs as a fossil from the Lower Miocene (Mediterranean, Aquitaine – [25]). *D. taaningi* Norman, 1930 (fig. 7/6) is a typical pseudoocenic element found over continental shelves and slopes in an interval between 40-475m. In the anoxic bottom environments (e.g. the Cariaco Trench) the fish also migrate over 250m depth during the day. *D. taaningi* was also identified in the Central Paratethys upper Badenian together with the fossil species *D. kokeni* as the only myctophids in this stratigraphic level (a more closed paleogeographic environment). *Hygophum hygomi* (Lütken, 1892) representing deep-water cosmopolite fishes (including the Mediterranean) necessitates a depth of 600m in the Recent during the day (fig. 7/8). Extant species of the genus *Lampadena* and *Notoscopelus* are previously oceanodromous, mesopelagic during the day and epipelagic at night. The genus *Lampichthys* is only presented by one species *L. procerus* (Brauer, 1904) in the extant seas. It is found circumglobal in the southern hemisphere (to Gibraltar) between 100-700m depth at night and deeper during the day. The fossil species *L. schwarzhansi* Brzobohaty, 1986 (fig. 7/9) was identified as uncommon in the lower Badenian of the Carpathian Foredeep up to this time [26–28]. For more on the other fossil species see the revision works about European Neogene myctophids [25, 29].

Gadidae. Cods are represented by *Gadiculus argenteus* Guichenot,1850 (fig. 7/17). In the recent seas this species lives marine, pelagic and nonmigratory at depths of 100-1000m and is widespread from North Scandinavia to Morocco in the North Atlantic Region (including the Mediterranean). Otoliths of this species are common in the Badenian sediments of the Central Paratethys.

Macrouridae. The grenadiers (rattails) of the subfamily Bathygadinae are represented by *Gadomus tejkali* (Brzobohaty & Schultz, 1978). Otoliths of this species (fig. 7/14) are a typical component of the bathymetric deepest otolith associations in the lower Badenian sediments of the Carpathian Foredeep. In the Mediterranean *G. tejkali* still occur in the Tortonian [30]. In the recent seas fishes of the *Gadomus* genus prefer water depths under 200m (with a peak of occurrence between about 600 to 1000m) as the component of the bathypelagic or bathydemersal assemblages in the tropical and subtropical regions apart from *G. aoteanus* McCann & McKnight, 1981 migrating in the temperate waters of the Southwest Pacific Region above 200m.

Trachichthyidae. Roughies mostly incline to a deep-water environment as well. Bathypelagic and cosmopolite *Hoplostethus mediterraneus* Cuvier, 1829 occurs in recent seas at depths of 100-1175m (including the Mediterranean). It's fossil otoliths are represented by numerous ontogenetic stages from juvenile (fig. 7/13, as "cf.") to adult specimens e.g. from the Borač locality (lower Badenian, Carpathian Foredeep, Czech Republic) [31].

5. Discussion

The association of deep-water species in the Lanžhot Beds of the studied borehole indicates a sedimentation environment at a depth below 200m and depths of more than 400m in the possible surroundings. It logically also indicates the presence of a mid-water habitat (the mesopelagic zone) in the Vienna Basin during the early Badenian. This habitat had to contain many life forms with special adaptations (e.g. color, photophores, diurnal vertical migration, reproductive patterns, etc. [32]). The fish assemblages are only part of them but are actually supported by otoliths in sediments in contrast to other groups (squids, shrimps etc.). This speaks for the excellent connection and communication of the Vienna Basin with the open sea and ocean in the early Badenian [30]. In the present day Adriatic Sea, for example, similar fish assemblages only live in the Southern Adriatic with a developed mesopelagic zone and a corresponding connection with the Western Mediterranean and the Atlantic [33].

It should be emphasized that the mesopelagic assemblages of the Vienna Basin lower Badenian clearly differ from the facially identical ones of the Karpatian. The sternoptychids are missing in Karpatian assemblages of the Vienna Basin, myctophids are generally poorly diversified (six species : fifteen species in the studied lower Badenian section) and show partly different species composition. Especially, two Karpatian myctophid species, *Lampanyctus carpaticus* (Brz.) and *Hygophum weileri* (Brz.), are restricted to the Vienna Basin and the Carpathian Foredeep. They do not appear in the thoroughly studied otolith faunas from the Lower Miocene of the Aquitanian Basin [34] and Northern Italy (Piemont - [35]). This is surprising since myctophids generally do not create endemic species [20]. Additional data on Karpatian otoliths in the Vienna Basin are required to make a more precise environmental comparison.

Otolith assemblages of deep dwelling fishes are also known in the Central Depression of the early Badenian Carpathian Foredeep in South Moravia [36]. The early Badenian connection between the Vienna Basin and the Carpathian Foredeep (fig. 4) resulting from the geological position and extension of sediments is traditionally accepted in the Niederleis-Mikulov-Hustopeče region [37]. Two explanations are argued here [38, 39]. The southern one passes from Niederleis Bay into the area between Grund and Krems - "Zaya Gate", Jiříček [40]. It was based on a dipping block in the Waschberg-Zone (crossing the Leiser Hills) and is supported by evidence of deposits corresponding to the upper part of the Lower Lagenidae Zone, cliff-like shore relief triggered by faults and sagging synchronous to sedimentation. Zaya Gate reached depths of 100m-500m in the deepest part at Niederleis as interpreted on bases of foraminiferal faunas. It was bordered by land to the south and north [41]. The otolith fauna from Niederleis with a predominance of deep-dwelling fish (*Diaphus, Coelorinchus, Rhechias*) supported such an interpretation [1].

The northern connection is indicated by lower Badenian deposits between Poysdorf-Staatz-Wildendürnbach and Hrušovany n. J. [38, 42, 43]. This way, "Mikulov Gate" [40], also involves a presumed communication through the so-called "Mušov Gate" between the Hustopeče- and Mikulov Highlands mentioned already by Stejskal [44] and other younger authors [see [43]]. This wider northern communication seems to be supported by

- sagging on the Schrattenberg Fault from the early Bade-

Fig. 4

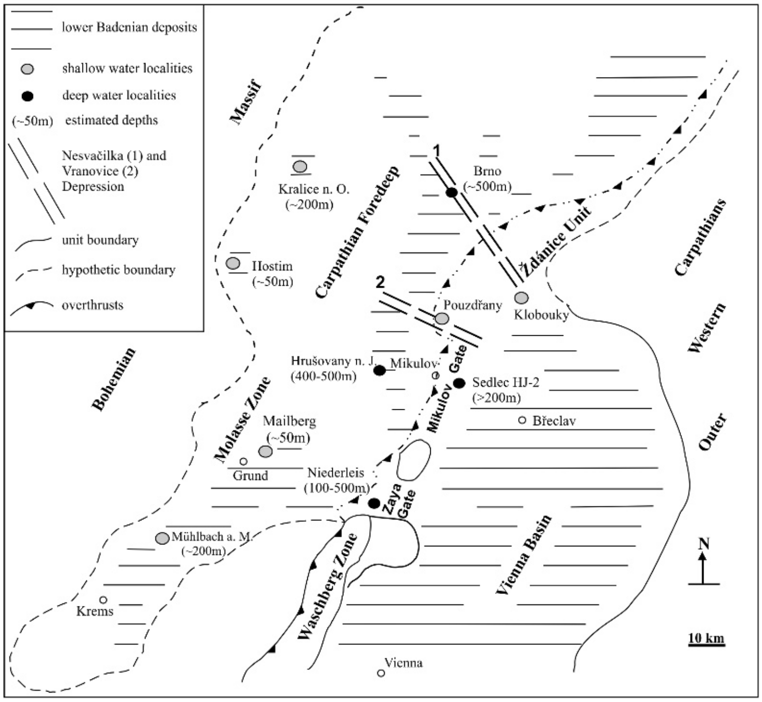

Figure 4. Simplified sketch of the marine connection in the early Badenian (Vienna Basin – Carpathian Foredeep). Paleobathymetry after [6, 36, 41, 53, 54].

Figure 5. Stolová Hora from SE (Pavlov Hills, Ernstbrunn Limestone, Tithonian, Photo I. Poul, 2009). Abrasion surface (Middle Miocene).

Fig. 6

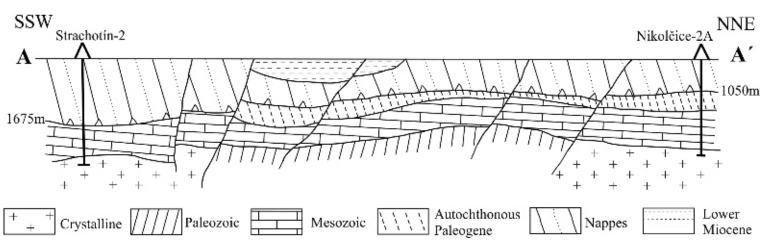

Figure 6. Geologic section A-A´ in the southern part of the Ždánice Unit (see fig. 1).

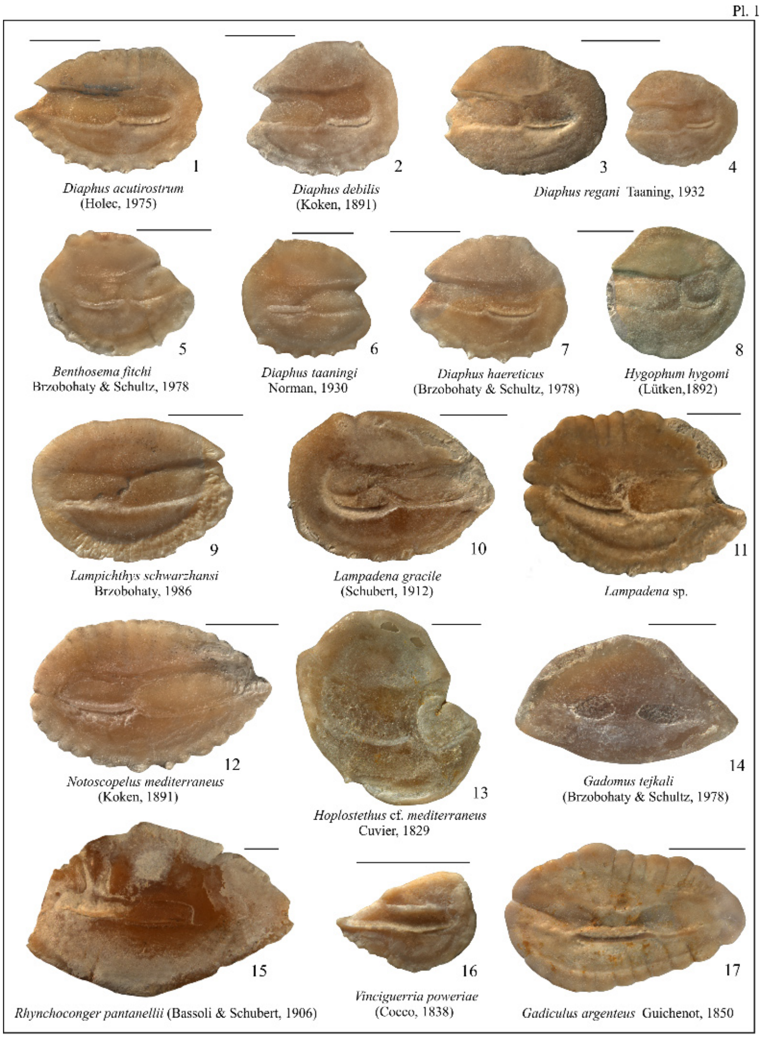

Figure 7. Explanation: All figures show inner views of otoliths. In the captions, L stands for left otolith and R for right otolith. In the plate, scale bar = 1 mm. Deposition - see chapter "Material and methods". 1: Diaphus acutirostrum (Holec, 1975), R, borehole Sedlec HJ-2: 35.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 298) 2: Diaphus debilis (Koken, 1891), R, borehole Sedlec HJ-2: 70.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 299). 3, 4: Diaphus regani Taaning, 1932, R, borehole Sedlec HJ-2: 23.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 300, 301). 5: Benthosema fitchi Brzobohaty & Schultz, 1978, L, borehole Sedlec HJ-2: 99.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 302). 6: Diaphus taaningi Norman, 1930, L, borehole Sedlec HJ-2: 102.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 303). 7: Diaphus haereticus (Brzobohaty & Schultz, 1978), R, borehole Sedlec HJ-2: 70.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 304). 8: Hygophum hygomi (Lütken, 1892), R, borehole Sedlec HJ-2: 35.5m, Vienna Basin, lower Badenian, (DGS MU Inv. Nr. O 305). 9: Lampichthys schwarzhansi Brzobohaty, 1986, L, borehole Sedlec HJ-2: 44.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 306). 10: Lampadena gracile (Schubert, 1912), L, borehole Sedlec HJ-2: 99.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 307). 11: Lampadena sp., L, borehole Sedlec HJ-2: 16.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 308). 12: Notoscopelus mediterraneus (Koken, 1891), L, borehole Sedlec HJ-2: 187.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 309). 13: Hoplostethus cf. mediterraneus Cuvier, 1829, L, borehole Sedlec HJ-2: 40.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 310). 14: Gadomus tejkali (Brzobohaty & Schultz, 1978), R, borehole Sedlec HJ-2: 42.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 311). 15: Rhynchoconger pantanellii (Bassoli & Schubert, 1906), R, borehole Sedlec HJ-2: 100.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 312). 16: Vinciguerria poweriae (Cocco, 1838), R, borehole Sedlec HJ-2: 44.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 313). 17: Gadiculus argenteus Guichenot, 1850, R, borehole Sedlec HJ-2: 34.5 m, Vienna Basin, lower Badenian (DGS MU Inv. Nr. O 314).

nian, evidence of a sharp boundary between basal clastics (if they exist) and overlaying pelites of Lanžhot Beds in the Sedlec Depression east of the Mikulov Block (in the basin there is a gradual transition) [8],

– deep-water pelites of these beds at the NW border of the Vienna Basin (without shallow water facies), a reworked lower Badenian microfauna in the Pannonian sediments of the Vienna Basin at the eastern margin of the Ždánice

Unit [45],

– and isolated occurrences of lower Badenian deposits in cross depressions of the Pouzdřany and Ždánice units (e.g., Pouzdřany, Klobouky, Slavkov – [46, 47]).

On the basis of otolith assemblages, the connection between the Vienna Basin and the Carpathian Foredeep proved to be sufficiently deep to facilitate a penetration of deep water fishes. In the last named basin these otolith faunas are known in the clays of the lower Badenian Central Depression south of the Moravian Gate [36, 48]. The southernmost locality in this sense is Hrušovany nad Jevišovkou (Grussbach am Gewitsch in German, the basement of the sugar works) with a possible paleobathymetry from 400 to 500 m. Therefore, the otolith assemblages of the lower Badenian clays bordering the Ždánice Unit to the east (Vienna Basin) and the west (Carpathian Foredeep) indicate a genuinely deep water environment of both basins in the Mikulov area.

A question arises if the early Badenian Mikulov Gate presented a continuous and relatively deep depression on the southern part of the Ždánice Unit or if it was divided by islands of cross single blocks. The presence of otolith faunas lead us to favour the first interpretation. In the Leiser Hills and the Niederleis Basin of Lower Austria cliff-like and abrasion surfaces were demonstrated [41, 49]. In the Pavlov Hills, abrasion surfaces (Stolová hora, fig. 5) and probably also trace fossils on the Ernstbrunn Limestone (Děvín) are also interpreted as a result of the Middle Miocene transgression [9].

The Mikulov Gate was situated south of cross paleovalleys (Vranovice and Nesvačilka depressions) cut into the pre Neogene basement in the NW-SE direction. Both depressions are filled with Paleogene deposits and buried below the Western Carpathian thrust belt and the rocks of the Neogene Foredeep. At the time of the nappe thrusting (Karpatian/Badenian boundary) they were situated on the sagging block, pronounced by a lateral ramp of the Pouzdřany Fault along which a conspicuous shift of nappe edges took place to the NW (∼ 4km, fig. 1 and 4) [50]. In the early Badenian an inversion processes occurred. An intensive sagging triggered by cross faults took place south of the Vranovice depression and a relatively deep connection between the Vienna Basin and the Carpathian Foredeep in the Mikulov area was established. North of the Dyje Valley the possible connection was shallower. The Mikulov Gate connection was closed by an uplift of the foredeep and nappe edges in South Moravia along with the moving of nappe activity to the north after the early Badenian.

The different depths of the base of the flysch nappes in wells demonstrate the present day different structural position of the Ždánice Unit and the Waschberg Zone. The Bulhary 1 well situated 8 km to the SE from the front of the Waschberg Zone reached a base at a depth of 3231m, whereas the Nikolčice 2A borehole demonstrated a base at a depth of 1050m in the same distance from the front of the Ždánice and Pouzdřany units (fig. 6).

6. Conclusions

The ecologically homogenous association of otoliths is demonstrated in the lower Badenian sediments of the Sedlec HJ-2 Borehole (NW tip of the Vienna Basin). A total of 18 nominal otolith-based species consist of the deep-dwelling fishes, no species of the typically shallow water environment was found. Among them *Benthosema fitchi, Diaphus cahuzaci, D. haereticus, D. regani, Hygophum hygomi, Lampadena gracile, L. speculigeroides, Lampichthys schwarzhansi, Gadomus tejkali* and *Hoplostethus* cf. *mediterraneus* have been identified in the Vienna Basin for the first time. This association corresponds to the facial similar otolith faunas in the southern part of the Carpathian Foredeep at Mikulov. Together with the analysis of the deep geological structure of the pre Neogene and nappe units in this region it infers the following interpretation.

– The connection between the Vienna Basin and the Carpathian Foredeep is situated in the large mobile Dyje (Thaya) depression on the old reactivated faults NW – SE direction between the Danube River and the Nesvačilka paleovalley during Mesozoic rifting. Inverse movements took place on these faults. The Pouzdřany Transfer Fault played an important role in this sense.

– In the Early Miocene, including the time of nappe thrusting (Karpatian/Badenian), the Waschberg Zone south of the Dyje River possessed a high structural position in relation to the Ždánice and Pouzdřany units in the North. This was demonstrated by Lower Miocene deposits in the basement of the Ždánice Nappe whereas these deposits are missing under the nappes of the Waschberg Zone.

– Inversion processes occurred in the early Badenian. From an analogy with the Niederleis Basin in Lower Austria the Mikulov Gate opened up as a connection of the Vienna Basin sea with the area of the Carpathian Foredeep on the sagging block of the Waschberg Zone. This gate presented a relatively deep channel (∼ 200m, of more than 400m depth in the surrounding) flooding in all probability the entire front of the nappes in this area.

– The middle Badenian uplift of the Waschberg Zone and the Carpathian Foredeep shut down the connection of both basins along with an intensive opening of the pull-apart

Vienna Basin along the left-lateral strike-slip faults and the counter clockwise rotation of the Outer Carpathians. In Northern Moravia the Subsilesian and Silesian units were thrust over the lower Badenian as a result of these movements [51].

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