A New Genus of the Corythoecidae (Paleozoic Radiolaria) from the Changhsingian (Uppermost Permian) Dalong Formation in Southern Guizhou, South China

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A new genus of the Corythoecidae (Paleozoic Radiolaria) from the Changhsingian (uppermost Permian) Dalong Formation in southern Guizhou, South China

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Abstract. **A new genus of the Corythoecidae (Albaillellaria, Radiolaria) was recovered from the Changhsingian (uppermost Permian) Dalong Formation in Guizhou Province, South China. *Qiania* Ito and Feng, gen. nov., containing *Q. foremanae* Ito and Feng, gen. et sp. nov. and *Q. uncinata* (Rudenko and Panasenko), is characterized by a conical shell consisting of an apical portion and an inflated region with a lateral foramen on the ventral side. The Corythoecidae were thought to range from the Late Devonian to Guadalupian (middle Permian). Therefore, this new find suggests the presence of this family until the latest Permian. Compilation of previous occurrences of corythoecids, in addition to those of *Qiania*, showed that most corythoecids including *Qiania* occurred in phosphate-rich facies, and that *Qiania* occurred in deeper facies than other corythoecids.**

Key words: Changhsingian, Corythoecidae, Dalong Formation, Paleozoic radiolaria, *Qiania*, South China

Introduction

The family Corythoecidae Nazarov in Nazarov and Rudenko, 1981, characterized by a bilaterally symmetrical shell with a lateral foramen, has long been known as having an anomalous morphology and occurring rarely worldwide. This family was thought to be a taxon ranging from the Late Devonian to the early Permian (De Wever *et al.*, 2001, p. 95–96). The range of this family was recently further extended to the Capitanian (middle Permian) based on the newly described *Camptoalatus volaticus* Maldonado and Noble from the Reef Trail Member of the Bell Canyon Formation, Texas (Maldonado and Noble, 2010).

We obtained a few specimens of *Qiania* Ito and Feng, gen. nov. from the Changhsingian (uppermost Permian) Dalong Formation of the Duanshan section in Duanshan Town of Huishui County, Guizhou Province, South China. Because this new genus is considered to belong to the Corythoecidae, it represents the first reported example of this family from South China. Additionally, previously reported specimens of the Corythoecidae from the Changhsingian in the Russian Far East (Rudenko and Panasenko, 1990) and Southwest Japan (Kuwahara and Yao, 1998; Takemura *et al.*, 2009) are thought to belong to *Qiania*. Although *Qiania* is sparsely found in China, the Russian Far East, and Japan, this indicates existence of the Corythoecidae until the latest Permian. Furthermore, we compiled previous occurrences of corythoecids and *Qiania*. This article describes this new genus and discusses some implications of the distribution of *Qiania* and Corythoecidae.

Material and methods

Permian marine strata are widely exposed in South China. The global stratotype for the Lopingian Series (upper Permian) has been defined based on the sequence in that region (Gradstein *et al.*, 2012). The Dalong Formation is characterized by siliceous and muddy rocks corresponding to the Changhsingian stage of the Lopingian (Yang *et al*., 1987; Feng *et al.*, 1990; Feng *et al.*, 2007). Several types of fossil such as radiolaria, conodonts, ammonoids, and bivalves occur in the Dalong Formation (Yang *et al.*, 1987; Feng *et al.*, 2007; Wu and Feng, 2008).

In this study, we investigated the Duanshan section (25°83′350″N, 106°58′047″E), which crops out as a roadside cliff in Goutou Village, *ca.* 5 km northwest of

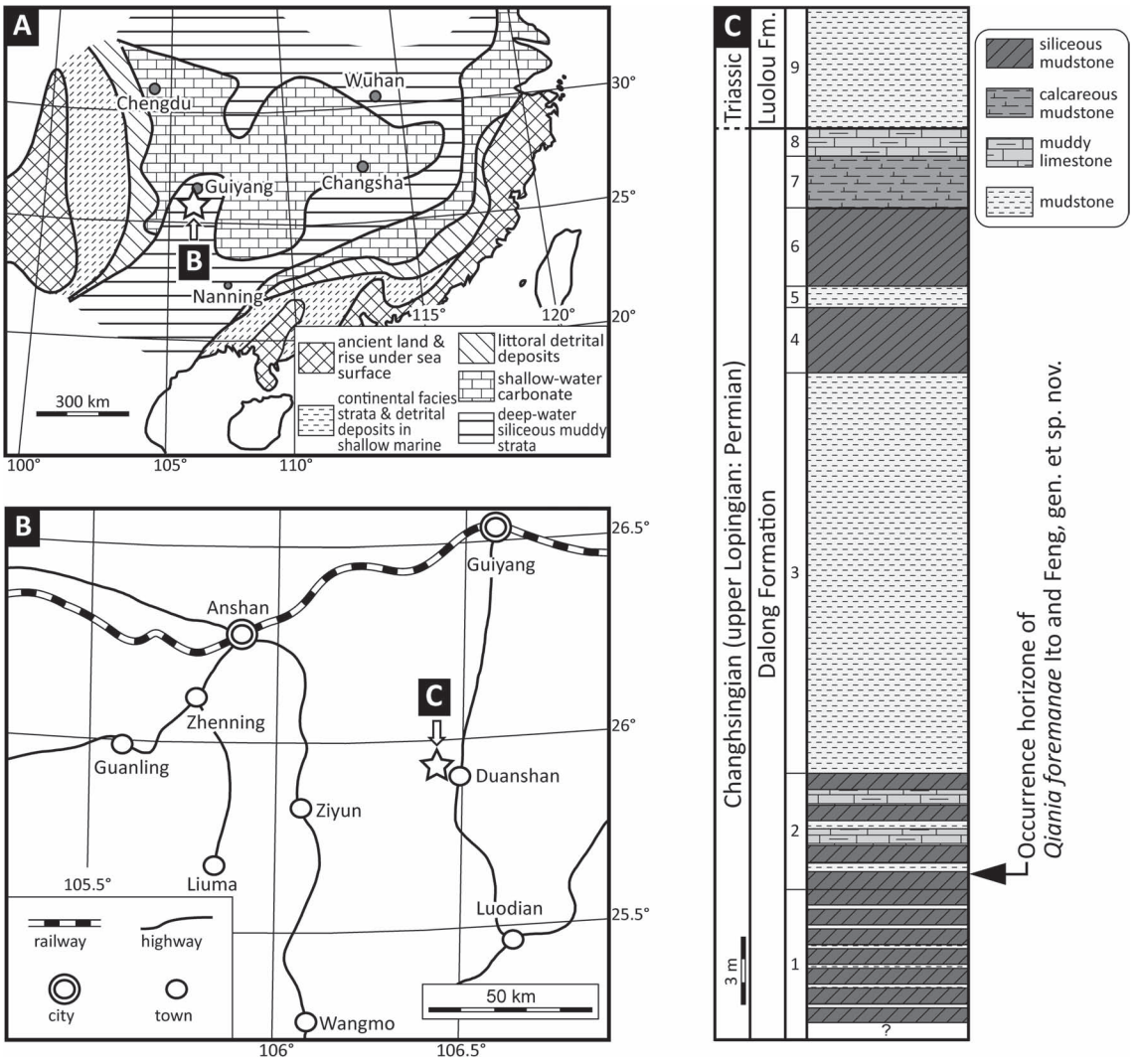

Figure 1. Index map of the Duanshan section. **A,** geologic map of South China (after Feng *et al.*, 2007); **B,** index map of southwest Guizhou Province showing the locality of the studied Duanshan section; **C,** columnar section of the studied Duanshan strata.

Duanshan Town and *ca.* 90 km south of Guiyang City, Guizhou Province, South China (Figure 1A, B). The section is *ca.* 50 m in total thickness and comprises the Dalong and conformably overlying Luolou formations. The lower limit of the Dalong Formation is not exposed. The section is divided into nine subsections according to the lithostratigraphic characteristics (Figure 1C). The Dalong Formation in this section (subsections 1–8) consists mainly of gray or greenish-gray bedded siliceous mudstones and gray or dark gray mudstones.

One of the authors (Y. Ai) collected 88 samples of siliceous rock from the Dalong Formation in the Duanshan section and extracted radiolarian fossils from them using the following method. Each sample weighed *ca.* 100 g. After being crushed into pieces a few centimeters in size, the collected samples were soaked in a diluted hydrofluoric acid (HF) solution (4%) for about 12 hours. The waste HF solution was then removed and the residue including radiolarian tests was collected. After repeating the process for two weeks, the collected residues were sieved (20 and 300 meshes) and oven-dried. The dried residues were distributed on a glass tray, and radiolarian fossils were picked out under a binocular microscope. The picked radiolarian fossils were mounted on copper stubs. These specimens on the stubs were photographed with a scanning electron microscope (SEM). In total, over 2,000 specimens were photographed. Three specimens of *Qiania foremanae* Ito and Feng, gen. et sp. nov. described here were obtained from one horizon (2-2) of a siliceous mudstone bed of subsection 2 of the Duanshan section.

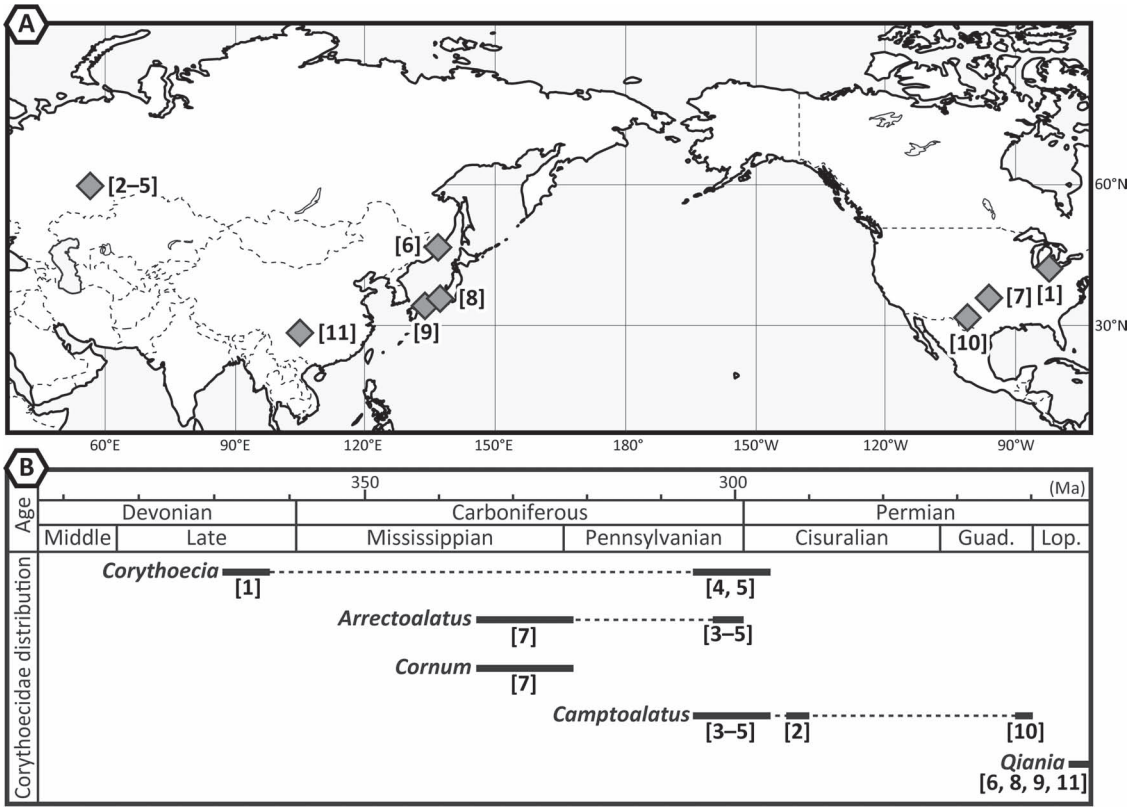

Figure 2. Occurrence sites (**A**) and age distributions (**B**) of the family Corythoecidae. Ages are after Gradstein *et al.* (2012). Numbers in square brackets correspond to the following references: 1, Foreman (1963); 2, Nazarov and Rudenko (1981); 3, Nazarov and Ormiston (1985); 4, Isakova and Nazarov (1986); 5, Nazarov (1988); 6, Rudenko and Panasenko (1990); 7, Schwartzapfel and Holdsworth (1996); 8, Kuwahara and Yao (1998); 9, Takemura *et al.* (2009); 10, Maldonado and Noble (2010); 11, this study. Guad., Guadalupian; Lop., Lopingian.

Systematic paleontology

Repository.—The specimens used in this study are deposited in the Geological Museum of China University of Geosciences, Wuhan, the People's Republic of China.

Order Albaillellaria Deflandre, 1953, emend.
Holdsworth, 1969
Family Corythoecidae Nazarov, 1981 in Nazarov and Rudenko, 1981, emend.
Schwartzapfel and Holdsworth, 1996

Type genus.—*Corythoecia* Foreman, 1963.

Occurrence.—Upper Devonian to Lopingian: U.S.A., Russia, Japan, and China (Figure 2, Table 1). Bian *et al.* (2004) reported *Camptoalatus* cf. *benignus* and *Camptoalatus* sp. from Mississippian?–Cisuralian? cherts in Buqingshan ophiolites, North Qinghai-Tibet Plateau, China. Saesaengseerung *et al.* (2009) reported *Arrectoalatus*? sp. from the Cisuralian in eastern Thailand. However, the illustrated specimens have unclear foramina, so these occurrences are not included in the figure and table of this article.

Genus ***Qiania*** Ito and Feng, gen. nov.

Type species.—*Qiania foremanae* Ito and Feng, gen. et sp. nov.

Diagnosis.—Corythoecidae with an imperforate conical shell consisting of an apical portion and an inflated region with a lateral foramen on the ventral side of the shell.

Description.—The conical shell is slightly curved to the ventral side, imperforate, and bilaterally symmetrical. The shell is composed of two parts: an apical portion and an inflated region. The apical portion is undulating. The lower part is globular without undulation or with very weak undulation. A lateral foramen is present on the ventral side.

Etymology.—From Qian (abbreviated name of Guizhou Province in Chinese), where the type locality is located. Feminine.

Table 1. List of genera and species of the family Corythoecidae.

Genus	Species	Age	Reference
Corythoecia Foreman	*C. dichoptera* Foreman	middle Famennian*	Foreman (1963)
	C. cf. *dichoptera* Foreman	Gzhelian**	Isakova and Nazarov (1986)
	C. loxosegmentata Nazarov	late Gzhelian–early Asselian**	Isakova and Nazarov (1986); Nazarov (1988)
Camptoalatus Nazarov and Rudenko	*C. monopterygius* Nazarov and Rudenko	late Sakmarian	Nazarov and Rudenko (1981); Nazarov (1988)
	C. aretinus Nazarov	late Gzhelian**	Nazarov and Ormiston (1985); Isakova and Nazarov (1986)
	C. benignus Nazarov and Ormiston	Gzhelian–early Asselian**	Nazarov and Ormiston (1985); Isakova and Nazarov (1986); Nazarov (1988)
	C. volaticus Maldonado and Noble	late Capitanian	Maldonado and Noble (2010)
Arrectoalatus Nazarov and Ormiston	*A. cernuus* Nazarov and Ormiston	middle Chesterian (Late Mississippian)–early Namurian (Early Pennsylvanian); late Gzhelian**	Nazarov and Ormiston (1985); Isakova and Nazarov (1986); Nazarov (1988); Schwartzapfel and Holdsworth (1996)
	A. eximus Nazarov	late Gzhelian**	Isakova and Nazarov (1986)
	A. bicorniger Nazarov	late Gzhelian**	Isakova and Nazarov (1986)
	Arrectoalatus? sp.	late Gzhelian**	Nazarov (1988)
Cornum Schwartzapfel and Holdsworth	*C. mittereri* Schwartzapfel and Holdsworth	middle Chesterian–early Namurian	Schwartzapfel and Holdsworth (1996)
	C. mullerae Schwartzapfel and Holdsworth	middle Chesterian–early Namurian	Schwartzapfel and Holdsworth (1996)
	C. repetskii Schwartzapfel and Holdsworth	middle Chesterian–early Namurian	Schwartzapfel and Holdsworth (1996)
	Cornum sp.	middle Chesterian–early Namurian	Schwartzapfel and Holdsworth (1996)
Qiania Ito and Feng, gen. nov.	*Q. uncinata* (Rudenko and Panasenko)	Changhsingian	Rudenko and Panasenko (1990); Kuwahara and Yao (1998); Takemura *et al.* (2009)
	Q. foremanae Ito and Feng, gen. et sp. nov.	Changhsingian	This study

Footnote: * based on Maletz (2011); ** based on Nazarov and Ormiston (1993).

Occurrences.—Changhsingian (upper Lopingian); South China, Southwest Japan, the Russian Far East.

Remarks.—*Qiania* has a conical and bilaterally symmetrical shell with a lateral foramen, which is an important characteristic of the Corythoecidae (Schwartzapfel and Holdsworth, 1996). *Qiania* differs from *Arrectoalatus* and *Camptoalatus* in having an imperforate shell. *Qiania* resembles *Cornum* in possessing an imperforate shell and similar outline of the shell. However, *Qiania* has an inflated region of the shell and a lateral foramen on the ventral side, whereas *Cornum* has no inflated region and has a lateral foramen on the dorsal side. *Qiania* differs from *Corythoecia* in having an undulating or weakly undulating apical portion of the shell.

Qiania foremanae Ito and Feng, gen. et sp. nov.

Figure 3

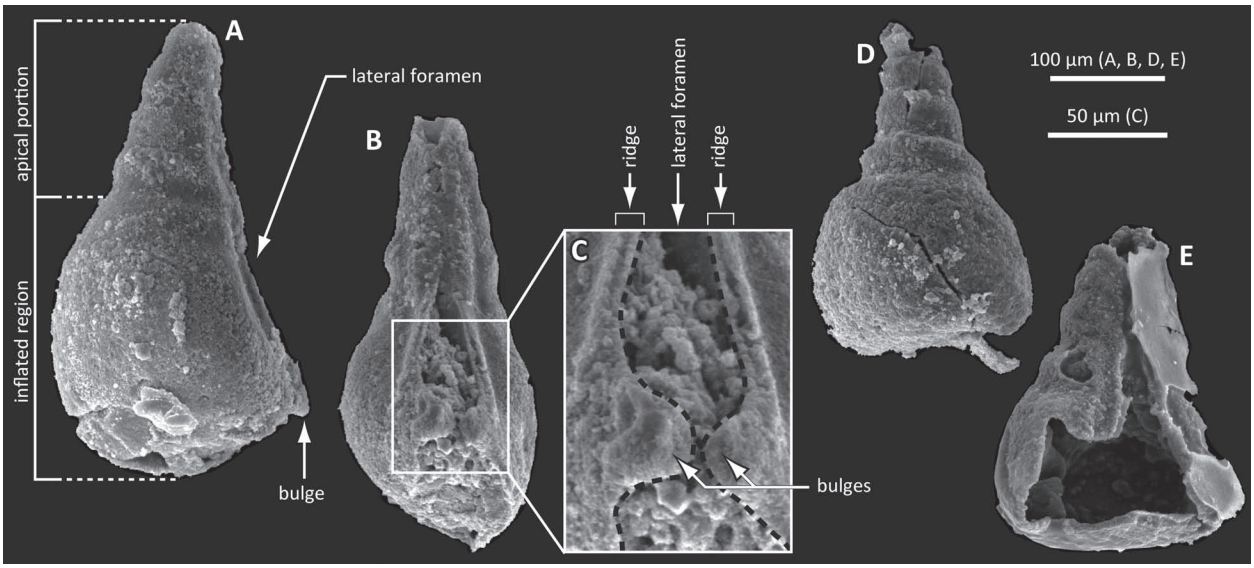

Figure 3. SEM images of *Qiania foremanae* Ito and Feng, gen. et sp. nov. from the Dalong Formation in the Duanshan section. **A–C,** DS2-2/101 (holotype); A, lateral view; B, ventral view; C, enlarged view of the ventral side; **D,** DS2-2/102 (paratype), dorsal view; **E,** DS2-2/103 (paratype), ventral view.

Diagnosis.—*Qiania* having a weakly undulating apical portion and a globular inflated region.

Description.—The conical shell is slightly curved to the ventral side, imperforate, and bilaterally symmetrical. The shell consists of two parts: an apical portion and an inflated region (Figure 3A). The apical portion is one-third or one-half of the shell in length. The apical portion is weakly undulating. Three to four obliquely transverse constrictions are observed on the surface (Figure 3A, D). The inflated region is globular without undulation. The base of the inflated region is hemispherical with an aperture (Figure 3A) or is flattened and closed (Figure 3E). A lateral foramen is developed throughout the ventral side of the shell (Figure 3B, E). This structure is composed of two parallel longitudinal ridges with a deep groove on the apical portion of the shell (Figure 3C). This deep groove widens to form the foramen on the final globular part of the shell (Figure 3C). Apparent wings cannot be observed in our material; however, a couple of small bulges are recognized in the inflated region (Figure 3C).

Etymology.—This species is named after the late H. P. Foreman in honor of her description of *Corythoecia* in 1963, which was subsequently established as the type genus of the Corythoecidae.

Type.—Holotype: Figure 3A–C, depositional number X0307-1 of the Geological Museum, China University of Geosciences, Wuhan. Paratype: Figure 3D, depositional number X0307-2; Figure 3E, depositional number X0307-3.

Measurements (µm).—Shell height 99–118; shell width 69; width of the foramen 14.

Material examined.—Three specimens were examined by SEM and illustrated.

Occurrence.—Changhsingian: siliceous mudstone bed of the Dalong Formation in the Duanshan section, Guizhou Province, South China.

Qiania uncinata (Rudenko and Panasenko, 1990) *sensu* emend. herein

Arrectoalatus? *uncinatus* Rudenko and Panasenko, 1990, pl. 11, figs. 1–3; Kuwahara and Yao, 1998, pl. 2, fig. 42.
Camptoalatus sp. Takemura *et al.*, 2009, pl. 1, fig. 5.

Emended diagnosis.—*Qiania* having a weakly undulating apical portion and very weakly undulating inflated region with a bladed wing.

Description.—The conical shell is curved to the ventral side, imperforate, and bilaterally symmetrical. The shell consists of two parts: an apical portion and an inflated region. The apical portion is about one-third of the length of the shell. The apical portion is weakly undulating. Several unclear obliquely transverse constrictions are present on the surface. The inflated region is very weakly undulating. The base of the inflated region is carinate. A lateral foramen is developed on the ventral side of the shell. A subtriangular bladed wing extends laterally from the basal part of the foramen.

Occurrence.—Changhsingian: carbonate-phosphate concretions in siltstones of the Yastrebovsk Formation, Primorye, the Russian Far East (Rudenko and Panasenko,

1990); bedded chert in the Funabuseyama Formation, the Mino terrane, Southwest Japan (Kuwahara and Yao, 1998); and a phosphatic nodule in Jurassic mélange of the Yusukawa Formation, the Northern Chichibu terrane, Southwest Japan (Takemura *et al.*, 2009).

Remarks.—The shell of this species can be divided into two parts: an apical portion and an inflated region; therefore, we consider this species to belong to *Qiania*. This species differs from *Q. foremanae* in having a more curved shell, a very weakly undulating inflated region, and a subtriangular bladed wing.

Discussion and implications

The Dalong Formation yields *Qiania foremanae* gen. et sp. nov., and has been deposited from deep water in a slope to basin environment of an interplatform trough (Feng *et al.*, 1990; Feng *et al.*, 2007; Feng and Algeo, 2014).

Qiania uncinata occurred in the Jurassic accretionary complexes along East Asia. The locality of *Q. uncinata* is the east bank of the Partizansk River, 1 km south of Orel, Primorye, Russia (Rudenko and Panasenko, 1990), where the Taukha terrane of the Jurassic accretionary complex is widely distributed (Kojima *et al*., 2000, 2008). The Taukha terrane is considered to be a direct northern extension of the North Kitakami terrane of Northeast Japan and the South Chichibu terrane (Suzuki *et al*., 2007). Meanwhile, the locality of *Q. uncinata* of Takemura *et al.* (2009) is placed in the North Chichibu terrane, and that of Kuwahara and Yao (1998) in the Gujo-hachiman section is placed in the Mino terrane.

Nishikane *et al.* (2014) examined conodont fauna from the Gujo-hachiman section and concluded that the paleoposition of the Permian deposits was a deep and open ocean area in the southernmost part of the Equatorial Warm Water Province of Mei and Henderson (2001). In addition, the *Qiania uncinata* from both the Taukha and North Chichibu terranes were obtained from phosphorus nodules. Because the deposition of phosphorus-rich sediments probably indicates nutrient-rich marine conditions (e.g. Patey *et al.*, 2008), *Q. uncinata* occurred mainly in deep-sea facies and nutrient-rich conditions.

In addition to *Qiania*, the Corythoecidae include four previously described genera: *Corythoecia*, *Arrectoalatus*, *Camptoalatus*, and *Cornum* (De Wever *et al.*, 2001). These corythoecids have not been reported from deep-water cherts.

Almost all species belonging to the Corythoecidae reported in Nazarov's papers (Nazarov and Ormiston, 1985, 1986; Isakova and Nazarov, 1986; Nazarov, 1988) were obtained from the upper Gzhelian in the South Urals (Nazarov and Ormiston, 1993). The upper Gzhelian deposits were formed on a platform that was presumably a shallow and open-ocean environment.

Corythoecia was reported from the Famennian Huron Member of the Ohio Shale of North America (Foreman, 1963). Schwartzapfel and Holdsworth (1996) reported *Arrectoalatus* species from the lower shale member of the Goddard Formation in Oklahoma. *Cornum* species were recovered from the lower shale member of the Goddard Formation and the Delaware Creek Member of the Caney Formation (Schwartzapfel and Holdsworth, 1996). The Huron Member, Goddard Formation, and Delaware Creek Member consist of organic-rich argillaceous shales, and these deposits are commonly associated with phosphate nodules. The high levels of organic matter and phosphate in the sediment imply nutrient-rich conditions. The depositional environments of the Huron Member, Goddard Formation, and Delaware Creek Member have been considered as shallow open ocean within upwelling regions (e.g. Heckel, 1977; Ettensohn and Barron, 1981).

Maldonado and Noble (2010) reported *Camptoalatus* from debris flows of the upper Capitanian Reef Trail Member of the Bell Canyon Formation in the Delaware basin, west Texas. Strata of the Reef Trail Member are interpreted to have been deposited in a basin margin setting adjacent to a nearby reef (Maldonado and Noble, 2010).

In summary, most corythoecids including *Qiania* occurred in phosphate-rich facies in the previous studies. This implies that they preferred nutrient-rich conditions. Meanwhile, all the corythoecid genera except for *Qiania* lived in the shallower open ocean on the platform and in the nutrient-rich upwelling regions. The currently known fossil record shows that *Qiania* has a wider distribution and occurrences from deeper facies than other genera of corythoecids.

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