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A First Record of Lower Jurassic (Toarcian) Coleoid Jaws in Siberia

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Abstract: In the present paper, we describe several coleoid jaws discovered in the lower Toarcian black shales, cropping out along the Vilyui River (Yakutia, Russia). This is the first record of a Lower Jurassic coleoid jaw outside Europe and the first report of such a finding from the Mesozoic of Siberia. The described coleoid jaws demonstrate the same mode of preservation and morphology as the coeval jaws previously reported from Europe. Their preservation in Siberia became possible due to the widespread occurrence of black shale facies associated with the early Toarcian oceanic anoxic event (TOAE).

Keywords: Yakutia; Mesozoic; palaeobiology; Cephalopoda

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1. Introduction

Despite the worldwide distribution of Toarcian black shale facies, suitable for preserving non-mineralized coleoid remains, such as their beaks, very few such findings have been reported so far. For the first time, belemnite jaws from the lower Toarcian Posidonienschiefer Formation of Germany were reported and figured by Riegraf and Hauff [1] and Reitner and Urlichs [2], and additional specimens were later provided by Schlegelmilch [3]. Recently, jaws of a putative diplobelid *Clarkeiteuthis* of the Toarcian age were figured by Jenny et al. [4]. However, all these specimens were poorly preserved, and the details of their shapes are unclear. Better preserved but also not clearly visible beaks are known for the octobrachian coleoids—vampyropods *Parabelopeltis* and *Jeletzkyteuthis* [5]. From the territory of Russia, the Toarcian coleoid jaws have never been described or depicted to date, although both in Siberia and in northeastern Russia, the marine Toarcian is the most extensively studied and geographically expanding wider than any other Lower Jurassic stage [6]. In the present paper, we provide the first report of coleoid jaws from the black shale strata, corresponding to the Toarcian oceanic anoxic event (TOAE), and discuss their possible affinity.

2. Geological Setting

The upper Pliensbachian and lower Toarcian deposits of the Vilyui River basin (Yakutia, Russia) crop out along the Vilyui River banks in its middle and upper reaches and are also known from Vilyui tributaries (Tyung, Markha, and Sinyaya rivers) [7–9].

The Upper Pliensbachian Tyung Formation consists of silts, sands, and sandstones with a total thickness of ca. 40 m and is subdivided into three members. Ammonite occurrences are uncommon, and only the lower member of the Tyung Formation is characterized by records of *Amaltheus* [7]. Nevertheless, the detailed subdivision of this formation can be carried out using bivalve assemblages [9], as they are the most common and diverse macrofossils met across the formation. Bladed glendonites showing gradual size increase upwards from ~0.5 to 30 cm in length are typical for the middle and upper parts of the

Tyung Formation throughout the Vilyui River basin [10] and were previously used for geological mapping purposes [8]. There are unfigured records of belemnites from the lower part of the formation [11], and from its top [12]; however, other authors who visited the same sections reported the absence of belemnites in the same strata (Nalnjaeva in [13], p. 142). Currently, the consensus is that the belemnites migrated to the Northern Siberian seas in the Early Toarcian, quickly forming endemic lineages and reaching the maximum diversity up to the late Toarcian–early Aalenian time [14,15].

The overlying lower Toarcian Suntar Formation (up to 60 m) is represented chiefly by mudstones (in the lowermost part, mainly thin-laminated clay intercalated with infrequent silty surfaces, or 'black shales') with numerous carbonate concretions. The lower 10–20 m of the succession contain rare bivalve findings. Until now, only a single occurrence of ammonite was reported from the lowermost part of the Suntar Formation ([7], figure 3): this specimen, identified as Pliensbachian *Paltarpites argutus* in the original publication, was later re-identified as Toarcian *Harpoceras* by M.S. Mesezhnikov (see [16]). Also, the 'black shale' strata at the base of the Suntar Fm contain numerous poorly preserved belemnite rostra ([8]; as 'fourth member' of the Pliensbachian Tyung Fm). Relatively common ammonites (*Dactylioceras* of *D. commune* group, *Harpoceras,* and *Zugodactylites*) and very numerous bivalves (mainly *Dacryomya*, *Tancredia*, *Lenoceramus*) and belemnites (*Catateuthis*, *Acrocoelites*, '*Nannobelus*,' *Clastoteuthis*, *Odontobelus*) occur in the upper part of the Suntar Formation [16–18], with bivalves and belemnites often forming allochthonous accumulations. Besides mollusks, the Pliensbachian–Toarcian beds of the Vilyui River basin are known for their ichthyosaurian and plesiosaurian occurrences [19].

As can be seen from this short overview, the Pliensbachian–lower Toarcian sequence at Vilyui River is poorly characterized by index macrofossils, and thus the stage boundary is primarily defined by using bivalves. Conventionally, the Pliensbachian/Toarican boundary in Siberia is aligned with the base of the organic-rich shale interval, widely spread in the region and known as 'Kiterbyut horizon' [15]; in the Vilyui River sections, it corresponds to the boundary between Tyung and Suntar Formations. However, as the black shale event in different parts of the world starts slightly above the base of the Toarcian [20,21] and there is no ground to assume its earlier appearance in Siberia, it cannot be excluded that the boundary between the Pliensbachian and the Toarcian falls into the upper part of the Tyung Formation, as was proposed by Repin [12].

3. Material

During the 2021 fieldwork on the Pliensbachian–Toarchian sequence of the Vilyui River (Yakutia; Figure 1), three slabs with coleoid jaws were collected from large carbonate concretions weathered out from the lower Toarcian black shales and lying loose on the beach at the exposure 6b. The base of the concretions, having a width of up to 1–1.5 m and height of 20 cm, is located at 1.2 m above the Pliensbachian/Toarcian boundary and can be traced throughout all the studied outcrops near the Sardanga settlement (sections 4a–d, 6b and 7 in Figure 2). The black shales unit is barren of macrofossils, except for belemnite rostra, frequently occurring in the lower 50 cm of the unit and scarcely above. They are poorly preserved and undeterminable, however, having elongated shapes typical for the genera *Passaloteuthis* and *Acrocoelites*.

Carbonate concretions, which occur between 0.5 and 1.2 m above the base of black shales (Figure 3), yielded infrequent bivalves (mainly *Kedonella* and *Tancredia*) and common fish scales. One of smaller concretions from the level 1 m above the Pliensbachian/Toarcian boundary in exposure 4d was found to contain numerous micro-onychites. Although the lowermost part of black shales throughout the Vilyui River basin lacks ammonites, the age of the studied unit can be deducted through bivalve occurrences, as *Kedonella mytileformis* collected from the jaw-bearing level is restricted to two lowermost lower Toarcian ammonite zones [22].

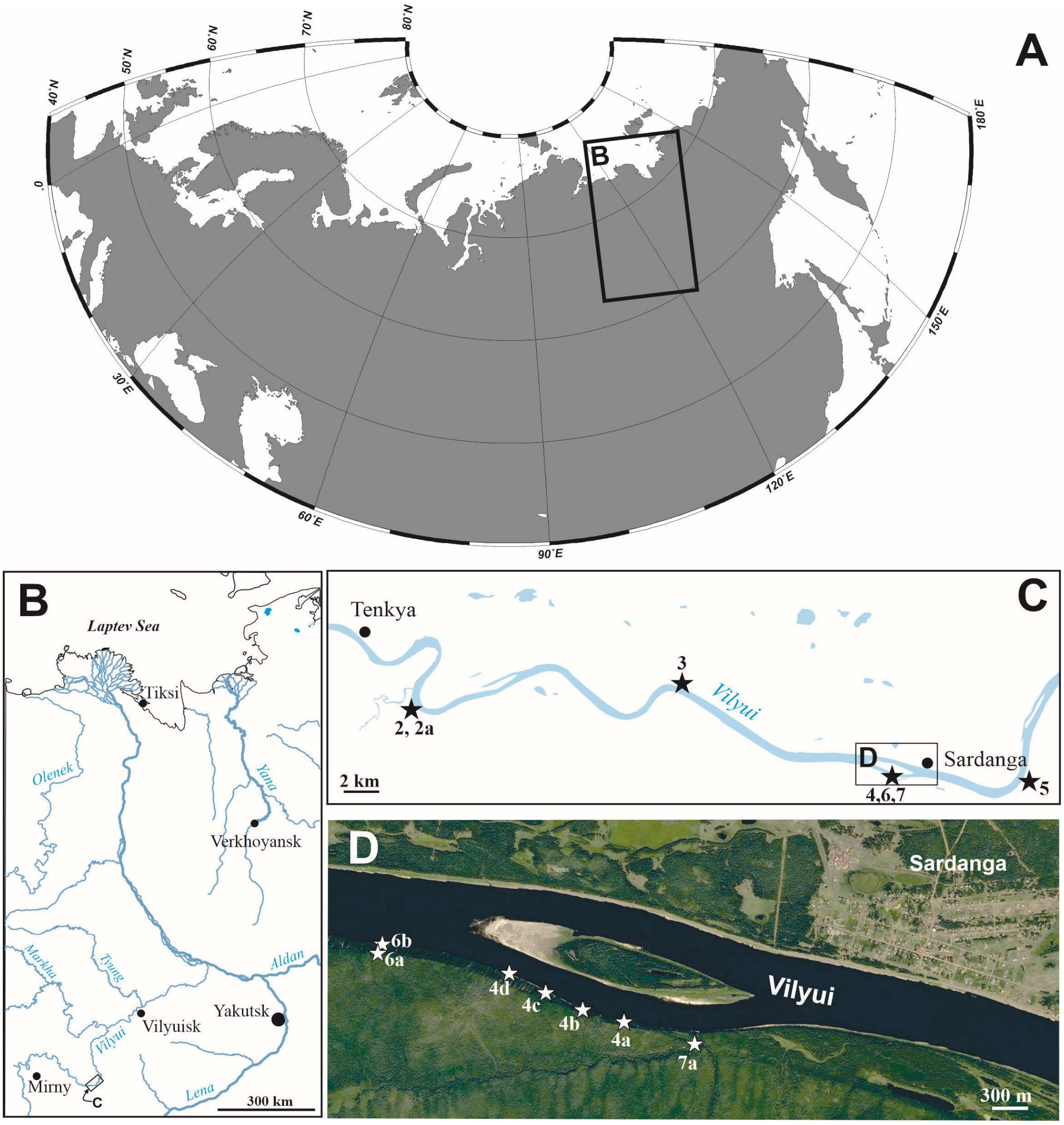

Figure 1. Maps showing the location of studied Lower Jurassic outcrops. (**A**)—position of the studied region on the map of Eurasia; (**B**)—map of the region; (**C**)—detailed map of the studied segment of the Vilyui River; (**D**)—satellite photo and the position of fossil localities near Sardanga settlement. Stars in (**C**,**D**) indicate the positions of the outcrops, numbers refer to their enumeration.

Our observations on the belemnite distribution across the succession confirm Repin's statement [12] on the first occurrence of belemnites within the 'Pliensbachian'. Near the top of the Tyung Formation, there is a level with poorly preserved belemnite rostra of the genus? *Passaloteuthis* accumulated at the intraformational discontinuity surface within the sandstone. This level is the earliest appearance of belemnites within the studied succession, which may reflect the early episode of mass migration of belemnites into the epicontinental seas of northeastern Eurasia in the late Pliensbachian–early Toarcian time.

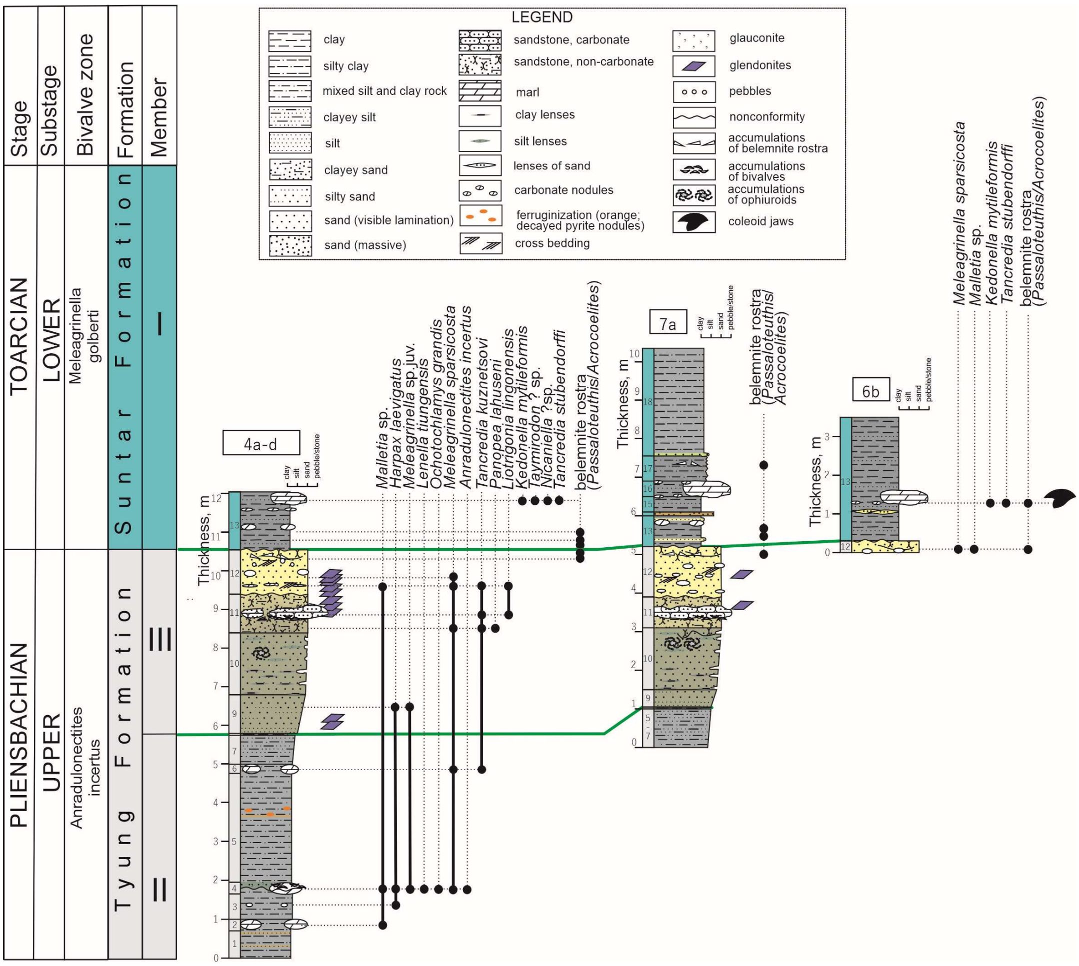

Figure 2. Logs of studied sections and their lithostratigraphic and biostratigraphic subdivision. 4a–d, 6b and 7a are the numbers of individual sections shown in Figure 1D.

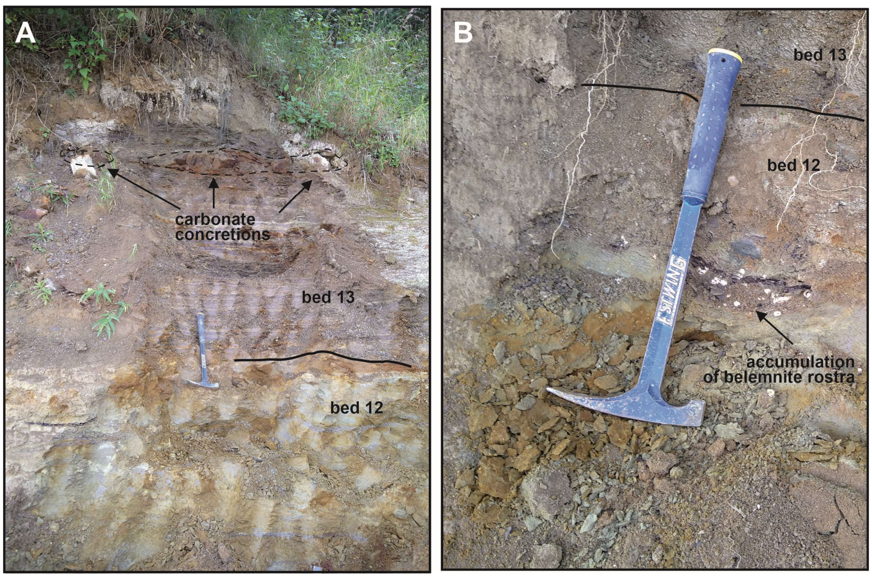

Figure 3. Field photos of the Pliensbachian/Toarcian boundary in the section 4b. (**A**)—general view on the boundary beds; large carbonate concretions 1.2 m above the boundary are well-visible; (**B**)—level of the first appearance of belemnites within the succession (topmost part of the Pliensbachian) is visible right from the hammer.

4. Description of Coleoid Jaws

All three specimens are preserved as a flattened imprint on the bedding surface and its counterpart.

Specimen No. 1 (MAR 3/1; Figure 4A,B) is an upper jaw having a total length of 14 mm and a height of 9 mm (upper total length, UTL, and upper total height, UTH, respectively according to [23], Figure 1). A well-preserved external plate of the jaw (hood) demonstrates a prominent anterior tip (rostrum) and both lateral wings behind it. The inner plate is partly visible along the lower-rear part of the wings, but its rear part is not preserved. The rostrum is robust and pointed, achieving almost 5 mm in length. Its inner margin is relatively straight and the angle between the rostrum and wings (jaw angle) is acute, circa 65°.

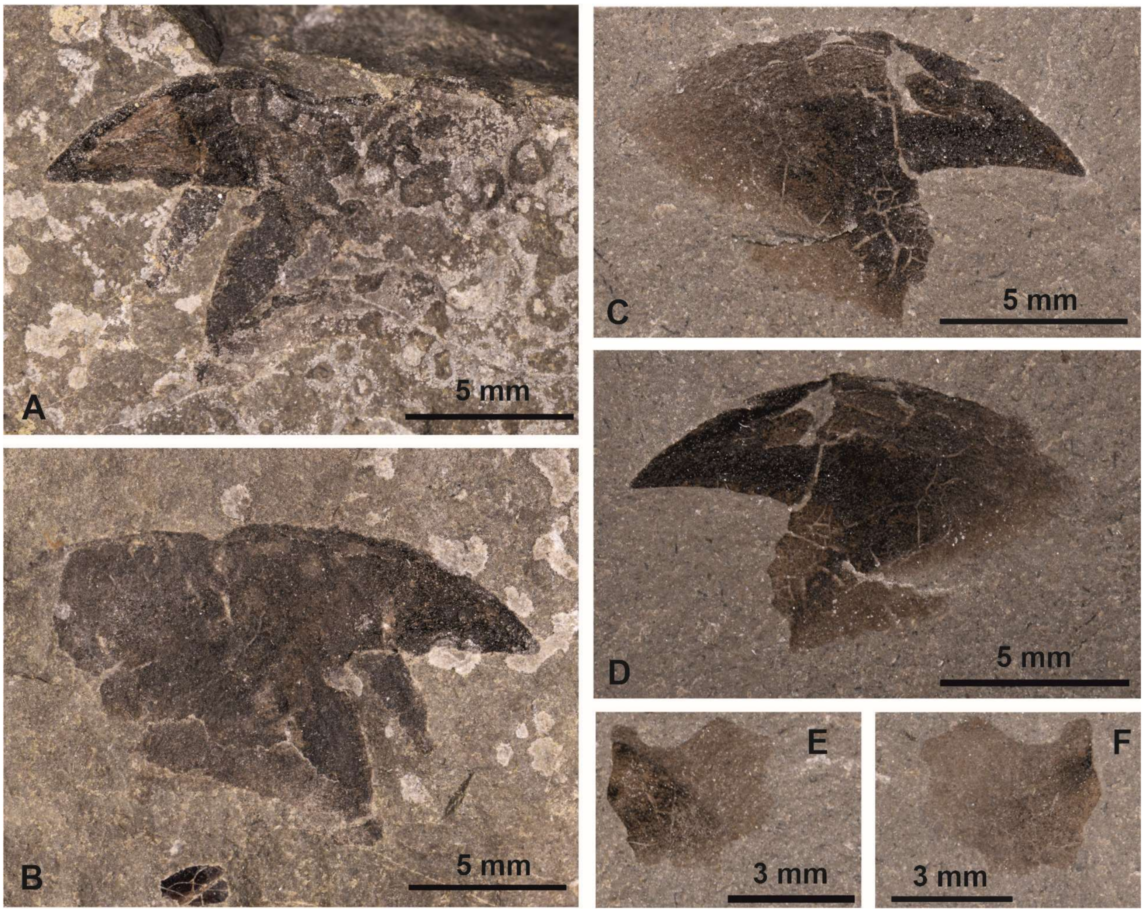

Figure 4. Coleoid jaws collected from bed 13 of section 6b. (**A**,**B**)—upper jaw, specimen MAR 3/1a and its counterpart, MAR 3/1b; (**C**,**D**)—upper jaw, specimen MAR 3/2a and its counterpart, MAR 3/2b; (**E**,**F**)—lower? jaw, specimen MAR 3/3a and its counterpart, MAR 3/3b.

Specimen No. 2 (MAR 3/2; Figure 4C,D) is an upper jaw having a length of 12 mm and a height of 7 mm. As in specimen No. 1, the outer plate of the jaw has a prominent rostrum, and one lateral wing is well-preserved on the bedding surface. The inner plate of the jaw is visible on the back of the wing and behind the hood, but its rear part is not preserved. In contrast to the first specimen, the inner edge of the rostrum looks not straight but slightly concave, which makes the rostrum slightly curved. The angle between the rostrum and wing is relatively straight and again close to 65°. Both upper jaws are slightly different from each other; however, it is not clear whether they belonged to various coleoid species or the differences are due to slightly varying positions of the specimens in the rock.

Specimen No. 3 (MAR 3/3; Figure 4E,F) is small (5 × 4 mm in size) and has a sub-square overall shape. It shows a curved outer plate and a narrower inner plate translucent throughout it. The edges of the specimen appear to have been incompletely preserved, making it difficult to understand the original shape. Tentatively we interpret it as an incomplete lower jaw—however, insufficient preservation leaves room for doubt in this case.

5. Discussion

5.1. Early Toarcian Palaeoenvironments and Taphonomy

Like in other regions with OAE-related facies recorded, in the Vilyui River basin, the lowermost Toarcian strata show evidence of deposition under oxygen-depleted environments. These are lack of bioturbation and fine parallel lamination, clearly visible both in shales and concretions (Figure 5), as well as taphonomical characters of macrofossils and general appearance of the assemblage. Bivalve specimens here are rare and mainly belong to the genus *Kedonella*, which had a pseudoplanctonic lifestyle, attaching to floating wood, ammonites, and other objects ([24,25]; in these papers, *Kedonella* was classified as *Pseudomytiloides*). However, the presence of *Tancredia*, an infaunal suspension feeder which needed well-oxygenated seawater [26] but which is tolerant to low salinity environments, suggests that near-bottom water at least sometimes exhibited normal oxygen contents. Belemnites, although numerous in the topmost part of the Tyung Formation and near the base of the Suntar Formation, become rarer and rarer upwards the black shale interval, completely disappearing above it. This may indicate the transformation of oxygen-depleted marine environments, still providing suitable habitats for nektonic organisms in the upper part of the water column into low-salinity environments and facies upward the succession.

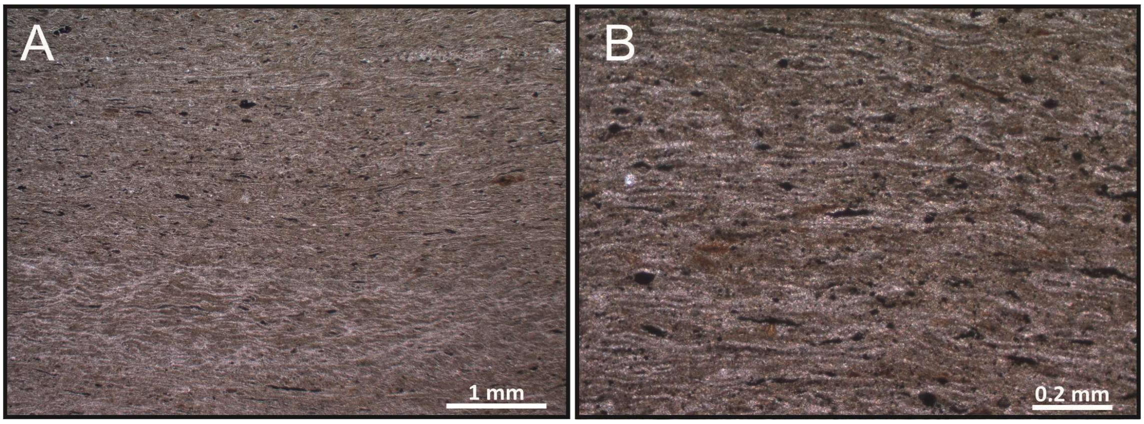

Figure 5. Thin section of the jaw-bearing concretion, showing clearly visible fine lamination. (**A**)—general view; (**B**)—details of fine lamination.

Finally, it should be noted that in contrast to other well-studied TOAE-related sections worldwide and in other parts of Siberia, the Viluyi succession shows numerous indicators of shallow depths, the proximity of the shoreline, and reduced salinities in most intervals. This explains why ammonite occurrences are uncommon in the studied area (and why they are more numerous in the offshore parts of the Vilyui Sea basin, available for study in the sections along the Tyung and Markha rivers).

All the organic coleoid remains (beaks, hooks) from the 'black shale interval' of the Vilyui River sections were collected from the carbonate nodules. In contrast, careful excavation and examination of the bedding surfaces within the shales provided no additional findings. The belemnite rostra, sometimes met in the black shale interval, are always heavily weathered up to the unidentifiable state (making problematic even the generic attribution), being recrystallized into the whitish calcite. The observed preservation of belemnite rostra results from seasonal weathering in severe climates with heavy snow cover, melting in spring and leaking deeply into the black shales along the silt interbeds and decaying the pyrite within the unit. As a result, most carbonate fossils as well as fragile organic fossils were destroyed, making the 'black shales' at Vilyui useless for surface collecting. In turn, carbonate concretions served as natural sarcophaguses protecting embedded chitinous elements from weathering.

5.2. Comparison of Described Coleoid Jaws with Known Mesozoic Records and Their Possible Affinities

The jaws described herein were found isolated from cephalopod remains. Therefore, the main basis for understanding the affinity of these jaws is their shape and structure, as well as some general assumptions. Three large groups of cephalopods inhabited the Toarcian seas: Nautilida, Ammonoidea, and Coleoidea, all having well-developed jaw apparatuses. However, starting at least from the Middle Triassic, nautilids demonstrate calcitic elements (rhyncholites and conchorhynchs) in their jaws [27]. Such calcitic elements are absent in the studied specimens; thus, nautilid affinity can be confidently excluded. The jaws also could not belong to ammonoids, since ammonoid jaws never had protruding wings on the sides of the external lamella [28]. Therefore, the hosts of jaws belonged to Coleoidea.

The overall shape of specimens MAR 3/1 and MAR 3/2, and particularly the presence of a long, pointed rostrum, indicates that the jaws belonged to decabrachian coleoids, characterized by such prominent rostra. In contrast, the tips of the octobrachian jaws are usually shorter and more rounded [29]. Among the decabrachian jaws published to date, the new findings are very similar to isolated upper jaws from the Bathonian and Callovian of European Russia, for which belemnite affinity was tentatively proposed [30,31]. Our jaws are also similar to an upper jaw from the Callovian of Poland ([32], Figure 1C), which also was interpreted as probably belonging to a belemnitid coleoid. However, our finds differ from the stratigraphically close belemnitid upper jaws from the Aalenian of Switzerland, and from the specimens from the Kimmeridgian of Germany, which have very thin and strongly curved rostra [33,34]. It should be additionally highlighted that the straight and robust rostra of the Toarcian jaws are similar to the giant coleoid jaws of presumed teuthid affinity, described from the Turonian (Upper Cretaceous) of Japan ([35], Figure 1), from where true belemnites are not known [36]. However, it is possible that the Early Jurassic and Late Cretaceous jaws could belong to different decabrachian taxa, which had similar feeding strategies and thus their similarity in convergent. It can be assumed that more robust and straight beaks could be used to hunt more sluggish but better-protected prey than thin and curved varieties.

Among Toarcian decabrachian coleoids, several taxonomic groups can be treated as the hypothetical hosts of the beaks. Belemnites are the most attractive candidates to be considered as beak hosts, as they are the only coleoid group clearly present within the black shale interval. However, considering the huge preservation potential of their massive calcitic rostra, it should be noted that only a single belemnite rostrum was found within the same concretionary level as beaks, while beak findings were more numerous.

The lower Toarcian interval is also well-known for highly diversified and abundant gladius-bearing coleoids (e.g., [5,37,38]) as well as for peculiar phragmocone-bearing taxa such as *Clarkeiteuthis* [4,39], the position of which within the coleoid system is not completely clear. As can be judged from the abundance of such fossils in the Toarcian Lagerstättes in Europe and Canada [38,39], these coleoid groups had a sub-global distribution in the Toarcian. However, due to taphonomical constraints, they had almost no chance of being preserved as fossils in the Vilyui River sections.

6. Conclusions

For the first time, well-preserved jaws of decabrachian coleoids are reported from the Lower Jurassic (Toarcian) of Siberia. The preservation constraints of the Vilyui River sections, along with the scarce records of this type of fossils in the literature, prevent us from their unequivocal attribution to any certain taxon.

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