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First record of the enigmatic coleoid genus *Longibelus* from Sakhalin (Far East Russia): a contribution to our understanding of Cretaceous coleoid habitats in the Pacific Realm

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Abstract

A newly collected specimen of the enigmatic coleoid genus *Longibelus* is recorded from lower Turonian strata along the River Shadrinka in Sakhalin (Russian Far East). To date, this is the first record of Late Cretaceous coleoid cephalopods from the island and, in fact, from the entire Pacific coast of the Russian Federation. Lithological characteristics, coupled with published geochemical analyses ($\delta^{13}\text{C}$ and C_{org} content), suggest the habitat of this coleoid taxon to have been the middle to outer (i.e. distal) shelf. Its provenance from the stratigraphical level that is known as the *Scaphites* Event, characterised by a mass occurrence of *Scaphites* and *Yesoites*, may be indicative of occasional or marginal overlap in ranges, rather than life in similar habitats. On the basis of lithological features and in view of the extremely rare occurrence of *Longibelus* in rich ammonite assemblages with clear ecological/bathymetric preferences, the natural habitat of *Longibelus* may have comprised neritic to mesopelagic zones over distal shelves and slopes.

Keywords: Cephalopoda, Coleoidea, Lower Turonian, West-Sakhalin Mountains, Japan

Introduction

In the Pacific Realm, coleoid cephalopods rank amongst the rarer macrofossils in Upper Cretaceous strata, the exception being stratigraphical levels assigned to the Yezo Group which were deposited in the forearc basin of the northwest Pacific (Fuchs et al., 2013). From Hokkaido (northern Japan) in particular, numerous specimens of the enigmatic orthoconic genus *Longibelus* Fuchs et al., 2013 have been recorded. This genus, which was erected on the basis of significant differences from members of *Naefia* Wetzel, 1930 includes forms that had formerly

been referred to that genus (Fuchs & Tanabe, 2010; Fuchs et al., 2013; Hayakawa & Takahashi, 1993; Hewitt et al., 1991; Hirano et al., 1991). To date, *Longibelus*, which ranges from the Cenomanian to the Maastrichtian in the Pacific Realm, comprises two species, i.e. the type species, *L. matsumotoi* (Hirano et al., 1991), and *L. kabanovi* (Doguzhaeva, 1996). Fuchs et al. (2013) and Fuchs (2019) interpreted *Longibelus* as a link between the superorders Decabrachia and Belemnoida; however, its systematic position at the order or family level is not yet clear. Some similarities to decabrachians are based on initial segments of the siphuncle, but it is not yet clear if the closing membrane was lost at the evolutionary stage illustrated by *Longibelus* (see Fuchs, 2019).

For now, the original natural habitats of 'longibelid' coleoids are poorly known (Fuchs et al., 2013). The present record from Sakhalin originates from

Editorial handling: Kenneth De Baets.

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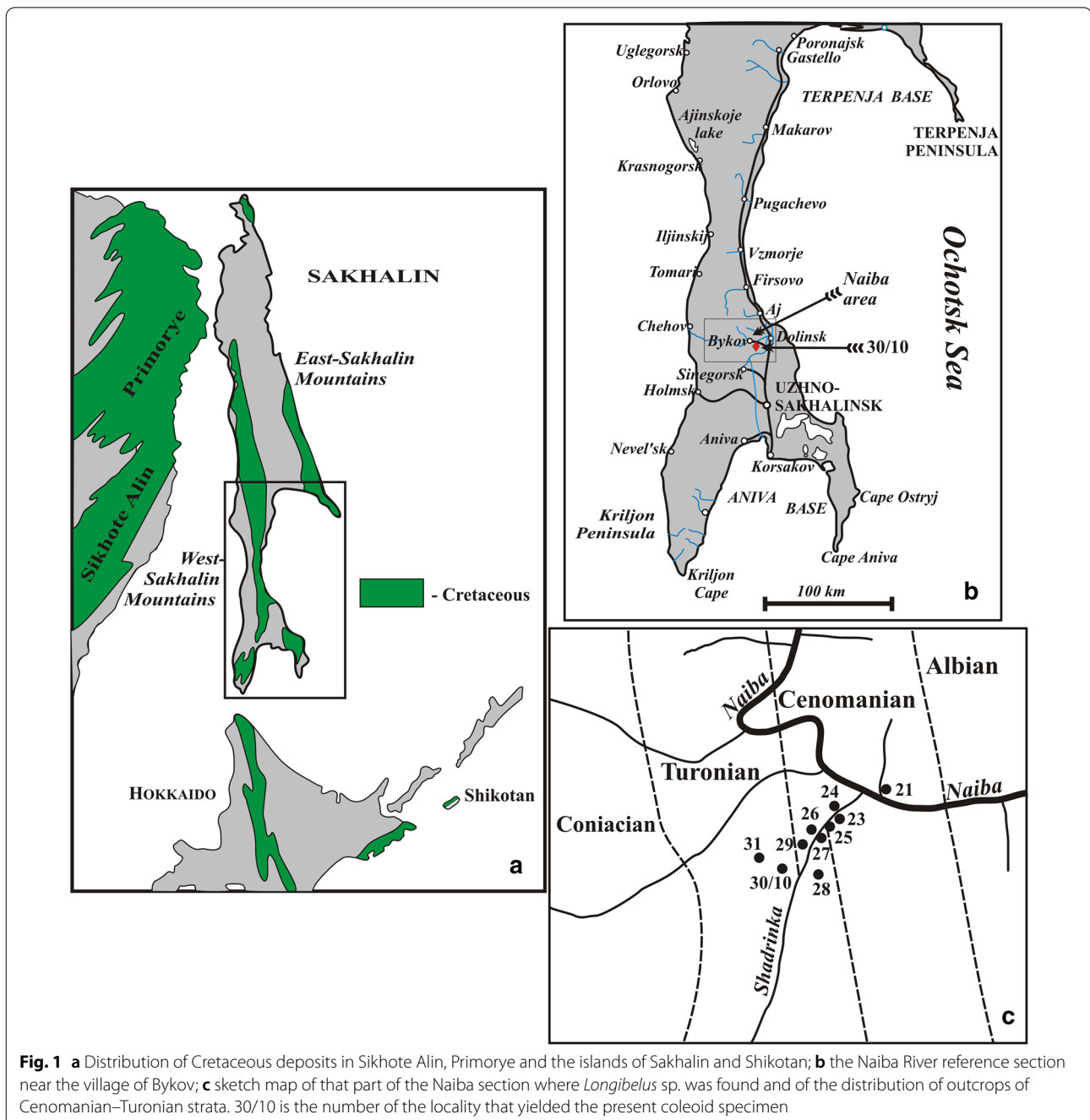


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fine-grained sedimentary rocks that illustrate deposition in the middle to outer shelf. In view of the fact that this specimen constitutes a disarticulated phragmocone in such a fine-grained matrix, a longer period of post-mortem floating in the water column may be excluded.

Geological setting

Sakhalin Island (Fig. 1) is part of the North Pacific island arc positioned along the continental margin; this includes the Japanese Islands. Cretaceous deposits are widely distributed here; an Albian–Maastrichtian sequence crops out in the West-Sakhalin Mountains (i.e. the Main Cretaceous Field), with a continuous (uninterrupted) reference section in the valley of the River Naiba (Matsumoto, 1942; Poyarkova, 1987; Kodama et al., 2002; Yazykova,



2004), that corresponds to the Yezo Group (Albian–lower Campanian) and Hacobuchi Group (upper Campanian–Maastrichtian) in Hokkaido (Matsumoto, 1959b). The lower Turonian portion in this sequence starts with sandy siltstone beds (Member III, sensu Zonova et al., 1993; Zonova & Yazykova, 1998), overlain by thin-bedded clayey siltstones. Up section, this grades into siltstones of middle Turonian age.

The present coleoid was recovered during field work at locality 30 on the left bank of the River Shadrinka which is an easterly tributary of the River Naiba (Figs. 1, 2) in 1987. The sequence outcropping is assigned to Member IV of the Bykov Formation; biostratigraphically it belongs to the *Scaphites planus* ammonite Zone and to the uppermost part of the *Mytiloides* aff. *labiatus* and the lower part of *Inoceramus hobetsensis*–*I. iburiensis* inoceramid Zones (Fig. 3). Generally, the Bykov Formation corresponds to the upper part of the Yezo Group in Hokkaido (northern Japan) on the evidence of ammonite and inoceramid bivalve faunas (Jagt-Yazykova, 2012; Matsumoto, 1959a, 1959b; Tanabe, 1979). The *Scaphites planus* ammonite Zone and *Inoceramus hobetsensis*–*I. iburiensis* inoceramid Zone in Sakhalin can be well correlated with the *Fagesia thevestensis*–*Mammites* aff. *nodosoides* ammonite Zone and *Mytiloides subhercinicus* and *Inoceramus costatus* inoceramid zones in Hokkaido, respectively (Toshimitsu et al., 1995).

Materials and methods

The single, incomplete specimen (field number 30/10) of *Longibelus* sp. is stored in the collections of the Chlupáč Museum of Earth History, Faculty of Science, Charles University (Prague) under registration number

CHMHZ-MK-01_21. Remains of the original shell, where present, have been diagenetically altered; there are no microstructures observable. This specimen has been studied in great detail using a digital microcamera. To bring out morphological details, it was coated with an ammonium chloride sublimate. The graphical program Corel Draw X7 has been used for the reconstruction of phragmocone parameters prior to deformation (Fig. 4). Our descriptive terminology follows Fuchs et al. (2013).

Systematic palaeontology

Subclass Coleoidea Bather, 1888

Superorder and family unknown

Genus *Longibelus* Fuchs et al., 2013

Longibelus sp.

Figures 4, 5

Compare

?1991 *Naefia matsumotoi* Hirano et al., p. 205, pls 1–4.

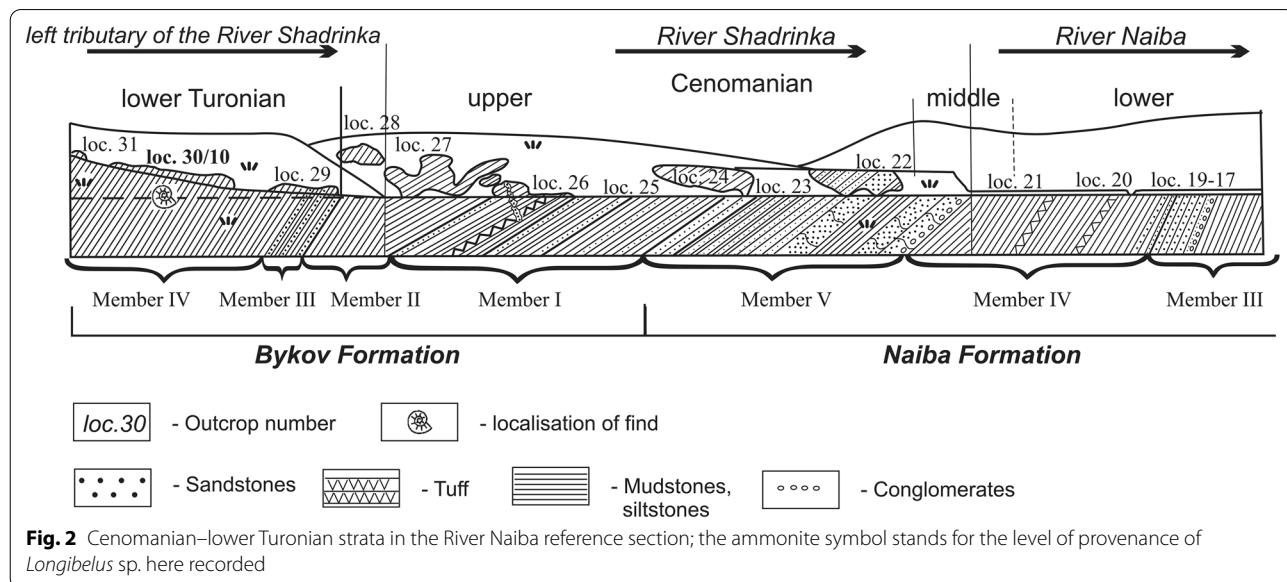
?1993 *Naefia matsumotoi*; Hayakawa and Takahashi, p. 61, Fig. 2.

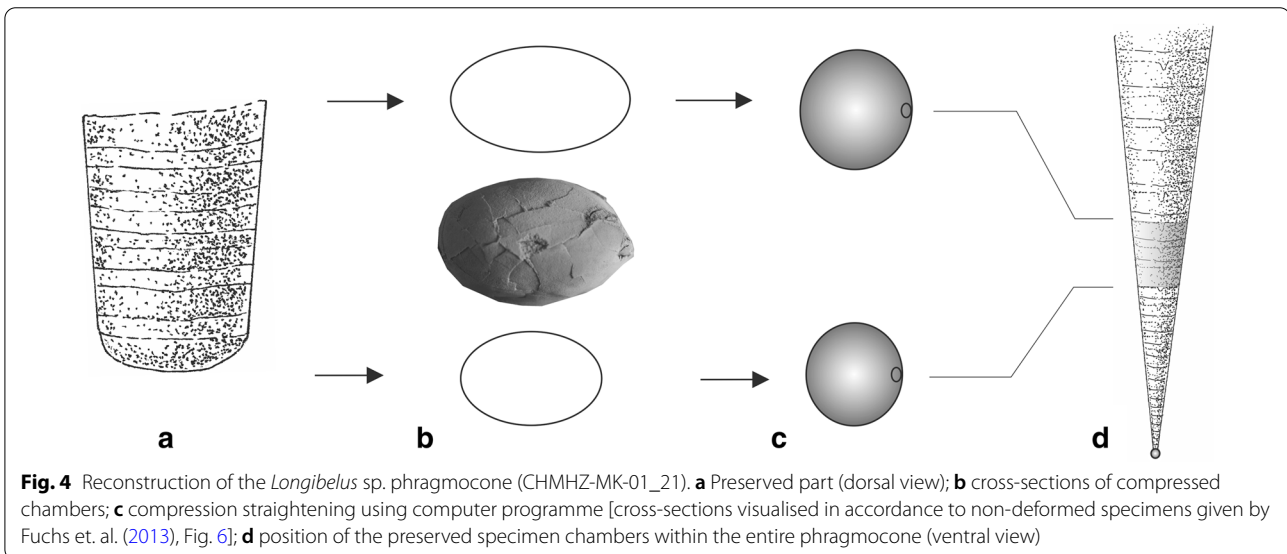
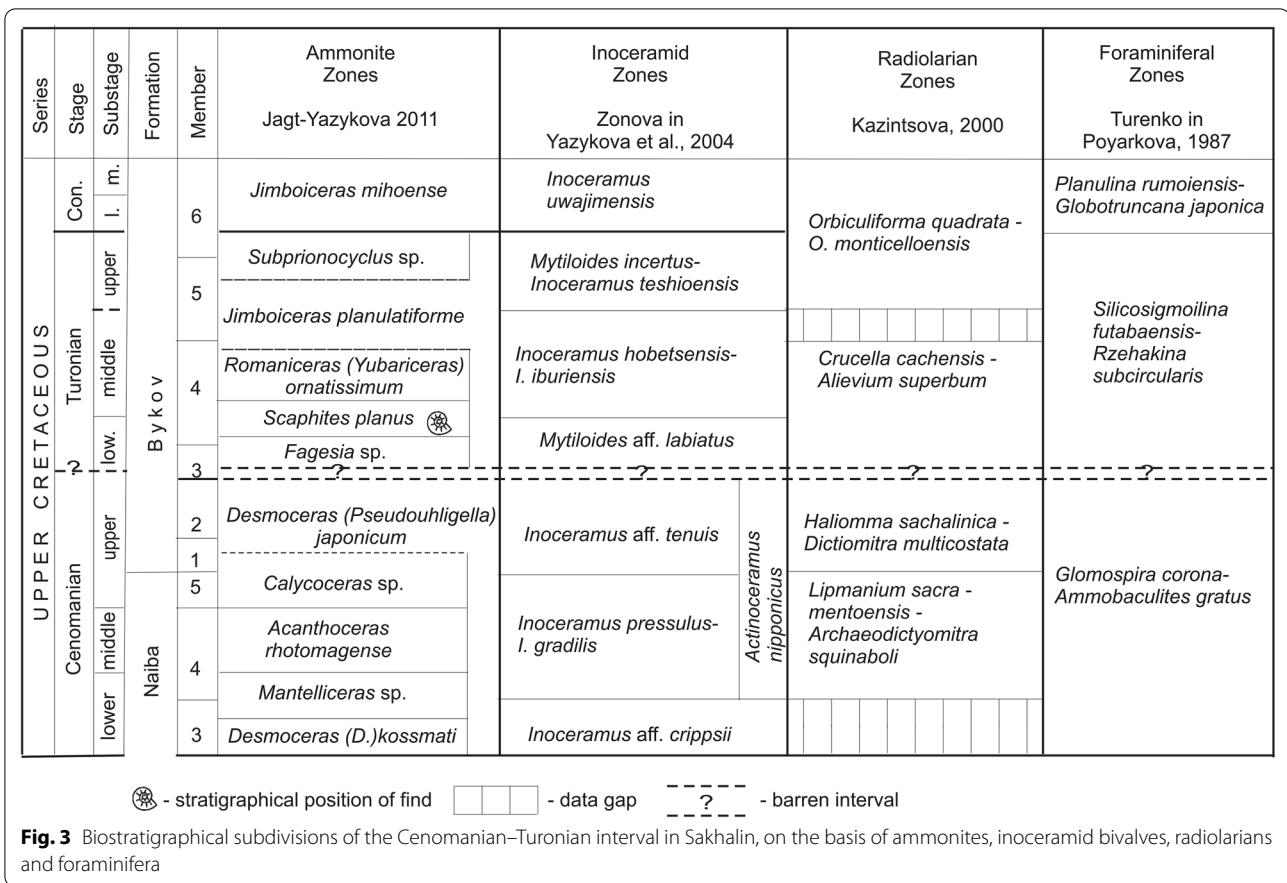
?2013 *Longibelus matsumotoi* (Hirano et al., 1991); Fuchs et al., p. 1090, Figs. 5, 6.

?2013 *Longibelus* sp. C; Fuchs et al., p. 1097, Fig. 9.

Material

A single, incomplete phragmocone comprising four chambers, held at the Chlupáč Museum of Earth History, Faculty of Science, Charles University (Prague) under registration number CHMHZ-MK-01_21; lower Turonian, lower part of the Member IV of the Bykov Formation, Sakhalin, Russia.





Description

Incomplete phragmocone, measuring (as preserved) 25 mm in overall length, consisting of four laterally compressed chambers (Fig. 4); diameter of chamber length

exceeding 5 mm. Apical angle 16°. Chamber length/diameter ratio ~0.36–0.42. Ventral suture lines slightly lobate (Fig. 5a, f), dorsal ones almost straight or very slightly undulated; siphuncle situated marginally, ventral

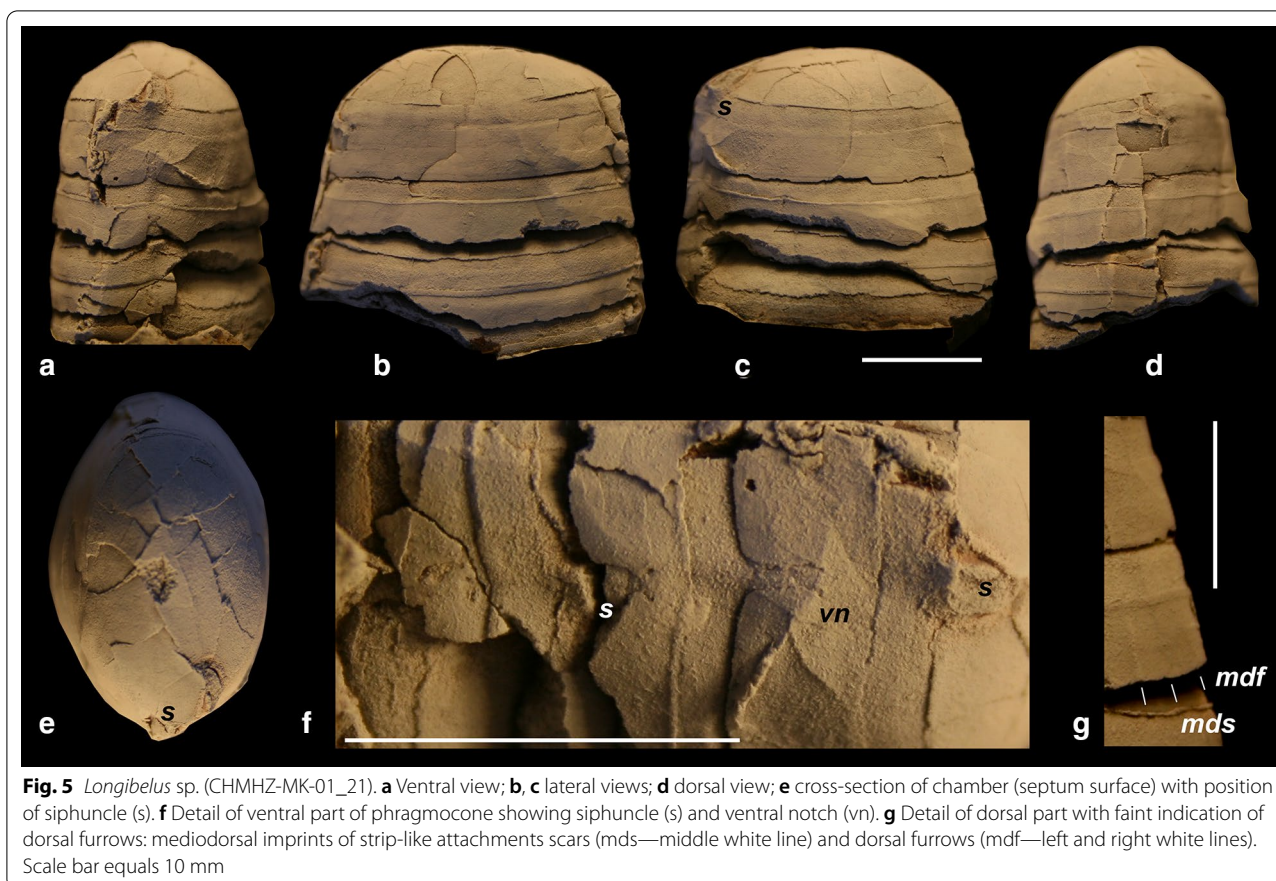


Fig. 5 *Longibelus* sp. (CHMHZ-MK-01_21). **a** Ventral view; **b, c** lateral views; **d** dorsal view; **e** cross-section of chamber (septum surface) with position of siphuncle (s). **f** Detail of ventral part of phragmocone showing siphuncle (s) and ventral notch (vn). **g** Detail of dorsal part with faint indication of dorsal furrows: mediodorsal imprints of strip-like attachments scars (mds—middle white line) and dorsal furrows (mdf—left and right white lines). Scale bar equals 10 mm

notches markedly developed (Fig. 5a, f), suggesting connection of septal necks with conotheca. Orientation of septa horizontal. Conotheca not preserved, but dorsal longitudinal parallel lines/furrows (mediodorsal strip-like attachment scars and mediodorsal furrows) faintly visible (Fig. 5g). Keel not preserved, its position corresponding to phragmocone side damaged by compression (Fig. 5d, e). No traces of rostrum; apical part of phragmocone, comprising protoconch, not preserved.

Discussion and remarks

In addition to other features, the existence of a marginal siphuncle, i.e. a markedly deep notch and the dorsal surface with longitudinal lines, allow placement of this phragmocone in the genus *Longibelus*. The diameter of chamber length fully corresponds to that of *L. matsumotoi* (Hirano et al., 1991). However, the apical angle (16 degrees) is greater than in typical specimens (10–13 degrees) of that species. Chamber length ratio has been calculated from the reconstructed (undeformed) cross-section (Corel Draw X7; see Fig. 4b, c) and the value 0.36–0.42 fits the range for *Longibelus* (i.e. 0.37–0.50; compare Fuchs et al., 2013). The ventral suture line forms a weak lobe only, in contrast to the distinct lobe seen in *L.*

matsumotoi. In this respect, *Longibelus* sp. from Sakhalin differs from its closest congener *L. matsumotoi*, and is, therefore, left in open nomenclature. The present fragment represents approximately the middle part of the phragmocone (Fig. 4d). This assumption should be supported by the fact that our specimen is significantly larger than a single Turonian specimen of *L. matsumotoi* from the Tappu area (Hokkaido, Japan) recorded by Hayakawa and Takahashi (1993). However, the above-mentioned differences from *L. matsumotoi* may indicate the presence of a new and unknown species within this genus.

Geographical distribution

West-Sakhalin Mountains, valley of the River Naiba (River Shadrinka tributary), Sakhalin.

Stratigraphical range

The present specimen stems from strata assigned to the *Scaphites planus* ammonite Zone and the lower part of the *Inoceramus hobetsensis*–*I. iburiensis* inoceramid Zone (Zonova & Zazykova, 1998). In lithostratigraphical terms, this is Member IV of the Bykov Formation (Zonova & Zazykova, 1998; Zonova et al., 1993). The closely related *Longibelus matsumotoi* ranges from the

Cenomanian to the Maastrichtian in northern Japan (Fuchs et al., 2013).

Discussion

In general, there are only very few records of Late Cretaceous coleoids from the Far East of the Russian Federation. Zakharov et al. (2010) described rostra referred to as *Belemnitella?* sp. and *Dimitobelus?* sp. from Campanian–Maastrichtian deposits of Pacific guyots (Magelland Rise). In the northern Pacific region, the true Belemnitida became extinct during the late Albian (Iba et al., 2011). The present phragmocone from the lower Turonian of Sakhalin thus is the first non-belemnite record of a coleoid cephalopod from this vast territory.

The widely distributed genus *Longibelus* has an extensive stratigraphical range from the Aptian to the Maastrichtian, with distinct species having been recorded, albeit under a different generic name, from India (Doyle, 1986; Vartak et al., 2010), the Caucasus (Doguzhaeva, 1996), Chile (Stinnesbeck, 1986; Bandel and Stinnesbeck, 2006), Mexico (Ifrim et al., 2004) and the northern Pacific region (Alaska, Hokkaido, Sakhalin; Fuchs et al., 2013 and references therein; present paper). Thus, the genus was able to survive major Cretaceous crises. Oceanic anoxic events (OAE) had an impact on the biodiversity in shelf ecosystems and resulted in preferred extinction of shallower-water organisms. Survival of perturbations during OAE1, OAE2 and OAE3 suggests that the habitats of these squid comprised distal neritic to oceanic settings. This assumption is in accordance with the palaeoenvironmental implications outlined by Fuchs et al. (2013).

Lithological comparisons of Turonian strata in Hokkaido and Sakhalin have provided important palaeoenvironmental background for our understanding of habitats. It is of note that both single records of *Longibelus* from these areas contrast markedly with the abundance of the genus in post-Turonian times. The lower Turonian strata of the Yezo Group in Hokkaido are characterised by bioturbated mudstones with intercalations of sandstone beds of probable turbiditic origin (Takashima et al., 2010). A similar lithology is seen in the Bykov Formation (Member III; see Fig. 3). The similarity in lithological characteristics is indicative of middle to outer shelf conditions (see below). Both Turonian specimens, however, differ in taphonomic aspects. *Longibelus matsumotoi* from Hokkaido shows a better preservation, is significantly smaller and more complete, comprising numerous chambers. This kind of preservation would rule out a longer period of transport (floating).

The single, incomplete 'longibelid' from Sakhalin originates from mass accumulations of scaphitid ammonites (Fig. 6) in the Bykov Formation. The rarity of this coleoid might be indicative of a different, i.e. deeper, habitat.



Fig. 6 Two examples of *Scaphites planus* (Yabe, 1910) from the lower Turonian *Scaphites* Event in Sakhalin. Locality: River Naiba (collected by E.A. Jagt-Yazykova), field numbers 031/2 and 030/1, respectively. Specimens will be stored in the collections of CNIGR Museum VSEGEI (Sankt Peterburg, Russia). Scale bar equals 10 mm

Scaphitids were inhabitants of inner to middle shelf zones, occurring at depths of less than 100 m (Landman et al., 2012 and references therein). This matches our assumption that was based on the lithology of the section in the River Naiba area (Fig. 7). Arkhipkin (2014) hypothesised that scaphitids were permanently attached to algae or branch-bearing invertebrates; in other words, nearsessile benthic cephalopods. This hypothesis was later rejected by Landman et al. (2016), who argued that scaphitids were able to move about by swimming. According to these authors, scaphitids were adapted to feed on smaller organisms in the water column on the basis of features of their aptychi and radula. However, these heteromorph ammonites lived close to the sea floor and had limited vertical and horizontal migratory capacities (Landman et al., 2012, 2016; Tanabe, 1979).

Well-oxygenated shelf conditions are substantiated by faunal recovery following the Cenomanian–Turonian Boundary Event (CTBE) in the Pacific Realm, inclusive of a rise in ammonite diversity, of which the so-called *Scaphites* Event in the upper lower to middle Turonian is an expression (Jagt-Yazykova, 2012). Stable isotope analyses for the Bykov Formation, as published by Hasegawa et al. (2003), reveal a negative shift in $\delta^{13}\text{C}_{\text{TOM}}$ (terrestrial organic matter) from -23 to -24.5% , and a positive trend in Organic Carbon Content (C_{org} , from 1.1 to 0.5 wt%). However, during the lower–middle Turonian interval, limiting conditions for benthic organisms have been suggested for the underlying strata only [i.e. Member III, as correctly pointed out by Yazykova et al. (2004)]. Important geochemical data that reflected global changes ($\delta^{13}\text{C}_{\text{TOM}}$) have been published in particular for the stratigraphical

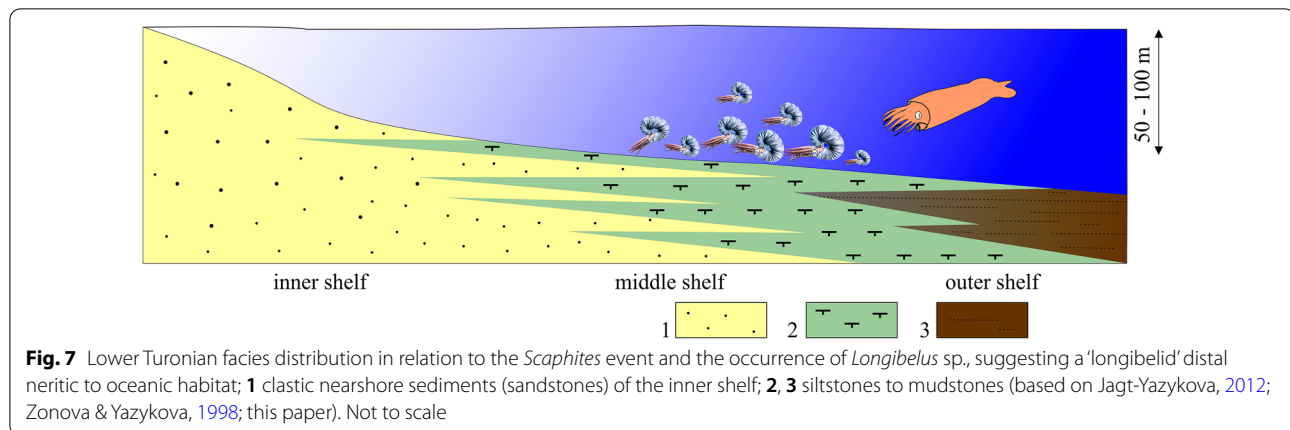


Fig. 7 Lower Turonian facies distribution in relation to the *Scaphites* event and the occurrence of *Longibelus* sp., suggesting a 'longibelid' distal neritic to oceanic habitat; **1** clastic nearshore sediments (sandstones) of the inner shelf; **2, 3** siltstones to mudstones (based on Jagt-Yazykova, 2012; Zonova & Yazykova, 1998; this paper). Not to scale

equivalent of Member III, i.e. the Yezo Group, in Hokkaido (Takashima et al., 2010; Uramoto et al., 2013). These are in agreement with data from Sakhalin in documenting a greenhouse environment with the highest sea level and temperatures reaching c. 16–17.5 °C in sublittoral basins of Sakhalin during the middle Turonian (Zakharov et al., 1999).

Here we can, in part, corroborate the assumption made by Fuchs et al. (2013) that 'longibelid' coleoids were inhabitants of rather distal neritic to oceanic settings, but this hypothesis is in need of more rigorous testing. The incomplete nature of the present *Longibelus* phragmocone, preserved in fine-grained strata (laminated siltstones), may rule out mechanical damage that is typical of higher water energy in inner shelf/nearshore environments. The fracturing might rather have resulted from predator or scavenger activity and probably does not reflect post-mortem drift of the shell.

Conclusions

We here document a new record of the coleoid genus *Longibelus* from the northern Pacific Realm and the first mention from Sakhalin Island (Russian Far East). The single specimen available is well constrained stratigraphically within the lower Turonian sequence on the basis of co-occurring ammonites and inoceramid bivalves. This novel record significantly contributes to the palaeobiogeographical distribution of the genus during the early Turonian and its presence at higher latitudes during that interval can be linked to greenhouse conditions. Survivor strategies at the CTBE, which expresses anoxic conditions on a global scale, suggest the original habitat of *Longibelus* to have been the outer shelf and open ocean. This assumption is here adopted; lithological, palaeoecological and taphonomic data have documented middle to outer shelf settings in the study area.

Acknowledgements

Martin Košťák gratefully acknowledges projects Progres Q45 and GAČR No. 21-30418J. We are grateful to have been invited to contribute to the Boletzky Special Issue and we thank the journal reviewers Dirk Fuchs and an anonymous reviewer as well as handling editor Kenneth de Baets who helped to improve the manuscript.

Authors' contributions

EJY collected the specimen and initiated the present project. All the authors wrote parts of the text, produced figures and proofread the final manuscript. All the authors read and approved the final manuscript.

Funding

MK was supported by the projects Progres Q45 and GAČR No. 21-30418J; EJY and JJ did not receive any funding for this project.

Availability of data and materials

The single specimen illustrated and described is stored in the collections of the Chlupáč Museum of Earth History (Faculty of Science, Charles University, Prague).

Declarations

Competing interests

The authors declare no conflict of interest nor of competition.

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Received: 1 April 2021 Accepted: 10 May 2021

Published online: 09 June 2021

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