

***Mooreocrinus liaoi* sp. nov. (Crinoidea, Echinodermata) from the Pennsylvanian (Upper Carboniferous) Outangdi Formation in Zhejiang, South China Block**

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ABSTRACT: A new crinoid species of the Order Cladida, *Mooreocrinus liaoi* Mao and Li sp. nov., is described from the Pennsylvanian (Upper Carboniferous) Outangdi Formation in Jiangshan, Zhejiang Province, representing the first record of *Mooreocrinus* Wright & Strimple, 1945 in China. The presence of *Mooreocrinus* in the South China Block extends the palaeogeographic record of this genus and indicates it to be a cosmopolitan taxon. Three other ancient tectonically-separated areas that are now combined into the modern China mass (Sibumasu, Junggar, North China) do not contain any record of *Mooreocrinus*. Overall, there is low biodiversity of the Late Paleozoic crinoid faunas in the South China Block. Our new materials provide further evidence for diversity assessment of crinoid faunas in peri-Gondwana blocks.

KEYWORDS *Mooreocrinus*; crinoid; Carboniferous; Zhejiang; eastern China

1 INTRODUCTION

Major changes in the evolution of crinoids took place in the early part of the Carboniferous Period (Ausich and Kammer, 2013), in the first two Ages of the Mississippian Series (Tournaisian and Viséan). Following the end-Devonian extinctions, the Middle Paleozoic Crinoid Evolutionary Fauna expanded in the Tournaisian but then declined in the Viséan, becoming replaced by the Late Paleozoic Crinoid Evolutionary Fauna radiation during the interval between Serpukhovian (late Mississippian) and Artinskian (middle Cisuralian Epoch, early Permian Period) Ages (Kammer and Ausich, 2006; Sallan et al., 2011). The Late Paleozoic Crinoid Macroevolutionary Fauna was dominated by advanced taxa of the crinoid order Cladida (e.g. Webster et al., 2004; Kammer and Ausich, 2006; Sallan et al., 2011; Ausich and Kammer, 2013), demonstrated by statistical datasets from Avalonia, Baltica, northern Gondwana and Laurentia (e.g. Baumiller and Messing, 2007; Gorzelak et al., 2016).

In this study, we describe some well-preserved crowns of the Cladid genus *Mooreocrinus* Wright & Strimple, 1945, from the Carboniferous Outangdi Formation (Bashkirian) at the Dawulong section, Jiangshan County of southern Zhejiang Province (Figure 1a). This genus has not been described previously in China. Furthermore, we recognise a new species *Mooreocrinus liaoi* Mao and Li sp. nov. Thus, this study aims to improve understanding of crinoid distributions in the late Carboniferous and provides a perspective of the importance of the South China Block in palaeogeographic patterns of crinoids.

2 GEOLOGICAL SETTING

Jiangshan is situated in the southeast margin of the Yangtze region, South China Block, a separate continent in Palaeozoic time. There is a major depositional hiatus between the Upper Ordovician and Carboniferous due to the expansion of the Cathaysian Land since the Kwangsi (approximately equivalent to the Caledonian) Orogeny (Chen, 1990). Tectonic subsidence basins were formed and controlled by active faulting along the western margin of Cathaysian Land in the Carboniferous. Depositional successions of the Carboniferous are dominated by pebbles, sandstones and siltstones sourced from erosion of the Cathaysian Land, mixed with a few carbonate beds of the Yejiatang and the overlying Outangdi Formations (Hao et al., 2006).

The Carboniferous Outangdi Bed (nowadays Outangdi Formation) named by Lu et al. (1955) in Jiangshan is composed of yellow siltstones intercalated with light grey thin-bedded nodular shelly limestones (Guo, 1994, 2004; Guo and Liang, 1994). This unit is assigned to the earliest Bashkirian in age based on the index marine fossils of the fusuliida taxa such as the *Fusulina pseudobockii*, *Profusulinella convolute*, *Pseudostaffella ozawai* and approximately equivalent to the wide-spreading Huanglong Formation in the main part of the Yangtze Platform. At the Dawulong quarry section, marine macrofossils were collected from thin-bedded nodular limestones (thickness about 4 m), indicating a thin shelly layer <<Please check if this is correct - I am not sure if “shallow” means ‘thin’ or means ‘shallow marine’>>. Overall, brachiopods are generally low in abundance, without coquina beds. Diverse shelly macrofossils are mostly well preserved and considered as *in situ* preservations in a calm marine environment. Brachiopods are listed here: *Dielasma* sp., *Dictyoclostus pugilis* (Phillips), *Wellerella delieatula* Dunbar et Condra, *Cleiothyridina hejiashanensis* Hu, *Dielasma* sp., *Hemiptychina* sp., *Neophricodothyris* sp., *Dictyoclostus* sp., *Buxtonia* cf. *markamica* Jing et Sun, *Crurithyris* sp., *Dictyoclostus pugilis* (Phillips), *Choristites fischeri* Fredericks, *Orthotetes* sp., *Neophricodothyris* sp., *Neochonetes* sp., *Dielasma mappingensis* Grabau, *Cleiothyridina kangshanensis* Wang, *Neophricodothyris* sp., *Neochonetes carboniferus* Keysuling, *Eomarginifera* sp., *Dictyoclostus pugilis* (Phillips), *Schuchertella* sp., *Cleiothyridina hejiashanensis* Hu. *Mooreocrinus liaoi* Mao et Li, sp. nov. was collected from the light grey thin-bedded nodular limestones in the lower Outangdi Formation (Figure 1b).

3 SYSTEMATIC PALAEOLOGY

Phylum Echinodermata Klein, 1754

Class Crinoidea Miller, 1821

Subclass Pentacrinoidea Jaekel, 1894

Parvclass Cladida Moore and Laudon, 1943

Magnorder Euclidida Wright, 2017

Cyathoformes incertae sedis: 'Poteriocrinida' Jaekel, 1918

Superfamily Cromyocrinacea Bather, 1890

Family Cromyocrinidae Bather, 1890

Genus *Mooreocrinus* Wright and Strimple, 1945

Type species **Cromyocrinus geminatus* Trautschold, 1879

Diagnosis. Crown tall, cylindrical, outer surface devoid of pronounced ornamentation, arms abutting closely. Cup bowl shaped with broad, flat base and erect lateral walls, sutures impressed; greatest width below the summit of the cup; subhorizontal infrabasal circlet; basals large with proximal portion in basal plane, flexing sharply to extend well up into lateral walls; radials wider than long, distal edges curved sharply inward to form a large forefacet; 3 anal plates normal or in advanced arrangement with radianal tending to migrate to posterior position and right tube plate barely notching cup summit. Arms 10, recti-uniserial, broad in proximal region but tapering to narrow width before attaining midheight, pinnulate; primibrachs 1 axillary, wide, with sharply inwardly sloped proximal surface. Stem relatively small (Moore and Strimple in Moore and Teichert, 1978; Lane, 1964).

Remarks. This genus was originally proposed for the reception of species formerly assigned to the genus *Dicromyocrinus* (Lane, 1964), which typify *Mooreocrinus* in having uniserial low, rectangular brachials, while *Dicromyocrinus* has cuneate brachials. *Mooreocrinus* is typically of Moscovian age, with five species reported including (*Mooreocrinus geminatus* (Trautschold, 1879); *M. magdalenensis* Strimple, 1975; *M. mendesi* (Lane, 1964); and *M. wilburni* Strimple and Watkins, 1969) from Pennsylvanian of United States, Russia and Brazil, and one (*M. glomerosus* Webster et al., 2004) from Mississippian of Algeria.

***Mooreocrinus liaoi* sp. nov. Mao et Li**

(Figure 2, 3)

Holotype. NIGPAS 175853; paratype 1 HS0590 A; paratype 2 HS0594.

Derivation of name. The species is named *liaoi* in the memory of Professor Liao Zuoting, who gave generous assistance during our field works in Jiangshan before he passed away in summer of 2020.

Horizons and localities. Six specimens of the species were available for study. The holotype (NIGPAS175853) is deposited in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, and the others (HS0590; HS0594; HS0574) are deposited in Zhejiang Institute of Geological Survey.

Diagnosis. Distinguished by the combination of the impressed sutures and lower cup with more rounded base.

Description. The crinoids in the nodular limestones are not compressed in taphonomy. Crown is higher than wide. The dorsal cup is medium, truncate, bowl-shaped with broad flattened base and almost vertical lateral sides, summit slightly constricted. In summit or basal views, the cup outline is symmetrically circular except for slightly impressed sutures. All plates are smooth, unornamented, and with impressed sutures. Five infrabasals form a moderately large pentagonal-shaped disc extending well beyond the slightly impressed circular columnar cicatrix. Five IBB, are flat or very gently convex; not visible in lateral view of the cup, downflaring proximally, horizontal distally; four sided and bear a small, circular,

radially grooved stem impression on their median tips; central stem impression moderately deep. Five basals are large, pentagonal plates, both longitudinally and transversely convex, flattened proximal well above basal plane, flex upward to participate strongly in lateral cup walls and becoming more convex near their distal borders. The right posterior basal is larger than the other basals. Five radial plates are largest plates in cup, wider than high, convex transversely and longitudinally, and the upper edges of the outer surfaces bordering the facets are flattened and gently inclined outward.

The radial facets are large, plenary, as wide as the radials, with long, wide outer ligament areas that slope gently outward. The outer ligament furrow is deepest next to the outer marginal ridge; the transverse ridge is denticulate on both sides. The inner ligament area and muscle areas are not exposed.

Three anal plates in primitive position. The radianal is large and elongated, quadrangular, oblique position, adjoined by C radial, BC and CD basals, secundanal, and tertanal, strongly convex longitudinally and gently convex transversely. Anal-X is also relatively large, gently convex, higher than wide, distal tip above radial summit, in contact with the radianal, posterior basal, and left-posterior radial. Another anal plate is small and high, above and to the right of anal-X, distal half above radial summit. This third anal plate and the anal-X separate the left-posterior and right-posterior radials and extend above the radial circlet.

There are two arms to each ray, branching on IB_{r1} which are axillary, large, wider than high, strongly convex transversely, gently convex longitudinally, and restricted in width just above the radials. Secundibrachs large, wedge shaped, outer surfaces convex, sides flattened and secundibrachial of adjacent arms in lateral contact. First secundibrachial is wider than high, and there is a gradual decrease in size of secundibrachial distally. More than twenty secundibrachs can be counted on the most completely preserved arm. 10 arms in total if no branching occurs above primibrachial. Stem round. The anal sac is unknown.

Remark. It is the first report of this genus from China. The holotype (fig. 2) of *Mooreocrinus liaoi* n. sp. retains parts of the B, C, D, and E ray arms up to the eleventh secundibrachial. Paratype 1 (fig. 3A) is a complete crown with arm more than thirty secundibrachial. Paratype 2 (fig. 3C) retains proximal parts of the C and D ray arms and more than twenty proximal columnals.

Mooreocrinus liaoi n. sp. differs from *M. geminatus* (Trautschold, 1879) in lacking surface ornamentation and having larger radial plates. This new species has more convex plates and impressed sutures than *Mooreocrinus glomeratus* Webster et al., 2004 and *M. magdalenensis*, Strimple, 1975. *M. mendesi* (Lane, 1964) differs from *Mooreocrinus liaoi* sp. nov. in that it has a more globose cup, more convex cup plates and more impressed sutures. *Mooreocrinus liaoi* sp. nov. is remarkably similar in size, shape and ornamentation to *M. wilhurni* Strimple and Watkins (1969), but has relatively more impressed sutures with relatively wider and more tumid radials. These differences are all of slight degree.

Measurements of the holotype in millimeters. Width of cup (maximum) 22.2; Height of cup 9.5; width of infrabasal circlet 9.1; length of basal 10.5; width of basal 10.1; length of suture between basals 7.2; length of radial 6.7; width of radial 10.9; length of suture between radials 4.1; length of radianal 6.1; width of radianal 4.9; length of anal X 5.1; width of anal X 3.1; diameter of columnar scar 2.2.

3 DISCUSSION

Generally, Carboniferous crinoids in Chinese tectonic blocks are found in a few fossil-rich beds in limited localities. Apart from a few records of deposits with high crinoid diversities in some Chinese blocks listed below, Carboniferous crinoids in the South China Block are rarely reported. Even though crinoid stems often occur with high abundance in shelly bank facies locally, crowns with diagnostic characteristics are rarely found; there is only one crown-preserved genus known. In order to provide an overview of crinoid taxa in China, we have compiled regional lists (Table 1), showing 34 genera and 62 species of Carboniferous crinoid taxa, plotted on a paleogeographic map with the main tectonic regions (Fig. 4).

The Mississippian crinoid fauna in Sibumasu is the oldest known Chinese Carboniferous crinoid fauna dominated by well-preserved Camerata (Chen, 1984; Chen and Yao, 1993; Wang et al., 1993; Chen et al., 1997; Webster et al., 2009). This fauna was the highest abundance and diversity, and more closely related to the coeval European faunas than those from North America. The Junggar crinoid fauna has a low-diversity in Camerates and generally poor-preserved in fragmentary status, showing greatest biological affinity at the family level with Moscovian crinoid faunas of Japan and North America (Lane et al., 1996; Webster, Waters, Liao et al., 2009a, b; Webster, Waters, Chen, 2009). The North China crinoid fauna dominated by Cladida is well-preserved with low diversity and abundance, and implies biological affinities with those recorded in North America (Tien, 1926; Webster, 2003; Sheffield, 2015). Carboniferous crinoid faunas from Sibumasu, Junggar and North China share with wide-spreading Platycrinites. Moreover, the Sibumasu and Junggar crinoid faunas both contain the cosmopolitan disparids genus *Synbathocrinus*.

Of critical importance to this study, *Mooreocrinus* is not recorded in any of the other three ancient geographic areas above (Fig. 4), confirming that *Mooreocrinus* therefore adds one new genus to the South China Block list and extends the palaeogeographic record of this genus, indicating it to be a cosmopolitan genus. The rare overlap of Carboniferous crinoids among the four Chinese blocks probably indicates a complicated palaeogeographic history of Chinese blocks (Fig. 4). However, although the list above shows a range of crinoid taxa from China, knowledge of biotic composition of the Carboniferous crinoid fauna in South China Block is very preliminary; and further fossil collections, systematic palaeontology, evolutionary and palaeogeographic studies are required to develop a comprehensive understanding of the faunal composition.

4 CONCLUSION

A new species of crinoid, *Mooreocrinus liaoi* nov. sp is described from the Outangdi Formation, representing the first record of *Mooreocrinus* in China. This taxon was thus a component of the expansion of the Late Palaeozoic crinoid fauna, and provides further evidence for the palaeogeographic distributions of *Mooreocrinus* Wright & Strimple, 1945, confirming it as a cosmopolitan genus.

ACKNOWLEDGEMENTS

Thanks to Professor Liao Zuoting for his helpful field work and discussion on the stratigraphy and identification on the brachiopods. We thank anonymous reviewers and editors for their

critical comments and constructive suggestions that largely improved the manuscript. This study is supported by Strategic Priority Research Program (B) of Chinese Academy of Sciences (Grant No. XDB26000000), State Key Laboratory of Palaeobiology and Stratigraphy (Nanjing Institute of Geology and Palaeontology, CAS, No. 20192105), the Youth Innovation Promotion Association of CAS (2019310) and Geological project of the Zhejiang Province No. 2018006 and 2018007.

CONFLICT OF INTEREST

We declare that all authors have no conflict of interest. We have data available.

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Figure 1 (A) Location of the Dawulong section in Jiangshan County of Zhejiang Province. (B) Outcrop of the light grey thin-bedded nodular limestones yielding *Mooreocrinus liaoi* Mao et Li, sp. nov.

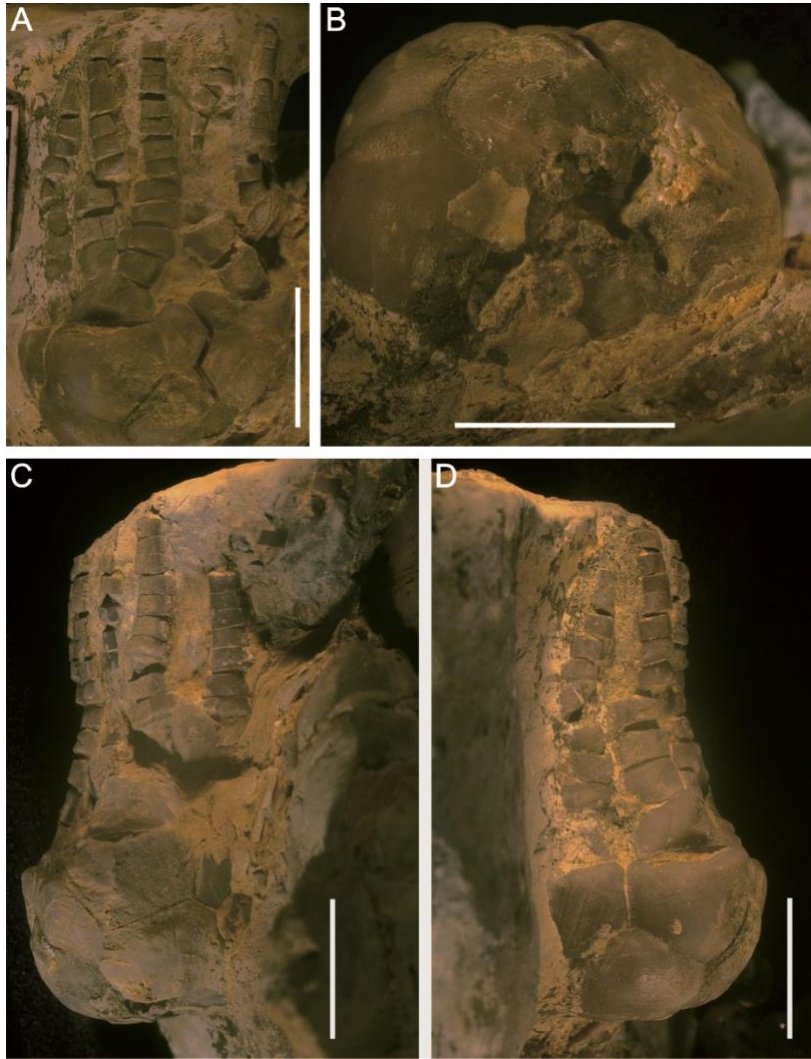


Figure 2 Morphology of the *Mooreocrinus liaoi* sp. nov. Mao et Li (I) NIGPAS 175853; (A) posterior view, (B) aboral view, (C) and (D) lateral view. See text for description.

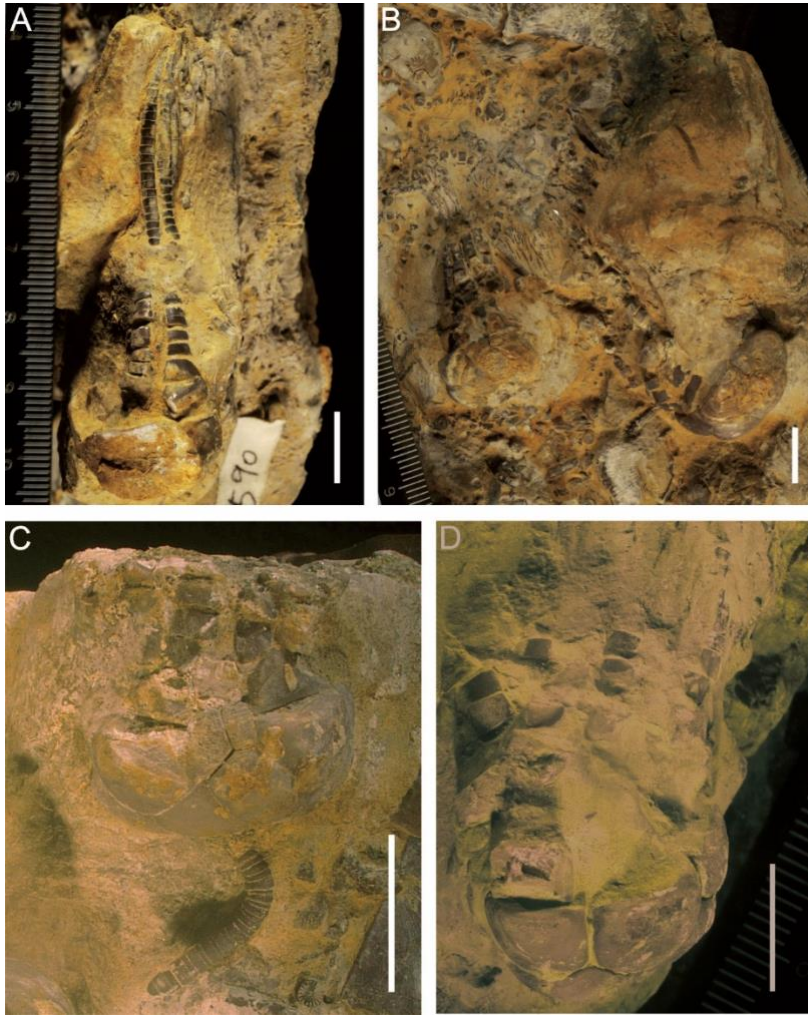


Figure 3 Morphology of the *Mooreocrinus liaoi* sp. nov. Mao et Li (II) (A) and (B) HS0590, lateral view, (C) HS0594, posterior view, (D) HS0574, lateral view.

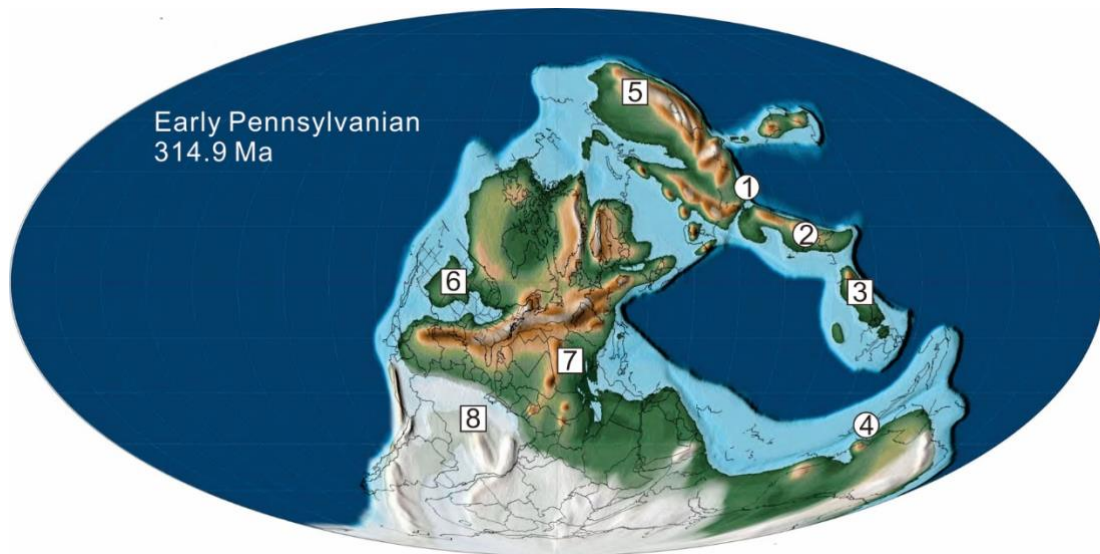


Figure 4 Paleogeographic map showing distributions of crinoids during Early Pennsylvanian, the squares indicate the blocks with *Mooreocrinus* Wright & Strimple, 1945 (based on Scotese, 2014). 1. Junggar ; 2. North China; 3. South China; 4. Sibumasu; 5. Russia; 6. United States; 7. Algeria; 8. Brazil.

Table 1 Carboniferous crinoids in China.

Age	Carboniferous				
	China	Sibumasu	Junggar	North China	South China
Locality	Yunnan	Xinjiang	Hebei	Guangxi	Zhejiang
References	Chen, 1984; Chen and Yao, 1993; Wang et al., 1993; Chen et al., 1997; Webster et al., 2009	Lane et al., 1996; Webster, Waters, Liao et al., 2009a, b; Webster, Waters, Chen, 2009	Tien, 1926; Webster, 2003; Sheffield, 2015	Chen et al., 1997	This paper
<i>Mooreocrinus liaoi</i> nov.					✓
<i>Rhodocrinites exquisitus</i>	✓				
<i>R. fortis</i>	✓				
<i>R. spinatus</i>	✓				
<i>R. intermedius</i>	✓				
<i>R. excavatus</i>	✓				
<i>R. baoshanensis</i>	✓				
<i>Rhodocrinites</i> sp.	✓				
<i>Gilbertocrinus</i> sp.	✓				
<i>Yunnanocrinus</i>	✓				
<i>Y. delicatulus</i>	✓				
<i>Y. tympaniformis</i>	✓				
<i>Amphocrinus atlas</i> ?	✓				
<i>A. bollandensis</i> ?	✓				
<i>A. cheni</i>	✓				
<i>A. gilbertsoni</i> ?	✓				
<i>A. pseudoturgidus</i>	✓				
<i>Pimlicocrinus</i>	✓				
<i>P. morocarpus</i>	✓				
<i>P. subconicus</i>	✓				
<i>Ectocrinus anthodeus</i>	✓				
<i>Stomiocrinus ovatus</i>	✓				
<i>Platycrinites s. s.</i>	✓				
<i>P. s. s. cupulatus</i>	✓				
<i>P. s. s. intermedius</i>	✓				
<i>P. s. s. mirabilis</i>	✓				
<i>P. s. s. xiyiensis</i>	✓				
<i>P. s. s. langbaensis</i>	✓				
<i>Synbathocrinus</i>	✓				
<i>S. yaoli</i>	✓				
? <i>Bollandocrinus erectus</i>	✓				
<i>Cyathocrinites conicus</i> ?	✓				
<i>Parabarycrinus</i>	✓				
" <i>Texacrinus</i> "	✓				
<i>Holocrinus irregularis</i>	✓				
<i>Paragassizocrinus</i> sp.		✓			
<i>Metacromyocrinus</i> sp.		✓			
<i>Binariocrinus alvus</i>		✓			
<i>Bassocrinus abyssus</i>		✓			
<i>Brabeocrinus asiaensis</i>		✓			
<i>Synbathocrinus</i> sp.		✓			
<i>Rhepocatillocrinus</i>		✓			
<i>Metaperimestocrinus</i>		✓			
<i>Dicromyocrinus</i> sp. 1		✓			
<i>Dicromyocrinus</i> sp. 2		✓			
<i>Stellarocrinus</i>		✓			
<i>Synbathocrinus labrus</i>		✓			
<i>Aexitrophocrinus</i> sp.		✓			
<i>Platycrinites</i> spp.		✓			
<i>Delocrinus houkouensis</i>			✓		
<i>Mathericrinus</i>			✓		
<i>M. pustulosus</i>			✓		
<i>Sinoocrinus houkouensis</i>			✓		
<i>S. linchengensis</i>			✓		
<i>S. microgranulosus</i>			✓		
<i>S. nodosus</i>			✓		
<i>Sinoocrinus nodosus</i>			✓		
<i>Gulinoocrinus bellus</i>				✓	
<i>G. ramosissimus</i>				✓	