# Extremely rare Turonian belemnites from the Bohemian Cretaceous Basin and their palaeogeographical importance

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**New records of extremely rare late Turonian belemnites are described from the Úpohlavy working quarry in the Bohemian Cretaceous Basin. These specimens are referred to *Praeactinocamax bohemicus* (Stolley, 1916). An alveolar fragment possibly represents *Praeactinocamax strehlensis* (Fritsch, 1872) and would be the third find of this species ever recorded. All finds derive from a thin horizon in the uppermost part of the Hudcov limestone (Teplice Formation, uppermost *Subprionocyclus neptuni* Ammonite Zone). The small faunule most likely had its origin in a taxon from the *Praeactinocamax manitobensis/walkeri/sternbergi* group of the North American Province, and its occurrence in Europe can be seen in the context of a southward shift of Boreal taxa in the course of a late Turonian cooling event.**

## Introduction

Large abundances of Turonian belemnites have been recorded from the East European Province (EEP), especially from the Russian Platform (Košťák 2004). Scattered occurrences are also known from the Middle (Cobban 1991) and Upper Turonian of North America and Greenland in the form of the *Praeactinocamax manitobensis/walkeri/sternbergi* group of the North American Province (NAP). As noted by Košťák et al. (2004), the EEP and Euramerican occurrences show no faunal relationship in the middle and late Turonian, and the faunal regions were palaeobiogeographically strictly separated.

Upper Turonian belemnites in Europe (e.g., Sweden, Bergström et al. 1973; northwest Germany, Wittler and Roth 2001) are rarities and mainly restricted to single occurrences. However, from the Upper Turonian of the Bohemian Cretaceous Basin, Czech Republic (BCB, Fig. 1) and Saxony, Germany, there are several records of two species (*Praeactinocamax bohemicus* [Stolley, 1916] and *Praeactinocamax strehlensis* [Fritsch in Fritsch and Schloenbach, 1872] see Geinitz 1875, Stolley 1916, Jeletzky 1950, 1961; Christensen 1982, 1997a, b; Christensen and Hoch 1983; Košťák 1996; Košťák et al. 2004)]. Most of the material was collected loose and was not attributed to a precise stratigraphic position (Fig. 2). Recently, two complete belemnite rostra and five fragments were collected in situ from the Upper Turonian of the Úpohlavy working quarry in the BCB. Of these, the two rostra and four of the fragments can be assigned to *P. bohemicus*; the excellent preservation of some of these specimens greatly enhances our knowledge of the rostral morphology of this species. A single alveolar fragment most probably represents *P. strehlensis*, which would then be the third record of this species. The occurrence of these taxa is briefly discussed in the context of palaeoclimatic changes during the late Turonian and its palaeobiogeographic implications, thereby enabling a better understanding of possible dispersal pathways of Turonian Belemnitellidae (Fig. 3).

*Institutional abbreviations*.—CIGP, Collections of the Institute of Geology and Palaeontology, Faculty of Science, Charles University Prague, Czech Republic; IGP, Institute of Geology and Palaeontology, Faculty of Science, Charles University Prague, Czech Republic; NM-O, National Museum Prague, Czech Republic.

*Other abbreviations*.—BCB, Bohemian Cretaceous Basin; EEP, East European Province; NAP, North American Province.

## Geological setting

The herein presented material comes from the the Úpohlavy working quarry, ca. 70 km NNW of Prague (Fig. 1). Lithostratigraphically, the quarried succession is part of the Teplice Formation. The belemnites were collected in situ from a thin horizon only ca. 20 cm thick at the top of a well developed limestone unit (Hudcov limestone). The integrated stratigraphic framework of biostratigraphy and $\delta^{13}C$ correlations permits a safe dating as uppermost *Subprionocyclus neptuni* Ammonite Zone or uppermost *Mytiloides labiatoidiformis/striatoconcentricus* Inoceramid Zone (Wiese et al. 2004; Fig. 2).

## Systematic palaeontology

### Family Belemnitellidae Pavlow, 1914

### Genus *Praeactinocamax* Naidin, 1964

### *Praeactinocamax bohemicus* (Stolley, 1916)

Fig. 4A–E.

*Holotype*: Specimen No. NM-O3217, stored in the National Museum in Prague, formerly described and figured as *Belemnites strehlensis* by Fritsch, in Fritsch and Schloenbach, 1872 (Fritsch and Schloenbach 1872: 19, pl. 16: 17). Designated later as *Actinocamax bohemicus* by Stolley (1916), for details see Christensen (1982) and Košťák et al. (2004).

*Type locality and horizon*: The Teplitzer Schichten (now Teplice Formation) at Koštice near Louny, in the Bohemian Cretaceous Basin, Czech Republic.



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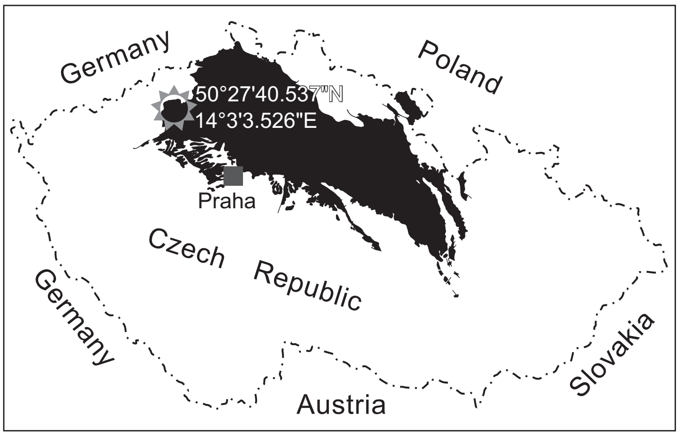


Fig. 1. Geographic position of belemnite locality Úpohlavy with GPS coordinates.

*Remarks*.—For a comprehensive synonymy see Stolley (1916), Christensen (1982), and Košťák (1996).

*Material*.—Two complete rostra and four fragments from the Upper Turonian of the Úpohlavy working quarry, IGP_Upo 2009/1-6. An additional fragment [PG Uy2002/1 (CIGP) registered now as IGP_Upo2009/7] was used for stable isotope analysis by Wiese et al. (2004; see Fig. 2) and is largely destroyed.

*Description*.—The complete rostra (IGP_Upo2009/1, 2) are of medium to small size, not exceeding 65 mm in length. The shape is highly conical in lateral view and cylindrical to subcylindrical in dorsoventral view (Fig. 4A–D). The alveolar end is low-conical (Fig. 4C–E; specimens IGP_Upo2009/1, 2, 4) to flat (specimen IGP_Upo2009/3; Fig. $4B_4$), with a shallow pit in the centre. The cross-section is oval (Fig. $4C_4$, $E_2$) to triangular (Fig. $4B_4$, $D_4$), with concentric and radial structures present (Fig. $4B_4$, $C_4$, $D_4$, $E_4$). Three marked concentric ribs were observed in the dorsal part of the alveolar end of all specimens (clearly visible in Fig. $4C_4$, $D_4$). The ventral furrow is well developed (not exceeding 3mm), with striation in the vicinity (Fig. 4B–E). Due to the exceptional preservation, new morphological features of the species were recognised. Granulation is observed over the entire surface of the rostrum, with coarser granules concentrating close to the alveolar end (= alveolar fracture, specimen IGP_Upo2009/2, Fig. $4C_1$–$C_3$). Additionally, striation occurs on the ventral side of the rostrum. Faint dorsolateral furrows were observed in specimens IGP_Upo2009/1, 2, 5; Fig. $4A_1$, $C_3$, $D_2$). Dorsolateral furrows have not previously been observed in this species, except in the case of the incomplete specimen from Särdal (Sweden) which probably belongs to *P. bohemicus* (Christensen 1982; Košťák et al. 2004). The double furrows in the Úpohlavy specimens are more readily felt than actually seen and are mostly invisible in less well preserved specimens.

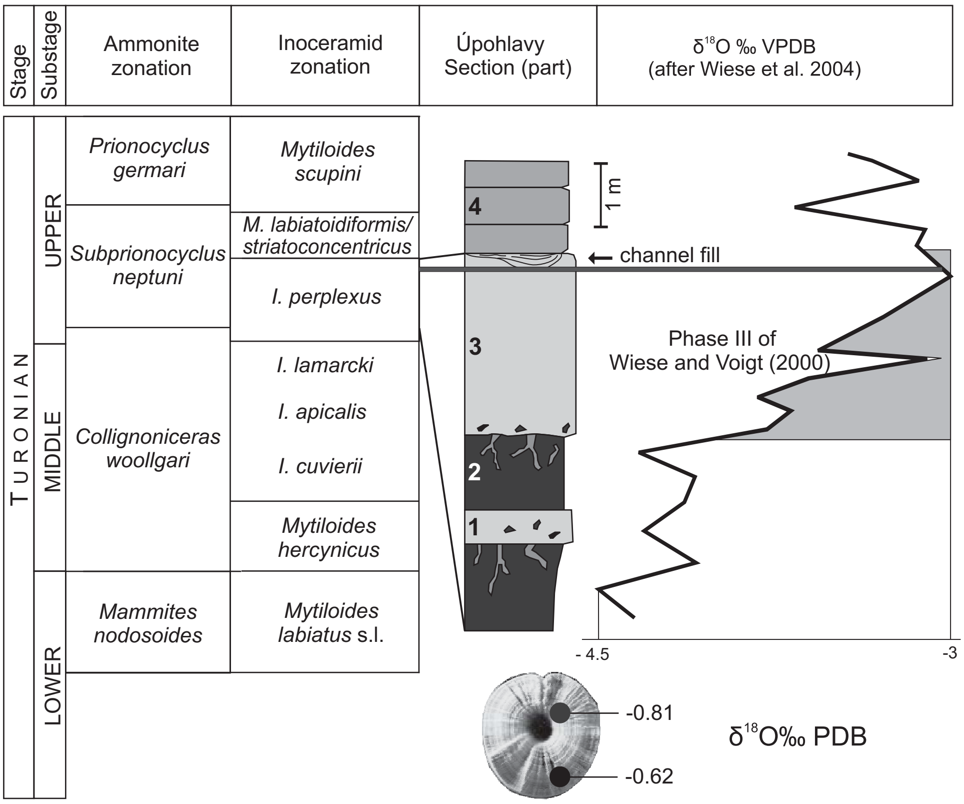


Fig. 2. Belemnite stratigraphic distribution in the Bohemian Cretaceous Basin. 1, Lower coprolite bed (the base of the Teplice Formation); 2, Dark marls; 3, Hudcov limestone with coprolite horizon at the base (Upper coprolite bed) and the position of belemnite finds (dark grey line); 4, Rhynchonellid beds. Ammonite and inoceramid zonation after Košťák et al. (2004). Part of section and stable oxygen isotope curve (VPDB) after Wiese et al. (2004). Belemnite specimen used for isotope analysis (No. PG Uy 2002/1 (CIGP)—reregistered as IGP_Upo2009/7, figured by Wiese et al. (2004) with the position of isotope sampling (dark grey dots) and their values.

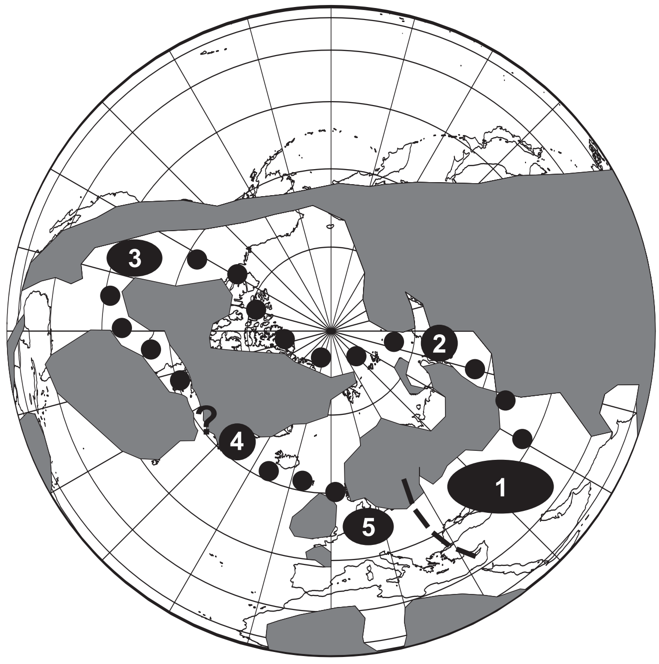


Fig. 3. Palaeogeographic map of the Northern hemisphere (North pole projection). 1, Cenomanian belemnitellid radiation centre (Russian Platform); 2, Lower Turonian records (Agapa river, northwest Siberia); 3, North American Middle Turonian records; 4, Upper Turonian record from Greenland; 5, Upper Turonian records from the Bohemian Cretaceous Basin, Germany and south Sweden. Dashed line indicates palaeobiogeographic barrier during the latest Cenomanian through early Coniacian. Dots indicate the possible migration pathway; grey are land areas during the Late Cretaceous, white are seas and oceans. Modified after Košťák and Wiese (2006, 2008).

*Discussion*.—*Praeactinocamax bohemicus* is a distinct species, which shows the greatest morphological similarities with the Middle Turonian *P. manitobensis*/*walkeri*/*sternbergi* group of the NAP (Košťák et al. 2004). "*Actinocamax* sp. aff. *strehlensis*" (Fritsch and Schloenbach, 1872) described by Jeletzky (1950: 12–17, text-fig. 2, pl. 3: 4, 5) from Manitoba, Canada, shows close similarities with *P. bohemicus* and may be conspecific.

*Stratigraphic and geographic range*.—Late Turonian *Subprionocyclus neptuni* and *Prionocyclus germari* zones. Czech Republic, Germany, Sweden (see also Košťák et al. 2004).

### *Praeactinocamax strehlensis* (Fritsch, in Fritsch and Schloenbach, 1872)

*Type material*: The lectotype (Fritsch and Schloenbach 1872: 19, pl. 16: 10) and the (implied) paralectotype (Fritsch and Schloenbach 1872: 19, pl. 16: 11, 12) designated by Birkelund (1956) and housed originally in the Dresden Museum, are believed to be lost.

*Type locality and horizon*: The Strehlen Limestone, Strehlen, Saxony.

*Remarks*.—For a comprehensive synonymy see Christensen (1982).

*Stratigraphic and geographic range*.— Late *Subprionocyclus neptuni* Ammonite Zone, late Turonian, Late Cretaceous. Strehlen Limestone (Germany) and Hudcov Limestone (Czech Republic). Both limestone units are stratigraphic equivalents of the upper part of the *Hyphantoceras* Event.

### *Praeactinocamax* cf. *strehlensis* (Fritsch, in Fritsch and Schloenbach, 1872)

Fig. 4F

*Material*.—IGP_Upo2009/8, a single incomplete specimen comprising an alveolar part of a rostrum.

*Description*.—The preserved alveolar part is 17.3 mm long. The cross-section is heart-shaped to triangular. The pseudoalveolus (depth 7.2 mm) and the ventral notch (length: 6 mm) are well developed. The lateral sides are slightly concave, which suggests that the entire rostrum had a lanceolate shape. The surface of the rostrum is partly granulated, and striation is visible in the vicinity of the ventral notch.

*Discussion*.—The figures by Fritsch of the lectotype and paralectotype (Fritsch and Schloenbach 1872: pl. 16: 10–12) show a lanceolate rostrum with a well developed ventral notch. The character of the anterior part (including the pseudoalveolus) is almost identical with our specimen. From Fritsch's drawing, it is not possible to determine the depth of the pseudoalveolus, which was probably infilled by sediment. Due to the good accordance with the figure of the lectotype of *P. strehlensis*, we are inclined to assign our alveolar fragment to this species, albeit in open nomenclature since the rostrum is incomplete. In the presence of granulation, the estimated size of the rostrum and the cross-section of the alveolar end, our specimen shows considerable similarities with *P. bohemicus*. However, our fragment clearly differs from *P. bohemicus* (and other European representatives of the genus, e.g., *P. primus*, *P. plenus*) in the occurrence of a pseudoalveolus instead of a small pit. The progressive calcification of the aragonitic posterior part of the rostrum (see Košťák and Wiese 2008 for discussion and photographic documentation), as observed in terminal Turonian and early Coniacian *Praeactinocamax* and in the *Goniocamax*–*Belemnitella* lineage (Ernst 1964; Christensen 1997a; Christensen and Schulz 1997), leads to the development of the pseudoalveolus. Thus, the occurrence of a pseudoalveolus in conjunction with the considerable morphological similarity to *P. bohemicus* suggests that *P. strehlensis* may represent an early anagenetic transition from *P. bohemicus*.

## Palaeogeographic implications

The late Turonian and early Coniacian was a period of progressive oceanic cooling with two well-developed cooling events observable in bulk rock $\delta^{18}O$ curves (Stoll and Schrag 2000, Voigt and Wiese 2000). The first cooling pulse (Phase I of Voigt and Wiese 2000) occured in the terminal Middle Turonian or Middle/Upper Turonian boundary interval, respectively, around the Pewsey Event, one of the $\delta^{13}C$ marker for interbasinal correlations within Europe established by Jarvis et al. (2006) (for detailed discussion of the Middle/Upper Turonian boundary interval see Wiese and Kaplan 2001; Jarvis et al. 2006; Wiese 2010). It was also recognised by combined $TEX_{86}$ data and $\delta^{18}O$ measurements from unaltered foraminifera in the tropical Atlantic (Demerara Rise, ODP Site 1259) by Bornemann et al. (2008).

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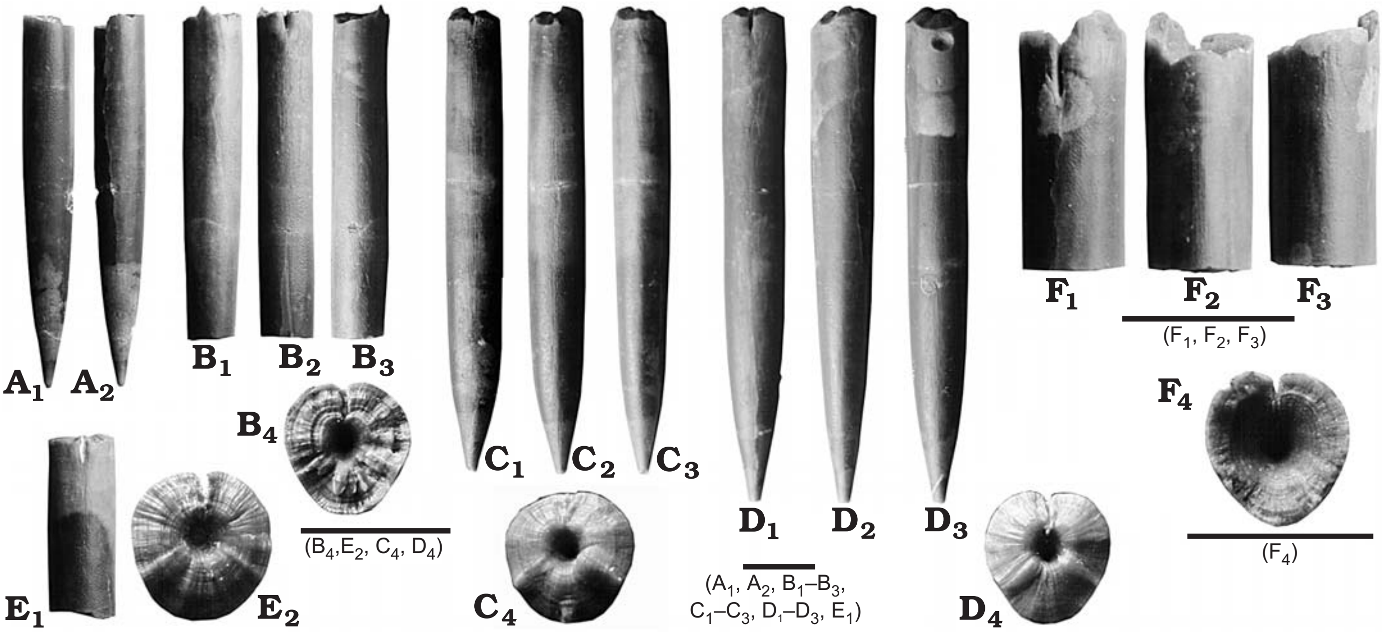


Fig. 4. New Upper Turonian belemnite specimens from the Bohemian Cretaceous Basin. **A**–**E**. *Praeactinocamax bohemicus* (Stolley) **A**. IGP_Upo2009/5 in lateral ($A_1$) and central ($A_2$) views. **B**. IGP_Upo2009/3 in lateral ($B_1$), ventral ($B_2$), dorsal ($B_3$) views, and alveolar end ($B_4$). **C**. IGP_Upo2009/2 in ventral ($C_1$), dorsal ($C_2$), and lateral ($C_3$) views, alveolar end ($C_4$). **D**. IGP_Upo2009/1 in ventral ($D_1$), lateral ($D_2$), and dorsal ($D_3$) views, alveolar end ($D_4$). **E**. IGP_Upo2009/4 in ventral view ($E_1$), alveolar end ($E_2$). **F**. *Praeactinocamax* cf. *strehlensis*, IGP_Upo2009/8 in ventral ($F_1$), dorsal ($F_2$), and lateral ($F_3$) views, pseudoalveolus ($F_4$). Scale bars 10 mm.

The second cooling pulse (Phase III of Voigt and Wiese 2000) occurred in the middle *Subprionocyclus neptuni* Ammonite Zone; Fig. 2), around the Hitch Wood Event $\delta^{13}C$ marker of Jarvis et al. (2006), also described by Voigt (2000) on the base of $\delta^{18}O$ measurements from unaltered brachiopod shells. As both coolings are associated with strong sea-level lowstands, Stoll and Schrag (2000) and Borneman et al. (2008) suggested for Phase I that these cooling pulses resulted from glaciations within the Cretaceous greenhouse period.

Both cooling phases are associated with a southward shift of Boreal faunas and an incursion of ammonites from the Western Interior Seaway into the European Cretaceous basins and even farther towards the south (Voigt and Wiese 2002). During Phase III, an increase of $\delta^{18}O$ values of ca. 1.5‰ can be observed in several European Cretaceous shelf basins (Voigt 2000; Voigt and Wiese 2000) suggested a cooling of ca. 2°.

Phase III is also well developed in the Bohemian Cretaceous Basin. In the Upohlavy working quarry, it is located in the uppermost *Subprionocyclus neptuni* Ammonite Zone, around the Hitch Wood Event (Wiese et al. 2004). As can be seen from Fig. 2, the event-like occurrence of *Praeactinocamax bohemicus* is restricted to the upper part of this cooling event, which—as in other areas—is associated with an increase in $\delta^{18}O$ values of ca. 1.5‰. The occurrence of *P. bohemicus* close to the Bohemian massif and its absence from the open shelf settings of e.g., northwest Germany or England is in accordance with the distribution pattern of the Cenomanian species of *Praeactinocamax* (see Wiese et al. 2009), which avoided open shelf settings. Migration most probably took place during the late Turonian glacioeustatic sea-level low associated with Phase III (indicated in the study areas by erosive channel deposits just above the find level), which provided large inner shelf areas favourable for belemnite migration (see Košťák and Wiese 2008 for a detailed discussion).

Literature and the authors' own data (Košťák et al. 2004; Košťák and Wiese 2008) show that the dispersal history of the Belemnitellidae was complex (Fig. 4). Košťák and Wiese (2008) suggested the immigration of *Praeactinocamax* from the Russian Arctic via the North Pole into the NAP, where the *Praeactinocamax manitobensis*/*walkeri*/*sternbergi* group evolved in the Middle Turonian. The strict palaeobiogeographic separation of the EEP and the Central and Western European shelf seas during the middle and late Turonian and the morphological similarities of *P. bohemicus* and the *P. manitobensis*/*walkeri*/*sternbergi* group suggest that the members of this group spread stepwise from the NAP via Greenland and Scandinavia during the late Turonian. The final dispersal as far southward as Bohemia was enabled by the late Turonian cooling event (Košťák et al. 2004; Košťák and Wiese 2006, 2008).

Finally, it needs to be highlighted that so far no satisfying model exists that explains the well-established, strict palaeobiogeographic barrier between the EEP and the European shelf seas.

## Conclusions

New, stratigraphically well constrained records of extremely rare belemnites in the Bohemian Basin show that their occurrence is restricted to a very limited horizon in the upper part of the Hudcov limestone, close to the maximum of a late Turonian cooling event, which is likewise associated with a glacioeustatic low. The low sea-level enabled the dispersal of *Praeactino-*

*camax* towards the south. Having originated in Arctic Russia, *Praeactinocamax* migrated into the Western Interior Basin of North America and from there, probably progressively and stepwise to Central Europe. Given the known occurrence pattern of the Cenomanian species of *Praeactinocamax*, it may be speculated whether or not the southward migration was also triggered by periods of low sea-levels. However, more data are needed to sustain this model.

The specimen tentatively assigned herein to *P.* cf. *strehlensis* probably represents an evolutionary derivation from the main *P. bohemicus* lineage.

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