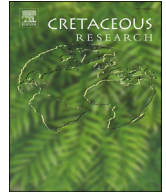




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Short communication

A latest Cretaceous gastropod fauna from the Jiaolai Basin of East Asia

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ARTICLE INFO

Article history:

Received 13 July 2020

Received in revised form

19 November 2020

Accepted in revised form 14 December 2020

Available online xxx

Keywords:

Late Cretaceous

Jiaozhou formation

Sedimentology

Palaeoecology

Recent congeners

ABSTRACT

A non-marine gastropod fauna from the continuous uppermost Campanian to Maastrichtian deposits of the Jiaolai Basin (eastern North China) was studied. Four species attributed to four genera and an undetermined species were described, including *Truncatella jiaozhouensis* sp. nov., ?Pomatiopsidae gen. et sp. indet., ?*Hydrobia datangensis* Yü, 1977, *Valvata jiaolaiensis* sp. nov., and *Physa* sp. Among them, two new species were established. The finding of ?*Hydrobia datangensis* is consistent with a Late Cretaceous age as previously inferred from the charophyte flora. Available sedimentological data of the gastropod-bearing beds combined with a gastropod taphonomical study suggest that all five species lived in shallow lakes, whereas ?Pomatiopsidae gen. et sp. indet. also inhabited floodplains. Furthermore, extant *Truncatella* species are either fully terrestrial or dwell amphibiously in the supralittoral zone in temperate to tropical regions, usually close to the water line, as well as near freshwater of river estuaries. Therefore, *Truncatella jiaozhouensis* sp. nov. supposedly has lived in the surrounding shorelines of the shallow lake.

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1. Introduction

Non-marine gastropods are important fossils for biostratigraphy and palaeoecology in the Mesozoic Era (Pan and Zhu, 2012). Non-marine gastropods have been widely studied in China, including the Junggar Basin in Xinjiang Province (Wei, 1989; Zhu, 1994), the Xishan Basin in Henan Province (Pan and Zhu, 2007), the Songliao Basin in Heilongjiang, Jilin and Liaoning Provinces (Zhu, 1980), southern Anhui Province (Yü et al., 1982), the North Jiangsu Basin in Jiangsu Province (Yü, 1977), the Nanxiong Basin in Guangdong Province (Yü et al., 1990), and the central area of Yunnan Province (Pan, 1977). These basins contain diverse mollusc faunas that have greatly increased our understanding of Late Cretaceous freshwater ecosystems in China. Faunas of similar age have also been reported from France, Spain, Romania, Serbia, Iran, Canada, United States and Mexico (e.g. Whiteaves, 1885; Pálffy, 1902; Russell, 1937; Pašić, 1951; Yen, 1954; Fabre-Taxy, 1951, 1959; Tozer, 1956; Paná et al., 2002;

Johnston and Hendy, 2005; Pacaud, 2007; Perrilliat et al., 2008; Vila et al., 2008; Vega et al., 2019). These studies present abundant and species-rich non-marine gastropods. Here, we report newly discovered continuous records of non-marine gastropods from the Campanian to Maastrichtian deposits of the Jiaozhou Formation in the Jiaolai Basin. The present fossils are described taxonomically, discussed in a palaeoecological context, and compared to their extant relatives.

2. Geological setting

The Jiaolai Basin is in the Jiaodong Peninsula, eastern Shandong Province, eastern North China (Fig. 1). It is a strike-slip and pull-apart basin that formed in the Cretaceous and has had a multi-episodic evolution that went through the Laiyang, Qingshan and Wangshi stages during the Late Jurassic to early Paleocene (Wang et al., 2016). The lithologic and sedimentological studies of the Jiaolai Basin have been studied by Hu (2001), Wang et al. (2016, 2019) and Li et al. (2020a, b). The uppermost Cretaceous to lowest Paleogene Wangshi Group can be subdivided into the Hongtuya, Shijiatun and

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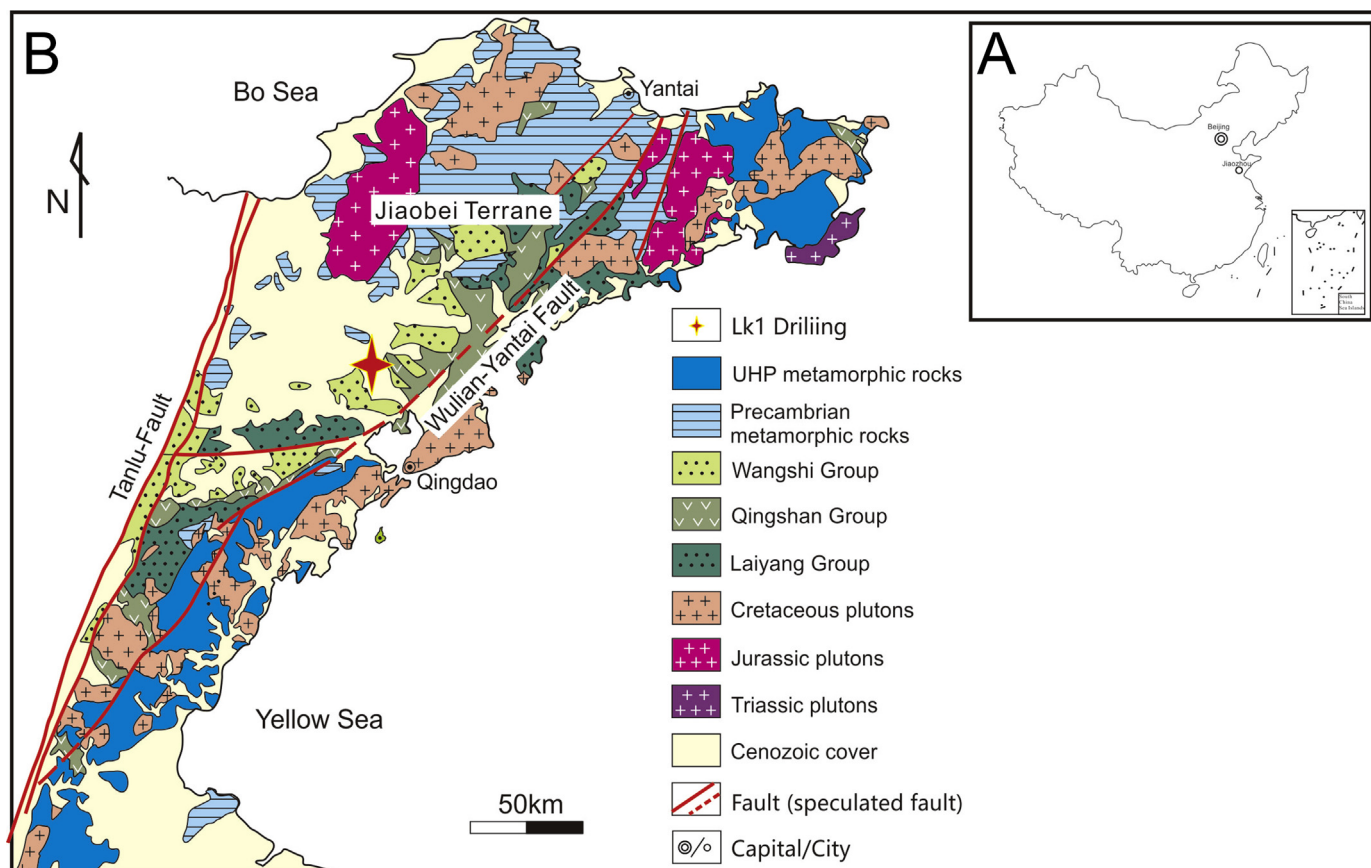


Fig. 1. Geological setting of the studied area. A. Geological sketch map of China showing location of the Jiaolai Basin, Shandong Province. B. Geological map of the study area (modified after Wang et al., 2016), with the location of the LK-1 borehole drilling site.

Jiaozhou formations, in ascending order. The lithology of the Wangshi Group is dark purple and brown red sandstone, siltstone, mudstone, conglomerate and a small amount of marl, and interbedded volcanic rock (Ding, 2016). The gastropods in this study derive from the Jiaozhou Formation. The formation consists of mainly red, grey and purple sandstones and claystones, which are sporadically interbedded with conglomerates. Abundant, well-preserved Campanian to early Maastrichtian ostracods have been reported from the Jiaozhou Formation in the Jiankou section (Wang et al., 2019), including 12 genera and 27 species, dominated by *Cypridea* Bosquet, 1852, *Talicypridea* Khand, 1977 and *Candoniella* Schneider, 1956. Other fossils found in the presently studied LK-1 borehole material (Fig. 1) comprise tiny vertebrate bones, bivalves, and charophytes (Li et al., 2020a, b).

3. Material and methods

The fossil materials are from the LK-1 borehole (36°15'55" N, 119°57'04" E). In total, 949 samples were recovered from claystone and siltstone intervals. Fifty grams of sediment per sample was first processed. Samples were disaggregated in water and then sieved through a 100 µm mesh. Gastropod fossils were handpicked under a stereomicroscope Stemi 508. Only 32 of the 949 samples yielded gastropod remains (Fig. 2). The horizons in which gastropods were found were resampled to obtain an adequate number of gastropods for the taxonomic study.

Well-preserved gastropods were selected and measured (H = shell height; D = greatest width of shell; h = aperture height; d = aperture width), and shell morphologies (general shape, apical

features, number of whorls, sutures, aperture, and sculpture of shell) were described. Species identifications were performed via comparison with the published literature on Chinese fossils, which sometimes presents generic allocations that are provisional, when compared with typically European or North American genera. In addition, the international latest classification system of <https://molluscabase.org/> (MolluscaBase eds., 2020) was used for the gastropod taxonomy in this study. Selected specimens were imaged using a scanning electron microscope at the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPAS). All the figured specimens are housed at the NIGPAS, under repository numbers running from NIGP168637 to NIGP168644.

4. Systematic palaeontology

Class Gastropoda Cuvier, 1795
Subclass Caenogastropoda Cox, 1960
Superfamily Truncatelloidea Gray, 1840
Family Truncatellidae Gray, 1840

Genus *Truncatella* Risso, 1826
Type species: *Truncatella costulata* Risso, 1826. France, Recent

***Truncatella jiaozhouensis* sp. nov.**
Fig. 3A–E

ZooBank reg nr.
urn:lsid:zoobank.org:act:A77B5B00-84D5-44E6-AA63-CA68A6193000

? *Truncatella* sp.: Gu and Wang, 1989: p. 168, figs. 3.19–20.

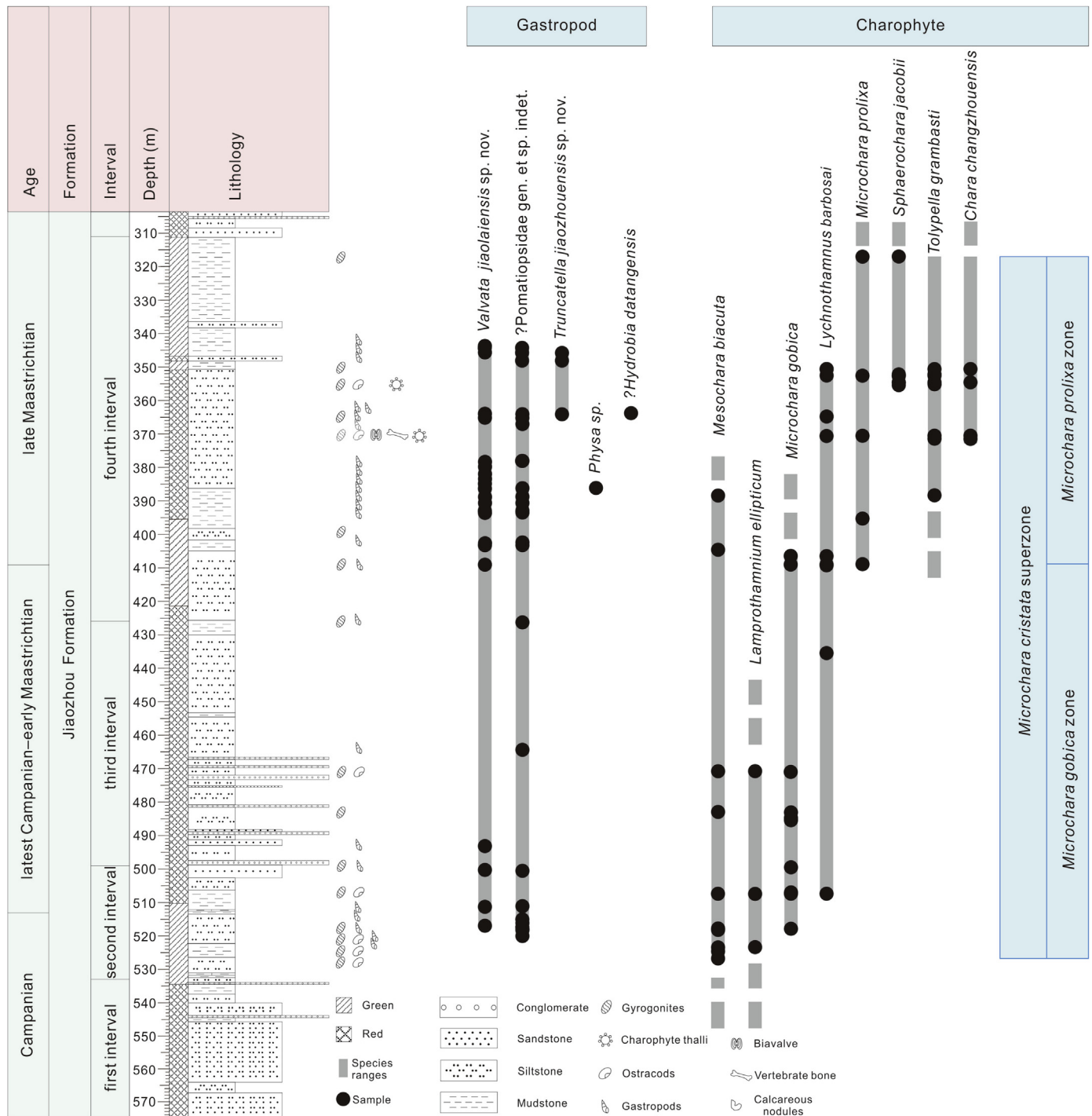


Fig. 2. Stratigraphic log of the Jiaozhou Formation in the Jiaolai Basin showing the position of gastropod and charophyte samples, Charophyte biozone after Li et al. (2020a, b).

Holotype.—NIGP168637.

Paratype.—NIGP168638.

Type locality. LK-1 borehole (36°15'55" N, 119°57'04" E), northern part of Jiaozhou city, Shandong Province, China.

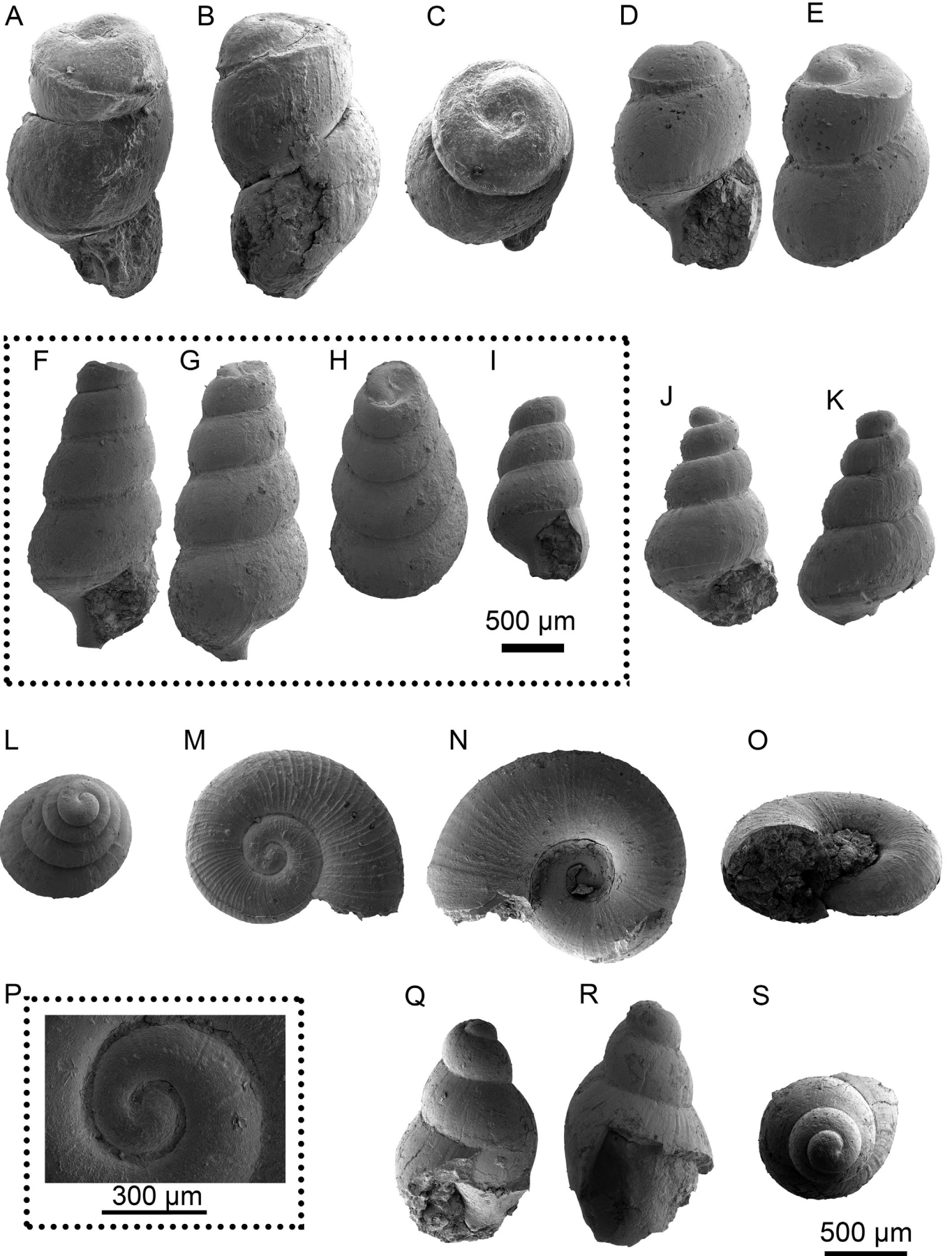
Type horizon. Jiaozhou Formation; sample taken at a depth of 370.5 m.

Further specimens. Three juveniles or apical fragments, poor to moderately preserved (Table 1).

Etymology. Named after the Jiaozhou Formation where the species was found.

Diagnosis. Shell minute, low-cylindrical outline, apex blunt and truncated, teleoconch whorl low and narrow, suggesting slender adult shell; columellar lip nearly straight.

Description. Shell minute (H: 1.38–1.74 mm; D: 0.89–1.04 mm; h: 0.62–0.69 mm; d: 0.48–0.72 mm), rather low-cylindrical outline, consisting of only two smooth whorls, with last one growing regularly downwards, suggesting slender adult shell. Apex blunt and truncated; apical angle c. 97°; truncation marked by narrow, sharp keel that is nearly perpendicular to shell axis. Teleoconch whorl moderately convex, with maximum convexity at mid-height



of whorl. Teleoconch surface poorly preserved but apparently ornamented by indistinct growth lines from abapertural view. Shell imperforate. Aperture broken, probably of slender ovate outline, with adapical part horny, abapical part widely rounded; columellar lip nearly straight.

Remarks. *Truncatella jiaozhouensis* sp. nov. fits well within the genus *Truncatella* due to its narrow cylindrical shell and typical truncated apex. *Truncatella jiaozhouensis* sp. nov. is considered to be identical to *Truncatella* sp. from the Taizhou Formation of the North Jiangsu Basin due to its similar minute and low-cylindrical shell consisting of only two smooth whorls and blunt and truncated apex (Gu and Wang, 1989). Despite the specimens being fragmentary, they are reasonably preserved and distinct from other Cretaceous species to establish a new species. This new species *T. jiaozhouensis* sp. nov. differs from *T. arcicostata* Wang, 1982 (in Yü et al., 1982) by its low-cylindrical shell with probably rounder-ovate aperture and nearly straight columellar lip (Yü et al., 1982); it differs from *T. maxima* Yü and Lee, 1983 and *T. xuan-chengensis* Pan, 1982 (in Yü et al., 1982) by its much smaller size and wider whorl profile (Yü, 1983; Yü et al., 1982); it can be distinguished from *T. crassolabia* Pan, 1982 and *T. rabora* Pan, 1982 by its nearly straight columellar lip (Yü et al., 1982); finally, *T. obesa* sp. nov. differs from *T. sanshuiensis* Yü and Zhang, 1982 by its non-thickened peristome (Yü and Zhang, 1982).

Except for *Truncatella*, the only other Truncatellidae genus from the Cretaceous of China is *Obtusospira* Yü, 1977 from the Upper Cretaceous of the Nanxiong Basin, Jiangxi Province. The type species *Obtusospira pericarinata* Yü, 1977 is characterised by a prominent keel on the whorl periphery, which clearly distinguishes the species (and genus) from *T. jiaozhouensis* sp. nov. Note that *Obtusospira* is probably not a Truncatellidae as suggested by Yü (1977) but rather related to Hydrobiidae.

Distribution. The species was previously reported (as *Truncatella* sp.) from the Maastrichtian first member of the Taizhou Formation in Jiangsu Province (Gu and Wang, 1989).

Family Pomatiopsidae Stimpson, 1865

?Pomatiopsidae gen. et sp. indet.

Fig. 3F–I

Material. Ninety-two specimens, moderately to well preserved (Table 1).

Description. Shell minute (H: 0.85–2.29 mm; D: 0.63–1.10 mm; h: 0.72–0.35 mm; d: 0.23–0.60 mm), slender conical, consisting of probably five whorls (no complete specimen preserved). Apex not preserved, apical angle c. 75°. Suture impressed and distinct. Shell imperforate. Aperture small, rounded-ovate in outline; angular above, lower part widely rounded; outer lip fragile and thin; columellar lip nearly straight. Teleoconch ornamented by fine and indistinct opisthocyrt growth lines.

Remarks. This species superficially resembles *Truncatella maxima* from the Sifangtai Formation in having a slender elongate shell with ovate aperture and nearly straight columellar lip (Yü, 1983). Note that *T. maxima* is probably conspecific with ?Pomatiopsidae gen. et sp. indet. from the K–Pg boundary in the Pingyi Basin, sharing the elongate smooth shell with a blunt apex. After reinvestigation of the holotype of *T. maxima* we conclude that the species does not belong to *Truncatella* or the Truncatellidae because it retains a complete apex.

The present species differs from ?Pomatiopsidae gen. et sp. indet. from the K–Pg boundary in the Pingyi Basin in having a more elongate shell, a narrower aperture and a nearly straight columellar lip (unpublished data).

Family Hydrobiidae Troschel, 1856

?Genus *Hydrobia* Hartmann, 1821

Type species: *Cyclostoma acutum* Draparnaud, 1805

?*Hydrobia datangensis* Yü, 1977

Fig. 3J–L

Hydrobia datangensis Yü, 1977: p. 197, figs. 2.10–11.

Material. Two specimens, moderately preserved (Table 1).

Description. Shell minute (H: 1.19–1.28 mm; D: 0.67–0.78 mm; h: 0.40–0.41 mm; d: 0.31–0.41 mm), conical in outline, consisting of about four whorls. Apex blunt and bulbous; no protoconch–teleoconch transition visible. Whorls convex, with maximum convexity at about mid-height; suture distinct. Body whorl broad, occupying more than half of shell height. Aperture broken, probably ovate in shape; columellar lip nearly straight and short. Shell imperforate. Surface ornamented by fine and indistinct, weakly opisthocyrt growth lines.

Remarks. Extant *Hydrobia* can be identified reliably only with molecular genetics or soft-part anatomy (Wilke and Davis, 2000), while fossil hydrobioids are classified mostly based on general shape, aperture and protoconch characteristics. Given the poor preservation and geographic and stratigraphic isolation from extant *Hydrobia*, the genus classification remains highly doubtful. The present specimens is very similar to ?*Hydrobia datangensis* from the Shanghu Formation (Yü, 1977) in having an inflated, convex body whorl. The species differs from *H. nemegetensis* Martinson, 1957, *H. langxiensis* Pan, 1982 and *H. pyramis* Yü and Zhang, 1982 by its conical shell with a bulbous protoconch and the convex whorls (Yü and Zhang, 1982; Yü et al., 1982; Wei, 1989). Furthermore, it differs from *H. turpanensis* Wei, 1984 by its imperforate shell (Guo and Wei, 1984) and from *H. anhuiensis* Pan, 1982 by the imperforate shell and the indistinct growth lines on the teleoconch (Yü et al., 1982).

Distribution. ?*Hydrobia datangensis* was previously found in the Upper Cretaceous to Paleocene Shanghu Formation of the Nanxiong Basin, Guangdong Province (Yü, 1977), and in the Uppermost Cretaceous to Paleocene deposits of the Pingyi Basin, Shandong Province (unpublished data).

Subclass Heterobranchia Burmeister, 1837

Superfamily Valvatoidea Gray, 1840

Family Valvatidae Gray, 1840

Genus *Valvata* Müller, 1774

Type species: *Valvata cristata* Müller, 1774

Valvata jiaolaiensis sp. nov.

Fig. 3M–P

ZooBank reg nr.

urn:lsid:zoobank.org:act:9B00988F-5C16-4156-A153-83148B1EA23C

Holotype. NIGP168642.

Paratype. NIGP168643.

Type locality. LK-1 borehole (36°15'55" N, 119°57'04" E), northern part of Jiaozhou city, Shandong Province, China.

Fig. 3. Non-marine gastropod shells from the Jiaozhou Formation in the Jiaolai Basin. A–E, *Truncatella jiaozhouensis* sp. nov., A–C, holotype NIGP168637, D–E, paratype NIGP168638, from sample depth 370.5 m. A, D, apertural view. B, E, abapertural view. C, apical view. F–I, ?Pomatiopsidae gen. et sp. indet., F–H, NIGP168639, I, NIGP168640, from sample depth 370.5 m. F, I, apertural view. G, abapertural view. H, apical view. J–L, ?*Hydrobia datangensis* Yü, 1977, NIGP168641, from sample depth 370.5 m. J, apertural view. K, abapertural view. L, apical view. M–P, *Valvata jiaolaiensis* sp. nov., M, N, P, holotype NIGP168642, O, paratype, NIGP168643, from sample depth 370.5 m. M, apical view. N, abapertural view. O, apertural view. P, details of the embryonic shell. Q–S, *Physa* sp. NIGP16864, from sample depth 392.8 m. Q, apertural view. R, abapertural view. S, apical view.

Table 1
Number of specimens and species of gastropods per sample from the Jiaozhou Formation in the Jiaolai Basin.

Depth (m)	<i>Truncatella jiaozhouensis</i> sp. nov.	?Pomatiopsidae gen. et sp. indet.	? <i>Hydrobia datangensis</i>	<i>Valvata jiaolaiensis</i> sp. nov.	<i>Physa</i> sp.	Number of specimens	Number of species
350.56				1		1	1
350.9		2		3		5	2
352.07	1			4		5	2
352.6		4		5		9	2
354.7	1	2				3	2
370.5	3	24	2	46		75	4
371.5		2		2		4	2
373.8		1				1	1
384.8		2		5		7	2
386.3				1		1	1
388.2				3		3	1
389.8				2		2	1
391.4				1		1	1
392.8		5		1	1	7	3
395.2		1		2		3	2
397.1		1		2		3	2
399.5		1		4		5	2
400		1		2		3	2
409		12		13		25	2
409.8		4		9		13	2
415.5				1		1	1
432.8		1				1	1
470.9		1				1	1
499.4				1		1	1
507		1		2		3	2
517.9		3		5		8	2
521.62		4				4	1
522.7		3		4		7	2
523.35		11		2		13	2
524.3		2				2	1
524.74		2				2	1
526.85		2				2	1

Type horizon. Jiaozhou Formation; sample taken at a depth of 370.5 m.

Etymology. Named after the Jiaolai Basin where the species was found.

Diagnosis. Shell minute, umbilicus wide and deep, aperture orthocone, circular Teleoconch ornamented with orthocone, thin, and closely spaced riblets, which are more prominent on apical side.

Description. Shell minute (H: 0.25–0.63 mm; D: 0.61–1.48 mm; h: 0.38–0.65 mm; d: 0.25–0.59 mm), nearly planispiral, consisting of up to c. 2.5 whorls. Whorls strongly convex, increase in diameter fairly rapidly. Suture distinct and deeply impressed. Apical side flattened, umbilicus broad and deep. Aperture broadly elliptical in outline. Teleoconch surface ornamented with thin, orthocone, and closely spaced riblets that are more prominent on apical side. Protoconch consists of c. 0.7 planispiral whorls; initial cap measuring 0.22 mm in width, maximum diameter c. 0.55 mm. Onset of teleoconch indicated by formation of dense growth lines gradually becoming stronger.

Remarks. *Valvata jiaolaiensis* sp. nov. fits well within the genus based on its low spire and circular aperture and orthocone growth lines. The present fossils are deemed to belong to a new species, as this unique set of characters is not found in any other *Valvata* known to date. *Valvata jiaolaiensis* sp. nov. shares some similarities with specimens reported erroneously as *V. cristata* from the upper Cretaceous Mingshui Formation in the Songliao Basin, NE China, but it differs from the latter in having only c. 2.5 much more convex whorls and more distinct protoconch character (Zhu, 1980). *Valvata jiaolaiensis* sp. nov. further differs from other Chinese fossil congeners (*V. yongkangensis* Yü, 1980, *V. dalaziensis* Zhu, 1980, and *V. sinensis* Yü and Lee, 1983) by its larger umbilicus and much more convex whorl profile (Yü and Pan, 1980; Zhu, 1980; Yü, 1983).

Superfamily Lymnaeoidea Rafinesque, 1815
Family Physidae Fitzinger, 1833

Genus *Physa* Draparnaud, 1801

Type species: *Bulla fontinalis* Linnaeus, 1758

Physa sp.

Fig. 3Q–S

Material. One specimen, poorly preserved (Table 1).

Description. Shell minute (H: 1.33 mm; D: 0.85 mm), sinistral, consisting of about three whorls. Apex blunt, apical angle about 75°; body whorl slightly dilated and convex, occupying about two thirds of shell height; whorl profile convex, rapidly tapering towards base; suture narrow. Shell imperforate. Teleoconch ornamented with fine indistinct growth lines. Aperture broken.

Remarks. The specimen is attributed to the genus *Physa* due to its sinistral shell with a dilated body whorl. It resembles *Physa dongtaiensis* Gu and Wang, 1989 from the Taizhou Formation in the Hai'an area, northern Jiangsu Province (Gu and Wang, 1989), but it differs in having a smaller shell with blunt apex. The incomplete preservation of the present specimen (apertural characters missing) precludes a more precise identification.

5. Discussion

Age. Freshwater gastropod fossils of Late Cretaceous to Paleocene age found in the Junggar Basin, the Songliao Basin, the North Jiangsu Basin, and the Nanxiong Basin include a wide range of families: the Ampullariidae, Viviparidae, Amnicolidae, Bithyniidae, Hydrobiidae, Pleuroceridae, Pomatiopsidae, Truncatellidae,

Valvatidae, Lymnaeidae, Planorbidae, and Physidae (Yü, 1983; Gu and Wang, 1989; Yü, 1977; Wei, 1989; Zhu, 1994). The present species-poor fauna has limited potential to constrain the stratigraphy of the deposits. Two species are new and two are identified only to genus level or above; only *?Hydrobia datangensis* provides information on the age. This species has been previously retrieved from Upper Cretaceous to Paleocene deposits of the Nanxiong Basin (Yü, 1977) and the Pingyi Basin (unpublished data) of China. However, the species is known here from only a single sample taken at the depth of 370.5 m from the Jiaozhou Formation. Additional biostratigraphic data is provided by the charophyte flora (Li et al., 2020a, b), partly obtained from the same core as the studied gastropods. The *Microchara gobica* and *M. proluxa* biozones classify the deposits into the uppermost Campanian to lower Maastrichtian and upper Maastrichtian, respectively.

Palaeoecology. The reconstruction of the palaeoenvironment is inferred based on the facies analysis (Tan, 2015) and compared to the paleoecology of the gastropod fauna as derived from the ecological characteristics of recent congeners. The Jiaozhou Formation is divided into seven parts according to Tan (2015). Fossil gastropods were recovered from the second, third and fourth interval. The second interval (533–499 m) consists of green siltstones and claystones, interbedded with red, fine sandstones and thin marlstones containing gypsum layers, calcareous concretions and carbonaceous plant fragments and developing horizontal bedding, being referred to shallow lake deposits (Tan, 2015; Li et al., 2020a, b). Fossil gastropods from this interval are slightly abraded and thus considered parautochthonous. The gastropod assemblage is composed of *V. jiaolaiensis* sp. nov. and *?Pomatiopsidae* gen. et sp. indet. Recent congeners of *Valvata* are known to live generally at the bottom of rivers or lakes, especially where submerged plants grow (Dillon, 2000; Lydeard and Cummings, 2019). This lifestyle is consistent with our fossil assemblage, given the discovery of an abundant and diverse submerged plants (fossil charophyte flora) in the same beds, represented by *Mesochara biacuta*, *Microchara gobica*, *Lamprothamnium ellipticum* and *Lychnothamnus barbosa* (Li et al., 2020a, b). The third interval (498–426 m) was subdivided into two parts: the lower part is formed by grain-supported conglomerates distributed in lenticular beds, and scoured base overlain by red sandstones, forming 6 cycles, being attributed to channels; the upper part is mainly composed of red siltstones that contain abundant calcareous nodules, interpreted as floodplain facies (Tan, 2015; Li et al., 2020a, b). Several shells are abraded and deformed and are considered parautochthonous. The gastropod assemblage is composed of *V. jiaolaiensis* sp. nov. and *?Pomatiopsidae* gen. et sp. indet. The fourth interval (425–311 m) consists of red and green siltstones and claystones, containing gypsum layers and calcareous nodules, representing shallow lake deposits (Tan, 2015; Li et al., 2020a, b). Gastropods from this part are well preserved (some with fine sculpture preserved), without abrasion, and represent an autochthonous assemblage. All these five species are present in this interval of the shallow lake. Modern *Physa* spp. are commonly found in quiet freshwater bodies and may occur in drifting assemblages along river margins; modern hydrobiids can live in both fresh and brackish water habitats such as springs, rivers, lakes, as well as estuaries and mudflats (Hershler and Longley, 1986; Yen, 1951; Böttcher et al., 2009; Dillon, 2000; Lydeard and Cummings, 2019). Extant *Truncatella* species are either fully terrestrial or dwell amphibiouly in the supralittoral zone in temperate to tropical regions, usually close to the water line, as well as near freshwater of river estuaries (Rosenberg, 1996; Welter-Schultes, 2012). The palaeoenvironments can be related to the modern environments where recent relatives of gastropod fossils live in.

6. Conclusions

This study reports for the first time non-marine gastropod assemblages in the uppermost Cretaceous Jiaozhou Formation in the Jiaolai Basin of China, discussing its taxonomic and paleoecological aspects. The fauna includes five non-marine species, with two new species established: *Truncatella jiaozhouensis* sp. nov., *?Pomatiopsidae* gen. et sp. indet., *?H. datangensis*, *V. jiaolaiensis* sp. nov., and *Physa* sp. This study is a first step towards revising the Chinese non-marine fossil mollusc faunas from a modern perspective, which will facilitate sound assessments of the species' biostratigraphic and biogeographic distributions and improve future comparisons with faunas worldwide.

Acknowledgements

We are grateful to H. Pan for assistance with identification and Y. Mao for scanning electron microscopy. This research was supported by the National Natural Science Foundation of China (41972018, 41688103, and 41730317), China Geological Survey (DD20190009), the Strategic Priority Pre-Research Program (B) of the Chinese Academy of Sciences (XDB26000000), and the State Key Laboratory of Palaeobiology and Stratigraphy (Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, No. 183101). This is a Leverhulme Emeritus Fellowship contribution for the EAJ. We are grateful to the Editor in Chief of Cretaceous Research, Eduardo Koutsoukos and to the reviewers Josep Sanjuan (American University of Beirut) and Baoyu Jiang (Nanjing University) for their constructive criticism during the peer-review process.

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