Proceedings of the Geologists' Association xxx (xxxx) xxx

Contents lists available at ScienceDirect

Proceedings of the Geologists' Association

journal homepage: www.elsevier.com/locate/pgeola

# Non-marine gastropods from the Cretaceous–Paleogene transition in the Pingyi Basin, eastern China

Tingting Yu [a,b], He Wang [a], Yanan Fang [a], Rodrigo B. Salvador [c], Sha Li [a,*], Edmund A. Jarzembowski [a,d], Han Yu [e], Haichun Zhang [a]

[a] State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology and Center for Excellence in Life and Paleoenvironment, Chinese Academy of Sciences, 39 East Beijing Road, Nanjing 210008, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Museum of New Zealand Te Papa Tongarewa, Wellington 6011, New Zealand
[d] Department of Earth Sciences, The Natural History Museum, London SW7 5BD, UK
[e] National Marine Environmental Forecasting Center, Beijing 100081, China

ARTICLE INFO

*Article history:*
Received 24 November 2020
Received in revised form 20 October 2021
Accepted 22 October 2021
Available online xxxx

*Keywords:*
K/Pg boundary
Taxonomy
*Cyathopoma pingyiensis* sp. nov.
Paleoecology
Paleoenvironment

ABSTRACT

Our results present a taxonomic and palaeoecological study on non-marine gastropods from the latest Cretaceous to Paleocene deposits of the Pingyi Basin, Shandong Province, eastern China. These gastropods are systematically described: three species belonging to three genera including *Physa dongtaiensis* Gu, 1989, *Hydrobia datangensis* Yü, 1977, and the newly established species *Cyathopoma pingyiensis* sp. nov.; two indeterminata genera and species including Truncatelloidea gen. et sp. indet., and Pomatiopsidae gen. et sp. indet. Among them, Truncatelloidea gen. et sp. indet. and *Cyathopoma pingyiensis* sp. nov. are the dominant species with the longest record. *Cyathopoma pingyiensis*, sp. nov. is the earliest representative of this widely distributed Asian extant genus. Sedimentological facies analysis of the gastropod-bearing beds suggested that Truncatelloidea gen. et sp. indet. lived in a small pond with a river inlet and a shallow lake, while *Ph. dongtaiensis*, ?Pomatiopsidae gen. et sp. indet, and ?*H. datangensis* only thrived in the shallow lake. *Cyathopoma pingyiensis* sp. nov. inhabited the land area around the shallow lake. Our results showed that no significant species change of the gastropod fauna across the K/Pg (Cretaceous/Paleogene) boundary was observed in the Pingyi Basin.



## 1. Introduction

Non-marine gastropods from the Cretaceous–Paleogene (K–Pg) transition have been widely studied in China, including faunas from the Xining-Minhe Basin in Qinghai Province (Li, 1988), the Liningbao Basin in Henan Province (Li, 1984), southern Anhui Province (Yü et al., 1982), the North Jiangsu Basin in Jiangsu Province (Yü and Wang, 1977), the Sanshui Basin (Yü and Zhang, 1982) and Nanxiong Basin in Guangdong Province (Yü et al., 1990). These basins have yielded diverse faunas with a high number of species. For example, 35 genera and 48 species were found in the Sanshui Basin, including the freshwater gastropod families Viviparidae, Valvatidae, Hydrobiidae, Amnicolidae, Truncatellidae, Bithyniidae, Physidae, Lymnaeidae, Planorbidae and the terrestrial gastropod families like Families Pupillidae, Succineidae, Zonitidae, Halicarionidae, Streptaxidae and Helicidae (Yü and Zhang, 1982). These faunas have been traditionally used for biostratigraphy to date and correlate the deposits for exploration of coal, oil and gas resources in China in the last century (Pan and Zhu, 2012). The resolution of sampling for biostratographic research in these basins is relatively low, with discussion focusing on differences of faunas from different formations, which is not enough to study the range of species and changes of faunas across the K/Pg boundary. Here, we studied non-marine gastropods of K–Pg transition from the Pingyi Basin (Shandong Province, eastern China), with 1-m-resolution for the K–Pg transition sediments, in order to find the changes of faunas across the K/Pg boundary. The palaeoecology of the gastropod fauna is studied based on ecological data of recent relatives and sedimentological analysis.

## 2. Geological setting

The Pingyi Basin, located in the Shandong Province, eastern China, is bounded by the Meng Mountain to the north and by Ni Mountain to the south, in a NW-SE-trending zonal distribution. It is a belt-shaped rift basin controlled by the high-angle normal Meng fracture, with the basement composed of the Neoarchaean and Paleozoic rocks and the overlying strata consisting of the Mesozoic–Cenozoic Zibo, Laiyang, Qingshan and Guanzhuang Groups (Fig. 1.1; Du et al., 2019). The Upper Cretaceous to lower Eocene deposits in the Pingyi Basin include the Gucheng, Bianqiao, Changlu and Zhujiagou formations in ascending order (Fig. 1.2). The Gucheng Formation consists mainly of alternating beds of variegated claystones and siltstones; the Bianqiao Formation,

* Corresponding author.
*E-mail address:* shali@nigpas.ac.cn (S. Li).

https://doi.org/10.1016/j.pgeola.2021.10.003
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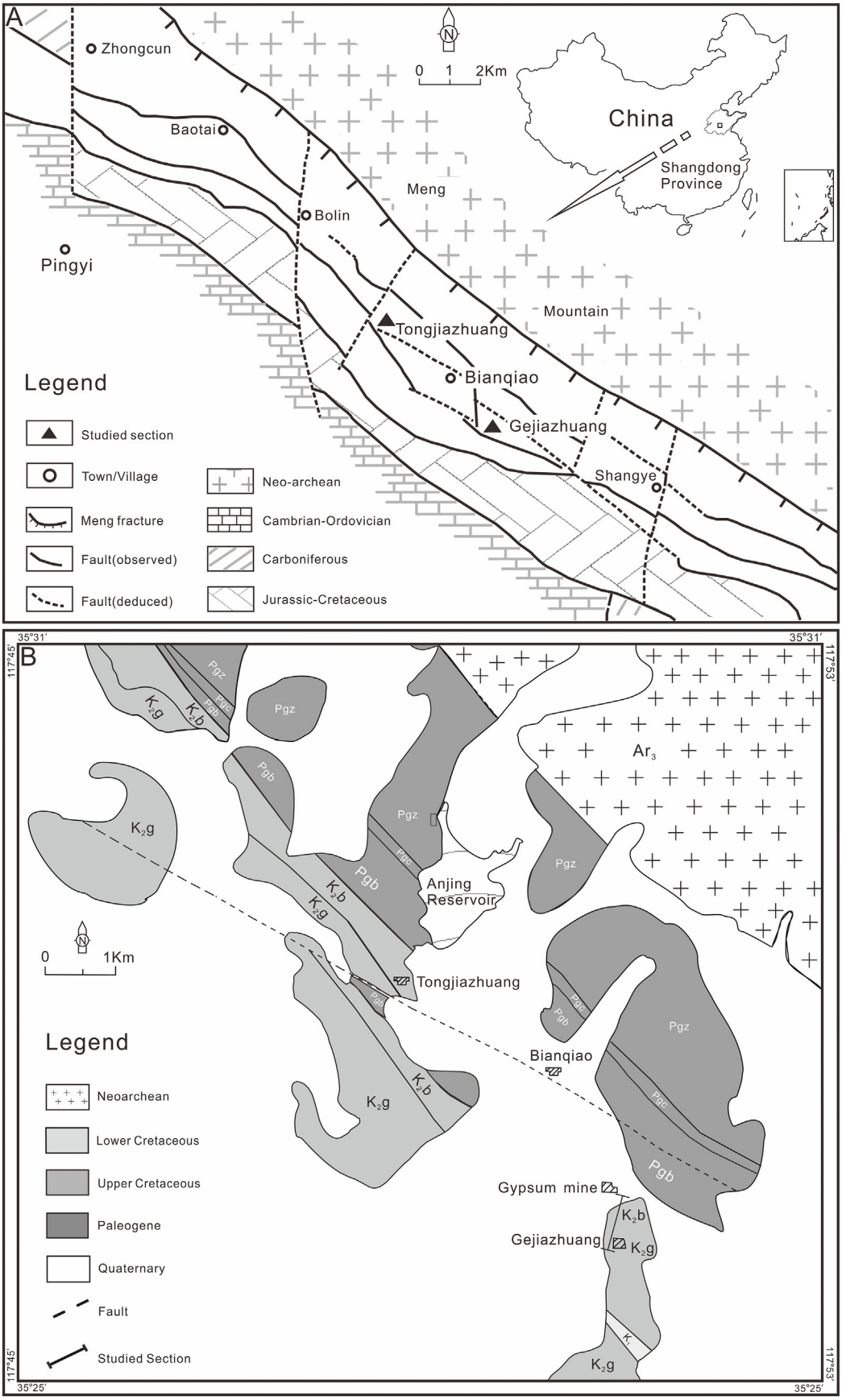


**Fig. 1.** Geological setting of the study area. (1). Geological sketch of the Pingyi Basin; (2). Geological map of the study area showing the location of the section studied. Legend: $Ar_3$, Neoarchaean rocks; $K_1$, Lower Cretaceous; $K_2g$, Gucheng Formation; $K_2b$ and Pgb, Bianqiao Formation; Pgc, Changlu Formation; Pgz, Zhujiagou Formation; Q, Quaternary deposits. Modified from Lin et al. (2011) and Zhang et al. (2014).

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of pale limestones and green to grey marlstones; the Changlu Formation, of greenish grey and greyish-red conglomerates, sandstones, calcilutite and silty mudstone; and the Zhujiagou Formation, of thick grey layers of upward-coarsening conglomerates, with clasts composed of dolomite, limestone, sandstone and granite (Li et al., 2016).

The biostratigraphy of charophytes was previously studied based on four sections, namely the East Gejiazhuang, West Gejiazhuang, South Tongjiazhuang and North Tongjiazhuang sections of the Pingyi Basin, covering the latest Campanian to early Danian *Microchara cristata* zone and Danian to early Eocene *Peckichara varians* zone (Li et al., 2016). Ostracods were also well studied, with the *Ziziphocypris-Cypridea-Rhinocypris* assemblage found in the upper part of the Gucheng Formation, *Frambocythere fangjiaheensis* occurring at the bottom of the Bianqiao Formation, and the *Lineocypris-Guanzhuangia-Paracandona-Candona* assemblage in the Bianqiao Formation in the East Gejiazhuang and North Tongjiazhuang sections (Yang et al., 2013).

## 3. Material and methods

The gastropods were obtained from the fluvial claystones and lacustrine marls of the uppermost Gucheng Formation to the lower Bianqiao Formation in the West Gejiazhuang section near Gejiazhuang village (Fig. 2) (base coordinates 35°25′29″N, 117°51′2″ E; top coordinates 35°26′27.9″ N, 117°51′10.38″E, Fig. 1). Samples were taken systematically every 10 m (in thickness) in claystones and siltstones of the Gucheng Formation; in marls of the Bianqiao Formation (K–Pg transition deposits), samples were collected every 1 m. Two hundred and fifty grams of sediment per sample (in some samples up to 1000 g) was comminuted to ~1–2 mm fragments with a hammer and dry sieved through two sieves with 95 μm and 1.43 mm meshes. Gastropods were picked out under a binocular microscope. Eventually, eleven samples provided fossil gastropods and were marked on the Fig. 2 and Table 1. Dirty specimens were cleaned with a fine wet brush. Well-preserved gastropods were identified and measured (H = shell height; D = greatest width of shell; h = aperture height; d = aperture width), and shell morphology including general shape, apical features, number of whorls, suture, aperture, and shell sculpture was described. Selected specimens were placed on stubs, coated with a gold alloy and photographed using a scanning electron microscope at the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPAS). All figured specimens are housed and catalogued at NIGPAS under the running numbers NIGP171872 to NIGP171882.

The age of the gastropod-bearing sediments was established by Li et al. (2016) using the biostratigraphical correlation of charophytes (Fig. 2) with European biozones that have been magnetostratigraphically dated. These gastropods are also palaeoecologically studied based on ecological data for recent relatives and considering the data on the sedimentary environment derived from the literature.

**Table 1**
Abundance of gastropods in the West Gejiazhuang section of the Pingyi Basin.

| Horizon (s) species | *Physa dongtaiensis* | ?*Hydrobia datangensis* | Truncatelloidea gen. et sp. indet. | ?Pomatiopsidae gen. et sp. indet | ?*Cyathopoma pingyiensis* sp. nov. |
|---|---|---|---|---|---|
| GJZ-1 | | | 4 | | 1 |
| GJZ-2 | 1 | | 2 | | 2 |
| GJZ-3 | | | 12 | 3 | 3 |
| GJZ-4 | | | 11 | 4 | 8 |
| GJZ-5 | | | | | 2 |
| GJZ-6 | | | 2 | | 2 |
| GJZ-7 | | | 2 | | |
| GJZ-8 | | 2 | | | |
| GJZ-9 | | 1 | | | |
| GJZ-10 | | 12 | | | 1 |
| GJZ-11 | | | 1 | | |

## 4. Systematic palaeontology

Class Gastropoda Cuvier, 1795
Superorder Hygrophila Férussac, 1822
Superfamily Lymnaeoidea Rafinesque, 1815
Family Physidae Fitzinger, 1833
Genus *Physa* Draparnaud, 1801
*Type species.*—*Physa fontinalis* Linnaeus, 1758.

*Physa dongtaiensis* Gu, 1989
Figure 3A–B

1989 *Physa dongtaiensis* Gu in Gu & Wang: 170, pl. 5, figs. 9–14 (Gu and Wang, 1989).

*Description.*—Shell minute (H: 1.6 mm; D: 0.86 mm; h: 0.80 mm; d: 0.22 mm), sinistral, consisting of three whorls rapidly increasing in dimensions. Apex blunt, apical angle nearly 105°; body whorl strongly dilated and slightly convex, occupying more than four-fifths of shell height; periphery wide rounded, rapidly inclined to base. Suture distinct and oblique; no umbilicus; aperture slightly broken, nearly semi-lunar in shape, with upper part narrow, lower part widely rounded, outer lip arc-like, and inner lip attached to columellar lip. Surface ornamented with fine, indistinct growth lines.

*Material.*—One specimen, moderately preserved.

*Remarks.*—The present specimen can be attributed to the genus *Physa* based on sinistral shell with dilated body whorl and further identified as *Physa dongtaiensis* based on its shell morphology. It is similar to *Physa shandongensis* Pan, 1983, but differs in having a shell with a moderate spire. It also resembles *Physa shakengensis* Yü and Zhang, 1982, but differs in having a much smaller shell with indistinct growth lines.

Superfamily Truncatelloidea Gray, 1840
Family Hydrobiidae Stimpson, 1865
?Genus *Hydrobia* Hartmann, 1821
Type species.—*Cyclostoma acutum* Draparnaud, 1805.

?*Hydrobia datangensis* Yü, 1977
Figure 3C–F

1977 *Hydrobia datangensis* Yü, 1977, pl. 2, figs. 10–11.

*Description.*—Adult shell minute (H: 0.99–1.26 mm; D: 0.59–0.77 mm; h: 0.27–0.45 mm; d: 0.34–0.51 mm), conical to cylindrical in shape, consisting of about four convex and regularly growing whorls; protoconch smooth; mature shell with an elevated spire and inflated body whorl; body whorl occupying nearly half of shell height; suture distinct and deeply impressed; periphery wide and rounded, at low whorl; aperture slightly broken, probably sub-circle in shape; shell imperforate; surface ornamented by fine and indistinct growth lines.

Juvenile shell tiny (H: 0.48–0.61 mm; D: 0.47–0.50 mm; h: 0.21–0.27 mm; d: 0.20–0.28 mm), broad cylindrical in shape, consisting of two convex whorls; protoconch circular and smooth; body whorl inflated and convex; suture impressed and straight; umbilicus narrow; aperture broken, probable ovate in shape.

*Material.*—Fifteen specimens, moderately to well preserved, with 10 shells from GJZ-10 measured.

*Remarks.*—Extant *Hydrobia* can be identified reliably only with molecular genetics or soft-part anatomy (Wilke et al., 2000), while fossil hydrobioids have been largely erroneously classified based on general shape, aperture and protoconch characteristics. Their simple

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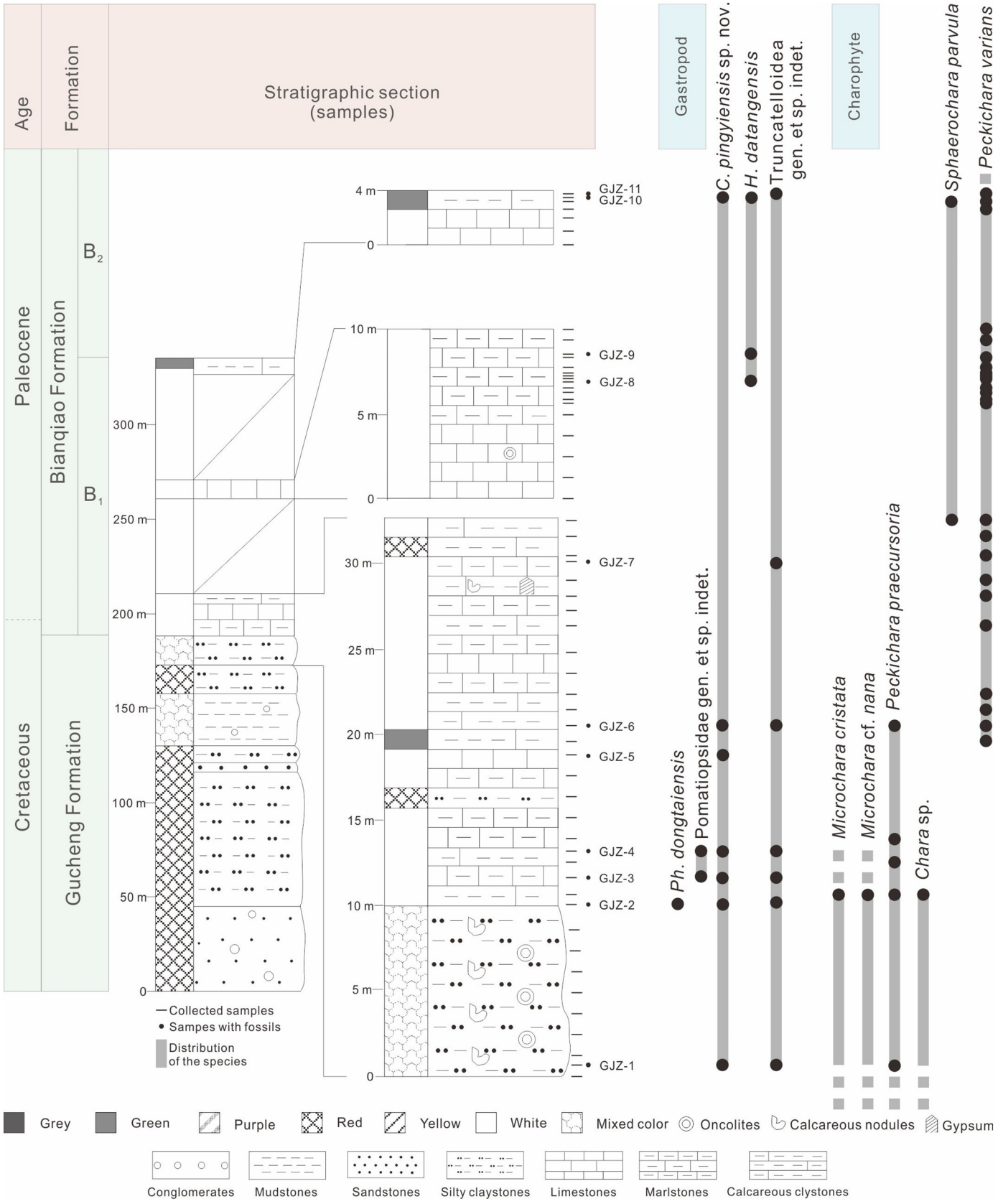


**Fig. 2.** Stratigraphical log of the Gucheng and Bianqiao formations in the West Gejiazhuang section showing the position of gastropod and charophyte samples. Charophyte samples are from Li et al. (2016).

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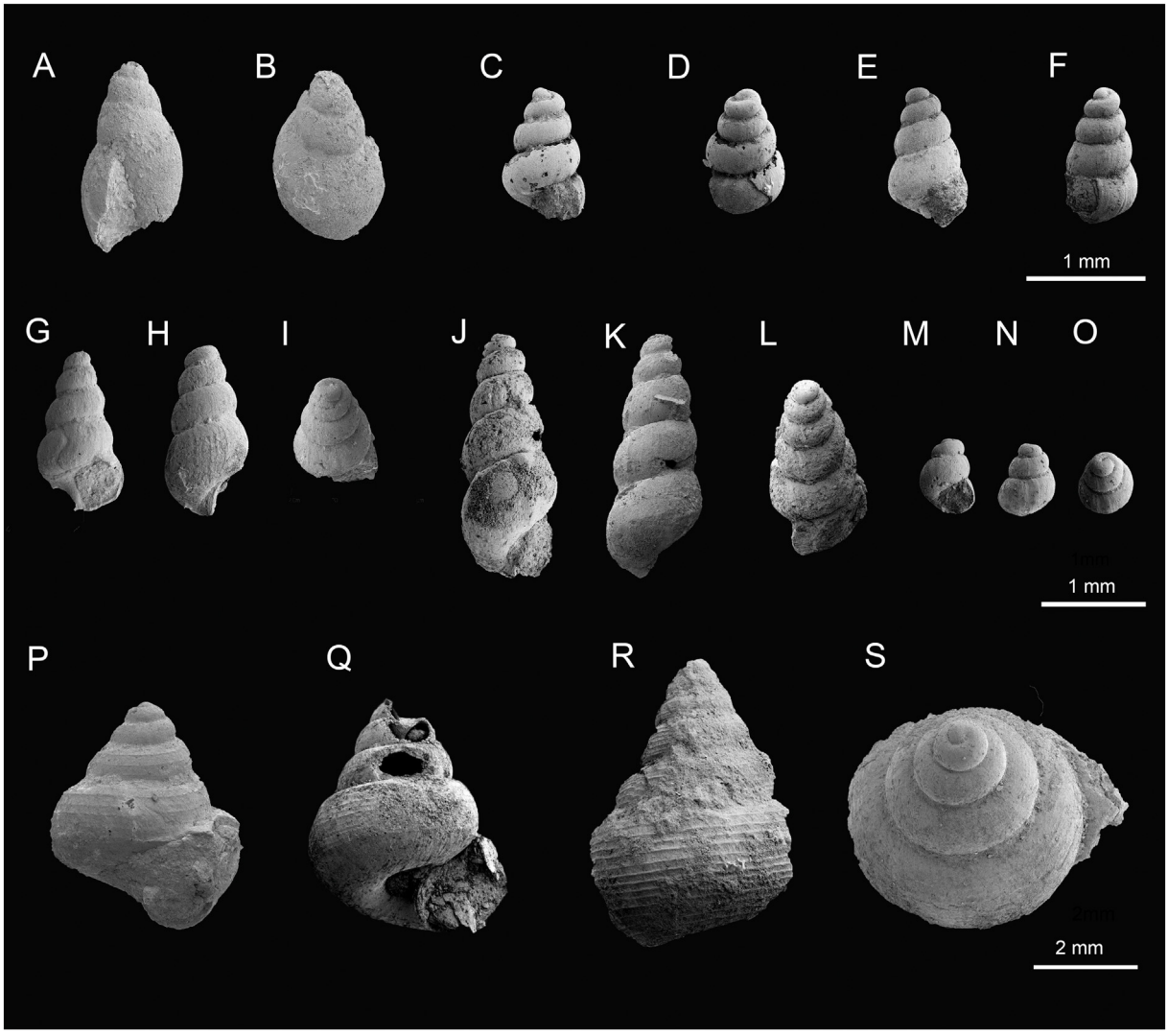


**Fig. 3.** Gastropods from the Gucheng and Bianqiao formations in the Pingyi Basin. (A, B), *Physa dongtaiensis*, NIGP171872, from GJZ-2. (A), Abapertural view. (B), apertural view. (C, D, E, F), ?*Hydrobia datangensis*, NIGP171880–NIGP171881, from GJZ-10. (C), (E), apertural view. (D), (F), abapertural view. (G, H, I), Truncatelloidea gen. et sp. indet. NIGP171873–NIGP171874, from GJZ-5. (G), apertural view, NIGP171873. (H), abapertural view, NIGP171873. (I), apical view, NIGP171874. (J, K, L), ?Pomatiopsidae gen. et sp. indet, NIGP171875–NIGP171876, adult, from GJZ-3. (J), apertural view, NIGP171875. (K), abapertural view, NIGP171875. (L), apical view, NIGP171876. (M, N, O), ?Pomatiopsidae gen. et sp. indet, NIGP171877, juvenile, from GJZ-3. (M), apical view. (N), abapertural view. (O), apertural view. (P, Q, R, S), ?*Cyathopoma pingyiensis* sp. nov., NIGP171878–NIGP171879, from GJZ-4. (P), (Q), apertural view, NIGP171878 (holotype). (R), abapertural view, NIGP171878 (holotype). (S), apical view, NIGP171879 (paratype). Three scale bars corresponding to A–F, G–O, P–S, from top to bottom, respectively.

plesiomorphic shells show high variability overlapping between taxa (Falniowski, 2018). Thus, the genus classification remains doubtful in this study.

Truncatelloidea gen. et sp. indet.
Figure 3G–I

*Description*.—Shell minute (H: 1–2.02 mm; D: 0.61–1.03 mm; h: 0.37–0.75 mm; d: 0.21–0.57 mm), subcylindrical in outline, consisting of four whorls. Apex blunt; spire moderately high, whorl profile flat to convex, body whorl occupying nearly one-half of shell height; suture distinct and oblique; aperture ovate to circular in outline, with adapical part horned, abapical part widely rounded, and columellar lip nearly straight; teleoconch ornamented with indistinct fine and coarse growth lines, more prominent on body whorl.

*Material*.—Thirty-four specimens, moderately to well preserved, with 9 shells from horizon GJZ-3 measured.

*Remarks*.—The subcylindrical shell shape and the sculpture of indistinct fine and coarse growth lines resemble those of highly convergent forms of hydrobioid snails (straight-sided in the lower half, opisthocyrt in the upper half).

Pomatiopsidae Stimpson, 1865
?Pomatiopsidae gen. et sp. indet.
Figure 3J–O

*Description*.—Adult shell minute (H: 3.24–3.62 mm; D: 1.2–1.54 mm; h: 0.86–1.14 mm; d: 0.5–0.61 mm), conical, with a highly turreted spire and moderately dilated body whorl. Teleoconch with approximately five whorls increasing gradually in size, closely coiled, with a convex profile. Apex papilliform; oblique suture well impressed by convexity of the whorls. Aperture broken, probably ovate-oblong in shape, adapical part angular, abapical part widely rounded, columella margin short and free. Shell imperforate. Teleoconch lacking sculpture, ornamented only by fine indistinct growth lines.

Juvenile shell tiny (H: 0.8 mm; D: 0.57 mm; h: 0.38 mm; d: 0.37 mm), conical, approximately three whorls; protoconch smooth, apex papilliform; body whorl inflated and convex, occupying more than half of the shell; suture impressed and straight; aperture large in size, occupying nearly half of the shell, and ovate in shape with adapical

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part angular, abapical part widely rounded. Shell imperforate. Surface ornamented only with indistinct fine growth lines.

*Material*.—Seven specimens, moderately to well preserved, with 4 shells from horizon GJZ-3 measured.

*Remarks*.—The specimens from the Pingyi Basin with their elongated smooth shell show a superficial resemblance in form to the extant subterrestrial genus *Pseudoiglica* Grego, 2018 from Southeast Asia. The present species is particularly similar to *Pseudoiglica phonsavanica* Grego, 2018 from Laos in the robust shell with drop-shaped aperture (Grego, 2018). ?Pomatiopsidae gen. et sp. indet. was also reported from the uppermost Campanian to Maastrichtian Jiaozhou Formation of the Jiaolai Basin, differed from the specimens in this study in having a more elongate shell, a narrower aperture and a nearly straight columellar lip (Yu et al., 2021).

Superfamily Cyclophoroidea Gray, 1847
Family Cyclophoridae Gray, 1847
?Genus *Cyathopoma* W. T. Blanford & H. F. Blanford, 1861
*Type species*.—*Cyathopoma filocinctum* (Benson, 1851)
?*Cyathopoma pingyiensis*, new species
Figure 3P–S

*Holotype*.—NIGP171878, from GJZ-4, the Bianqiao Formation, Pingyi Basin, Shandong, eastern China.

*Diagnosis*.—Small shell; spire narrower than congeners, with whorls increasing regularly in size; teleoconch sculptured by numerous regular and fine spiral cords, spiral cords were weaker than congeners; aperture apparently narrower than congeners.

*Description*.—Shell minute (H: 1.88–3.13 mm; D: 1.59–2.69 mm; h: 0.78–1.28 mm; d: 0.68–1.24 mm), conico-trochiform, with an elevated and narrow spire and an inflated body whorl. Protoconch small, rounded and smooth, apparently with 2 whorls. Teleoconch increasing regularly in size at first but more rapidly towards body whorl; body whorl approximately 1/2 shell height. Whorl profile convex; suture distinct and deeply impressed. Teleoconch ornamented by indistinct growth lines and regularly spaced fine spiral cords, separated by flat to slightly concave interspaces of greater width than cords. Umbilicus wide, and deep. Aperture broken but apparently ovate, with adapical angulation; parietal margin thickened.

*Etymology*.—Named after its discovery locality, Pingyi County.

*Material*.—Holotype (NIGP171878–NIGP171879) from GJZ-4 and 17 paratypes, moderately preserved, with 4 shells from horizon GJZ-4 measured.

*Remarks*.—The specimens of ?*C. pingyiensis* are incomplete, and the aperture is incompletely preserved in adult shells. However, several features are well preserved enough to allow classification in Cyclophoridae, and tentatively in the widely distributed Asian extant genus *Cyathopoma* (Raheem et al., 2014), namely, the conico-trochiform shell; the teleoconch sculptured by parallel spiral cords; the wide and deep umbilicus.?*Cyathopoma pingyiensis* shows a superficial resemblance with *Procyclotopsis* Wenz, 1924 (in family Pomatiidae Newton, 1891) on the shell shape and sculpture with spiral cords. ?*Cyathopoma pingyiensis* is assigned tentatively to the genus *Cyathopoma* rather than *Procyclotopsis* because of the sculpture with indistinct growth lines. In addition to the morphological evidence, there are a large amount of records of *Cyathopoma* in Asia, but fossil records of *Procyclotopsis* is rarely known from West Asia (Harzhauser et al., 2015). ?*Cyathopoma pingyiensis* derived from latest Cretaceous to Paleocene of China, East Asia was the earliest representatives of this extent genus, suggesting that ancestors of *Cyathopoma* probably originated in the latest Cretaceous to Paleocene at least in East Asia.

## 5. Discussion

### 5.1. Age

The gastropods from the uppermost Gucheng Formation and the lower Bianqiao Formation include *Physa dongtaiensis*, Truncatelloidea gen. et sp. indet., ?Pomatiopsidae gen. et sp. indet, ?*Hydrobia datangensis* and ?*Cyathopoma pingyiensis* sp. nov. (Fig. 3). Among them, *Ph. dongtaiensis* was reported from the uppermost Cretaceous to the Paleocene second member of Taizhou Formation in the North Jiangsu Basin, China (Pan and Zhu, 2012); ?*Hydrobia datangensis* was found from the uppermost Cretaceous to Paleocene Shanghu Formation in Guangdong province, western China and the uppermost Cretaceous of Jiaozhou Formation in Jiaolai Basin, eastern China (Yü, 1977; Yu et al., 2021). These results strongly indicate that the gastropod fauna has a latest Cretaceous to Paleocene age, similar to the conclusion of the charophyte flora (Li et al., 2016). Charophyte species *Peckichara varians* Grambast, 1957 was only reported in the Paleocene and lower Eocene (Li et al., 2016), so we concluded that this species could be used to indicate the age of Paleocene, or the K/Pg boundary (dotted line in Fig. 2) was very closed to the occurrence of this species. Therefore, Truncatelloidea gen. et sp. indet., ?*H. datangensis* and ?*Cyathopoma pingyiensis* sp. nov. are concluded to range into the Paleocene.

### 5.2. Paleoecology

In the West Gejiazhuang section, the 189 m-thick Gucheng Formation is composed of alternating beds of variegated claystones and siltstones, with an oncolite bed at the top (Fig. 2). The terrigenous sediments represent floodplain facies, and the top oncolite bed represents a small pond with a river inlet (Li et al., 2016). The Truncatelloidea gen. et sp. indet. found in this oncolite bed are poorly to moderately preserved, probably resulted from a relatively high-energy environment. The overlying strata are the 141 m-thick first unit of the Bianqiao Formation ($B_1$) consisting of pale limestones and green to grey marlstones interbedded with calcareous claystones and silty claystones (Fig. 2). The basal to middle $B_1$ is composed of marlstones interbedded with limestones, calcareous claystones and silty claystones, containing sporadic gypsum with calcareous nodules, representing shallow lake deposits. This part contains well-preserved gastropods, including *Ph. dongtaiensis*, ?Pomatiopsidae gen. et sp. indet, Truncatelloidea gen. et sp. indet., ?*H. datangensis*, and ?*Cyathopoma pingyiensis* sp. nov. The gastropod fauna is preserved together with the charophyte flora, including *Microchara cristata* Grambast, 1971 and *M. cf. nana* Vicente, 2016, *Peckichara praecursoria* Karczewska and Ziembinska-Tworzydlo, 1981, *P. varians* and *Chara* sp. (Li et al., 2016). The palaeoenvironment can be reconstructed from extant relatives of the fossil gastropod species, so we explore living environment of these extant relatives first. Extant hydrobiids commonly live in great diversity in springs, streams and rivers, lakes, groundwater systems, caves, estuarine marshes and mudflats; extant species of Pomatiopsidae inhabit rivers, permanent wetlands, stream edges, as well as some saline springs/lakes; extant Physidae live in ponds, wetlands, eutrophic streams, temporary aquatic habitats, and springs (Strong et al., 2007). So living environment of these extant relatives are consistent with palaeoenvironment reconstructed by facies analysis. Furthermore, Physids prefer to live among a dense vegetation of submerged plants (Taylor, 2003), which is consistent with the discovery of an abundant charophyte flora from the same beds. At the top of $B_1$, the 4 m-thick deposits are composed of green and grey limestones and calcareous claystones, referring to shallow lake deposits. It yields the gastropods Truncatelloidea gen. et sp. indet., ?*H. datangensis* and ?*Cyathopoma pingyiensis* sp. nov. These gastropods are moderately preserved and thus probably represent an parautochthonouos assemblage. In conclusion, Truncatelloidea gen. et sp. indet. lived in a small pond

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with a river inlet and a shallow lake, while *Ph. dongtaiensis*, ? Pomatiopsidae gen. et sp. indet, and ?*H. datangensis* only thrived in the shallow lake with a dense vegetation of charophytes and ?*Cyathopoma pingyiensis* sp. nov. thrived on land close to the lake bank.

## 6. Conclusion

The gastropod fauna from the K–Pg transition in the Pingyi Basin, Shandong Province, eastern China is reported here for the first time, and one new species is established; the fauna includes *Ph. dongtaiensis*, Truncatelloidea gen. et sp. indet., Pomatiopsidae gen. et sp. indet, *Hydrobia datangensis* and *Cyathopoma pingyiensis* sp. nov. *Physa dongtaiensis* and *Hydrobia datangensis* are widely distributed in the fossil record of China and can be used to make biostratigraphical correlations. The sedimentological facies of the gastropod-bearing deposits indicated that Truncatelloidea gen. et sp. indet. inhabited a small pond with a river inlet and a shallow lake, while *Ph. dongtaiensis*, Pomatiopsidae gen. et sp. indet, and *H. datangensis* thrived in the shallow lake. *Cyathopoma pingyiensis* sp. nov. inhabited the land area around the lake. The discovery of the earliest representatives of *Cyathopoma* in latest Cretaceous to Paleocene of China, East Asia suggested that its ancestors originated in latest Cretaceous to Paleocene at least.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Tingting Yu and Sha Li on behalf of the other authors.

## Acknowledgements

We are grateful to H. Pan and Thomas A. Neubauer for assistance with taxonomy and Y. Mao for scanning electron microscopy. This research was supported by the National Natural Science Foundation of China (41972018, 41688103 and 41730317), the Strategic Priority Research Programme of the Chinese Academy of Sciences (XDA19050101 and XDB26000000), and the State Key Laboratory of Palaeobiology and Stratigraphy (Nanjing Institute of Geology and Palaeontology, CAS) (No. 183101). This is a Leverhulme Emeritus Fellowship contribution for the EAJ. The English text was corrected by Springer Nature (https://authorservices.springernature.com).

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Please cite this article as: T. Yu, H. Wang, Y. Fang, et al., Non-marine gastropods from the Cretaceous–Paleogene transition in the Pingyi Basin, eastern China, Proceedings of the Geologists' Association, https://doi.org/10.1016/j.pgeola.2021.10.003