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PERMIAN CRINOIDS FROM THE SAIWAN AND KHUFF FORMATIONS, SOUTHEASTERN OMAN

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Abstract. Early Permian (Sakmarian) crinoids are described from six horizons in the Saiwan Formation of the Huqf area of southeastern Oman. Each horizon yielded only one to three taxa. All specimens lived in a shallow water environment characterized by mixed siliciclastic or siliciclastic-carbonate sedimentation. Disarticulated arm plates of an indeterminate articulate crinoid are described from a tempestite bed in the Khuff Formation (Wordian) of the Haushi area. The Saiwan Sakmarian crinoids are some of the earlier, although not the earliest Permian crinoids known. Representatives of both primitive (sycocrinids) and advanced (scytalocrinids, blothrocrinids, texacrinids, and cromyocrinids) cladids and articulates are present in the Saiwan crinoids that are dominated by advanced dendrocrinids and belong to families previously reported from the Carboniferous or Permian. They show greatest affinity to the late Sakmarian/early Artinskian fauna from the Callytharra Formation of Western Australia.

New taxa described herein double the number of genera (three) previously reported from the same area. The diversity of the Saiwan crinoids is relatively low when compared to the large faunas reported from Timor, Western Australia, Russia, and North America. However, they show affinity with each of the larger faunas. New taxa described are *Coeliocrinus arenaceous* n. sp., *Moapacrinus*? *omanensis* n. sp., *Huqficrinus biserialis* gen. n., n. sp., and *Campbellicrinus nodosus* n. sp.

Riassunto. Nel presente lavoro vengono descritti crinoidi di età Permiano Inferiore (Sakmariano) campionati in sei livelli nella Formazione Saiwan affiorante nella regione di Huqf nell'Oman sudorientale. Da ciascun livello provengono solo da uno a tre taxa. L'ambiente nel quale vivevano tutti gli esemplari studiati consisteva in una piattaforma di acque basse a sedimentazione mista terrigeno-carbonatica. Inoltre vengono descritte le piastre brachiali di un crinoide articolato indeterminato campionato in una tempestite della sovrastante Formazione Khuff (Wordiano) della regione di Haushi.

I crinoidi Sakmariani della Formazione Saiwan sono tra i crinoidi più antichi del Permiano, sebbene siano note faune più vecchie. Tra di essi sono presenti sia forme primitive (sycocrinidi) che avanzate (scytalocrinidi, blothrocrinidi, texacrinidi e cromyocrinidi) di cladidi e articolati, dominate da dendrocrinidi più avanzati. Tutti appartengono a famiglie già note nel Carbonifero e nel Permiano. Essi mostrano grande affinità alle faune della Formazione Callytharra del Sakmarian superiore/Artinskiano inferiore dell'Australia occidentale.

I nuovi taxa descritti raddoppiano i tre generi riportati in precedenza in questa regione. Sebbene la diversità dei crinoidi della Formazione Saiwan sia relativamente bassa se paragonata alle ricche faune di Timor, Australia occidentale, Russia e America settentrionale, essi mostrano affinità con ciascuna delle associazioni maggiori. Vengono descritti quattro nuovi taxa: *Coeliocrinus arenaceous* n. sp., *Moapacrinus*? *omanensis* n. sp., *Huqficrinus biserialis* gen. n., n. sp., *Campbellicrinus nodosus* n. sp.

Introduction

Permian strata were recognized in the mountains of northeastern Oman by Lees (1928) when he described four sections and noted the occurrence of brachiopods and corals in a number of the units. He also referred to fossils listed by Pilgrim (1908) but did not give an age determination within the Permian. Hudson (1960) subdivided the Permian succession into ages of Sakmarian, Artinskian and an unassigned overlying sequence when he recognized two carbonate formations and reported fusulinids and a brachiopod fauna from three sections in northeastern Oman. Hughes Clarke (1988), working in the interior of Oman, reported the occurrence of two units of Sakmarian into Artinskian age with carbonates in the latest Sakmarian and Artinskian. The Saiwan Formation was introduced by Dubreuilh et al. (1992) for the Haushi limestone, which had been informally named by Hudson & Sudbury (1959).

The Khuff Formation was proposed by Steineke et al. (1958) and includes Middle - Upper Permian strata

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best exposed along the north-western flank of the Haushi Uplift. Al-Aswad (1997) summarized the stratigraphy and sedimentology of the Khuff Formation in south-central Saudi Arabia.

Mapping by the French Bureau of Geological and Mineral Resources (BRGM) and the discovery of commercial petroleum deposits in Oman has lead to a modern interpretation of the regional structural and stratigraphic relationships within Oman and their relationship to the Arabian block. Although many problems remain to be resolved, the Permian stratigraphy is becoming more refined, and new stratigraphic units are

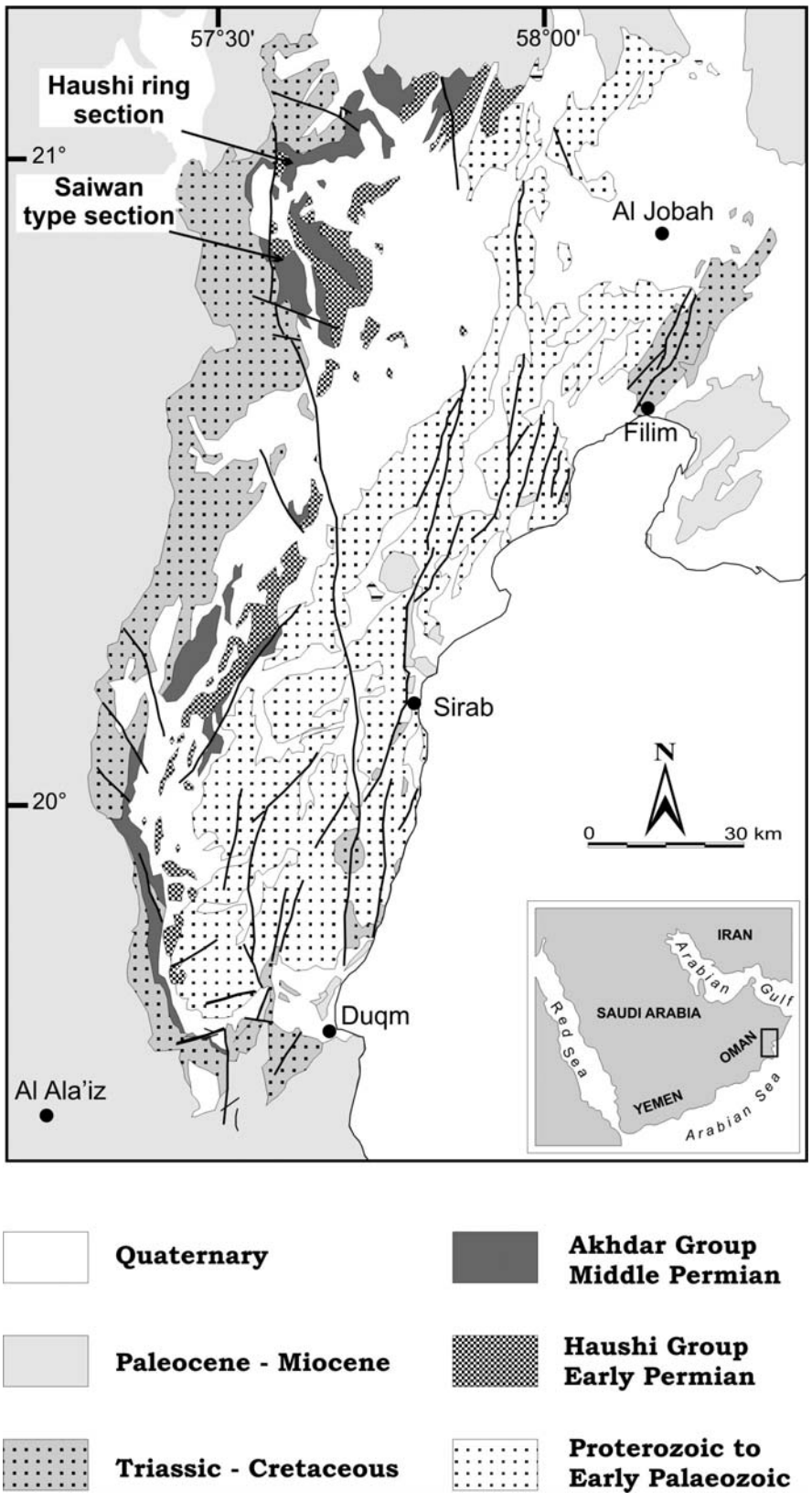


Fig. 1 - Index map of the Sultanate of Oman with the location of the exposed section of the Saiwan Formation in the northwestern part of the Haushi-Huqf Area from which the crinoids were collected.

being proposed to define the stratigraphy within various structural elements within Oman (i.e. Béchennec et al. 1992; among others) as summarized in the field guides for the International Conference on the Geology of Oman (Angiolini et al. 2001; Baud et al. 2001). More recently, Permian stratigraphy of southeastern Oman has been the subject of syntheses by Angiolini et al. (2003a, b; 2004), Osterloff et al. (2004a, b) and Weidlich (2007).

Few Permian crinoids have been reported from Oman, but crinoid fragments were reported in the fossil lists by Hudson & Sudbury (1959) and Hughes Clark (1988). Jell & Willink (1993) described the first cups and crowns from the Early Permian Gharif Formation (partially equivalent to Saiwan Formation; see Angiolini et al. 2006) of the Haushi-Huqf area (Fig. 1). Sakmarian blastoids and a crinoid reported from the Batain Plain of the Al Ashkharah area, eastern Oman, by Webster & Sevastopulo (2007) were related to the Permian deposits of Timor and show no relationship to those of the Haushi-Huqf area.

Crinoid crowns and cups were collected from several Early Permian horizons by one of us (AT) and colleagues from the Universitá degli Studi di Milano during sedimentologic and stratigraphic studies of the Huqf and Haushi areas in the late 1990s. Members of the 2001 field excursion AO2 of the International Conference, Geology of Oman (Angiolini et al. 2001), recovered additional specimens from the same and other Permian horizons in the Huqf and Haushi areas. Both collections form the basis of this paper and are compared to Permian crinoids worldwide.

Stratigraphy

The Saiwan Formation was introduced by Dubreuilh et al. (1992, p. 26) for the marine fossiliferous sandy limestones previously informally named Haushi limestone ('*Bellerophon* Limestone' and '*Metalegoceras* Limestone') by Hudson & Sudbury (1959). At the type section (latitude 20°52′04″ N, longitude 57 °36′27″ E) (Fig. 2), the Saiwan Formation unconformably overlies red fine-grained sandstones and green siltstones (= "basal sandstones" of Petroleum Department Oman (PDO) geologists, see Angiolini et al. 2006) or directly above the diamictite of the Al Khlata Formation (Angiolini et al. 2003a). The upper boundary of the Saiwan Formation is believed to be bounded by an unconformity, separating it from the overlying Gharif Formation sensu Dubreuilh et al. (1992, p. 29).

In its type-section the Saiwan Formation consists of coarse-grained, cross-laminated bioclastic sandstones, red and green mudrocks, and sandy calcarenites grading upward into coarse-grained and cross-lami-

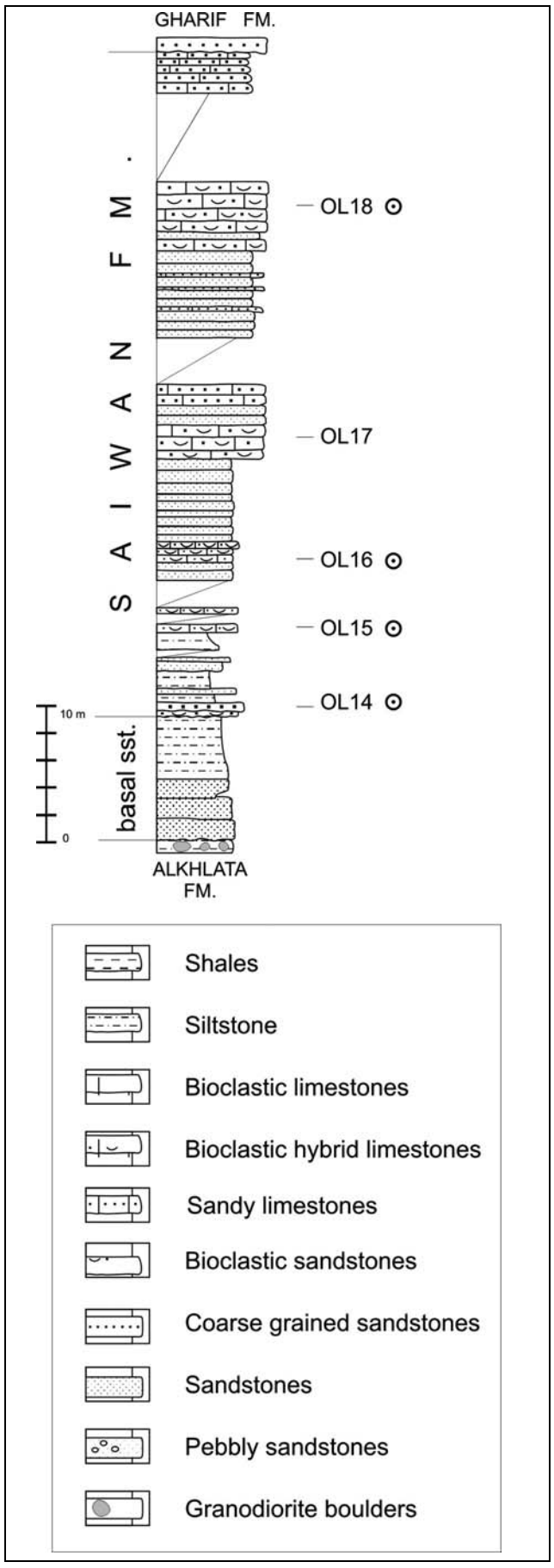


Fig. 2 - Stratigraphic column of the Saiwan Formation at the Saiwan type section.

nated sandy calcarenites, bioclastic limestones, and marlstones. The P10 Maximum Flooding Surface (MFS) of Sharland et al. (2001, p. 169) is located in the shales immediately below bed OL15. The age of the Saiwan Formation is late Sakmarian based on fusulinids, brachiopods and cephalopods (Angiolini et al. 2003a, 2004, 2006).

In the Haushi-Huqf area, the Khuff Formation is about 30 m thick. It comprises three members: Member 1 with cross-bedded, bioclastic sandstone at the base grades upwards into bioclastic limestone and marlstone; Member 2 consists of outer-shelf burrowed marlstones and marly limestones, interbedded with bioclastic tempestites; Member 3 is a bioclastic limestone with mud intraclasts at the base and is transitional upwards into biocalcirudite and sandy biocalcarenite, interbedded with marly limestone and marlstone. The rich bioclastic beds are interpreted as tempestites. The age of the Khuff Formation is Wordian (Angiolini et al. 2003b, 2004).

Crinoid occurrences

Crinoidal remains were reported from 12 horizons in the Saiwan Formation by Angiolini et al. (2001, fig. 3). All of these horizons yielded columnals and pluricolumnals with five of the horizons also yielding cups and crowns and one also yielding disarticulated cup plates. All crinoidal horizons are in calcarenitic sandstones or siliclastic calcarenites. Each of the six horizons yielding cups and crowns or disarticulated cup plates with the crinoids identified in it is listed below (Fig. 2).

1. Basal 1 m of sandstone (*Pachycyrtella* bed of Angiolini et al. 2003a) of the Saiwan Formation at the type section (latitude 20°52′04″ N, longitude 57°36′27″ E). OL14

Coeliocrinus arenaceous n. sp.

Texacrinus? sp.

Indeterminate Cladid, sets of arms

The basal unit of the Saiwan Formation (OL14), approximately 1 m thick, is a poorly sorted, cross-bedded sandstone, loosely cemented by carbonate deposited unconformably on the "basal sandstones" (Angiolini et al. 2006). Crinoids were buried in a rapid manner with the crowns inverted (arms down) with the partially splayed arms and pinnules forming a cone swamped in the sand. This is the trauma response posture or starbust down (oral surface down) as described by Baumiller et al. (2008). The crinoid ossicles were penetrated by quartz sand grains as a result of pressure solution. Later cementation by calcite was concentrated around the outside of the crowns. Lesser amounts of cement within the crowns and surrounding the specimen allowed modern exhumation and weathering to remove the sand from the center of the cone and from around the specimen. Unfortunately the cup has been lost on all of the specimens of the Indeterminate Cladid crinoid. The crown of *Coeliocrinus arenaceous* n. sp. has the distal parts of the arms above the tegmen partly splayed and the crown of *Texacrinus*? sp. has the arms closed in. The columns were not present with these specimens suggesting that they were ripped up from the living site and transported an unknown distance to the burial site. The nature of burial suggests a strong storm or possibly tsunami event that disrupted and buried the specimens.

2. Calcarenitic sandstone 7 m above base of the Saiwan Formation. OL 15

Campbellicrinus compactus Jell & Willink, 1993

Campbellicrinus nodosus n. sp.

Moapacrinus? *omanensis* n. sp.

Huqficrinus biserialis gen. n., n. sp.

Abundant pluricolumnals

The most diverse fauna occurs in three thin limey sandstone/sandy limestone beds 6 m above the base of the Saiwan Formation (OL15) (Fig. 2). It is easily recognized in the field by the abundance of white weathering pluricolumnals. Articulated crowns of the articulate crinoids *Campbellicrinus compactus* Jell & Willink, 1993 and *Campbellicrinus nodosus* n. sp. are moderately abundant in the unit. One cup of *Moapacrinus*? *omanensis* n. sp., a partial crown of *Huqficrinus biserialis* n. gen., n. sp., and a few disarticulated cup plates were also found in this unit. The abundance of the pluricolumnals and preservation of the crowns suggests these specimens were buried in situ with little or no transport.

3. Sandy limestone and siltstones 12-13 m above the base of the Saiwan Formation (OL16 and above)

Sycocrinid, genus indeterminate, infrabasals

Disarticulated cup plates: a minimum of two genera of indeterminate cladids

Disarticulated cup plates and pluricolumnals were recovered from the basal arenaceous limestone and siltstones 12 to 13 m above the base of the Saiwan Formation (OL16 and above). Although most of the plates are considered to belong to indeterminate cladids the presence of infrabasals of an indeterminate sycocrinid genus shows that the diversity of the Saiwan crinoids is greater than what is represented by the articulated cups and crowns.

4. Siliciclastic calcarenite 39 m above the base of the Saiwan Formation. OL18

Texacrinus haushiensis Jell & Willink, 1993

Omanicrinus secundus Jell & Willink, 1993.

The well preserved crowns and associated pluricolumnals of *Texacrinus haushiensis* and *Omanicrinus secundus* in the arenaceous limestone 28 m above the base of the upper member of the Saiwan Formation were deposited in situ. All crowns have been broken from the holdfast, but some retained a short amount

of the proximal stem. The longest stem observed still attached to the crown is 4.3 cm long and the longest pluricolumnal is 7.5 cm long.

5. Siliciclastic calcarenite 38 m above base of the Saiwan Formation at the Haushi ring section (latitude 21°00′26″N, longitude 57°37′23″E). OM32

Texacrinus sp.

The crown of *Texacrinus* sp. is enclosed and encased in poorly sorted siliciclastic calcarenite. No stem is preserved, either as a result of original taphonomy or recent erosion. The lack of other specimens suggests the specimen was transported an indeterminate distance from the living site.

6. Sandstone in the middle part of Saiwan Formation (latitude 20°52′15″N, longitude 57°36′23″E) northwestward of the type section at Saiwan. OM58 (possibly correlatable to OL17).

Moapacrinus? omanensis n. sp.

The partial cup of *Moapacrinus? omanensis* is abraded and only partly preserved. It has sand grains penetrating some cup plates as a result of pressure solution. The specimen was probably transported an indeterminate distance from the living site.

Six other horizons in the Saiwan Formation yielded crinoid pluricolumnals and solitary columnals, which are not described. These horizons are 2 m, 4 m, 8 m, 25 m, and 35 m above the base of the Saiwan Formation.

Single columnals and pluricolumnals were collected from one horizon each in the middle and upper parts of Member 3 of the Khuff Formation. In the uppermost horizon disarticulated arm plates of an indeterminate articulate crinoid were found in a thin tempestite bed. Encrusting bryozoans completely encircle some of the pluricolumnals indicating the crinoids were living at the time of the encrustation.

Significance of the crinoid faunas

The Saiwan crinoids are some of the earliest Permian crinoids recognized, although a few earlier Permian crinoids are reported from the Midcontinent of the United States. These earliest Permian faunas from the United States are not diverse, each consisting of only one or two genera, such as *Arrectocrinus abruptus* (Moore & Plummer, 1940) in the Moran Formation of northern Texas, among others. The Saiwan crinoids were living at approximately 40°S (Golonka 2002, Angiolini et al. 2003a, b).

The overall diversity of the crinoids in the Saiwan Formation is relatively low, with recognized representatives of one cyathocrinid family, five advanced dendrocrinid families, and one articulate family. Additional families may be recognized in the future if identifiable cups and crowns are found in the horizons yielding only disarticulated cup ossicles, columnals, and pluricolumnals. This is based on the diversity of disarticulated cup ossicles, which will probably increase the advanced cladid diversity.

At the family level the Saiwan crinoids are younger representatives of Pennsylvanian or Mississippian families some of which were previously recognized in the Permian. The assignment of *Omanicrinus* Jell & Willink, 1993 to the Scytalocrinidae is questioned because it has more than 10 arms. *Omanicrinus* is probably related to genera currently assigned to the Blothrocrinidae Moore & Laudon, 1943, but is not considered to belong to the Blothrocrinidae sensu stricto as noted under the discussion of the genus. *Huqficrinus* gen. n. is considered an advanced blothrocrinid with biserial brachials.

Coeliocrinus White, 1863 extends the range of both the genus and of the family Cercidocrinidae Moore & Laudon, 1943 from the Middle Mississippian upward into the Sakmarian and the paleogeographic range from North America into the western part of the Palaeo-Tethys. The Texacrinidae Strimple, 1961 were previously reported from Oman by Jell & Willink, 1993 and *Texacrinus* Moore & Plummer, 1940 is known also from the Early Permian of Western Australia (Webster & Jell 1999b).

Genera of the Cromyocrinidae Bather, 1890 are not common in the Permian as may be noted in the compilation of Webster (2003). However, the specimen here identified as *Moapacrinus? omanensis* n. sp. has the typical stitched sutures and thick cup plates of the family and a cup morphology and shape like *Moapacrinus* Lane & Webster, 1966. It extends the paleogeographic range of the family to Oman and shows relationship to Western Australia where the genus was reported by Webster & Jell (1999b).

Webster & Jell (1999b) assigned *Campbellicrinus* Jell & Willink, 1993 to the articulate family Corythocrinidae Strimple & Watkins, 1969. *Campbellicrinus* is the only known Permian representative of the family and the only corythocrinid known from the Palaeo-Tethys. As currently known *Omanicrinus, Huqficrinus,* and *Campbellicrinus* are Oman endemics.

Comparison of the number of genera and species within the Saiwan crinoids with those of other Permian crinoid faunas (Tab. 1) shows that only two genera are shared with other faunas. These are *Texacrinus* in the Callytharra Formation of Western Australia and questionably *Moapacrinus* in the Bird Spring Formation of southern Nevada and the Callytharra Formation. However, at the generic level, the Saiwan crinoids are dominated by advanced cladids as are all of the other faunas, with the exception of the Wandagee fauna of Western Australia in which three advanced cladid genera are accompanied by two genera each of camerates, primitive cladids, and articulates. The Saiwan crinoids have greatest affinity with the late Sakmarian/early Artinskian

Locality	Camerates	Disparids	Cladids, Cyathocrinitids, and Dendrocrinids	Cladids, Advanced Dendrocrinids	Flexibles	Articulates
Basleo, Timor "Wordian"	12 (30)	6 (14)	16 (26)	45 (113)	11 (40)	1 (2)
Callytharra, W. Australia Sakmarian/Artinskian	6 (16)	4 (6)	3 (3)	7 (29) **1, !?**	3 (7)	1 (4)
Bird Spring, S. Nevada Middle Wolfcampian	1*(1)	1 (1)	1 (2)	32 (53) **1?**	3 (4)	1* (1)
Southern Urals, Russia Artinskian	2 (2)	3 (4)	4 (4)	13 (13)	3 (4)	
Cibolo Limestone, Texas Wolfcampian				6 (9)	1 (2)	
Wandagee, W. Australia Middle Artinskian	2 (2)		2 (2)	3 (3)		2 (10)
Djebel Tebaga, Tunisia Wordian	2 (2)			5 (5)	2 (2)	
Sosio Formation, Sicily Wordian	1 (1)	1 (1)	1 (1)	5 (5)	1 (1)	
Saiwan Formation, Oman Sakmarian			1(1)	5 (5)		1 (2)
Copacabana, Bolivia Artinskian			1 (1)	3 (4)	2 (4)	

*Genus not identified

Tab. 1 - Generic composition of major Permian crinoid faunas of the world. Numbers compiled from literature compilation by Webster (2003) and Webster and Lane (2007). Number of species given in parentheses ( ) after the number of genera. Numbers in **bold face** are genera in common with the Saiwan Formation.

Callytharra fauna of Western Australia. No camerates, disparids, or flexibles are recognized among the Saiwan crinoids. It is uncertain if this reflects adverse environmental conditions or the southern latitude of the location in early Permian time.

The Saiwan crinoids occur in highly siliciclastic or siliciclastic carbonate environments as noted above under crinoid occurrences. Other Permian faunas occurring in such environments are the Wandagee (sandstone), Callytharra (siliciclastic carbonate), and Djebel Tebaga (siliciclastic carbonate) faunas. The Basleo faunas occur in carbonates associated with volcaniclastics. All of the other faunas are in carbonates lacking siliciclastics although they may occur in carbonates interbedded with clastics lacking crinoids such as the Copacabana fauna.

The low diversity in the faunal successions within the Saiwan Formation is judged to be the result of fluctuating environmental conditions in a shallow marine environment under the influence of waves and tidal currents and rich in siliciclastics. Shifting of the environments may have occurred so rapidly that more diverse crinoid faunas did not have sufficient time to become established and the siliciclastics may have been a restrictive influence on larvae capable of inhabiting those environments.

Systematic paleontology

Specimens are reposted in the Museum of the Dipartimento di Scienze della Terra "A. Desio" of Milan (Italy) and bear numbers preceded by MPUM (MPUM 9853-9902). Morphologic terms follow Moore & Teichert (1978) and classification follows Simms & Sevastopulo (1993) with Articulata as modified by Webster & Jell (1999b). Measurement terminology is after Webster & Jell (1999a), anal terminology after Webster & Maples (2006), and noditaxis patterns after Webster (1974).

Class **Crinoidea** J. S. Miller, 1821

Subclass **Cladida** Moore & Laudon, 1943

Order **Cyathocrinina** Bather, 1899

Superfamily Codiacrinoidea Bather, 1890

Family Sycocrinitidae Lane, 1967

Indeterminate Sycocrinid

Pl. 1, figs 1, 2

Discussion. Four infrabasal plates, one large (length 8 mm, width 9.2 mm) and three small, lacking ornamentation are parts of a tripartite infrabasal circlet. They are judged to be plates of a codiacrinid. Most codiacrinids have very low infrabasals that do not form a major part of the cup wall, whereas, sycocrinids have strongly upflaring infrabasals that form a major part of the cup wall. These specimens are tentatively recognized as parts of three or four specimens of an indeterminate sycocrinid. They add to the diversity of the Saiwan crinoids and are the first reported from the Permian of Oman. Sycocrinids are known from four genera (*Allosycocrinus* Wanner, 1924, *Metasycocrinus* Wanner, 1920, *Monobrachiocrinus* Wanner, 1916, and *Parasycocrinus* Marez Oyens, 1940) in the Permian of Timor. The steeply upflared structure of the Oman specimens suggests possible affinity with *Metasycocrinus* or *Monobrachiocrinus*, both of which have steeply upflared infrabasals forming a large part of the cup wall. The infrabasals of *Allosycocrinus* and *Parasycocrinus* are lower or tend to flare sharply outward distally. *Monobrachiocrinus* has been reported from the Artinskian of Russia (Arendt 1970) and the Wordian of Sicily (Yakovlev 1930); the other three genera are known only from Timor.

Material and Occurrence. Illustrated infrabasal MPUM9853 and one lot of three specimens MPUM9854. From thin marly bed in shale interval above OL 16, Saiwan Formation.

Order **Dendrocrinida** Bather, 1899

Superfamily Scytalocrinoidea Moore & Laudon, 1943

?Family Scytalocrinidae Moore & Laudon, 1943

Genus *Omanicrinus* Jell & Willink, 1993

Type species: *Omanicrinus secundus* Jell & Willink, 1993

Discussion. Assignment of *Omanicrinus* to the Scytalocrinidae by Jell & Willink (1993) is here questioned because cup plates are relatively thicker, there are more than 10 arms, and the arm branching is confined to the single primibrachial and second secundibrachial. This differs from the 10 arms of *Scytalocrinus* Wachsmuth & Springer, 1880 and other 10-armed genera assigned to the Scytalocrinidae. Also, the arm branching pattern differs from genera with more than 10 arms (with the second branching on more distal brachials) that were previously included in the Scytalocrinidae by Moore & Strimple (in Moore & Teichert 1978). These genera have recently been transferred to the Sostronocrinidae Lane et al. (2001). Webster & Waters (in press) agreed that the genera Lane et al. (2001) included in the Sostronocrinidae (*Sostronocrinus* Strimple & McGinnis, 1969; *Tundracrinus* Yakovlev, 1928; and *Haeretocrinus* Moore & Plummer, 1940) do not belong in the Scytalocrinidae. *Sostronocrinus* has a truncate highly-conical cup with deep apical pits, isotomously branching arms, four arms per ray, and moderately cuneate brachials. *Haeretocrinus* has a medium-conical cup with gently impressed sutures, 8 to 10 arms per ray, exotomously branching arms, and gently cuneate brachials. *Tundracrinus* has a medium-bowl cup, 10 to 12 arms per ray, endotomously branching arms, and rectilinear brachials. Webster & Waters (in press) considered that these three genera were probably derived from different lineages and therefore belong in separate families. We agree with the assessment of Webster & Waters (in press) that these three genera belong in separate families.

Omanicrinus has a bell shaped cup, four arms per ray, isotomously branching arms, and rectilinear to faintly cuneate brachials. These characters do not agree with the characters used to define any of the three genera Lane et al. (2001) included in the Sostronocrinidae precluding its assignment therein. Therefore, we questionably leave *Omanicrinus* in the Scytalocrinidae.

Omanicrinus probably evolved from the same lineage that some of the younger genera with rectilinear brachials that are currently assigned to the Blothrocrinidae Moore & Laudon, 1943. However, the arm branching pattern differs from those genera and shows advanced character in the more proximal location of the branching. *Omanicrinus* is not transferred to the Blothrocrinidae because it is judged to be derived from a different lineage than that of *Blothrocrinus* Kirk, 1940 (see discussion under Blothrocrinidae below).

Omanicrinus secundus Jell & Willink, 1993

Pl. 1, fig. 21

Discussion. One poorly preserved partial crown of *Omanicrinus secundus* Jell & Willink (1993) shows the bell-shaped cup in broken section, the relatively thick cup plates, and retains parts of the arms of the B and C rays. The poorly sorted sandstone matrix has infilled the visceral cavity and is well cemented around the specimen. Jell & Willink (1993) noted some variation in the anals of *O. secundus,* pointing out that the radianal (primanal herein) was in contact with the BC basal in some specimens and not in contact in others. Among the four specimens of which they illustrate the posterior interray the primanal is in contact with the BC basal in three specimens (Jell & Willink 1993, figs. B, F, and G) and not in contact with the BC basal in one specimen (ibid, fig. M). In all four specimens the primanal is partly (ibid, figs. F and G) or entirely (ibid, figs. B and M) below the secundanal. This demonstrates the evolutionary trend of the primanal to migrate to the left and upward in the cup with the secundanal and tertanal migrating upward and out of the cup repeatedly in the Paleozoic in different lineages of the cladids as recog-

nized by Wanner (1916), Wright (1920, 1926, 1927, 1934), and Sprinkle (1982). It also led Webster & Maples (2006) to recommend the use of primanal, secundanal, and tertanal for the terms applied to the anals in the cladids because the primanal becomes the only anal in the cup in many advanced cladids. Previously the second anal (here called secundanal) as well as the only anal in the cup were referred to as anal X. When the only anal in the cup is actually the primanal it is a misnomer to call it anal X as noted by Webster & Maples (2006).

Material and Occurrence. Figured specimen MPUM9855. From bed OL18, Saiwan Formation.

Family Blothrocrinidae Moore & Laudon, 1943

Emended description. To include forms with biserial arms.

Discussion. The diagnostic characters of the Blothrocrinidae, as given by Moore et al. in Moore & Teichert (1978, p. 648), are: "Crown tall, cylindrical or expanded upward. Cup conical, five or three upflared infrabasals readily visible from side, radial articular facets plenary, bearing transverse ridge and ligament pits; three anals in normal arrangement. Anal sac tall, cylindrical. Arms uniserial, pinnulate, branching two or more times. Stem long, transversely circular." Genera assigned to the Blothrocrinidae include older forms (among others *Blothrocrinus* Kirk, 1940 and *Culmicrinus* Jaekel, 1918, both Early Mississippian) with cuneate brachials and the first branching on primbrachials two or higher and younger forms (among others *Moscovicrinus* Jaekel, 1918 and *Woodocrinus* de Koninck, 1854, both Pennsylvanian) with rectilinear brachials and the first branching on the first or second primibrachial. Although the evolutionary trend is for first arm branchings to become lower, the trend for brachial evolution is from rectilinear to cuneate. This suggests that the younger genera with rectilinear brachials currently assigned to the Blothrocrinidae are from another lineage and did not evolve from the older Blothrocrinidae forms with cuneate brachials. Other genera that we consider to belong to the Blothrocrinidae sensu stricto are: *Carcinocrinus* Laudon, 1941; *Culmicrinus* Jaekel, 1918; *Fifeocrinus* Wright, 1951; and *Ulrichicrinus* Springer, 1926. All other genera have rectilinear brachials. The Blothrocrinidae are in need of a systematic revision that is beyond the scope of this paper.

Huqficrinus gen. n.

Fig. 3

Type species: *Huqficrinus biserialis* gen. n., n. sp.

Etymology: From the region where the specimen was found.

Diagnosis: Crown expanding distally; cup conical, base truncated, sutures flush, granular to anastomosing ridge ornament; infrabasal circlet upflared; radial facet peneplenary; anals 3, menoplax sub-

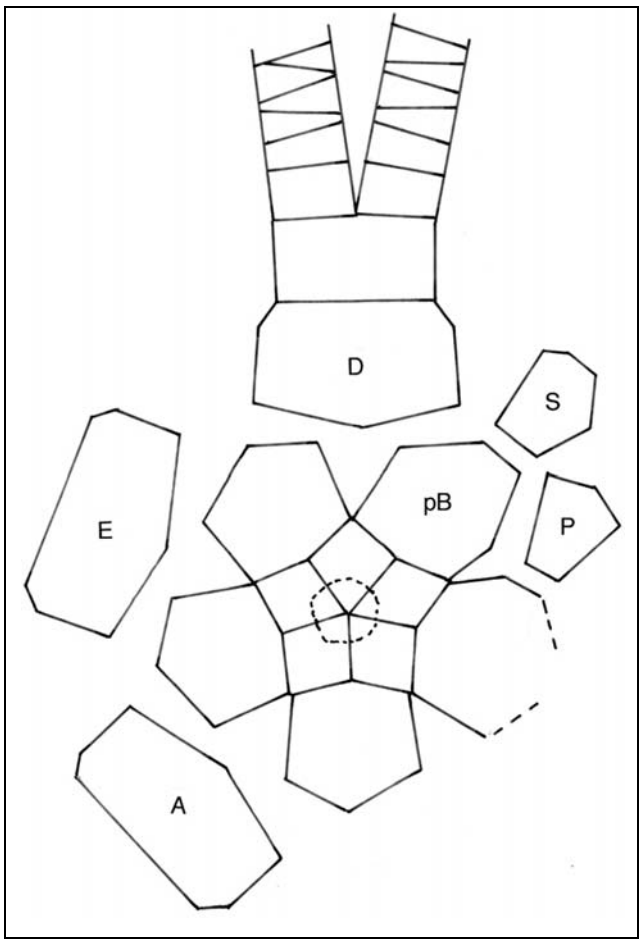


Fig. 3 - Plate diagram of *Huqficrinus* gen. n. Designated plates are: radials - A, E, D; posterior basal - pB; primanal - P; secundanal - S.

condition; arms biserial, isotomous branching on single primibrachial and seventh secundibrachial; brachials wedge-shaped; tegmen recurved, formed of polygonal plates in columns; columnals holomorphic, roundly pentagonal, heteromorphic. The plate diagram (Fig. 3) is based on the holotype.

Description. See description of *Huqficrinus biserialis.*

Discussion. *Huqficrinus* gen. n. has a cup comparable to *Blothrocrinus* and other primitive genera of the Blothrocrinidae. The arms have an advanced character with branching on the first primibrachials and the secundibrachials are biserial. It probably evolved from *Blothrocrinus* by lowering of the branching to the first primibrachials and the brachials becoming biserial throughout the arms. However, it could have evolved from *Moscovicrinus* or *Woodocrinus* by the brachials becoming biserial.

Huqficrinus biserialis gen. n., n. sp.

Pl. 1, figs 3-5

Etymology: With reference to the biserial arms.

Type locality: Saiwan, coord. base of section: latitude 20°52′04″ N, longitutde 57 °36′27″ E.

Type level: OL15, Saiwan Formation

Holotype: MPUM9856.

Diagnosis: See diagnosis of *Huqficrinus* gen. n.

Description. Crown expanding distally. Cup high conical, base truncated, sutures flush. Ornamentation medium granular to short anastomosing ridges. Infrabasal circlet proximally horizontal for stem attachment, distally steeply upflaring, estimated diameter at distal rim 13 mm. Infrabasals 5, dart shaped, form lower 1/4 of cup wall, visible length 4 mm, width 4.5 mm. Basals 5, BC and CD septagonal, all others hexagonal, gently convex longitudinally and transversely, wider than long, steeply upflaring, forming central 2/5 of cup wall; DE basal length 9 mm, width 12.8 mm. Radials 5, pentagonal, except C radial which is hexagonal, wider than long, straight to slightly concave longitudinally, moderately convex transversely, steeply upflaring; E radial length 6.7 mm, width 12.1 mm. Radial facets peneplenary, width radial facet/width radial 10.6:12.1 = 0.88, subhorizontal; articular facet abraded, poorly preserved, with transverse ridge, ligament pit, denticulate outer marginal ridge. Interradial notches narrow. Anals 3, menoplax 2 subcondition. Primanal pentagonal, length 6.2 mm, width 4.7 mm; in contact with C radial, BC and CD basals, partly under secundanal, and supporting tertanal. Secundanal hexagonal, length 6 mm, width 5 mm, supporting 2 plates distally. Axillary single primibrachial rectilinear, length 6.1 mm, width 9.7 mm. Secundibrachials wedge-shaped, becoming biserial on fifth or sixth secundibrachial, strongly rounded transversely, straight longitudinally, bearing pinnule on wide side. Branching isotomously on primibrachial and 7th secundibrachial in one half of E ray. Tegmen recurved, extends to 6th secundibrachial, formed of small polygonal plates in columns. Columnals holomorphic, roundly pentagonal in transverse section; noditaxis N3231323 proximally.

Discussion. The partial crown of *Huqficrinus biserialis* n. sp. has the infrabasal circlet displaced upward into the basal circlet, the cup is partially flattened, and the specimen lacks the distal arms of the D ray, all other arms, and the distal part of the stem. The tegmen is best preserved in the recurved distal part, but is weathered and only faintly visible. The arms appear uniserial in lateral view because the strongly transversely rounded wedge-shaped brachials only show the biserial nature on the distal ends, visible along the inner sides of the arms.

Material and Occurrence. Holotype, MPUM9856. From bed OL15, Saiwan Formation.

Family Cercidocrinidae Moore & Laudon, 1943

Discussion. The Cercidocrinidae contains three genera, two of which have narrow cuneate brachials (*Coeliocrinus* White, 1863, and *Ascetocrinus* Kirk, 1940) and *Cercidocrinus* Kirk, 1938 which has wide rectilinear brachials. All have endotomous branching distally, are Osagean in age, and known from the United States. The different type of brachials of *Cercidocrinus* suggests that it is derived from a different lineage than the other two genera which may not belong in the same family.

Genus *Coeliocrinus* White, 1863

Type species: *Poteriocrinus dilatatus* Hall, 1861

Emended diagnosis: Crown widely flaring distally. Cup medium bowl with basal invagination. Infrabasals 5, proximally gently downflaring beneath stem, distally upflared, form low circlet at base of cup. Basals 5, large, slightly outflaring distally. Radials 5, wider than long, slightly outflaring distally. Radial facets peneplenary. Anals 3. Anal tube recurved, 2/3 length of arms. Arms branch biendotomously after isotomous branching on single primibrachial; up to 10 arms per ray. Brachials gently cuneate.

Discussion. The diagnosis of *Ceoliocrinus* is emended to include forms with a recurved anal tube.

Coeliocrinus arenaceus n. sp.

Pl. 1, figs 22-24

Etymology: From the Latin, *arena*, meaning sand, refers to the sand matrix encasing the specimen.

Type locality: Saiwan, coord. base of section: latitude 20°52′04″ N, longitude 57 °36′27″ E.

Type level: OL14, Saiwan Formation

Holotype: MPUM9857.

Diagnosis: Distinguished by the combination of the higher cup and tegmen not extending above the arm tips.

Description. Crown flaring distally, arms splaying above tegmen; length 87 mm, width 74 mm near distal arm tips. Cup medium bowl, length 19.7 mm, width 21.35 mm average at radial summit. Infrabasal circlet proximally downflared under stem, distally widely out- and upflaring. Infrabasals 3; 2 large, length 8 mm, width 12.4 mm; 1 small in A ray, length 7.8 mm, width 6.6 mm. Basals 5, large, form over half cup wall; DE basal length and width 11.7 mm. Radials 5, large, wider than long; D radial length 8.3 mm, estimated width 12.6 mm. Radial facets peneplenary, width radial facet/width radial 10.2/12.6 = 0.81, gently declivate. Interradial notches wide. Anals 3, menoplax 2 subcondition. Distal tip of primanal preserved. Secundanal large, above CD basal, distal half above radial summit. Tertanal above primanal, distal half above radial summit. Anal tube recurved, extending 2/3 length of arms, formed of polygonal plates laterally interlocking. Bra-

chials gently cuneate, bearing single pinnule on alternate sides of arm. Single axillary primibrachials and single axillary secundibrachials isotomously branched. Biendotomous branching on tertibracihials 5 or 6, quartibrachials 8 or 9, and pentibrachials 8 or 9. Pinnulars slender, longer than wide; proximal pinnular with wide base. Arms 10 in D ray, 50 total if branching is the same in all rays. Stem facet round, diameter 5.7 mm; columnals unknown.

Discussion. The crown of *Coeliocrius arenaceus* n. sp. has the distal half of the arms splaying away from the tegmen which they would have covered when enclosed. Sand grains have penetrated the calcite plates as a result of pressure solution and exposed plates are partly dissolved and wind abraded. The BC and CD basals are only partly preserved. It is distinguished from all other species of *Coeliocrinus* by the higher cup and the tegmen not extending above the tips of the arms. This extends the stratigraphic range of *Coeliocrinus* upward into the Sakmarian from the Mississippan and the geographic range into the Middle East from North America.

Material and Occurrence. Holotype MPUM9857. From the basal bed OL14, Saiwan Formation.

Superfamily Texacrinoidea Strimple, 1961

Family Texacrinidae Strimple, 1961

Genus *Texacrinus* Moore & Plummer, 1940

Type species: *Texacrinus gracilis* Moore & Plummer, 1940

Texacrinus haushiensis Jell & Willink, 1993

Pl. 1, figs 6-20

Texacrinus haushiensis Jell & Willink, 1993, p. 311, figs. 5-7.

Emended Description. The following description supplements that of Jell & Willink, 1993. Brachials biserial distally on some arms. Pinnules formed of 10 or more pinnulars. First pinnular wider at its base; all pinnulars approximately twice as long as wide, strongly rounded transversely, straight longitudinally. Anal tube formed of 8 interlocking columns of hexagonal plates; at least 3 columns become hexagonal plicate plates with central rib distally. Holomeric stem noditaxis N434243414342434 at unknown distance from cup.

Discussion. *Texacrinus haushiensis* Jell & Willink, 1993 is the most abundant species recovered from the Saiwan Formation. The white calcite plates of the specimens contrast with the tan sand matrix making the specimens easy to see in contrast to the tan specimens of *Campbellicrinus compactus* Jell & Willink, 1993 which blend with the matrix. The discovery of 23 partial crowns of *T. haushiensis* provided the additional morphologic information adding to the original description.

Material and Occurrence. Figured specimens MPUM9858-9863; from bed OL18. Lot of 5 specimens, MPUM9864; from bed OL15. Lot of 13 crowns MPUM9865 from bed OL14. All from the Saiwan Formation.

Texacrinus sp.

Pl. 2, fig. 3

Description. Partial crown 48 mm long, 36 mm wide, lacking stem, infrabasals, basals and proximal tips of radials, and distal tips of arms. Radial facets peneplenary, narrow interradial notches. Brachials cuneate, moderately convex transversely. Single primibrachial axiallary, isotomous branching. Subsequent branching exotomous on 7th or 8th secundibrachial, 6th tertibrachial and 6th quartibrachial. Eight arms per ray.

Discussion. The specimen probably represents a new species as the primibrachials are shorter, interradial notches are obvious, and the brachials are less convex than those of *T. haushiensis.* Unfortunately the speci-

PLATE 1

Fig. 1, 2 - Indeterminate Sycocrinid, infrabasal plate, MPUM 9853; 1) external view; 2) internal view; x2.

Fig. 3-5 - *Huqficrinus biseralis* gen. n., n. sp, partial crown, holotype MPUM9856; 3) D ray view; 4) posterior view; 5) tegmen view; x1.5.

Fig. 6, 7 - *Texacrinus haushiensis* Jell & Willink 1993, distal part of partial set of arms, MPUM9858; 6) exterior view of distal arms; 7) internal view showing distal part of abraded tegmen; x2.

Fig. 8, 9 - *Texacrinus haushiensis* Jell & Willink 1993, partial set of arms MPUM9859; 8) external view; 9) internal view showing pinnules; x2.

Fig. 10-13 - *Texacrinus haushiensis* Jell & Willink 1993, partial crown MPUM9860; 10) oral view; 11) posterior view; 12) A ray view; 13) basal view; x2.

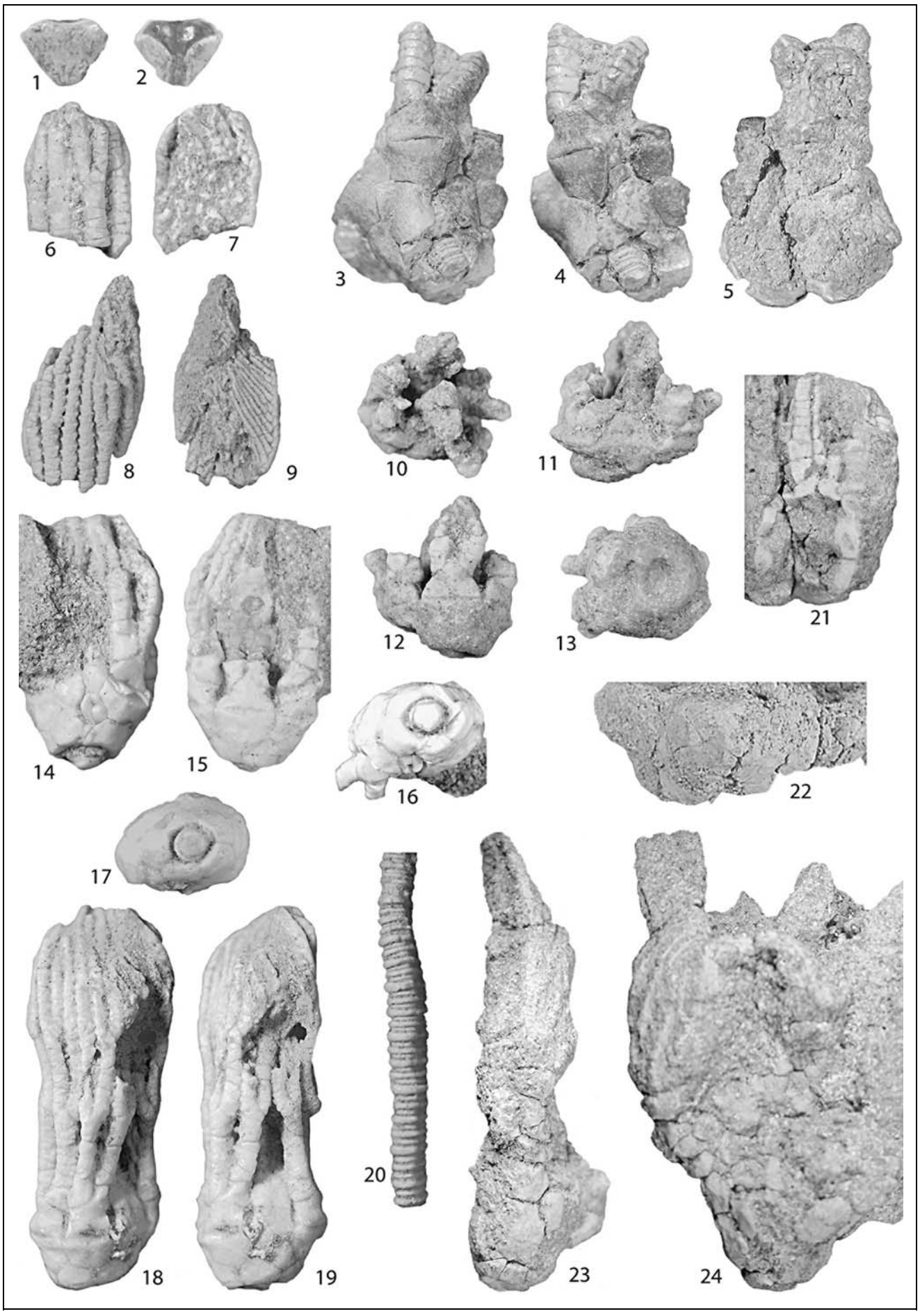
Fig. 14-16 - *Texacrinus haushiensis* Jell & Willink 1993, partial crown, MPUM9861; 14) posterior view; 15) A ray view showing anal opening below summit of tegmen; 16) basal view; x2.

Fig. 17-19 - *Texacrinus haushiensis* Jell & Willink 1993, crown, MPUM9862; 17) basal view; 18) D ray view; 19) posterior view; x2.

Fig. 20 - *Texacrinus haushiensis* Jell & Willink, 1993, lateral view of pluricolumnal, MPUM9863; x1.

Fig. 21 - *Omanicrinus secundus* Jell & Willink 1993, C-D interray view of eroded partial crown, MPUM9855; x1.

Fig. 22-24 - *Coeliocrinus arenaceus* n. sp., partial crown, MPUM 9857; 22) basal view; 23) D ray view; 24) posterior view showing recurved tegmen; x1.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men is so incomplete that it is not suitable to serve as a holotype.

Material and Occurrence. Figured specimen MPUM9867. From bed OM32, Saiwan Formation

Texacrinidae? sp.

Pl. 2, figs 1, 2

Description. Crown flaring distally, length 69 mm, width 52 mm. Cup medium cone, length 12.8 mm, width average 18.7 mm. Infrabasals mostly covered, upflaring distally. Basals 5, approximately equidimensional; AB basal length 8 mm, width 8.1 mm. Radials 5, much wider than long; B radial length 5.1 mm, width 11 mm. Radial facets peneplenary, variable, width radial facet/width radial 7.3/8.3 = 0.88 (B ray), 6.6/8.8 = 0.75 (D ray), gently declivate. Interradial notches wide. Anals 3, menoplax 2 subcondition. Primanal large, partly under secundanal. Secundanal large, directly above CD basal. Tertanal not preserved, mostly below radial summit above primanal. Brachials gently cuneate, bearing single pinnule on wide side. Isotomous branching on axillary single primibrachial, exotomous branching on secundibrachial 4 or 5, tertibrachials 6-10, and quartibrachials 8-11. Arms 8 in D ray, 40 total if branching same in all arms. Stem unknown.

Discussion. The crown of Texacrinidae? sp. has the arms splayed, is slightly compacted parallel to the A ray-posterior plane of symmetry, and has sand grains penetrating the calcite plates. In addition, exposed surfaces are partly dissolved and wind abraded. The specimen is questionably assigned to the Texacrinidae because it has wide interradial notches. It probably represents a new genus because few late Paleozoic cladids (Timorechinidae Jaekel, 1918; Stellarocrinidae Strimple, 1961; Texacrinidae Strimple, 1961; and Sostronocrinidae Lane et al., 2001) have exotomous branching arms. The specimen has characters that significantly differ from all of these families except the Texacrinidae. Even there it differs by the presence of the wide interradial notches. A genus or species is not proposed for the specimen because the infrabasal circlet is poorly preserved and the cup is poorly exposed.

Material and Occurrence. Figured specimen MPUM9868. From the basal bed OL14, Saiwan Formation.

Superfamily Cromyocrinoidea Bather, 1890

Family Cromyocrinidae Bather, 1890

Genus *Moapacrinus* Lane & Webster, 1966

Type species: *Moapacrinus rotundatus* Lane & Webster, 1966

Moapacrinus? omanensis n. sp.

Pl. 5, figs 1-4

Etymology: For Oman.

Type locality: Saiwan, coord. base of section: latitude 20°52′04″ N, longitude 57 °36′27″ E.

Type level: OL15, Saiwan Formation

Holotype: MPUM9869.

Diagnosis: Distinguished by presence of three anals in cup and medium granular to anastomosing ridge ornament.

Description. Cup medium bowl, length 12 mm, width 21.9 mm average, base flat, walls slightly outflaring distally, deeply impressed stitched sutures, medium granular to anastomosing ridge ornament. Infrabasal circlet horizontal proximally with deep stem impression, distal tips barely upflaring, barely visible in lateral view. Infrabasals 5, dart shaped, A ray visible length 3.3 mm, width 4.3 mm. Basals 5, CD septagonal, all others hexagonal, moderately convex longitudinally and transversely, slightly wider than long; BC basal length 8.5 mm, width 9.2 mm; CD basal length 8.8 mm, width 10.2 mm. Radials 5, C radial hexagonal, all others pentagonal, moderately convex longitudinally and transversely, wider than long; A radial length 7.5 mm, width 11.7 mm. Radial facets plenary, slightly inclinate, advanced morphology; transverse ridge narrow, not denticulate; ligament pit deep, 1/3 facet width, sloping under transverse ridge; ligament pit furrow narrow; outer ligament ridge rounded; outer ligament furrow shallow; outer marginal ridge weakly developed in middle of facet; muscle field large, concave, rounded orally; intermuscular furrow narrow, long; central pit not widened, merging orally with shallow intermuscular furrow. Anals 3, menoplax 5 subcondition; primanal quadrangular, length 4.9 mm, width 4.2 mm, partly under secundanal, in contact with C radial, CD basal, secundanal and tertanal; secundanal directly above CD basal; tertanal directly above primanal, proximally well below radial summit. Primibrachial rectilinear, axillary;

PLATE 2

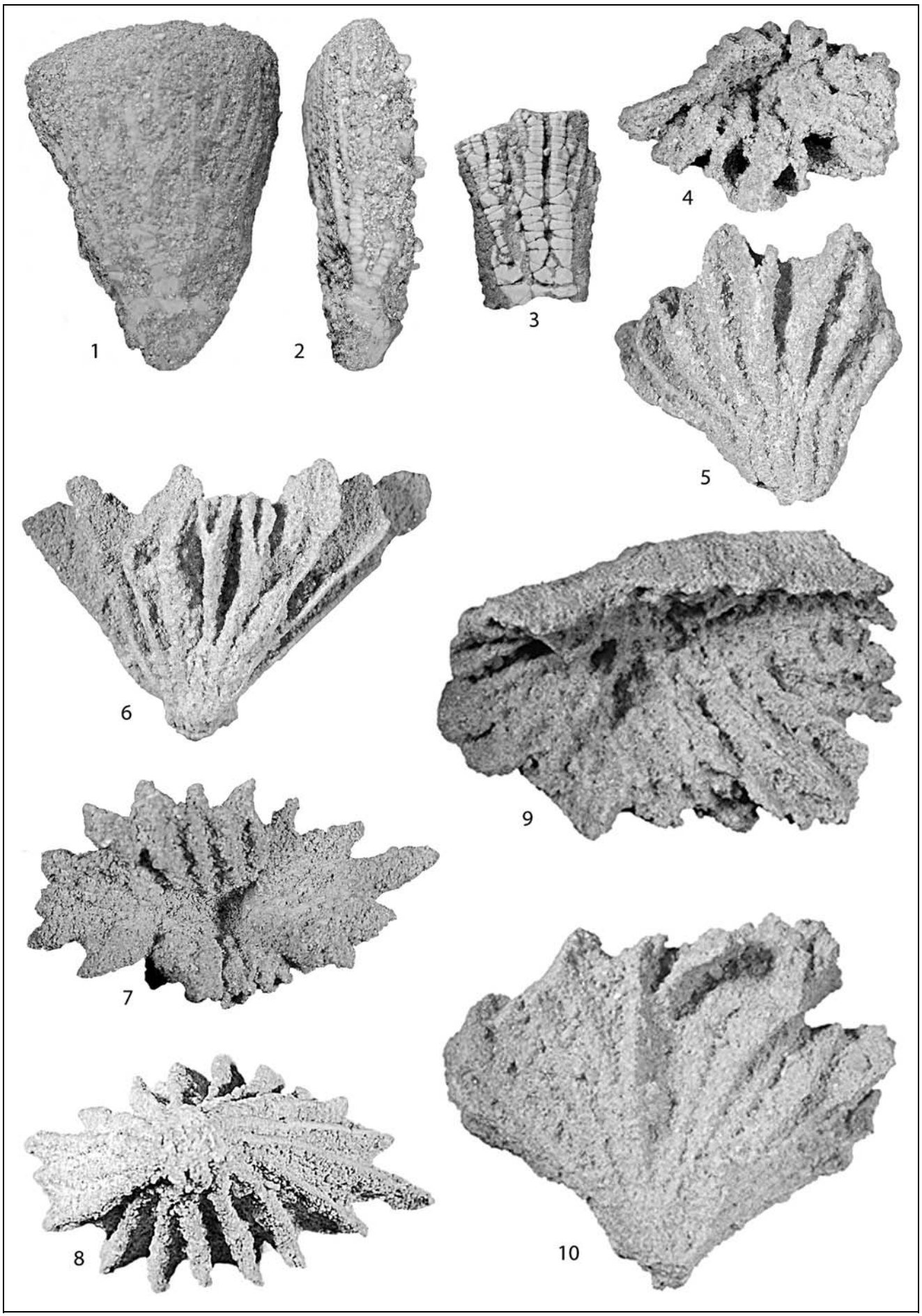
Fig. 1, 2 - Texacrinidae? sp., partial crown, MPUM9868; 1) lateral view of uncertain ray; 2) lateral view of uncertain ray; x1.

Fig. 3 - *Texacrinus* sp. MPUM9867; lateral view of partial crown; x1.

Fig. 4, 5 - Indeterminate Cladid, set of arms, MPUM9871; 4) oral view; 5) lateral view, orientation uncertain, x1.

Fig. 6-8 - Indeterminate Cladid, set of arms, MPUM9872; 6) lateral view of uncertain orientation; 7) oral view; 8) basal view; x1.

Fig. 9, 10 - Indeterminate Cladid, set of arms, MPUM9873; 9) oral view; 10) lateral view of uncertain orientation; x1.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branching isotomous. Distal arms and pinnules unknown. Stem holomeric, round, diameter 4.1 mm. Columnal facet with narrow crenularium, wide areola, pentalobate lumen; crenulae coarse, short. Distal stem unknown.

Discussion. *Moapacrinus*? *omanensis* n. sp. is the first cromyocrinid with three anals reported from the Permian. Webster (1981, fig. 1) showed a general evolutionary trend for the cromyocrinids to decrease the number of anals in their Carboniferous to Permian range. It is possible that *M. omanensis* represents a new genus or that the generic diagnosis of *Moapacrinus* should be redefined to include forms with one or three anals. The lack of the arms on the two Saiwan specimens precludes an unquestioned generic assignment. The cup shape is remarkably similar to that of *M. rotundatus* Lane & Webster, 1966 but the ornament is not as coarse. Permian species of *Parulocrinus* Moore & Plummer, 1940 have two anals and the cup base is slightly upflaring. *Moapacrinus* has 10 uniserial arms whereas *Parulocrinus* has 14 - 18 biserial arms. *Parulocrinus* ranges from the Middle Pennsylvanian into the Early Permian and has been reported from South America and North America (Webster et al. 2004).

Material and Occurrence. One cup MPUM9869 slightly compressed along the A ray - posterior symmetry plane, slightly abraded, lacking secundanal and tertanal, and with one primibrachial and one secundanal partially inside the visceral cavity. From bed OL15, Saiwan Formation.

One abraded partial cup MPUM9870 lacking the DE basal, EA basal, all radials except C radial, secundanal, and tertanal. The primanal is barely in contact with BC basal. From bed OM58, Saiwan Formation.

Indeterminate Cladid, sets of arms

Pl. 2, figs 4-10; Pl. 3, fig. 1-4

Description. Sets of arms splayed with pinnules partly splayed, all lack cups. Brachials faintly cuneate, strongly convex transversely, straight longitudinally, bearing one pinnule on wide side. Axillary primibrachial followed by isotomous branchings on secundibrachial 3, tertibrachials 7-11, and much higher quartibrachials on a few arms; 8 arms per ray. Cup and stem unknown.

Discussion. The nine specimens, all lacking cups, are preserved with the arms partly to strongly splayed as well as the pinnules partly opened in a poorly sorted sand matrix. The specimens were preserved in a mouth down position with the opened arms and partly opened pinnules below the cup. This is the starburst down position of Baumiller et al. (2008). The cups have been lost by weathering. The depositional position is not normal for crinoids and suggests a catastrophic event disrupted the living organisms and as they were transported they were quickly buried, with the crown in a trauma response partly opened trying to reorient or remove itself from the sand matrix entombing them.

The lack of cups precludes identification at the generic level. The first branching is judged to be on the axillary primibrachial, because the arms are all closely bunched, splaying distally. However, the number of primibrachials is unknown. The distal most branching is irregular and developed on only two arms of one specimen. The eight arms in one ray suggesting 40 arms total if branching is uniform in all rays. Specimen MPUM9876 has 32 arms exposed, the maximum observed. Specimens with fewer arms may represent less mature individuals or variation. There is no tegmen present or preserved in the open area near the base of the arms. The faintly cuneate brachials, arm branching pattern, and lack of a large or elongate tegmen suggest that the taxon may be derived from the blothrocrinids or pachylocrinids.

Material and Occurrence. Six solitary specimens MPUM9871-9876 and one cluster of three MPUM9877. From OL14, Saiwan Formation

Indeterminate Cladid columnals and cup ossicles

Discussion. An abundance of round columnals and pluricolumnals up to 69 mm long, occur 7 meters above the base of the Saiwan Formation (MPUM9878, OL 15). Three different noditaxis patterns of N212, N3231323, and N434243414342434 are recognized among the pluricolumnals. They probably represent different parts of the stem of a single taxon as the facets and latus are of the same type on all three. The crenularium is wide with culmina splitting on the distal ends and new culmina were added between older culmina on the outer half of the crenularium. The smooth or irregular areola is narrow and the lumen is pentagonal. The latus is convexly rounded and cirri facets are in round depressions on the nodals. An indeterminate infrabasal

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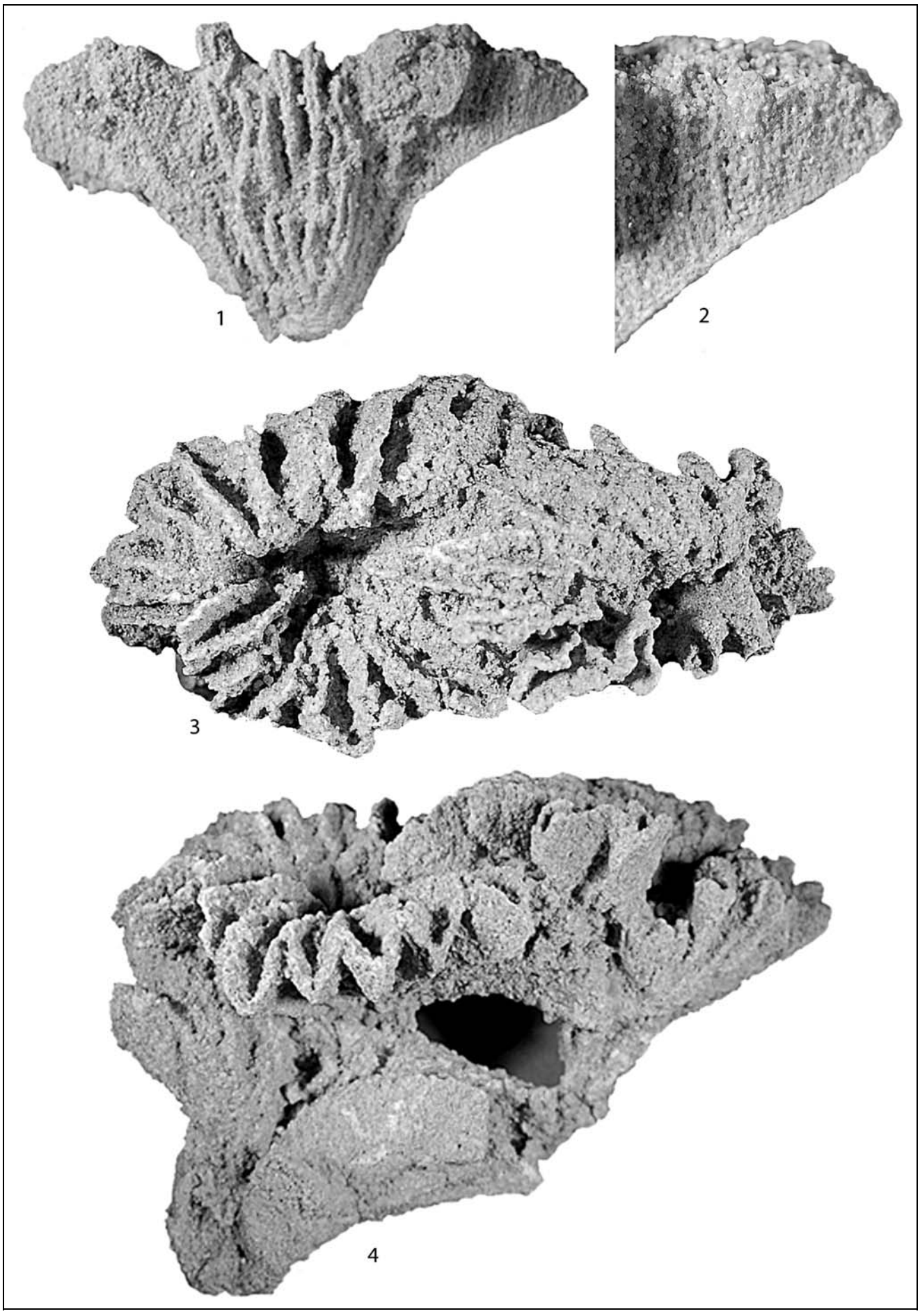
PLATE 3

Fig. 1, 2 - Indeterminate Cladid, set of arms, MPUM9874; 1) lateral view of uncertain orientation, x1; 2) enlargment of distal tip of arm shown in Fig. 1, x2.4.

Fig. 3, 4 - Indeterminate Cladid, association of three sets of arms, MPUM9877; 3) oral view showing two specimens; 4) lateral view of the three specimens, with the third specimen attached to the proximal parts of the other two specimens; x1.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circlet and basal plate (MPUM9879) occur with the columnals.

Numerous relatively small and thick disarticulated ossicles and pluricolumnals of indeterminate crinoids occur in a thin marly bed above the limy interval (OL 16) approximately 15 meters above the base of the Saiwan Formation in the Huqf section. These include two infrabasal circlets (MPUM9880), 20 basal plates (MPUM9881), two radials (MPUM9882), and a large assortment of columnals and pluricolumnals (MPUM 9883). The two infrabasal circlets represent two different genera, one with a round stem impression and the other with a pentagonal stem impression and axial canal. The 20 basal plates probably represent a minimum of three genera based on differences in thickness, curvature, ornamentation or lack thereof, and facets of the specimens. Some of the basal plates are judged to belong to the same taxa as the two infrabasal circlets. The two radials represent one genus with fine anastomosing ornamentation. The best preserved radial is 5.1 mm long and 8 mm wide and belongs to the same species as the septagonal CD basal that is 7.5 mm long and 9.2 mm wide; both have the same fine anastomosing ornamentation and may represent a cromyocrinid. Columnals and pluricolunals from this horizon are similar to many of those found in OL15. At least three genera are present in this fauna and all are judged to be different species than those described from other horizons in the Saiwan Formation.

Material and Occurrence. Columnals (MPUM 9878) and cup ossicles (MPUM9879) from bed OL15, Saiwan Formation. Infrabasal circlets (MPUM9880), basal plates (MPUM9881), radials (MPUM9882), and columnals (MPUM9883) from bed OL16, Saiwan Formation.

Subclass **Articulata** Zittel, 1879

Order Ampelocrinida Webster & Jell, 1999b

Family Corythocrinidae Strimple & Watkins, 1969

Genus *Campbellicrinus* Jell & Willink, 1993

Type species: *Campbellicrinus nodosus* Jell & Willink, 1993

Emended diagnosis: To include forms with a pentastellate or quadrate stem in cross-section.

Discussion. When defining *Campbellicrinus*, Jell & Willink, 1993 described the stem as round. Topotypic specimens of *C. compactus* Jell & Willink, 1993 discussed below have a pentastellate or quadrate stem in cross-section.

Campbellicrinus compactus Jell & Willink, 1993

Pl. 4, figs 6-8, 14-16, 20, 21

Campbellicrinus compactus Jell & Willink, 1993, p. 308, figs. 3, 4.

Discussion. Four topotypic specimens of *Campbellicrinus compactus* fit the original description of Jell & Willink (1993) except for the stem. The proximal columnal or parts of the stem are preserved on three of the new specimens. Two of these are pentastellate and that of the longest specimen is quadrate in cross-section. The quadrate stem has six rays, two of which are fused alternating with a single ray, giving the quadrate shape in cross-section. It may be a variant or aberrant specimen. The fourth specimen lacks the proximal columnal, but retains a faint pentastellate stem impression.

Material and Occurrence. Figured specimens MPUM9884-9886, and unfigured specimen MPUM 9887 (lacking the proximal columnal). From bed OL15, Saiwan Formation

Campbellicrinus nodosus n. sp.

Pl. 4, figs 1-5, 9-13, 17-19, 22-26

Etymology: Latin referring to the ornamentation.

Type locality: Saiwan, coord. base of section: latitude 20°52′04″ N, longitude 57 °36′27″ E.

PLATE 4

Fig. 1, 2 - *Campbellicrinus nodosus* n. sp., cup, paratype 4 MPUM9890; 1) oral view; 2) B ray view; x2.

Fig. 3-5 - *Campbellicrinus nodosus* n. sp., cup, paratype 2 MPUM9892; 3) oral view; 4) A ray view; 5) posterior view; x2.

Fig. 6-8 - *Campbellicrinus compactus* Jell & Willink, 1993, partial crown, MPUM9886; 6) posterior view; 7) E-A interray view; 8) basal view; x2.

Fig. 9-11 - *Campbellicrinus nodosus* n. sp., partial cup, paratype 5 MPUM9893; 9) internal view; 10) D ray view; 11) basal view; x2.

Fig. 12, 13 - *Campbellicrinus nodosus* n. sp., partial crown, paratype 3 MPUM9891; 12) posterior view; 13) A-B interray view; x2.

Fig. 14-16 - *Campbellicrinus compactus* Jell & Willink, 1993, partial crown, MPUM9884; 14) C ray-posterior interray view; 15) E-A interray view; 16) basal view; x2.

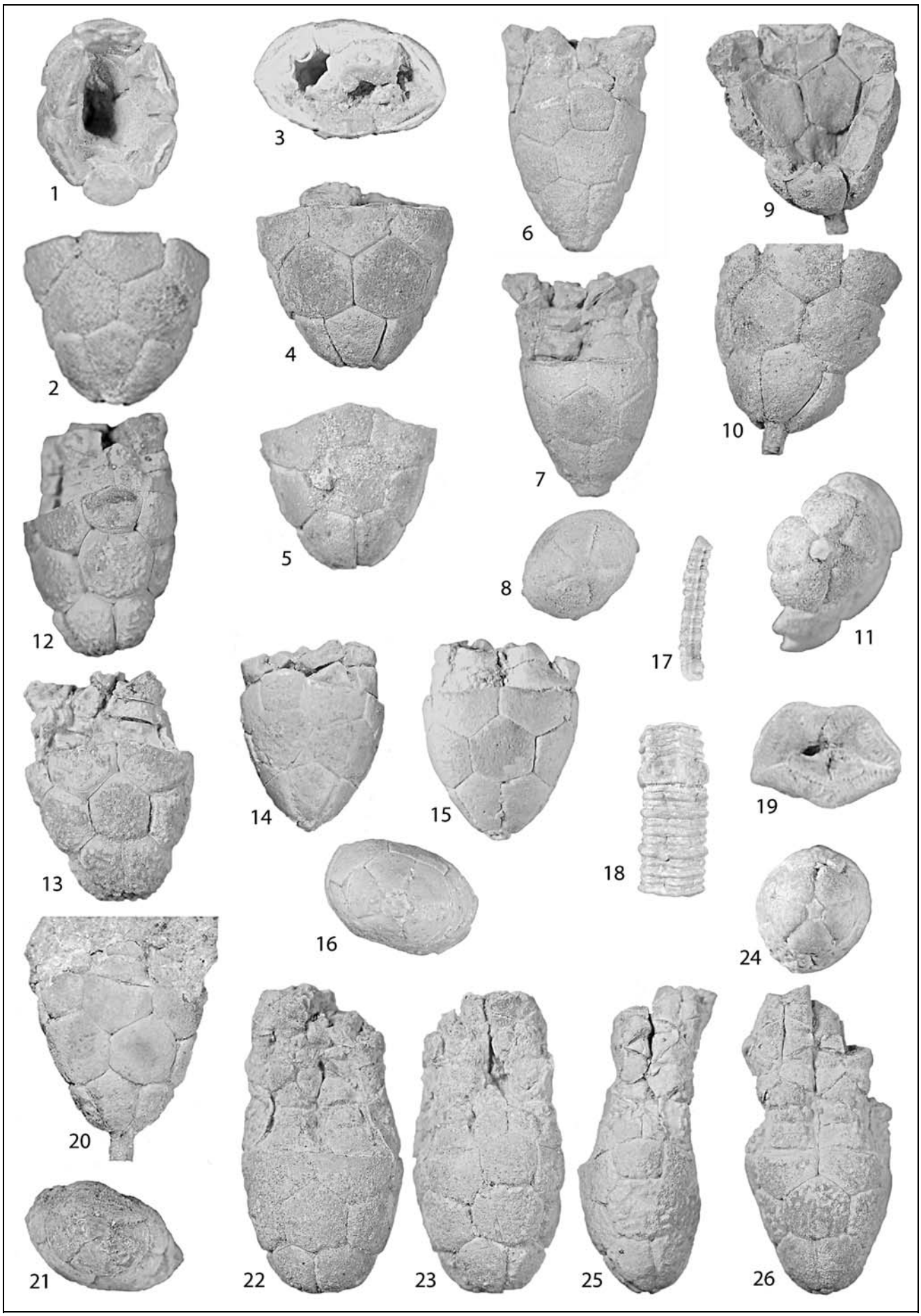
Fig. 17 - *Campbellicrinus nodosus* n. sp., lateral view of pluricirral, paratype 8, MPUM9896; x2.

Fig. 18, 19 - *Campbellicrinus nodosus* n. sp., pluricolumnal, paratype 7, MPUM9895; 18) lateral view; x2; 19) facet view, x4.

Fig. 20, 21 - *Campbellicrinus compactus* Jell & Willink, 1993, partial crown, MPUM9885; 20) C ray view; 21) basal view, x2.

Fig. 22, 23 - *Campbellicrinus nodosus* n. sp., partial crown, paratype 1 MPUM9889; 22) A-B interray view; 23) posterior view, x2.

Fig. 24-26 - *Campbellicrinus nodosus* n. sp., partial crown, holotype MPUM9888; 24) basal view; 25) posterior view; 26) A-B interray view; x2.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Specimen	Holotype	Paratype 1	Paratype 2
Crown length (partial)	30	22.6	
Crown width (average)	14.2	16.5	
Cup length	13	12.6	14.4
Cup width (maximum)	14	16.4	17.6
Cup width (minimum)	11.7	10.4	10,3
Cup width (average)	12.85	13.4	13.95
Infrabasal circlet diameter	8.6	9.1	9.3
A ray infrabasal length	4.7	4.5	4.6
A ray infrabasal width	4.7	4.8	5.4
AB basal length	7	6.3	7
AB basal width	7	6.3	7
CD basal length	6.7	6.6	7
CD basal width	7.5	6.6	6.6
A radial length	4.3	4.9	5.1
A radial width	6.5	6.9	7.1
Radial facet width	6.5	6.9	7.1
First primibrachial length	3.1	2.4	
First primibrachial width	6.5 (base)	6.9 (base)	
Primanal length	4	4.9	4
Primanal width	4.8	5.1	5
Length proximal columnal	0.2		0.2
Diameter proximal columnal	2.1		2

Tab. 2 - Measurements in mm for *Campbellicrinus nodosus* n. sp.

Type level: OL15, Saiwan Formation.
Holotype: MPUM9888.
Diagnosis: Distinguished by the coarse nodose ornament on the cup and proximal arm plates and deeply impressed sutures.

Description. Crowns slender, cylindrical. Cup medium bowl, longer than wide, base upflared, deeply impressed sutures, coarse nodose to anastomosing ridge ornamentation continuing onto proximal brachials. Infrabasal circlet conical, steeply upflaring distally, forms lower 1/3 of cup wall, bearing small pentastellate stem impression or columnal on proximal end. Infrabasals 5, dart shaped, subhorizontal on proximal tips, upflaring thereafter, equidimensional to slightly wider than long. Basals 5, CD septagonal, all others hexagonal, equidimensional, gently convex longitudinally, moderately convex transversely, steeply upflaring, form middle 1/3 of cup wall. Radials 5, pentagonal, wider than long, gently convex longitudinally, moderately convex transversely, steeply upflaring, forming upper 1/3 of cup wall. Radial facets plenary, inclinate, advanced complex morphology; transverse ridge narrow, smoothly rounded; ligament pit 1/2 radial width, deep, slightly sloping under transverse ridge; outer ligament furrow shallow; outer ligament ridge rounded, widening toward center of facet; outer marginal furrow shallow; outer marginal ridge weakly developed; muscle fields triangular, deeply concave; intermuscular furrow narrow merging without enlargement with central pit; two shallow depressions, one on either side of the central pit representing terminations of entoneural canals. Single large pentagonal primanal, opioplax 1 subcondition, directly above CD basal extending to radial summit, bearing two tube plates distally. Anal tube short. Primibrachials rectilinear, third primibrachial axillary, isotomous branching. Secundibrachials and tertibrachials cuneate, uniserial, paired syzygial articulation. Arms 12, 3 each on C and D rays, with second and third arms on posterior side; 2 arms all other rays. Stem holomeric, pentastellate in cross-section; noditaxis N434243414342434. Columnals with strongly rounded latus; facet with narrow crenularium, wide areola, small pentagonal lumen. Crenulae coarse, longest between apex of rays, becoming shorter towards points of rays. Cirri pentastellate in cross-section, noditaxis N212. Measurements given in Table 2.

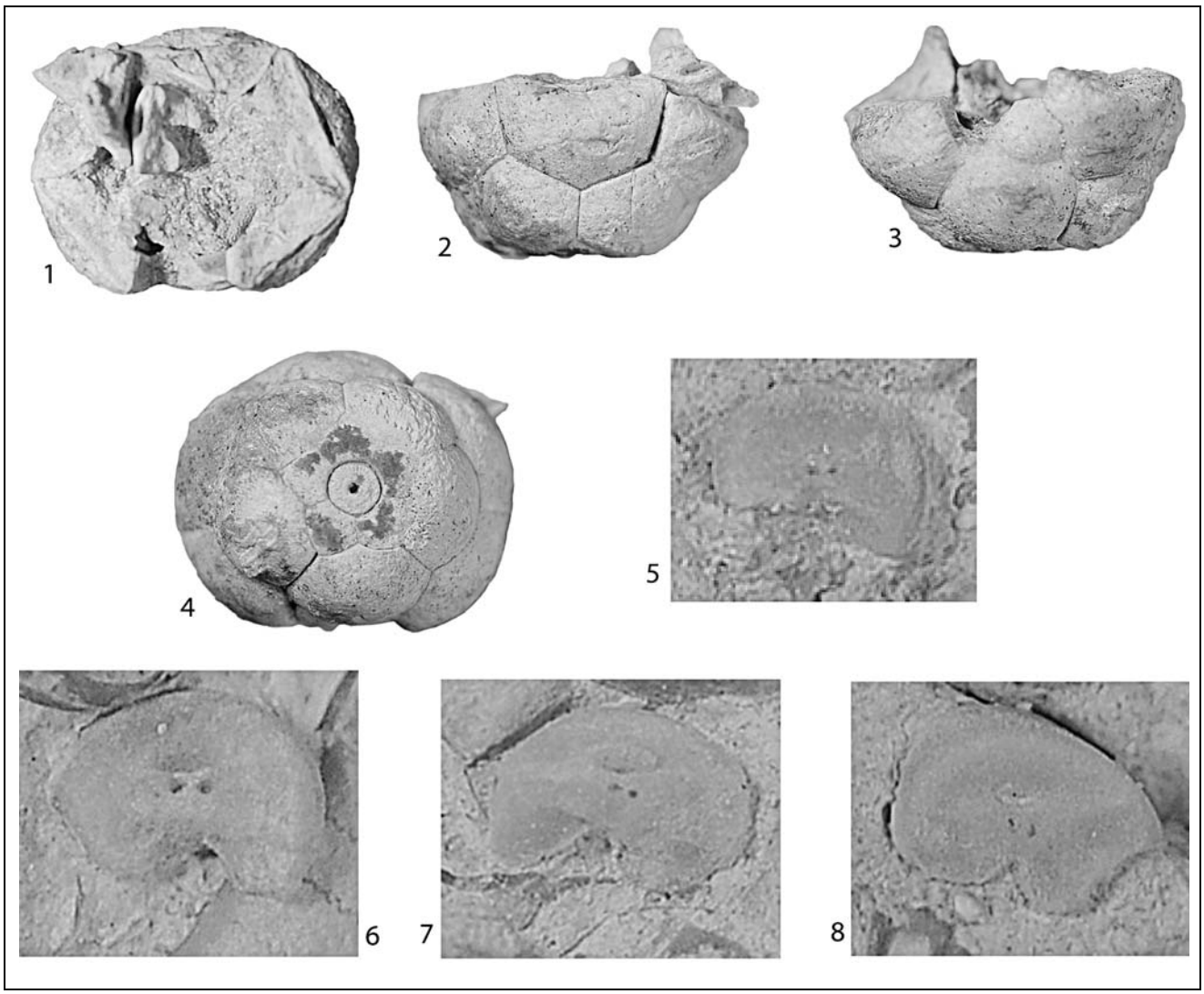
Discussion. All of the specimens of *Campellicrinus nodosus* n. sp. are slightly crushed, probably from compaction, and most of the specimens show some wind abrasion from weathering in the desert environment. None of the crowns have the distal parts of the arms preserved. The partial crowns show no trace of the tegmen within the arm circlet, at the level of the preserved proximal six to eight secundibrachials indicating the tegmen is short. The nodose ornament and deeply impressed sutures readily distinguish *C. nodosus* from *C. compactus.*

Material and Occurrence. Three partial crowns, holotype MPUM9888, and paratypes 1 and 3, MPUM 9889, MPUM9891; four cups, paratypes 2 and 4-6, MPUM9890 and MPUM9892-9894; a pluricolumnal, paratype 7, MPUM9895; a pluricirral, paratype 8, MPUM9896; two additional partial crowns MPUM 9897-9898, two additional cups MPUM9899-9900,

PLATE 5

Fig. 1-4 - *Moapacrinus*? *omanensis* n. sp., cup and two associated brachials, holotype MPUM9869; 1) oral view; 2) A ray view; 3) posterior view; 4) basal view, x2.

Fig. 5-8 - Indeterminate Articulate; 5-8) facet views of four brachials from one slab, MPUM9902; 5) synostosial facet view; 6-8) articular facet views of three secundibrachials; note the ligament pit and transverser ridge; x15.



and one lot of two pluricirrals, MPUM9901. All from OL15 Saiwan Formation.

Indeterminate Articulate

Pl. 5, figs 5-8

Description. Primibrachials rectilinear, moderately convex transversely, slightly convex longitudinally, much wider than long. Secundibrachials cuneate wedge-shaped, strongly convex transversely, slightly convex to straight longitudinally, no ornamentation, bearing articular facet on one surface, synostosial facet on opposing surface, and pinnule facet on wider lateral surface. Articular facet trifacial, bearing narrow transverse ridge with centrally located paired-entoneural canals on adoral side and short deep ligament pit on aboral side; aboral fossa wide, arcuate crescent merging with round outer marginal ridge; adoral fossa triangular, shallowly concave, unequal, larger extending nearly twice adorally smaller; wide V-shaped intermuscular notch; no intermuscular furrow or central pit. Synostosial facet shallowly concave, bearing paired-entoneural canals centrally towards adoral side and narrow crenularium in central part of outer marginal ridge.

Discussion. Only one partly exposed primibrachial was found on the slab containing all brachials plates observed. The secundibrachials are syzygial paired, bearing an articulating facet on one side and a synostosial facet on the opposing side. The combination of the syzygial pairing and paired-entoneural canals in the brachials allies them with the articulate crinoids. One pentagonal columnal that is considered to belong to the same taxon as the brachials occurs on the slab. Lacking the cup plates an identification is not made. Crinoid columnals, pluricolumnals, and pluricirrals are also common on the slab. They probably belong to an unknown cladid. All disarticulated crinoid ossicles are associated with abundant bivalves, bryozoans, bellerophontid gastropods, and scaphopods. Similar articulate brachials associated with camptocrinid columnals occur in a tempestite bed in Member 1 of the Khuff Formation.

Material and Occurrence. One slab, MPUM9902, from a tempestite bed in Member 3 of the Khuff For-

mation, Wordian, Haushi area (latitude 21°02′30″N, longitude 57°42′00″E). (Stop 7 of Angiolini et al. 2001).

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