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A new crinoid fauna from the Taiyuan Formation (early Permian) of Henan, North China

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Abstract.—A diverse Permian crinoid fauna is reported from the Taiyuan Formation, Dajian Member (Asselian) at Anyang, northeastern Henan Province of the North China Craton. The specimens are well preserved, including articulated crowns and cups. The fauna contains representatives of each of the major Paleozoic crinoid clades: Cladida (including the Flexibilia), Disparida, and Camerata. Identified genera suggest a greater affinity with North American faunas than with Tethyan faunas. Four new species, *Neoprotencrinus anyangensis*, *Ulocrinus qiaoi*, *Artichthyocrinus limani*, and *Synbathocrinus chenae*, are proposed herein.

UUID: http://zoobank.org/D08DDDCD-485C-45CC-A014-C1CB58C26588

Introduction

Permian crinoids are relatively rare compared with crinoids from earlier parts of the Paleozoic (Table 1). The most diverse and abundant articulated Permian crinoid crowns and cups were reported from Timor (Wanner, 1916, 1924, 1937, among others; Webster, 2012a; Webster and Donovan, 2012). Although the stratigraphic position was uncertain, it was considered to be Artinskian by Charlton et al. (2002). In addition, early Permian crinoid faunas are known from Russia (Yakovlev, 1926, 1927, 1930; Yakovlev and Ivanov, 1956), the United States (the midcontinent: Moore and Plummer, 1940; Pabian and Strimple, 1974; southern Nevada: Lane and Webster, 1966; Webster and Lane, 1967, 2007), Australia (eastern: Willink, 1978, 1979a, b, 1980; Webster and Jell, 1999b; Western Australia: Webster, 1987, 1990; Webster and Jell, 1992; Teichert and Webster, 1993; Tasmania: Sieverts-Doreck, 1942), Oman (Webster and Sevastopulo, 2007; Webster et al., 2009b), Thailand (Webster and Jell, 1993), British Columbia (Webster et al., 2009a), Greece (Webster, 2012b), Bolivia (Branisa, 1965; Strimple and Moore, 1971; Burke and Pabian, 1978), Mexico (Strimple, 1971), China (Tien, 1926; Chen and Yao, 1993), and Spitsbergen/Norway (Gorzelak et al., 2013). Crinoid faunas are also known from the middle Permian of Tunisia (Valette, 1934; Lane, 1979), Europe (Gregorio, 1930; Ramovš and Sieverts-Doreck, 1968; Strimple and Sevastopulo, 1982), and Pakistan (Waagen, 1887), as well as from upper Permian strata of Europe (e.g., Donovan et al., 1986; Reich, 2007). Among them, the Timor, southern Nevada, Western Australia, and southern Ural Mountains faunas are the four main early Permian faunas representing more than 40 genera. The only Permian crinoids reported previously from China are *Separocrinus discoides* Chen and Yao, 1993 (Webster et al., 2009c) from the early Permian Sakmarian to Artinskian of Yunnan and one possible crinoid fauna from North China (southern Hebei Province), Taiyuan Series (exact age uncertain), including *Delocrinus*, *Mathericrinus*, and *Sinocrinus* (Tien, 1926).

The fossils described herein were collected from an outcrop at Tianxi Village, Shanying Town, southern Anyang City, Henan Province (36.24730°N, 114.65929°E) (Fig. 1), approximately 120 km south of the Lincheng Coal Field Section of southern Hebei Province studied by Tien (1926). The present study adds to our knowledge of the diversity of crinoids during the earliest Permian in the North China Block.

Geologic setting and stratigraphy

Lower Paleozoic strata of the eastern part of the North China Block (or Sino-Korean Platform) are composed dominantly of shallow marine carbonates (Feng et al., 1990). The block was largely uplifted during Ordovician time. A remarkable sedimentary gap (parallel unconformably) is present at the top of the Cambrian or Ordovician. The dividing line is from Xiaxian to Dengfeng. In the south of the dividing line, the gap is at the top

Table 1. Most significant previous localities, ages, and formations of Permian crinoid publications.

Author(s)	Locality	Geologic age	Formation
Wanner, 1916; Wanner, 1924; Wanner, 1937; Webster, 2012a; Webster and Donovan, 2012	Basleo, Timor	Artinskian	Either the Maubisse Formation or Atahoc and Cribas Formation
Yakovlev, 1926; Yakovlev, 1927; Yakovlev, 1930; Yakovlev and Ivanov, 1956	Ural Mountains, Russia	Artinskian	Div'ya Formation
Moore and Plummer, 1940	Texas, United States	Wolfcampian	Cibolo Limestone
Pabian and Strimple, 1974	Nebraska, United States	Wolfcampian	Foraker Formation
Lane and Webster, 1966; Webster and Lane, 1967; Webster and Lane, 2007	Nevada, United States	Middle Wolfcampian	Bird Spring Formation
Willink, 1978; Willink, 1979a; Willink, 1979b; Willink, 1980; Webster and Jell, 1999b	Eastern Australia	Artinskian–Roadian	Wandrawandian Siltstone; Catherine Sandstone; Berry Formation; Condamine Beds
Webster and Jell, 1992; Webster, 1987	Western Australia	Late Sakmarian–early Artinskian	Callytharra Formation
Webster, 1990; Teichert and Webster, 1993	Western Australia	Artinskian–Tatarian	Wandagee Formation; Cundlego Formation; Quinnanie Shale:Billidee Formation
Sieverts-Doreck, 1942	Tasmania, Australia	Sakmarian–Artinskian	Darlington Limestone
Webster and Sevastopulo, 2007; Webster et al., 2009b	Northeastern Oman	Sakmarian	Al Jil Formation; Saiwan Formation
Webster and Jell, 1993	Southern Thailand	Artinskian?	Phuket Group and Rat Buri Limestone
Webster et al., 2009a	British Columbia	Sakmarian?	Mount Mark Formation
Webster, 2012b	North-central Crete, Greece	Asselian–Artinskian?	The point of rocks
Branisa, 1965; Burke and Pabian, 1978; Strimple and Moore, 1971	Bolivia	Sakmarian–Artinskian	Copacabana Group
Tien, 1926	Northern China	Pennsylvanian?	Taiyuan Series
Chen and Yao, 1993; Webster et al., 2009c	Southwestern China	Sakmarian–Artinskian	Dingjiazhai Formation
Gorzelak et al., 2013	Spitsbergen	Late Artinskian–Roadian	Kapp Starostin Formation
Valette, 1934; Lane, 1979	Tunisia	Wordian/Guadalupian	Djebel Tebaga
Gregorio, 1930; Ramovš and Sieverts-Doreck, 1968; Strimple and Sevastopulo, 1982	Sicily	Wordian	Sosio Formation
Waagen, 1887	Salt Range, Pakistan	Wordian	Wargal Formation
Donovan et al., 1986	Northeast England	Guadlupian–Lopingian	Ford Formation
Reich, 2007	Eastern Thuringia, Germany	Wuchiapingian	Werra-Karbonat Formation

of the Cambrian; in the north of the line, the sedimentary gap lies at the top of the Ordovician. No Upper Ordovician, Silurian, Devonian, or Mississippian deposits occur. Unconformably overlying the Cambrian or Ordovician limestones is the Pennsylvanian Benchi Formation, which is dominated by terrestrial deposits (e.g., Hou et al., 1987; Lü and Chen, 2014). The Benchi Formation is composed dominantly of siltstone and contains abundant vascular plant fossils and bauxite. It is biostratigraphically dated by the conodont *Idiognathodus delicates–I. podolskensis* Assemblage Zone as the middle to upper Moscovian, Pennsylvanian. Strata above the Pennsylvanian Benchi Formation are the Permian Taiyuan, Shanxi, Shihezi, and Shiqianfeng formations in ascending order (Hou et al., 1987; Wu et al., 1987). The base of the Taiyuan Formation is currently defined by the first occurrence of the limestones sharply differing from the Benchi Formation below. The Taiyuan Formation is composed of tens to hundreds of meters of strata and is characterized by limestones interbedded with siltstones and mudstones with rare coal beds indicating alternating of marine and terrestrial facies (Bureau of Geology and Mineral Resources of Henan Province, 1990). Conodont dating suggests that it is earliest Permian, Asselian, in age (Wang et al., 1987; Lang and Wang, 2007).

Anyang is located in the central part of the North China Block. Coal, iron, limestone, and bauxite of Pennsylvanian and Permian age are important economic resources of this region. Upper Paleozoic outcrops along the Tianxi section are discontinuous. The lower part of the Taiyuan Formation is covered by roads and houses and partly measured as 15 m in thickness (Fig. 2). Brown siltstones yielding fossils of vascular plants, especially ferns, and insect fossils are indicators of a nonmarine environment. The marine fossil-bearing unit consists of thin-bedded calcareous siltstones and thick-bedded bioclastic limestones and is the Dajian Member, middle part of the Taiyuan Formation. Above the Dajian Member are sandstones of the Mojie Member (Wang et al., 1987). Thus, the Dajian Member biologically and lithologically indicates a dramatic transgressional interval yielding a shallow marine fauna.

Well-preserved crinoid fossils are concentrated within the calcareous siltstones in an interval approximately 1.5 m thick. Co-occurring macrofossils are the trilobite *Ditomopyge* sp.;

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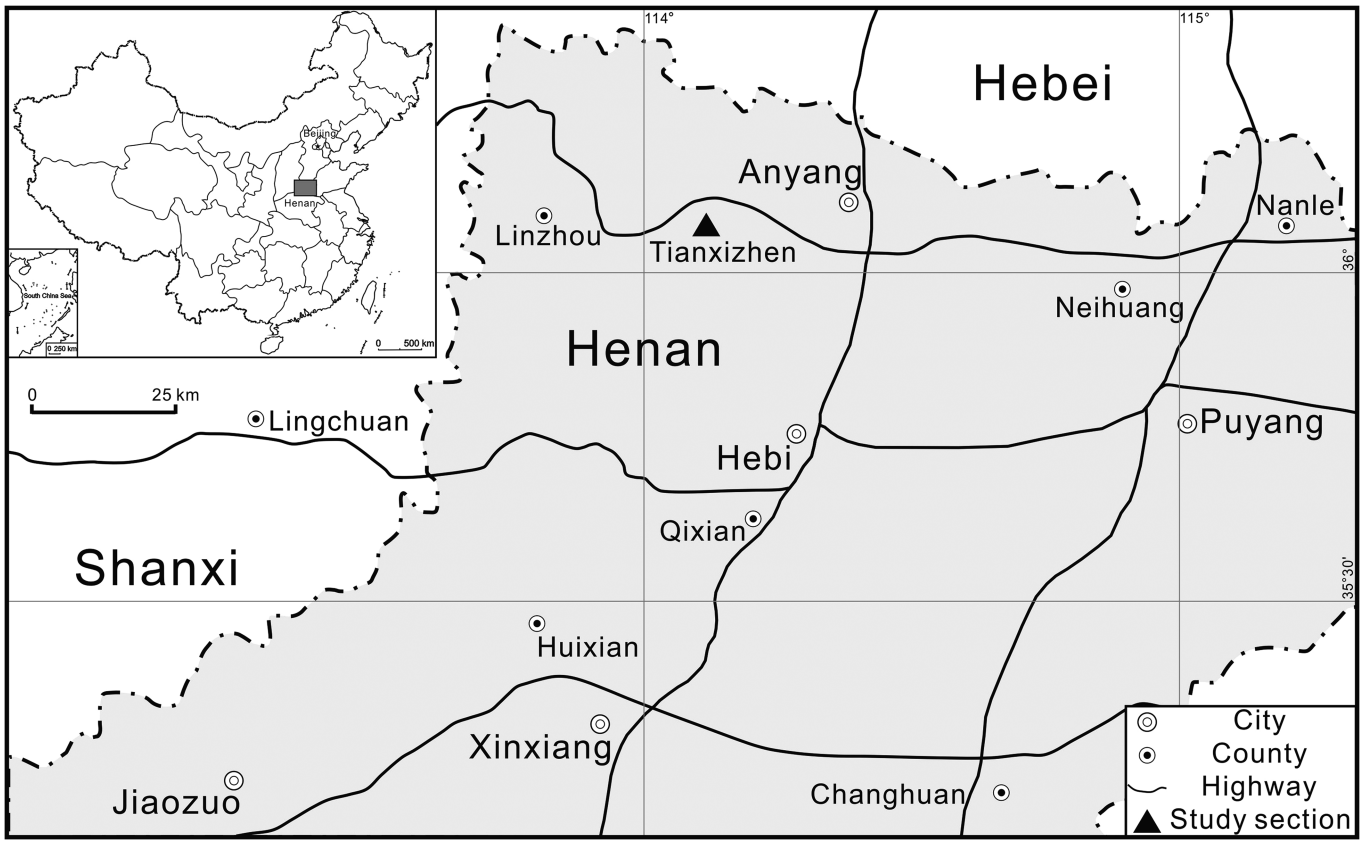

Figure 1. Map showing the section locality at Tianxi Village, Shanying Town, southern Anyang City of Henan Province.

brachiopods *Choristites* sp., *Martinia* spp., *Eomarginifera* sp., *Punctospirifer* sp., *Neospirifer* sp., *Cleiothyridina* sp., and *Echinoconchus* sp.; gastropod *Pseudozygopleura* sp.; rugose corals *Lophocarinophyllum*, *Yakovleviella*, and *Tachylasma*; and bryozoan *Streblotrypa*. These are common elements of the Taiyuan Formation (Wang et al., 1987; Zhao, 1987; Zhao and Liang, 1989). Sponge spicules are less common and preserved as fragments. The index conodont fossil, *Streptognathodus cristellaris* Chernykh and Reshetkova, 1987, is from the thick-bedded bioclastic limestones, approximately 20 cm above the argillaceous limestone. *S. cristellaris* is representative of the second conodont zone of the Permian Asselian in Russia (Chernykh, 2006).

Faunal analysis

The Henan crinoid fauna is diverse and contains several new species. It contains representatives of each of the major groups of the crinoids known in the Paleozoic: Cladida (including Flexibilia), Disparida, and Camerata. Cladid crinoids (~59%) dominate the fauna as they do in nearly all post-Mississippian faunas. The fauna is divisible into two groups: cosmopolitans of the equatorial belt during the Permian and taxa known from the Americas. No endemic genera are present. *Platycrinites*, *Synbathocrinus*, and sagenocrinitids are all cosmopolitan in the equatorial belt in the Permian (Webster, 2003). All genera in the Henan fauna are recognized in North America in the Carboniferous. The disparid *Synbathocrinus* and the eucladid *Apographiocrinus* are also known from early Permian (Artinskian) strata of North America as well as in Timor and Western Australia. *Celonocrinus* was reported from the middle Wolfcampian of North America by Lane and Webster (1966). In addition, *Erisocrinus* was reported from middle Permian strata of Russia by Yakovlev and Ivanov (1956), and *Artichthyocrinus* was described from the early Permian (possibly within the Asselian to Artinskian) of Greece by Webster (2012b).

The Henan crinoid fauna is considered to have the greatest affinity with North American faunas. *Ulocrinus* and *Neoprotencrinus* have not previously been reported from Permian strata, and their ranges are extended upward into the Permian. The paleogeographic range of these genera is extended to include China. The Henan crinoid fauna is from the early Asselian; it may be helpful in understanding migration routes of fossil taxa and will be of fundamental value in helping paleontologists undertake paleogeographic reconstructions of the Permian globe.

Materials

Repository and institutional abbreviation.—All specimens are deposited in the Nanjing Institute of Geology of Paleontology (NIGP), Chinese Academy of Sciences (NIGPAS).

Systematic paleontology

Crinoid morphologic terms follow Moore and Teichert (1978) with anal and radial facet modifications by Webster and Maples (2006, 2008). Measurement terminology follows Webster and

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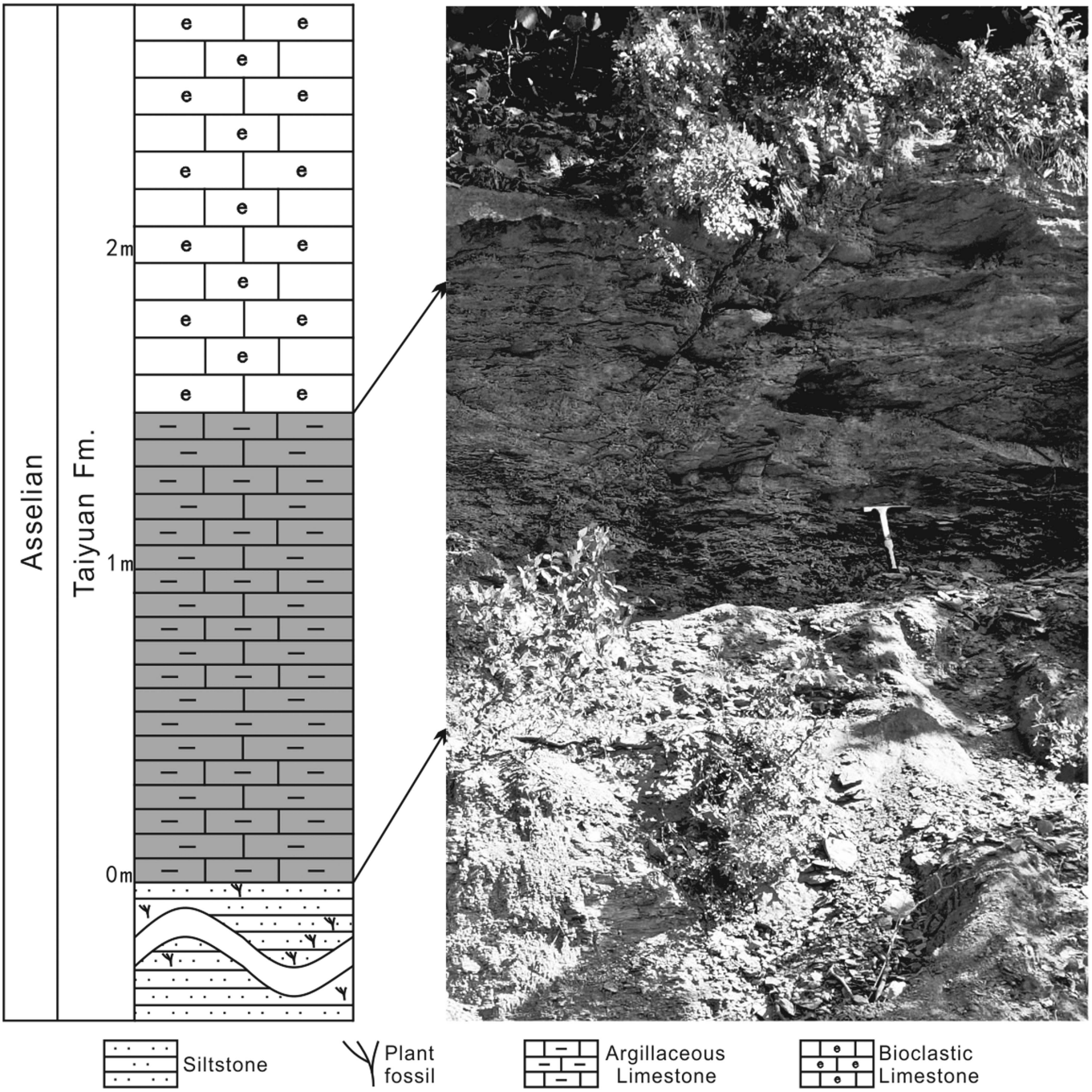

Figure 2. Stratigraphic log of the section at Tianxi Village, Shanying Town, southern Anyang City of Henan Province.

Jell (1999a). The classification follows Simms and Sevastopulo (1993), Wright et al. (2017), and Wright (2017b).

Class Crinoidea Miller, 1821
Subclass Pentacrinoidea Jaekel, 1894
Infraclass Inadunata Wachsmuth and Springer, 1885
Parvclass Cladida Moore and Laudon, 1943
Magnorder Eucladida Wright, 2017a
Clade Articuliformes Wright, 2017b
Cyathoformes incertae sedis
Family Stellarocrinidae, Strimple, 1961
Genus *Celonocrinus* Lane and Webster, 1966

Type species.—*Celonocrinus expansus* Lane and Webster, 1966.

Celonocrinus cf. *C. expansus* Lane and Webster, 1966
Figure 3.1–3.3

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Crown spreading out and curling back in over the top; dorsal cup faint low and broad shape; cup plates smooth. Basals pentagonal in outline, curved longitudinally. Radials

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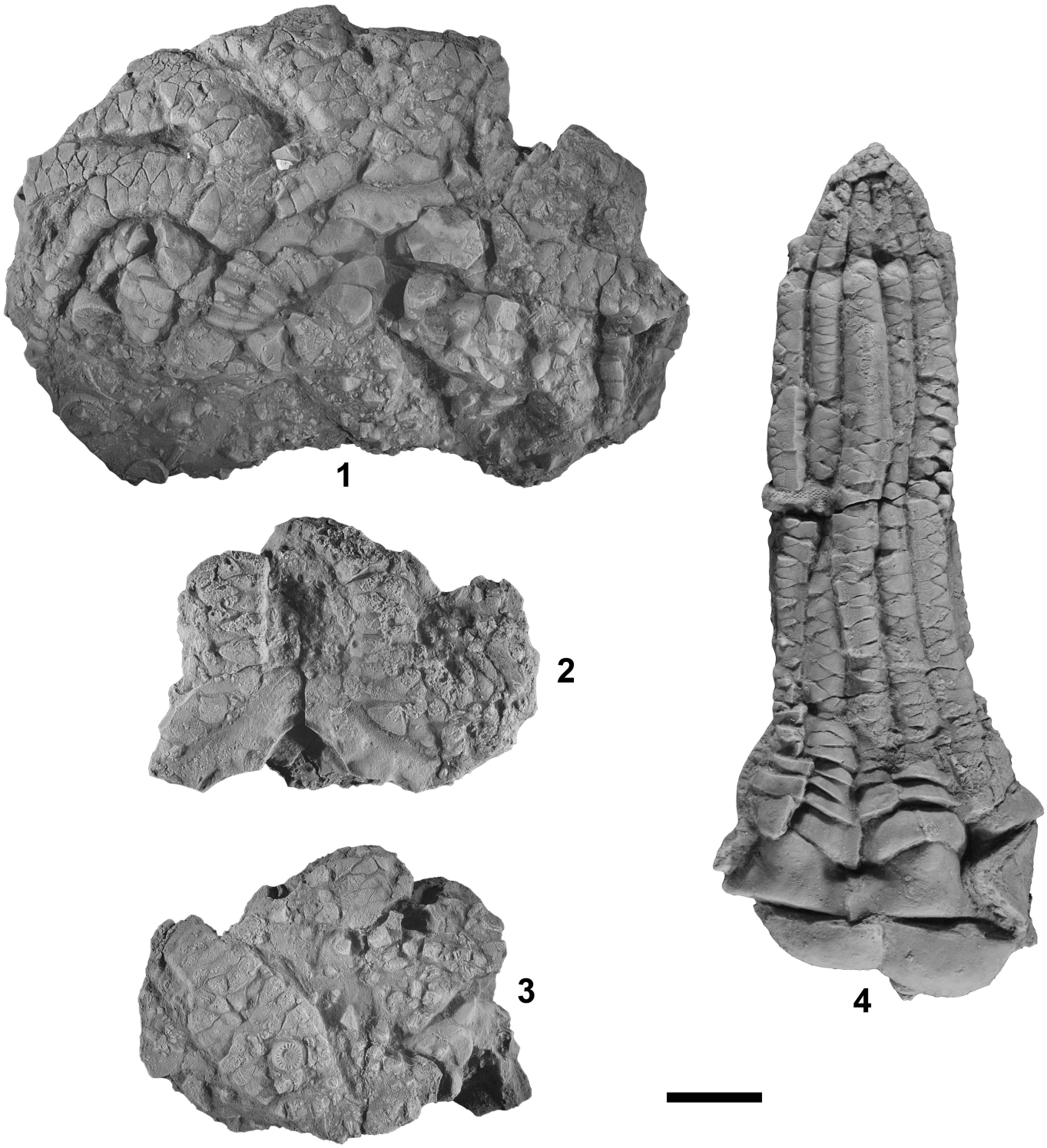

Figure 3. Crinoids from the Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block. (**1–3**) *Celonocrinus* cf. *C. expansus* Lane and Webster, 1966, NIGP 166462 and NIGP 166463; (**1, 2**) basal views; (**3**) oral view. (**4**) *Neoprotencrinus anyangensis* n. sp., holotype, NIGP 166464, lateral view. Scale bar = 1 cm.

gently convex, short, much wider than long, with long basal-radial sutures that meet at a high angle; radial facet plenary, in contact with first primibrachial in the middle and first secundibrachials at lateral edges.

Arms branch isotomously twice, adjacent branches not in lateral contact proximally; first primibrachial small, short, triangular, and axillary in all rays, failing to extend fully across radials; first secundibrachials quadrangular, biserial, with angulated edges, in contact with the radial at lateral edges; higher branches on about secundibrachial eight; all brachials are broad, with flat outer surface. Column transversely round with crenulae.

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Table 2. Measurements for *Celonocrinus* cf. *C. expansus* specimens. Units = mm.

Plates/specimens	NIGP 166462	NIGP 166463
Length basal	5.8	
Width basal	8.2	
Length radial	4.7	5.5
Width radial	14	18
Length primibrachial 1	3	4
Width primibrachial 1	7	5
Length primibrachial 2	1.8	2
Width primibrachial 2	6.3	6.8

Measurements for plates of the specimens are given in Table 2.

Materials.—Figured specimens NIGP 166462 and NIGP 166463.

Remarks.—The two cups are not well preserved; NIGP 166462 (Fig. 3.1) retains one relatively complete radial, one basal, and 12 arm fragments, but only two fragmentized arms and radials of NIGP 166463 are preserved (Fig. 3.2, 3.3). Although not complete, the pentagonal basals, wide and short radials, radial facet in contact with both first primibrachial and first secundibrachials, wide and flat arms and flat brachials, and branching mode are very suggestive of *Celonocrinus expansus*.

Superfamily Erisocrinacea Wachsmuth and Springer, 1886
Family Erisocrinidae Wachsmuth and Springer, 1886
Genus *Neoprotencrinus* Knapp, 1969

Type species.—*Paradelocrinus subplanus* Moore and Plummer, 1940.

Neoprotencrinus anyangensis new species
Figure 3.4

Holotype.—NIGP 166464.

Diagnosis.—*Neoprotencrinus* with radials not in basal circlet, primibrachials and six uniserial secundibrachials, and slightly impressed sutures.

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Crown elongate cylindrical, length 85 mm; cup low bowl shape, length 6.5 mm, width 27 mm; basal concavity very shallow to flat; plates smooth, sutures depressed. Basals not visible in side view; radials large, length 6.5 mm, width 14 mm, width commonly about twice the length. Proximal tips of radials not in the basal circlet; radial facets plenary. No anal plates visible with arms attached. Arms 10, moderately long, closely appressed; branching isotomously on first primibrachials; first primibrachials slightly spinose; primibrachials and six uniserial secundibrachials.

Etymology.—Named after Anyang city, Henan Province, which hosts the type locality.

Material.—Holotype: NIGP 166464.

Remarks.—One flattened specimen is assigned to *N. anyangensis*. Only one side of holotype NIGP 166464 (Fig. 3.4) is preserved and is slightly crushed without anal plates. Large first secundibrachials are followed by five quadrate uniserial secundibrachials with the sixth uniserial secundibrachials with an angular distal suture for the reception of the first wedge-shaped brachial. Thereafter, the brachials are biserial.

Webster and Kues (2006) moved *Neoprotencrinus* from the Protencrinidae, transferring it to the Erisocrinidae because of its biserial arms. *Neoprotencrinus* are reported from the Pennsylvanian of the United States, including one species, *N. brachiatus* Moore and Plummer, 1940, with the arms preserved. The differences in shape of the radials and primibrachials along with the difference in the number of nonbiserial secundibrachials are the justification for the species. *N. anyangensis* is distinguished from *N. brachiatus* by the nonbiserial secundibrachials, from *N. gutschicki* Webster and Kues, 2006 by more impressed sutures, and from *Neoprotencrinus cranei* Strimple, 1949, *N. regulates* Strimple, 1949, *N. disculus* Strimple, 1949, and *N. subplanus rockensis* Moore and Plummer, 1940 by proximal tips of radials not in the basal circlet.

Family Protencrinidae Knapp, 1969
Genus *Protencrinus* Jaekel, 1918

Type species.—*P. moscoviensis* Jaekel, 1918.

Protencrinus baliensis Webster, 2012b
Figure 4.1–4.3

Occurrences.—Early Permian, series undesignated, Crete, Greece; Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Cup flat bowl shape (Fig. 4.3), medium-sized basal concavity, pentagonal in oral outline, smooth plate sculpturing, length 5 mm, width 23 mm. Infrabasals five, pentagonal, truncated distally in contact with radials, equal size, longer than wide, length 5 mm, width 4 mm; infrabasal circlet confined to basal concavity, down-flaring. Basals five, small quadrangular, not in lateral contact (Fig. 4.1), length 3 mm, width 3 mm, proximal tips in basal concavity, distal tips up-flaring with tips barely visible in lateral view. Radials five, hexagonal, much wider than long, length 5 mm, width 14 mm, gently convex transversely, moderately convex longitudinally, proximal tips in basal concavity, distally up-flaring form lateral walls; radial facet plenary (Fig. 4.2), deep ligament pit; narrow outer marginal area; deep central pit and intermuscular furrow; muscle fields shallowly concave; narrow lateral ridges. Anal notch not visible in lateral view with a narrow distinct V-shaped groove on the internal edge (Fig. 4.3). Column facet circular, 4 mm in diameter, impressed in infrabasal circlet.

Material.—Figured specimen NIGP 166465.

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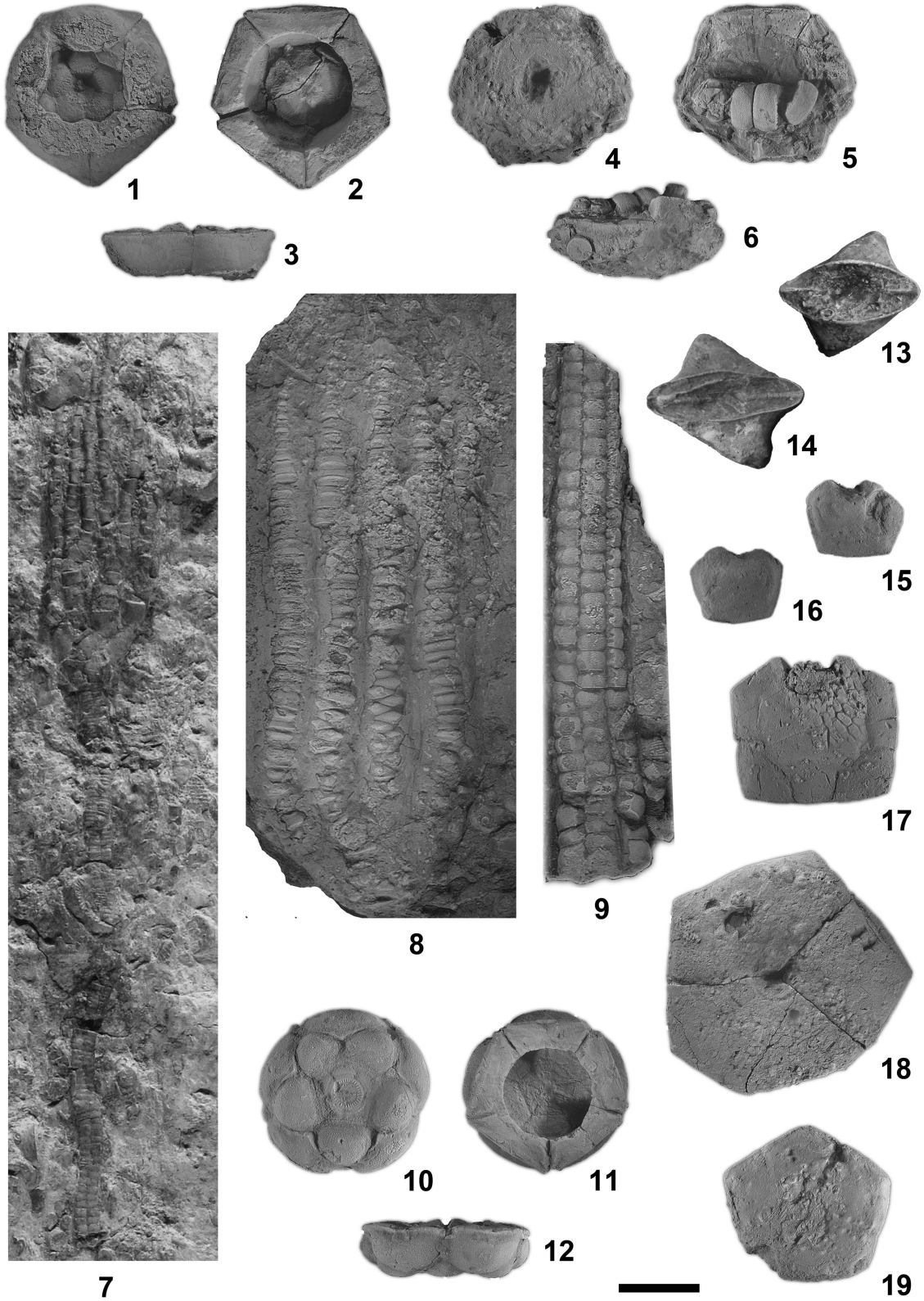

Figure 4. Crinoids from the Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block. (**1–3**) *Protencrinus baliensis* Webster, 2012b, NIGP 166465, basal, oral, and lateral posterior views; (**4–6**) *Apographiocrinus* sp., NIGP 166466, basal, oral, and lateral posterior views; (**7**) gen. indet. sp. indet., NIGP 166467, lateral view; (**8**) family indet. gen. indet. sp. indet., NIGP 166468, lateral view; (**9**) Anal sac indeterminate, NIGP 166469, lateral view; (**10–12**) *Sinocrinus sheareri* Strimple and Watkins, 1969, NIGP 166471, basal, oral, and lateral posterior views; (**13–19**) platycrinitid gen. indet. sp. indet., NIGP 166477–166483; (**13, 14**) facet views of columnals; (**15–17**) radial plates, basal views; (**18, 19**) basal circlets, basal views. Scale bar = 1 cm.

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Remarks.—One well-preserved cup is assigned to *P. baliensis* Webster, 2012. It has a little deeper basal concavity than the specimens illustrated by Webster (2012b). The stratigraphic range of *Protencrinus* is Pennsylvanian to early Permian, and the paleogeographic range is North America, Russia, and Crete and, herein, is extended to North China.

Superfamily Apographiocrinoidea Moore and Laudon, 1943
Family Apographiocrinidae Moore and Laudon, 1943
Genus *Apographiocrinus* Moore and Plummer, 1940

Type species.—*A. typicalis* Moore and Plummer, 1940.

Apographiocrinus sp.
Figure 4.4–4.6

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Cup low bowl shape (Fig. 4.6), length 6.6 mm, width 22.2 mm; basal cavity deeply concave in middle of cup; plates of cup slightly bulbous with fine nodose sculpture. Infrabasals not preserved, leaving small five-pointed star at bottom of basal concavity (Fig. 4.4). Proximal part of basals in basal plane, interbasal sutures faint. Radials five, length 5.5 mm, width 11.5 mm; transversely convex giving slightly scalloped appearance to summit of radials in dorsal view; radial articular facets thick, plenary, not well preserved in B, C, and D rays; ligament pits well defined, transverse ridge prominent with fine denticles; narrow, deep lateral furrows in E and A rays (Fig. 4.5). Single anal plate in cup between posterior radials, extending above radial summit (Fig. 4.6).

Material.—Figured specimen NIGP 166466.

Remarks.—The specimen is assigned to the *Apographiocrinus* on the basis of low bowl shape, small basal concavity, slightly bulbous plates, and single anal plate, but not preserved infrabasals, crushed plate surfaces, and faint sutures cannot be identified to a species. Judging from the phylogenetic position and the developmental biology of living crinoids, the single anal plate is almost certainly the radianal (Wright, 2015).

Family Pachylocrinidae Kirk, 1942
Genus indeterminate species indeterminate
Figure 4.7

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Crown slender, cylindrical; cup slightly crushed, truncate bowl shape. Arms uniserial, faintly pinnulate; arm branching isotomously on primibrachial 1 and higher on secundibrachials 5 or 6; brachials narrow and long, rectangular to cuneate. Crushed column long.

Material.—Figured specimen NIGP 166467.

Remarks.—This specimen is assigned to Pachylocrinidae for truncate bowl shape, uniserial arms, and branching isotomously twice, but it is too incomplete to assign to a genus.

Family indeterminate
Genus indeterminate species indeterminate
Figure 4.8

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—One poorly preserved slender elongate cylindrical cladid crown with a low conical-shaped cup (Fig. 4.8). Four uniserial arms of two rays in enclosed lateral contact, branching on primibrachials 1; brachials very wide, rectangular to cuneate, ornament coarse nodes.

Material.—Figured specimen NIGP 166468.

Remarks.—This specimen is heavily weathered and cannot be identified to a genus.

Anal sac indeterminate
Figure 4.9

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Material.—Figured specimen NIGP 166469.

Remarks.—A partial anal sac consisting of three columns of plates moderately well preserved is not identifiable (Fig. 4.9). Plates are hexagonal and bulbous and interlock laterally with adjacent plates; distinctive one to three variable lengths along the lateral edges of some plates.

Superfamily Cromyocrinoidea Bather, 1890
Family Cromyocrinidae Bather, 1890
Genus *Ulocrinus* Miller and Gurley, 1890

Type species.—*U. buttsi* Miller and Gurley, 1890.

Ulocrinus qiaoi new species
Figure 5.1–5.4

Holotype.—NIGP 166470.

Diagnosis.—Distinguished by the thick plates, pronounced irregular protrusions on plates, and three anals in cup.

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Cup high conical with convex base (Fig. 5.1, 5.2), length 20 mm, width 42.7 mm; plate sculpture irregular pronounced bulbous protrusions, impressed sutures; three cup circlets all visible in side view. Infrabasals five, up-flared strongly, length 6 mm, width 7 mm. Basals five, unequal size, hexagonal, large, length 12 mm, width 12.2 mm; basals larger than infrabasals. Radials five, pentagonal, unequal size, much

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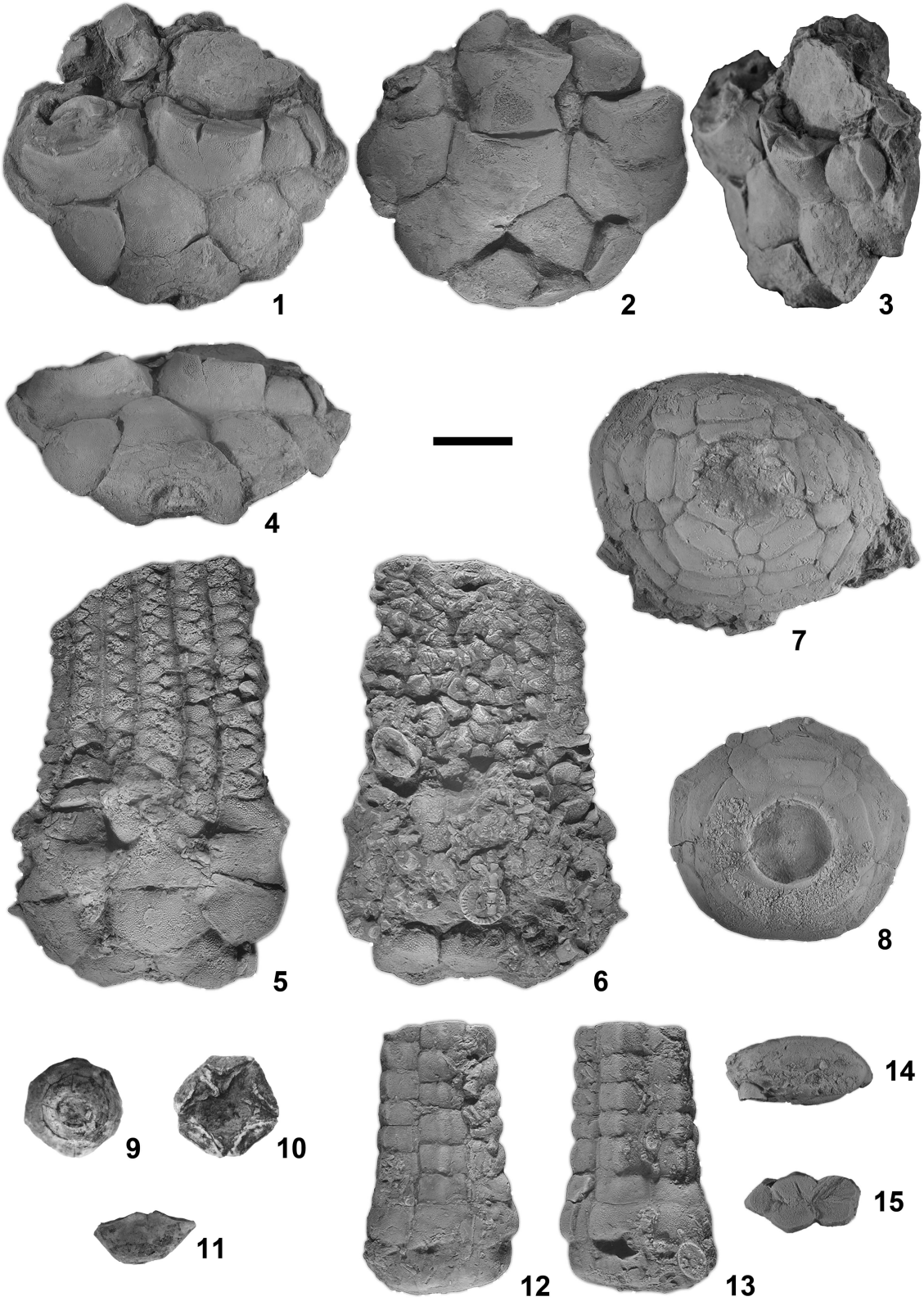

Figure 5. Crinoids from the Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block. (**1–4**) *Ulocrinus qiaoi* n. sp., holotype, NIGP 166470, lateral view, B ray view, anal view, and basal view; (**5, 6**) *Erisocrinus* cf. *E. longwelli* Lane and Webster, 1966, NIGP 166472, lateral view; (**7, 8**) *Artichthyocrinus limani* n. sp., holotype and paratype, NIGP 166473 and NIGP 166474, basal view of holotype and paratype; (**9–11**) *Synbathocrinus campanulatus* Wanner, 1916, NIGP 166475, basal, oral, and lateral posterior views; (**12–15**) *Synbathocrinus chenae* n. sp., NIGP 166476, A ray view, anal view, basal view, and oral view. Scale bar = 1 cm.

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wider than long, length 9.4 mm, width 15.5 mm; articular facets plenary, subhorizontal broad, transverse ridge marked by fine crenulations (Fig. 5.1). Three anal plates in cup, large primanal (equivalent to the radianal) obliquely between two basals, mostly to left of C radial, not in contact with D radial, supporting secundanal (equivalent to the anal X) and tertanal above (Fig. 5.3). Arms transversely well rounded, branching isotomously on first primibrachials; three thick first primibrachials (Fig. 5.2), length 6 mm, width 13 mm; secundibrachials cuneate in proximal portions, length 4 mm, width 6.8; distal part of arms not preserved. Column circular, 6 mm in diameter (Fig. 5.4).

Etymology.—The specific name is in honor of amateur collector Mr. Qiao Liman, Anyang, for help with fieldwork.

Material.—Holotype: NIGP 166470, only known specimen of this species.

Remarks.—The partial crown of *U. qiaoi* n. sp. is crushed flat. It differs from the most similar *U. neverovoensis* Mirantsev and Rozhnov, 2011 by having thicker plates and more impressed sutures. The new species also differs from *U. grishini* Mirantsev and Rozhnov, 2011 in the less elongate cup and relatively long infrabasal circlet and differs from *U. karchevskyi* Mirantsev and Rozhnov, 2011 in the strongly up-flared infrabasal circlet. It differs from all North American congeners in the presence of surface ornamentation.

Superfamily Erisocrinacea Wachsmuth and Springer, 1886
Family Erisocrinidae Wachsmuth and Springer, 1886
Genus *Sinocrinus* Tien, 1926

Type species.—*Sinocrinus granulatus* (Wanner, 1924).

Remarks.—Note *Sinocrinus* was erected based on *Sinocrinus microgranulosus* Tien, 1926, which is a junior subjective synonym of *Sinocrinus granulatus* Wanner, 1924 (cf. Sheffield, 2015).

Sinocrinus sheareri Strimple and Watkins, 1969
Figure 4.10–4.12

1969 *Sinocrinus sheareri* Strimple and Watkins, p. 182, pl. 39, figs. 8–11.

1976 *Sinocrinus asymmetricus*; Strimple, p. 636, fig. 3A–B.

1977 *Sinocrinus sheareri*; Webster, p. 156.

1986 *Sinocrinus asymmetricus*; Webster, p. 284.

2015 *Sinocrinus sheareri*; Sheffield, p. 468, figs. 7, 9A–C.

Occurrences.—Pennsylvanian, Atokan, Big Saline Formation, Soldiers Hole Member, United States, Texas; Pennsylvanian, Moscovian, Bashkirian? Spain; Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Dorsal cup flat, asymmetrically bowl-shaped (Fig. 4.12), length 6 mm, width 21.4 mm; plate ornamentation dense nodes, impressed sutures. Infrabasals five, fuse into a single plate, not in contact with radials; infrabasal circlet subhorizontal, positioned slightly above basal plane, width 8.3 mm, not as high as radial circlet; only basal and radial plates visible in side view. Basals five, tumid, unequal size with the smallest one in the posterior, the proximal portion of basals in the basal plane and the distal portion sharply upward to form part of lateral walls, length 6 mm, width 6 mm; interbasal sutures short. Radials tumid, equal size, the proximal tips of radials in basal plane of cup but not entering basal concavity, length 5.2 mm, width 11.8 mm; radial facets plenary (Fig. 4.11), outer ligament furrow poorly developed, sharply defined ligament pit, wide transverse ridges bearing fine denticles, well-developed oblique furrows, broad muscle scars, and small V-shaped intermuscular notch. No anal plate in external view, small internal anal notch on distal extremities of adjacent C and D radials in Figure 4.12. Column large, circular, with strongly crenulated cicatrix.

Material.—Figured specimen NIGP 166471.

Remarks.—Sheffield (2015) refined *Sinocrinus* Tien, 1926 using principal component analysis and neighborhood cluster analysis and extended the temporal span of the genus from the late Carboniferous (Moscovian) through the early Permian (Sakmarion). *Sinocrinus asymmetricus* Strimple, 1976 was rejected as the junior synonym of *S. sheareri* Strimple and Watkins, 1969 because of their qualitative and quantitative similarities with one another.

Sinocrinus is mainly reported from the Houkou Limestone, Taiyuan Series of northern China. This specimen is distinguished from *S. microgranulosus* Tien, 1926, *S. microgranulosus pentalobus* Tien, 1926, and *S. linchenensis* Tien, 1926 in having a proportionately lower, asymmetric dorsal cup, a proportionately larger column, lesser part of basals in cup walls, and short interbasal sutures. Three other forms are described by Tien (1926) as S. *houkouensis*, *S. nodosus*, and *S. nodosus spinosus* based on disarticulated plates.

Sinocrinus sheareri has been reported from the Pennsylvanian of United States and Spain. One well-preserved specimen is assigned to *S. sheareri*, extending the stratigraphic range of *S. sheareri* to early Permian and the paleogeographic range to include China.

Genus *Erisocrinus* Meek and Worthen, 1865.

Type species.—*E. typus* Meek and Worthen, 1865.

Erisocrinus cf. *E. longwelli* Lane and Webster, 1966
Figure 5.5, 5.6

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Partial crown crushed flat, elongate cylinder (Fig. 5.5), length 52.7 mm; dorsal cup large, medium bowl-shaped, length 13 mm, width 33 mm; plate ornament dense nodes. Infrabasals not preserved. Basals large, length 7.8 mm, width 11 mm, two preserved in Figure 5.5 and two visible in Figure 5.6. Radials large, length 8 mm, width 14 mm, swollen

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slightly in middle; radial facets plenary; no discernible notch for an anal plate between any of the radials or above the cup view from the well-preserved side. Six total arms on one side, branching isotomously on large first primibrachials, biserial, slightly convex, closely apposed; first primibrachial large, quadrangular, more than twice as wide as long, length 6 mm, width 14 mm, strongly spinose, supporting a large quadrangular first secundibrachial on each shoulder; first secundibrachial quadrangular, length 3.8 mm, width 7 mm; secundibrachial 2 smaller than first secundibrachial, biserial just above the first secundibrachial, brachials smaller distally. Column circular.

Material.—Figured specimen NIGP 166472.

Remarks.—The specimen most closely resembles *E. longwelli* in size, but the infrabasals and the other side are crushed. Thus, it is assigned to *Erisocrinus* cf. *E. longwelli*.

Superorder Flexibilia Zittel, 1895
Order Sagenocrinida Springer, 1913
Superfamily Sagenocrinoidea Roemer, 1854
Family Euryocrinidae Moore and Strimple, 1973
Genus *Artichthyocrinus* Wright, 1923

Type species.—*Artichthyocrinus springeri* Wright, 1923.

Artichthyocrinus limani new species
Figure 5.7, 5.8

Holotype.—NIGP 166473.

Diagnosis.—*Artichthyocrinus* with circular column impression covering infrabasals, basals, and most of radials. Circlet of plates beyond column impression includes interradials and anal plates.

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Crown bowl-shaped with a shallow depressed base, wider than long; cup discoid (Fig. 5.7, 5.8); broad shallow calyx formed by rigidly sutured plates; plates smooth, much wider than long, sutures flush. Infrabasal and basal circlets entirely concealed by proximal columnal. Radials five, much wider than long, widely out-flaring, lateral sutures fused in part; radial facets plenary, not exposed; one column of interradial plates in each interray, interradials and anal plates not easy differentiated, interradials in AB, BC, and AE relatively larger; smallest anal plate followed by additional small quadrangular or hexagonal plates in posterior interray. Arms branching on primibrachials 2; arms nearly flat outer surfaces; brachials fitted smoothly together laterally or interlocked. Column circular, large, impression surrounded by a flange. Measurements for plates of the specimens are given in Table 3.

Etymology.—The specific name is after Mr. Qiao Liman, Anyang, the collector of the holotype.

Table 3. Measurements for *Artichthyocrinus qiaoi* n. sp. specimens. Units = mm.

Plates/specimens	NIGP 166473	NIGP 166474
Width crown	37	30
Width cup	15	13
Length radial	2	1.5
Width radial	8	6
Length primibrachial 1	3	3
Width primibrachial 1	9	8
Length primibrachial 2	3.5	4
Width primibrachial 2	10	10.5
Length secundibrachial 1	2.5	2.8
Width secundibrachial 1	7.5	6.5
Diameter of column	11	10

Materials.—Holotype: NIGP 166473; paratype: figured specimen NIGP 166474.

Remarks.—Two specimens are assigned to *A. limani* n. sp. The crown of holotype, NIGP 166473 (Fig. 5.7), is slightly distorted, only two secundibrachials are preserved, and the distal parts of the arms are lost. Paratype NIGP 166474 (Fig. 5.8) is relatively smaller, only one secundibrachial in each ray, distal parts of the arms are lost, and the suture lines between these plates cannot be determined with certainty.

A. limani n. sp. differs from *A. springeri* Wright, 1923 and *A. koenigi* Webster, 2012b in having a column of interradials, more anal plates, and no basals extending beyond the circular column impression. The paleogeographic range of *Artichthyocrinus* extended to include China.

Parvclass Disparida Moore and Laudon, 1943
Superfamily Belemnocrinacea Miller, 1883
Family Synbathocrinidae Miller, 1889
Genus *Synbathocrinus* Phillips, 1836

Type species.—*Synbathocrinus conicus* Phillips, 1836.

Synbathocrinus campanulatus Wanner, 1916
Figure 5.9–5.11

1916 *Symbathocrinus campanulatus* Wanner, p. 16, pl. 96, figs 5, 6; text-figs 3, 4.

1924 *Symbathocrinus campanulatus*; Wanner, p. 310, pl. 20, figs 23–25.

1942 *Synbathocrinus campanulatus*; Moore and Ewers, p. 105.

1943 *Synbathocrinus campanulatus*; Bassler and Moodey, p. 694.

1948 *Synbathocrinus campanulatus*; Branson, p. 215.

1973 *Taidocrinus campanulatus* (Wanner); Webster, p. 252.

1973 *Taidocrinus inflatus* (Wanner); Webster, p. 252.

1987 *Synbathocrinus campanulatus*; Webster, p. 114, Figs. 9A–L; 10A–D.

1993 *Synbathocrinus campanulatus*; Teichert and Webster, p. 4, pl. 65, figs. 7–10.

1993 *Synbathocrinus campanulatus*; Webster, p. 114.

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Occurrences.—Early Permian, late Sakmarian, Callytharra Formation, Western Australia, Australia; Permian, Artinskian, Basleo, West Timor; Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—One well-preserved dorsal cup small, medium conical, truncate base with shallow basal concavity, length 4 mm, width 12.5 mm, perfect pentameral symmetry except very small anal plate articulated to mutual shoulders of C–D radial (Fig. 5.11); plate ornamentation nodose, flush sutures; basals and radials expand in width distally constant to slightly increasing rate of distal widening. Basals three, low, unequal, with small one in A–E interray, length 1.5 mm; the basal circlet visible in side view of cup, width 7 mm; ratio of basal circlet length/distal basal circlet width is 0.21, and basal plate circlet 37.5% of aboral cup length. Radials up-flaring, length 2.5 mm, distal-to-proximal radial plate width ratio about 1.79; radial articular facets plenary, subhorizontal, narrowing orally, triangular shape, with transverse ridge and ligament pit; anal notch obvious V-shape on distal extremities of adjacent C and D radials. Column circular.

Material.—Figured specimen NIGP 166475.

Remarks.—Webster (1987) pointed out that the degree of the anal notch of *Synbathocrinus* has varied throughout the geological range of the genus and is not a reliable specific or generic character and recommended the suppression of *Taidocrinus* as a subjective junior synonym of *Synbathocrinus*.

Synbathocrinus chenae new species
Figure 5.12–5.15

Holotype.—NIGP 166476.

Diagnosis.—Distinguished by low bowl-shaped cup, slender elongate anal plate, relatively long, wide transversely convex brachials.

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Crown elongate, slender (Fig. 5.12, 5.13), length 32 mm; cup small, broadly bowl-shaped, length 5.5 mm, width 19 mm; sutures between plates slightly impressed; plate sculpturing coarse nodes; basal circlet slightly impressed. Radials five, subquadrangular in outline, slightly wider than long, length 5.2 mm, width 6.8 mm, distal inclinate; narrow and deep concavity between radials and primibrachials; articular facets plenary. Anal plate slender, elongate, in notch on C and D radials, and nearly out of the cup (mostly above the cup). Arms five, long and slender, atomous, closely appressed when enclosed, only seven primibrachials preserved in each ray; first primibrachial approximately as wide as radial, quadrangular, gently convex, length 4.7 mm, width 6.8 mm; second primibrachial wider than long, length 3 mm, width 5.7 mm; brachials relatively long, wide, convex; longitudinal ridges present in middle of each brachial. Column circular.

Etymology.—The specific name honors Mrs. Chen Guangjü, the holotype collector.

Material.—Holotype: NIGP 166476, only known specimen of this species.

Remarks.—The holotype NIGP 166476 of *S. chenae* n. sp. is elongate and slender, and the distal portions of the arms are not preserved (Fig. 5.12, 5.13). The basal of the cup is crushed and flattened, resulting in an elliptical column scar and small basal circlet (Fig. 5.14).

S. chenae n. sp. is assigned to the Synbathocrinidae on the basis of confinement of the elongate and slender crown, small bowl-shaped cup, wide and inclinate radial articular facets, five arms, and anal plate notching upper corners of C and D radials and nearly out of cup. It differs from most *Synbathocrinus* species in the low bowl-shaped cup and relatively long, wide, and convex brachials.

Subclass Camerata Wachsmuth and Springer, 1885
Infraclass Eucamerata Cole, 2017
Order Monobathrida Moore and Laudon, 1943
Suborder Glyptocrinina Moore, 1952
Superfamily Platycrinitacea Austin and Austin, 1842
Family Platycrinitidae Austin and Austin, 1842
Genus indeterminate species indeterminate
Figure 4.13–4.19

Occurrence.—Taiyuan Formation, Dajian Member, early Permian (Asselian), Anyang, Henan, North China Block.

Description.—Several loose ossicles of unidentified platycrinitids, including two columnals (Fig. 4.13, 4.14), three radials (Fig. 4.15–4.17), and two basal circlets (Fig. 4.18, 4.19).

NIGP 166477–166478, two columnal nodals, much wider than long, bearing elliptical articula with latus smooth; angular divergence of upper and lower fulcra about 65° on opposite sides of the nodals in facet view.

NIGP 166479–166481, radial plates, subquadrangular in outline, being slightly wider than long; articulate facets rather narrow, less than half width; NIGP 166479 (length 10.2 mm, width 11.8 mm) and NIGP 166480 (length 10.2 mm, width 11.2 mm) quite smaller with a smoother surface than NIGP 166481 (length 18 mm, width 20.5 mm).

NIGP 166482 and 166483, two different basal circlets with perfect pentamerous symmetry; NIGP 166482, three smooth plates, width 30 mm; NIGP 166483, five plates with irregular nodes on the surface, width 21.2 mm.

Materials.—Figured specimens NIGPA 166477–166483.

Remarks.—Ausich and Kammer (2009) summarized the generic concepts of Platycrinitidae. The occurrence of thecal ossicles of *Platycrinites* in lower Permian rocks has been reported several times from Australia (Etheridge, 1892; Marez Oyens, 1940; Webster and Jell, 1999b), Timor (Wanner, 1916), China (Tien, 1926), Russia (Yakovlev and Ivanov, 1956), the United States (Webster and Lane, 1967; Broadhead and Strimple, 1977), and Oman (Webster and Sevastopulo, 2007).

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The taxonomy of platycrinitids is, to a great extent, based on arm-branching patterns and tegmen plate arrangement. Such characters have no value in dealing with loose plates.

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