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Research paper

# New Pennsylvanian (Moscovian) echinoderms from Xinjiang Uyghur Autonomous Region, western China

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## Abstract

The few Pennsylvanian echinoderm faunas reported from the Paleotethys are from China, Japan, and Australia. The Japanese and Chinese faunas contain camerates that are rare in Pennsylvanian faunas worldwide. Genera of one monobathrid camerate, two disparids, five cladids, one flexible, one blastoid, and one archaeocidarid are reported from the late Moscovian uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation in the Taoshigo Valley near Taoshuyuan Village, Xinjiang Uyghur Autonomous Region, China. They are here referred to as the Aoertu fauna, which is most closely allied with Pennsylvanian crinoids reported from a slightly older fauna from the Qijiagou Formation in the Taoshigo Valley and with faunas known from Japan and North America. Most taxa are identified to the genus level and left in open nomenclature because of poor or partial preservation. In addition, camerate ossicles and a cup of *Synbathocrinus* are reported from the early Moscovian part of the Sanquanzi Formation at Yamansu, southeast of the Taoshigo Valley. New taxa described are: *Synbathocrinus labrus* n. sp., *Stellarocrinus qijiagouensis* n. sp. and *Metaperimestocrinus aoertuensis* n. sp.

*Keywords:* Echinoderms; Pennsylvanian; Moscovian; Qijiagou Formation; Sanquanzi Formation; Northwest China

## 1. Introduction

Pennsylvanian crinoids rarely have been reported from the Paleotethys. This is the fifth report of Pennsylvanian crinoids from China and is herein referred to as the Aoertu fauna. Tien (1926) described a small cladid-dominated fauna from northern China based on disarticulated plates and cups reconstructed from specimens that were partly dislocated. A moderately diverse Pennsylvanian, Moscovian, crinoid fauna was described by Lane et al. (1996) and Webster et al. (2009) from the Qijiagou Formation in the Taoshigo Valley, of western China. That fauna was dominated numerically by camerates, which is highly unusual for Pennsylvanian crinoid faunas. A reportedly Pennsylvanian

cup from western Yunnan described by Chen and Yao (1993) was demonstrated to be Permian by Wang et al. (2007).

The majority of the taxa described below were collected in 1995 by J. Waters, N.G. Lane, C.G. Maples, and Z.T. Liao in a carbonate bed in the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation. The specimens were collected at latitude 43° 19' 01" N, longitude 88° 52' 52" E near Taoshuyuan Village and near the section in the Taoshigo Valley described by Lane et al. (1996) (Fig. 1). This locality is part of a section described by Liao et al. (1987) and discussed in Carroll et al. (1995). Part of the uncertainty about the stratigraphic placement of the crinoid-bearing limestones results from differing definitions of the boundary between the Qijiagou and Aoertu formations. Liao et al. (1987) placed the boundary between the formations below the youngest limestones, which contain the echinoderm faunas, but Carroll et al. (1995) placed the boundary above these limestones. Wang (1988) and Liao et al. (1992) discussed the same stratigraphic interval near Urumqi and recognized up to 66 m of limestone in the basal part of the

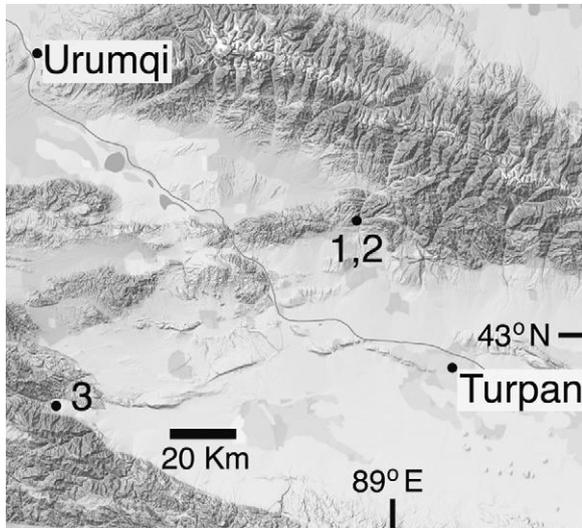


Fig. 1. Map showing localities in the Qijiagou Formation in Taoshiago Valley and the Aoertu Formation near Taoshuyuan Village (1 and 2) and Yamansu (3) in the Xinjiang Uyghur Autonomous Region, northwestern China. Latitude and longitude coordinates of collecting localities given in text.

Aoertu Formation. The age of these beds is late Moscovian based on fossil assemblages described in Liao et al. (1987).

In addition, numerous disarticulated blastoid radials were collected from a coeval locality at latitude  $43^{\circ}01.016'N$ , longitude  $87^{\circ}36.36'E$ . The specimens were collected from thinly bedded limestones interlayered with maroon and green shales. The limestone is a poorly bedded crinoidal grainstone. Also included in this report are some platycrinid plates and a synbathocrinid cup from an early Moscovian horizon in the Sanquanzi Formation near Yamansu, Hami county at latitude  $41^{\circ}54.196'N$ , longitude  $93^{\circ}42.588'E$ . The Qijiagou fauna as modified by newer collections described by Webster et al. (2009), and specimens described in this report are listed in Table 1.

Approximately 2300 m of Upper Carboniferous and Permian rocks crop out near the village of Taoshuyuan including sections in the Taoshigo Valley (Liao et al., 1987). The Upper Carboniferous includes shallow-marine limestone and sandstone of the Qijiagou and Aoertu formations, which are interbedded with intermediate to felsic volcanic rocks and represent the transition from marine to continental deposition in an active-margin setting. The sediments were deposited as the central Tian Shan terrane converged with the Tarim block during the Carboniferous to form the Tian Shan orogenic belt. Marine carbonate environments persisted on Tarim's northwest margin and the Central Tian Shan terrane through late Carboniferous (Pennsylvanian) including those containing the echinoderm faunas described below. The active-margin nature of the sedimentation is recorded in the thick volcanoclastic debris flows deposited in the Qijiagou Formation that contained the echinoderm communities described by Lane et al. (1996) from the Taoshigo Valley. The faunas described in this paper are found in shallow-water carbonate grainstones and packstones that contain a small volcanic component.

Table 1

Comparison of the echinoderm taxa reported from a horizon within the Qijiagou Formation in the Taoshigo Valley and the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation near Taoshuyuan, western China. Note, four taxa (*Rhepocatillocrinus tienshanensis*, *Binariacrinus alvus*, *Bassocrinus abyssus*, and *Brabeocrinus asiaensis*) listed in the Qijiagou Formation were proposed by Webster et al. (2009). All except *Brabeocrinus* were new genera.

Qijiagou Fauna. Qijiagou Formation, Taoshigo Valley (Lane et al., 1996; Webster et al., 2009)	Aoertu Fauna. Uppermost part of Qijiagou or lowermost part of Aoertu Formation, near Taoshuyuan
<b>CAMERATES:</b>	<b>CAMERATES:</b>
<i>Platycrinites</i> (2+ species)	<i>Platycrinites</i> spp. (minimum 3 species)
Paragariocrinidae, 2 species	
<i>Actinocrinites</i>	<b>FLEXIBLES:</b>
Acrocrinidae	<i>Aexitrophocrinus</i> sp.
<b>DISPARIDS:</b>	<b>DISPARIDS:</b>
<i>Synbathocrinus</i> sp.	<i>Synbathocrinus labrus</i> n. sp.
<i>Rhepocatillocrinus tienshanensis</i>	
<b>CLADIDS:</b>	<b>CLADIDS:</b>
Cyathocrinitidae gen. and sp. indet.	Blothocrinid indeterminate
<i>Paragassizocrinus</i> sp.	<i>Stellarocrinus qijiagoensis</i> n. sp.
<i>Metacromyocrinus</i> sp.	<i>Dicromyocrinus</i> sp. 1
	undesignated
<i>Binariacrinus alvus</i>	<i>Dicromyocrinus</i> sp. 2
	undesignated
<i>Bassocrinus abyssus</i>	<i>Metaperimestocrinus aoertuensis</i> n. sp.
<i>Brabeocrinus asiaensis</i>	
Pirasocrinidae gen. indet.	<b>ECHINOIDEA:</b>
Catacrinidae gen. indet.	<i>Archaeocidaris</i> sp.
Cladid indeterminate	
<b>BLASTOIDEA:</b>	<b>BLASTOIDEA:</b>
Troosticrinidae genus indet.	Troosticrinidae genus indet.

## 2. Faunal analysis

The Aoertu echinoderm fauna is dominated by cladids both in diversity and individual numbers. Only one camerate, one disparid, four cladid genera, one flexible, one blastoid, and one echinoid occur among the 221 individuals identified to genus or family level (Table 2). However, there are at least seven unidentifiable crinoid genera in one lot of 17 radials, five of which are considered to be cladids and two that may belong to other crinoid groups. Thus the identifiable cladid genera in the Aoertu fauna are the dominant clade within the fauna while representing less than half of the total cladid diversity among the specimens.

Numerically *Metaperimestocrinus* may be the most abundant taxon in the Aoertu fauna. If indeterminate plates, among the disarticulated individuals, are disregarded, ossicles of *Metaperimestocrinus* are the most abundant (125 radials, brachials, and tegmen spines; 3 partial crowns). Although only three cups of *Metaperimestocrinus* were found, the 96 radials would represent a minimum of 20 additional individuals because there are 5 radials in one individual. However, because of their large size, the numbers of the *Metaperimestocrinus* plates compared with other taxa may represent collection bias. The large size also may have attributed to their preservation. *Dicromyocri-*

Table 2  
Number of specimens of taxa recognized in the Aoertu fauna.

Taxon	Number of specimens
<i>Platycrinites</i> spp. basal circler	2
<i>Platycrinites</i> spp. radials	5
<i>Platycrinites</i> spp. columnals	12
Platycrinid basal circler	1
<i>Synbathocrinus labrus</i> cups	4
Blothocrinid indet. cup	2
<i>Stellarocrinus quijiagouensis</i> crown	1
<i>Stellarocrinus quijiagouensis</i> arms	1
<i>Dicromyocrinus</i> sp. 1 cup	1
<i>Dicromyocrinus</i> sp. 1 infrabasal circler	2
<i>Dicromyocrinus</i> sp. 1 basals	2
<i>Dicromyocrinus</i> sp. 1 radials	1
<i>Dicromyocrinus</i> sp. 1 anals	1
<i>Dicromyocrinus</i> sp. 2 cups	2
<i>Metaperimestocrinus aoertuensis</i> crowns	3
<i>Metaperimestocrinus aoertuensis</i> radials	96
<i>Metaperimestocrinus aoertuensis</i> primibrachials	5
<i>Metaperimestocrinus aoertuensis</i> brachials	12
<i>Metaperimestocrinus aoertuensis</i> tegmen spines	12
<i>Aexitrophocrinus</i> sp.	1
Troosticrinid radial	1
<i>Archaeociadaris</i> sp. interamb plates	12
<i>Archaeociadaris</i> sp. spine	2
Radials, genus indeterminate	17
Columnals indeterminate	23
Total	221

*nus* cups (3 specimens) and ossicles (6 specimens) represent the second most abundant taxon in the fauna, followed by cup ossicles of *Platycrinites* (7 specimens) and *Synbathocrinus* (4 cups). Ossicles of both *Dicromyocrinus* and *Platycrinites* are large, which again may have attributed to their preservation and collection.

This report extends the geographic distribution of *Stellarocrinus* to China and is the first report of the genus outside North America. The genus was previously reported from Atokan-Virgilian strata of North America (Pabian and Rushlau, 2002; Webster, 2003). The paleogeographic distribution of *Dicromyocrinus* is extended to China and is the second report of the genus outside North America and Russia. Webster et al. (2004) reported the genus from the Serpukhovian and Bashkirian of Algeria. *Dicromyocrinus* is one of the longest ranging genera of the cromyocrinids, ranging from the Serpukhovian into the Virgilian (Webster, 2003; Webster et al., 2004).

The geographic distribution of *Metaperimestocrinus* is extended to China and is the first report of the genus outside North America. *Metaperimestocrinus* supports the Moscovian age of the Aoertu fauna because the genus previously was reported only from the Desmoinesian and Missourian of the U.S. (Webster, 2003).

*Synbathocrinus* ranges from the Devonian to Permian and is one of the few cosmopolitan crinoid genera (as compiled by Webster, 2003). The genus is common in equatorial and temperate faunas and was reported previously from the Tournaisian of Baoshan County in southwestern China (Chen and Yao, 1993). The apex of the genus was in the Mississippian. Most species are known from a single locality or a few localities in close geo-

graphic proximity to one another. Thus, species are of limited stratigraphic value, but the genus supports a Pennsylvanian age for the fauna.

Platycrinitids, ranging from the Devonian into the Permian, were most abundant in the Mississippian, cosmopolitan in the equatorial and temperate regions, and rare in the Pennsylvanian (Bowsher and Strimple, 1986). *Platycrinites* is the most common platycrinid in the Pennsylvanian, as noted by Webster (2003), largely because of its distinctive disarticulated cup plates and segmented twist columnals. The basal circler of an indeterminate platycrinid in the Aoertu fauna and a slightly older horizon at Yamansu probably represent a new genus.

*Aexitrophocrinus* is known from the Mississippian of Russia and Scotland, but is most diverse and common in the Pennsylvanian of North America (Webster, 2003). This is the first report of the genus from the Paleotethys, extending the Pennsylvanian paleogeographic range into China.

The record of fragmentary specimens of troosticrinid blastoids from the Aoertu Formation is the first occurrence of the family reported from Pennsylvanian-aged rocks worldwide, and may form a bridge between well documented troosticrinid genera from the Mississippian of North America and the Permian of Timor. The only other Asian report of troosticrinid blastoids is *Uyghuroblastus* from the Upper Devonian of Xinjiang Uyghur Autonomous Region, China (Lane et al., 1997).

In summary, the Aoertu fauna is dominated by cladids as are nearly all Pennsylvanian crinoid faunas. The Aoertu fauna is most closely allied with Pennsylvanian crinoids reported from a slightly older fauna in the Qijiagou Formation from the Taoshigo Valley (Lane et al., 1996; Webster et al., 2009) and with faunas described from Japan by Hashimoto (1984, 2001) as well as faunas reported by numerous authors from North America as listed by Webster (2003).

### 3. Systematics

The classification follows Simms and Sevastopulo (1993). Crinoid measurement terminology follows Webster and Jell (1999). Anal terminology follows Webster and Maples (2006). All specimens are deposited in the Nanjing Institute of Geology and Paleontology (NIGP).

Class BLASTOIDEA Say, 1825

Order TROOSTICRINIDA Bather, 1900, emend. Waters et Horowitz, 1993

Family TROOSTICRINIDAE Bather, 1899

Troosticrinid indeterminate

(Fig. 2R)

*Types*: Radial plate, NIGP 149185.

*Discussion*: Radial plates of an unidentified troosticrinid blastoid were collected from several localities in the Qijiagou and Aoertu Formations. The radials are large with a narrow ambulacral sinus. Embedded ambulacra are narrow with side plates overlapping lancets. Morphologically troosticrinid radials are diagnostic. These specimens are similar to radials seen in *Tri-coelocrinus*, which is known from the Mississippian of North

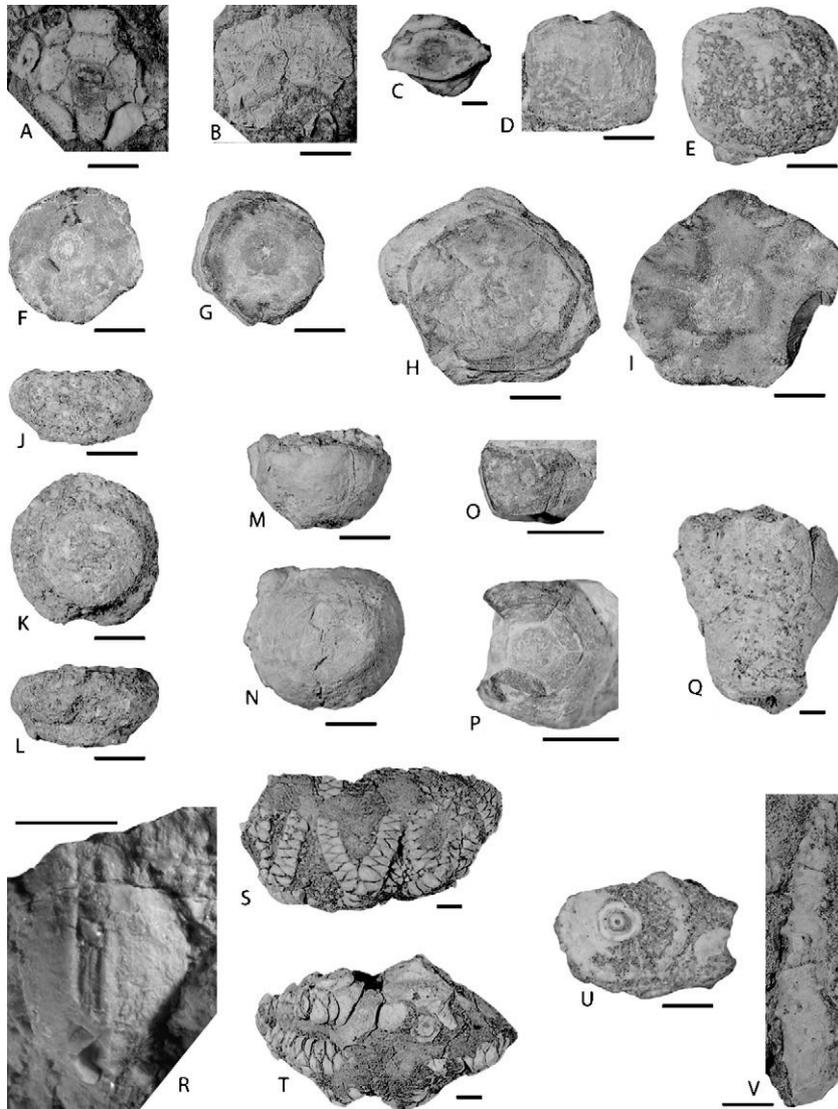


Fig. 2. Scale bar = 5 mm. (A) *Aexitrophocrinus* sp., NIGP 149184, basal view of weathered partial calyx. (B, F–I) Platycrinitid indeterminate; (B) NIGP 149154, oral view of weathered basal circllet; (F and G) NIGP 149156, aboral and oral views of basal circllet; (H and I) NIGP 149155, oral and aboral views of basal circllet. (C–E) *Platycrinites* sp.; (C) NIGP 419153, axial view of single internodal above nodal pluricolumnal; (D) NIGP 149151, lateral view of weathered radial; (E) NIGP 149152, lateral view of radial encrusted with fenestrate bryozoan. (J–N) *Synbathocrinus labrus* n. sp.; (J–L) paratype 2, NIGP 149159, A ray, basal and posterior view of matrix encrusted cup; (M and N) holotype, NIGP 149157, A ray and basal views of cup. (O and P) *Synbathocrinus* sp., NIGP 149161, lateral and basal views of cup, rays uncertain. (Q) Blothrocridid indeterminate, NIGP 149162, lateral view of partial cup, ray uncertain. (R) Troosticridid indeterminate, NIGP 149185, lateral view of radial retaining ambulacral plates. (S and T) *Stellarocrinus qijiagouensis* n. sp.; (S) paratype, NIGP 149165, lateral view of set of arms, ray uncertain; (T) holotype, NIGP 149164, basal view of partial crown. (U and V) *Archaeocidaris* sp.; (U) NIGP 149186, oral view of interambulacral spine-bearing plate; (V) NIGP 149188, lateral view of weathered partial spine.

America and *Calycoblastus*, which is known from the Permian of Timor. They are unlike radials from other taxa of Pennsylvanian blastoids.

Although the collection is fragmentary, the report is important because troosticrids have not been reported previously from Pennsylvanian strata. With the exception of *Uyghuroblastus*, which was described from the Late Devonian of Xinjiang Uyghur Autonomous Region, China, all other Silurian to Mississippian troosticridid genera are known from Europe or North America.

**Occurrence:** Radials are rare in the echinoderm communities described by Lane et al. (1996) from volcanoclastics in the Qijiagou Formation at the Taoshigo Valley locality, but have

been collected from multiple locations in the limestones of the uppermost part of the Qijiagou Formation or the basal part of the Aoertu Formation. Radials are very abundant from interbedded coarse echinodermal limestones and maroon and green shales located at latitude 43°01.016'N, longitude 87°36.36'E. These limestones lie stratigraphically in the boundary zone between the Qijiagou and Aoertu formations as discussed above. Liao collected a single radial from the Ewirgou Quarry in Toksun County, Xinjiang Uyghur Autonomous Region from similar coarse crinoidal grainstones.

Class CRINOIDEA J.S. Miller, 1821

Subclass CAMERATA Wachsmuth et Springer, 1885

Order MONOBATHRIDA Moore et Laudon, 1943  
Suborder GLYPTOCRININA Moore, 1952  
Superfamily PLATYCRINITOIDEA Austin et Austin, 1842  
Family PLATYCRINITIDAE Austin et Austin, 1842  
Genus PLATYCRINITES J.S. Miller, 1821

*Platycrinites* spp.

(Fig. 2C–E)

*Types:* Described specimens: Basal cirlet (NIGP 149150); Radial (NIGP 149152); Pluricolumnal (NIGP 149153). Figured specimen: Radial (NIGP 149151).

*Description:* Basal cirlet, medium cone, large, length 11 mm, diameter 28.5 mm, plates fused, surface smooth, moderately up- and outflaring, bearing large stem facet on truncated base. Proximal columnal thin, probably elliptical.

Radial NIGP 149152, plate quadrate, length 16.5 mm lacking distal tip, width 18 mm, moderately convex longitudinally and transversely, bearing nodes in aligned linear rows. Radial facet angustary 6.3 mm wide, ovate.

Columnals segmented twist type. Nodals quadrangular, longer than wide, corners rounded and protruding slightly, apposing articular facets offset approximately 30°. Internodals elliptical, approximately twice as long as wide, ends protruding, apposing facets surfaces parallel. Facet surface with narrow marginal rim, circular central depression, and divided into mirror images by transverse ridge. Transverse ridge narrow, widens distally splitting into narrow parallel ridges before marginal rim. Lumen small, round.

*Discussion:* The smooth basal cirlet probably belongs to a different species than the ornamented radials found in this association of loose ossicles. Radial ornamentation is distinctive and appears as ridges on weathered specimens. The illustrated pluricolumnal specimen is a twist nodal with one attached nontwist internodal. This segmented twist type nodal developed in the late Tournaisian and continued into the Permian, whereas the continuous twist columnals of *Platycrinites* became extinct at the end of the Mississippian (Webster, 1997).

All specimens are solution weathered and most bear fragments of fenestrate bryozoans in the attached matrix. Lacking articulated specimens and not being able to confidently relate any of the disarticulated ossicles with the other parts of the crown, we left all specimens, which probably represent two or three species, in open nomenclature.

*Occurrence:* NIGP 149150, NIGP 149151, NIGP 149153: Limestones from the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation, Taoshuyuan Village; late Moscovian. NIGP 149152: Sanquanzi Formation, Yamansu, Hami County; Moscovian.

Platycrinitidae genus indeterminate

(Fig. 2B, F–I)

*Types:* Figured specimens, three basal cirlets (NIGP 149154–149156).

*Description:* NIGP 149154. Basal cirlet, low, slightly upflaring distal edges, pentagonal in outline, scalloped with shallow depressions in interray positions and gently rounded elevations widening distally in ray positions; plates smooth, fused, diameter 23.4 mm. NIGP 149155–149156. Diameter large specimen

19.7 mm; small specimen 13.2 mm. Stem facet of large specimen elliptical, 4 mm by 3 mm; of small specimen round, 2 mm diameter.

*Discussion:* The two basal cirlets (NIGP 149155–149156) are weathered free and show the scalloped nature of the plates on both the oral and aboral surfaces because the plates are of uniform thickness. The basal cirlet of NIGP 149154 has the aboral surface embedded in matrix, but the scalloped nature of the plate is present on the oral surface and compares with those of NIGP 149155–149156. The three plates are considered congeneric. These basal cirlets are atypical of *Platycrinites* Miller, 1821 which usually are moderately to strongly upflared and the surface may be smooth or with nodose ornament, but not scalloped. An elliptical stem facet is sometimes present on the basal cirlet of platycrinitids, but more commonly is circular with the columnals rapidly becoming elliptical distally from the cup. The platycrinitids *Plemnocrinus* Kirk, 1946 and *Eucladocrinus* Meek, 1872 have very low to horizontal basal cirlets, which may have shallow basal depressions. The three basal cirlets may belong to one of these genera or may represent a new genus. Lacking the radials and other parts of the crown, they are left in open nomenclature.

*Occurrence:* NIGP 149154: Limestones from the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation, Taoshuyuan Village. NIGP 149155, 149156: Sanquanzi Formation, Yamansu, Hami County; Carboniferous, Moscovian.

Subclass DISPARIDA Moore et Laudon, 1943

Superfamily BELEMMOCRINOIDEA S.A. Miller, 1883

Family SYNBATHOCRINIDAE S.A. Miller, 1889

Genus SYNBATHOCRINUS Phillips, 1836

*Synbathocrinus labrus* n. sp.

(Fig. 2J–N)

*Types:* Holotype, NIGP 149157; paratypes 1–3, NIGP 149158–149160.

*Etymology:* From the Latin *labrum*, meaning lip or brim and referring to the basal cirlet forming a vertical or rounded base of the cup.

*Diagnosis:* Distinguished by the flange-like basal cirlet with the wall flaring up- and outward from the distal ends of the basals.

*Description:* Cup truncated medium bowl, walls convex to slightly concave. Basal cirlet low, flange-like, formed by three plates, two equally large, one small in AE interray; bearing shallow round stem impression proximally, distally upflared tips forming vertical to slightly rounded base of cup. Radials 5, pentagonal, moderately convex transversely, convex or slightly concave longitudinally; flare up- and outward from distal tips of basals. Radial facet plenary, slightly declivate, bears straight transverse ridge, other morphology masked. Anal notch small, slightly wider on C radial than D radial. Stem impression round; axial canal pentalobate. Arms and stem not preserved. Measurements given in Table 3.

*Discussion:* The holotype of *Synbathocrinus labrus* n. sp. is slightly distorted with some solution weathering and bearing some imbedded matrix grains. Paratype 1 is solution weathered and mostly covered with embedded sand grains. Paratype

Table 3  
Measurements in mm of *Synbathocrinus labrus* n. sp.

Specimen	Holotype	Paratype 1
Cup length	7.2	7
Cup width, minimum	13.6	14.4
Cup width, maximum	15	15
Cup width, average	14.3	14.7
A radial length	7	5.9
A radial width	13.7	8.6
Diameter stem impression	3.4	4.2

2 is largely grain encrusted. It differs from the other two Pennsylvanian species (*S. melba* Strimple, 1938, and *S. alaskaensis* Strimple et al., 1971) by the presence of the flange-like basal circlet forming the base of the cup. The other two Pennsylvanian species have straight or convex walls merging with the basals. The basals appear rounded when encrusted with sand grains of the matrix.

**Occurrence:** Limestones from the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation, Taoshuyuan Village.

*Synbathocrinus* sp. (Fig. 2O, P)

**Types:** Figured specimen (NIGP 149161).

**Description:** Cup small, medium cone, width 9 mm. Radials 5, pentagonal, length 4.2 mm, width 6 mm. Gently convex longitudinally and transversely, gently outflaring, no ornament.

**Discussion:** The partial cup of *Synbathocrinus* sp. lacks the basal circlet, one radial, arms and stem. It differs from *S. labrus* in having straight gently outflaring walls. Lacking the basal circlet, it is left in open nomenclature.

**Occurrence:** Sanquanzi Formation, Yamansu, Hami County; Carboniferous, Moscovian.

Subclass CLADIDA Moore et Laudon, 1943

Order DENDROCRINIDA Bather, 1889

Superfamily SCYTALOCRINOIDEA Moore et Laudon, 1943

Family BLOTHROCRINIDAE Moore et Laudon, 1943

Blothrocrinid indeterminate

(Fig. 2Q)

**Types:** Two partial cups (NIGP 149162, measured, and NIGP 149163).

**Description:** Cup high-truncated cone, plates relatively thin, sutures flush, no ornament. Infrabasals 5, proximally horizontal, steeply upflared distally forming lower third of cup, length 7.6 mm, width 8.6 mm. Basals 5, hexagonal, form middle third of cup wall, gently convex transversely, straight longitudinally, distal tips incurved suggesting apical pits, length 11.3 mm, width 9.3 mm. Proximal columnals round, diameter 9.5 mm, heteromorphic, N1 noditaxis. Radials, anals, arms, tegmen, and distal stem not preserved.

**Discussion:** Two partial cups lack the radials and distal parts of some basals. Both specimens are solution weathered and the unmeasured specimen is slightly distorted. The combination of large size, high conical shape, and relatively thin plates is not

a common feature among Pennsylvanian cladid crinoids except in the blothrocrinids. Because the cups are incomplete, they are left in open nomenclature.

**Occurrence:** Limestones from the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation near Taoshuyuan Village.

Superfamily LOPHOCRINOIDEA Bather, 1899

Family STELLAROCRINIDAE Strimple, 1961

Genus STELLAROCRINUS Strimple, 1940

*Stellarocrinus qijiagouensis* n. sp.

(Fig. 2S, T)

**Types:** Holotype, NIGP 149164; paratype, NIGP 149165.

**Etymology:** Named for the region wherein the specimens were found.

**Diagnosis:** Distinguished by the transversely aligned nodes below the radial facet on the radials.

**Description:** Crown low, distorted by crushing, probably globose, length 23.8 mm, maximum width 48.4 mm, minimum width 28.2 mm, average width 38.3 mm. Cup low bowl to discoid, shallow basal concavity; ornament of coarse nodes on radials; length 8.4 mm, width 25 mm (estimate). Infrabasal circlet small, 6.1 mm diameter, mostly covered by proximal columnal. Infrabasals 5, proximally covered by proximal columnal, distal tips downflaring, not visible in lateral view. Basals hexagonal, convex transversely and longitudinally; DE basal length 5.8 mm incomplete, width 6.3 mm. Radials septagonal, much wider (13.6 mm) than long (9.6 mm), moderately convex transversely and longitudinally, bear 3–4 coarse nodes in transverse alignment below facet. Radial facets angustary (width-facet/width-radial  $9.4/13.6 = 0.69$ ), strongly declivate, morphology not visible. Interradial notches wide. Anals 3, mesoplax 4 subcondition, primanal not preserved; secundanal did not touch posterior basal; tertanal with proximal tip below radial summit. Arms 20, biserial, flat transversely, widely spreading, isotomous branching on single triangular primibrachial and again near tenth secundibrachial. Brachials cuneate chisels. Axillary secundibrachial small, triangular. Tegmen elongate, reaching nearly to distal tips of arms, formed of polygonal plates. Proximal columnal round, diameter 4.5 mm; lumen roundly pentagonal.

**Discussion:** The cup of the holotype of *Stellarocrinus qijiagouensis* n. sp. retains the infrabasal circlet, CD and DE basals, D and E radials, secundanal, and tertanal. The arms are crushed in or broken between the single axillary primibrachials and the axillary secundibrachials leaving the exact number of secundibrachials uncertain. The tegmen probably had a spine ring around the summit as one slightly elongate plate is mostly embedded in the matrix. The paratype is a crushed set of arms.

The very low cup and widely spreading arms with a slender tegmen are characteristics of the Stellarocrinidae, a family ranging from the Late Mississippian–Permian. The aligned nodes on the radials distinguishes *S. qijiagouensi* from all other species of the genus, most of which have two to four ridges extending from the basals onto the radials or have a transverse ridge on the radials. This is the first report of *Stellarocrinus* outside North America.

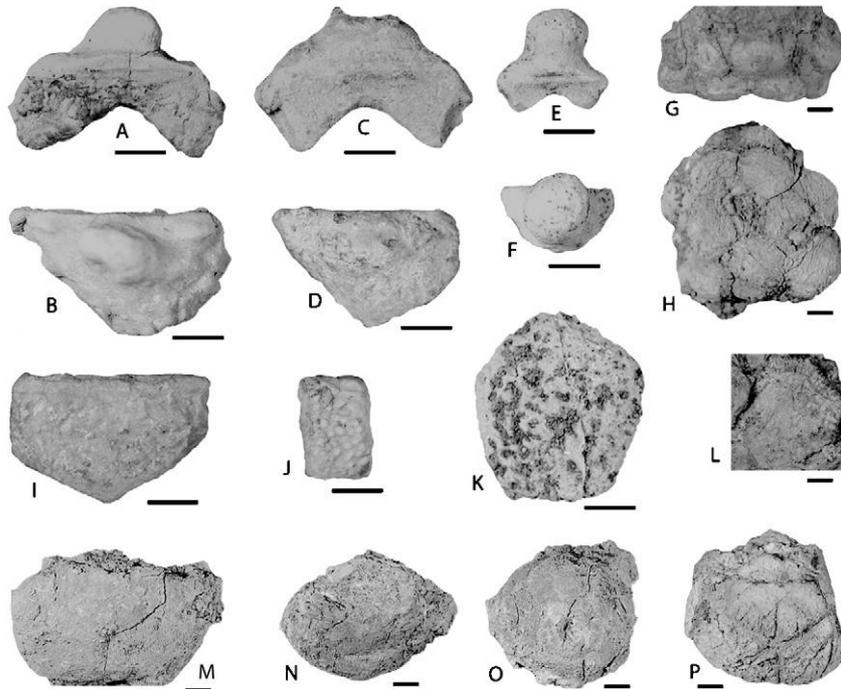


Fig. 3. Scale bar = 5 mm. (A–H) *Metaperimestocrinus aoertuensis* n. sp.; (A and B) paratype 2, NIGP 149177, oral and lateral view of mature radial with coarse node ornament; (C and D) paratype 3, NIGP 149178, oral and lateral view of mature inflated radial with irregular surface with small nodes; (E and F) paratype 4, NIGP 149179, oral and lateral views of immature radial with coarse node ornament; (G and H) holotype, NIGP 149175, C ray and basal views. (I–M) *Dicromyocrinus* sp. 1; (I) NIGP 149170, lateral view of radial; (J) NIGP 149171, lateral view of anal; (K) NIGP 149168, lateral view of basal; (L) NIGP 149169, lateral view of weathered posterior basal; (M) NIGP 149166, E ray view of cup. (N–P) *Dicromyocrinus* sp. 2; (N and O) NIGP 149174, lateral and basal views of weathered cup; (P) NIGP 149173, C ray view of weathered cup.

**Occurrence:** Limestones from the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation, Taoshuyuan Village.

Superfamily CROMYOCRINOIDEA Bather, 1890

Family CROMYOCRINIDAE Bather, 1890

Genus DICROMYOCRINUS Jaekel, 1918

*Dicromyocrinus* sp. 1 undesignated

(Fig. 3I–M)

**Types.** Figured specimens: cup (NIGP 149166); basal (NIGP 149168); posterior basal (NIGP 419169); radial (NIGP 149170); anal (NIGP 149171). Unfigured infrabasal circllet (NIGP 149167); lot of loose ossicles (NIGP 149172).

**Description:** Cup large bowl, shallow basal concavity, ornament of coarse nodes to short anastomosing ridges on basals and radials, stitched sutures impressed; length 23.3 mm, width maximum 41.5 mm, minimum 32.5 mm, average 37 mm. Infrabasal circllet downflaring, not visible in lateral view, mostly covered by matrix. Basals hexagonal, gently convex transversely, moderately convex longitudinally; EA basal length and width 18.5 mm. Radials pentagonal, subvertical, slightly incurving distally, gently convex longitudinally and transversely; A and E radials length 11.6 mm, width 19.8 mm; D radial length 11.4 mm, width 17.5 mm. Radial facets plenary, subhorizontal; characters on loose radials: straight transverse ridge, deep narrow wide ligament pit, rimmed overhanging marginal ridge, wide shallowly concave muscle fields. Arms and stem not preserved.

**Discussion:** One cup, two infrabasal circllets, two basals, two radials, and one anal are assigned to *Dicromyocrinus* sp. 1 undesignated. The large ornamented bowl-shaped cup is characteristic of *Dicromyocrinus*. The specimens probably represent a new species distinguished by the overhanging marginal rim on the radials. Because the anals are only partly preserved and mostly masked by matrix and the arms and stem are not preserved, the specimens are left in open nomenclature.

**Occurrence:** Limestones from the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation, Taoshuyuan Village.

*Dicromyocrinus* sp. 2 undesignated (Fig. 3N–P)

**Types:** Figured cups (NIGP 149173 and NIGP 149174, measured).

**Description:** Cup large, globose, widest at proximal tip of radials, stitched sutures impressed, coarse granular ornament; length 25 mm, width 33.6 mm. Infrabasal circllet gently upflared, barely visible in lateral view, diameter 17.6 mm. Infrabasals dart-shaped, gently upflaring, length 9.3 mm, width 9.8 mm. Basals hexagonal, gently convex longitudinally and transversely, length 17.3 mm, width 16.6 mm. Radials pentagonal, gently convex longitudinally and transversely, incurving distally, length 11.2 mm, width 19.5 mm. Radial facets plenary, morphology covered. Stem impression deep, round, diameter 5.4 mm. Anals, arms and stem not preserved.

**Discussion:** Two partial cups are assigned to *Dicromyocrinus* sp. 2 undesignated. Solution weathering and penetration inter-

growths have destroyed most of the ornament. The upflared infrabasal cirlet and globose shape distinguish *Dicromyocrinus* sp. 2 from *D.* sp. 1. Lacking the anals and arms, *D.* sp. 2 is left in open nomenclature.

*Occurrence:* Limestones from the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation, Taoshuyuan Village.

Superfamily PIRASOCRINOIDEA Moore et Laudon, 1943  
Family PIRASOCRINIDAE Moore et Laudon, 1943  
Genus METAPERIMESTOCRINUS Strimple, 1962

*Metaperimestocrinus aoertuensis* n. sp.  
(Fig. 3A–H)

*Types:* Holotype, NIGP 149175; paratype1 (partial cup), NIGP 149176; paratypes 2–4 (radials), NIGP 149177–149179; lot of loose radials (NIGP 149180); lot of primibrachials (NIGP 149181); lot of axillary spinose brachials (NIGP 149182); fragmentary tegmen spines (NIGP 149183).

*Etymology:* From the formation in which the specimen was found.

*Diagnosis:* Distinguished by the coarse protruding knobs on the radials.

*Description:* Cup low bowl, length 13.2 mm, width 40 mm, shallow basal concavity, 3 mm depth. Infrabasal cirlet downflaring slightly, in basal concavity, not visible in lateral view, distorted, average diameter 9.7 mm. Infrabasals 5, proximally bear shallow stem impression, distal tips projecting beyond stem impression, length 6 mm, width 4.8 mm. Basals 5, AB, BC, DE, and EA hexagonal, CD octagonal; bulbous, strongly convex transversely and longitudinally, form base of cup, proximally downflaring in basal concavity, distally widely up- and outflaring; AB basal length 10 mm, width 11.9 mm; BC basal length 12.5 mm, width 14.6 mm. Radials 5, pentagonal except C radial hexagonal; subvertical, wider than long, bear transversely elongate roundly protruding knob, proximal tip above basal plane; A radial length 14 mm, width 20.1 mm; C radial length 13.5 mm, width 16.5 mm; D radial length 14.8 mm, width 16.4 mm. Radial facets plenary in immature specimens, peneplenary (width-facet/width-radial = 0.8) in larger specimens, gently declivate, bear straight transverse ridge, narrow wide ligament pit, narrow outer marginal area, upflaring triangular shaped muscle fields. Interradial notches narrow. Anals 3, mesoplax 5 condition; primanal largest, length 9.4 mm, width 7.4 mm; secundanal proximal tip in contact with posterior basal, length 9.2 mm, width 5.2 mm; tertanal more than half above radial summit. Axillary primibrachials short, much wider than long, bear transversely elongate roundly protruding knob, branch isotomously. Axillary secundibrachials bear blunt spine or rounded knob, branch isotomously. Arms 20. Stem impression round, 5.7 mm diameter; axial canal round, 1 mm diameter.

*Discussion:* The description of *Metaperimestocrinus aoertuensis* n. sp. is based on two cups, one partial cup, 96 loose radials, 5 primibrachials, and 11 secundibrachials. There are 12 spine fragments that are probably from the tegmen of *M. aoertuensis*. The species is distinguished by the protruding knobs on the radials, which are not present on the other two species *M. spiniferous* Strimple, 1961, and *M. trapezoidalis* Strimple, 1962, both from

the United States. This is the first report of the genus outside North America.

*Occurrence:* Limestones from the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation, Taoshuyuan Village.

Subclass FLEXIBILIA Zittel, 1895

Order SAGENOCRINIDA Springer, 1913

Superfamily SAGENOCRINITOIDEA Roemer, 1854

Famiy DACTYLOCRINIDAE Bather, 1899

Genus AEXITROPHOCRINUS Strimple et Watkins, 1969

*Aexitrophocrinus* sp.

(Fig. 2A)

*Type:* Figured specimen (NIGP 149184).

*Description:* Partial crown of dorsal cup and two first primibrachials and two interrarial plates. Cup flat with shallow basal impression. Infrabasals concealed by matrix. Basal tips barely visible along edges of matrix with posterior basal extended nearly to distal tips of radials. Posterior basal adjoined distally by one anal plate. Radials 5, pentagonal, much wider (4.6 mm) than long (2.5 mm), slightly upflaring distally. First primibrachial rectangular, wider (5 mm) than long (2.5 mm). First interrarial plate singular. Stem and other parts of crown unknown.

*Discussion:* The partial crown of *Aexitrophocrinus* sp. is recrystallized and solution weathered modifying any ornamentation that was initially present. It is assigned to *Aexitrophocrinus* because: (1) some of the distal tips of the basals are visible beyond the matrix and would have been visible beyond the proximal columnal, (2) there was a single anal above the posterior basal, (3) the first primibrachial is not axillary, and (4) there is a single first interrarial plate. These are all characters of the genus. The specimen may represent a new species, but is left in open nomenclature because of the incomplete preservation.

*Occurrence:* Limestones from the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation, Taoshuyuan Village.

Subphylum ECHINOZOA Haeckel in Zittel, 1895

Class ECHINOIDEA Leske, 1778

Subclass PERISCHOECHINOIDEA M'Coy, 1849

Order CIDAROIDA Claus, 1880

Family ARCHAEOCIDARIDAE M'Coy, 1844

Genus ARCHAEOCIDARIS M'Coy, 1844

*Archaeocidaris* sp.

(Fig. 2U, V)

*Types:* Figured specimens: Interambulacral plate (NIGP 149186); spine (NIGP 149188). Lot of 10 ambulacral plates (NIGP 149187); lot of 2 spine fragments (NIGP 149189).

*Discussion:* A poorly preserved disarticulated interambulacral plate and partial spine of *Archaeocidaris* sp. are illustrated for completeness of the echinoderm fauna of the Qijiagou Formation.

*Occurrence:* Limestones from the uppermost part of the Qijiagou Formation or lowermost part of the Aoertu Formation, Taoshuyuan Village.

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