New Ordovician bivalves from the Indo-China Palaeoplate in Dali, western Yunnan, SW China and their palaeogeographic significance

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Abstract.

A centre of radiation for Ordovician bivalves is identified based on an abundant and diverse fauna from the Hsiangyang Formation (Darriwilian, Middle Ordovician) of Dali, western Yunnan Province, SW China. It consists of 18 genera and 22 species, including one new genus and four new species: *Rhomboconcha tresdentes* n. gen. et n. sp., *Fasciculodonta curvata* n. sp., *Glyptarca symmetrica* n. sp., and *Paracyclas initium* n. sp.; and three taxa known from elsewhere but initially found in Dali include *Praeleda* sp., *Glyptarca* sp., and *Redonia deshayesi*, as well as other taxa previously reported by Fang and Cope, 2004. Numerical analysis on the distribution of eleven Middle Ordovician bivalve faunas from different areas shows two distinct faunal groups, the HPL group, representing the bivalves that lived in higher palaeolatitudes, and the LPL group (including Australia and South China) in lower palaeolatitudes. The bivalve fauna from Dali correlates with both groups, indicating that the Indo-China Palaeoplate was located between these two groups, i.e. in middle–high palaeolatitudes. Thus, the Indo-China Palaeoplate was probably an isolated centre for bivalve radiation during the Middle Ordovician, and those genera confined to Dali did not then spread to other palaeoplates.

Keywords. Bivalve, Darriwilian, Indo-China Palaeoplate, Dali, Palaeogeography.

1 Introduction.

Bivalvia is, today, one of the most diverse benthic marine and non-marine invertebrates groups, but in Ordovician, bivalves lived in the shadow of brachiopods, which were the main components of the Palaeozoic marine ecosystem (Zhan et al., 2007; Zhan et al., 2008; Guo et al., 2023). Globally there are several areas that have records of rich and relatively diverse Ordovician bivalves, for example the Amadeus Basin in Australia (Jakobsen et al., 2016), Morocco (Polechová, 2016; Ebbestad et al., 2022), Spain (Babin and Gutiérrez Marco, 1991), Argentina (Sánchez, 1999, 2005; Sánchez and Vaccari, 2003; Sánchez and Benedetto, 2007), Czech Republic (Kříž and Steinová, 2009; Polechová, 2013, 2022), Britain (Cope, 1996, 1999), and a few locations in China (Liu, 1979; Gong, 1991; Niu et al., 2018) including Yunnan (Guo, 1985, 1988; Fang and Cope, 2004).

Yunnan Province is geologically unique in China. It consists of three major tectonic units during the Ordovician, i.e., the southwestern part of South China Palaeoplate in eastern Yunnan, the northern extension of the Indo-China Palaeoplate and the Sibumasu terrane respectively, in western Yunnan (Zhou et al., 2001). The study area, Dali, is located in the eastern part of western Yunnan (Fig. 1B), belonging to the northern extension of the Indo-China Palaeoplate (Fang, 1991, 1994). Guo (1985) was the first to report Ordovician bivalves in Dali, but only three genera and species were described briefly at that time. Fang and Cope (2004) conducted a preliminary systematic study on the Ordovician bivalves from Xiangyang and Mingzhuang villages of Dali, reporting 14 genera and 15 species. Recently, on the basis of new field excursions, an abundant and diverse bivalve fauna was collected, including one new genus and three new species, as well as three already established genera and species initially discovered in Dali. The bivalve fauna at this locality is a Middle Ordovician assemblage containing 18 genera and 22 species, just slightly fewer than those reported in the Middle Ordovician of Guangdong, China (Niu et al., 2018; Zhang et al., 2020; Niu et al., 2023, see the appendix). Reports of large numbers of bivalves in the Middle Ordovician are not common in a marine ecosystem dominated by brachiopods, trilobites and graptolites. The goal of this paper is therefore to describe the new Middle Ordovician bivalve taxa from the Hsiangyang Formation, and to investigate the macroevolutionary and palaeobiogeographic significance of this bivalve fauna.

2 Geological setting and Material.

The type section of the Hsiangyang Formation is located at Xiangyang village, northern Haidong town, eastern Dali (Fig. 1C, Xiangyang section, GPS 25°43’8” N–25°43’30” N, 100°15’28.7” E–100°15’29.4” E). This section crops out on small hill named Heshanding, and the exposures occur along a narrow hill road extending from the backyard of a farmer’s house to the hill top. Only the Hsiangyang Formation is exposed at this section, where it can be divided into three members (Zhou et al., 1998; Zhang et al., 2014). Most of the fossils studied in this paper were collected from the lower member, including 22YDX-1 to 22YDX-22 and 22YDX-25. The lithology of the lower member of the Hsiangyang Formation mainly consists of grey to dark grey, or yellow to greenish yellow siltstone and silty mudstone (Fang and Cope, 2004; Zhang et al., 2014). Besides, there is another site 5.2 km north of Xiangyang village, and just adjacent to Yulong village, where two supplementary fossiliferous collections were made (Fig. 1C, Yulong section, GPS 25°46’2.2” N, 100°15’31.0” E), 22YDY-1 and 22YDY-2. The lithology of the Hsiangyang Formation at the Yulong section is mainly greyish green or yellowish green mudstone and siltstone that are slightly metamorphosed, and belong to the middle member of the Hsiangyang Formation.

The fossils at the Xiangyang section are dominated by bivalves, with some brachiopods, trilobites, and a few gastropods and cephalopods. We collected at 23 fossiliferous horizons, from the lower to the upper levels through the lower-middle members of the Hsiangyang Formation, which total 1016 rock specimens with thousands of individuals, especially abundant at collections 22YDX-3, 22YDX-6, 22YDX-9, 22YDX-19, 22YDX-20, and 22YDX-21 (see Fig. 2). According to the graptolite and trilobite fossils from the middle and upper members of the Hsiangyang Formation, this formation could be considered as the Darriwilian (Zhou et al., 1998). The bivalve fossils are normally preserved as disarticulated left and right valves, and internal or external moulds, but conjoined valves are also common and even dominate some collections. Almost all the shells are complete and lie on each stratum horizontally without any apparent orientation and sorting. So, it is reasonable to suggest that the bivalves were buried with very short transportation or without any post–mortem transportation, i.e., *in situ* preservation. All the specimens studied in this paper are stored in the Specimen Museum of Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPAS).

3 Systematic Palaeontology

Phylum Mollusca Linnæus,1758 in 1758–1759

Class Bivalvia Linnæus, 1758 in 1758–1759

Subclass Protobranchia Pelseneer, 1889

Order Solemyida Dall, 1889

Superfamily Afghanodesmatoidea Scarlato and Starobogatov, 1979

Family Afghanodesmatidae Scarlato and Starobogatov, 1979

Genus *Praeleda* Pfab, 1934

Type species. *Nucula compar* Barrande, 1881, from the Upper Ordovician, Zahořany Formation, Loděnice, Czech Republic.

Occurrence. Late Dapingian to Hirnantian (Middle–Late Ordovician); occurring in southwestern China, UK, France, Czech Republic and elsewhere.

Praeleda sp.

Fig. 3, A

Materials. One internal mould of a right valve at 22YDX-25.

Measurement.

Number	H/mm	L/mm	L/H
NIGP203569	4.93	6.17	1.25

Description.

A small shell of sub-rhomboidal outline with concave posterior margin and a weak posterodorsal alation, inequilateral. The umbo is slight projected, situated posterior to the middle of the hinge line, prosogyrate. The posterior and anterior umbonal ridges are apparent, separating the flank from anterior and posterior two sub-trigonal areas. Adductor scars are not impressed. The dentition is not preserved. Inner surface is with a lamellar mark parallel to the shell margin, which may be the pallial line.

Remarks.

There is only one specimen without dentition in our collection, whose shell form is similar to the genera *Praeleda*, *Deceptrix* and *Praenucula*, amongst which there are many discussions and problems (McAlester, 1969; Bradshaw, 1970; Tunnicliff, 1982; Babin and Gutiérrez-Marco, 1991; Cope, 1997, 1999).

It is difficult to recognize the specimen clearly without the evidence of dentition. And most species of *Praeleda* show an elongate anterior half of shell (Bradshaw, 1970) and posterior umbo (Cope, 1999), but there are also some *Praeleda* such as *P. subtilis* Cope, 1999 from the Darriwilian in mid-Wales showing the subcentral umbo, which appears in our specimen. Meanwhile, our specimen also has postero-dorsal alation similar to that of *P. subtilis*. However, the posterodorsal margin of *P. subtilis* extends nearly horizontally, while that of our specimen is tilted toward the ventral side, and the posterior ridge is more acute in our specimen. Based on comparison with *P. subtilis*, we are inclined to tentatively assign our specimen in open nomenclature to the genus *Praeleda*.

Compared with other species of *Praeleda*, *P. compar* Barrande, 1881 from late Sandbian in Bohemia (Kříž and Steinová, 2009), *P. multidentata* Cope, 1999 from the Darriwilian in mid-Wales, *P. ciae* Sharpe, 1853 and *P. costae* Sharpe, 1853 from the Darriwilian in France (Bradshaw, 1970), *P. contrastans* Barrande, 1881 and *P. pulchra* Barrande, 1881 (Pfab, 1934), our specimen has the umbo sitting more anteriorly with a shorter anterior part of shell.

Subclass Autobranchia Grobben, 1894

Infraclass Pteriomorphia Beurlen, 1944

Order Arcida Gray, 1854

Superfamily Glyptarcoidea Cope, 1996

Family Glyptarcidae Cope, 1996

Genus *Glyptarca* Hicks, 1873

Type species. *Glyptarca primaeva* Hicks, 1873, from the Floian, Ramsey Island, Pembrokeshire, UK.

Occurrence. Late Tremadocian to Darriwilian (Early–Middle Ordovician); southwestern China, UK, Spain, Morocco, Iran and elsewhere.

Glyptarca symmetrica n. sp.

Fig. 3, B–H, 6, A

Etymology. Latin *symmetrica*, meaning symmetric, indicating the sub-equilateral shell.

Materials. Ten internal moulds of right valve, one internal mould of left valve.

Type specimens. Holotype, NIGP203572, internal mould of the right valve, figured on Fig. 3D, G; Paratypes, NIGP203575, internal mould of the left valve, figured on Fig. 6A, NIGP203578, internal mould of the right valve, figured on Fig. 3E, H, NIGP20357, 1internal mould of the right valve, figured on Fig. 3B, NIGP203576, internal mould of the left valve, figured on Fig. 3C, NIGP203573, internal mould of the left valve, figured on the Fig. 3F.

Occurrence. Darriwilian (late Middle Ordovician); Collections 22YDX-3, 23YDX-30 of Hsiangyang Formation, Xiangyang section, Dali, China.

Measurement.

Number	H/mm	L/mm	L/H
NIGP203570	12.16	16.75	1.38
NIGP203571	12.01	17.50	1.46
NIGP203572	10.81	15.70	1.45
NIGP203573	9.12	12.08	1.32
NIGP203574	12.29	13.60	1.11
NIGP203575	7.01	9.46	1.35
NIGP203576	8.29	11.08	1.34
NIGP203577	9.19	11.57	1.26
NIGP203578	8.95	12.70	1.42

Diagnosis. *Glyptarca* with sub-equilateral shell and broad but strongly incurved umbo. One posterior crenulated tooth and two to four anterior teeth.

Description.

Medium-sized shell, rectangular to sub-pentagonal, equivalve, sub-equilateral. Umbo is projected and broad, about half shell length, situated medially or slightly anterior of the shell, incurved over the hinge plate, prosogyrate. Anterior adductor scar is not well impressed, ovate, in holotype NIGP203572, there is a small pedal retractor scar placed dorsally to the anterior adductor scar (Fig. 4, D). Posterior adductor scar rounded and larger than anterior one, but not well preserved. There may be an entire pallial line preserved in paratype NIGP203575 (Fig. 4, F); pallial sinus is absent.

The dentition is well preserved in holotype, consisting of two to three anterior teeth in right valve, and three to four in left valve, and one crenulated posterior tooth in both valves, the crenulation persists throughout its length.

The surface ornamentation and ligament are not preserved.

Remarks.

This species differs from *G. primaeva* Hicks, 1873 and *G. serrata* Cope, 1996 from Wales in lacking the carinate postero-umbonal ridge. It differs from *G. radnorensis* Cope, 1999 from Wales and *G. sinensis* Fang and Cope, 2004 from China in having fewer anterior teeth and a sub-equilateral shell.

Glyptarca sp.

Fig. 3, I–K

Materials. One conjoined internal mould, and one deformed internal mould of right valve.

Measurement.

Number	H/mm	L/mm	L/H
NIGP203579	15.45	32.37	2.10

Description.

Large shell, elongately elliptical, equivalve, inequilateral. The umbo is rounded, projected over the hinge plate, situated in anterior third of shell, prosogyrate. Anterior adductor scar rounded, not deeply impressed. Posterior adductor scar is not preserved.

The dentition is clear in the conjoined shell, with six anterior teeth in right valve, with five in left valve, and two posterior, lamellar teeth in each valve. Anterior and posterior teeth overlap beneath the umbo, and there is a lamellar umbonal tooth. The deformed shell only shows two posterior and anterior teeth (fig. 3 K).

The surface ornamentation and ligament not preserved.

Remarks.

Both the posterior and umbonal teeth of the current material lack crenulations, which is one of the key features of glyptarcids. But the overlap of the anterior and posterior teeth beneath the umbo is also one feature shared by glyptarcids, which is well preserved in our material. Our specimens could be a representative of *Glyptarca* demonstrating a clear variation in its shell or teeth.

This species differs from other species of the genus by its two posterior teeth, which only can be observed in *G. radnorensis* Cope, 1999 from Wales, and these two species also share very similar anterior teeth; but the inflated shell and less impressed posterior adductor scar of our material differ from those of *G. radnorensis*.

Order Actinodontida Deschaseaux, 1952

Superfamily Anodontopsoidea Miller, 1889

Family Cycloconchidae Ulrich, 1894

Genus *Fasciculodonta* Fang and Cope, 2004

Type species. *Fasciculodonta impressa* Fang and Cope, 2004, from the Hsiangyang Formation (Darriwilian) at Xiangyang village, Dali, western Yunnan Province, China.

Occurrence. Darriwilian (late Middle Ordovician); southwestern China.

Fasciculodonta curvata n. sp.

Fig. 4, A–L

Etymology. Latin *curvata*, meaning curved, indicating the strongly curved umbo.

Materials. Six internal moulds of right valve, five internal moulds of left valve.

Type specimens. Holotype, NIGP203591, internal mould of right valve, figured on Fig. 4I, L; Paratypes, NIGP203585, internal mould of the right valve, figured on Fig. 4G, NIGP203583, internal mould of the right valve, figured on Fig. 4H, K, NIGP203581, internal mould of the left valve, figured on Fig. 4A, NIGP203618, internal mould of the left valve, figured on Fig. 4B, NIGP203586, internal mould of the left valve, figured on Fig. 4C, NIGP203589, internal mould of the left valve, figured on Fig. 4D, J, NIGP203587, internal mould of the left valve, figured on Fig. 4E, NIGP203584, internal mould of the right valve, figured on Fig. 4F.

Occurrence. Darriwilian (late Middle Ordovician); Collections 22YDX-14 and 22YDX-20 of Hsiangyang Formation, Xiangyang section, Dali, China.

Measurement.

Number	H/mm	L/mm	L/H
NIGP203581	10.54	13.31	1.26
NIGP203582	10.15	13.88	1.37
NIGP203583	10.03	14.79	1.47
NIGP203584	10.90	16.14	1.48
NIGP203585	8.88	13.83	1.56
NIGP203586	10.46	17.69	1.69
NIGP203587	7.38	12.57	1.70
NIGP203588	6.95	11.79	1.70
NIGP203589	10.50	18.07	1.72
NIGP203590	9.35	16.16	1.73
NIGP203591	11.04	20.64	1.87

Diagnosis. *Fasciculodonta* with strongly incurved umbo over hinge plate and a narrow and acute postero-umbonal ridge.

Description.

Medium-sized shell, sub-trigonal to sub-rectangular, equivalve, inequilateral. The umbo is broad, situated in the anterior third to fourth part of the shell, strongly incurved over the hinge plate, prosogyrate. Ventral margin straight to slightly arcuate. Postero-umbonal ridge is strong. Anterior adductor scar rounded, impressed, posterior myophoric buttress prominent, and a small elliptical pedal retractor scar situated near the dorsal margin of anterior adductor scar. Posterior adductor scar is indistinct, ovate, slightly larger than anterior adductor scar.

In the right valve, two to three anterior pseudocardinal teeth, and the first tooth forms an inverted V, one posterior pseudolateral tooth. In the left valve, there are two anterior pseudocardinal teeth, and two posterior pseudolateral teeth, the dorsal one is longer and extends to posterior margin, the ventral one is short and situated beneath the umbo.

The surface ornamentation and ligament are not preserved.

Remarks.

This species differs from other species of *Fasciculodonta* by its strongly incurved umbo, narrow and acute postero-umbonal ridge and less anteriorly situated pseudocardinal teeth. Although there are only a few specimens, the shell variation is marked, with the shell outline divisible into three types. Type one, the shell is sub-trigonal, with a contracted posterior margin which can be viewed as a part of the postero-umbonal ridge. This shell outline is similar to *Redonia deshayesi* Rouault, 1851, after removing the umbo (Fig. 6, H, K) we can distinguish these two species by their contrasting dentition. Type three, the shell is sub-rectangular, with a broader umbo and postero-umbonal ridge than type one. Type two, the shell outline is intermediate between the former two types. From the type one to the type three, the L/H gradually increases, the umbo and postero-umbonal ridge becomes broader, and the ventral margin is also straighter.

Family Redoniidae Babin, 1966

Genus *Redonia* Rouault, 1851

Type species. *Redonia deshayesi* Rouault, 1851, from the upper Darriwilian of Postolonnec Formation, France.

Occurrence. Floian to Darriwilian (Early–Middle Ordovician); UK, Spain, France, Argentina, Bolivia, Morocco, Czech Republic, southwestern China and elsewhere.

Redonia deshayesi Rouault, 1851

Fig. 6, B–K

1851 *Redonia deshayesiana* Rouault, p. 364, figs 1–2.
1881 *Redonia bohemica* Barrande, pl. 268, figs 1–26.
1881 *Nucula faba* Barrande, pl. 273, figs IV/1–4.
1918 *Redonia deshayesiana var. duvaliana* Born, p. 341, pl. 25, figs 2a–f.
1934 *Redonia deshayesi* Gouzien, p. 179.
1950 *Redonia bohemica* Termier, p. 87, pl. 165, figs 1–3, 6–9.
1950 *Redonia megalodontoides* Termier, p. 87, pl. 165, figs 4–5.
1951 *Redonia deshayesiana* Gigout, p. 296, pl. 2, figs 14.
1966 *Redonia deshayesi* Babin, p. 246, pl. 10, figs 13–16.
1970 *Redonia deshayesi* Bradshaw, p. 638, pl. 25, figs 16–21.
1978 *Redonia bohemica* Pojeta, p. 233, pl. 4, figs 1–4.
1990 *Redonia deshayesi* Babin and Destombes, p. 246, pl. 1, fig 12.
1991 *Redonia deshayesi* Babin and Gutiérrez-Marco, p. 129, pl. 9, figs a–e.
2003 *Redonia deshayesi* Babin and Beaulieu, p. 197, pl. 3, fig 1.
2013 *Redonia deshayesi* Polechová, p. 442, figs 6G–N.

Materials. Nine internal moulds of right valve, five internal moulds of left valve.

Measurement.

Number	H/mm	L/mm	L/H
NIGP203592	6.98	8.55	1.22
NIGP203593	8.94	12.00	1.34
NIGP203594	5.13	6.90	1.35
NIGP203595	4.92	6.91	1.40
NIGP203596	4.48	6.30	1.41
NIGP203597	5.53	7.62	1.38
NIGP203598	5.15	7.11	1.38
NIGP203599	4.89	6.94	1.42
NIGP203600	4.13	6.04	1.46
NIGP203601	6.80	9.28	1.36
NIGP203602	5.04	6.97	1.38
NIGP203603	5.73	7.77	1.36
NIGP203604	5.79	8.44	1.46
NIGP203605	6.02	incomplete	
NIGP203606	4.17	6.58	1.58
Average	5.48	7.60	1.39

Description.

Small shell, ovate or elliptical, equivalve, strongly inequilateral. The umbo is prominent, incurved over hinge plate, situated in anterior fourth of the shell, prosogyrate. The adductor scars well preserved, anterior one circular with a deep myophoric buttress on its posterior side, and the posterior one is less pronounced but larger than anterior adductor scar. There are one anterior and one posterior pedal retractor scars situated dorsally of the adductor scars.

The dentition well preserved; in the right valve, there are one stout anterior pseudocardinal teeth with a socket posterior to hold the tooth in left valve, and two posterior pseudolateral teeth, parallel to the dorsal margin. In the left valve, the dentition consists of one anterior pseudocardinal tooth and two posterior pseudolateral lamellar teeth.

External surface is smooth or ornamented with slight concentric growth lines.

Remarks.

Redonia deshayesi has been reported from the Middle Ordovician of many areas, including Spain (Babin and Gutiérrez Marco, 1985, 1991), France (Babin, 1966; Bradshaw, 1970; Babin and Beaulieu, 2003), Czech Republic (Barrande, 1881; Polechová, 2013), Morocco (Babin and Destombes, 1990), Bohemia (Barrande, 1881; Steinová, 2011). This is the first report of this genus and species in China.

The shell of *R. deshayesi* is similar to *R. condorensis* Sánchez and Benedetto, 2007 from the Floian–Darriwilian of Argentina, but without the subumbonal carina and *R. deshayesi* has two posterior teeth in the right valve. *R. riojana* Sánchez, 1997 from the Dapingian of Argentina differs in having a less incurved umbo. *R. suriensis* Sánchez and Babin, 1994 also from the Floian–Darriwilian of Argentina has a stronger umbo *R. michelae* Babin, 1982 from Floian of France is smaller than *R. deshayesi* and has a larger anterior myophoric buttress. *R. bohemica* Barrande, 1881 and *R. anglica* Salter in Murchison, 1859 may be conspecific with *R. deshayesi* due to the same chevron-shaped socket and dentition (Babin and Gutiérrez Marco, 1991; Polechová, 2013).

R. deshayesi is also close to *Yunnanoredonia laevis* Fang and Cope, 2004 in having similar shells together with a distinct anterior adductor scar and myophoric buttress. But their dentitions are different and *R. deshayesi* is slightly more elongated than *Y. laevis*.

Clade of Ischyrodontidae, Nepiomorphia, Arcida, Eupteriomorphia[1]

Clade Ostreomorphi Férussac, 1822 in 1821–1822

Family Ischyrodontidae Scarlato and Starobogatov, 1979

Type genus. *Ischyrodonta* Ulrich, 1890, from the top of the Cincinnati Group, Oxford, Ohio, and Indiana, USA.

Genus *Rhomboconcha* n. gen.

Etymology. Latin *rhomb-*, rhombus, *concha-*, shell, referring to the rhomboidal shell of the new genus.

Type and only species. Designated here, *Rhomboconcha tresdentes* n. gen. et n. sp., from the Hsiangyang Formation (Darriwilian) in Dali, western Yunnan, China.

Occurrence. Darriwilian (late Middle Ordovician); southwestern China.

Diagnosis. Ischyrodontidae with two cardinals and one posterior lateral tooth in each valve; with or without a postero-umbonal ridge.

Description.

Middle to large size shell in rhomboidal to elongate ovate form, equivalve and inequilateral. The umbo is situated in the anterior of the shell, slightly projects over the hinge line, prosogyrate. Anterior adductor muscle scars rounded, poor impressed. Posterior adductor muscle scar not preserved. The dentition consists of two short cardinal teeth and one long posterior lateral tooth in each valve. Ligament structure and external ornamentation not preserved.

Remarks.

The family Ischyrodontidae was erected by Scarlato and Starobogatov (1979), with the genus *Ischyrodonta* Ulrich, 1890, whose hinge plate is wide and strong without posterior lateral teeth, but with two strong cardinal teeth in left valve (Ulrich, 1893). The hinge in *Modiolodon* Ulrich, 1894 is much like that of *Ischyrodonta* with several distinct cardinal teeth and the external ligament depression in the posterior hinge (see the figures in Pojeta, 1971). *Matheria* Billings, 1858a shows the similar hinge to *Ischyrodonta* with cardinal teeth and external ligament, but without laterals (Billings, 1858b). *Rhomboconcha* differs from these genera by the dentition, *Rhomboconcha* has one posterior lateral tooth in each valve, but these genera above have a wider hinge plate and lack posterior laterals.

Saffordia Ulrich, 1894 may be the only genus with posterior teeth in this family, consisting one anterior and posterior tooth in left valve, and the corresponding depressions in the right valve. While hinge of *Rhomboconcha* consists of two anterior and posterior teeth in each valve. *Montanaria* Spriestersbach, 1909 also can show a posterior lateral in some shells, but has at least two cardinals in

[1] "Clade of Ischyrodontidae, Nepiomorphia, Arcida, Eupteriomorphia" and "Clade Ostreomorphi Férussac" see Carter J G, in press.

each valve, which may be more than that of *Rhomboconcha*. The postero-umbonal ridge is predominant in some specimens of this genus, such as NIGP203617, NIGP203619 and NIGP203607, and such ridge is also present in *Saffordia*.

Comparing with other genera in this family, the hinge plate is narrow in *Eurymyella* Williams, 1912, similar to that in *Rhomboconcha*, but it is without lamellar teeth; *Callodonta* Isberg, 1934 and *Radiatodonta* Dahmer, 1921 also only have cardinal teeth.

Rhomboconcha tresdentes n. sp.

Fig. 7, A–I

Etymology. Latin *tres-*, three, *-dentes*, teeth, indicating the dentition consisting of two cardinal teeth and one posterior lateral tooth.

Materials. Eight internal moulds of the left valve, and six internal moulds of the right valve.
Type species. Holotype NIGP203627, internal mould of the left valve, figured on Fig. 7A, B; Paratypes NIGP203616, internal mould of the left valve, figured on Fig. 7F, NIGP203607, internal mould of the right valve, figured on Fig. 7H, I, NIGP203622, internal mould of the left valve, figured on Fig. 7C, NIGP203611, internal mould of the left valve, figured on Fig. 7D, NIGP203612, internal mould of the left valve, figured on Fig. 7E, NIGP203615, internal mould of the right valve, figured on Fig. 7G.
Occurrence. Darriwilian (late Middle Ordovician); Collections 22YDX-20 and 22YDX-21 of Hsiangyang Formation, Xiangyang section, Dali, China.
Measurement.

Number	H/mm	L/mm	L/H
NIGP203607	7.12	12.19	1.71
NIGP203608	8.13	12.90	1.59
NIGP203609	8.80	13.54	1.54
NIGP203610	9.35	14.38	1.54
NIGP203611	5.79	8.59	1.48
NIGP203612	7.92	11.75	1.48
NIGP203613	8.75	12.33	1.41
NIGP203614	12.39	16.78	1.35
NIGP203615	4.76	6.44	1.35
NIGP203616	9.08	12.01	1.32
NIGP203617	6.75	8.65	1.28
NIGP203618	7.56	9.64	1.28
NIGP203619	7.94	9.95	1.25
NIGP203620	11.64	13.71	1.18
NIGP203621	21.32	25.07	1.18
NIGP203622	9.82	10.18	1.04

Diagnosis. As for the genus.

Description.

Shell medium to large size, rhomboidal to elongately ovate, equivalve and strongly inequilateral. The umbo is situated in the anterior third of the shell, prosogyrate. Anterior and posterior margins are rounded, ventral margin is nearly oblique, straight, forming the postero-ventral angle, which can be rounded, or acute in some specimens. The anterior adductor muscle scar is slightly impressed, ovate rounded. Posterior adductor scar not preserved.

Dentition well preserved consisting of two short subparallel cardinal teeth originated under the umbo region, and one long posterior lateral tooth paralleled to the dorsal posterior margin in each valve. Ligament not preserved.

In NIGP203620 and NIGP203622, there are suggestions of a concentric ornamentation; and radial ornamentation is lacking. Specimen NIGP203622 probably possesses pallial line, but badly preserved (Fig. 7C).

Remarks.

Rhomboconcha tresdentes is herein compared with species of Ischyridontidae possessing posterior lamellar teeth. *Saffordia ventralis* Ulrich, 1894 from USA has shorter shell, and more rounded ventral margin. *S. sulcodorsata* Ulrich, 1892 from USA seems to be very similar in shell shape but has different dorsal sulcus and concentric fold ornamentation.

The shells of the holotype NIGP203627 (Fig. 7, A, B) and paratype NIGP203607 (Fig. 7, H, I) are slightly different because paratype has lager L/H ratios and possesses postero-umbonal ridge. We recognize them as the same species based on the same dentition and the modioliform shell outline, therefore, these differences are interpreted as variation in the shell of *R. tresdentes*.

Order Lucinida Gray, 1854

Superfamily Lucinoidea Fleming, 1828

Family Paracyclidae Johnston, 1993

Genus *Paracyclas* Hall, 1843

Type species. *Paracyclas elliptica* Hall, 1843, from the Devonian of western New York State, USA.
Occurrence. Middle Ordovician to Devonian; southwestern, South and North China, USA, Bolivia, France and elsewhere.

Paracyclas initium n. sp.

2004 *Paracyclas* sp. Fang and Cope, p. 1145–1146, pl. 2, figs 1–2.

Fig. 6, L–O

Derivation of name. Latin *initium*, the beginning, meaning the stratigraphically lowermost occurrence of this genus.
Materials. Three internal moulds and one external mould of right valve.
Type species. Holotype NIGP203625, external mould of the right valve, figured on Fig. 6L; Paratypes NIGP203624, internal mould of the right valve, figured on Fig. 6M, NIGP203626, internal mould of the right valve, figured on Fig. 6O, NIGP203623, internal mould of the right valve, figured on Fig. 6N.
Occurrence. Darriwilian (late Middle Ordovician); Collection 22YDX-9 of Hsiangyang Formation, Xiangyang section, Dali, China.
Measurement.

Number	H/mm	L/mm	L/H
NIGP203623	15.51	17.14	1.11

NIGP203624	22.23	23.09	1.04
NIGP203625	24.34	25.21	1.04
NIGP203626	18.74	18.70	1.00

Diagnosis. *Paracyclas* with a broad umbo slightly projected over the hinge line. Ovate shell, ornamented by concentric ribs.

Description.

Large shell, sub-circular, equivalve, sub-equilateral, with a broad umbo situated nearly central on the dorsal margin, and slightly projected over the hinge line. The umbo nearly orthogyrate or slightly prosogyrate. Adductor scars are not well preserved, the elongate anterior rut showed in NIGP203625 may suggest the anterior adductor scar.

The dentition is edentulous, but Babin (1966) mentioned there are one or two very small cardinal teeth on the hinge plate of *P. marginata* (Maurer). In specimen NIGP203623 and NIGP203624, there may be narrow ligament grooves extending from the beak, which are parallel to the dorsal margin.

The ornamentation is prominent, consisting of concentric striae and ribs or subdued radial lines noted by Fang and Cope (2004). Specimen NIGP203625 probably has a pallial line (Fig. 3, B). The distortion and radial cracks on the shell indicate the original shell was thin (Bailey, 1983).

Remarks.

Before the discovery of this species, the earliest known *Paracyclas* was *P. minor* Hind, 1910 from the middle Llandovery of the Girvan District, Scotland. *P. initium* n. sp. differs from *P. minor* in its larger shell and broader umbo. *P. insueta* Reed, 1927 from the Ludlow of the Welsh Borderland is similar to *P. initium* n. sp. in having a suborbicular shell and strong concentric growth ridges, but its umbo does not extend over the hinge line. And the type species *P. elliptica* Hall, 1843 differs in having an elongate elliptical shell.

4 Palaeobiogeographic significance

The palaeobiogeographic significance of the Middle Ordovician bivalves studied in this paper was studied with reference to eleven Darriwilian bivalve faunas from nine palaeoplates and terranes (Indo-China, South China, Australia, South America, Northeastern Africa, Armorica, Avalonia, Iberia, Perunica). The data were compiled together for multivariate numerical analyses. Cluster analysis, and Principal Component analysis were conducted to interrogate the data matrix.

Among the 63 genera involved, there are only three (4.8%, *Redonia*, *Modiolopsis*, *Ctenodonta*) that occur in five or more palaeoplates, and six (9.5%, *Glyptarca*, *Praeleda*, *Similodonta*, *Tancrediopsis*, *Praenucula*, *Cardiolaria*) in four palaeoplates. Over two–thirds (44 genera, 69.8%) are endemic that are confined to their particular palaeoplates of origin. Therefore, Sánchez and Babin (2003) concluded that bivalves are not effective palaeobiogeographic indicators, because of the low percentage of shared genera among different faunas. So, we did not use the traditional binary dataset (i.e., the “1-0” coded method, “1” refers to the genus existing in the fauna, and “0” refers not), but coded by the number of species of each genus; both numerical analyses are based on this dataset. The PCA and CA reveal the following results.

1. In the graph of scores on the Principal Components, only the faunas GZC (Guangzhou in China) and ABA (Amadeus Basin in Australia) are positively related on Component 1 due to the shared genera *Nuculites*, *Cyrtodonta* and *Sthenodonta*, the last being found only in these two faunas.

The palaeogeographical location of fauna GZC is controversial. It has been suggested to reside on the Yunkai block (Zhang et al., 2021), which may not be a part of South China Palaeoplate, and has affinity with Australia or the Gondwana supercontinent (Wu, 2000). Wang et al. (2016) noted that the Wuyi-Yunkai arc area belongs to the Cathaysian block of the South China Palaeoplate. Ordovician bivalves may have possessed lecithotrophic larvae (Babin, 1995; Sánchez and Babin, 2003) that can help bivalves spread over short distance via palaeo-ocean currents. Thus, the close position between GZC and ABA in the PCA plot suggests that the Middle Ordovician bivalves of these two faunas have a close relationship both palaeoecologically and palaeogeographically.

2. Both PCA and CA diagrams show one group including the faunas COA (Cordillera Oriental in Argentina, South America Palaeoplate), MWB (mid Wales in Britain, Avalonia Palaeoplate), CPF (Finistère in France, Armorica Palaeoplate), HMS (Hesperian Massif in Spain, Iberia Palaeoplate), AAP (Águeda in Portugal, Iberia Palaeoplate), PBC (Prague Basin in Czech Republic, Perunica block) and LAM (l'Anti-Atlas in Morocco, Northwestern Africa Palaeoplate), sharing the genera *Redonia*, *Praeleda*, *Praenucula*, *Cardiolaria*, *Babinka* and *Coxiconchia*. *Babinka* and *Coxiconcha* only occur in the above mentioned faunas. Palaeogeographically, these faunas were all close to the south pole during the Middle Ordovician (Torsvik and Cocks, 2013) at middle–high palaeolatitudes. Cope (2002) summarized the relationship between various taxa of Ordovician bivalves and palaeolatitudes, and pointed out that the Heteroconchia may prefer higher latitudes, while the Pteriomorphia tends to be in lower latitudes. Nuculoids show similar distributions across the latitudes but at lower latitudes with greater diversity. Except for the AAP, the faunas in this group possess more Heteroconchia than Pteriomorphia (see fig. 9), indicating the high palaeolatitudinal preference of this group in Middle Ordovician (named this group HPL below). On the contrary, the more Pteriomorphia, and the higher diversity of nuculoids, suggests a lower palaeolatitudinal preference for the faunas of GZC and ABA (named these two faunas LPL below).

3. The SYC (Sanya in China) fauna is isolated from any other faunas in the PCA diagram, because the diversity of the genus *Modiolopsis*, totaling five species (including three species under open nomenclature), but only one or two in the other faunas. The systematic work on the SYC fauna was conducted many years ago, so a taxonomic revision is probably needed. So, the positions of SYC in the PCA and CA diagrams also need to be rearranged after the taxonomic revision. The SYC fauna may have an affinity with DLC (Dali in China) palaeobiogeographically, and both may belong to the Indo-China Palaeoplate during the Ordovician (Wang, 2016; Zhang et al., 2021).

4. The fauna DLC is dominated by the genera *Fasciculodonta*, *Glyptarca*, *Taselasmodum* and *Yunnanoredonia*, and is separated from the other faunas in the PCA diagram because of a number of new genera described by Fang and Cope (2004) and herein. Both the PCA and CA diagrams show the DLC fauna is closely related to the HPL group because of the shared taxa of *Redonia*, *Praeleda*, and *Glyptarca*. Additionally, Heteroconchia is also one of the major taxa in the DLC, indicating a high palaeolatitude similar to the HPL group. The same phenomenon was also noted by Fang and Cope (2008). However, on the other hand, the genus *Taselasmodum* was firstly reported from the lower Meitan Formation (lower Dapingian) in Weixin, northeastern Yunnan Province (Guo, 1985), which is stratigraphically much older than the Hsiangyang Formation (mostly the upper Middle Ordovician, i.e. Darriwilian), indicating that *Taselasmodum* was derived from South China and gradually migrated to the Indo-China Palaeoplate and diversified at Haidong, Dali, western Yunnan Province. The Indo-China Palaeoplate, therefore, might be the bridge that linked the bivalves of higher and lower palaeolatitudes between the HPL and LPL groups during the Middle Ordovician.

5. From this study, there is one new genus, and four new species (*Rhomboconcha tresdentes* n. gen. et n. sp., *Fasciculodonta curvata* n. sp., *Glyptarca symmetrica* n. sp., *Paracyclas initium* n. sp.)

recorded from the Hsiangyang Formation of Dali, western Yunnan Province, China. Three already known taxa (*Praeleda* sp., *Redonia deshayesi*, *Glyptarca* sp.) are documented in Dali and in Indo-China Palaeoplate for the first time herein. Together with those reported by Fang and Cope (2004), the bivalve fauna from the Hsiangyang Formation (Darriwilian) includes 18 genera and 22 species. Such a diverse and abundant bivalve fauna is not common in the Ordovician, probably indicating that Dali was a centre for bivalve radiation during the Middle Ordovician. According to the various studies (e.g., Babin, 1993a, b, 1995, 2000; Cope and Babin, 1999; Cope, 2004; Fang, 2006a, 2006b), the Ordovician bivalve radiation had two diversity acmes, one in Floian and another in Sandbian respectively. The radiation of the bivalves in Dali, western Yunnan Province, SW China (Indo-China Palaeoplate) was thought to be in Darriwilian (late Middle Ordovician), apparently lagging the main radiation peak of other benthos during the Early Ordovician.

5 Conclusions.

1. One new bivalve genus, four new species and three already-known taxa are documented for the first time from Dali, Yunnan Province, China and Indo-China Palaeoplate. According to the results of PCA and CA from analysis of eleven different Middle Ordovician bivalve faunas, three different faunal groups from different palaeolatitudes are recognized. GZC and ABA faunas are assigned to the LPL group indicating a lower palaeolatitude. COA, MWB, CPF, HMS, AAP, PBC and LAM faunas belong to the HPL group that was living at a higher palaeolatitude. And DLC fauna, i.e. the fauna documented herein does not belong to the LPL nor the HPL, but possesses some taxa in common, indicating that DLC is a mixed fauna or a transitional fauna. The Indo-China Palaeoplate served as a bridge between the LPL and HPL groups and probably was situated in the mid-high palaeolatitude during the Middle Ordovician.

2. It is proposed that, in the Early Ordovician, bivalves radiated around peri-Gondwana reaching their first diversity acme at the generic and species level in the Floian. Afterwards, some genera spread to the Indo-China Palaeoplate, which was close to Gondwana and the South China Palaeoplate. Owing to the changes in palaeogeography and palaeo-ocean currents, together with the unique environmental and geological settings of the Indo-China Palaeoplate during the Middle Ordovician, the bivalves experienced major peripatric speciation (Mayr, 1963, 1970, 1982, Fang, 1990), which facilitated the bivalve radiation on this palaeoplate. Such an explanation might reasonably account for the composition of the DLC fauna in which there are many new taxa as well as several others effectively related to other palaeoplates; the radiation also lagged the main acme of benthic faunas in the Floian that occurred in South China and on some other palaeoplates. Clearly, it is important to locate and describe the ancestors of those bivalves in Dali and investigate their sedimentary environments for further investigations on the macroevolution of bivalves in China.

Acknowledgements.

We express our sincere thanks to Luan Xiao-cong, Gong Fang-yi, Zhou Xiao-yuan and Kong De-xian for their help in the field, to the journal editors and reviewers for their beneficial and insightful comments and suggestions. Financial support is from the National Key Research and Development Program of China (2023YFF0803602), and the Ministry of Science and Technology (2021FY200102). This is also a contribution to the IGCP 735: Rocks and the rise of Ordovician life.

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Fig. 1. Location map of the study area. A. Map of China with the study area indicated by a grey rectangle. B. Enlarged view of the grey area in A showing the main transportation routes between Dali and surrounding cities. C. Close-up view of the study area.

Fig. 2. Lithological column of the Middle Ordovician Hsiangyang Formation and the stratigraphical range of the bivalves from Dali, western Yunnan. L. O.: Lower Ordovician, M. M.: Middle Member. U. M.: Upper Member. Legends: (1) Mudstone, (2) Argillaceous siltstone, (3) Siltstone, (4) Argillaceous sandstone, (5) Sandstone, (6) Limestone, (7) Conglomerate, (8) Collection levels.

Fig. 3. A, *Praeleda* sp. NIGP203569; internal mould, right valve. B–H. *Glyptarca symmetrica* n. sp. B, paratype, NIGP203571; internal mould, right valve. C, paratype, NIGP203576; internal mould, left valve. D, G, holotype, NIGP203572; internal mould (D) and its hinge view (G) shows the dentition, right valve. E, H, paratype, NIGP203578; internal mould (E) and its hinge view (H) shows the dentition, right valve. F, paratype, NIGP203573; internal mould, left valve. I–K. *Glyptarca* sp. I–J, NIGP203579; internal mould (I) and the enlarged view of hinge and dentition (J), left valve. K, NIGP203580; internal mould, deformed left valve.

Fig. 4. *Fasciculodonta curvata* n. sp. A, paratype, NIGP203581; internal mould, left valve. B, paratype, NIGP203618; internal mould, left valve. C, paratype, NIGP203586; internal mould, left valve. D, J, paratype, NIGP203589; internal mould (D) and the dentition (J, removing the umbo), left valve. E, paratype, NIGP203587; internal mould, left valve. F, paratype, NIGP203584; internal mould, right valve. G, paratype, NIGP203585; internal mould, right valve. H, K, paratype,

NIGP203583; internal mould (H) and the dentition (K), right valve. I, L, holotype, NIGP203591; internal mould (I) and its hinge view (L), right valve. Scale bars = 2 mm.

Fig. 5. Shell variation in *Fasciculodonta curvatum* n. sp. Type one, the sub-trigonal shell with contracted posterior margin; type two, the shell morphology between type one and type three; type three, sub-rectangular shell with a broader umbo and posterior umbonal ridge. Scale bar: 1 cm.

Fig. 6. A. *Glyptarca symmetrica* n. sp. paratype, NIGP203575; internal mould, left valve. B–K. *Redonia deshayesi* B, NIGP203602; internal mould, left valve. C, NIGP203604; internal mould, left valve. D, NIGP203597; internal mould, left valve, shows the possible pallial line. E, NIGP203599; internal mould, left valve. F, NIGP203601; internal mould, right valve. G, H, NIGP203596; internal mould (G) and its dentition (H), right valve. I, NIGP203595; internal mould, right valve. J, K, NIGP203592; internal mould (J) and its dentition (K), right valve. L–O. *Paracyclas initium* n. sp. L, holotype, NIGP203625; external mould, right valve. M, paratype, NIGP203624; internal mould, right mould. N, paratype, NIGP203623; internal mould, right valve. O, paratype, NIGP203626; internal mould, right valve.

Fig. 7. *Rhomboconcha tresdentes* n. gen. et n. sp. A, B, holotype, NIGP203627; internal mould (A) and its dentition (B), left valve. C, paratype, NIGP203622; internal mould, left valve, shows the concentric sculpture and probably pallial line. D, paratype, NIGP203611; internal mould, left valve. E, paratype, NIGP203612; internal mould, left valve. F, paratype, NIGP203616; internal mould, left valve. G, paratype, NIGP203615; internal mould, right valve. H, I, paratype, NIGP203607; internal mould (H), shows the posterior tooth, and its dentition (I), right valve.

Fig. 8. Numerical analyses diagrams of eleven Middle Ordovician bivalve faunas in the world, see the appendix for the details of faunas. PCA: Matrix: Variance-covariance, Groups: Disregard, Missing values: Mean value imputation, Bootstrap N = 10000. CA: Algorithm: Ward's method, Similarity index: Euclidean, Boot N = 10000, Cophen. Corr.: 0.7628. (**HMS**: Hesperian Massif, Spain; **LAM**: l'Anti-Atlas, Morocco; **AAP**: Águeda, Portugal; **CPF**: Finistère, France; **COA**: Cordillera Oriental, Argentina; **MWB**: mid Wales, UK; **PBC**: Prague Basin, Czech Republic; **DLC**: Dali, China; **SYC**: Sanya, China; **GZC**: Guangzhou, China; **ABA**: Amadeus Basin, Australia.

Fig. 9. Pie diagram of the faunal composition and diversity of eleven bivalve faunas during the Middle Ordovician, for the detailed composition see appendix.

Appendix.

1. **Dali, China; the Hsiangyang Formation, Darriwilian.** *Similodonta* sp., *Phestia* sp., *Biseriodonta simplex*, *Praeleda* sp., *Glyptarca sinensis*, *G. symmetrica* n. sp., *G.* sp., *Trigonoglyptarca magna*, *Erhaiconcha xiangyangensis*, *Fasciculodonta impressa*, *F. fengyiensis*, *F. curvata* n. sp., *Taselasmodum decussatum*, *Redonia deshayesi*, *Yunnanoredonia laevis*, *Paracyclas initium* n. sp., *Daliella daliensis*, *Goniophorina (Goniophorina) contracta*, *Modiolopsis* sp., *Rhomboconcha tresdentes* n. gen. et. n. sp., *Haidongoconcha radialis*, *Eopterinea aequiconcha*. (18 genera, 22 species, this paper; Fang and Cope, 2004).

2. **Yaxian (Sanya), China; the Jianling Formation, Middle Ordovician.** *Ctenodonta* sp., *Tancrediopsis* cf. *dulankarensis*, *Similodonta similis*, *Psiloconcha* cf. *minima*, *Modiolopsis difficilis*, *M.* sp. A, *M.* sp. B, *M.* sp. C, *M. hinomotoensis*, *Paraphtonia cardiformis*, *P.* sp., *Cymatonota*

houghuaensis, *Cycloconcha*? *subovata*. (8 genera, 13 species, Liu, 1979).

3. **Guangzhou, China; the Dongchong Formation, Dapingian to Darriwilian.** *Praenucula* cf. *sharpei*, *P.* sp., *Homilodonta regularis*, *Similodonta similis*, *S.* cf. *cerys*, *S.* sp., *Trigonoconcha acuta*, *Concavodonta* sp., *Arcodonta* sp., *Sthenodonta* cf. *eastii*, *S.* sp., *Nuculites* cf. *cylindricus*, *N.* sp., *Phestia* sp., *Cardiolaria*? sp., *Inaequidens* cf. *davisi*, *I.* sp., *Mytilarca*? sp., *Cyrtodonta* sp., *Modiolopsis* spp., *Carminodonta* sp., *Famatinodonta* sp., *Yunannia gankengensis*, *Y. yunkaiensis*, *Yuexiconcha duplicata*. (18 genera, 25 species, Niu et al., 2018; Zhang et al., 2020; Niu et al., 2023).

4. **Amadeus Basin, Australia; the Stairway Sandstone, Darriwilian.** *Nuculites wattii*, *Ctenodonta*? sp., *Johnmartinia cordata*, *Sthenodonta eastii*, *S. paensymmetrica*, *S.* sp. A, *S.* sp. B, *S.* spp., *Cyrtodonta carberryi*, *C. staffordae*, *C.* sp. B, *C.* spp., *Modiolopsis pojetai*, *Colpantyx*? sp., *Sphenosolen draperi*. (8 genera, 15 species, Jakobsen et al., 2016).

5. **Hesperian Massif, Spain; the 'Tristani Beds', upper Darriwilian.** *Ctenodonta* cf. *escosurae*, *Praenucula costae*, *P. sharpei*, *Cardiolaria beirensis*, *Ekaterodonta hesperica*, *Myolusia bilunata perdentata*, *Cadomia britannica*, *Goniophora (Cosmogoniophora)* sp., *Modiolopsis*? *elegantulus*, *Cyrtodontula* sp., *Glyptarca*? *lusitanica*, *Ananterodonta oretanica*, *Babinka prima*, *Coxiconcha britannica*, *Redonia deshayesi*, *Dulcineaia manchega*. (15 genera, 16 species, Babin and Gutiérrez-Marco, 1991).

6. **Águeda, Protugal; the 'Cabril Formation', upper Darriwilan to lower Sandbian.** *Praenucula* sp., *Cardiolaria* cf. *beirensis*, *Praeleda* cf. *ribeiroi*, *Hemiprionodonta* cf. *lusitanica*, *Myoplusia*? sp., *Tancrediopsis escosurae*. (6 genera, 6 species, Pereira et al., 2021).

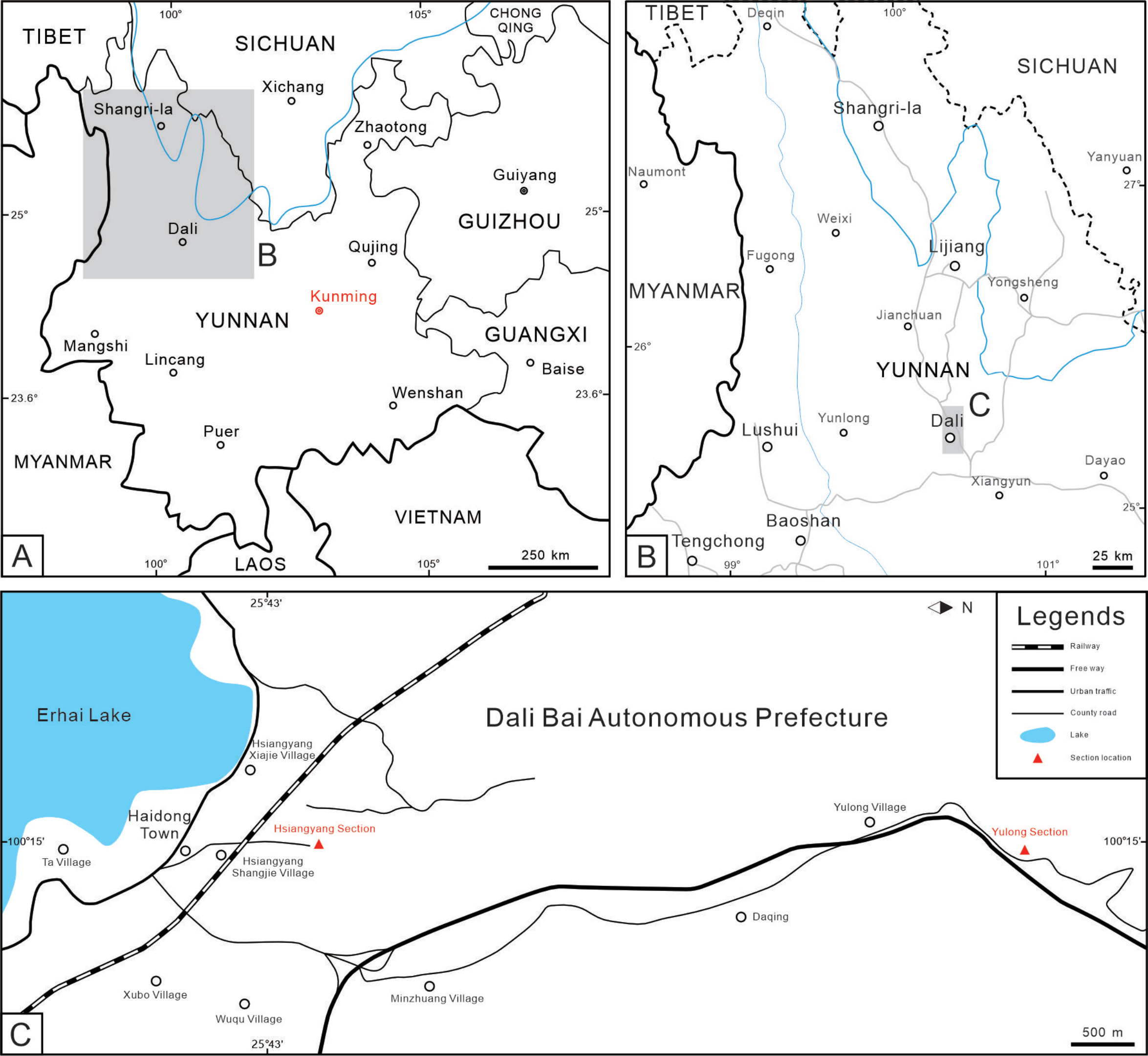
7. **Cordillera Oriental, Argentina; the Alto del Cóndor Formation, upper Dapingian to lower Darriwilan.** *Cadomia* sp., *Modiolopsis* sp., *Palaeoconcha* sp., *Redonia condorensis*, *Pseudoredonia radialis*, *Pucamya wira*, *Konduria coloradoensis*. (7 genera, 7 species, Sánchez and Babin, 1994; Sánchez, 2007).

8. **Prague Basin, Czech Republic; the Šárka Formation, lower to middle Darriwilian.** *Praenucula dispar*, *P. bohemica*, *P. applanans*, *Concavodonta ponderata*, *Pseudocyrtodonta ala*, *P. incola*, *Tatula petula*, *Redonia deshayesi*, *Modiolopsis* sp., *Cyrtodonta* sp., *Babinka prima*, *Coxiconcha britannica*. (9 genera, 12 species, Polechová, 2013).

9. **Mid Wales, Britain; lower part of *Digymograptus murchisoni* Biozone, Darriwilian.** *Tancrediopsis* sp., *Arcodonta regularis*, *Similodonta ceryx*, *S.* sp., *Praeleda subtilis*, *P. multidentata*, *Eritropis peregrinata*, *Lyrodesma* cf. *secure*, *Redonia anglica*, *Babinka prima*, *Glyptarca radnorensis*, *Camnantia ampla*, *Modiolodon ellesae*. (11genera, 13 species, Cope, 1999).

10. **Finistère, France; Middle Ordovician.** *Cardiolaria beirensis*, *Tancrediopsis ezquerrae*, *Praeleda ciae*, *P. costae*, *Actiondonta naranjoana*, *Redonia deshayesi*, *Ctenodonta ribeiroi*, *C. britannica*. (6 genera, 8 species, Babin, 1966; Bradshaw, 1970).

11. **l'Anti-Atlas, Morocco; Darriwilian.** *Redonia deshayesi*, *R.* sp., *Ctenodonta escosurae*, *Praenucula* cf. *sharpei*, *Coxiconcha* sp., *Cardiolaria beirensis*, *C. beirensis*, *Cyrtodotula*? sp., *Glyptarca*? *lusitanica*. (7 genera, 9 species, Babin and Descombes, 1990).



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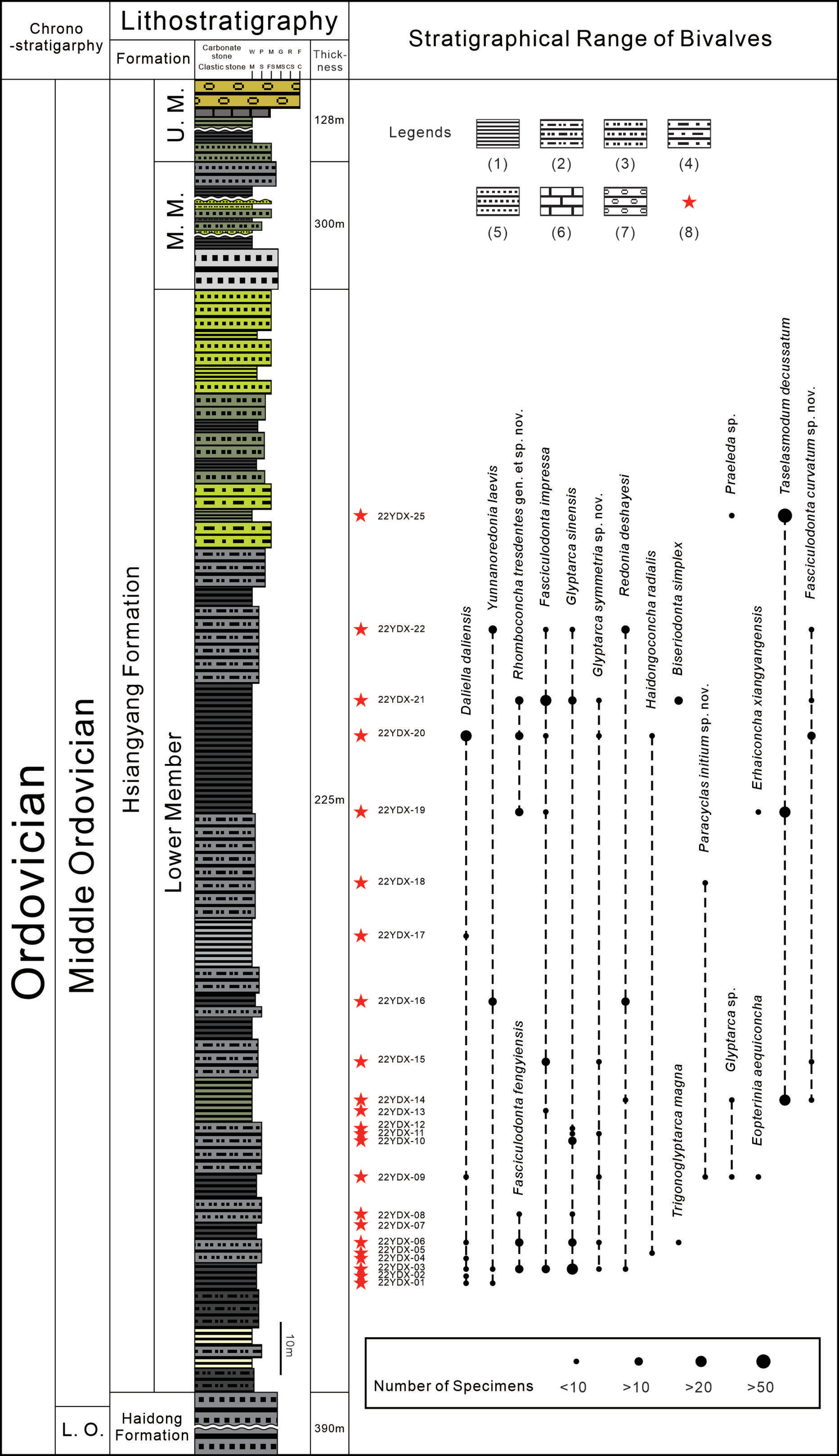

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Hsiangyang Formation
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Fasciculodonta fengyiensis
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Glyptarca symmetria sp. nov.
Redonia deshayesi
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Paracyclas initium sp. nov.
Praeleda sp.
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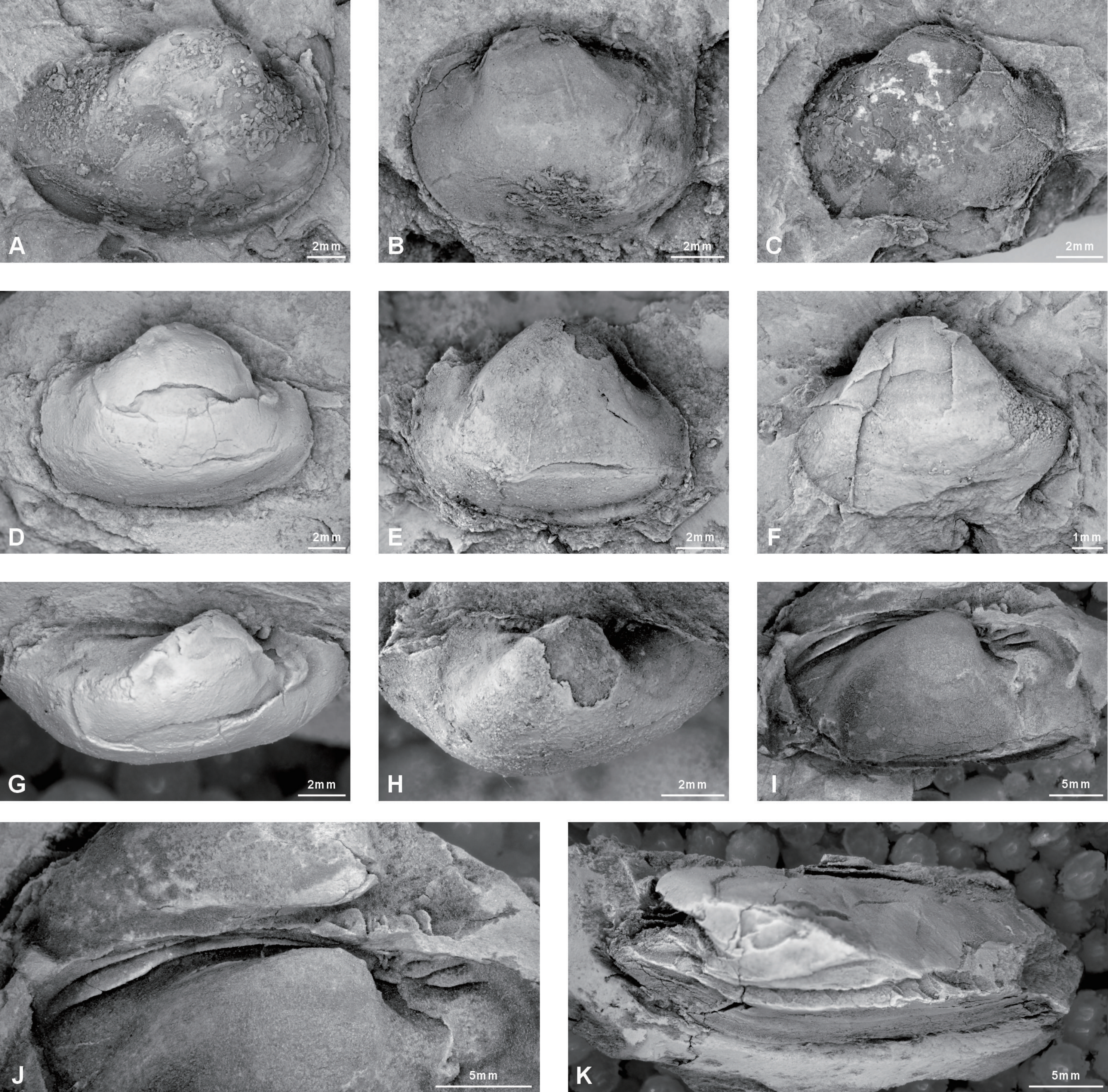
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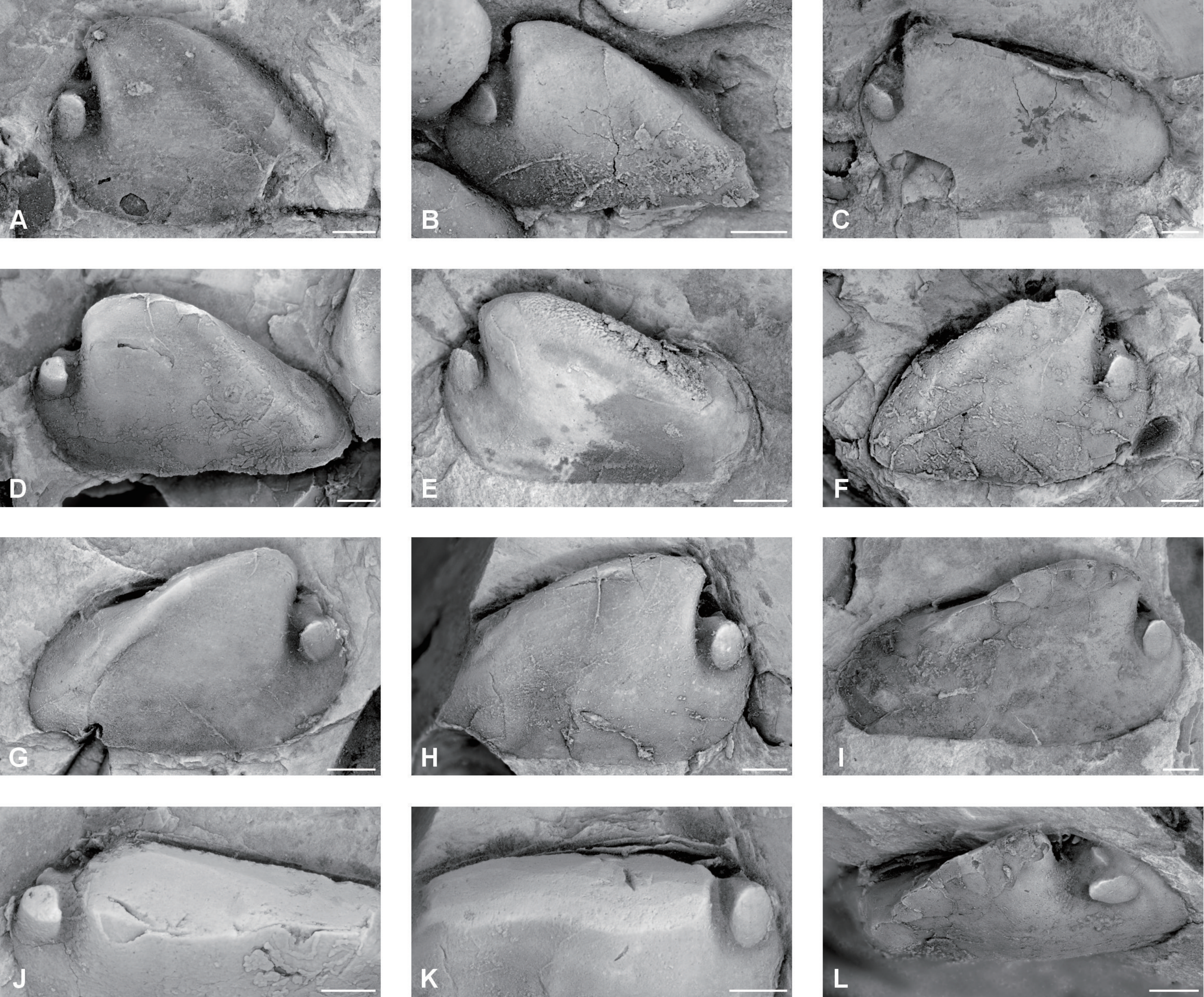
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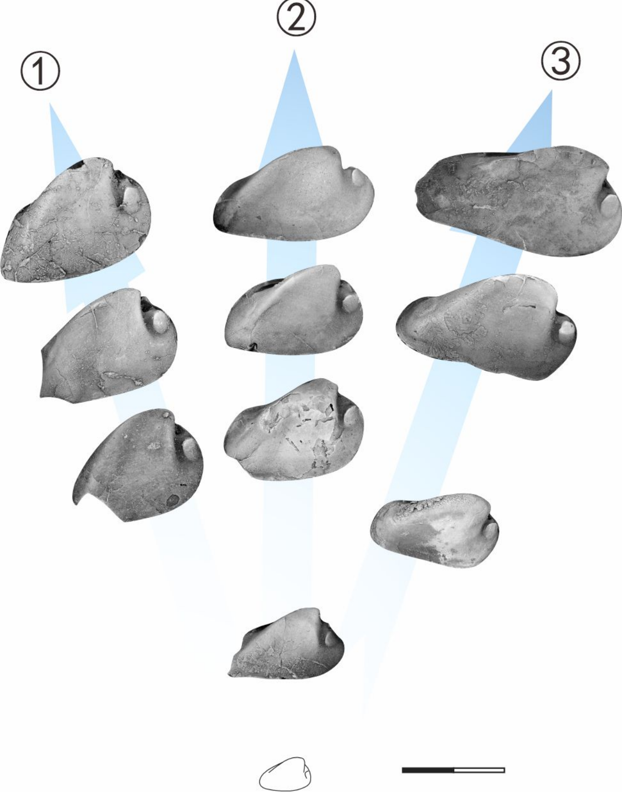
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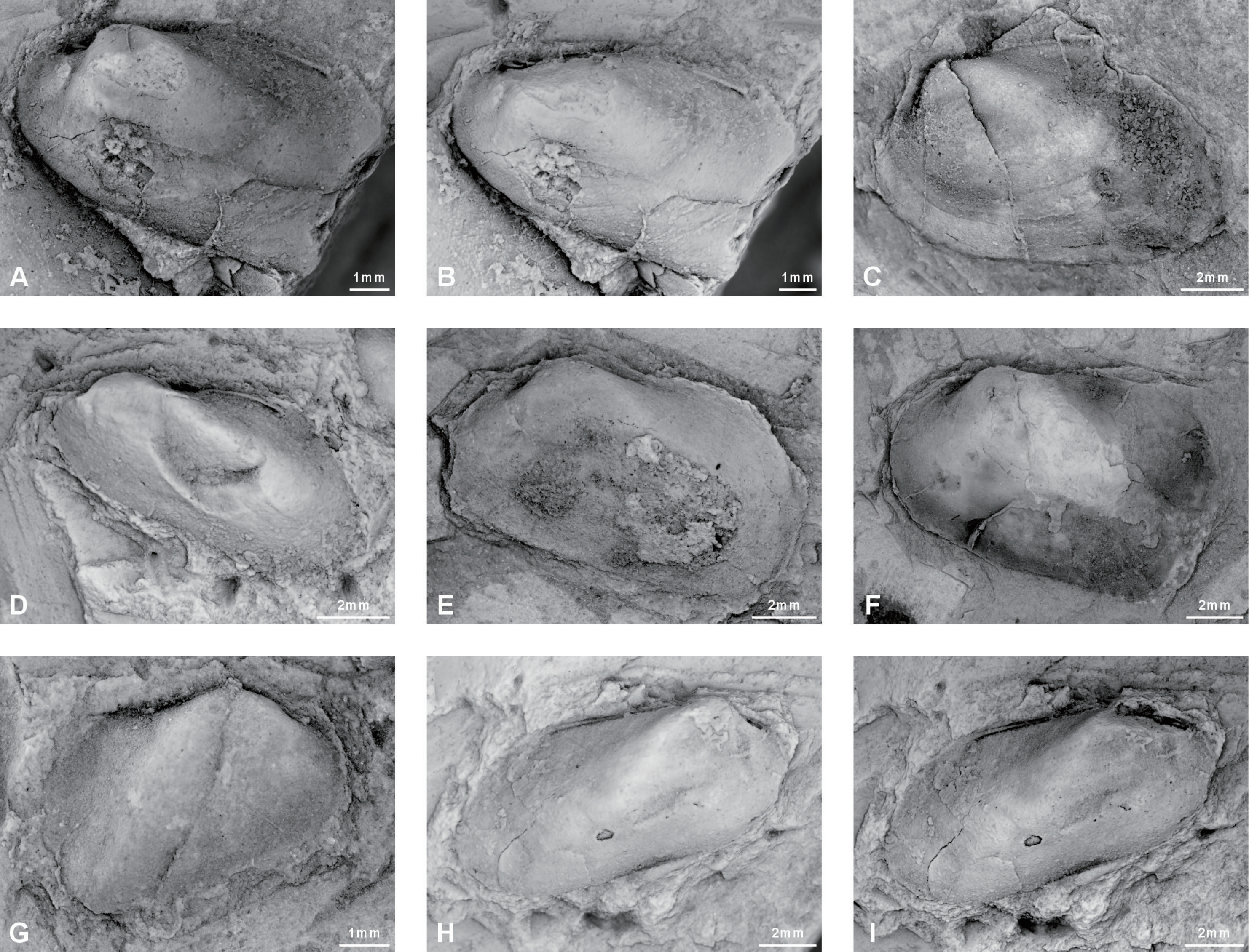
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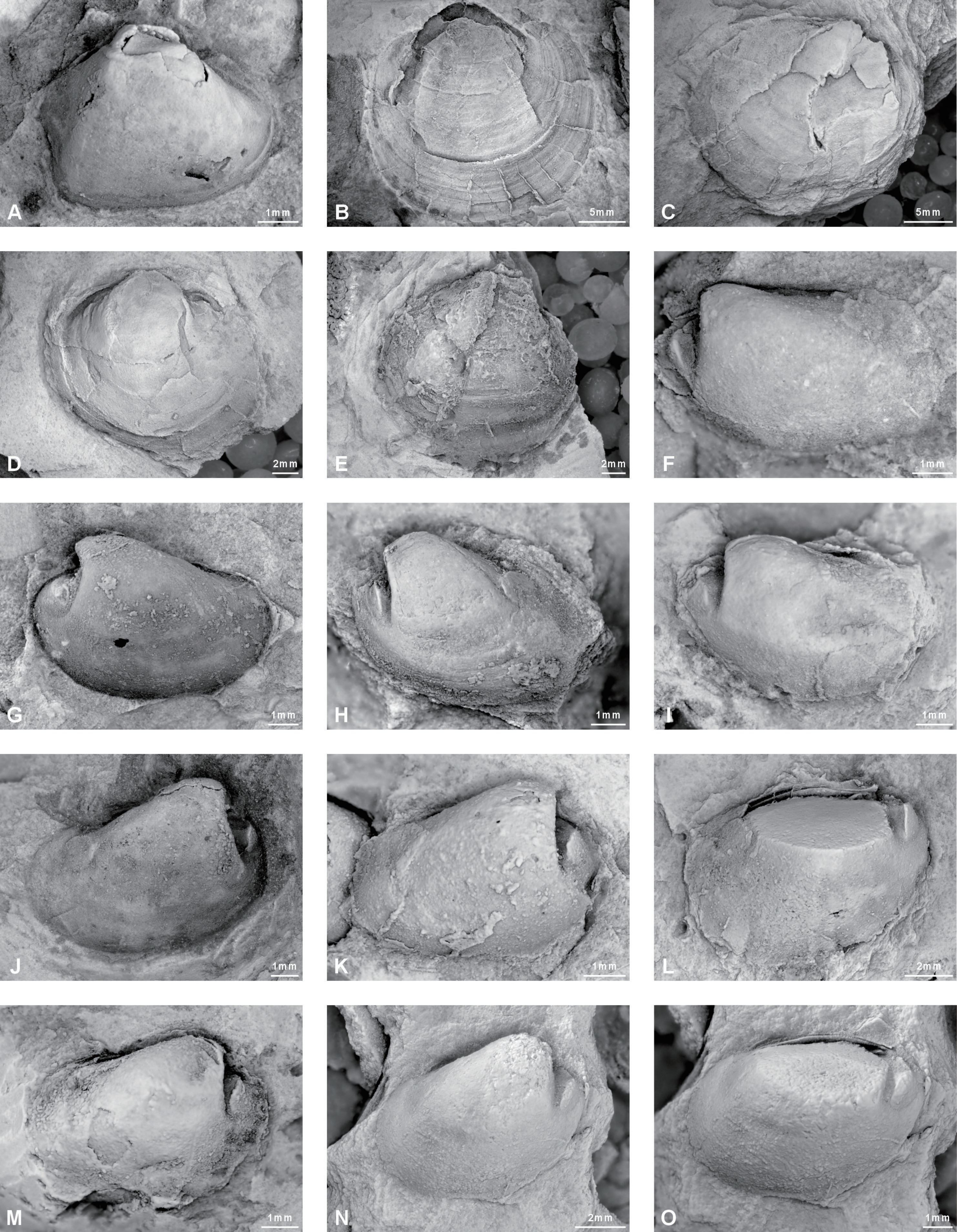
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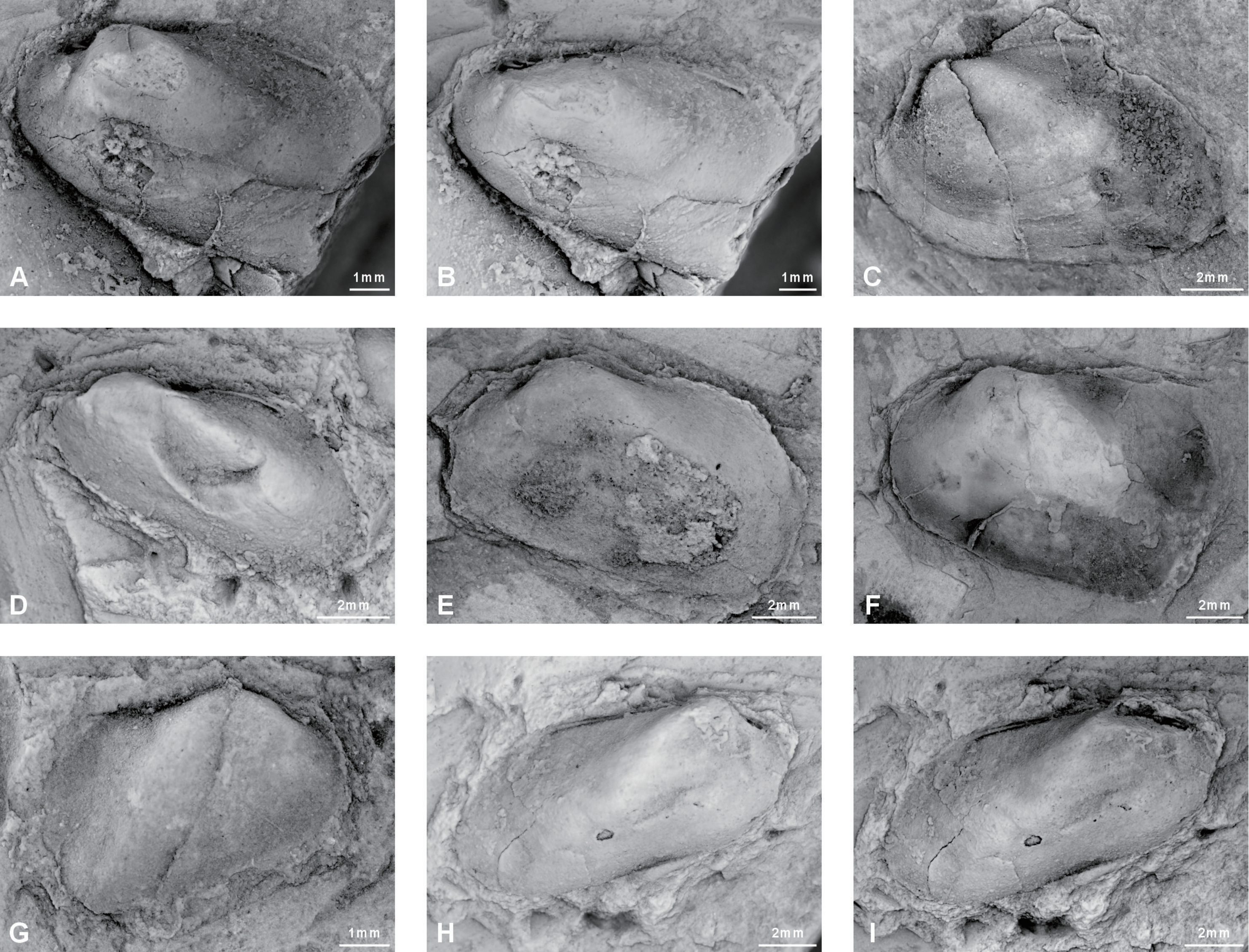
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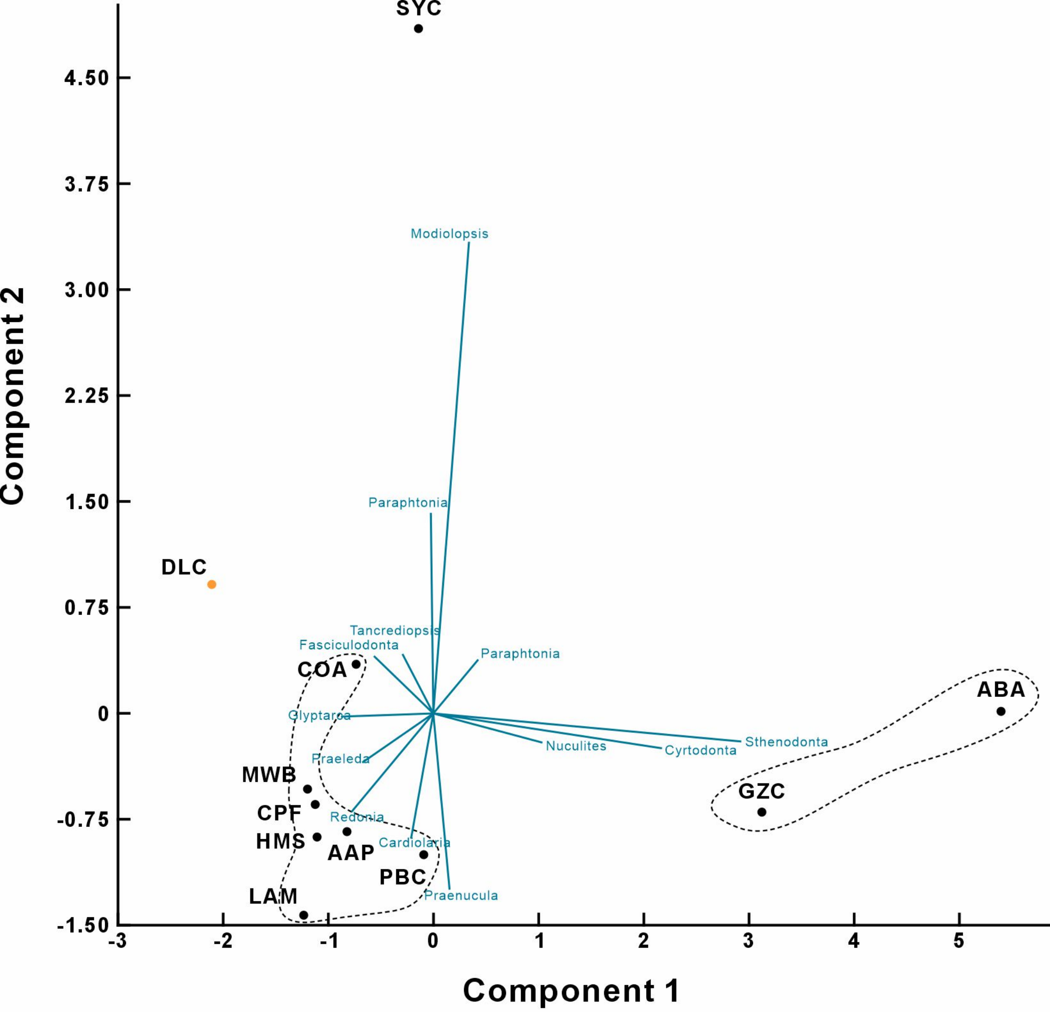

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Paraphtonia
Glyptarca
Praeleda
Redonia
Cardiolaria
Praenucula
Nuculites
Cyrtodonta
Sthenodonta
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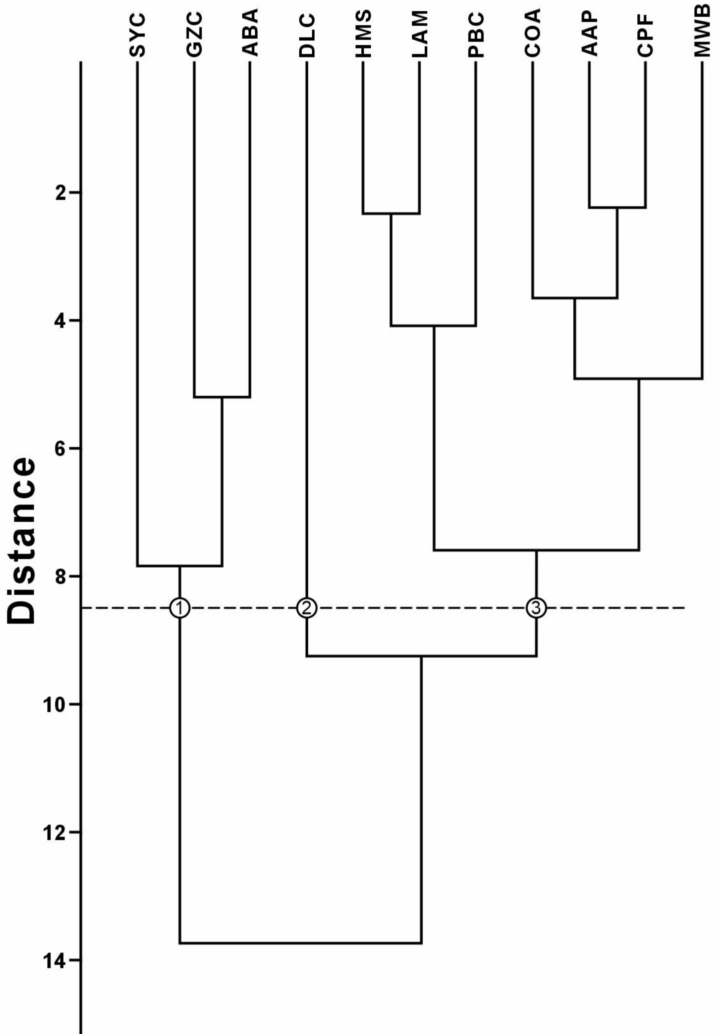
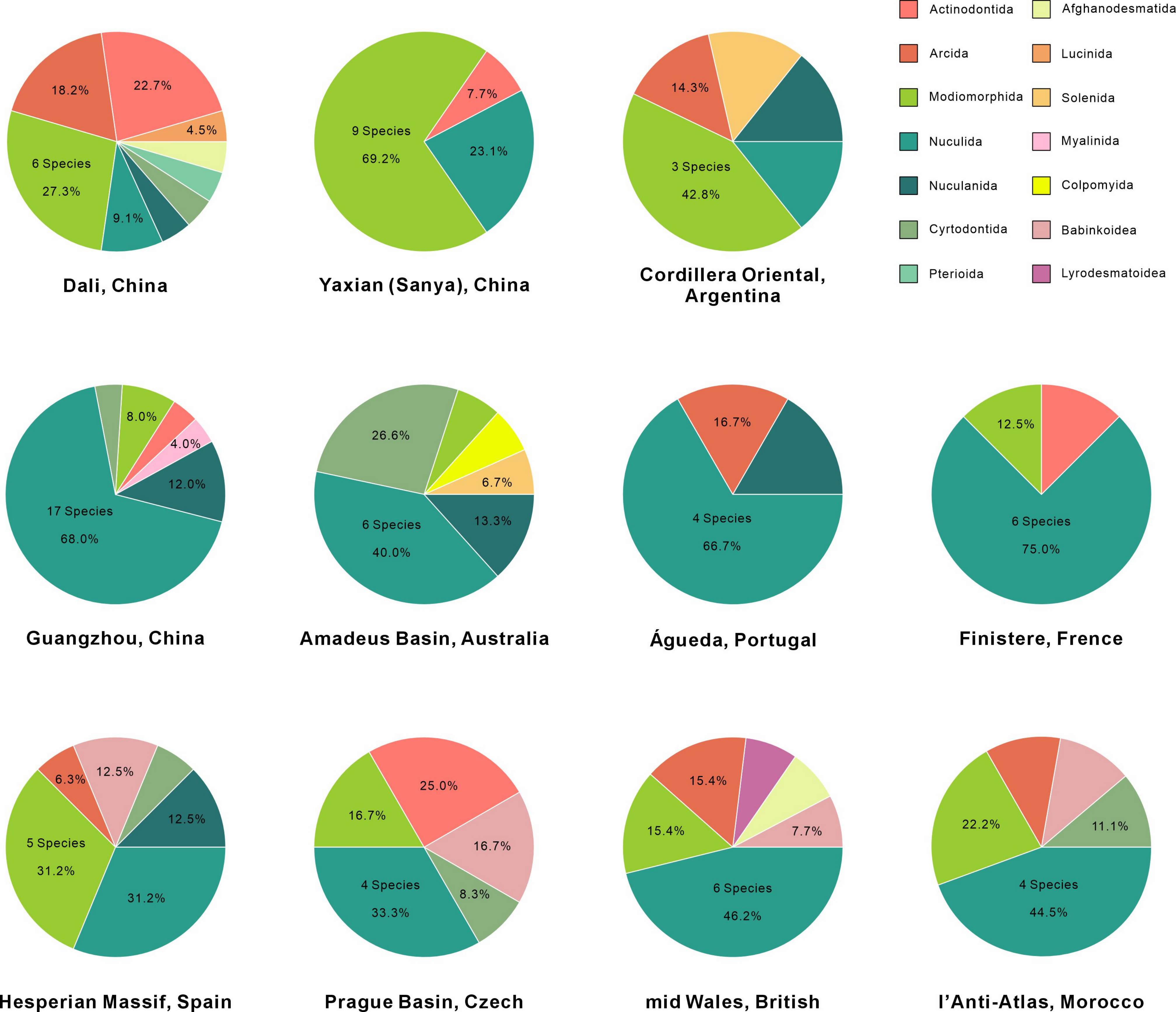
Component 2
Component 1



SYC
GZC
ABA
DLC
HMS
LAM
PBC
COA
AAP
CPF
MWB
2
4
6
8
10
12
14
Distance
1
2
3


Actinodontida
Afghanodesmatida
Arcida
Lucinida
Modiomorphida
Solenida
Nuculida
Myalinida
Nuculanida
Colpomyida
Cyrtodontida
Babinkoidea
Pterioida
Lyrodesmatoidea
22.7%
18.2%
4.5%
6 Species
27.3%
9.1%
Dali, China
7.7%
9 Species
69.2%
23.1%
Yaxian (Sanya), China
14.3%
3 Species
42.8%
Cordillera Oriental, Argentina
8.0%
4.0%
12.0%
17 Species
68.0%
Guangzhou, China
26.6%
6.7%
6 Species
40.0%
13.3%
Amadeus Basin, Australia
16.7%
4 Species
66.7%
Águeda, Portugal
12.5%
6 Species
75.0%
Finistere, Frence
6.3%
12.5%
12.5%
5 Species
31.2%
31.2%
Hesperian Massif, Spain
25.0%
16.7%
16.7%
4 Species
33.3%
8.3%
Prague Basin, Czech
15.4%
15.4%
7.7%
6 Species
46.2%
mid Wales, British
22.2%
11.1%
4 Species
44.5%
l'Anti-Atlas, Morocco