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# The microcrinoid taxonomy, biostratigraphy and correlation of the upper Fredericksburg and lower Washita groups (Cretaceous, middle Albian to lower Cenomanian) of northern Texas and southern Oklahoma, USA

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ABSTRACT:

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The stratigraphy of the upper Fredericksburg and lower Washita groups of northern Texas and southern Oklahoma is described, and biostratigraphical correlation within the region, and further afield, using microcrinoids, ammonites, planktonic foraminiferans and inoceramid bivalves is summarised. The taxonomy of the roveacrind microcrinoids is revised by the senior author, and a new genus, *Peckicrinus*, is described, with the type species *Poecilocrinus porcatus* (Peck, 1943). New species include *Roveacrinus proteus* sp. nov., *R. morganae* sp. nov., *Plotocrinus reidi* sp. nov., *Pl. molineuxae* sp. nov., *Pl. rashallae* sp. nov. and *Styracocrinus thomasae* sp. nov. New formae of the genus *Poecilocrinus* Peck, 1943 are *Po. dispandus* forma *floriformis* nov. and *Po. dispandus* forma *discus* nov. New formae of the genus *Euglyphocrinus* Gale, 2019 are *E. pyramidalis* (Peck, 1943) forma *pyramidalis* nov., *E. pyramidalis* forma *radix* nov. and *E. pyramidalis* forma *pentaspinus* nov. The genera *Plotocrinus* Peck, 1943, *Poecilocrinus* and *Roveacrinus* Douglas, 1908 form a branching phylogenetic lineage extending from the middle Albian into the lower Cenomanian, showing rapid speciation, upon which a new roveacrinid zonation for the middle and upper Albian (zones AlR1–12) is largely based. Outside Texas and Oklahoma, zone AlR1 is recorded from the lower middle Albian of Aube (southeastern France) and zones AlR11–CeR2 from the Agadir Basin in Morocco and central Tunisia. It is likely that the zonation will be widely applicable to the middle and upper Albian and lower Cenomanian successions of many other regions.

**Key words:** Roveacrinida; Integrated biostratigraphy; Ammonites; Planktonic foraminifera.

## INTRODUCTION

Roveacrinids are small pelagic crinoids that were locally abundant in the shelf seas of the mid- to Late Cretaceous (Albian to Maastrichtian), and became extinct at the K/Pg boundary (Gale *et al.* 2018). They have been found in North America (Peck 1943, 1973; Hess 2015), South America (Ferré and Berthou 1994; Dias-Brito and Ferré 2001; Ferré *et al.* 2005), Africa (Ferré and Granier 2001; Ferré *et al.* 2017; Gale 2020), Europe (Peck 1955; Rasmussen 1961, 1971; Jagt 1999; Gale 2016, 2018, 2019; Zítt *et al.* 2019), Iran (Ferré *et al.* 2016) and India (Jain and Mallikarjuna 1996). Roveacrinida were used to construct a zonation for the Albian to Campanian stages of Europe and North Africa (Gale 2018, 2019, 2020). They are only very rarely preserved as articulated individuals being usually found as disarticulated cups and brachials in sediment residues, or seen in thin sections of limestones.

One of the most remarkable papers written about Mesozoic microcrinoids was the description of abundant and diverse Roveacrinidae from the Cretaceous of Texas and Oklahoma by Raymond Elliot Peck (1904–1984), of the University of Missouri, based initially on material picked from residues collected and processed by the micropalaeontologists Alfred R. Loeblich (1914–1994) and Helen Nina Tappan Loeblich (1917–2004). Previous to this, accounts of the group, based on rather limited northwest European material (Douglas 1908; Bather 1924; Sieverts 1932, 1933) had only identified one genus, and a few species, but Peck described an unexpected diversity of genera and species, all beautifully illustrated by airbrushed images made by his wife, Vaona Hedrik Peck. There has been rather little subsequent research on North American roveacrinids; Peck himself described the saccocomid *Applinocrinus* (Peck 1973) and Scott *et al.* (1977) recorded articulated material of *Poecilocrinus* from Texas. Hess (2015) redescribed five of Peck's original species from the Albian and Cenomanian of Fort Worth, Tarrant County, Texas.

One of us (ASG) discovered an equally diverse and abundant fauna of microcrinoids in the Campanian chalk of the United Kingdom (Gale 2016, 2019) and visited Texas in the company of FH in 2016 in order to assess the possibility of collecting material with which to revise Peck's (1943) work on the Albian and Cenomanian microcrinoids. This led to a series of field campaigns (2016–2019) in which we visited and logged numerous outcrops in northern Texas and southern Oklahoma, and sampled extensively (see below, under Methods). JMR became involved in the fieldwork in 2018. The discovery that Peck's figured types were missing, although supposedly placed in the University of Missouri collections, was made through the careful investigation of Professor Ken McLeod. Unfigured paratypes in the USNM were made available by Mark Florence. The present paper is largely based upon the material collected recently, augmented by Peck's unfigured paratypes in the Smithsonian collections.

Raymond Elliot Peck (1904–1984)

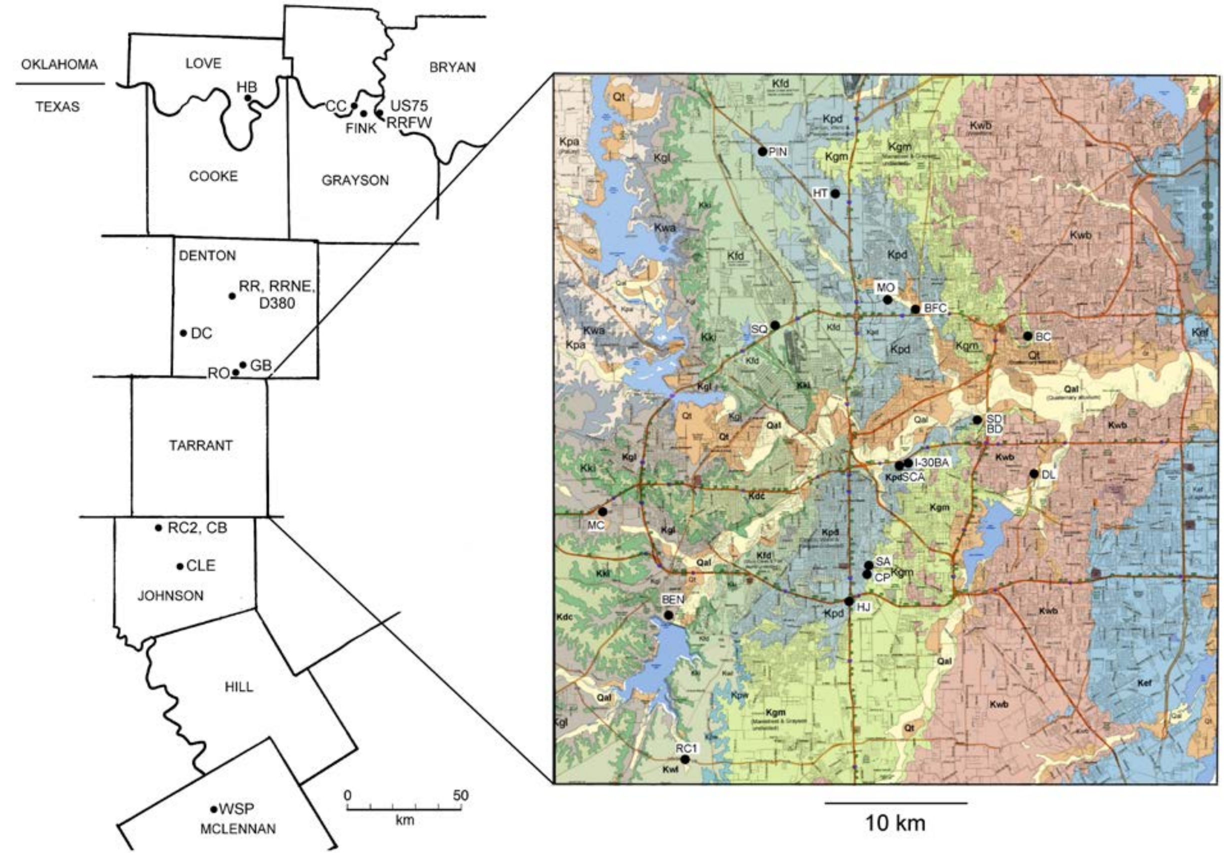
## LOCALITIES AND STRATIGRAPHY

Localities mentioned in the text are shown in Text-fig. 1, and other details, including co-ordinates, listed in Table 1. The stratigraphic scheme, to which reference is made, is in Text-fig. 2.

### Fredericksburg Group

#### *Goodland Formation*

The Goodland Formation (Taff and Leverett 1893) comprises massive bioclastic and peloidal limestones with thin marly units and partings. Winton and Adkins (1919) and Adkins (1923) used the term Goodland for the lowest of three units of a 'Fredericksburg limestone', overlain successively by the Comanche Peak and Edwards formations in Tarrant and Mclennan counties. Winton and Scott (1922), Winton (1925) and subsequent authors (e.g., Bybee and Bullard 1927; Bullard 1931; papers in Hendricks (Ed.) 1967) have used the term Goodland Formation for this unit. In Tarrant County, Perkins (1960) subdivided the




Text-fig. 1. Localities in northern Texas and southern Oklahoma. A – county map to show all localities. Oklahoma: HB, cliff on Red River, Horseshoe Bend; US75/RRFW, cliff on Red River east of US Highway 75. Texas: RR, RRNE, Rayzor Ranch, Denton; D380, cutting on US 380 in Denton; CC, Cedar Bayou; RO, Roanoke; DC, Denton Creek; GB, Grayson Bluff; RC, Rock Creek 1, 2; CLE, Cleburne, roadcut on US77; WSP, Waco Shale Pit. B – map of Tarrant County to show localities. MC, Marys Creek; BEN, Benbrook dam spillway; HJ, Hobo Junction; CP, Carter Park; SA, Salvation Army; SCA, Scott Avenue; SQ, Saginaw Quarry; DL, Dottie Lynn; SD, Sunset Oak Drive; BD, Bridgewood Drive; BC, Billy Creek; HT, Heritage Trace; I-30BA, I-30 Ben Avenue; MO, Motorola site; BFC, Big Fossil Creek; PIN, Pinnacle Ridge. For details of localities, reference is made to Table 1.

Goodland into a lower Marys Creek Marl Member and an upper Benbrook Limestone Member.

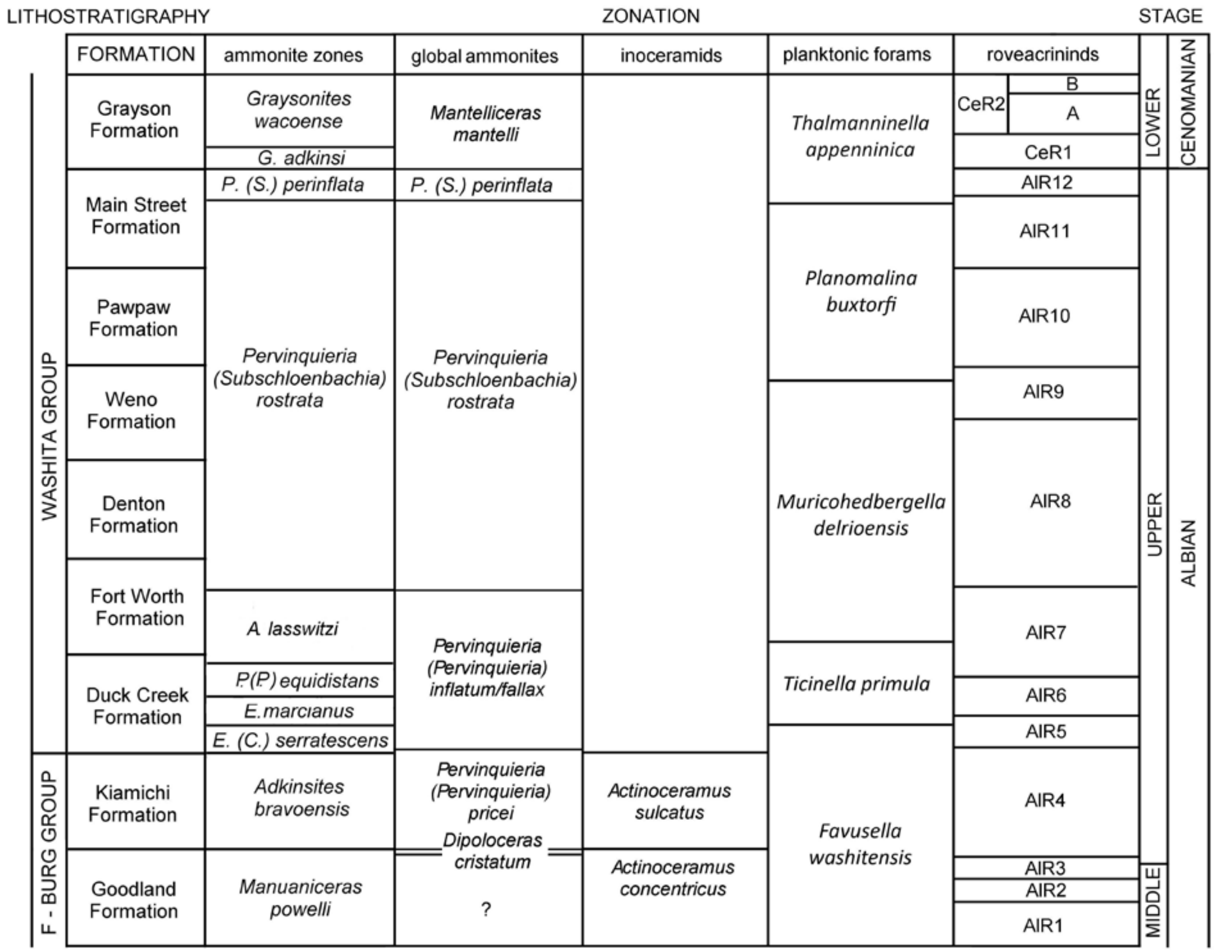
The stratigraphy of the Goodland used here (Text-fig. 3) is based upon the complete section at Marys Creek provided by Scott *et al.* (2003, fig. 5). We have logged and sampled the lowest 10 m of the formation at Marys Creek itself, and the marly unit approximately 20 m above the base of the formation at Benbrook dam spillway (Text-fig. 3; Table 1). Material of the highest fauna, from Cragin Knobs, Old Foundry Road, Fort Worth (Perkins 1960; section no longer accessible), comes from approximately 8 m beneath the top of the formation; it was provided by Dr Merlynd K. Nestell.

The Goodland contains numerous large specimens of the ammonite genus *Manuaniceras* Spath, 1925, which form the basis of Young's subdivision into a lower *M. carbonarium* and a higher *M. powelli* Zone (Young 1966). The correlation of these units to other regions is uncertain. The higher part of the Goodland has yielded the earliest late Albian zonal ammonite *Dipoloceras cristatum* (Brongniart, 1822) and the inoceramid bivalve *Actinoceramus concentricus* forma *parabolicus* Crampton, 1996, indicative of the basal upper Albian (Kennedy *et al.* 1999), but the precise position of these specimens within the succession remains uncertain, and it is very unlikely that they extend as low as inferred by Scott *et al.* (2003).

Marly units within the Goodland yield common to abundant roveacrinids, which represent three successive faunas that are characterised by species of *Plotocrinus* (AlR1, AlR2, AlR3; see Text-fig. 2). Although the boundaries of these zones cannot be

| Locality and abbreviation | Type of exposure | Formation | Town, county | Coordinates |
|---|---|---|---|---|
| Benbrook dam spillway BEN | Cuttings and floor of spillway | Goodland Fm | Benbrook, Tarrant Co. | 32º39'38.86" N 97º27'41.17" W |
| Big Fossil Creek BFC | S side of creek | Denton and Weno Fms | Haltom City, Tarrant Co. | 32º50'28.53" N 97º15'59.84" W |
| Billy Creek BC | Creek bed and banks | Main Street and Grayson Fms | Hurst, Tarrant Co. | 32º48'44.06" N 97º11'45.46" W |
| Bridgewood Drive BD | Cutting and scraped surface | Grayson Fm | Hurst, Tarrant Co. | 32º46'36.70" N 97º12'59.70" W |
| Buck Bell Fm CB | Slope and stream banks | Fort Worth, Denton Fms | Off 920 FM road, Johnson Co. | 32º32'41.12" N 97º26'23.53" W |
| Carter Park CP | Cliff on E side of Sycamore Creek | Weno Fm | Fort Worth, Tarrant Co. | 32º41'08.03" N 97º18'12.19" W |
| Cedar Bayou CC | Cliff on Lake Texoma | Pawpaw, Main Street, Grayson, Woodbine Fms | Sherwood Shores, Grayson Co. | 33º50'45.98" N 96º51'01.51" W |
| Cleburne CLE | Cutting on US 67, south side | Weno Fm | Johnson Co. | 32º22'46.92" N 97º22'59.16" W |
| Denton 380 D380 | Drainage ditch E of US 35W | Main Street and Grayson Fms | Denton Co. | 33º14'00.38" N 97º10'22.94" W |
| Denton Creek DC | Creek banks | Duck Creek Fm | Denton Co. | 33º03'48.71" N 97º16'07.17" W |
| Dottie Lynn DL | Drainage, cleared ground | Grayson Fm (Hess 2015) | Tarrant Co. | 32º44'24.47" N 97º10'35.24" W |
| Grayson Bluff GB | Degraded cliff | Grayson Fm (Perkins and Albritton 1955) | Denton Co. | 33º02'23.40" N 97º10'31.63" W |
| Heritage Trace Parkway HT | Drainage ditch | Weno Fm | Tarrant Co. | 32º54'43.69" N 97º20'06.55" W |
| Hobo Junction HJ | Bank of Sycamore Creek | Weno Fm | Tarrant Co. | 32º39'55.09" N 97º19'16.70" W |
| Horseshoe Bend HB | Cliff of Red River | Duck Creek Fm (Peck 1943) | Love Co., Oklahoma | 33º50'52.23" N 97º05'28.90" W |
| I-30 BA | Road cutting | Denton, Weno Fms | Tarrant Co. | 32º44'51.00" N 97º16'44.21" W |
| Marys Creek MC | Creek banks | Goodland Fm (Perkins 1961; Scott *et al.* 2003) | Tarrant Co. | 32º43'15.63" N 97º30'39.21" W |
| "Motorola" Fossil Ridge Circle MO | Cleared ground | Denton, Weno Fms | Fort Worth, Tarrant Co. | 32º50'49.82" N 97º17'12.39" W |
| Pinnacle Ridge PIN | Drainage channel | Fort Worth Fm | Saginaw, Tarrant Co. | 32º56'09.94" N 97º22'50.89" W |
| Rayzor Ranch RR, RRNE | Cleared land and cuttings | Grayson Fm | Denton, Denton Co. | 33º13'17.01" N 97º10'01.74" W |
| Roanoke, Roseville Dr RO | Drainage channel | Pawpaw, Main Street, Grayson Fms | Denton Co. | 33º1'01.26" N 97º12'04.88" W |
| Rock Creek 1 RC1 | Banks of creek | Kiamichi, Duck Creek Fms | Crowley, Tarrant Co. | 32º34'09.69" N 97º26'58.35" W |
| Rock Creek 2 RC2 | Banks and floor of creek | Duck Creek, Fort Worth Fms | Johnson Co. | 32º32'43.34" N 97º26'23.53" W |
| Saginaw Quarry SAG | Disused quarry | Duck Creek Fm (Reichelt 2005) | Saginaw, Tarrant Co. | 32º49'58.15" N 97º22'30.48" W |
| Salvation Army, Seminary Drive SA | Cutting | Weno, Pawpaw Fms | Fort Worth, Tarrant Co. | 32º41'08.03" N 97º18'33.07" W |
| Scott Avenue SCA | Cutting, cleared ground | Denton, Weno Fms | Tarrant Co. | 32º44'51.00" N 97º16'58.28" W |
| Sunset Oaks Drive SD | Road cutting | Main Street, basal Grayson Fm (Scott *et al*. 2003) | Hurst, Tarrant Co. | 32º46'35.15" N 97º13'07.54" W |
| US75 RRFW | Old river banks | Middle Duck Creek Fm (Peck 1943) | Bryan Co. Oklahoma | 33º49'26.17" N 96º31'46.99" W |
| Waco Shale Pit WSP | Disused clay pit | Grayson Fm (Kennedy *et al.* 2005) | McLennan Co. | 31º36'00.54" N 97º12'34.58" W |

Table 1. Locality details in northern Texas and southern Oklahoma.




Text-fig. 2. Summary stratigraphy of the upper Fredericksburg (F-Burg) and lower Washita groups in northern Texas.

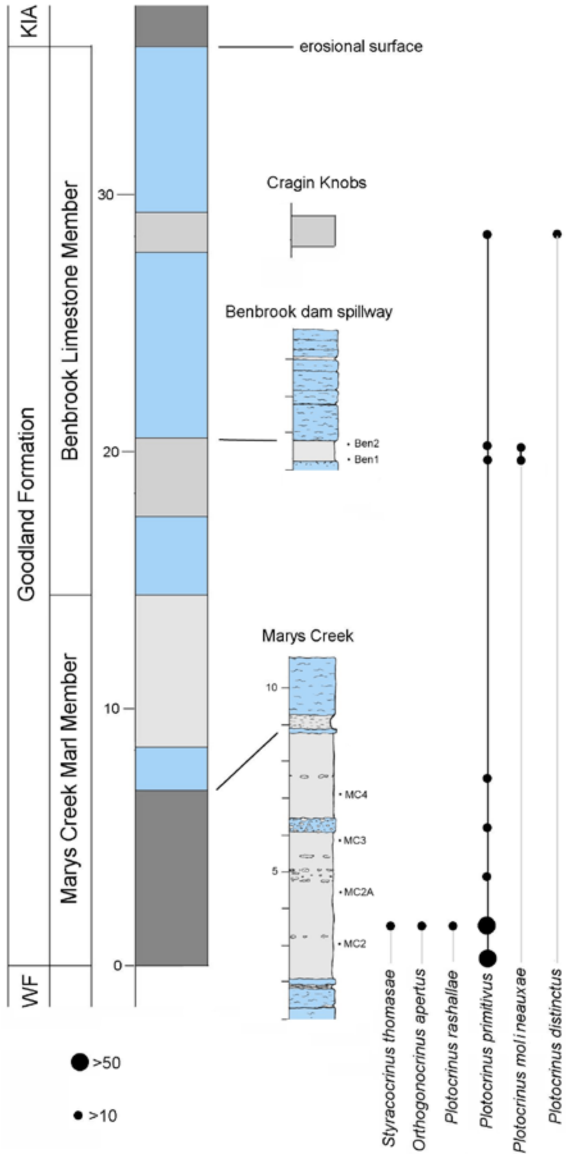
defined precisely, each fauna is distinctive. Elements of the lowest fauna are present in the middle Albian of Aube (eastern Paris Basin, France).

Planktonic foraminiferans are rare in the Goodland, with the exception of *Favusella washitensis* (Carsey, 1926), which occurs commonly throughout the unit. The *F. washitensis* Zone, the base of which is in the underlying Walnut Formation, is characterised by *F. washitensis* and rare, small specimens of *Microhedbergella* spp.

*Kiamichi Formation*

The argillaceous Kiamichi Formation (formerly Kiamatia; Hill 1891) has an extensive outcrop in northern Texas and southern Oklahoma and extends eastwards into Arkansas (Winton and Adkins 1919; Winton and Scott 1922; Winton 1925; Bybee and Bullard 1927; Bullard 1931; Bishop 1967). Bishop (1967) provided a detailed study of the formation, which demonstrated a progressive southward thinning, with the unit averaging 10–15 m in Tarrant County.

The Kiamichi rests with marked disconformity upon the upper surface of the Goodland (Scott *et al.* 2003), and in northern Texas comprises 10–20 m of dark grey clays containing concretionary limestones and thin, storm-deposited sandstones (Kennedy *et al.* 1999); in the upper part lenses of oysters, i.e., *Texigryphaea navia* (Hall, 1856), are present. The only common ammonites are large specimens of *Oxytropidoceras* sp., and the Kiamichi is characterised by *Adkinsites bravoensis* (Böse, 1910), taken as the zonal marker (Gale and Kennedy 2020). Rarer finds include specimens of *Pervinquieria* (*Pervinquieria*) *pricei* (Spath, 1922), *Pervinquieria* (*Deiradoceras*) *bipunctatum* (Spath, 1933) and *Hysteroceras varicosum* (J. de C. Sowerby, 1824), which are indicative




Text-fig. 3. Stratigraphy of the Goodland Formation, based on Scott *et al.* (2003, fig. 5), to show distribution of microcrinoids. These have only been found in three thin marly intervals. WF, Walnut Formation; KIA, Kiamichi Formation. Scale on left of column in metres. Colours as in Text-fig. 6.

of the *P.* (*P.*) *pricei* Zone (Text-fig. 2; Kennedy *et al.* 1999; Gale and Kennedy 2020). The inoceramid bivalve *Actinoceramus sulcatus* (Parkinson, 1819) is locally common (Kennedy *et al.* 1999) and the morphotypes present are indicative of the *P.* (*P.*) *pricei* Zone in Europe and elsewhere (Crampton and Gale 2009). Roveacrinids are poorly preserved and uncommon in the Kiamichi, but material collected by Peck and deposited in the Smithsonian as unfigured paratypes, includes a new species of *Plotocrinus* (*P. reidi* sp. nov.) which occurs uniquely in the Kiamichi and characterises AlR4 (Text-fig. 2). The planktonic foraminiferan assemblage does not include stratigraphically diagnostic forms.

## Washita Group

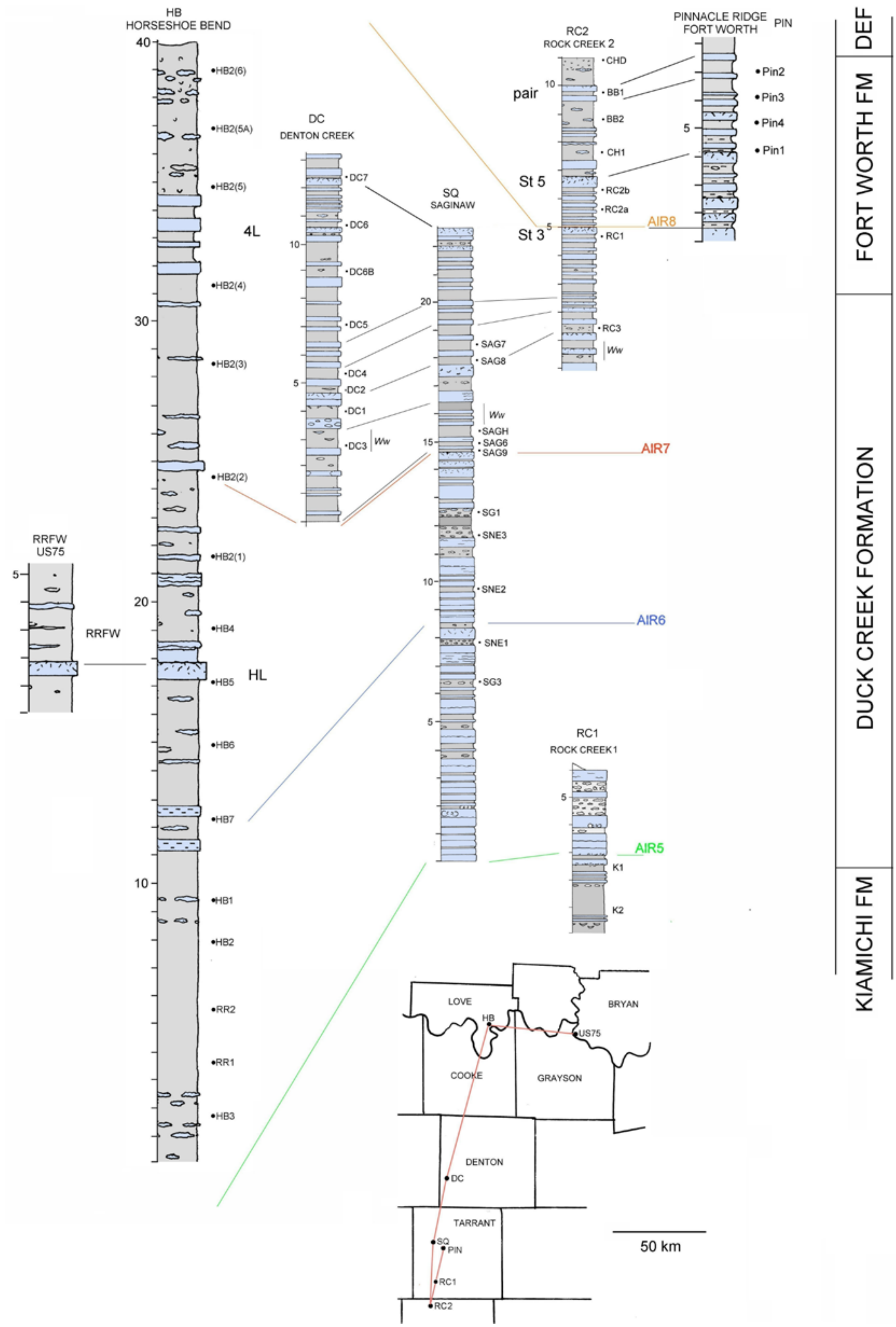
### *Duck Creek Formation*

The Duck Creek was named by Hill (1891), with the type locality north of Denison in Grayson County, Texas. The formation comprises alternations of thin concretionary limestones and marls, of variable thickness, conspicuously bioturbated by *Thalassinoides* isp. The formation extends across southern Oklahoma and northern Texas, as far west as El Paso, and displays considerable variations in thickness and development. It is thickest (c. 40 m) in the Red River valley, in Grayson and Cooke counties, Texas and Love and Bryan counties, Oklahoma, where the limestones are thin and the succession is dominated by marl (Text-fig. 4). The formation thins progressively southwards to approximately 20 m in Tarrant County, 6–7 m in Austin (Travis County) and further south amalgamates with other units into the Georgetown Limestone (Sellards *et al.* 1966).

The expanded middle part of the Duck Creek in the northern outcrop develops lensoid concretionary limestones including large *Thalassinoides* isp. systems; it was incorrectly referred to the Fort Worth Formation (e.g., Peck 1943; H. Tappan Loeblich localities 28 and 77). The roveacrinid faunas indicate that these fall within AlR6, in the middle part of the formation.

We have sampled the Duck Creek at the Saginaw Quarry section in Tarrant County; the expanded succession on the Red River, at Horseshoe Bend, Love County, and adjacent to US Highway 75 in Bryan County, both in Oklahoma (Table 1; Text-fig. 4). It is important to note that the 10.5-m-succession identified as ‘Kiamichi’ in the lower part of Saginaw Quarry by Reichelt (2005, fig. 12; Meacham Field) all belongs to the Duck Creek Formation. The quarry originally extended almost to the base of the formation, and the floor yielded abundant specimens of the ammonite *Elobiceras* (*Craginites*) *serratescens* (Cragin, 1893).

The ammonite faunas of the Duck Creek (Gale and Kennedy 2020) are dominated by endemic mortoniceratids which permit division into three zones, those of *Elobiceras* (*Craginites*) *serratescens*, *Eopachydiscus marcianus* and *Pervinquieria* (*P.*) *equidistans*. The presence of rare specimens of *Pervinquieria*




Text-fig. 4. Stratigraphy and correlation of the Duck Creek and Fort Worth formations, to show localities and sampled horizons. The relatively thin limestone-marl succession in the south (Johnson and Tarrant counties) expands northwards into southern Oklahoma and becomes more marly. Roveacrinid zones are shown. The letters/numbers St3 and St5 refer to beds described and correlated by McGill (1967), and the pair refers to the two thin limestones which he identified as terminating the Fort Worth. Scale in metres. Colours as in Text-fig. 6.

(*Pervinquieria*) *fissicostata* (Spath, 1932) permits a broad correlation with the *Pervinquieria* (*Pervinquieria*) *inflata* Zone of the international standard.

The roveacrinid faunas of the Duck Creek enable a three-fold division of the formation (AlR5, AlR6 and AlR7) which can be traced from the Red River valley south to Tarrant and Johnson counties (Text-fig. 4), and the boundaries approximate to McGill's (1967) divisions into Lower, Middle and Upper members. Successive zones are characterised by, respectively, *Poecilocrinus spiculatus* Peck, 1943 (AlR5), *P. pendulus* Peck, 1943 (AlR6) and *P. latealatus* (Peck, 1943) (AlR7), which form an evolutionary succession.

The Duck Creek yields the planktonic foraminiferans *Favusella pessagnoi* Michael, 1972, *F. washitensis* and *Ticinella primula* Luterbacher, in Renz et al., 1963. Although rare in the lower part of the Duck Creek, *T. primula* is the dominant planktonic form throughout the middle and upper part of the formation and its presence marks the base of the *T. primula* Zone. Locally, *T. primula* occurs significantly higher than in other regions and the base of the *T. primula* Zone of northern Texas and southern Oklahoma should not be considered correlative with the international standard.

### *Fort Worth Formation*

The Fort Worth Formation was named by Hill (1891), without reference to a type locality, and extends across northern Texas and southern Oklahoma with a consistent thickness of about 10 m. It comprises decimetre-thick bioclastic limestones and marls, some of which are laterally impersistent and lensoid within individual exposures; large *Thalassinoides* isp. galleries (10–20 cm in diameter) are common. The base of the Fort Worth is difficult to define, because there is a gradual transition up from the upper Duck Creek Formation. McGill (1967) took a triplet of thin limestones to mark the base of the formation in Tarrant County, an approach followed here. McGill (1967) also identified two laterally persistent limestones within the formation (his strata 3 and 5) which are incipient hardgrounds (Text-fig. 4), extending from Tarrant to Johnson counties. The uppermost 3 m of the formation are marly and clay rich, contain lensoid limestones and are capped by a pair of thin micritic limestones (McGill 1967), which can be identified across Tarrant and Johnson counties. We have sampled the Fort Worth Formation in Rock Creek, Johnson County, and the Pinnacle Drive section in Saginaw, Tarrant County (Table 1; Text-fig. 4).

The ammonite fauna of the Fort Worth is dominated by species of *Angolaites* Spath, 1922, but careful collecting by J.P. Conlin, at the Buck Bell Farm site on Rock Creek in Johnson County, has demonstrated the presence of *Pervinquieria* (*Subschloenbachia*) *rostrata* (Sowerby, 1817) in the uppermost 1.5 m of the formation (Kennedy *et al.* 1998; Gale and Kennedy 2020). The Fort Worth spans the boundary between microcrinoid zones AlR7 and AlR8, represented by the upper limit of *Poecilocrinus latealatus* and the first occurrence of *Po. dispandus* Peck, 1943. The boundary can be precisely identified as falling between samples RC1 and RC2a on Rock Creek, Johnson County (Text-fig. 4).

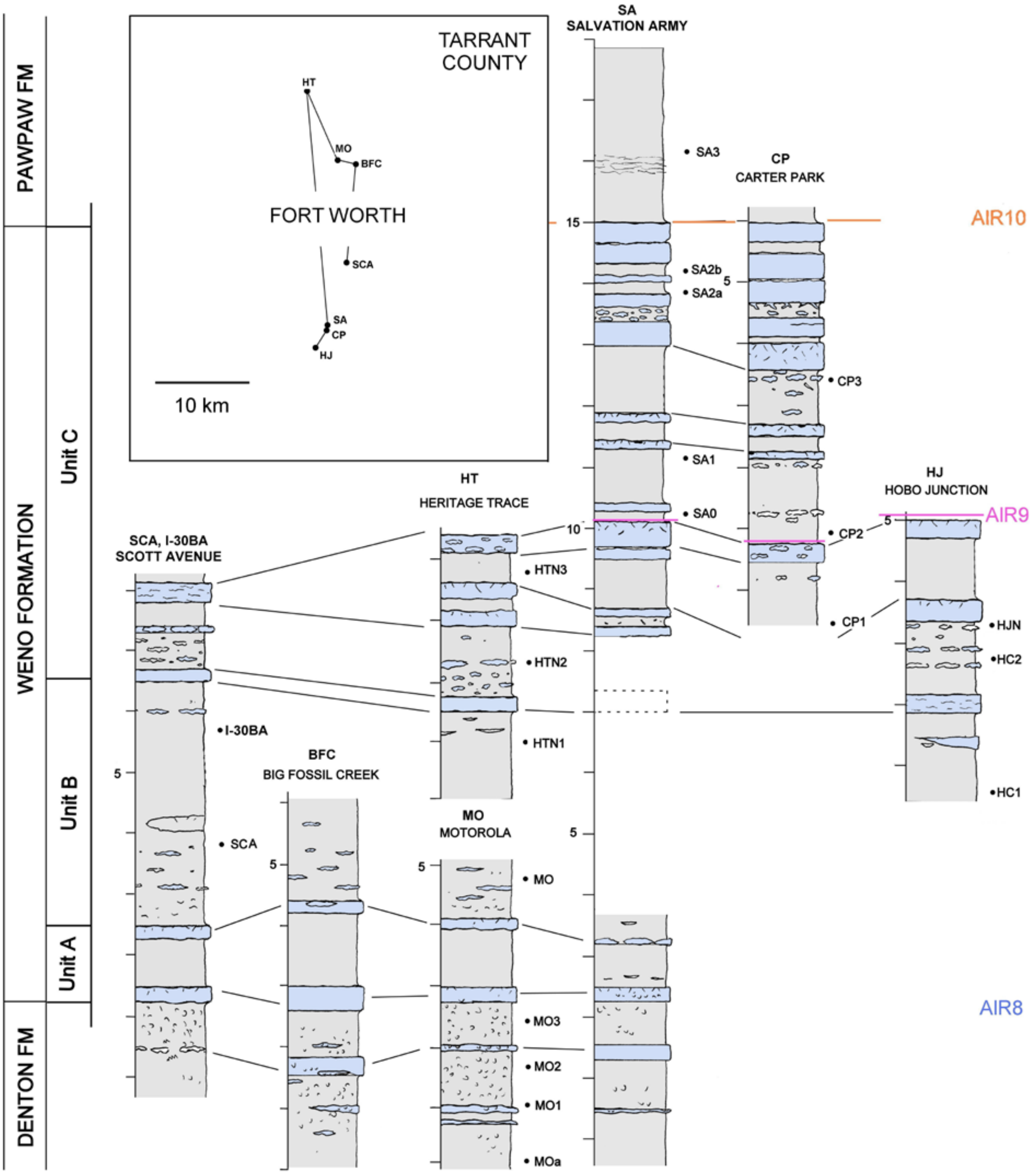
The planktonic foraminiferan *Muricohedbergella delrioensis* (Carsey, 1926) first occurs in the lower part of the Fort Worth and marks the base of the *M. delrioensis* Zone. On Rock Creek, *M. delrioensis* has been recovered from RC1, RC2a and CH1 (Text-fig. 4). Previous reports of *M. delrioensis* as low as the Goodland in northern Texas probably refer to small ticinellids or species of *Microhedbergella* identified prior to the recent revisions in hedbergellid taxonomy.

### *Denton Formation*

The Denton Formation was named by Taff and Leverett (1893) on the basis of sections in Denton Creek in Denton County, and comprises marls with infrequent carbonate concretions. It is 8–10 m thick in Tarrant County and thins to the south to 3 m in Travis County. The upper part of the formation contains lenses densely packed with the oyster *Texigryphaea washitaensis* (Hill in Hill and Vaughan, 1889) and rarer *Rastellum* sp. are present. Several thin, laterally impersistent limestones are present in the upper 2 m of the formation. We have sampled the lower Denton on Rock Creek in Johnson County (Text-fig. 4), and the upper part at the Motorola site in Fort Worth (Text-fig. 5).

The Denton Formation has yielded rather few ammonites (Kennedy *et al.* 1998; Gale and Kennedy 2020), but these include *Pervinquieria* (*Subschloenbachia*) *rostrata,* indicative of the eponymous zone. The microcrinoid assemblage is dominated by *Poecilocrinus dispandus* forma *discus* nov., and the Denton falls within the zone AlR8.

The Denton has a sparse assemblage of planktonic foraminiferans, yielding *Favusella washitensis*, *Muricohedbergella delrioensis* and *Ticinella primula*, and is included within the *M. delrioensis* Zone.




Text-fig. 5. Stratigraphy and correlation of the upper Denton, Weno and lower Pawpaw formations in Tarrant County, Texas, to show localities and sampled horizons. Roveacrinid zones are shown. Inset map of Tarrant County. Scale in metres. Colours as in Text-fig. 6.

*Weno Formation*

The Weno Formation was described by Hill (1891) with a type section close to the abandoned village of Weno on the Red River north of Denison in Grayson County. It comprises marls containing carbonate concretions, layers of laminated silt and bioclastic limestones of variable thickness and lateral development. The formation thins southwards from the Red River, where it is 36 m thick, to 13–15 m in Tarrant County

(Text-fig. 5), 7 m in Bell County, and less than 3 m in Travis County. We have used a number of exposures in the vicinity of Fort Worth, Tarrant County, to develop a composite section (Text-fig. 5). The lower part of the Weno (Unit A) comprises two thin micritic limestones, separated by 1–1.5 m of marl, and can be recognised across the region. It is overlain by 4–5 m of marls (Unit B) containing carbonate concretions and aragonitic molluscs replaced by calcite, most commonly the gastropod genus *Turritella* sp. Large (2–3 mm diameter) *Poecilocrinus dispandus* forma *discus* nov. are common on weathered surfaces, and the bivalves *Gervillopsis* sp. and *Peilinia quadriplicata* (Shumard, 1860) are characteristic of this unit (Perkins and Albritton 1955). We have studied the lower two units at Scott Avenue, Motorola and Heritage Trace Parkway in Fort Worth, Tarrant County (Table 1; Text-fig. 5). The highest part of the formation, Unit C, comprises thin limestones and marls containing carbonate concretions, and is capped by 1.5–2 m of limestone, subdivided by marly partings into five beds. The upper part of the succession is well exposed at the Salvation Army locality on Seminary Drive, and in the banks of Sycamore Creek in Carter Park, in the south of Fort Worth (Text-fig. 5; Table 1).

The Weno Formation yields diverse and common ammonites (Kennedy *et al.* 1998; Gale and Kennedy 2020), dominated by endemic species of *Angolaites*, but also including specimens of *Pervinquieria* (*Subschloenbachia*) *rostrata*, an international index fossil (Text-fig. 2). The microcrinoid fauna is dominated by *Po. dispandus*, of which different formae characterise successive horizons. The lower Weno (Units A, B) belong to the upper part of AlR8, and yield abundant large *Po. dispandus* forma *discus* nov.; *Po. dispandus* forma *elongatus* Peck, 1943 appears in abundance 3 m above the base of Unit C, defining the base of zone AlR9.

The planktonic foraminiferal assemblage of the lower part of the Weno (Units A, B) includes *T. primula*, *M. delrioensis* and abundant *F. washitensis*. *Muricohedbergella praelibyca* (Petrizzo and Huber, 2006), although rare, first occurs in sample HC1 at Hobo Junction in the upper part of Unit B (Text-fig. 5). Numerous species of planktonic foraminiferans characteristic of the upper part of the Albian first occur in the upper part of the Weno (Unit C), including *Muricohedbergella planispira* (Tappan, 1940) between samples CP1 and CP2 of the Carter Park section (Text-fig. 5), *Praeglobotruncana delrioensis* (Plummer, 1931) approximately 3 m below the top of the formation in the Carter Park section, and *Paracostellagerina libyca* (Barr, 1972) directly below the uppermost limestone bed of the Weno on Seminary Drive. Material provided by Dr Merlynd Nestell from the southeast corner of I-20 and I-35W in south of Fort Worth (now inaccessible) yielded *Planomalina buxtorfi* (Gandolfi, 1942), which occurs 0.5 m below the appearance of *P. libyca*. The base of the *P. buxtorfi* Zone is placed at approximately 1 m beneath the top of the Weno Formation.

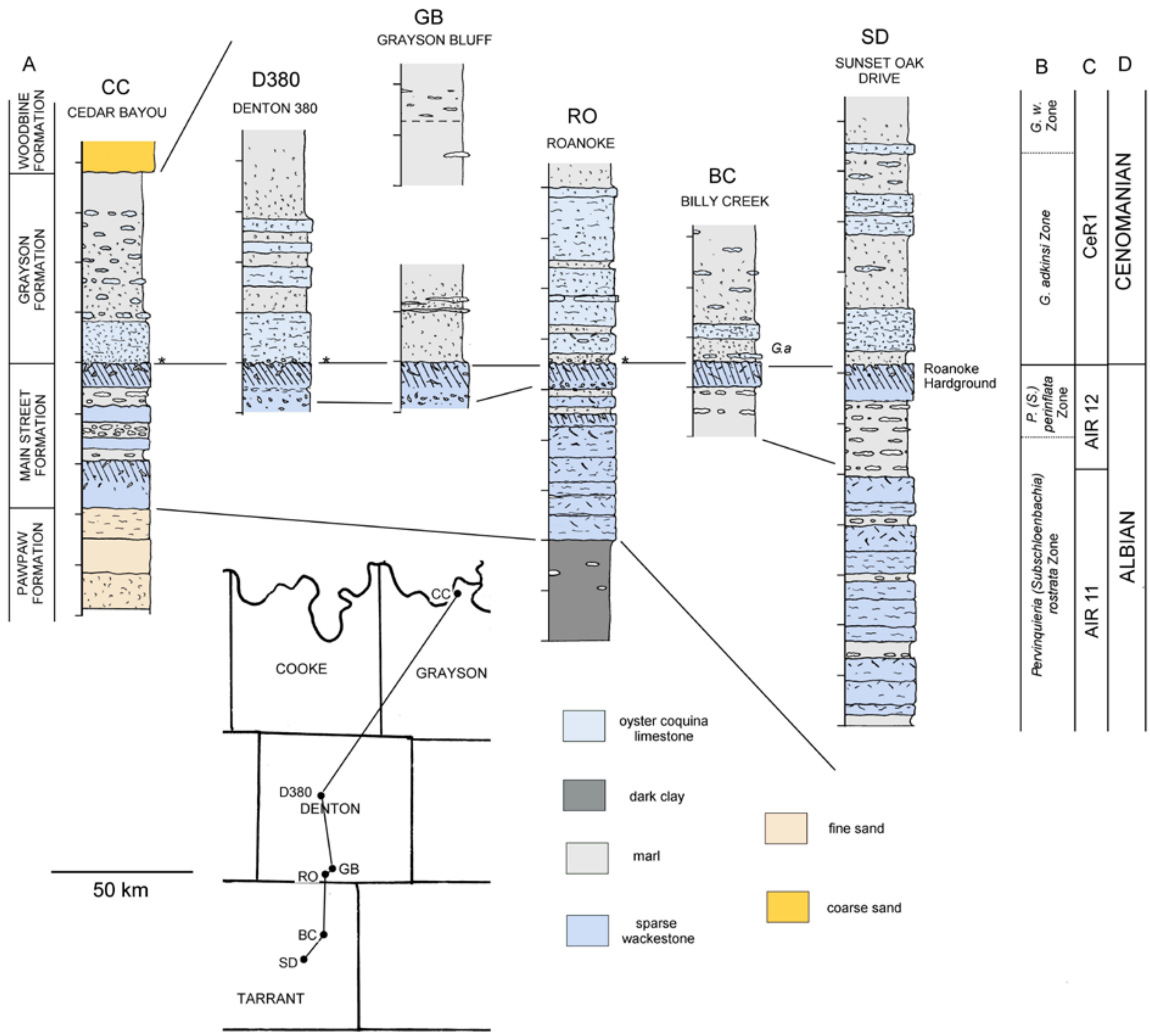
*Pawpaw Formation*

The Pawpaw Formation was named by Hill (1891), with a type section on Pawpaw Creek, north of Denison in Grayson County. The Pawpaw comprises dark clays, containing sideritic concretions, pyrite nodules and thin, laminated silty lenses; it locally yields an abundant fauna, typically including echinoderms, pyritised ammonites, bivalves and vertebrates, especially sharks' teeth. It is 17 m thick at the type locality and thins southwards to an average thickness of 6–7 m in Tarrant County (Sellards *et al.* 1966). The Pawpaw is sandy in the northern part of its outcrop, as at Cedar Bayou on Lake Texoma (Text-fig. 6). In the present study, we have concentrated on the section exposed at the Salvation Army locality on Seminary Drive, in the south of Fort Worth, but have included material from other temporary exposures, such as the cutting at the junction of the I-35W and the I-20 in the south of Fort Worth.

There has been considerable confusion between the Pawpaw and lower Weno formations in Tarrant County, because both are developed in similar facies (clays containing originally aragonitic molluscs preserved as calcite) and locally both yield exceptionally well-preserved fossils, including echinoderms (Blake and Reid 1998) and vertebrates (e.g., Lee 1996). The famous Motorola site in Fort Worth (Table 1), which yielded the skull of the dinosaur *Pawpawsaurus* Lee, 1996, actually exposed the lower Weno Formation, not the Pawpaw Formation (Text-fig. 5).

The Pawpaw locally yields abundant pyritised ammonites, indicative of the *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone (Kennedy 2004). Microcrinoids are common in residues, belonging to the AlR10 roveacrinid zone, characterised especially by the presence of *Roveacrinus proteus* sp. nov.

The planktonic foraminiferal assemblage of the Pawpaw is dominated by *Muricohedbergella praelibyca*, *Paracostellagerina libyca*, *Ticinella primula*, *Favusella washitensis* and *Praeglobotruncana delrioensis* with less common forms such as *Planomalina buxtorfi*, *Thalmanninella* sp. and *Muricohedbergella delrioensis*, characteristic of the *P. buxtorfi* Zone.



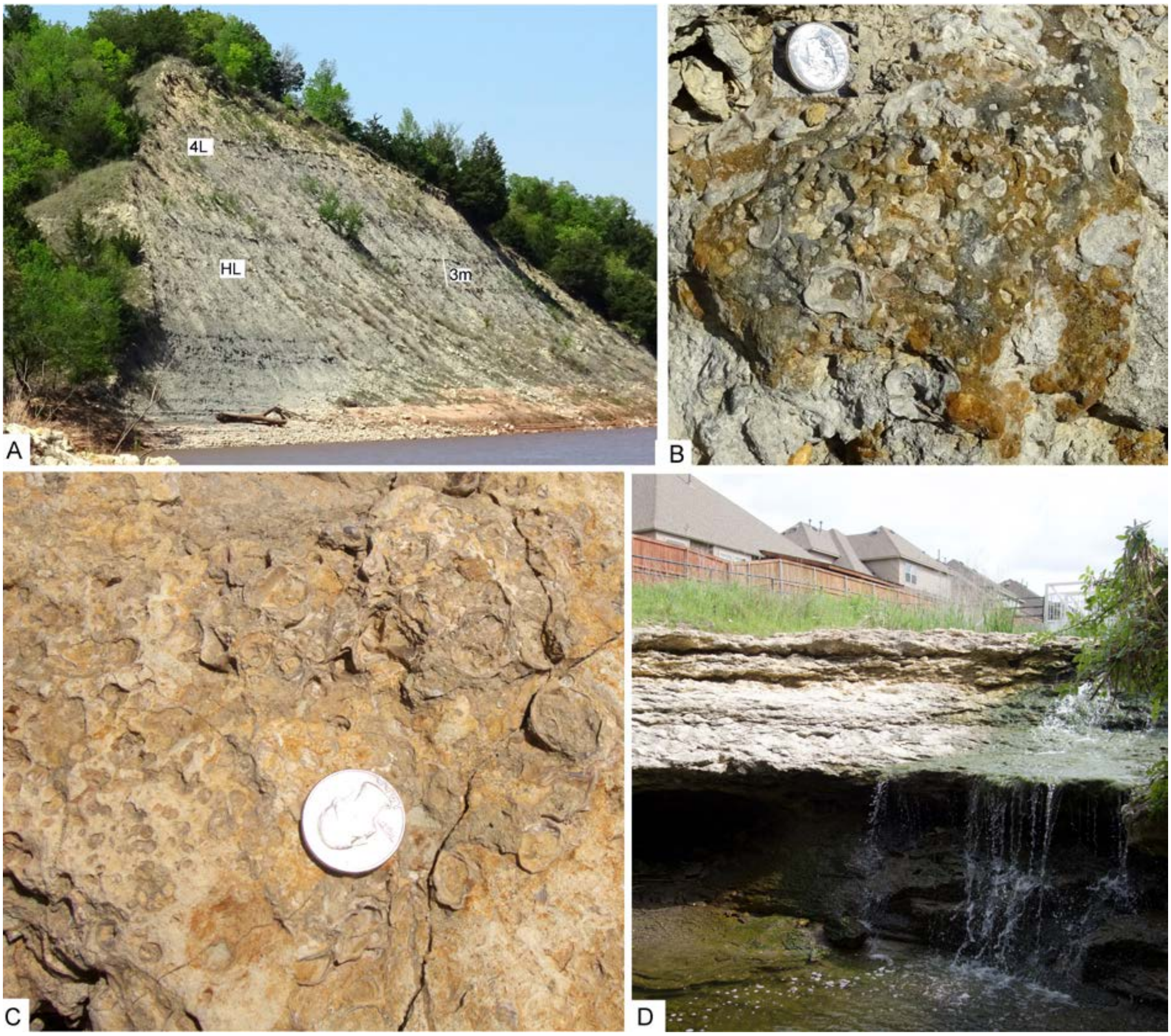

Text-fig. 6. Stratigraphy and correlation of the upper Pawpaw, Main Street and lower Grayson formations in north Texas. The Main Street thins northwards, and the Roanoke Hardground at its summit is a significant break; the surface becomes bored and encrusted northwards from Tarrant County. A, formations; B, ammonite zones; C, microcrinoid zones; D, stages. The asterisks mark the upper surface of the Roanoke Hardground. Scale in metres.

*Main Street Formation*

The Main Street Limestone was named by Hill (1894) with the type locality in East Main Street, Denison (Grayson County). The Main Street Formation comprises thickly-bedded bioclastic limestones, separated by thinner marly partings in which carbonate nodules are common. The Main Street is 2.9 m thick on Lake Texoma in Grayson County, and thickens gradually southwards, to 3.5 m at Roanoke, Denton County and about 7.5 m in Tarrant County (Text-fig. 6). As the formation thins, hardgrounds, present at two levels, become more lithified and the marly partings are occluded between the limestone beds.

The top of the Main Street is a 0.5-m-thick hardground, here named the Roanoke Hardground, which can be distinguished by its pale grey colouration and open *Thalassinoides* isp. burrow systems. In Denton, Grayson and Cooke counties, the top surface is bored, encrusted by oysters and serpulid worms, and iron mineralised (Text-fig. 7B, C); the surface represents a significant depositional break which possibly coincides with the Albian–Cenomanian boundary (see below).

In the present study, we have concentrated on the




Text-fig. 7. Field photographs of the study area. A – View of bluff on the Red River, Horseshoe Bend, Love County, Oklahoma, exposing most of the Duck Creek Formation. Markers HL (Horseshoe Limestone) and 4L (group of four limestones) are indicated. B – Roanoke Hardground, upper surface of Main Street Limestone, at Denton 380 locality, Denton, Denton County, Texas (Text-fig. 6), to show iron-mineralised, bivalve-bored (*Gastrochaenolites* spp.) surface, encrusted with oysters. C – Roanoke Hardground, uppermost surface of Main Street Limestone at Cedar Bayou on Lake Texoma, Grayson County, Texas, to show boring and encrustation (Text-fig. 6). D – exposure of Main Street Limestone, here 3.5 m in thickness, overlying dark clays of the Pawpaw Formation, Roseville Drive, Roanoke, Denton County, Texas (Text-fig. 6). Coin is 25 mm in diameter.

only good exposure of expanded Main Street which currently exists in Tarrant County, the section on Sunset Oaks Drive (Text-fig. 6). In the more condensed developments of the formation, to the north, in Denton and Grayson counties, the marls are poorly developed and do not yield identifiable microcrinoid material.

The Main Street contains the turrilitid ammonite *Mariella* (*Wintonia*) *brazoensis* (Roemer, 1852) in abundance, but stratigraphically significant ammonites are scarce and most are poorly located within the formation (Kennedy *et al.* 2005, p. 351). They include specimens of *Pervinquieria* (*Subschloenbachia*) *rostrata* and *P.* (*S.*) *perinflata* (Spath, 1922), indicating the presence of the eponymous Albian zones, and the boundary between the two presumably lies within the middle part of the formation. In the J.P. Conlin Collection (USNM) are four specimens of *Graysonites adkinsi* Young, 1958, recorded as coming from the uppermost 2.4 m of the Main Street on Calloway (Walker) Branch in Haltom City, Fort

Worth (Kennedy *et al.* 2005, p. 352). Conlin was a meticulous collector, but it is remarkably easy to identify the strongly lithified 'transitional zone' (basal part of the Grayson Formation, see below) as the upper part of the Main Street, a mistake made by one of us (ASG) on initial examination of the Denton County sections. *Graysonites adkinsi* is frequent in the basal 1 m of the Grayson on Billy Creek in Fort Worth (Text-fig. 6), but examination of the extensive exposures of the upper 2 m of the Main Street at this locality yielded only *Mariella* (*Wintonia*) *brazoensis*.

The Main Street yields abundant roveacrinids, which characterise, successively, zones AlR11 and AlR12, also identified in the Agadir Basin, Morocco (Gale 2020). The boundary between the two falls approximately 3.5 m beneath the top of the formation.

The Main Street includes two zones of planktonic foraminiferans with distinct assemblages. The *Planomalina buxtorfi* Zone, which includes the lower part of the Main Street, is characterised by the typical Albian forms seen throughout the Pawpaw and upper part of the Weno, such as *P. buxtorfi*, *Ticinella primula*, *Muricohedbergella praelibyca* and *Paracostellagerina libyca*, in addition to numerous long-ranging species. The presence of *Thalmanninella appenninica* (Renz, 1936) in the upper part of the Main Street marks the base of the *T. appenninica* Zone. Albian forms common throughout the *P. buxtorfi* Zone are rare or absent in the *T. appenninica* Zone. Locally, *T. appenninica* occurs significantly later than in other regions and the base of the *T. appenninica* Zone of northern Texas and southern Oklahoma should not be considered correlative with the international standard.

*Grayson Formation*

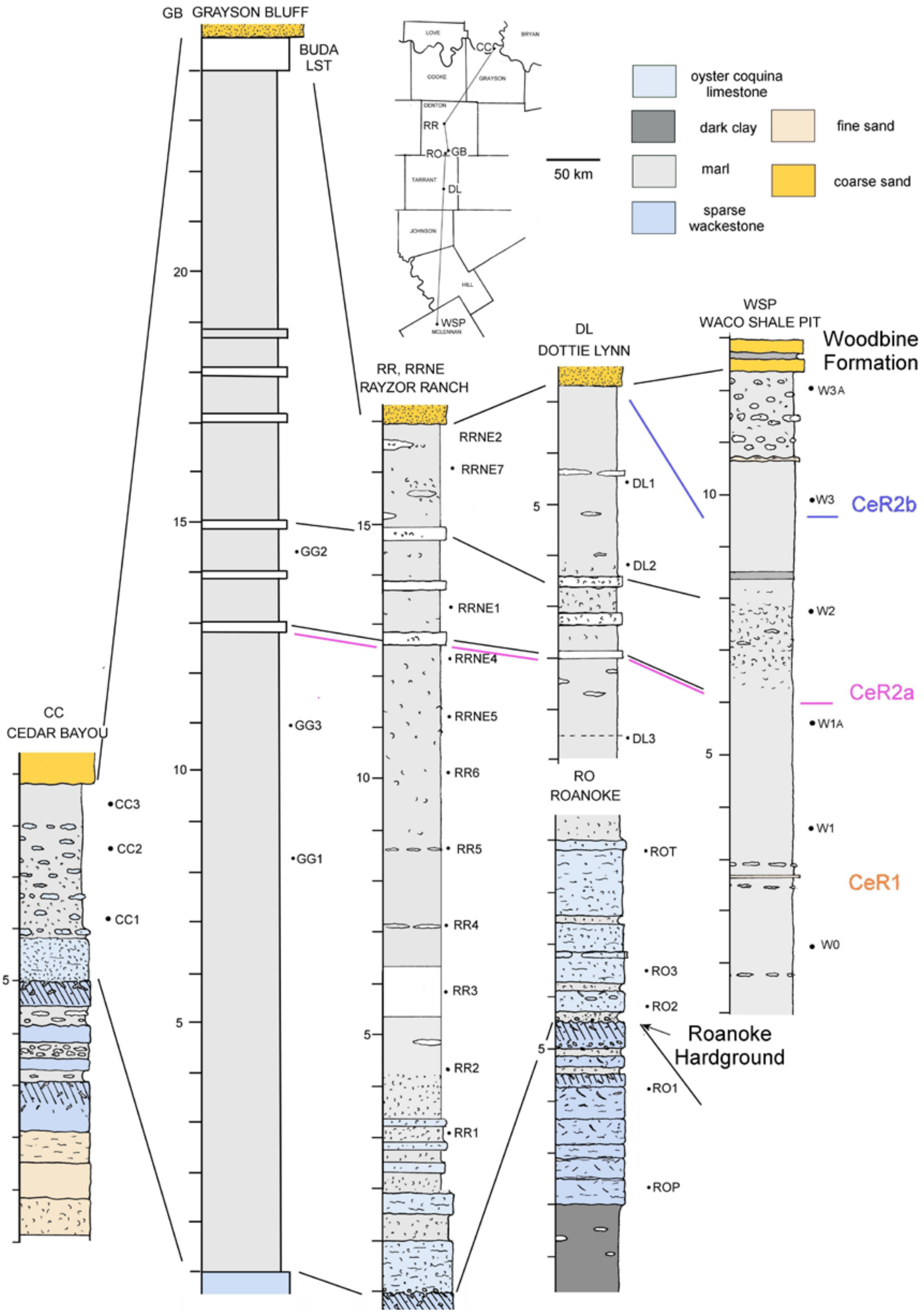
The Grayson Formation was named by Cragin (1894) for a section near Denison, and comprises 2 to 25 m of pyritic marls, and the lower part (2–3 m) contains variably developed, thin nodular limestones containing an abundance of the small oyster *Ilmatogyra arietina* (Roemer, 1852). In places, for instance, at the Denton 380 locality and at Roanoke (Text-fig. 6), the lowest 2–3 m of the Grayson is strongly lithified, and rests upon the encrusted and bored Roanoke Hardground at the top of the Main Street. Such developments have been called a 'transition zone' in the literature (Young 1979) and have probably led to the incorrect placement of ammonites as coming from the Main Street, rather than from the Grayson Formation. The basal unit is overlain by pale clays containing the oyster *Texigryphaea graysonana* (Stanton, 1947).

The middle part of the Grayson Formation (3–5 m) is more calcareous and contains thin nodular limestones in which *T. graysonana* and other calcitic bivalves are abundant, and an equivalent level extends southwards to the Waco Shale Pit in McLennan County (Text-fig. 8). The uppermost part of the Grayson is weakly nodular and only preserved very locally, as the pre-Woodbine Formation erosional surface has removed both the upper part of the formation and the overlying Buda Limestone in almost all localities except Grayson Bluff (Perkins and Albritton 1955; see Text-fig. 8 here). In Grayson County, Bullard (1931) recorded localities in which the entire Grayson was absent, and the Woodbine Formation rested directly upon the Main Street.

The classic type section, on Grayson Bluff, in Denton County (see photograph in Winton 1925, pl. 1) which formerly exposed the entire formation, has now almost disappeared completely beneath vegetation and houses. We were able to use the log of Perkins and Albritton (1955, fig. 1) to identify horizons and collect a few samples (Text-fig. 8). Temporary exposures through most of the formation at Rayzor Ranch, Denton, Denton County (Text-fig. 8; Table 1) provided a useful source of material, and the lowest part of the formation was sampled at Bridgewood Drive and Billy Creek, Fort Worth, Tarrant County (Text-fig. 6). The thin, but excellent, section at Cedar Bayou, on Lake Texoma, Grayson County (Text-fig. 6) has yielded few microcrinoids. The highest part of the Grayson is not presently exposed in Tarrant County, but samples collected from a temporary exposure at Handley, Fort Worth by Dr Merlynd K. Nestell, yielded microcrinoids, as did the upper part of the formation in the Waco Shale Pit, McLennan County. Mancini (1978) listed the occurrences of some of the Grayson microcrinoids.

The succession in an overgrown clay pit at Waco Lake, called the Waco Shale Pit, has been assigned to the Del Rio Formation by various authors (see Kennedy *et al.* 2005), presumably on account of a supposedly higher clay content. However, the lithology is identical to that developed in the middle Grayson in Denton County, and we therefore apply the term Grayson Formation to this locality.

The Grayson Formation contains numerous ammonites, which permit division into a lower *Graysonites adkinsi* and an upper *Graysonites wacoense* Zone (Kennedy *et al.* 2005). The uppermost part of the formation at Waco has yielded *Sharpeiceras* Hyatt, 1903, indicative of the presence of the *S. schlueteri* Subzone of western Europe. The microcrinoid faunas have recently been discussed by Gale




Text-fig. 8. Stratigraphy and correlation of the Grayson Formation in northern Texas. Roveacrinid zones are shown. The formation rests disconformably upon the Roanoke Hardground, and its upper surface is truncated by an erosional surface at the base of the Woodbine Formation in all localities except Grayson Bluff, where a thin representation of the Buda Limestone is preserved (Perkins and Albritton 1955). In Grayson County, the Woodbine Formation locally rests directly upon the Main Street Formation (Bullard 1931).

(2020), who identified zone CeR1 in the lower part of the formation, and CeR2 in the upper part. It has since been discovered that a higher fauna, here identified as CeR2B, is locally preserved in the uppermost Grayson, beneath the pre-Woodbine Formation erosional surface. This fauna has only been found at three localities: the section (now covered) on a tributary of Little Mineral Creek, in Grayson County (H. Tappan Loeblich locality HTL 5; Peck 1943), a temporary exposure at Handley, Fort Worth, and the Waco Shale Pit, McLennan County (Text-fig. 8).

The planktonic foraminiferal assemblage of the Grayson Formation is dominated by *Muricohedbergella delrioensis*, *Muricohedbergella planispira* and *Protoheterohelix washitensis* (Tappan, 1940). More uncommon forms include *Favusella washitensis*, *Praeglobotruncana delrioensis*, *Thalmanninella appenninica* and *Thalmanninella brotzeni* Sigal, 1948. The Grayson falls within the *T. appenninica* Zone.

## MICROCRINOID BIOSTRATIGRAPHY

### AlR1

This zone is defined by the first occurrence of *Plotocrinus primitivus* Peck, 1943, *Styracocrinus thomasae* sp. nov., *Orthogonocrinus apertus* Peck, 1943 and *Plotocrinus rashallae* sp. nov. in the basal part of the Marys Creek Member of the Goodland Formation. The top is defined by the lowest occurrence of *Plotocrinus molineuxae* sp. nov. in the overlying Benbrook Member. Two of the species noted (*Plotocrinus primitivus* and *Plotocrinus rashallae* sp. nov.) also occur in the lower middle Albian of Aube, eastern Paris Basin (France). Sections collected in Tarrant County, Texas were Marys Creek and Benbrook dam spillway (Text-fig. 3).

### AlR2

The base of this zone is defined by the first occurrence of *Plotocrinus molineuxae* sp. nov., and the fauna includes rarer *Plotocrinus primitivus*. The top of the zone is taken beneath the first occurrence of *Plotocrinus distinctus* Peck, 1943. The fauna is currently known only from the Benbrook dam spillway, Benbrook, Tarrant County (Text-fig. 3).

### AlR3

The base of this zone is taken at the first occurrence of *Plotocrinus distinctus*, within the top part of the Goodland Limestone (Text-fig. 3). The top is taken at the lowest occurrence of *Plotocrinus reidi* sp. nov. in the Kiamichi Formation. The occurrence is probably within the range of the ammonite *Dipoloceras cristatum*, hence of earliest late Albian age.

### AlR4

This zone is defined by the lowest occurrence of *Plotocrinus reidi* sp. nov., in the Kiamichi Formation. The top is defined by the lowest occurrence of *Poecilocrinus spiculatus*, in the lowermost part of the Duck Creek Formation. The precise level of its first occurrence is not known, because roveacrinids are sparse and poorly preserved in the formation. Rare *Styracocrinus* sp. and *Plotocrinus primitivus* occur within the zone, which correlates with the international zone of *Pervinquieria* (*Pervinquieria*) *pricei* (Text-fig. 2).

### AlR5

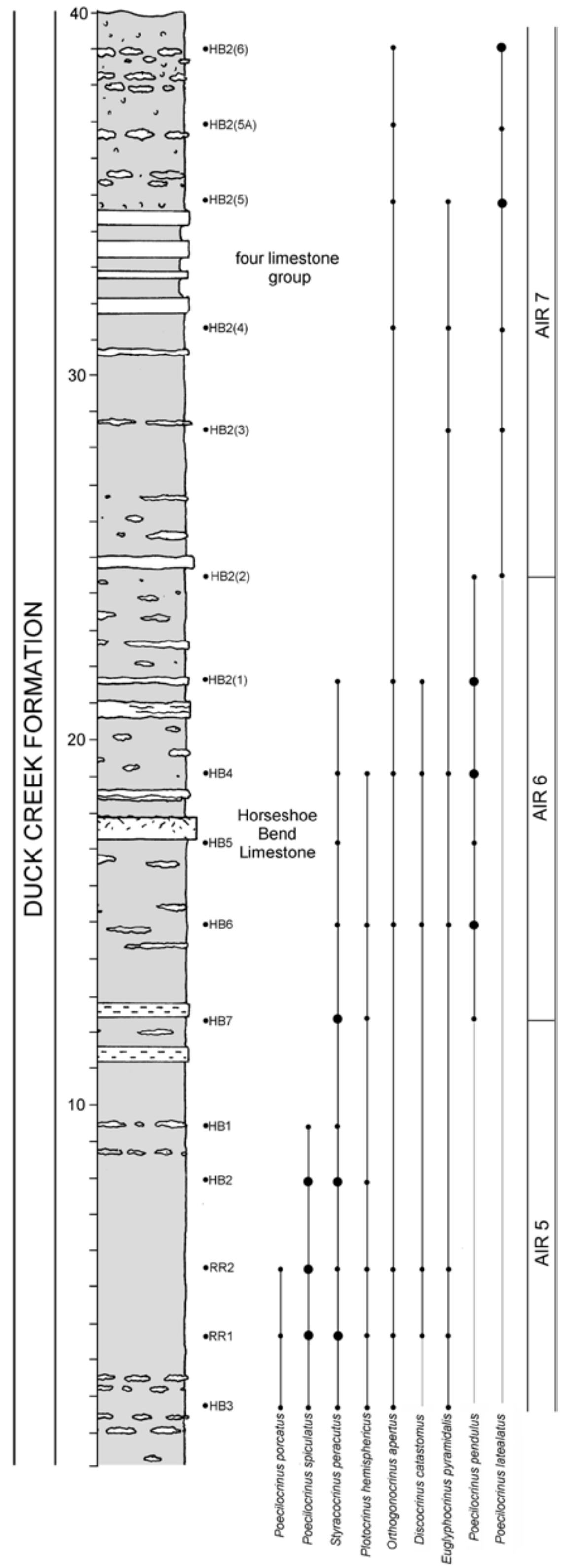
The base of this zone is defined by the lowest occurrence of *Poecilocrinus spiculatus*, low in the Duck Creek Formation (*Eopachydiscus marcianus* Zone), the top by the lowest occurrence of *Poecilocrinus pendulus*. The accompanying fauna is diverse, including *Peckicrinus porcatus* (Peck, 1943), *Orthogonocrinus apertus*, *Styracocrinus peracutus* (Peck, 1943), *Plotocrinus hemisphericus* Peck, 1943, *P. modulatus* Peck, 1943, *Euglyphocrinus pyramidalis* forma *pyramidalis* nov. and *Discocrinus catastomus* Peck, 1943. The zone is present in the lower third of the Duck Creek Formation (Text-figs 9 and 10), across northern Texas and southern Oklahoma (Text-fig. 4).

### AlR6

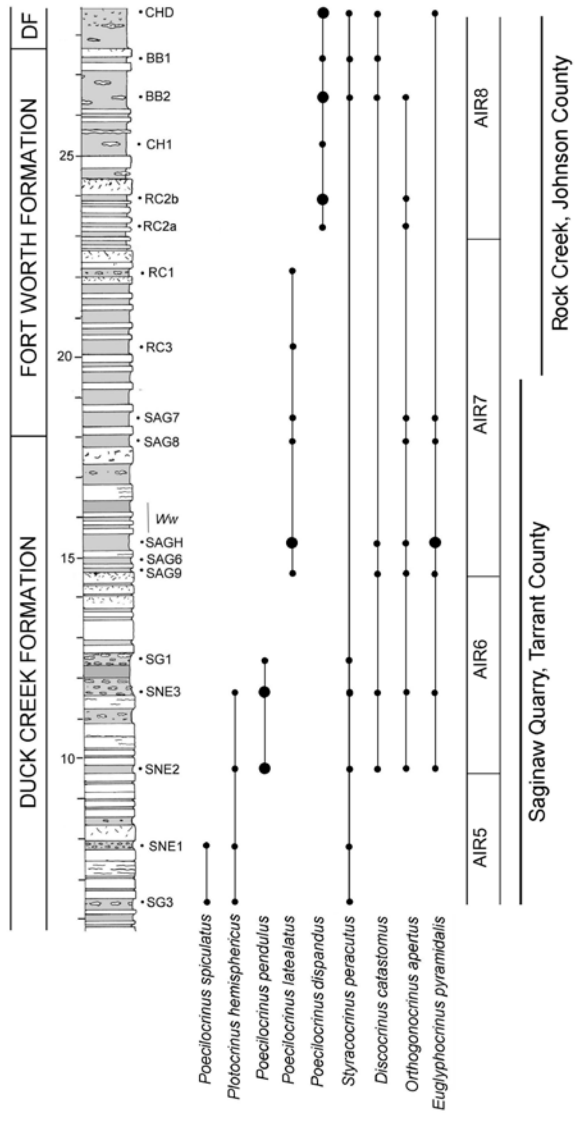
The base of zone AlR6 is defined by the lowest occurrence of *Poecilocrinus pendulus*, the top by the lowest occurrence of *Poecilocrinus latealatus*. *Poecilocrinus pendulus* is common, and other species present include *Orthogonocrinus apertus*, *Styracocrinus peracutus*, *Plotocrinus hemisphericus, Euglyphocrinus pyramidalis* forma *pyramidalis* nov. and *Discocrinus catastomus* (Text-figs 9 and 10).

### AlR7

The base of zone AlR7 is taken at the first occurrence of *Poecilocrinus latealatus* in the upper Duck

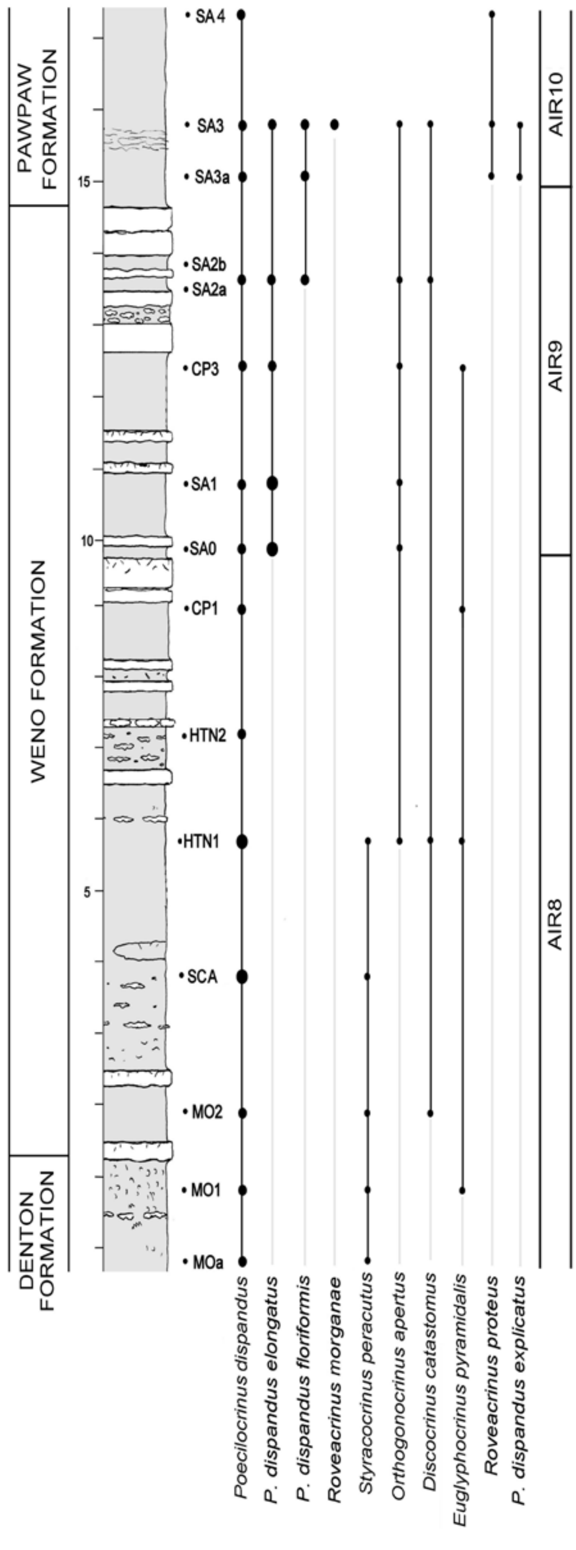



Text-fig. 9. Distribution of microcrinoids in the Duck Creek Formation of the Red River cliff at Horseshoe Bend, Love County, Oklahoma, with samples indicated. Scale in metres.




Text-fig. 10. Distribution of microcrinoids in the Duck Creek Formation, composite section based upon the Saginaw Quarry section, Tarrant County and Rock Creek, Johnson County. Scale in metres.

Creek Formation, the top by the first occurrence of *Po. dispandus* within the Fort Worth Formation. The replacement of *Po. latealatus* by *Po. dispandus* occurs between samples RC1 and RC2a in Rock Creek, Johnson County, an interval of less than 1 m (Text-fig. 4). The fauna is dominated by *P. latealatus*, *Euglyphocrinus pyramidalis* forma *radix* nov., with rarer *Orthogonocrinus apertus* and very rare *Discocrinus catastomus*. This fauna was described by Hess (2015) from the upper Duck Creek Formation in Saginaw Quarry.




Text-fig. 11. Distribution of microcrinoids in the upper Denton, Weno and lower Pawpaw formations, based upon samples from Fossil Creek (MO), Scott Avenue (SCA), Heritage Trace (HTN), Salvation Army (SA) and Carter Park (CP). Scale in metres.

**AlR8**

The base of this zone is taken at the lowest occurrence of *Poecilocrinus dispandus*, the top beneath the first occurrence of *Po. dispandus* forma *elongatus*. The zone is characterised by an abundance of large (3 mm) cups of *Po. dispandus* forma *discus* nov., visible on weathered outcrops. Other species are less common and include *Orthogonocrinus apertus*, *Euglyphocrinus pyramidalis* forma *pentaspinus* nov. and *Discocrinus catastomus* (Text-figs 5, 10, 11).

**AlR9**

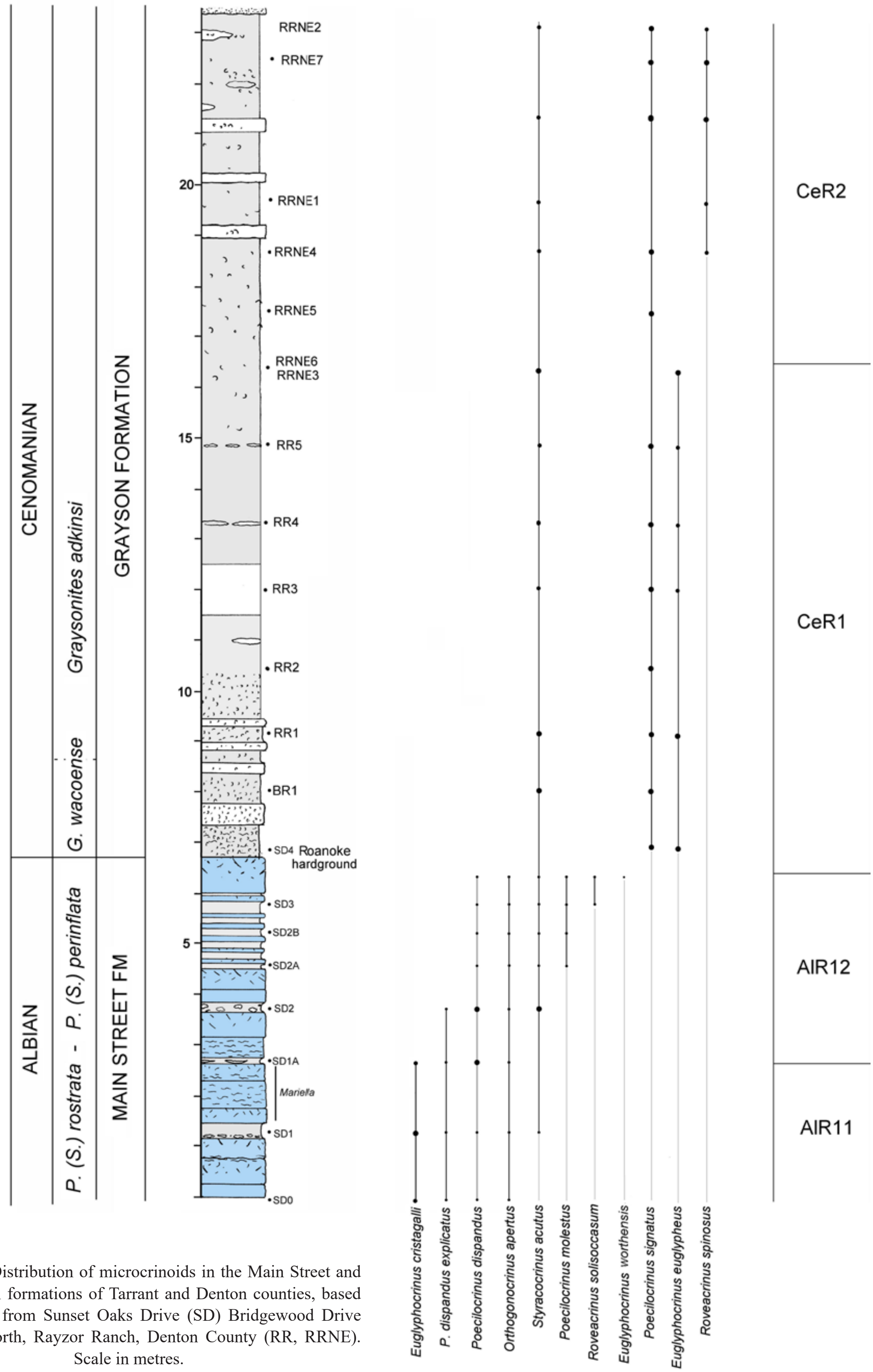
The base of zone AlR9 is defined by the lowest occurrence of *Po. dispandus* forma *elongatus* in the Weno Formation, the top by the first occurrence of *Roveacrinus proteus* sp. nov. in the basal Pawpaw Formation. The zone yields rarer specimens of *Discocrinus catastomus*, *Orthogonocrinus apertus* and *Euglyphocrinus pyramidalis* forma *pentaspinus* nov. The upper part of the zone also yields common *Po. dispandus* forma *floriformis* nov. Zone AlR9 falls within the *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone.

**AlR10**

Zone AlR10 is defined by the total range of the species *Roveacrinus proteus* sp. nov., which is present throughout the Pawpaw Formation. It is found in an assemblage dominated by *Po. dispandus* forma *floriformis* nov. and *Po. dispandus* forma *discus* nov., which also contains rarer *Discocrinus catastomus* and *Orthogonocrinus apertus*. This zone is equivalent to the upper part, but not highest, part of the *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone.

**AlR11**

AlR11 is defined as the total range of *Euglyphocrinus cristagalli* Gale, 2020, which occurs in the lower part of the Main Street Formation. It is accompanied by *Po. dispandus* forma *explicatus* Peck, 1943, which is characteristic of the zone, other formae of *Po. dispandus*, *Styracocorinus peracutus* and *Orthogonocrinus apertus* (Text-fig. 12). This fauna occurs in the uppermost part of the *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone in Texas and the Agadir Basin, Morocco.




Text-fig. 12. Distribution of microcrinoids in the Main Street and lower Grayson formations of Tarrant and Denton counties, based upon samples from Sunset Oaks Drive (SD) Bridgewood Drive (BR), Fort Worth, Rayzor Ranch, Denton County (RR, RRNE). Scale in metres.

**AlR12**

The base of zone AlR12 was defined by the highest occurrence of *Euglyphocrinus cristagalli*, and the top by the lowest occurrence of *Poecilocrinus signatus* (Peck, 1943) and *Euglyphocrinus euglypheus* (Peck, 1943). Typical taxa, restricted to the zone, include *Poecilocrinus molestus* Peck, 1943 and *Roveacrinus solisoccasum* Gale, 2020, accompanied by formae of *Po. dispandus*, *Styracocrinus peracutus* and *Orthogonocrinus apertus.* The zone is present in the uppermost part of the Main Street Formation in Tarrant County (Text-fig. 12) and is also known from the Agadir Basin, Morocco (Gale 2020). It corresponds with the *Pervinquieria* (*Subschloenbachia*) *perinflata* Zone.

**CeR1**

The base of CeR1 (Gale 2020) is marked by the lowest occurrence of *Poecilocrinus signatus* Peck, 1943 and *Euglyphocrinus euglypheus*, and is precisely coincident with the base of the Grayson Formation. *Styracocrinus peracutus* is common, while *Discocrinus* sp. (brachials only) is rare. An identical microcrinoid succession is found in the Agadir Basin, Morocco, where a CeR1 fauna appears at the same level as *Graysonites adkinsi* and marks the base of the Cenomanian.

**CeR2a**

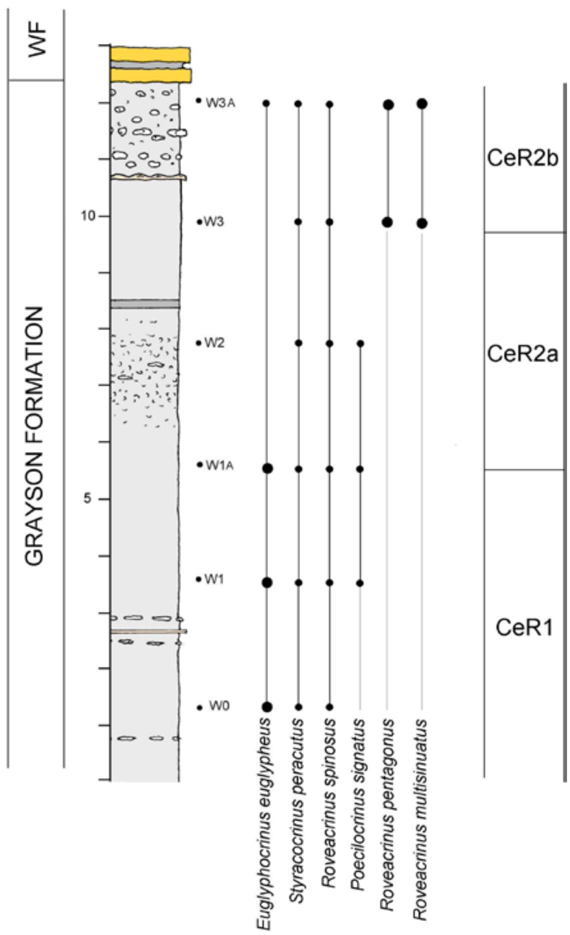
The base of zone CeR2 was taken by Gale (2020) above the highest occurrence of *Euglyphocrinus euglypheus* and characterised especially by the common occurrence of *Roveacrinus spinosus* (Peck, 1943) and *Poecilocrinus signatus* (Text-fig. 12). However, *E. euglypheus* extends, very rarely, into CeR2 in Texas (Text-fig. 13), so the base of the zone there is identified by the appearance of *R. spinosus* in the middle part of the Grayson. The faunal assemblage of this zone is characterised by the co-occurrence of *P. signatus*, *R. spinosus* and *Styracocrinus peracutus*.

**CeR2b**

This a local subzone, defined by the concurrent ranges of the distinctive species *Roveacrinus multisinuatus* Peck, 1943 and *R. pentagonus* Peck, 1943; currently only exposed in the uppermost 2.5 m of the Grayson Formation at the Waco Shale Pit (Text-fig. 13). This subzone was not found in North Africa (Gale 2020) and appears to be a local development in Texas. It was apparent, from the work of Peck (1943), that a distinctive microcrinoid fauna, including *R. multisinuatus* and *R. pentagonus* was present in the Grayson Formation assemblage which he recorded from a cutting south of Fink, in Grayson County (his locality HTL5; this no longer exists). The same fauna was subsequently discovered in a sample from the uppermost Grayson formerly exposed in a temporary section at Handley, Tarrant County (Dr M. Nestell, pers. comm., November 2019) and in the uppermost part of the formation in the Waco Shale Pit, McLennan County.

METHODS

Large samples (10–100 kg) of clays and marls were collected with reference to detailed logs, and screened using 0.5-m-diameter, 0.5-mm-mesh sieves in locally available water sources (creeks and lakes).




Text-fig. 13. Distribution of microcrinoids in the Grayson Formation of Waco Shale Pit, McLennan County, Texas. WF, Woodbine Formation. Scale in metres.

The residues were dried, subdivided into fractions and picked under a binocular microscope. Specimens were cleaned in an ultrasonic tank, mounted on stubs and coated with gold-palladium for SEM study. The images were taken on the JEOL SEM in the Biology Department of the University of Portsmouth.

**Repositories of specimens**

NHMUK, The Natural History Museum, London, United Kingdom.
USNM, United States National Museum, Washington DC, USA.
NMB, Naturhistorisches Museum Basel, Switzerland.

## SYSTEMATIC PALAEONTOLOGY (ASG)

Order Roveacrinida Sieverts-Doreck in Ubaghs, 1953

REMARKS: As currently defined, the Roveacrinida is effectively a 'sack term' for all Mesozoic stemless microcrinoids (Gale 2019), because in the definition of Hess and Messing (2011, p. 207) "sloping, synarthrial IBr1-2 and IIBr1-2" is plesiomorphic for the Articulata as a group (Simms 1988; Simms and Sevastopulo 1993). It is clear, however, that the Jurassic and Cretaceous forms (Saccocomidae, Roveacrinidae) form a monophyletic clade, reinforced by the discovery that the IIBr3–IIBr4 articulation is synostosial in the saccocomid *Saccocoma* Agassiz, 1836 (Brodacki 2006) and the roveacrinids *Roveacrinus marocensis* Gale, 2019 (Text-fig. 14A, B, E) and *Poecilocrinus dispandus* (Text-fig. 15A, B). This information makes it probable that saccocomids evolved from articulates from within one of the groups of Isocrinida, Comatulida, Hyocrinida and Cyrtocrinida, which share this synapomorphy, rather than Millericirinida in which the articulation IIBr4–IIBr5 is synostosial/syzygial (Simms and Sevastopulo 1993, text-fig. 3).

Extant crinoids, all of which have a synostosial/syzygial IIBr3–4 articulation, have been identified by molecular analysis as falling within two clades (Cohen and Pisera 2017), the SfU (stalked and facultatively unstalked, including all Comatulida) and the SqS (stalked and quasi-stalked, including Isocrinida, Cyrtocrinida, Hyocrinida). Thus, roveacrinids were therefore derived from an ancestor which was stalked, at least during early ontogeny. However, there is no evidence whether or not the free-living roveacrinids went through a stalked stage in early ontogeny. The smallest juvenile specimens all show the presence of external basals and a small centrale (Gale 2020; see below), and it is quite likely that they were attached by a stalk after metamorphosis of the larvae, and subsequently became free-living.

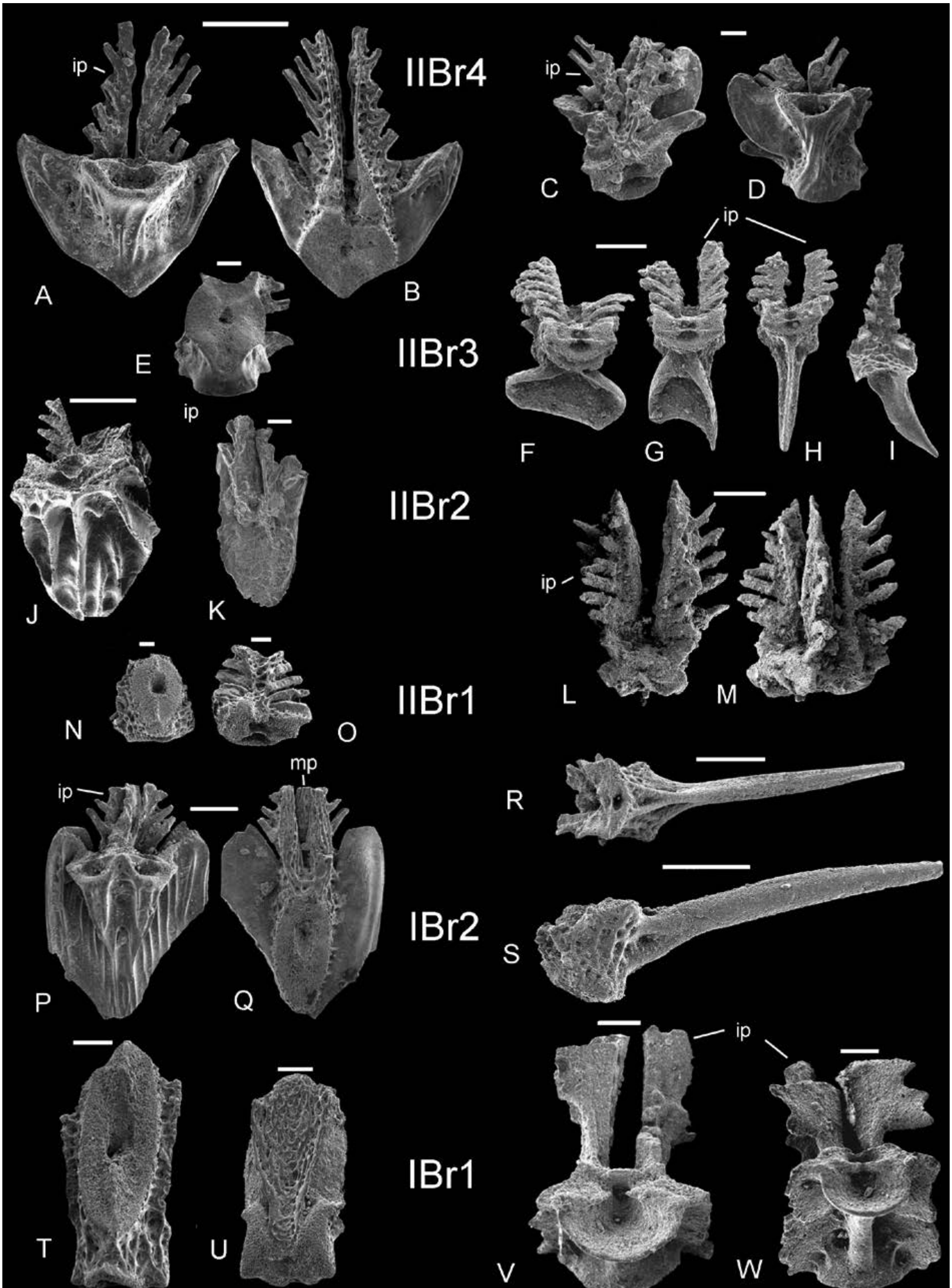
Family Roveacrinidae Peck, 1943
Subfamily Orthogonocrininae Gale, 2020

DIAGNOSIS: Cup pyriform or conical, elongated aborally; adoral surface bearing tall, usually bladed, interradial processes; radial cavity shallow, narrow, base formed by small basals, not visible on cup exterior; basal cavity elongated, adoral surface of cavity

| | |
|---|---|
| df | distal articular facet of brachial |
| dsf | distal synarthrial facet of brachial |
| ip | internal process on brachial |
| lp | lateral process on brachial |
| mf | muscle facet |
| mp | median process on brachial |
| psf | proximal synarthrial facet on brachial |

Table 2. Abbreviations used for roveacrinid brachial morphology.

Text-fig. 14. Brachial structure in Roveacrinidae. **A–E**, **K**, **P**, **Q**, **T**, **U** – *Roveacrinus marocensis* Gale, 2019. A, B – external and internal views of IIBr4, original of Gale (2019, pl. 19, fig. 9; NHMUK IC EE 16881); C, D – brachial from midarm portion, original of Gale (2019, pl. 19, fig. 11; NHMUK IC EE 16882); E – IIBr3, distal surface (Gale 2019, pl. 19, fig. 6, NHMUK IC 16878); K – internal view of IIBr2 (NHMUK PI EE 17703); P, Q – IIBr2, holotype, external and internal views, original of Gale (2019, pl. 18, figs 5, 6; NHMUK PI EE 16889); T, U – IBr1, original of Gale (2019, pl. 19, fig 5; pl. 20, fig. 5; NHMUK PI EE 16890, 16877). **F–I** – *Poecilocrinus dispandus* Peck, 1943. Brachials of midarm (F, G) and distal arm portions (H, I, NHMUK PI EE 17704–17707). **J**, **N**, **O** – *Roveacrinus gladius* Gale, 2020. J – IIBr2, external view, original of Gale (2019b, pl. 13, fig. 1; NHMUK PI EE 17477). N, O – IIBr1, originals of Gale (2019, pl. 13, fig. 1; NHMUK PI EE 17483, 17484). **L**, **M** – *Roveacrinus falcifer* Gale, 2019. Distal brachial to show double internal processes, original of Gale (2019, pl. 11, fig. 11; NHMUK PI EE 16780). **R**, **S** – *Roveacrinus spinosus* Peck, 1943. Distal brachials, bearing elongated spine (NHMUK PI EE 17708, 17709). **V**, **W** – *Hessicrinus filigree* Gale, 2016. Brachials of midarm portion, bearing broad, bladed internal processes. W – original of Gale (2016, fig. 10N; NHMUK PI EE 16107). V, (NHMUK PI EE 17710). A–E, K, P, Q, T, U are from the lower Turonian, *Mammites nodosoides* Zone, Asfla, Moyen Atlas, Morocco. J, N, O are from the lower Cenomanian, Aït Lamine Formation, Abouda Plage, Agadir Basin, Morocco. F–I are from the *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone, Weno Formation, Cleburne, Johnson County, Texas. L, M are from the middle Turonian, *Terebratulina lata* Zone, Dieppe, France. R, S are from the lower Cenomanian, Grayson Formation, Waco Shale Pit, McLennan County, Texas. V, W are from the lower Campanian, *Gonioteuthis quadrata* Zone, Culver Chalk Formation, Warningcamp, Arundel, Sussex, UK. Scale bars equal 0.2 mm (C–E, K, N, T–W), 0.5 mm for all others. See Table 2 for explanation of abbreviations. →


IIBr4
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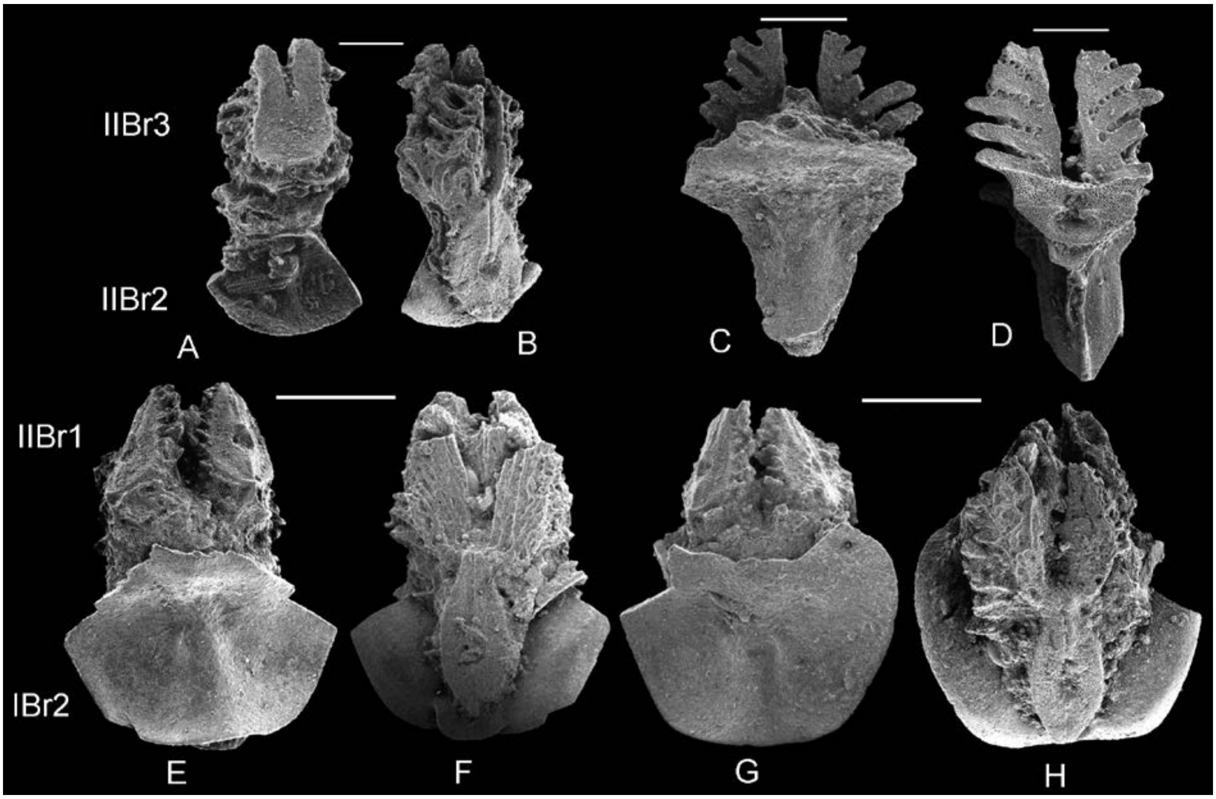



Text-fig. 15. Associated brachials of *Poecilocrinus dispandus* Peck, 1943. A, B – articulated IIBr2, 3. Note internal processes on IIBr2, and distal synostosial articulation of IIBr3 (NHMUK PI EE 17711). C – type B IBr2, retaining internal processes (NHMUK PI EE 17712). D – distal brachial, with internal processes preserved (NHMUK PI EE 17713). E-H – IBr2 and articulated IIBr1, with preserved internal processes (NHMUK PI EE 17714, 17715). Sample SA2, upper Weno Formation, upper Albian, *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone, Salvation Army site, Seminary Drive, Fort Worth, Tarrant County, Texas. Scale bars equal 0.5 mm.

bearing five radially placed pits that each housed a ball-shaped structure; brachials highly modified, IBr1 very short, IBr2 elongated, distal secundibrachials elongated, bearing pinnules.

Genus *Discocrinus* Peck, 1943

DIAGNOSIS: Cup low, broad, with tall muscle fossae on radials; radial cavity floored by thin sheet, perforated by irregularly sized oval holes; basals form pentagonal centre to sheet; central aboral surface of cup non-mineralised; arms robust, IIBr2 elongated.

TYPE SPECIES: *Discocrinus catastomus* Peck, 1943, by original designation.

OTHER INCLUDED SPECIES: In addition to the type species, *Discocrinus wrighti* Peck, 1955 and *D. africanus* Gale, 2019.

REMARKS: *Discocrinus* is a distinctive and unusual roveacrinid, in which the low cup superficially resembles the centrodorsal of some comatulids, but is made up almost entirely of radials, and entirely lacks cirral sockets; the basals are small and form the pentagonal central part of the transverse sheet which floors the radial cavity (Pl. 1, Fig. 16). Earlier I placed the genus in the Orthogonocrininae (Gale 2020), on account of the non-mineralised aboral surface of the cup, the elongated IBr2 and the presence of lateral radial tubes. However, a key synapomorphy of the subfamily, sub-basal balls, are absent in *Discocrinus*.

Recognition of the highly distinctive brachials makes it possible to record the genus in the absence of the rarer cups (Gale 2019, 2020). *Discocrinus* is locally common in the Albian of Texas and known from two specimens from the lower Cenomanian of the United Kingdom (Peck 1955; Rasmussen 1961). The genus is also common in the lower Cenomanian of the Agadir Basin, Morocco, and present in the

Cenomanian of central Tunisia. Detailed reassessment of the genus is based upon abundant and exceptionally well-preserved material from the Weno Formation (upper Albian) of Cleburne, Johnson County, Texas, which includes over 100 cups that demonstrate morphological variation and the structure of the proximal arms.

OCCURRENCE: Upper Albian and Cenomanian of the United Kingdom, Texas, Oklahoma, Morocco and Tunisia.

*Discocrinus catastomus* Peck, 1943
(Pl. 1, Figs 1–22)

*1943. *Discocrinus catastomus* Peck, p. 474, pl. 72, figs 9–11.
1955. *Discocrinus catastomus* Peck; p. 1028.
1961. *Discocrinus catastomus* Peck; Rasmussen, p. 387, pl. 56, fig. 7.
2019. *Discocrinus catastomus* Peck; Gale, p. 474, pl. 35, figs 2, 4, 5, 7–9.
2020. *Discocrinus catastomus* Peck; Gale, p. 15, pl. 1, figs 9–13.

DIAGNOSIS: *Discocrinus* in which the cup is proportionately low, and the radial facets relatively small in size.

TYPE: The cup figured by Peck (1943, pl. 72, figs 9–11) is the holotype. Upper Albian, middle Duck Creek Formation, H. Tappan Loeblich locality 28, cliff on north side of Red River, east of US Highway 77, Bryan County, Oklahoma. This locality is not in the Fort Worth Formation (see above). University of Missouri collections, number E-13-5; not found and presumed lost.

MATERIAL: 142 cups and brachials from the Weno Formation roadcut in Cleburne, Johnson County, Texas, and approximately 25 cups from the Duck Creek, Weno and Pawpaw formations in Tarrant County, Texas. Peck's unfigured paratypes (USNM 128356) include three cups from the Duck Creek Formation, H. Tappan Loeblich locality 57, roadcut on US Highway 77 just south of bridge over Red River, Cooke County, Texas.

DESCRIPTION: The cups are low and have a pentagonal outline, with the corners formed by the robust radial facets (Pl. 1, Figs 1, 7, 16). The radial cavity is broad and shallow, and is floored by a thin, transverse sheet of stereom, usually broken, perforated by holes of irregular size and shape (Pl. 1, Figs 1, 7). Basals were present in the central region of the transverse sheet, as indicated by a pentagonal void (Pl. 1, Fig. 16). The radial facets are large, heart shaped, and project from the lateral margins of the cup in ad- and aboral views. The aboral ligament pits and central canals are large and round and the muscle fossae are fused adoral to the central canal. The regions of the cup surface between the radial facets are slightly inset and made up of irregularly coarse, perforate stereom; the interradial contact is slightly raised. Tall, triangular interradial processes are present, but seldom completely preserved (Pl. 1, Fig. 9), and these rise above the narrow lateral radial tubes. The aboral surface of the cup (Pl. 1, Figs 1, 16) displays the buttress-like radial facets, conjoined to interradial ridges, which are poorly developed in some specimens (e.g., Pl. 1, Fig. 7) and strongly developed in others (Pl. 1, Fig. 16). The interradial ridges fuse with the transverse sheet and extend centrally almost to the basals (Pl. 1, Fig. 16). The same specimen demonstrates that a central, petal-shaped region of the aboral cup was not mineralised. All cups found are small and fall within the size range of 0.8 to 1.4 mm in diameter. The main variation is in the height/breadth ratio of the cup, varying from 1/4 in low specimens (e.g., Pl. 1, Figs 1, 7, 14), and 1/3 in tall ones (Pl. 1, Fig. 15). The proximal brachials are individually distinctive and the arms can be reconstructed up to IIBr2 (Pl. 1, Figs 9–12). IBr1 (Pl. 1, Figs 20–22) is trapezoidal in lateral view, and internally bears tall muscle facets. In distal view, the synarthrial articulation for IBr2 is flat. Axillary IBr2 (Pl. 1, Figs 3–6) are three times as tall as broad, very robust, and constructed of openly reticulate stereom; the distal end is triangular, with facets for two IIBr1. There is considerable variation in the morphology of this ossicle, from short, robust forms (Pl. 1, Figs 3, 11) constructed of openly reticulate stereom, to strongly elongate forms with a smooth central region made of imperforate stereom (Pl. 1, Fig. 4). IIBr1 (Pl. 1, Figs 17–19) are triangular in lateral view, and distally carry a synarthrial facet for IIBr2. Distal brachials have well-developed muscular articulations (Pl. 1, Fig. 2) and some bear a single, oval pinnular facet (Pl. 1, Fig. 8).

REMARKS: *Discocrinus catastomus* differs from the Cenomanian *D. wrighti* and *D. africanus* in the lower cup and proportionately smaller radial facets.

OCCURRENCE: Duck Creek to Pawpaw formations of Texas and Oklahoma. The species occurs frequently in the lower and rarely in the upper part of the Duck Creek Formation. It is rare in the Fort Worth, Pawpaw and Denton formations, but locally common in the Weno Formation. Isolated brachials from the Main Street and Grayson formations are referred to as *Discocrinus* sp.

*Orthogonocrinus* Peck, 1943

DIAGNOSIS: Cup tall, radial facets divided into surfaces set at right angles and separated by the articular ridge. Radials in contact only in adoral portion of cup; aborally, they separate into tapering strips, and the aboral part of the cup was not mineralised. Interradial processes tall and bladed, radial cavity narrow.

TYPE SPECIES: *Orthogonocrinus apertus* Peck, 1943, by original designation.

OTHER INCLUDED SPECIES: In addition to the type species, only *Orthogonocrinus cantabrigensis* Gale, 2019.

REMARKS: Two species of *Orthogonocrinus* have been described to date. The type species, from the middle to upper Albian of Texas and Oklahoma, also occurs in the middle Albian of the United Kingdom (Smith *et al*. in Young *et al*. 2010, fig. 18.1a). The other, *O. cantabrigensis*, is widespread but uncommon in the lower Cenomanian of Europe (Germany, United Kingdom), Morocco and Tunisia. The arm structure in *Orthogonocrinus* is similar to that in *Lebenharticrinus* Žítt, Löser, Nekvasilová, Hradecká and Svabenická, 2019 (see Gale 2019, pl. 40).

*Orthogonocrinus apertus* Peck, 1943
(Pl. 2, Figs 1–5, 7–13; Pl. 3, Figs 1–13)

*1943. *Orthogonocrinus apertus* Peck, p. 464, pl. 76, figs 2–8.
non 1955. *Orthogonocrinus apertus* Peck; pl. 106, figs 7–9.
pars 1961. *Orthogonocrinus apertus* Peck; Rasmussen, p. 385, fig. 5 only.
2010. *Orthogonocrinus apertus* Peck; Young *et al*., p. 256, text-fig. 18.1a.
pars 2015. *Orthogonocrinus apertus* Peck; Hess, fig. 11d–p only; fig. 12a–g, i–l only.
pars 2015. *Roveacrinus pyramidalis* Peck; Hess, fig. 10a–i only.
non 2015. *Orthogonocrinus apertus* Peck; Hess, fig. 13a–h.
2019. *Orthogonocrinus apertus* Peck; Gale, p. 478, pl. 34, figs 1–4; pl. 36 fig. 9.
2020. *Orthogonocrinus apertus* Peck; Gale, p. 17, pl. 4, figs 7–9, 11, 12.

DIAGNOSIS: Cup cylindrical, radials carrying median blade extending from the radial facet aborally. Lateral surface of radial facet large, U-shaped. Cup surface made up of finely perforate stereom.

TYPES: The cup figured by Peck (1943, pl. 76, figs 4, 6, 7) (E-21-5) is the holotype. Duck Creek Formation, upper Albian, H. Tappan Loeblich locality 57, roadcut on US Highway 77, just south of bridge over Red River, Grayson County, Texas. University of Missouri collections; not found, presumed lost.

MATERIAL: Over 150 cups and 300 brachials from the middle Albian Marys Creek Marl Member to the upper Albian Main Street Limestone Formation. The species is most common in the upper part of the Duck Creek Formation. Peck's unfigured paratypes (USNM 128352, 128353) include four cups from the Duck Creek Formation, near Denison, Grayson County, Texas.

DESCRIPTION: The cup is pentagonal and cylindrical, tapering gradually aborally (Pl. 2, Figs 1, 2, 4, 5, 8). The radials articulate for a short distance aboral to the radial facets, then separate into triangular processes which do not articulate (Pl. 2, Fig. 9; Pl. 3, Fig. 13); the complete aboral termination is unknown. The adoral surface bears five tall, triangular, blade-like interradial processes, and the opening of the radial cavity is narrow, representing about 25% of the width of the cup. The radial facets are separated by the articular ridge into separate adoral and lateral surfaces, which are angled at approximately 70º. The lateral surface is U-shaped and concave and the aboral ligament pit is deep but poorly defined. The adoral surface of the radial facet (Pl. 2, Figs 5, 8) bears a large, circular central canal and low, fused muscle fossae (e.g., Pl. 2, Fig. 8); lateral radial tubes are well developed in some individuals (e.g., Pl. 2, Figs 4, 5). On the interior of the cup, radially positioned concavities for sub-basal balls can be seen (Pl. 2, Fig. 13), and the basals form the central part of a transverse partition separating the radial and basal cavities (Pl. 2, Fig. 7). In the smallest individuals (Pl. 2, Figs 10, 11) the radials remain in contact to the aboral margin of the cup and appear to have blunt terminations.

IBr1 (Pl. 3, Figs 16–18) are short and kite shaped and the proximal face (Pl. 1, Fig. 18) bears a raised, triangular region on which the muscle fossae are situated. The distal surface (Pl. 1, Fig. 16) is a synarthrial articulation surface for IIBr2 (Pl. 3, Figs 6–8, 11). These are very elongated, slightly laterally compressed and oval in cross section, and the swollen distal termination bears two facets for IIBr1. The processes of the distal articulation of IBr2 are usually broken, but two elongated processes for muscle facets are present (see Hess 2015, fig. 10a–c). IIBr1 (Pl. 3, Figs 10, 14, 15) are short, laterally compressed, and carry two long processes for muscular articulation with IBr2. The distal articulation of IIBr1 is a flat synarthry. IIBr2 (Pl. 3, Figs 3–5, 9) is elongated, laterally compressed, and the distal articulation is muscular. More distal brachials (e.g., Pl. 3, Figs 1, 2) are also elongated, laterally compressed and have muscular articulations, and some bear pinnule sockets.

REMARKS: This species differs from its presumed descendant, the Cenomanian *O. cantabrigensis*, in the larger radial facets on the lateral surfaces of the cup, and the finer, non-rugose stereom of the cup exterior. Note that the distinctively elongated brachials figured by Hess (2015) as belonging to *Roveacrinus pyramidalis* Peck, 1943 actually belong to *O. apertus*, as discussed by Gale (2019). Material from the Cenomanian of the United Kingdom referred to this species by Peck (1955) should be placed in *O. cantabrigensis*.

OCCURRENCE: This species occurs from the middle Albian Marys Creek Marl Member to the upper Albian Main Street Limestone Formation of Texas and Oklahoma; one cup has been recorded from the middle Albian Gault Clay of the United Kingdom (Young *et al*. 2010). The species is locally common in the middle Albian *Anahoplites intermedius* Subzone of Aube (France) and the lower Cenomanian of the Agadir Basin, Morocco.

### *Styracocrinus* Peck, 1955

DIAGNOSIS: Cup tall, conical, extended aborally to an acute point. Interradial processes tall, pointed; IBr2 elongated, flattened, bearing a narrow rounded central ridge and lateral flanges.

TYPE SPECIES: *Drepanocrinus peracutus* Peck, 1943, by the original designation of Peck (1955).

INCLUDED SPECIES: In addition to the type species, *S. rimafera* Gale, 2020 and *S. thomasae* sp. nov.

### *Styracocrinus peracutus* (Peck, 1943)
(Pl. 4, Figs 1–17)

*1943. *Drepanocrinus peracutus* Peck, p. 463, pl. 76, figs 9–22, 26, 28.
1955. *Styracocrinus peracutus* Peck; p. 1022, pl. 106, figs 10–12.
1961. *Styracocrinus peracutus* (Peck); Rasmussen, p. 383, pl. 56, figs 1–3.
?1971. *Styracocrinus peracutus* (Peck); Schmid, p. 73, pl. 1, figs 1–15.
2015. *Roveacrinus peracutus* Peck; Hess, p. 25, fig. 17a–f.
pars 2015. *Orthogonocrinus apertus* Peck; Hess, fig. 12h only.
pars 2015. *Roveacrinus spinosus* Peck; Hess, fig. 14a–c only.
2019. *Styracocrinus peracutus* (Peck); Gale, p. 476, pl. 37, figs 1–9.
2020. *Styracocrinus peracutus* (Peck); Gale, p. 18, pl. 5, figs 1–11.

DIAGNOSIS: *Styracocrinus* in which the radials articulate closely and form an acuminate aboral termination; external surface bearing irregularly spaced small rugosities.

HOLOTYPE: The cup, figured by Peck (1943, pl. 76, fig. 21), from the lower Cenomanian Grayson Formation of Grayson Bluff, Roanoke, Denton County, Texas (H. Tappan Loeblich locality HTL1) is the holotype. University of Missouri collections; not found, presumed lost.

MATERIAL: Numerous cups and brachials from the upper Albian and lower Cenomanian, Duck Creek to Grayson formations of northern Texas and southern Oklahoma. Peck's unfigured paratypes (USNM 128354, 128355) include ten cups from the Duck Creek Formation, Cooke County, Texas.

DESCRIPTION: The cups are conical, with an acute aboral termination and a maximum breadth at the base of the radial facets. There is considerable variation in height/breadth ratio, with low forms about 1/1, and tallest individuals 2/1. The lateral surfaces of the cups are glossy and carry fine, irregularly spaced rugosities. The inset adoral, interradial regions of the cups are finely reticulate. Narrow, sharp median radial ridges extend from the aboral margins of the radial facets to the aboral pole. The radial facets are inclined at approximately 45º to the cup axis, and are triangular, narrowing aborally. The central canal is rounded and large (e.g., Pl. 4, Figs 2–4); the aboral ligament pits are small and rounded and the interradial processes are tall and triangular. Deep, rounded recesses are present on the interior surfaces of the radials (Pl. 4, Fig. 14), which housed sub-basal balls (Pl. 4, Fig. 15). The basals formed a pentagonal structure in the transverse ridge separating radial and basal cavities (Pl. 4, Fig. 14). In small individuals (Pl. 4, Figs 1, 10) the radials do not all extend aborally to the pole, and the aboral portions of the radials are rounded and convex, narrowing at the level of the radial facets.

IBr1 were not collected during the present study, but Peck (1943, pl. 76, fig. 9) illustrated an individual on which these are attached to the cup; they are short, with a large, oval, synarthrial facet for articulation of IIBr2. The primibrachials IBr2 (Pl. 4, Figs 16, 17) are elongated and oval and bear a narrow median ridge flanked by thin flanges. The distal region for articulation of the secundibrachials is robust and has a small central depression. Small, laterally compressed brachials which bear a synarthrial articulation on one end and a muscular one on the other represent either IIBr1 or IIBr2 (Pl. 4, Fig. 12).

REMARKS: *Styracocrinus peracutus* differs from *S. thomasae* sp. nov. (see below) in the finely rugose sculpture of the lateral surfaces of the radials; these are smooth in the latter species. It differs from *S. rimafera* in that the radials are in contact at the aboral pole and are of equal height.

OCCURRENCE: Duck Creek Formation (upper Albian) to Grayson Formation (lower Cenomanian) of Texas and Oklahoma. Upper Albian and Cenomanian of the United Kingdom, Germany, France.

### *Styracocrinus thomasae* sp. nov.
(Pl. 4, Figs 6–9, 18, 19)

DIAGNOSIS: *Styracocrinus* in which the lateral surfaces of the radials are smooth or coarsely reticulate; the interradial contact forms a raised seam.

TYPES: The cup figured in Pl. 4, Figs 6, 7 is the holotype (NHMUK PI EE 17746), the individual in Pl. 4, Figs 8, 9 is a paratype (NHMUK PI EE 17747). Both are from sample MC2, middle Albian, Marys Creek Member of the Goodland Limestone Formation, Marys Creek, Fort Worth, Tarrant County, Texas.

MATERIAL: 13 cups from the same horizon and locality as the types.

DERIVATION OF NAME: For Katherine Marie Thomas, who helped greatly with the fieldwork in Texas.

DESCRIPTION: Only the adoral portions of the cups are preserved, presumably because the aboral parts were very thin and fragile (Pl. 4, Figs 6–9). The cup is pentagonal, the radial facets large and triangular, with a strong articular ridge and large, round central canal. The muscle fossae are low and fused, and low, triangular, interradial processes are inclined laterally in some specimens (Pl. 4, Fig. 7). The interradial contacts form a rounded ridge which extends to the base of the interradial processes. The surfaces of the radials adjacent to the radial facets are coarsely reticulate, the rest of the external surfaces of the radials are smooth. IBr2 (Pl. 4, Figs 18, 19) are elongated and carry a rounded central ridge, flanked by flat processes. The distal articular region for the IIBr1 is robust.

REMARKS: *Styracocrinus thomasae* sp. nov. differs from *S. peracutus* in the smooth external surface of the cup and the presence of a raised interradial suture. In *S. peracutus* the interradial suture is flat and the cup bears fine rugosities.

OCCURRENCE: *Styracocrinus thomasae* sp. nov. occurs in the lower part of the Marys Creek Member of the Goodland Limestone in Tarrant County, Texas.

### *Euglyphocrinus* Gale, 2019

DIAGNOSIS: Cup conical to aborally truncated conical, very coarsely reticulate, with tall interradial processes. Five small globular structures (sub-basal balls) are present in cavities in the radials in the roof of the basal cavity. Brachials bear thorn-like spines.

TYPE SPECIES*: Roveacrinus euglypheus* Peck, 1943, by original designation.

INCLUDED SPECIES: In addition to the type species, *Euglyphocrinus pyramidalis* (Peck, 1943), *E. jacobsae* Gale, 2020, *E. truncatus* Gale, 2020, *E. cristagalli* Gale, 2020 and *E. worthensis* Gale, 2020.

REMARKS: The genus was transferred from the Roveacrininae to the Orthogonocrininae on account of the presence of sub-basal balls in *E. pyramidalis*, a synapomorphy of the Orthogonocrininae (Gale 2019, 2020). Large external basals are present in *E.*

*euglypheus* and *E. worthensis*, a characteristic of juvenile roveacrinids of genera such as *Poecilocrinus* (see below), and may be evidence that paedomorphic evolution took place in *Euglyphocrinus*.

*Euglyphocrinus euglypheus* (Peck, 1943)
(Pl. 6, Figs 7, 8, 10, 11; Pl. 7, Figs 11–14)

*1943. *Roveacrinus euglypheus* Peck, p. 469, pl. 72, figs 18–23.
1961. *Roveacrinus euglypheus* Peck; Rasmussen, p. 370, pl. 53, fig. 13.
2019. *Euglyphocrinus euglypheus* (Peck); Gale, p. 472, pl. 35, fig. 11.
2020. *Euglyphocrinus euglypheus* (Peck); Gale, p. 22, pl. 8, figs 7–12; text-fig. 12A–C.

DIAGNOSIS: *Euglyphocrinus* in which the external basals form a rosette surrounding a centrale; plate sutures are slightly raised.

TYPES. The specimen figured by Peck (1943, pl. 72, fig. 22), from H. Tappan Loeblich locality 94, Grayson Formation, Barton Creek, Austin, Travis County, Texas, is the holotype. University of Missouri collections; not found, presumed lost.

MATERIAL: Several hundred cups and brachials from the Grayson Formation in northern Texas. Peck's unfigured paratypes (USNM 128335) include three cups from the Grayson Formation of Grayson Bluff, Denton County, Texas.

DESCRIPTION: The cups (Pl. 6, Figs 7, 8, 10, 11) are conical and the height is aprroximately the same as the width. The radials are convexly rectangular in lateral outline and the radial facets are triangular, with a broad central canal and raised interradial processes. The basals form a pentagonal rosette occupying 2/3 of the diameter of the base of the cup (Pl. 6, Figs 7, 10), surrounding a small centrale. The cup is constructed of coarsely reticulate stereom, and the sutures between the radials and basals are raised in some specimens (e.g., Pl. 6, Figs 7, 8). Aborally and aborally-laterally directed spines are present on the central surfaces of the radials and basals (Pl. 6, Figs 11, 12). IBr1 (Pl. 7, Figs 10, 14) is twice as tall as broad, laterally compressed and carry a sharp external ridge which bears blunt spines. The distal articulation is synarthrial and contacts the proximal surface of IBr2 (Pl. 7, Figs 11–13). IBr2 is triangular, very robust, and the external surface has three short, blunt spines; IIBr2 (Pl. 7, Fig. 9) carries two spines. Distal brachials (Pl. 7, Figs 21–23) are constructed of irregularly ridged imperforate stereom and bear irregularly developed lateral spines.

REMARKS: *Euglyphocrinus euglypheus* is a highly distinctive species, in which the external basals form a rosette surrounding a centrale, separating it from all congeners.

OCCURRENCE: *Euglyphocrinus euglypheus* occurs throughout the lower Cenomanian Grayson Formation of Texas, but is abundant only in the lower third of that unit. It has also been found in the Agadir Basin, Morocco, at an equivalent level (Gale 2020).

*Euglyphocrinus cristagalli* Gale, 2020
(Pl. 5, Figs 1–3; Pl. 6, Fig. 3; Pl. 7, Figs 1–8, 24–26)

*2020. *Euglyphocrinus cristagalli* Gale, p. 22, pl. 4, figs 1–6, 12, 13.

DIAGNOSIS: *Euglyphocrinus* in which a denticulate ridge of irregular, laterally-aborally deflected spines is present on the median crest of each radial; a cluster of short, aborally directed spines is present on the aboral pole. Stereom very coarse, irregular.

TYPES: The cup from sample SD1, Main Street Formation, Sunset Oaks Drive, Fort Worth, Tarrant County, Texas (Pl. 5, Fig. 2) is the holotype (NHMUK PI EE 17384). The other figured cups from the same locality (Pl. 5, Figs 1, 3; Pl. 6, Fig. 3) are paratypes (NHMUK PI EE 17385–17387).

MATERIAL: Over 100 cups and brachials from the Main Street Limestone of the Sunset Oak Drive road cutting, Fort Worth, Tarrant County, Texas.

DESCRIPTION: The cup is slightly taller than broad, and the aboral pole is rounded (Pl. 5, Figs 1–3). Strong mid-radial ridges, composed of smooth, imperforate stereom, extend from the base of each radial facet to the aboral margin. These bear 3–5 blunt spines, which are directed aborally-laterally and are variable in size and development; the more adoral spines are longest and aborally recurved (Pl. 5, Fig. 2). In some individuals, they are of more regular length (Pl. 5, Figs 1, 3). A cluster of short, aborally directed spines is present on the aboral portion of the cup; these develop lateral and aboral to the mid-radial spines. The region between the radial ridges is made up of very coarse, irregular trabeculae. A specimen in which the base of the cup is broken away (Pl. 6, fig. 3) shows the transverse partition which separates the radial and basal cavities, composed of very fine stereom, attached to the wall of the cup by coarse trabeculae. The basals are very small and form a pentagonal star in the centre of the cup. IBr1 is laterally compressed, with an obliquely inclined distal synarthrial facet and a lateral lip which overhangs the rounded lateral margin (Pl. 7, Figs 3, 4, 7). IBr2 is triangular, with a prominent median process and bears two to three pairs of aborally directed short spines and a tall median process (Pl. 7, Figs 1, 2, 6). The distal brachials (Pl. 7, Figs 24–26) are composed of coarsely perforated stereom, and bear spines at both proximal and distal ends.

REMARKS: *Euglyphocrinus cristagalli* differs from *E. pyramidalis* in the strongly developed spines on the median radial ridges and in the cluster of aborally directed spines on the aboral pole of the cup. It differs from *E. worthensis* and *E. euglypheus* in the absence of external basals.

OCCURRENCE. Upper Albian, zone AlR12, *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone, Aït Lamine Formation, Agadir Basin, Morocco, and lower part of Main Street Limestone, Texas.

### *Euglyphocrinus worthensis* Gale, 2020
(Pl. 6, Figs 4–6)

*2020. *Euglyphocrinus worthensis* Gale, p. 23, pl. 8, figs 1–3, text-fig. 12A, B.

DIAGNOSIS: *Euglyphocrinus* in which the flattened aboral surface is formed by a pentagonal arrangement of five basals; a centrale is not present. Interradial regions concave.

TYPES: The specimen figured in Pl. 6, Figs 4–6 is the holotype (NHMUK PI EE 17424). Uppermost Main Street Limestone, Sunset Oaks Drive, Fort Worth, Tarrant County, Texas, sample SD4 (Text-fig. 12).

MATERIAL: A single cup from the upper Albian Main Street Limestone, Fort Worth, Tarrant County, Texas.

DESCRIPTION: The very well-preserved holotype (Pl. 6, Figs 4–6) was gold coated for SEM study and thus revealed the plating of the base. The specimen is slightly taller than broad in lateral view, conical, and the aboral margin is flat. The median radial ridges bear short, aborally deflected spines and the interradial regions are concave. The radial facets are large and broad and large, rounded aboral ligament pits and central canals are present; the radial cavity is broad adorally. The surface of the cup is coarsely reticulate. The aboral portion of the cup is made up of the five basal plates, which form the aboral third of the cup in lateral view. In aboral view, the basals are triangular and together have a pentagonal outline.

REMARKS: *Euglyphocrinus worthensis* differs from the later *E. euglypheus* in the pentagonal, rather than rosette-like form of the basal portion of the cup, the absence of a centrale and the lack of narrow raised ridges at plate sutures. It is likely that *E. worthensis* gave rise to *E. euglypheus* around the Albian–Cenomanian boundary.

OCCURRENCE: *Euglyphocrinus worthensis* occurs in the uppermost Albian zone AlR12 in central Texas and in the Agadir Basin, Morocco.

### *Euglyphocrinus pyramidalis* (Peck, 1943)
(Pl. 5, Figs 4–12; Pl. 6, Figs 1, 2; Pl. 7, Figs 16–20)

*1943. *Roveacrinus pyramidalis* Peck; p. 468, pl. 72, figs 24–29.
1961. *Roveacrinus pyramidalis* Peck; Rasmussen, p. 371, pl. 53, figs 10, 11.
pars 2015. *Roveacrinus pyramidalis* Peck; Hess, fig. 9a–k, fig. 10j–l, n–r only.
2019. *Euglyphocrinus pyramidalis* (Peck); Gale, p. 472, pl. 35, fig. 10; pl. 36, figs 10, 11.
2020. *Euglyphocrinus pyramidalis* (Peck); Gale, p. 22, pl. 9, figs 9, 15.

DIAGNOSIS: *Euglyphocrinus* in which the conical cup is composed of very coarse, irregularly perforate stereom; radial spines absent on aboral portion of cup.

TYPES: The cup figured by Peck (1943, pl. 72, fig. 24) is holotype. The specimen came from the Duck Creek Formation, upper Albian, H. Tappan Loeblich locality 13, sample 114, from the west bank of the Red River at Horseshoe Bend, Love County, Oklahoma, probably from the lower part of the formation. University of Missouri collections; not found, presumed lost.

MATERIAL: Several hundred cups and brachials, from the Duck Creek to Weno formations of northern Texas and southern Oklahoma. Peck's unfigured paratypes (USNM 128338) include three cups from the Duck Creek Formation, near to the Texas Christian University, Fort Worth, Tarrant County, Texas, and eight cups (USNM 128339) from the Weno Formation of Concord, Johnson County, Texas.

DESCRIPTION: The cups (Pl. 5, Figs 4–12; Pl. 6, Figs 1, 2) are, not including the interradial processes, as tall as broad. They are constructed of coarsely reticulate stereom and the aboral termination is either convex (Pl. 6, Figs 1, 2) or flat (e.g., Pl. 5, fig. 12). Radial ridges are variably well defined, and bear spines or branching processes, the morphology of which is used to define stratigraphically restricted formae (see below). The radial facets are triangular, and large, deep aboral ligament pits are present. The interradial processes, when entire (e.g., Pl. 9, Fig. 5) are tall and expand adorally. Specimens with broken aboral regions display the interior of the basal cavity and house spherical sub-basal balls, positioned radially. IBr1 (Pl. 7, Figs 17, 18; see also Hess 2015, fig. 10k, l, n–q) are approximately twice as tall as broad, and the external surface is smooth and rounded. Both proximal and distal ends are slightly expanded and the lateral margins bear a short, thin flange in the inner margin. The distal termination is a synarthrial articulation for IBr2, angled to the axis of the ossicle at approximately 35º. Axillary IBr2 (Pl. 7, Fig. 16) are poorly preserved, but are robust and triangular in lateral outline, and bear an oval, bifid, patch of smooth stereom on the proximal external surface. Distal brachials (Pl. 7, Figs 19, 20) are moderately elongated, smooth, and carry elongated spines at the proximal and distal margins.

REMARKS: *E. pyramidalis* differs from its descendant *E. cristagalli* in its possession of sub-basal balls and the morphology of the radial spines, which are concentrated immediately aboral to the radial facets.

OCCURRENCE: *Euglyphocrinus pyramidalis* is known exclusively from northern Texas and southern Oklahoma and occurs rather uncommonly in the lower part of the Duck Creek Formation, yet commonly in the upper part of that formation (Text-figs 9, 10).

*Euglyphocrinus pyramidalis* forma *pyramidalis* nov.
(Pl. 5, Figs 10–12; Pl. 6, Figs 1, 2)

DIAGNOSIS: *Euglyphocrinus pyramidalis* in which the radials carry irregularly developed, short, blunt lateral spines.

TYPE: The cup figured by Peck (1943, pl. 72, fig. 24) is the holotype. The specimen came from the Duck Creek Formation, upper Albian, H. Tappan Loeblich locality 13, sample 114, from the west bank of the Red River at Horseshoe Bend, Love County, Oklahoma, probably from the lower part of the formation.

MATERIAL: Fourteen cups from the lower Duck Creek Formation of Tarrant County, Texas, and Love and Bryant counties, Oklahoma.

DESCRIPTION: The median ridges on the radials of the type forma (Pl. 5, Figs 10–12; Pl. 6, Figs 1, 2) carry irregularly developed short, blunt or pointed processes, two to four in number, which are usually differently developed on individual radii. These extend from the radial facet to the aboral margin of the cup.

OCCURRENCE: This forma occurs in the lower part of the Duck Creek Formation, in Tarrant County, Texas, and in Love and Bryant counties, Oklahoma.

*Euglyphocrinus pyramidalis* forma *radix* nov.
(Pl. 5, Figs 7–9)

2015. *Roveacrinus pyramidalis* Peck; Hess, fig. 9e–k.

DIAGNOSIS: *Euglyphocrinus pyramidalis* in which the radials bear flattened, irregularly branching spines immediately aboral to the radial facets.

TYPES: The specimen figured by Hess (2015, fig. 9i), refigured here (Pl. 5, Fig. 7), is the holotype (NMB MI 1589).

MATERIAL: Approximately 50 cups from the upper Duck Creek Formation, at Saginaw Quarry, Tarrant County, and at Denton Creek, Denton County, Texas.

DERIVATION OF NAME: Latin *radix*, meaning root, in allusion to the form of the radial processes.

DESCRIPTION: The radials bear laterally or laterally-aborally directed, bluntly terminated, flattened processes, which may be single (e.g., Pl. 5, Fig. 9) or extend as a diverging cluster from a bladed process (Pl. 5, Figs 7, 8). These are highly variable in form, even within a single cup.

REMARKS: *Euglyphocrinus pyramidalis* forma *radix* nov. is distinguised from other forms of the species by the root-like, irregularly branching radial processes.

OCCURRENCE: This form occurs exclusively in the marly Upper Duck Creek Formation and is common in Denton Creek and at Saginaw Quarry (see above).

*Euglyphocrinus pyramidalis* forma *pentaspinus* nov.
(Pl. 5, Figs 4–6)

DIAGNOSIS: *Euglyphocrinus pyramidalis* in which the radials bear a single, robust, laterally directed spine.

TYPES: The specimen figured in Pl. 5, Figs 5, 6, from the lower Weno Formation of Creasote Road, Fort Worth, Tarrant County, Texas, is the holotype (NHMUK PI EE 17750). The other figured cup, from the upper Weno Formation of Carter Park, Fort Worth, Tarrant County, Texas, sample CP2 (Pl. 5, Fig. 4) is paratype (NHMUK PI EE 17751).

DERIVATION OF NAME: Latin *pentaspinus*, in reference to the five radial spines.

MATERIAL: Ten cups from the upper Albian Weno Formation of Tarrant County, Texas.

DESCRIPTION: The cups are conical and robust, and each radial carries a single, laterally directed spine, which arises immediately aboral to the radial process. The spines are cylindrical (Pl. 5, Fig. 4) or slightly laterally flattened (Pl. 5, Figs 5, 6), and a flange joins the aboral surface to the cup.

REMARKS: This forma differs from all others of the species in the presence of the sharply terminated, laterally directed radial spines.

OCCURRENCE: Forma *pentaspinus* nov. occurs rather uncommonly and sporadically in the Weno Formation and has been recorded from the Creosote Road and Carter Park sections.

Subfamily Plotocrininae Gale, 2019

DIAGNOSIS: Roveacrinids in which the external surfaces of the brachials bear regions of smooth imperforate stereom which form dish-shaped concavities or paired, divergent spines united by a narrow flange on the proximal brachials.

INCLUDED GENERA: *Poecilocrinus* Peck, 1943 and *Plotocrinus* Peck, 1943 and possibly *Peckicrinus* gen. nov.

REMARKS: The brachial structure in the two included genera is distinctive and consistently present in all species, even though cup morphology is more diverse. Material assigned to *Plotocrinus* has been described from the lower Albian of Bully, France (Destombes 1984), but this will shortly be described as a new genus. *Plotocrinus* is abundant in the middle Albian to low upper Albian of Texas and Oklahoma (Peck 1943). It gave rise to *Poecilocrinus*, possibly via the species *Plotocrinus modulatus* Peck, 1943, which developed short, bifid concave processes aboral to the radial facets on the cup. In the probable descendant, *P. spiculatus*, the process is enlarged and develops a concave aboral surface.

*Plotocrinus* Peck, 1943

DIAGNOSIS: Plotocrinines in which the conical cup bears short, laterally compressed radial processes.

TYPE SPECIES: *Plotocrinus hemisphericus* Peck, 1943, by original designation.

INCLUDED SPECIES: In addition to the type species, *Plotocrinus distinctus* Peck, 1943, *P. modulatus* Peck, 1943, *P. molineuxae* sp. nov., *P. primitivus* Peck, 1943, and *P. reidi* sp. nov.

REMARKS: *Plotocrinus* is the basal genus of the main lineage of roveacrinids, which leads to *Poecilocrinus*, *Roveacrinus* and *Drepanocrinus* (Gale 2019, 2020). These genera share many synapomorphies, including, importantly, the presence of distinctive, comb-like paired internal processes on the brachials. *Plotocrinus* first appeared near the base of the middle Albian, in Texas and France, and extends up into the upper Albian, where it disappeared in the middle part of the Duck Creek Formation. The species *P. monocarinatus* Destombes, 1984, from the lower and middle Albian of France, is morphologically distinct and belongs to a new genus which will be described in a future publication.

*Plotocrinus primitivus* Peck, 1943
(Pl. 8, Figs 1–8; Pl. 9, Figs 2–11, 13, 14; Pl. 10, Figs 9–16)

*1943. *Plotocrinus primitivus* Peck, p. 470, pl. 71, figs 6, 19–22.
1961. *Roveacrinus pyramidalis* Peck; Rasmussen, p. 371.
non 1961. *Roveacrinus* cf. *primitivus* Peck; Rasmussen, pl. 53, fig. 12.

DIAGNOSIS: *Plotocrinus* in which the cup is made up of very coarse reticulate stereom, of which the trabeculae are oriented ad-aborally; radial flanges bladed, bearing irregularly developed processes.

TYPES: The specimen figured by Peck (1943, pl. 71, fig. 3) from the Goodland Formation at H. Tappan Loeblich locality 169, sample 670, Marys Creek bank adjacent to the Weatherford road, Fort Worth, Tarrant County, Texas. University of Missouri collections, E-9-3; presumed lost.

MATERIAL: Over 150 cups and numerous brachials from the type locality; 10 cups from the middle Albian of Aube, France. Peck's unfigured paratypes (USNM 128360) include six cups from the Goodland Formation of Marys Creek, Tarrant County, Texas.

DESCRIPTION: Cup conical, approximately as tall as broad, aboral margin pointed, flat or convex. The external surface of the cup is made up of coarsely reticulate stereom, of which the trabeculae are elongated in an ad-aboral direction. The radials bear bladed median flanges, which form irregular triangular processes (Pl. 8, Figs 2, 5; Pl. 9, Figs 13, 14), or short, blunt spines (Pl. 8, Fig. 1). The flanges extend to the aboral pole. The radial facets are large, broad, and have a short articular ridge which separates the deep, oval aboral ligament pits and central canal. The muscle fossae are large and triangular. The interradial processes are elongated, diverge slightly from the cup's axis and have an external groove. Cups of smaller individuals (Pl. 8, Figs 7, 8) are relatively broad and low and lack radial processes. IBr1 (Pl. 9, Fig. 10) are slightly taller than broad and bear a slanted synarthrial articulation for IBr2. Some specimens carry symmetrical, paired, bladed processes (Pl. 10, Fig. 11). IBr2 are robust, triangular and bear either paired bladed processes (Pl. 10, Figs 13, 15) or blunt spines (Pl. 9, Fig. 9); well-preserved specimens show the presence of a median process and comb-like, paired, internal processes (Pl. 10, Figs 14, 15). IIBr 1 (Pl. 9, Fig. 13) are short, broad, and have large synarthrial articulation surfaces for IIBr2. IIBr2 (Pl. 9, Fig. 7) are triangular and carry a broad, muscular distal articulation for IIBr3. Distal brachials possess internally directed, paired internal processes (Pl. 10, Fig. 16), and paired, divergent spines (Pl. 9, Figs 4, 5), sometimes united by a concave, thin flange (Pl. 9, Fig. 11; Pl. 10, Fig. 16).

REMARKS: *Plotocrinus primitivus* differs from *P. rashallae* sp. nov. in the elongated trabeculae, the presence of radial processes and the absence of interradial concavities at the level of the aboral margins of the radial facets. It differs from *P. molineuxae* sp. nov. in the shape of the cup, the absence of raised interradial ridges and the elongated trabeculae.

OCCURRENCE: Goodland Limestone and Kiamichi formations, middle and lower upper Albian, northern Texas and Aube, France.

### *Plotocrinus rashallae* sp. nov.

(Pl. 8, Figs 9–12; Pl. 9, Fig. 12)

DIAGNOSIS: *Plotocrinus* in which the conical cup lacks radial processes; paired concavities present in each interradius immediately aboral to the radial facets.

TYPES: The specimen illustrated in Pl. 8, Figs 10, 11 is the holotype (NHMUK PI EE 17787). The specimen in Pl. 8, Fig. 9 is a paratype (NHMUK PI EE 17786), as are the cups figured in Pl. 9, Figs 1, 12 (NHMUK PI EE 17798, 17799), and Pl. 10 Fig. 9 (NHMUK PI EE 17806). Lower part of the Marys Creek Member of the Goodland Limestone, at Marys Creek, west of Fort Worth, Tarrant County, Texas.

DERIVATION OF NAME: For Jenny Rashall, PhD student at the University of Texas at Arlington, Texas, who helped considerably with the fieldwork.

MATERIAL: 9 cups from the lower part of the Marys Creek Member of the Goodland Limestone, at Marys Creek, west of Fort Worth, Tarrant County, Texas.

DESCRIPTION: Cup conical with convex aboral margin, lateral surface of radials made up of irregularly reticulate stereom with a flat surface. Radial processes poorly developed, consisting of short, blunt projections where present. Interradial regions embayed, with a double concavity present on the sides of the cup, immediately aboral to the radial facets. Interradial processes tall (Pl. 9, Fig. 1), grooved on the external margin and broadening adorally. Radial facets large, with deeply impressed aboral ligament pits and large, transversely oval central canal.

REMARKS: *Plotocrinus rashallae* sp. nov. differs from *P. primitivus* in the relatively smooth cup, which lacks radial flanges, and in the presence of paired interradial depressions.

OCCURRENCE: Lower part of Marys Creek Member of the Goodland Limestone, at Marys Creek, west of Fort Worth, Tarrant County, Texas. The species occurs also in the middle Albian *Anahoplites intermedius* Subzone of Aube, France.

### *Plotocrinus molineuxae* sp. nov.
(Pl. 10, Figs 1–8; Pl. 11, Figs 10–12)

DIAGNOSIS: *Plotocrinus* in which the cup is waisted; narrow interradial ridges present, mid-radial ridges poorly developed.

TYPES: The cup figured in Pl. 11, Fig. 11 is the holotype (NHMUK PI EE 17819). The other figured cups (Pl. 10, Figs 1–3; Pl. 11, Fig. 12) are paratypes (NHMUK PI EE 17800–17802, 17820). All are from the sample Ben1, Benbrook Limestone Member, Benbrook dam spillway, Tarrant County, Texas; middle Albian.

DERIVATION OF NAME: After the late Ann Molineux, curator of invertebrates at the Texas Memorial Museum, Austin, who did so much to encourage research on the Cretaceous fossils of Texas.

MATERIAL: 20 cups and over 100 brachials, from the type locality.

DESCRIPTION: Cups conical, approximately as broad as tall, aboral margin flat or gently convex, slightly waisted beneath radial facets (Pl. 11, Figs 10, 11). Cup surface composed of coarsely reticulate stereom; raised, narrow interradial ridges extend to the aboral pole (Pl. 11, Fig. 12). Mid-radial ridges variably developed, comprising a low flange of smooth stereom, which may bear irregular lateral processes. Radial facets broad, large, lateral margin rounded; articular ridge weakly developed, aboral ligament pit and central canal rounded, of moderate size. Interradial processes relatively low, broad based. Proximal brachials highly distinctive, found attached to cup (Pl. 10, Fig. 2) and in an articulated group (Pl. 11, Fig. 3). IBr1 is trapezoidal, with two lateral wings, external face biconcave, bearing a central process (Pl. 10, Figs 3, 7, 8). IIBr2 rectangular, distal articular region robust, external face concave, bearing a median ridge. IBr2 low, broad, with distal synarthrial facet.

REMARKS: The cup of *P. molineuxae* sp. nov. differs from that of its congeners in its waisted form, the presence of well-developed interradial ridges and the poorly developed mid-radial processes. The proximal brachials, with concave external surfaces, are quite different from those of other species of the genus in which the brachials are known.

OCCURRENCE: The species occurs only in the marly interval of the Benbrook Member of the Goodland Limestone which is found approximately 20 m beneath the top of the formation, in Tarrant County, Texas. This level falls in the upper middle Albian.

### *Plotocrinus distinctus* Peck, 1943
(Pl. 11, Figs 4, 5, 7–9)

*1943. *Plotocrinus distinctus* Peck, p. 470, pl. 71, figs 1–3.
1961. *Roveacrinus distinctus* (Peck); Rasmussen, p. 369, pl. 54, figs 8, 9.
non 1971. *Roveacrinus distinctus* (Peck); Rasmussen, p. 289, pl. 1, fig. 4; pl. 3, figs 14–16.

DIAGNOSIS: *Plotocrinus* in which the radials carry broad, median flanges of imperforate stereom; the interradial sutures form thin, raised ridges.

TYPES: The cup figured by Peck (1943, pl. 72, fig. 13), from H. Tappan Loeblich locality 73, sample 317; upper Goodland Limestone, Cragin Knobs, west of Fort Worth, Tarrant County, Texas. University of Missouri collections E-12-3; presumed lost.

MATERIAL: Five cups from the type locality, M. Nestell Collection, from the upper Goodland Formation at Cragin Knobs, Fort Worth, Texas.

DESCRIPTION: Cup conical, slightly taller than broad, aboral margin rounded. Radials bear broad median flanges of smooth imperforate stereom, with rounded margins, which project adorally-laterally beneath the radial facets. Narrow, raised interradial ridges present, which may extend to the aboral pole (Pl. 11, Fig. 5) or terminate adoral to it (Pl. 11, Figs 4, 8). Lateral surfaces of radials composed of moderately coarse reticulate stereom. Radial facets broad, narrow; aboral ligament region bearing large, transversely oval, deep pit; central canal of similar size and shape. Muscle fossae tall, vertically oriented; interradial processes tall, diverging slightly from axis of cup. Brachials unknown.

REMARKS: *Plotocrinus distinctus* is morphologically intermediate between the older *P. molineuxae* sp. nov., from which it differs in the presence of broad, smooth radial flanges, and the younger *P.*

*reidi* sp. nov., which lacks the divergent adoral spur on the radial flanges, has a discrete region of very fine stereom aboral to the radial facets and deep pits on the muscle fossae.

OCCURRENCE: Uppermost Goodland Limestone, marly interval approximately 7 m beneath the top of the formation, Cragin Knobs, Fort Worth, Tarrant County, Texas. Upper Albian, *Dipoloceras cristatum* Zone.

*Plotocrinus reidi* sp. nov.
(Pl. 11, Figs 1–3, 6)

DIAGNOSIS: *Plotocrinus* in which the adoral portion of the radials is constructed of very fine labyrinthic stereom; paired, deep pits are present on the radial facets, at the base of the muscle fossae.

TYPES: The holotype (Pl. 11, Figs 1, 2) is USNM 128561, the paratypes are USNM 128361.2 and USNM 128361.3 (Pl. 11, Figs 3, 6). *Pervinquieria* (*Pervinquieria*) *pricei* Zone, upper Albian, Kiamichi Formation, slope and bank of Red River, north of Denison, Grayson County, Texas.

DERIVATION OF NAME: After Robert Reid III, of Fort Worth, Texas, an exceptional fossil collector.

MATERIAL: Three cups from the type locality, USNM collections.

DESCRIPTION: Cup conical, slightly taller than broad, radial cavity broad and deep (Pl. 11, Fig. 6). The triangular radial plates bear median flanges of even width, constructed of smooth, imperforate stereom, which extend from the radial facet to unite at the aboral pole of the cup (Pl. 11, Fig. 1). The adoral portion of the flange forms a short process. Interradial sutures sharp, but not raised; aboral part of the lateral surfaces of the radials is made of moderately coarse reticular stereom, the adoral part, adjacent to the radial facet, of very fine labyrinthic stereom. Interradial processes short, triangular, radial facet broad. Aboral ligament area narrow, with deep central pit; articular ridge transversely short, central canal rounded and large. Muscle fossae rounded, with paired deep depressions. Brachials unknown.

REMARKS: *Plotocrinus reidi* sp. nov. is close to *P. distinctus* from the Goodland Formation, but differs in the absence of raised interradial ridges, the very fine stereom forming the lateral, aboral surface of the radials, and the presence of deep pits adjacent to the muscle fossae on the radial facets.

OCCURRENCE: Upper Kiamichi Formation, upper Albian, of northern Texas.

*Plotocrinus hemisphericus* Peck, 1943
(Pl. 12, Figs 10–12; Pl. 13, Figs 1–13)

*1943. *Plotocrinus hemisphericus* Peck, p. 469, pl. 71, figs 4, 5, 7–15, 24.
1943. *Plotocrinus inornatus* Peck, p. 470, pl. 71, figs 6, 19–22.
pars 1961. *Plotocrinus hemisphericus* Peck; Rasmussen, p. 375, pl. 54 fig. 13 only.
1961. *Plotocrinus inornatus* Peck; Rasmussen, p. 376, pl. 54, figs 14, 15.

DIAGNOSIS: *Plotocrinus* in which the aboral margin of the cup is convex; interradial regions of cup inset, made of fine stereom; median portions of radials coarsely reticulate, bearing short, irregular flanges; interradial processes elongated.

TYPE: The cup figured by Peck (1943, pl. 71, figs 11, 14) from the Duck Creek Formation of H. Tappan Loeblich locality 35, roadcut near Texas University Campus, Fort Worth, Tarrant County, Texas. University of Missouri collections, E-10-2; presumed lost.

SYNONYM: *Plotocrinus inornatus* Peck, 1943.

MATERIAL: Approximately 50 cups and over 100 brachials from the lower Duck Creek Formation, Tarrant County, Texas, and Love and Bryan counties, Oklahoma. Peck's unfigured paratypes (USNM 128357) include seven cups from the lower Duck Creek Formation, road cut on east side of US Highway 77, just south of bridge across Red River, Cooke County, Texas.

DESCRIPTION: Cup slightly broader than tall (not including interradial processes), aboral margin convex. Central regions of radial lateral surfaces composed of coarse, irregularly reticulate stereom, coarser adorally, from which one to three short, narrow, bladed processes extend immediately aboral to the radial facets in some individuals (Pl. 13, Figs 6–8) which can extend to the aboral pole. Interradial regions of radials made up of fine, labyrinthic stereom; raised interradial seams variably developed. Radial facets very large, rounded (e.g., Pl. 12, Fig. 12), articular ridge weakly developed, aboral ligament pit large and deep. Central canal oval, large; muscle fossae concave, separated from interradial processes by groove. Interradial processes very tall, tapering adorally, bearing external deep groove. IBr1 (Pl. 13, Figs 13, 14) twice as tall as broad, proximal external surfaces bear irregularly developed short, vertically oriented flanges; distal surface with large, oval, synarthrial articulation for IBr2. IBr2 (Pl. 13, Figs 1, 2, 13) robust, triangular, with three symmetrically arranged flanges on external surface. Articulations for IIBr1 bear deep ligament pits. Median process robust, tall; comb-like internal processes present on well-preserved specimens. IIBr1 (Pl. 13, Figs 10, 17) short, flat, asymmetrical, interior surface ridged, exterior surface with synarthrial articulation surface. IIBr2 (Pl. 13, Fig. 9) robust, triangular, carrying external flange, distal surface is a muscular articulation for IIBr3. Possible distal brachials (Pl. 13, Figs 11, 12, 16; these may equally well belong to *Poecilocrinus pendulus*) bear divergent, bifid processes, conjoined by a flange.

REMARKS: *Plotocrinus hemisphericus* differs from the contemporaneous *P. modulatus* in the rounded aboral portion of the cup and the absence of complex radial processes aboral to the articular facets. However, some specimens have flat aboral surfaces, and the two species are closely related.

OCCURRENCE: Lower to middle part of the Duck Creek Formation, zones AlR6 and AlR7, upper Albian, in northern Texas (Cooke and Tarrant counties) and southern Oklahoma (Bryan and Love counties). It is the youngest species of *Plotocrinus* known.

### *Plotocrinus modulatus* Peck, 1943
(Pl. 12, Figs 1–6, 8, 9)

*1943. *Plotocrinus modulatus* Peck, p. 470, pl. 71, figs 16–18, 23.

non 1961. *Plotocrinus modulatus* Peck; Rasmussen, p. 376, pl. 54, figs 16, 17.

DIAGNOSIS: Cup with flat aboral margin, bearing five narrow radial ridges; adoral surfaces of radials carrying box-shaped lateral processes, on which a transversely arranged pair of deep cavities is present; interradial processes short.

TYPE: The cup figured by Peck (1943, pl. 71, figs 17, 18), H. Tappan Loeblich locality 57, sample 291; lower Duck Creek Formation, road cut on east side of US Highway 77, just south of bridge across Red River, Cooke County, Texas. University of Missouri collections, E-11-3; presumed lost.

MATERIAL: Only a single small cup was recovered during the present study, so description and illustration are based on unfigured paratypes in the Smithsonian collections (USNM 128358), from the same locality, and probably the same sample, as the holotype and figured paratypes.

DESCRIPTION: Cup rectangular to trapezoidal in lateral aspect, aboral margin flat; aboral to the radial facet each radial carries a box-shaped, rectangular process in which two deep, laterally adjacent cavities are present (Pl. 12, Figs 6, 9). In one specimen (Pl. 12, Fig. 3) a third, unpaired cavity is present. Lateral margins of processes broken, as is evident in aboral view (Pl. 12, Figs 5, 8); they may have extended significantly further laterally. Interradial regions of radials deeply inset, composed of fine stereom. Aboral surface of cup made of coarsely reticulate stereom, bearing five narrow, sharp median radial ridges, extending from the margin of the radial processes to the aboral pole. Radial facets large, aborally convex, adorally concave; articular ridge inconspicuous, aboral ligament pit large, transversely oval; central canal rounded, large, muscle fossae triangular. Interradial processes triangular, short. Small cup (Pl. 13, Figs 4, 5) conical in lateral view, interradial regions composed of fine stereom, radial processes small. Arms unknown.

REMARKS: *Plotocrinus modulatus* is similar to *P. hemisphericus* in the very large radial facets but differs in the flat aboral surface of the cup, the presence of box-shaped radial processes and the shorter interradial processes. However, some individuals of *P. hemisphericus* have flat bases (e.g., Pl. 13, Figs 6, 7), and the two species are closely related. *Plotocrinus modulatus* also shares features with *Poecilocrinus spiculatus* (Pl. 14, Figs 1–19), in which the aboral shelf of the radial process has extended laterally and become bifid. Paired concavities similar to those seen in *P. modulatus* are also present in *Po. spiculatus* (compare Pl. 12, Figs 3, 6, 9 with Pl. 14, Figs 16, 17, 19) and it appears likely that the latter evolved from the former.

OCCURRENCE: Uncommon, lower part of Duck Creek Formation, upper Albian (AlR6) in northern Texas (Cooke County) and southern Oklahoma (Love County).

### *Peckicrinus* gen. nov.

DIAGNOSIS: Plotocrinine in which the radial facet and region aboral to this are set within a concave, oval structure, separated from the adjacent radial by a deep groove. A bladed rib extends from the midline of the radial to the aboral pole.

TYPE SPECIES: *Poecilocrinus porcatus* Peck, 1943.

DERIVATION OF NAME: In honour of the pioneering work on the Cretaceous microcrinoids from Texas by the late Raymond E. Peck.

REMARKS: The cup structure of *Pe. porcatus* is quite unlike that of both *Plotocrinus* and *Poecilocrinus* in that the lateral surface of the radials forms an oval, concave structure which incorporates the radial facet and bears a transverse bar aboral to the facet. The aboral margin of the concave facet is joined to the aboral pole by a centrally placed bladed ridge.

#### *Peckicrinus porcatus* (Peck, 1943)
(Pl. 15, Figs 1–6)

*1943. *Poecilocrinus porcatus* Peck, p. 474, pl. 75, figs 3, 5, 9, 10, 13.
1961. *Plotocrinus porcatus* (Peck); Rasmussen, p. 377, pl. 54, fig. 18.

DIAGNOSIS: As for genus.

TYPE: The cup figured by Peck (1943, pl. 72, fig. 3), E-13-1, University of Missouri collections; presumed lost. H. Tappan Loeblich locality 77, sample 324. Stream bank adjacent to US Highway 77, and cutting on highway, 0.9 miles (1.4 km) south of the road bridge over the Red River, Cooke County, Texas. Although the horizon is described as ‘lower Fort Worth’, this locality (no longer accessible) was in the lower part of the Duck Creek Formation.

MATERIAL: Two cups from the lower Duck Creek Formation at Horseshoe Bend, Love County, Oklahoma. Peck’s unfigured paratypes (USNM 128349) include four cups from the type locality (above).

DESCRIPTION: Cup small, approximately 1 mm in maximum dimension, subconical to oblately spherical in lateral view. Each radial bears an oval, subtriangular, concave flange which extends from the base of the interradial processes to the aboral cup and incorporates the radial facet and a short transverse ridge aboral to the facet (Pl. 15, Figs 3, 6). The aboral margin of the flange is joined to the aboral pole by a bladed, median ridge. The flanges on individual radials are separated by deep interradial grooves. The interradial processes are elongated and diverge from the axis of the cup. The radial facets are transversely elongated, the aboral ligament pit is narrow and deep, and the central canal is large. Arms unknown.

OCCURRENCE: Uncommon in the lower Duck Creek Formation, upper Albian, Texas (Cooke County) and Oklahoma (Love County).

### *Poecilocrinus* Peck, 1943

TYPE SPECIES: *Poecilocrinus dispandus* Peck, 1943, by original designation.

DIAGNOSIS: Plotocrinines in which a shelf-like flange is present immediately aboral to each radial facet; the flanges fuse in fully-grown specimens to form a rounded to petaloid or circular rosette and aborally, an outer wall to the cup.

REMARKS: *Poecilocrinus* is a typical genus of the upper Albian and lower Cenomanian of Texas and Oklahoma, where it is locally extremely abundant, and one species (*Po. dispandus*) reaches a sufficiently large size (6 mm) that it can be collected in the field. Little new material of the genus has been figured since Peck’s 1943 paper, with the exception of *Po. latealatus* (Hess 2015) and Gale (2020), in which material of the species *Po. dispandus*, *Po. molestus* and *Po. signatus* were recorded and illustrated from the Agadir Basin, Morocco, and the ontogeny of *Po. dispandus* was described.

#### *Poecilocrinus spiculatus* Peck, 1943
(Pl. 14, Figs 1–19)

*1943. *Poecilocrinus spiculatus* Peck, p. 472, pl. 73, figs 6, 8, 13.
1961. *Poecilocrinus spiculatus* Peck; Rasmussen, p. 382, pl. 55, fig. 1.

DIAGNOSIS: *Poecilocrinus* in which the terminations of the radial processes are bifid and declined aborally.

TYPE: The cup figured by Peck (1943, pl. 73, fig. 6) from H. Tappan Loeblich locality 77, sample 324, Stream bank adjacent to US Highway 77, and cutting on highway, 0.9 miles (1.4 km) south of the road bridge over the Red River, Cooke County, Texas. Although the horizon is described as 'lower Fort Worth', this locality (no longer accessible) was in the lower part of the Duck Creek Formation. University of Missouri collections E-16-4; presumed lost.

MATERIAL: Two unfigured paratype cups (USNM 128350) from the type locality. Several hundred cups and brachials from the lower part of the Duck Creek Formation, Horseshoe Bend cut on the Red River, Love County, Oklahoma (Text-figs 4, 7).

DESCRIPTION: Cup of approximately equal breadth and height, rectangular in lateral aspect. Bifid, aborally concave processes develop aboral to radial facets, and are declined aboro-laterally. Transversely arranged pair of small concavities present between radial processes and radial facet. Ridge extending from base of radial process towards aboral pole, in some some cases develops a flange. Interradial regions depressed, formed of finely perforate stereom, interradial suture slightly raised. Radial facets broad, aboral ligament pits and central canals very large. Muscle fossae triangular, extending up sides of moderately tall interradial processes.

Smallest individuals, cup diameter of 0.7 mm, conical in lateral aspect, depressed interradial regions; radial ridges short, poorly developed (Pl. 14, Figs 1–4). Cups of diameter 0.7–1.0 mm develop short, aborally concave radial processes immediately aboral to radial facet (Pl. 14, Figs 7–10) and short median blades running from the base of the processes to aboral pole. Radial processes enlarge, becoming increasingly concave on aboral surface, strongly concave adorally, and lateral margins develop bifid lateral terminations. IBr1 (Pl. 16, Figs 11, 12) bears large, triangular, laterally deeply concave process adjacent to radial facet; IIBr2 (Pl. 15, Figs 7, 8, 10) rectangular-rhomboidal, broader than tall, external surface weakly concave. IIBr2 (Pl. 15, Fig. 9) also bears large, rounded, externally concave flange.

REMARKS: *Poecilocrinus spiculatus* differs from later species of the genus in the bifid, aborally declined form of the radial processes. It shares some features with the probable ancestral form, *Plotocrinus modulatus*, notably the flat base with radial ridges, and the presence of paired concavities aboral to the radial facets (see above).

OCCURRENCE: Lower part of the Duck Creek Formation, level of *Eopachydiscus marcianus*, upper Albian, Texas (Tarrant County) and southern Oklahoma (Bryan and Love counties).

*Poecilocrinus pendulus* Peck, 1943
(Pl. 16, Figs 1–17)

*1943. *Poecilocrinus pendulus* Peck, p. 474, pl. 75, figs 3, 5, 9, 10, 13.
1961. *Poecilocrinus pendulus* Peck; Rasmussen, p. 380, pl. 55, fig. 1.

DIAGNOSIS: *Poecilocrinus* in which the large, rounded, aborally concave radial processes are not fused, and form a flower-like margin to the cup in aboral view.

TYPE: Cup figured by Peck (1943, pl. 75, figs 5, 9, 10) from H. Tappan Loeblich locality 28, 'Lower Fort Worth Formation' (actually middle Duck Creek Formation, see above), north bank of Red River, east of US Highway 75, Bryan County, Oklahoma. University of Missouri collections E-20-3; presumed lost.

MATERIAL: Two unfigured paratype cups (USNM 128345) from the Duck Creek Formation of Krum, Denton County; 50 cups and numerous brachials from the middle part of the Duck Creek Formation, from the type locality in Bryan County, from Horseshoe Bend, Love County, Oklahoma, and from Saginaw Quarry, Fort Worth, Tarrant County, Texas.

DESCRIPTION: Cup petaloid in outline in aboral-adoral views, margin formed by paddle-shaped, aborally concave, rounded radial processes. These abut in fully-grown individuals (Pl. 16, Figs 16, 17) but do not fuse. Single, narrow mid-radial ridges extend internally from close to the aboral pole to the base of the concave flanges; these are poorly developed in large individuals. The adoral part of the cup is constructed of the radial facets and interradial processes (Pl. 16, Figs 16, 17), separated from the radial flanges by a low, transverse recess, which comprises two concavities in some individuals. The radial facets are separated by concave interradial regions and large and a sharp, narrow articular ridge is present. The aboral ligament pit is rounded, and the central canal is very large. The interradial processes are tall, but not completely preserved in any specimens that I have seen. The smallest cups (diameter of 0.65 mm; Pl. 16, Figs 1, 2) are conical with a flat aboral margin; at a diameter of 0.9 mm, short, V-shaped radial processes are present (Pl. 16, Figs 3, 4). These enlarge and develop an adoral flange which progressively broadens and the lateral margin becomes rounded. IBr1 (Pl. 15, Figs 16, 17) is triangular to rectangular in outline and carries a small, concave cup on the aboral external surface. IBr2 (Pl. 15, Figs 13, 14) is pentagonal in outline and the external surface is concave. Type B IBr2 (Pl. 15, Fig. 15) is triangular in lateral outline, concave and possesses a robust median process.

REMARKS: *Poecilocrinus pendulus* is distinguished from the earlier *Po. spiculatus* in its possession of rounded, subrectangular, aborally concave radial processes which have an entire margin; these are bifid in the latter species. It differs from small individuals of the later *Po. latealatus* (e.g., Pl. 17, Figs 15–18) in the complete absence of a median ridge extending onto the aboral surface of the radial processes. It should be noted that *Po. latealatus*, *Po. dispandus* and *Po. signatus* all pass through a developmental stage which closely resembles *Po. pendulus*; they can be distinguished only by reference to fully-grown individuals in the same sample.

OCCURRENCE: *Poecilocrinus pendulus* is restricted to a level in the middle part of the Duck Creek Formation, 6–12 m in thickness (Text-figs 7, 9) and defines zone AlR6. It occurs in Texas (Tarrant and Cooke counties) and Oklahoma (Bryan and Love counties).

### *Poecilocrinus latealatus* (Peck, 1943)

(Pl. 17, Figs 1–22; Pl. 18, Figs 1–27)

*1943. *Roveacrinus latealatus* Peck, p. 468, pl. 73, figs 9–12; pl. 76, fig. 1.

1961. *Poecilocrinus latealatus* (Peck); Rasmussen, p. 380, pl. 55, fig. 4.

2015. *Poecilocrinus latealatus* (Peck); Hess, p. 18, figs 4–8.

DIAGNOSIS: *Poecilocrinus* in which the broad radial flange is conjoined to the aboral cup by narrow ridges, which extend onto the inner part of the flat or concave aboral surfaces.

TYPE: The cup figured by Peck (1943, pl. 73, fig. 14) is the holotype, H. Tappan Loeblich locality 39, sample 225; Fort Worth Formation near Krum, Denton County, Texas. University of Missouri collections E-17-3; presumed lost.

MATERIAL: Six unfigured paratype cups (USNM 128340) from the type locality; several hundred cups and brachials from the upper Duck Creek Formation at Saginaw Quarry, Tarrant County, and Denton Creek, Denton County.

DESCRIPTION: Cup almost circular to rounded, pentagonal, stellate in aboral/adoral aspect; radial flanges broad, thin, horizontal, smooth, fused to form circlet around central region of cup. Lateral margin of flanges smooth, rarely denticulate (Pl. 18, Fig. 4). Aboral part of cup made up of low, convex central region and five robust radial ribs which extend towards aboral pole, and laterally onto inner portion of marginal flange. Marginal flange separated from radial facets by low concavity; interradial regions of radials deeply inset. Radial facets large, broad, aboral ligament pit and central canal large, of equal size and similar shape. Interradial processes very tall, diverge adorally from cup axis. Smallest individuals (Pl. 17, Figs 8, 9, 12, 13; 0.6 mm diameter) conical with flat base, showing tumid basals surrounding small inset centrale. Lateral radial processes develop at cup diameter of 1 mm (Pl. 17, Fig. 14), comprising small, bluntly terminated flanges joined to aboral cup by single median ridge. These progressively enlarge and broaden (Pl. 17, Figs 15–18) to form paddle-shaped projections, which eventually abut (Pl. 17, Figs 19, 20) and then fuse (Pl. 17, Figs 21, 22). There are numerous variations in the form of the cup, some probably pathological, including double development of the radial flange (Pl. 17, Fig. 1) and irregular flanges and processes on the aboral surface (Pl. 17, Fig. 2). IBr1 (Pl. 18, figs 13–16) taller than broad, bears a rounded to oval, concave cup close to the aboral margin, and a distal synarthrial facet for articulation with IBr2. IBr2 (Pl. 18, Figs 7, 8) is rounded rectangular, with deeply concave external surface and smaller, interior articular region. Concavity displays an aboral-adoral narrow ridge, paralleling development on the radial flanges. Proximal secundibrachials (Pl. 18, Figs 9–11, 17) also bear cup-shaped external processes, which elongate on more distal brachials (Pl. 18, Figs 18, 22, 23); distal secundibrachials bear a sharply terminated spine (Pl. 18, Figs 19, 20, 24). Some short distal brachials have synostosial articulations (Pl. 18, Fig. 26).

REMARKS: The morphology of this species was described in considerable detail by Hess (2015) and is therefore only outlined here. *Poecilocrinus latealatus* differs from *Po. pendulus*, its probable ancestor, in the development of a rounded, pentagonal horizontal marginal flange formed by fusion of the radial processes, aborally flattened. It differs from the probable descendant, *Po. dispandus*, in the presence of five mid-radial ridges which extend from the aboral pole onto the inner portions of the radial flanges.

OCCURRENCE: *Poecilocrinus latealatus* is restricted to the upper Duck Creek and lower Fort Worth formations in Texas and Oklahoma, where it serves to define the upper Albian AlR8 zone.

*Poecilocrinus dispandus* Peck, 1943
(Pls 19–25; Pl. 26, Figs 7–12; Text-figs 14F–I, 15A–H)

*1943. *Poecilocrinus dispandus* Peck, p. 471, pl. 75, figs 1, 2, 6, 8, 12.
1961. *Poecilocrinus dispandus* Peck; Rasmussen, p. 378, pl. 55, fig. 7.
1977. *Poecilocrinus dispandus* Peck; Scott *et al*., p. 346, pls 1, 2.

DIAGNOSIS: *Poecilocrinus* in which a broad, horizontally oriented, fused flange is present aboral to the radial facets, which has a circular to petaloid margin and lacks aboral ribs. The aboral process of the cup bears five, interradially positioned notches.

TYPE: The specimen from the Upper Fort Worth Limestone (upper Albian, probably *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone) of Fort Worth, Tarrant County, Texas, H. Tappan Loeblich locality 43, sample 145, figured by Peck (1943, pl. 75, fig. 2) is the holotype. University of Missouri collections (E-19-5); presumed lost.

MATERIAL: Five unfigured paratypes (USNM 128344); numerous specimens (several hundred) cups and brachials from the upper Fort Worth, Denton, Weno, Pawpaw and Main Street formations of Texas.

DESCRIPTION: Cup circular to rounded pentagonal in aboral-adoral views; a broad, smooth flange of fused radial processes makes up 2/3 of diameter. In aboral and lateral aspects, the cup has a convex process comprising five short radial ridges, separated by triangular concavities. The ridges fuse at the aboral pole, and the convex base of the cup is visible in the intervening depressions (Pl. 21, Figs 4, 5; Pl. 23, Fig. 10). There are numerous morphological variations, including those in which the aboral process is tall (forma *elongatus*), those in which the radials separate in the fully-grown cup (forma *floriformis* nov.) and those with strongly concave aboral radial surfaces (forma *explicatus* Peck, 1943). Many of these formae have stratigraphical value and are described below.

ONTOGENY: The ontogeny of *Po. dispandus* is shown (Pl. 19, Figs 3–10); the smallest cups found (0.6–0.7 mm in diameter; Pl. 19, Figs 3, 4) are small and conical in form, with a flat base which is made up of pentagonal basals surrounding a small centrale. By a diameter of 1 mm, aborally concave flanges develop on the radials (Pl. 19, Figs 6, 7), which expand laterally and become paddle-shaped (Pl. 19, Fig. 8). The flanges eventually fuse to form a petaloid to subcircular, shelf-like margin to the cup (Pl. 19, Figs 9, 10). In individuals in which the aboral portion of the cup is elongated, the flanges extend aborally and form a secondary outer wall to the cup, best seen in individuals which have broken longitudinally (Pl. 19, Fig. 1). The interradial cavities formed between the cup and the outer wall open on the aboral pole of the cup (Pl. 19, Figs 9, 10) between the short radial ridges.

ARMS: Part of the articulated material of *Po. dispandus* from the Weno Formation of Fort Worth figured by Scott *et al.* (1977) is re-illustrated here (Pl. 20, Figs 1, 8). However, it must be pointed out that the distal arm fragment with large pinnules they illustrated (Scott *et al.* 1977, pl. 1, fig. 5) does not belong to a roveacrinid, but is probably from a comatulid crinoid. Secondly, the very thin arm illustrated in their pl. 1, fig. 3 is certainly regenerated and not indicative of narrowing of all arms in the lower IIBr (see Pl. 20, Fig 8, marked sa); their reconstruction (Scott *et al.* 1977, text-fig. 2B; reused also by Hess and Messing 2011 and Hess 2015, fig. 15) is therefore not accurate. What the well-preserved arms actually show (Pl. 20, Fig. 1) is that the distal arms were long and slowly tapering and were made up of brachials bearing a short, distally directed blade (Pl. 20, Figs 9, 10) and elongated internal processes. Examination of the isolated brachials shows that they lacked pinnules entirely. A cup, with brachials up to IIBr2 (Pl. 25, Figs 5–7) preserved shows the form of the proximal arms. IBr1 (Pl. 20, Fig. 7; Pl. 21, fig. 7) are twice as tall as broad, and carry an elongated, oval, synarthrial articulation for IBr2. They lack the cup-shaped process on the external proximal margin present on *Po. spiculatus*, *Po. pendulus* and *Po. latealatus* and are not visible externally on the articulated cup (Pl. 25, figs 5, 7) as they are covered entirely by IBr2. Type A IBr2 (Pl. 20, Figs 4–6; Pl. 25, Figs 5–7, 12) are trapezoidal in outline, broader distally, and the external surface is concave and smooth. When exceptionally preserved (Text-fig. 15E–H) the interior surface is seen to bear distally directed, comb-like internal processes, thin, divergent lateral processes and a median process. Type B IBr2 (Pl. 21, Figs 8, 9; Text-fig. 15C) are triangular and the external face is concave; median and internal processes are well developed. IIBr1 (Pl. 21, Figs 8, 9; Text-fig. 15E–H) are similar in form to IBr1, but are slightly asymmetrical, and the inner surface bears divergent grooves. The distal face is a sloping synarthrial articulation for IIBr2. IIBr2 (Pl. 25, Figs 5–7; Text-fig. 15A, B) are oval in outline and the outer surface is deeply concave; on the articulated cup, they completely cover IIBr1. The interior of IIBr2 (Text-fig. 14B) bears tall internal processes. IIBr3 is short and the distal surface is synostosial (Text-fig. 15A). IIBr distal to this include those (Pl. 20, Figs 2, 3) which bear asymmetrical, concave, spatulate lateral processes and inwardly directed comb-like internal processes. The distal brachials, which make up most of the arms (Pl. 20, Fig. 1) carry a distally flexed spur, of which the proximal margin is bladed (Pl. 20, Figs 9, 10). The internal processes have toothed margins.

REMARKS: *Poecilocrinus dispandus* differs from *Po. latealatus*, *Po. molestus* and *Po. signatus* in the absence of an extension of the mid-radial ridges onto the radial flange, and the presence of interradial cavities on the central part of the aboral cup.

OCCURRENCE: *Poecilocrinus dispandus* first occurs in the upper part of the Fort Worth Formation, where is succeeds *Po. latealatus,* and is common to abundant up to the top of the Main Street Formation in northern Texas. It also occurs in the upper Albian of the Agadir Basin, Morocco (Gale 2020). Scott *et al.* (1977) discussed Peck's varieties of *Po. dispandus*, and suggested that more material and future refinement of their stratigraphical distribution might justify their elevation to species rank. Here, they are treated as formae.

*Poecilocrinus dispandus* forma *discus* nov.
(Pl. 19, Figs 2–10; Pl. 21, Figs 1–11; Pl. 22, Figs 1–6; Pl. 23, Figs 7–10; Pl. 25, Figs 3–7)

DIAGNOSIS: *Poecilocrinus dispandus* in which the margin of the cup is rounded-pentagonal in outline to nearly circular.

TYPES: The cup figured in Pl. 20, Fig. 1 is the holotype (NHMUK PI EE 17895). The other figured cups from the lower Weno Formation (Pl. 21, Figs 1–10) are paratypes (NHMUK PI EE 17896–17902).

DERIVATION OF NAME: Latin *discus*, in allusion to the rounded, flattened shape of the cup.

MATERIAL: Several hundred cups from the lower Weno Formation of Tarrant County, Texas.

DESCRIPTION: Cup rounded pentagonal to circular in aboral/adoral outline; both surfaces of the radial flange are smooth, and the sutures between the fused radials are visible in many specimens. The aboral surface of the flange is concave at its inner margin (Pl. 21) and the external part is flat.

OCCURRENCE: *Poecilocrinus dispandus* forma *discus* nov. occurs throughout the range of the species, and in the upper Fort Worth, Denton and lower Weno formations is the only forma present; it is rare in the Pawpaw and Main Street formations. In the lower 5 m of the Weno Formation it occurs in flood abundance, and cups with a diameter of up to 4 mm in diameter litter outcrops of the clays.

*Poecilocrinus dispandus* forma *floriformis* nov.
(Pl. 23, Figs 1–5; Pl. 24, Figs 1–11; Pl. 25, Figs 1, 2)

DIAGNOSIS: *Poecilocrinus dispandus* in which the radial flanges are separate in the fully-grown cups; these are highly variable in form, from triangular, leaf shaped, oval to spearhead-shaped.

TYPES: The specimen figured in Pl. 23, Figs 3–5 is the holotype (NHMUK PI EE 17916). Upper Weno Formation, sample SA2, Salvation Army site, Seminary Drive, Fort Worth, Texas. Other cups from the same sample are paratypes (Pl. 23, Figs 1, 2; Pl. 24, Figs 1–11, NHMUK PI EE 17916, 17924–17929).

DERIVATION OF NAME: Latin *floriformis*, meaning flower-like.

MATERIAL: Approximately 35 cups from the uppermost Weno, Pawpaw and Main Street formations, Tarrant County, Texas.

DESCRIPTION: Outline of fully-grown cups stellate, radial flanges widely separated or rarely in partial contact. The shape of the flanges is highly variable, from short, rounded-triangular (Pl. 23, Figs 1, 2) to trifoliate (Pl. 23, Figs 3–5; Pl. 24, Fig. 5) and spearhead-shaped (Pl. 24, Figs 1–3, 8–11). In some, the aboral surfaces of the processes are concave (Pl. 23, Figs 3–5; Pl. 24, Figs 1–3, 8), but in others, a median rib extends across the internal part of the process (Pl. 24, Figs 4, 6, 11); there is considerable variation in the development of the ribs, and they may be present in only one radius (Pl. 24, Fig. 9). The aboral surface of the radial processes is flat to gently concave.

REMARKS: In spite of the greatly varied morphology of the radial processes, this forma retains the diagnostic characters of *Po. dispandus*, specifically, radial ridges running from the aboral pole to the radial flanges, separated by concavities in which the base of the cup is visible. Individuals in which one to five median ribs are present on the concave aboral surface of elongated radial flanges (e.g., Pl. 24, Figs 5, 6, 9, 11) are transitional to *Roveacrinus proteus* sp. nov. (see below) and forma *floriformis* nov. represents an intermediate morphology between the genera *Poecilocrinus* and *Roveacrinus*. Assignation of some specimens to either of the two genera is difficult. This transition can be interpreted as paedomorphic evolution, because the descendant *Roveacrinus* closely resemble juveniles of species of *Poecilocrinus*. A juvenile *Po. latealatus* is illustrated in Pl. 29, Fig. 4, to compare with fully-grown *Roveacrinus proteus* sp. nov.

OCCURRENCE: *Poecilocrinus dispandus* forma *floriformis* nov. first occurs in the uppermost 1 m of the Weno Formation, where it represents approximately 10% of individuals of the species. It is present, but not common, in the overlying Pawpaw and Main Street formations.

*Poecilocrinus dispandus* forma *elongatus* Peck, 1943
(Pl. 22, Figs 7–11; Pl. 23, Figs 11, 12)

*1943. *Poecilocrinus dispandus* var. *elongatus* Peck, p. 471, pl. 75, fig. 7.
1961. *Poecilocrinus dispandus elongatus* Peck; Rasmussen, p. 379, pl. 55, fig. 9.
2020. *Poecilocrinus dispandus* forma *elongatus* Peck; Gale, p. 32, pl. 21, figs 10, 11.

DIAGNOSIS: *Poecilocrinus dispandus* in which the aboral portion of the cup, beneath the radial flange, forms an elongated process, terminated aborally by five short radial ridges.

TYPE: The specimen figured by Peck (1943, pl. 75, fig. 7) is the holotype. H. Tappan Loeblich locality 46, upper Weno Formation, Burleson Highway, Fort Worth, Tarrant County, Texas. University of Missouri collections (E-21-1); presumed lost.

MATERIAL: Six unfigured paratype cups (USNM 128347) from the type locality; numerous cups from the upper Weno Formation, upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, Salvation Army locality, Seminary Drive, Fort Worth, and road cutting in Cleburne, Johnson County, Texas.

DESCRIPTION: The portion of the cup aboral to the radial flanges forms an elongated, parallel-sided to conical process, such that cups are approximately as tall as broad. Narrow, short, mid-radial ribs are present aborally and these converge on the aboral pole where they may conjoin (e.g., Pl. 22, Figs 7, 10, 11) to form a rounded aboral margin, or are drawn out into a sharp, conical process (Pl. 23, Fig. 11).

REMARKS: *Poecilocrinus dispandus* forma *elongatus* is an extreme end-member of continuous variation in the length of the aboral part of the cup, but is found only in the upper part of the Weno Formation.

OCCURRENCE: *Poecilocrinus dispandus* forma *elongatus* is common to abundant in the upper part of the Weno Formation and does not occur beneath this level. This form also occurs, more uncommonly, in the Pawpaw and Main Street formations, all upper Albian *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone. It is common in Tarrant County, Texas, and occurs in the lower Aït Lamine Formation of the Agadir Basin, Morocco (Gale 2020, pl. 21, fig. 11).

*Poecilocrinus dispandus* forma *explicatus* Peck, 1943
(Pl. 26, Figs 7–11)

*1943. *Poecilocrinus dispandus* var. *explicatus* Peck, p. 472, pl. 75, figs 11, 14.
1961. *Poecilocrinus dispandus explicatus* Peck; Rasmussen, p. 379, pl. 55, fig. 8.
2020. *Poecilocrinus dispandus* forma *explicatus* Peck; Gale, p. 33, pl. 21, figs 1–6.

DIAGNOSIS: *Poecilocrinus dispandus* in which the aboral portion of the cup is conical; radial flanges strongly concave with a central depression.

TYPE: The specimen figured by Peck (1943, pl. 75, figs 11, 14) from the Main Street Limestone, locality 55 of H. Tappan Loeblich, southeast of Fort Worth, Tarrant County, Texas. University of Missouri collections (no. 1012); not found, presumed lost.

MATERIAL: Three unfigured paratype cups (USNM 128348); fifteen cups from the lower part of the Main Street Limestone, Sunset Oaks Drive, Tarrant County, Texas.

DESCRIPTION: Aboral outline of cup rounded-pentagonal, conical in lateral view with rounded aboral margin. The aboral surface of the radial flanges is evenly concave and has a small, centrally positioned depression.

REMARKS: There is every transition between *Po. dispandus* forma *explicatus* and typical *Po. dispandus.*

OCCURRENCE: Collecting in Texas has demonstrated that this forma is restricted to the lower part of the Main Street Limestone Formation, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone. It occurs in northern Texas and the Agadir Basin, Morocco.

*Poecilocrinus molestus* Peck, 1943
(Pl. 26, Figs 1–6)

*1943. *Poecilocrinus dispandus molestus* Peck, p. 472, pl. 75, fig. 4.
1961. *Poecilocrinus dispandus molestus* Peck; Rasmussen, p. 379, pl. 55, fig. 10.
2020. *Poecilocrinus molestus* Peck; Gale, p. 34, pl. 22, figs 1–6.

DIAGNOSIS: *Poecilocrinus* in which the upper parts of the radial flanges are concave and triangular and bear a short, central strut; the aboral portions of the radial flanges form broad ribs which extend to the aboral pole.

TYPES: Cup figured by Peck (1943, pl. 75, fig. 4), Main Street Limestone, overpass of Santa Fé railroad over Belton-Temple Highway, Bell County, Texas. University of Missouri collections (E-20-5); presumed lost.

MATERIAL: 15 cups from the upper part of the Main Street Limestone, Sunset Oaks Drive (samples SA3, SA4).

DESCRIPTION: Cup margin in aboral/adoral aspect pentagonal, stellate, with rounded or pointed radial flanges. Cups variable in lateral aspect, low and conical (Pl. 26, Figs 2, 6) in some specimens, taller and aborally broader in others (Pl. 26, Figs 4, 5; Peck 1943, pl. 75, fig. 4). Mid-radial ridges extend adorally from the aboral pole and are laterally displaced (Pl. 26, Fig. 1) or interrupted (Pl. 26, Figs 4, 5) at the base of the concave radial flanges (see also Gale 2019, pl. 22, figs 4, 5). The aboral surface of the cup is made up of coarse radial ridges, separated by concavities in some individuals (Pl. 26, Figs 4, 5); in others, the perforate surface of the inner cup is visible (Pl. 26, Figs 1, 6). The radial facets are narrow and separated by depressed interradial regions.

REMARKS: *Poecilocrinus molestus* is morphologically transitional between *Po. dispandus* and *Po. signatus*, in the incipient development of mid-radial ribs which extend adorally onto the radial flange and are interrupted at the base of the flange. These are absent in *Po. dispandus* from the Main Street Formation (uppermost Albian); in the later *Po. signatus* from the overlying Grayson Formation (Cenomanian), the ribs extend as uninterrupted flanges from the aboral pole onto the concave radial flanges (Pl. 27, Figs 7–12). The species has a short, but discrete range in the uppermost Albian in Texas and North Africa (Gale 2020).

OCCURRENCE: Peck (1943) had a single specimen of this species, now lost, but new collecting has shown that it is restricted to and common in the uppermost part (1 m) of the Main Street Limestone in Tarrant County, Texas (Text-fig. 12) and in the uppermost Albian in the Agadir Basin, Morocco (Gale 2020).

*Poecilocrinus signatus* (Peck, 1943)
(Pl. 27, Figs 1–20)

*1943. *Roveacrinus signatus* Peck, p. 466, pl. 74, figs 1–5, 11–14.
1961. *Poecilocrinus signatus* (Peck); Rasmussen, p. 381, pl. 55, figs 2, 3.
pars 2015. *Roveacrinus alatus* Douglas; Hess, fig. 14d, t only.
2020. *Poecilocrinus signatus* (Peck); Gale, p. 34, pl. 22, figs 7–12.

DIAGNOSIS: *Poecilocrinus* in which a narrow, sharp-edged radial ridge extends from the aboral pole, along the mid-line of each radial plate, terminating within the concave aboral surface of the flanged radial extensions.

TYPE: The specimen figured by Peck (1943, pl. 74, figs 3, 5, 14), from the lower Cenomanian Grayson Formation of Grayson Bluff, Roanoke, Denton County, Texas (H. Tappan Loeblich locality HTL1), is the holotype. University of Missouri collections (E-18-1); not found, presumed lost.

MATERIAL: Nine unfigured paratype cups in the Smithsonian collections (USNM 128337) from the Grayson Formation on Village Creek, Everman, Tarrant County, Texas; several hundred cups from the Grayson Formation of Tarrant, Denton, Grayson and McLennan counties, Texas.

DESCRIPTION: Fully-grown cups are pentagonal, slightly stellate, with convex margins to the radial processes in aboral/adoral aspect (Pl. 27, Fig. 12). In lateral view, they are conical, the aboral margin is convex, and the radial flanges are narrow. Five narrow mid-radial ribs, of constant breadth, coalesce at the aboral pole and extend adorally to the concave surfaces of the radial flanges. The aboral surface of the cup, between the ribs, is evenly convex and perforated by irregularly sized pores. The radial facets are narrow and relatively small, and interradial cavities extend adorally between them. The central canals and aboral ligament pits are small and round, and the interradial processes short and slightly divergent from the cup's axis. The smallest cups are 1 mm in diameter (Pl. 27, Fig. 1, 2) and these carry a simple, vertically oriented mid-radial ridge, the adoral portion of which expands laterally to form the radial flanges (Pl. 27, Figs 3–6). The paddle-shaped radial flanges broaden with increasing cup size and coalesce in the largest individuals (Pl. 27, Fig. 12). IBr1 (Pl. 27, Fig. 18) is twice as tall as broad, rectangular, and distally carry a sloping synarthrial articulation for IBr2. Type A IBr2 (Pl. 27, Figs 14, 15) is rounded trapezoidal in outline and the external surface is concave bearing a centrally placed group of fine rugosities. Type B IBr2 (Pl. 27, Fig. 20) is triangular, robust, and the external surface is concave. A tall median process is present, and the centre of the external face is also finely rugose. IIBr1 (Pl. 27, Fig. 19) are flattened and slightly asymmetrical and have a distal synarthrial articulation for IIBr2. Proximal secundibrachials, of unknown exact position (Pl. 27, Fig. 17), bear an aborally concave cup.

REMARKS: The species is distinguished from its probable ancestor, *Po. molestus*, by the presence of a strong, narrow ridge which extends, unbroken and of even width, from the aboral pole to the aboral edge of the radial flange (Pl. 27, Figs 7–12). In *Po. molestus*, the ridge is interrupted by a lateral growth from the flange (Pl. 26, Figs 1–6). This small morphological difference is quite consistent.

OCCURRENCE: Grayson Formation of Tarrant, Denton, Grayson and McLennan counties, Texas, and the Aït Lamine Formation, Agadir Basin, Morocco. *Poecilocrinus signatus* appears at the base of the lower Cenomanian *Graysonites adkinsi* Zone, together with *Euglyphocrinus euglypheus* and together these species characterise zone CeR1.

Subfamily Roveacrininae Peck, 1943

DIAGNOSIS: Roveacrinidae in which the radial cavity is floored by solid basals; the primibrachials IBr2 and IIBr2 are flat and proportionately low and broad.

INCLUDED GENERA: *Roveacrinus* Douglas, 1908; *Drepanocrinus* Jækel, 1918; *Caveacrinus* Gale, 2019 and *Dentatocrinus* Gale, 2019.

*Roveacrinus* Douglas, 1908

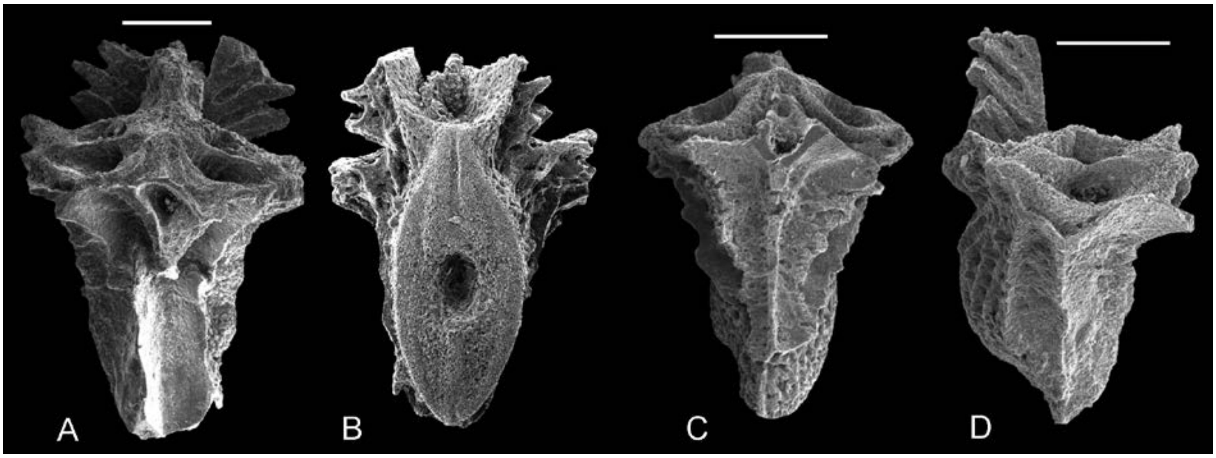
DIAGNOSIS: Roveacrininae characterised by delicately constructed, adorally broad cups which bear elongated, aborally flanged, alar extensions from each lateral radial margin and possess a globular basal cavity clearly visible on the exterior of the cup. IBr2 and IIBr1 triangular, possess lateral spines and flanges. Basals completely internal.

REMARKS: In the present paper, *Roveacrinus* is shown to have evolved from *Poecilocrinus* in the upper Albian *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone, probably by retention of a stellate juvenile morphology into the adult form. *Roveacrinus* became a dominant genus in the Cenomanian and continued to the mid-Coniacan (Gale 2019).

*Roveacrinus spinosus* Peck, 1943
(Pl. 31, Figs 1–16; Text-fig. 16A–D)

*part 1943. *Roveacrinus spinosus* Peck, p. 467, pl. 74, figs 6, 9 only; pl. 76, figs 37, 39.
1943. *Roveacrinus spinalatus* Peck, p. 467, pl. 74, figs 8, 10.
1961. *Roveacrinus spinosus* Peck; Rasmussen, p. 373, pl. 54, figs 5, 6.
1961. *Roveacrinus spinalatus* Peck; Rasmussen, p. 373, pl. 54, fig. 7.
pars 2015. *Roveacrinus spinosus* Peck; Hess, fig. 14e–s only.
pars 2015. *Roveacrinus alatus* Douglas; Hess, fig. 14d only.
2019. *Roveacrinus spinosus* Peck; Gale, p. 440, pl. 7, figs 5–7.
2020. *Roveacrinus spinosus* Peck; Gale, p. 25, pl. 11, figs 7–16.

DIAGNOSIS: *Roveacrinus* bearing elongated radial spines, the robust adoral margins of which are declined at approximately 50–60º to the axis of the cup. A thin flange extends from the aboral margin of




Text-fig. 16. Proximal brachials of *Roveacrinus spinosus* Peck, 1943. A, B – external and internal views of IBr2 which retains bases of comb-like internal processes (NHMUK PI EE 17716). C – IBr2, to show usual preservation (NHMUK PI EE 17717). D – IIBr2 with internal process and broad distal muscular articulation (NHMUK PI EE 17718). All are from the lower Cenomanian, Grayson Formation, Waco Shale Pit, McLennan County, Texas. Scale bars equal 0.5 mm.

the spines to the base of the cup, narrowing laterally towards the tips of the spines. Exterior of basal cavity swollen, perforate.

TYPE: The cup figured by Peck (1943, pl. 74, fig. 9) from the lower Cenomanian Grayson Formation of Grayson Bluff, Roanoke, Denton County, Texas (H. Tappan Loeblich locality HTL1) is the holotype. University of Missouri collections (E-18-5); not found, presumed lost.

SYNONYM: *Roveacrinus spinalatus* Peck, 1943.

MATERIAL: Unfigured paratype cup (USNM 128342), from H. Tappan Loeblich locality 5, south of Fink, Grayson County; numerous cups and brachials from the Grayson Formation of Dottie Lynn, Tarrant County, Grayson Bluff and Rayzor Ranch, Denton County, and the Waco Shale Pit, McLennan County, Texas.

DESCRIPTION: The cup is stellate in aboral/adoral aspects, bearing elongated radial spines, the broad, rounded adoral surfaces of which are declined. A thin, concave (in lateral aspect) aboral flange extends from the tip of the spine to conjoin at the radial pole; in some specimens (e.g., Pl. 31, Fig. 9) additional aborally directed processes develop from the flange. The radial spines are fragile and seldom completely preserved on cups, but are found entire as dissociated radials (Pl. 31, Fig. 7). The aboral portion of the cup, external to the basal cavity, is variably swollen and perforate. The radial facets are narrow and triangular, separated by broad interradial regions; the aboral ligament pits and central canals are small; the interradial processes are invariably broken. IBr1 (Pl. 31, Fig. 14) are rectangular, twice as tall as broad, and carry an inclined, distal synarthrial facet for articulation with IBr2. IBr2 are triangular, and carry short ridges on the external surface (Pl. 31, fig. 16; Text-fig. 16C), which develop into two to three elongated spines on large specimens (Pl. 31, Figs 13, 15), paralleling the spines on the cup. On exceptionally well-preserved specimens (Text-fig. 16A, B), comb-like internal processes are present. IIBr2 (Text-fig. 16D) possess a broad, distal muscular articulation, and internal processes. The distal brachials (Pl. 31, Fig. 12) have extremely elongated, laterally directed spines.

REMARKS: *Roveacrinus spinosus* differs from its probable ancestor, *R. solisoccasum* (Pl. 30), in its more elongated, declined, radial spines and the rounded, rather than concave, adoral surface of the spines. *Roveacrinus pentagonus* (Pl. 32; Pl. 34, Figs 1, 2) differs in the broader, narrower, radial flanges, the adoral margins of which are horizontal rather than declined.

OCCURRENCE: Lower Cenomanian Grayson Formation, Texas (Peck 1943; Hess 2015), Chalk Marl, Cambridge, United Kingdom (Gale 2019) and Aït Lamine Formation, Abouda, Agadir Basin, Morocco (Gale 2020).

*Roveacrinus bifidus* Gale, 2019
(Pl. 27, Fig. 16)

*2019. *Roveacrinus bifidus* Gale, p. 442, pl. 7, figs 1, 2.

DIAGNOSIS: *Roveacrinus* in which the aboral, interradial regions of the cup carry an irregular, reticulate coating. The radial facets are supported by three ridges, separated by shallow concavities. The brachials IBr2 carry a pair of narrow flanges, separated by a concave region.

TYPE: The cup figured by Gale (2019, pl. 7, fig. 1) from the Chalk Marl (lower Cenomanian, *Mantelliceras mantelli* Zone) of Cambridge (UK) is the holotype (NHMUK E 48540).

MATERIAL: A single cup from the Grayson Formation (sample RR3) of Rayzor Ranch, Denton, Denton County, Texas (NHMUK PI EE 17956).

DESCRIPTION: The single, incomplete cup (only one side is preserved) is as broad as tall, and bears short, bladed radial flanges which narrow aborally from the radial facets to conjoin at the aboral pole. The flanges are recessed immediately aboral to the radial facets, and a concave structure bearing lateral flanges is present in the left hand side of the imaged cup. The basal cavity is swollen and bears numerous perforations. The interradial regions are inset and a raised interradial seam is present.

REMARKS: This specimen is similar in shape, the presence of short radial flanges and the inset interradial regions to the type specimen (Gale 2019, pl. 7, fig. 1), but the bifid adoral portions of the radial flanges are not well preserved.

*Roveacrinus solisoccasum* Gale, 2020
(Pl. 30, Figs 1–12)

*part 1943. *Roveacrinus spinosus* Peck, pl. 74, fig. 7 only.
2020. *Roveacrinus solisoccasum* Gale, p. 26, pl. 11, figs 1–6.

DIAGNOSIS: *Roveacrinus* in which a spearhead-shaped radial process, bearing an aboral median ridge, is present on each radial.

TYPES: The well-preserved cup from the top of the Main Street Limestone, Sunset Oaks Drive, Hurst, Fort Worth, Texas, is the holotype (Pl. 30, Figs 1–3). Sample SD3 (NHMUK PI EE 17456).

MATERIAL: Ten cups from the uppermost metre of the Main Street Limestone, Sunset Oaks Drive, Fort Worth, Texas (sample SD3).

DESCRIPTION: Cup stellate in adoral and aboral aspects, the extremities formed by spearhead-shaped radial flanges which are concave on both ad- and aboral surfaces. A strong ridge extends from the aboral pole of the cup to the tips of flanges, weaking aborally and defining symmetrical concavities on either side of the lateral portions of the flanges. In lateral aspect, the cup is broader than tall and the aboral portion is swollen and coarsely perforate; the perforations are irregularly aligned with the radial flanges and interradial sutures. The adoral interradial regions are inset and concave, and a low, raised ridge marks the interradial suture. The adoral margin of the radial cavity is broad, and the radial facets are broad and short. Large, rounded aboral ligament pits and central canals are present. Arms unknown.

REMARKS: *Roveacrinus solisoccasum* differs from the stratigraphically younger *R. spinosus* in the broad, strongly and coarsely perforate aboral portion of the cup, and the short, concave, spearhead-shaped radial flanges which carry a median aboral ridge. It is known from the upper part of the Main Street Formation in Texas (Text-fig. 12) and the Aït Lamine Formation in Morocco (Gale 2020).

OCCURRENCE: Uppermost Albian zone AlR12, in Texas and Morocco.

*Roveacrinus pentagonus* Peck, 1943
(Pl. 32, Figs 1–12; Pl. 34, Figs 1–3, 6, 11)

*1943. *Roveacrinus pentagonus* Peck, 1943, p. 467, pl. 74, figs 6, 7, 9; pl. 76, figs 37, 39.
1961. *Roveacrinus alatus* Douglas; Rasmussen, p. 364.

DIAGNOSIS: *Roveacrinus* in which the delicately constructed cup bears thin radial flanges which extend to the aboral pole; brachials carry three thin flanges, arranged symmetrically about the midline.

TYPE: The cup figured by Peck (1943, pl. 73, figs 5, 7) is the holotype. H. Tappan Loeblich locality 5, sample 59. Grayson Formation, lower Cenomanian, road cut and stream bank of tributary to Little Mineral Creek, south of Fink, Grayson County, Texas. University of Missouri collections (E-16-3); presumed lost.

MATERIAL: 23 cups from the type locality (USNM

128341, 140177); 20 cups from the upper part of the Grayson Formation, Waco Shale Pit, McLennan County; six cups from the upper part of the Grayson Formation of Handley, Fort Worth, Tarrant County, Texas.

DESCRIPTION: The cups are conical and bear thin, bladed radial flanges which extend laterally from beneath the radial facets to a maximum breadth, then narrow to the aboral pole where they conjoin. In some cups, the flanges are simple flattened structures (e.g., Pl. 32, Figs 3, 5–8; Pl. 34, Fig. 2) in others, they develop a pair of secondary, smaller, usually paired flanges (Pl. 32, Figs 1, 2, 4; Pl. 34, Figs 1, 9). The size of the secondary flanges is variable, and they may develop asymmetrically. The radial facets are small and widely separated by deep recesses; the articular ridge is low and the aboral ligament pits and central canals are small. The interradial processes are short and laterally divergent. IIBr2 (Pl. 32, figs 9, 10) have a rounded, rectangular outline, and bear broad, thin lateral flanges. Three symmetrically arranged flanges are present on the exterior surface. The distal brachials (Pl. 34, Fig. 3) also carry three flanges of the same size.

REMARKS: *Roveacrinus pentagonus* is a distinctive form, which differs significantly from its probable ancestor, *R. spinosus*, in the more delicate cup structure and the shorter, less aborally declined radial flanges. It differs from *R. multisinuatus* in the presence of only a single pair of secondary radial flanges.

OCCURRENCE: *Roveacrinus pentagonus* is present only in the uppermost part of the lower Cenomanian Grayson Formation, rarely preserved beneath the erosion surface at the base of the overlying Woodbine Formation in Grayson, Tarrant and McLennan counties, Texas.

### *Roveacrinus multisinuatus* Peck, 1943
(Pl. 33, Figs 1–12; Pl. 34, Figs 4, 5)

*1943. *Roveacrinus multisinuatus* Peck, p. 466, pl. 72, figs 14–17.

1961. *Roveacrinus multisinuatus* Peck; Rasmussen, p. 370, pl. 54, figs 12, 13.

DIAGNOSIS: *Roveacrinus* in which multiple, paired lateral flanges develop from the narrow, primary radial flanges in the lateral surfaces of the cup. IIBr2 bear a symmetrical, triangular, adorally narrowing, paired concave process on the outer surface.

TYPE: Cup figured by Peck (1943, pl. 72, fig. 17). H. Tappan Loeblich locality 5, sample 59, road cut and stream bank of tributary to Little Mineral Creek, south of Fink, Grayson County, Texas. University of Missouri collections, E-14-3; presumed lost.

MATERIAL: Ten unfigured paratype cups and two brachials (IBr2) from the type locality (USNM 128343); five cups from the upper Grayson Formation of Handley, Fort Worth, M. Nestell Collection.

DESCRIPTION: The cup is conical, as broad as tall, and the aboral margin is convex. The lateral margins of the cup are made up of vertical flanges; these diverge, usually symmetrically, from five primary radial flanges. The primary flanges conjoin at the aboral pole, and up to three sets of nested, secondary processes are developed, the largest appearing close to the aboral margin, and successively smaller ones more adorally. The symmetrical development is lost in some individuals (e.g., Pl. 33, Figs 7–9), in which irregular processes appear. The first formed pairs of flanges are in some cases fused with those from the adjacent radials. The radial facets are narrow and the aboral ligament pits and central canals are large and rounded. Short interradial processes are present. IBr2 (Pl. 33, Figs 10–12) are triangular, bear thin lateral flanges and their external faces bear symmetrical, triangular, adorally narrowing processes on the outer surface, made up of two concavities separated by a median ridge.

REMARKS: *Roveacrinus multisinuatus* differs from all congeners in the presence of nested, paired secondary flanges developed on the radial ridges, and the unique double, triangular, concave surfaces of IIBr2. The species probably evolved from *R. pentagonus*, in which small, paired lateral flanges are present on the radial ridges of some cups, by the development of further paired flanges.

OCCURRENCE: *Roveacrinus multisinuatus* is present only in the uppermost part of the lower Cenomanian Grayson Formation, rarely preserved beneath the erosion surface at the base of the overlying Woodbine Formation in Grayson, Tarrant and McLennan counties, Texas.

### *Roveacrinus proteus* sp. nov.
(Pl. 28, Figs 4–11; Pl. 29, Figs 1–8)

DIAGNOSIS: A robust *Roveacrinus*, in which the elongated radial ridges carry a rounded ridge aborally; the aboral part of the cup is formed by a swollen stellate structure, formed from radial ribs.

TYPES: The specimen figured in Pl. 29, Figs 4–6 is the holotype (NHMUK PI EE 17965). The other figured specimens are paratypes (Pl. 28, Figs 4–11; NHMUK PI EE 17962–17964; Pl. 29, Figs 1–3, 5–8, NHMUK PI EE 17966–17970).

MATERIAL: 32 cups from the Pawpaw Formation, upper Albian *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone of the Salvation Army locality, Seminary Drive, southern Fort Worth, Tarrant County, Texas.

ORIGIN OF NAME: Proteus, a Greek god who could change his shape at will, in allusion to the variable morphology of the species.

DESCRIPTION: The cup is stellate, with robust, elongate, terminally pointed radial processes which either taper evenly to the tip or broaden and then taper laterally. The processes are either horizontal or slightly declined aborally; each process comprises two narrow lateral flanges and a rounded aboral rib, rarely absent (Pl. 29, Fig. 6). The aboral surface of the cup is made up of a variably shaped, irregularly swollen, stellate structure, centred on the aboral pole; ridges from this structure extend adorally along the lateral margins of the cup (Pl. 28, figs 4, 7, 10) and laterally along the radial processes for a variable distance. The adoral surfaces of the radial processes carry a groove. The radial facets are not well preserved, but a weak articular ridge and rounded aboral ligament pits are visible (Pl. 28, Fig.10). There appears to be little ontogenetic change; the smallest cups (Pl. 29, Fig. 5) are similar to the largest ones (Pl. 29, Fig. 7).

REMARKS: *Roveacrinus proteus* sp. nov., the oldest species of the genus *Roveacrinus*, evolved from *Po. dispandus* forma *floriformis* nov. by development of longitudinal aboral ridges on the radial processes, while retaining consistently elongated, pointed processes. Some specimens could be placed in either species, such as the individual (Pl. 29, Fig. 6) which lacks aboral ridges. *Roveacrinus proteus* sp. nov. differs from its probable descendant, *R. solisoccasum*, in the presence of robust, smooth aboral radial ridges which cover the aboral cup; in the latter species (Pl. 30, Figs 1–12), the mid-radial ridges are narrower and the convex, perforated surface of the aboral cup is clearly visible.

OCCURRENCE: *Roveacrinus proteus* sp. nov. is known only from the Pawpaw Formation, *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone of Tarrant County, Texas.

*Roveacrinus morganae* sp. nov.
(Pl. 28, Figs 1–3)

DIAGNOSIS: *Roveacrinus* in which the radial processes are arranged in two tiers, which decrease in breadth aborally.

TYPES: The cup figured here is the unique holotype (NHMUK PI EE 17961). Pawpaw Formation of a temporary section at the junction of US highways 35W and I 20, southern Fort Worth, Tarrant County, collected on the outcrop by FH.

ORIGIN OF NAME: After Roz Morgan, a friend of Frank Holterhoff, with whom he collected and studied fossils.

DESCRIPTION: The cup is conical, as broad as tall, and stellate in aboral:adoral views. An adoral tier of flat, petaloid, rounded-triangular radial processes are developed immediately aboral to the radial facets. Aboral to these, a lower tier of shorter, blunt processes is present, separated from the adoral tier by paired depressions. Broad, rounded ridges descend from the lower tier, terminating adoral to the base of the cup which is formed by a short, blunt, conical process. The radial facets show rounded, large aboral ligament pits and central canals. The interradial processes are low.

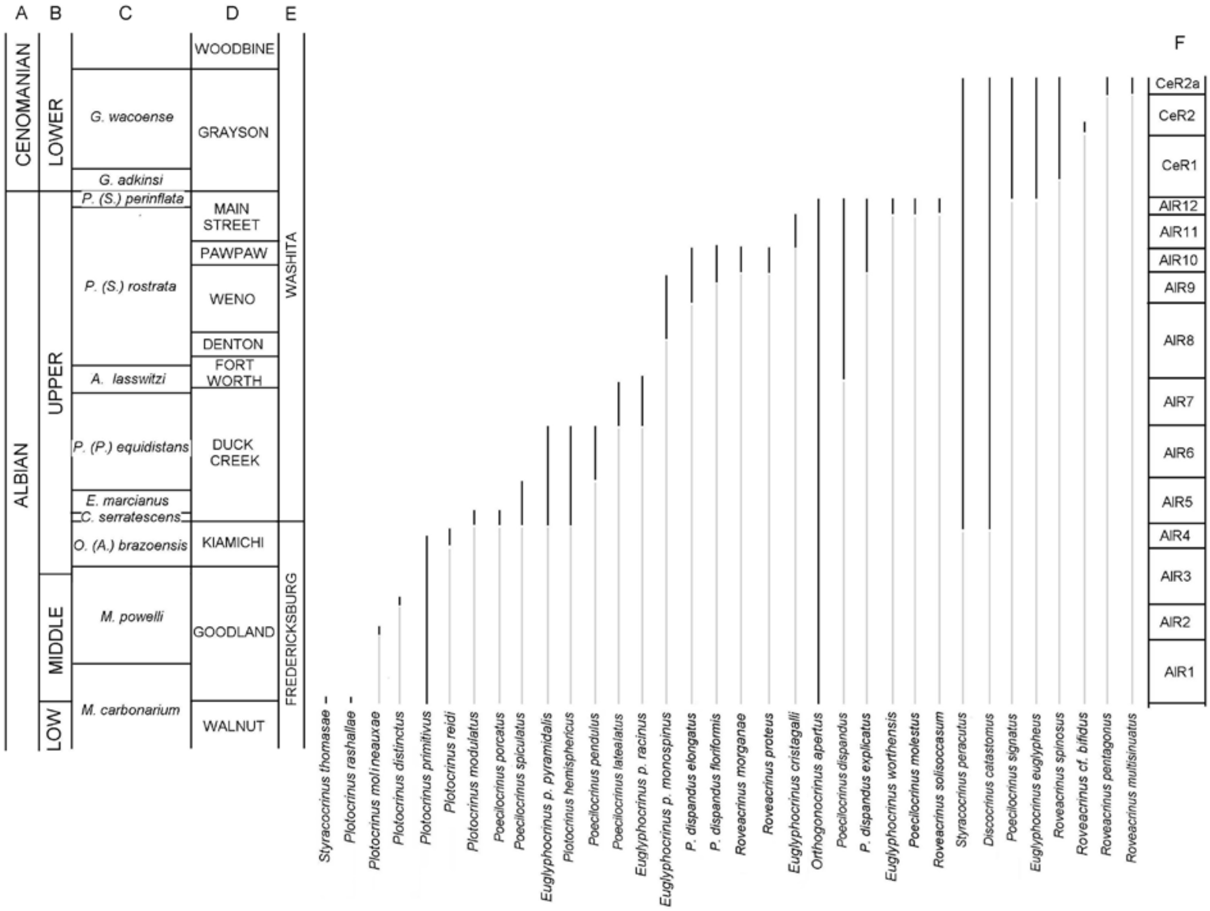
REMARKS: *Roveacrinus morganae* sp. nov. has a unique morphology, in the possession of tiered, aborally narrowing radial processes. In lateral profile (Pl. 28, Fig. 2), the form of the aboral cup is similar to that of *R. proteus* sp. nov. (compare with Pl. 28, Fig. 4), and it possibly evolved from that species by developing tiered radial processes.

OCCURRENCE: Known only from the Pawpaw Formation, upper Albian of Tarrant County, Texas.

## DISCUSSION

### Evolutionary history of the Roveacrinidae

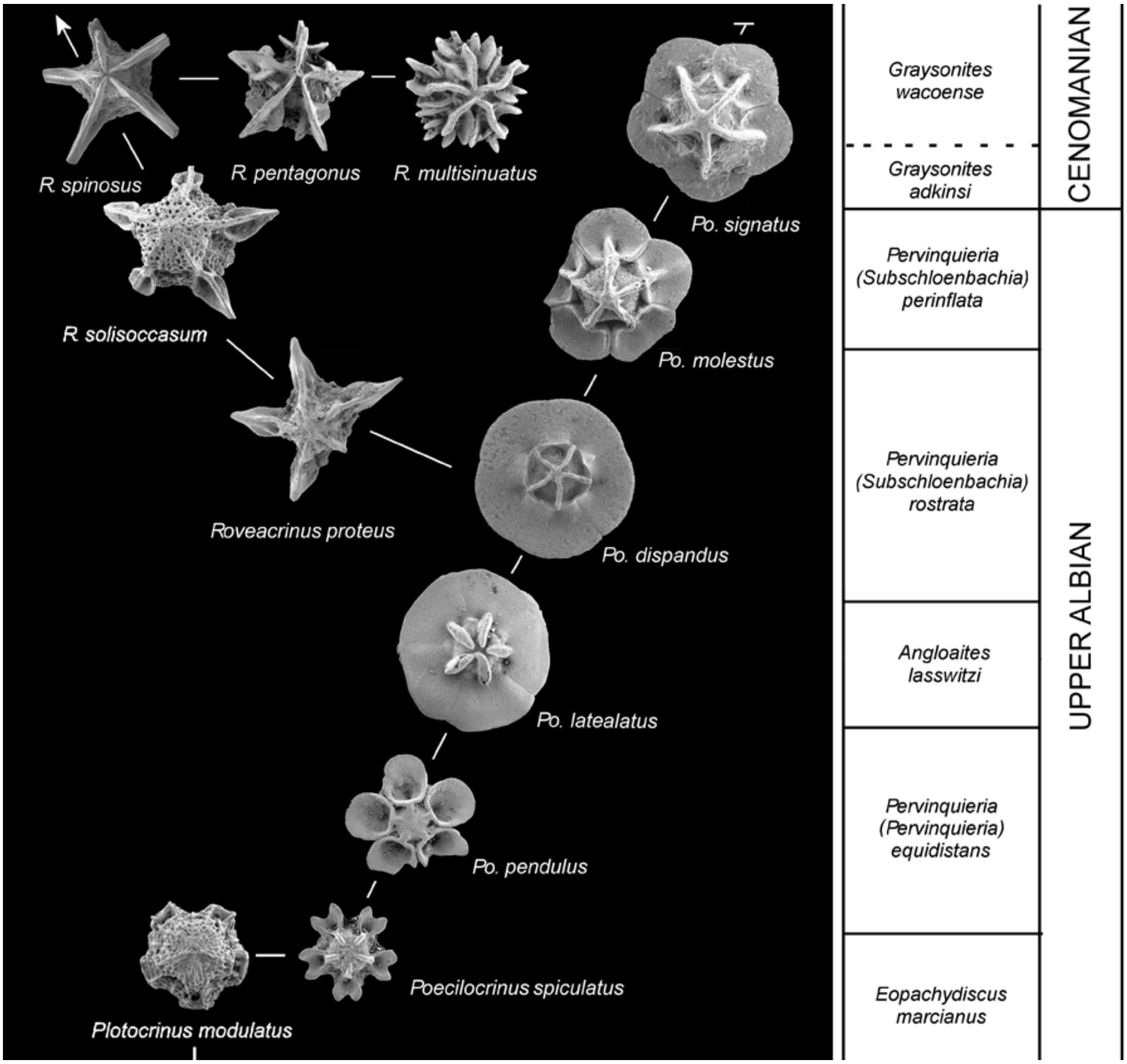
The oldest (pre-middle Albian) part of the history of the family remains very poorly known, with only three species described from the lower




Text-fig. 17. Distribution of roveacrinids in the upper Fredericksburg and lower Washita groups in northern Texas and southern Oklahoma. Columns from left, are A, stage, B, substage, C, ammonite zone, D, formation, E, group and F, proposed microcrinoid zonation.

Albian (Destombes 1984; Hess and Gale 2010) and none from older Cretaceous strata. The subfamilies Orthogonocrininae and Plotocrininae were already diversified, so the history of the family must extend significantly further back, but sampling of Aptian and Barremian sedimentary rocks in North Africa has so far not yielded any material. The middle Albian to lower Cenomanian record of Roveacrinidae in Texas, representing about 13 myr, appears to be remarkably complete (see Text-fig. 17), with the exception of the lower upper Albian Kiamichi Formation in which specimens are rare. The record provides contrasting stories: of stasis, or very slow evolution in the Orthogonocrininae (*Styracocrinus*, *Discocrinus* and *Orthogonocrinus*); of moderately frequent speciation and successive formae (*Euglyphocrinus*); and rapid evolution, including transitions between genera, in the abundant Plotocrininae and Roveacrininae (Text-fig. 18; *Plotocrinus–Poecilocrinus–Roveacrinus*). The main features of the latter group are:

- appearance of *Plotocrinus* close to the base of the middle Albian;
- rapid speciation of *Plotocrinus* through the middle and lower upper Albian;
- origin of *Poecilocrinus* from *Plotocrinus modulatus* in the upper Albian lower Duck Creek Formation;
- rapid evolution of *Poecilocrinus* in a succession of species through the upper Albian into the lower Cenomanian (*Po. spiculatus–Po. pendulus–Po. latealatus–Po. distinctus–Po. molestus–Po. signatus*);
- origin of *Roveacrinus* from *Po. dispandus* in the late Albian *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone;
- rapid evolution of *Roveacrinus* during the latest Albian and early Cenomanian (*R. proteus–R. soli-*




Text-fig. 18. Evolution of *Poecilocrinus* and *Roveacrinus* during the late Albian and early Cenomanian. *Poecilocrinus spiculatus* evolved from *Plotocrinus modulatus*, and a succession of species of *Poecilocrinus* (*Po. spiculatus*, *Po. pendulus*, *Po. latealatus*, *Po. dispandus*, *Po. molestus* and *Po. signatus*) characterise levels within the uppermost Albian and lower Cenomanian. *Poecilocrinus* gave rise to *Roveacrinus* within the *Pervinquieria* (*Subschloenbachia*) *rostrata* Zone, by paedomorphic evolution (see text). The oldest *Roveacrinus*, *R. proteus* sp. nov., evolved from *Po. dispandus* forma *floriformis* nov., and gave rise, successively, to *R. solisoccasum* and *R. spinosus*. The two species, *R. pentagonus* and *R. multisinuatus* evolved from *R. spinosus*. *Plotocrinus modulatus*, *Po. spiculatus, Po. pendulus* and *Po. latealatus* are only known from Texas and Oklahoma, but *Po. dispandus*, *Po. molestus* and *Po. signatus*, plus *R. solisoccasum* and *R. spinosus* also occur in the Agadir Basin, Morocco (Gale 2020).

*soccasum–R. spinosus–R. pentagonus–R. multisinuatus*);
– extinction of *Poecilocrinus* in the lower Cenomanian.

The evolutionary diversification of Roveacrininae continued through the Cenomanian and Turonian (Gale 2019, 2020) and the subfamily became extinct in the middle Coniacian. The descendant subfamily, Hessicrininae, appeared in the Turonian, diversified in the Santonian and extended to the K/Pg boundary (Gale 2016, 2018; Gale *et al.* 2018), where the order Roveacrinida became extinct.

**Significance for interregional stratigraphical correlation**

The middle and late Albian record of roveacrinids described above is based largely upon material from Texas and Oklahoma. However, the presence of middle Albian species typical of the lower Goodland Formation in Aube (Anglo-Paris Basin, northeast France), provides an important correlation between the Texas and European successions. In the middle Albian, the northern European ammonite fauna was dominated by the Boreal superfamily Hoplitoidea, and the Texan record by large Mojsisovicziinae (Young 1966), such that correlation at a zonal level is impossible. The occurrence of *Plotocrinus primitivus* and *P. rashallae* sp. nov. in the basal part of the Goodland Formation of Texas (mid-*Manuaniceras carbonarium* Zone) and in the lower middle Albian (*Hoplites dentatus* and *Anahoplites intermedius* ammonite zones) of Aube (France) provides a useful interregional correlation. The major transgressive event at the base of the Goodland Formation (Scott *et al.* 2003) can thus be tentatively correlated with the lower middle Albian transgression identified in the Anglo-Paris Basin (Hesselbo *et al.* 1990; Amédro 2009). Microcrinoids occur rather infrequently in the middle and upper Albian clay facies of northwest Europe, and when they do occur, are mostly either long-ranging taxa (*Styracocrinus* in northern Germany; Schmid 1971; *Orthogonocrinus apertus* in the UK; Smith *et al.* in Young *et al.* 2010) or endemic forms (*Hyalocrinus* in the Anglo-Paris Basin; Destombes 1984; Gale 2019).

Late Albian and early Cenomanian roveacrinids are present in the Agadir Basin, Morocco (Gale 2020) in a succession of species and formae essentially identical to those found in Texas, including zones AlR11, AlR12 and CeR1, CeR2. The contemporaneity of the occurrences is confirmed independently by co-occurring ammonite faunas which are also very similar [*Pervinquieria* (*Subschloenbachia*) *rostrata*, *Pervinquieria* (*Subschloenbachia*) *perinflata* and *Graysonites adkinsi*]. These similarities in the faunas, over a distance of 5,300 km, indicates a very widespread original distribution, for some intervals at least, of these pelagic crinoids in the southwestern Tethys and central Atlantic. It is likely that further discoveries of Albian roveacrinid taxa in Africa, and probably also Brazil (see Dias-Brito and Ferré 2001) will be made in the future. There have been very few studies of these tiny crinoids, and much material from other regions is probably undiscovered or overlooked. However, it is evident that some forms, such as the Texan early Cenomanian *Roveacrinus pentagonus* and *R. multisinuatus*, are not found in expanded successions of identical age in Morocco and it is likely that some species, like these, were endemic to specific regions.

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PLATES 1–34

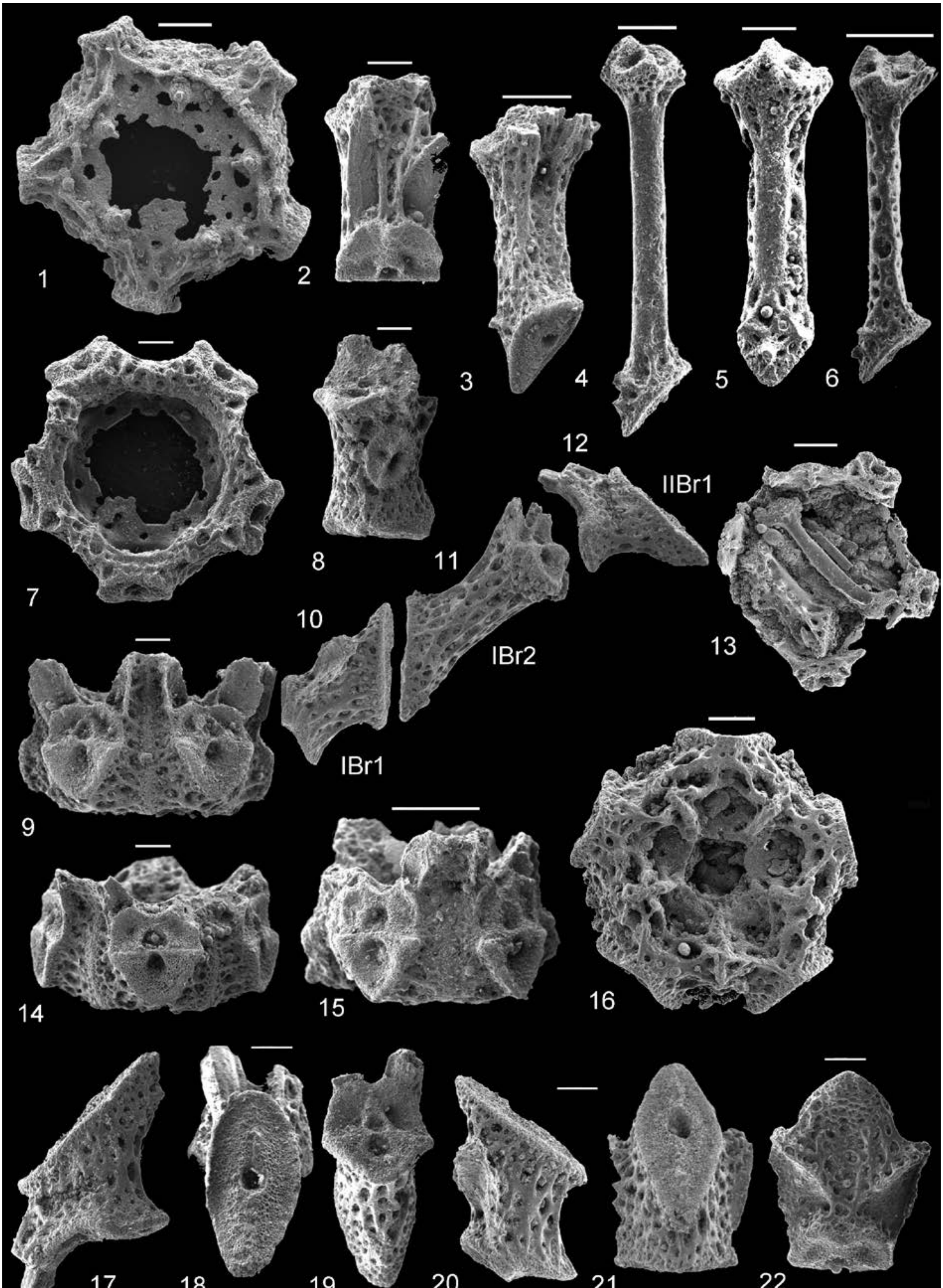
# PLATE 1

*Discocrinus catastomus* Peck, 1943

1 – cup in aboral view, the original of Gale (2019, pl. 36, fig. 2; NHMUK PI EE 16147); 2 – internal view of distal brachial (NHMUK PI EE 17719); 3 – IBr2 in oblique internal view (NHMUK PI EE 17720); 4-6 – IBr2 in lateral (4, 6) and external (5) views, 4, 5 are the originals of Gale (2019, pl. 36, figs 8, 9; NHMUK PI EE 16143, 16144), 6 is the original of Gale (2019, pl. 36, fig. 8; NHMUK PI EE 16156); 7 – cup in adoral view, original of Gale (2019, pl. 36, fig. 4; NHMUK PI EE 16139); 8 – distal brachial in oblique lateral view, to show pinnule attachment site, original of Gale (2019, pl. 36, fig. 3; NHMUK PI EE 16148); 9-12 – cup and proximal brachials in lateral view, original of Gale (2019, pl. 36, fig. 8; NHMUK PI EE 16151–4); 13 – small cup in adoral view, with brachials inside (NHMUK PI EE 17721); 14, 15 – cups in lateral view (NHMUK PI EE 17722, 17723); 16 – cup in aboral view (NHMUK PI EE 17724); 17-19 – IIBr2 in lateral, distal and proximal views, respectively, original of Gale (2019, pl. 36, fig. 6; NHMUK PI EE 16154); 20, 21, – IBr1 in lateral (20) and external (21) views, original of Gale (2019, pl. 36, fig. 6; NHMUK PI EE 16152); 22 – IBr1 in internal view, original of Gale (2019, pl. 36, fig. 3; NHMUK PI EE 16154).

Figures 1-3, 7-15, 17-22 are from the upper Albian *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, middle part of Weno Formation, roadcut for US Highway 77, Cleburne, Johnson County, Texas. Figures 4-6 are from the upper Albian, lower Duck Creek Formation, Bryan County, Oklahoma (sample RRFW). Figure 16 is from the upper Albian, lower Duck Creek Formation, Red River, Horseshoe Bend, Love County, Oklahoma (sample HB6).

Scale bars equal 0.2 mm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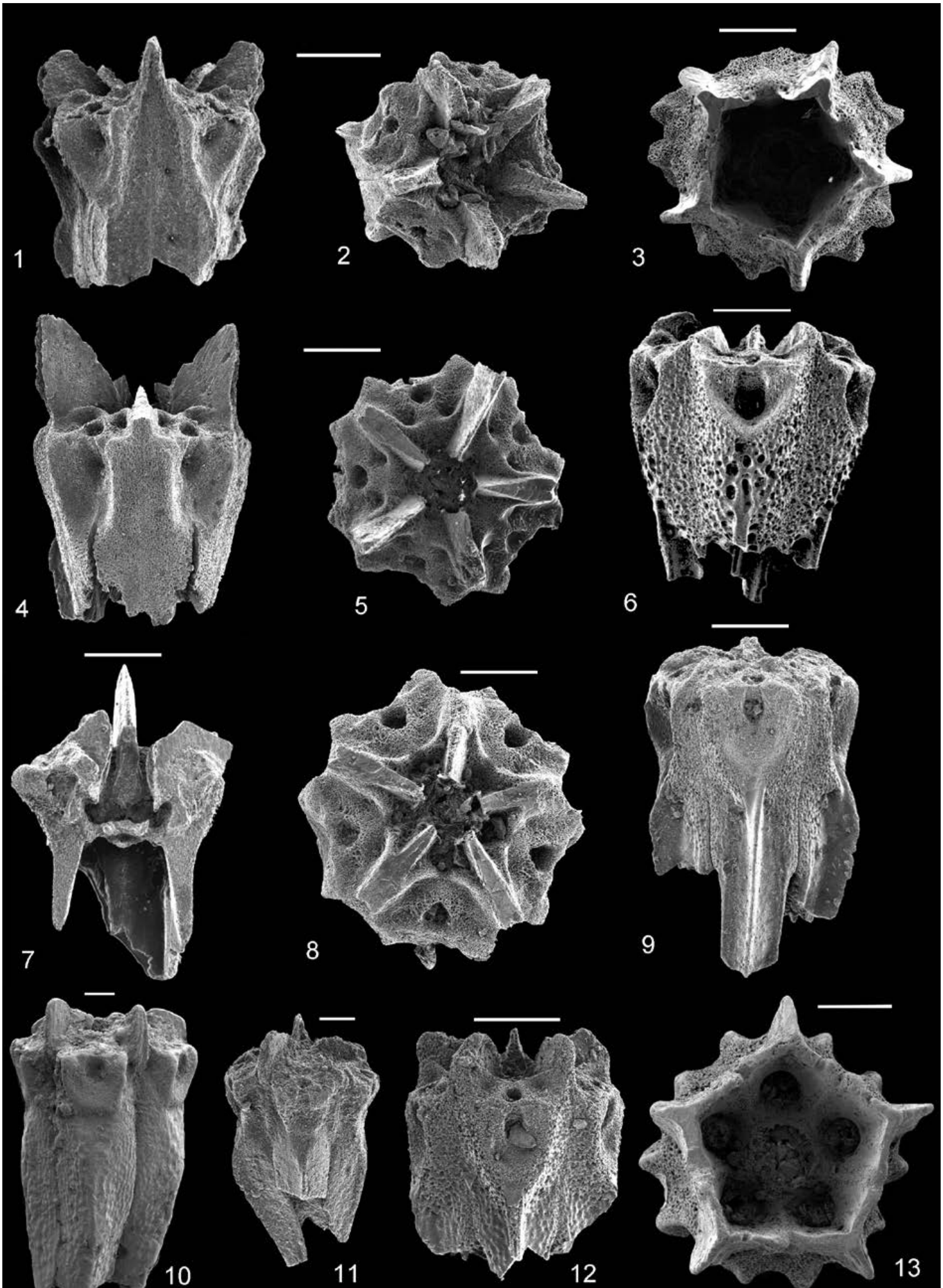
# PLATE 2

**1-5**, **7-13** – *Orthogonocrinus apertus* Peck, 1943. 1, 2 – cup in interradial lateral and adoral views, respectively (NHMUK PI EE 17724); 3, 8, 9 – broken cup in aboral, adoral, and lateral views, respectively (NHMUK PI EE 17725); 4, 5 – cup in lateral and adoral views, respectively (NHMUK PI EE 17726); 7 – cup split lengthways, showing small basal ring which separates radial and basal cavities (NHMUK PI EE 17727); 10 – small cup in lateral view, radials apparently complete, original of Hess (2015, fig. 12g; NMB M1169); 11 – small cup in lateral view (NHMUK PI EE 11728); 12 – adoral portion of cup in lateral view (NHMUK PI EE 17729); 13 – interior of cup from aboral view, original of Hess (2015, fig. 12e; NMB M11607), note five rounded depressions for sub-basal balls.

**6** – *Orthogonocrinus cantabrigensis* Gale, 2019, cup in lateral view, original of Gale (2020, pl. 3, fig. 4; NHMUK PI EE 16913).

Figures 1, 2, 11, 12 are from the middle Albian, basal Marys Creek Marl Member, Goodland Formation, Marys Creek, Fort Worth, Tarrant County, Texas (sample MC0). Figures 3-5, 7-9 are from the upper Albian, upper Duck Creek Formation, Fort Worth, Tarrant County,Texas. Figures 10, 11, 13 are from the upper Albian, upper Duck Creek Formation, Saginaw Quarry, Fort Worth, Tarrant County, Texas (sample Sag.h). Figure 6 is from the lower Cenomanian, Aït Lamine Formation, Abouda Plage roadcut, Agadir, Morocco (sample SA2).

Scale bars equal 0.2 mm (3, 6, 10, 11, 13) and 0.5 mm for all others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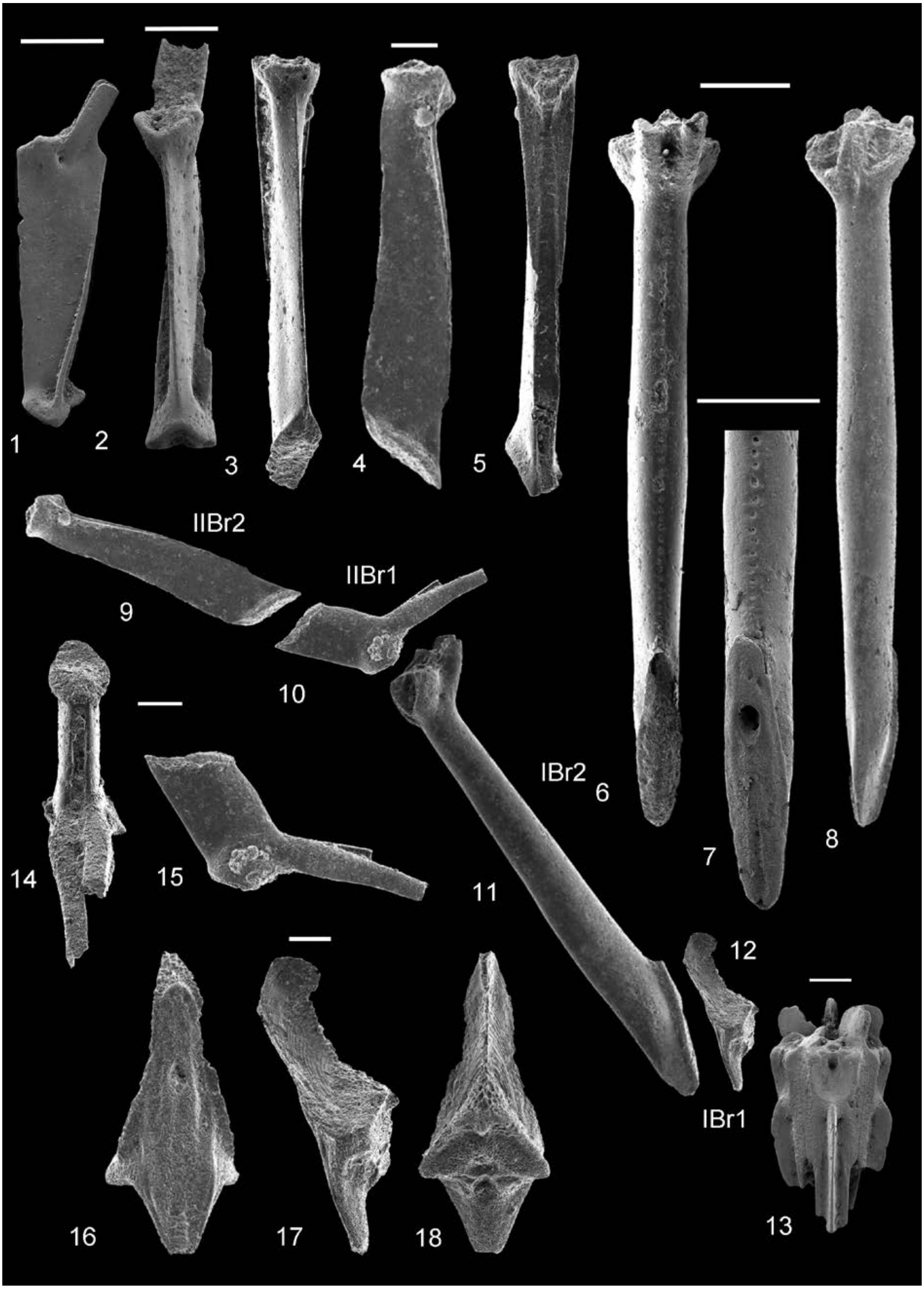
# PLATE 3

*Orthogonocrinus apertus* Peck, 1943

1 – secundibrachial, possibly IIBr3, in lateral view, original of Hess (2015, fig. 11h; NMB M11688, figured as *Roveacrinus pyramidalis*); 2 – distal secundibrachial in external view (NHMUK PI EE 17730); 3-5 – secundibrachial IIBr2 in external, lateral and internal views, respectively (NHMUK PI EE 17731); 6, 8, 11 – primibrachial IBr2 in internal, external and lateral views, respectively (NHMUK PI EE 17732); 7 – primibrachial IBr2 in proximal internal view to show synarthrial articulation with IBr1; original of Hess (2015, fig. 10g; NMB M11625); 10, 14, 15 – secundibrachial IIBr1 in lateral (10, 15) and internal (14) views (NHMUK PI EE 17733); 12, 16-18 – primibrachial IBr1 in lateral (12, 17), proximal (18) and distal views (16) (NHMUK PI EE 17734); 13 – cup in lateral view, original of Hess (2015, fig. 12a; NMB M11606).

All specimens are from the upper Albian, upper Duck Creek Formation, Saginaw Quarry, Fort Worth, Tarrant County, Texas (sample Sag.h).

Scale bars equal 0.2 mm (1-5, 14-18) and 0.5 mm for all others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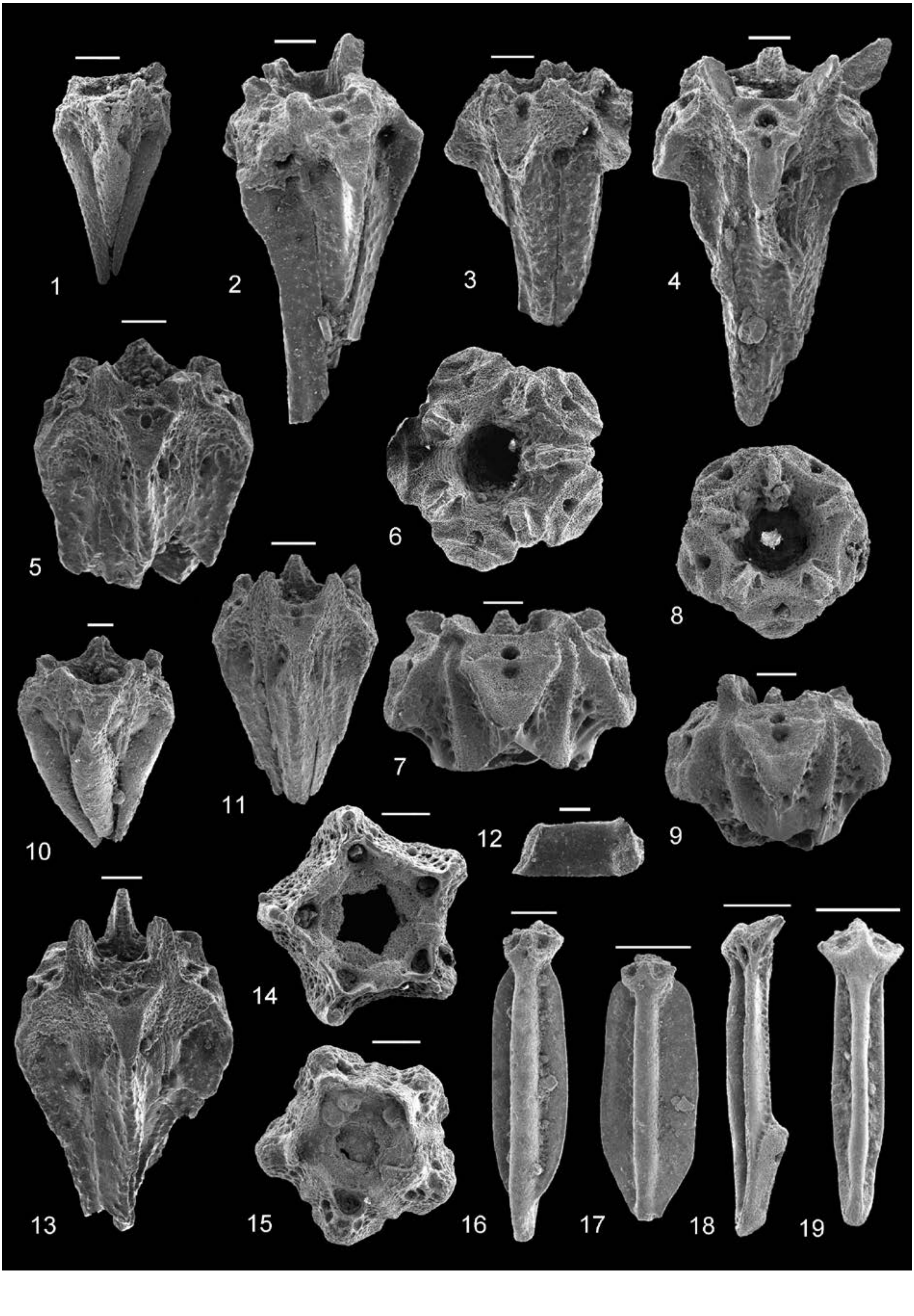
# PLATE 4

**1-5**, **10-17** – *Styracocrinus peracutus* (Peck, 1943). 1-4 – cups in lateral view (NHMUK PI EE 17735–17738); 5 – cup in lateral view, original of Gale (2020, pl. 5, fig. 4; USNM 128355 b); 10 – small cup in lateral view (NHMUK PI EE 17739); 11 – cup in lateral view (NHMUK PI EE 17740); 12 – brachial IIBr1 in lateral view (NHMUK PI EE 17741); 13 – cup in lateral view, original of Gale (2019, pl. 5, fig. 5; USNM 128355a); 14, 15 – broken cups in aboral view (NHMUK PI EE 17742, 17743); 16, 17 – primibrachials IBr2 in external views (NHMUK PI EE 17744, 17745).

**6-9**, **18**, **19** – *Styracocrinus thomasae* sp. nov. 6, 7 – holotype cup in adoral and lateral views, respectively (NHMUK PI EE 17746); 8, 9 – paratype cup in adoral and lateral views, respectively (NHMUK PI EE 17747); 18, 19 – primibrachials IBr2 in oblique lateral and external views, respectively (NHMUK PI EE 17748, 17749)

Figures 1-4 are from the lower Cenomanian, *Graysonites wacoense* Zone, Grayson Formation, Waco Shale Pit, Waco, McLennan County, Texas (sample Wa3). Figures 10-12, 14-17 are from the upper Albian, lower Duck Creek Formation, Red River, Horseshoe Bend, Love County, Oklahoma (sample RR1). Figures 5, 13 are from the upper Albian, Duck Creek Formation, south of Red River, close to US Highway 77, Cooke County, Texas. Figures 6-9, 18, 19 are from the middle Albian, basal Marys Creek Marl Member, Goodland Formation, Marys Creek, Fort Worth, Tarrant County, Texas (sample MC2; Text-fig. 3).

Scale bars equal 0.1 mm (1, 10), 0.2 mm (2–16) and 0.5 mm (4, 17, 19)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## PLATE 5

**1-3** – *Euglyphocrinus cristagalli* Gale, 2020. Cups in lateral view. 1 – original of Gale (2020, pl. 4, fig. 2; NHMUK PI EE 17386); 2 – holotype, original of Gale (2020, pl. 4, fig. 10; NHMUK PI EE 17384); 3 – original of Gale (2020, pl. 4, fig. 1; NHMUK PI EE 17385).

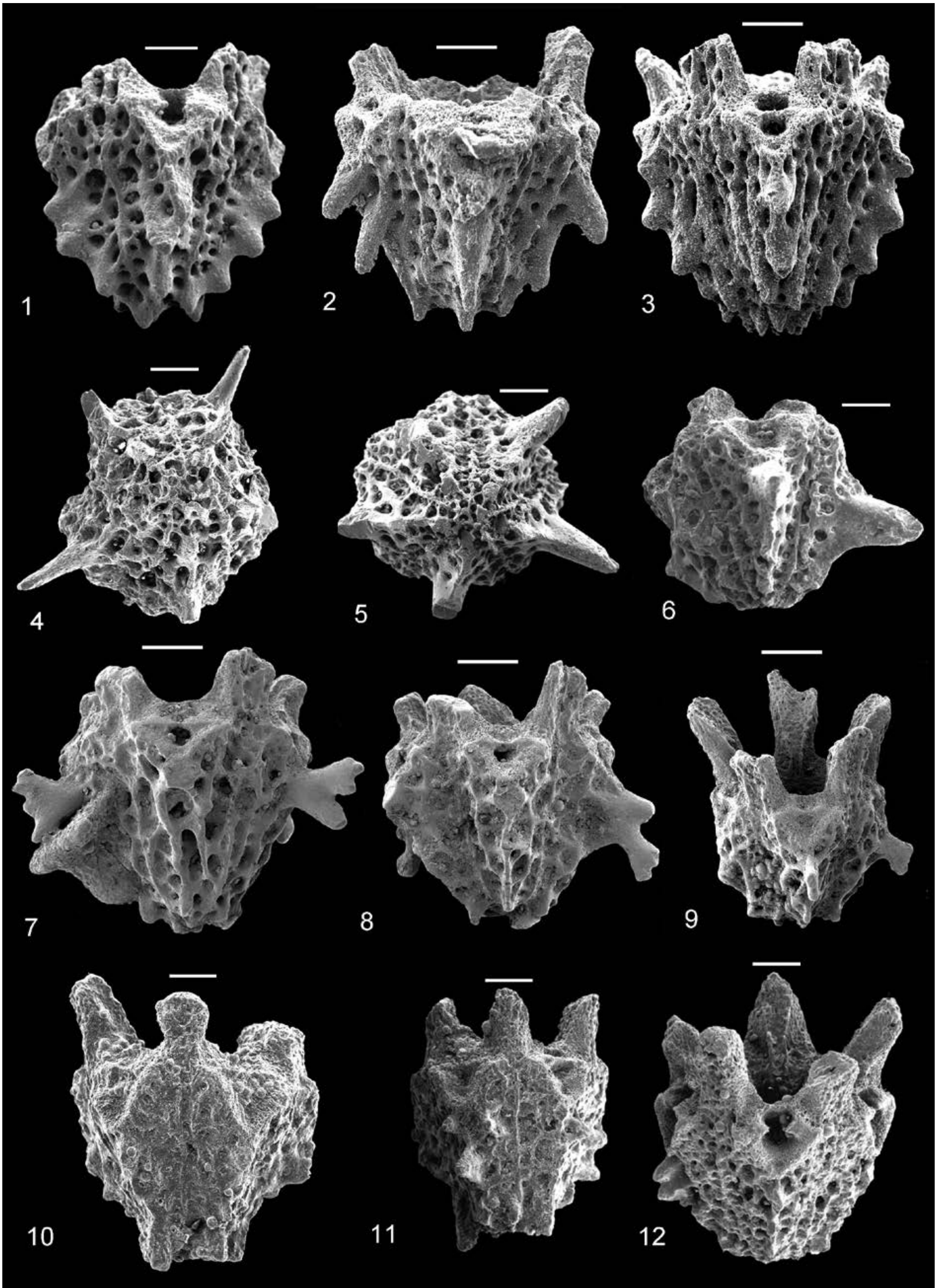
**4-6** – *Euglyphocrinus pyramidalis* forma *pentaspinus* nov. 4 – paratype cup in aboral view (NHMUK PI EE 17751); 5, 6 – holotype cup in aboral and lateral views, respectively (NHMUK PI EE 17750).

**7-9** – *Euglyphocrinus pyramidalis* forma *radix* nov. Cups in lateral view. 7 – original of Hess (2015, fig. 9i; M11589); 8 – original of Hess (2015, fig. 9g; M11591); 9 – original of Hess (2015, fig. 9h; M11592).

**10-12** – *Euglyphocrinus pyramidalis* forma *pyramidalis* Peck, 1943. Cups in lateral view (NHMUK PI EE 17752–17754).

Figures 1-3 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, Main Street Limestone, Sunset Oak Drive, Hurst, Tarrant County, Texas (sample SD1). Figure 4 is from the upper Albian, upper Weno Formation, Sycamore Creek, Carter Park, Fort Worth, Tarrant County, Texas (sample CP2). Figures 5, 6 are from the upper Albian, middle Weno Formation, Creasote Drive, Heritage Parkway, Fort Worth, Tarrant County, Texas. Figures 7-9 are from the upper Albian, upper Duck Creek Formation, Saginaw Quarry, Fort Worth, Tarrant County, Texas (sample Sag.h). Figures 10-12 are from the upper Albian, lower Duck Creek Formation, Red River, Love County, Oklahoma.

All scale bars equal 0.2 mm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# PLATE 6

**1**, **2**, **9** – *Euglyphocrinus pyramidalis* (Peck, 1943). 1, 2 – paratype cup in lateral and aboral views, respectively, original of Gale (2019, pl. 35, fig. 10; USNM 128339a); 9 – broken cup in aboral view, to show sub-basal balls, original of Hess (2015, fig. 9b; M11594).

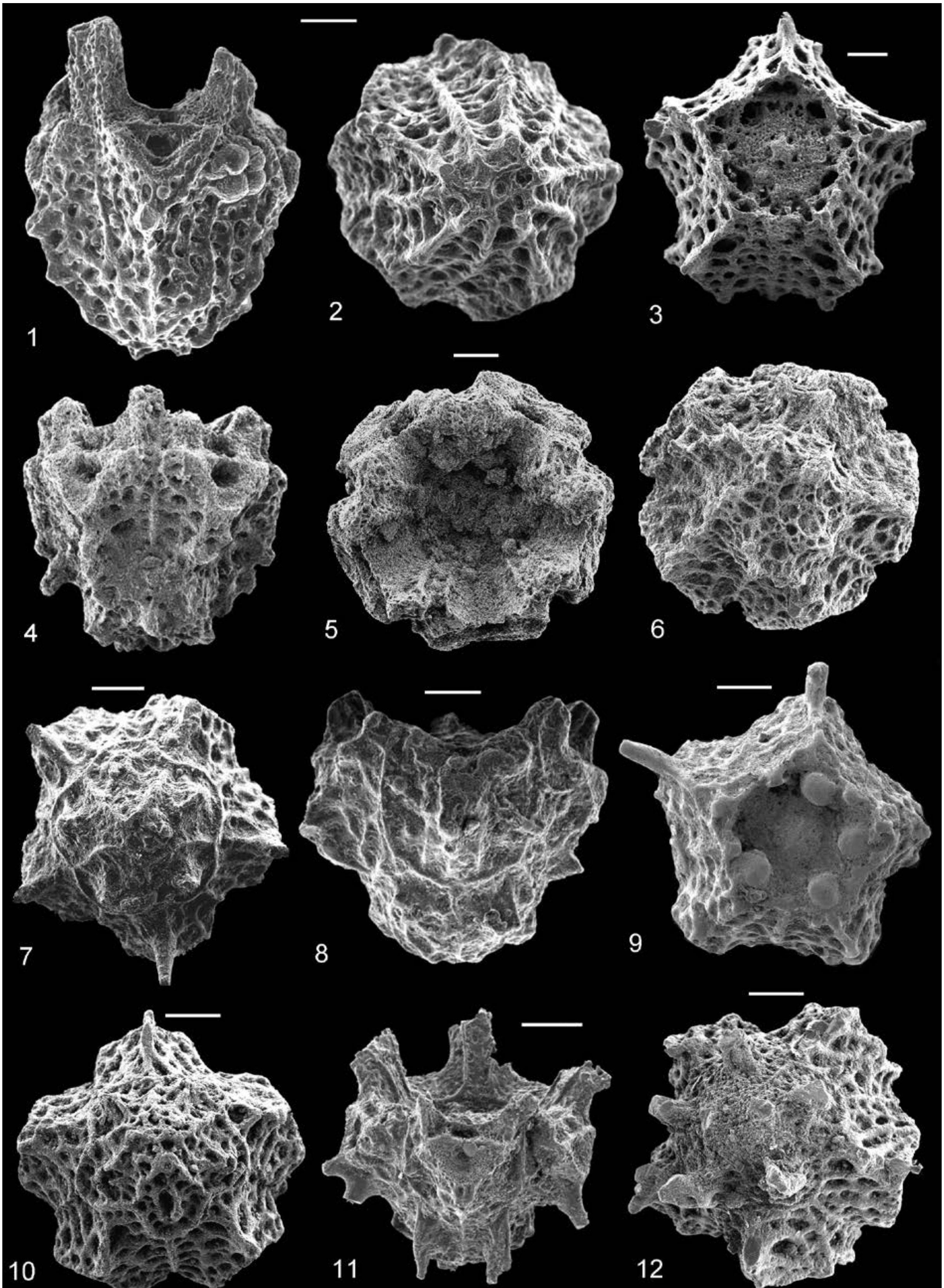
**3** – *Euglyphocrinus cristagalli* Gale, 2020. Paratype cup in aboral view, original of Gale (2019, pl. 4, fig. 3; NHMUK PI EE 17387).

**4-6** – *Euglyphocrinus worthensis* Gale, 2020. Holotype cup in lateral, adoral and aboral views, respectively, original of Gale (2020, pl. 8, figs 1–3; NHMUK PI EE 17424).

**7**, **8**, **10-12** – *Euglyphocrinus euglypheus* (Peck, 1943). 7 – cup in aboral view, original of Gale (2020, pl. 8, fig. 10; NHMUK PI EE 17430); 8 – paratype cup in lateral view, original of Gale (2020, pl. 8, fig. 7; USNM 128335b); 11, 12 – cups in oblique lateral and aboral views, respectively (NHMUK PI EE 17755, 17756).

Figures 1-3 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, Main Street Limestone, Sunset Oak Drive, Hurst, Tarrant County, Texas (sample SD2). Figures 4-6 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *perinflata* Zone, Main Street Limestone, Sunset Oak Drive, Hurst, Tarrant County, Texas (sample SD4). Figures 7, 11 are from the lower Cenomanian, *Graysonites wacoense* Zone, Grayson Formation, Grayson Bluff, Denton County, Texas (sample G1). Figure 8 is from the same locality (horizon unknown). Figures 11, 12 are from the lower Cenomanian, *Graysonites wacoense* Zone, Grayson Formation, Waco Shale Pit, Waco, McLennan County, Texas (sample Waco3a). Figure 9 is from the upper Albian, upper Duck Creek Formation, Saginaw Quarry, Fort Worth, Tarrant County, Texas (sample Sag.h).

Scale bars equal 0.1 mm (3) and 0.2 mm for all others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# PLATE 7

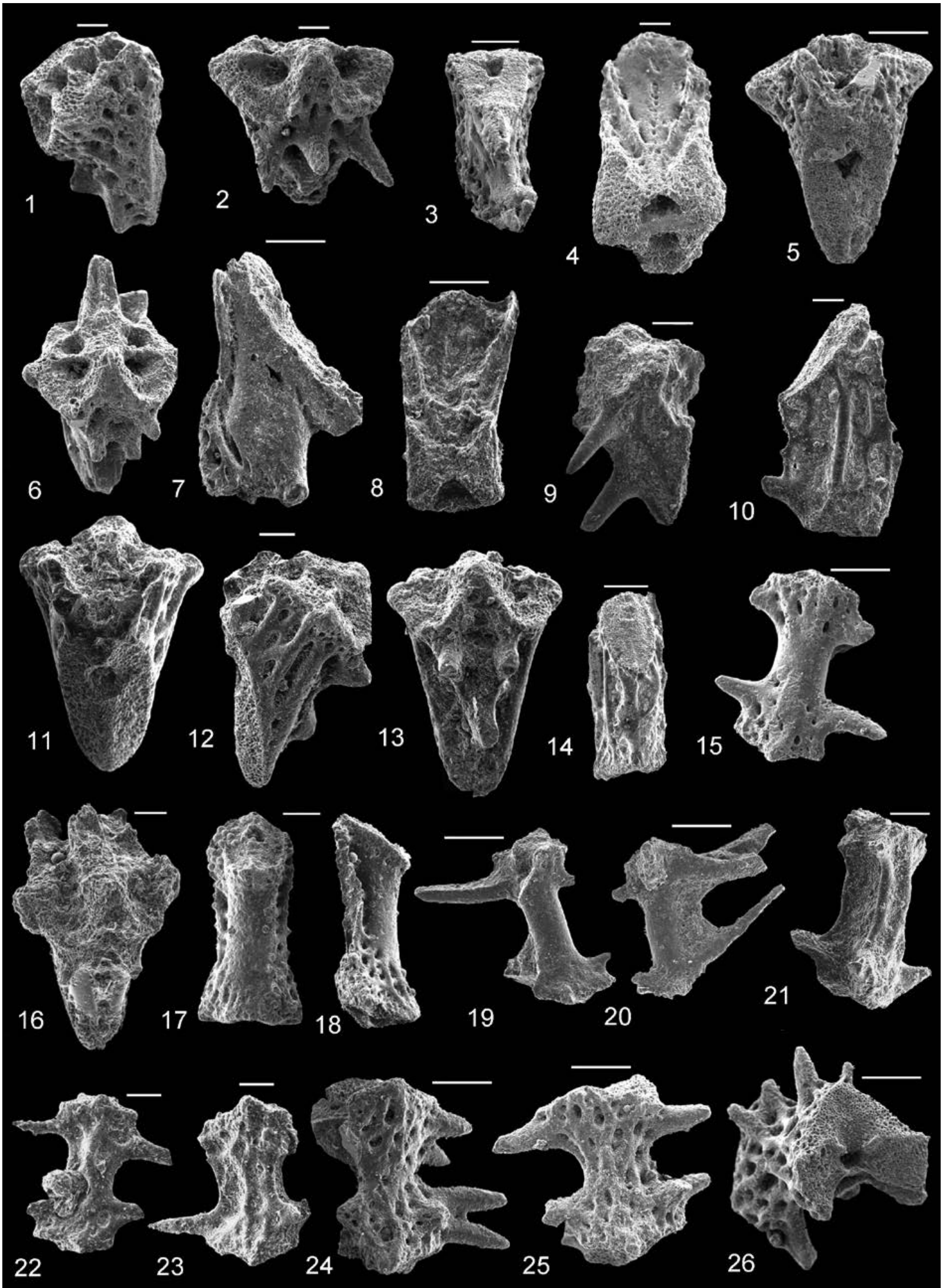
**1-7**, **15**, **24-26** – Brachials of *Euglyphocrinus cristagalli* Gale, 2020. 1, 2, 5, 6 – IBr2 in external (2, 6), lateral (1) and internal (5) views (NHMUK PI EE 17757–17760); 3, 4, 7 – IBr1, in external, internal and lateral views, respectively (NHMUK PI EE 17761–17762, 17780); 15, 24-26 – distal brachials (NHMUK PI EE 17763, 17764–17766).

**8-14**, **21-23** – Brachials of *Euglyphocrinus euglypheus* (Peck, 1943). 11-13 – IBr2 in internal, lateral and external views, respectively (NHMUK PI EE 17770–17772); 8, 10, 14 – IBr1, in internal, lateral and external views, respectively (NHMUK PI EE 17767, 17769, 17773); 9 – IIBr1 in lateral view (NHMUK PI EE 17768); 21-23 – distal brachials in lateral view (NHMUK PI EE 17774, 17775, 17781).

**16-20** – Brachials of *Euglyphocrinus pyramidalis* (Peck, 1943). 16 – IBr2 in external view (NHMUK PI EE 17776); 17, 18 – IBr1 in external and lateral views, respectively (NHMUK PI EE 17777); 19, 20 – distal brachials in lateral view (NHMUK PI EE 17778, 17779).

Figures 1-7, 24-26 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, Main Street Limestone, Sunset Oaks Drive, Hurst, Tarrant County, Texas (sample SD2). Figures 8-14, 21-23 are from the lower Cenomanian, *Graysonites wacoense* Zone, Grayson Formation, Grayson Bluff, Denton County, Texas (sample G1). Figures 16-20 are from the upper Albian, upper Duck Creek Formation, Saginaw Quarry, Fort Worth, Tarrant County, Texas (sample Sag.h).

Scale bars equal 0.1 mm (9-13, 16, 21-23, 25, 26) and 0.2 mm for all others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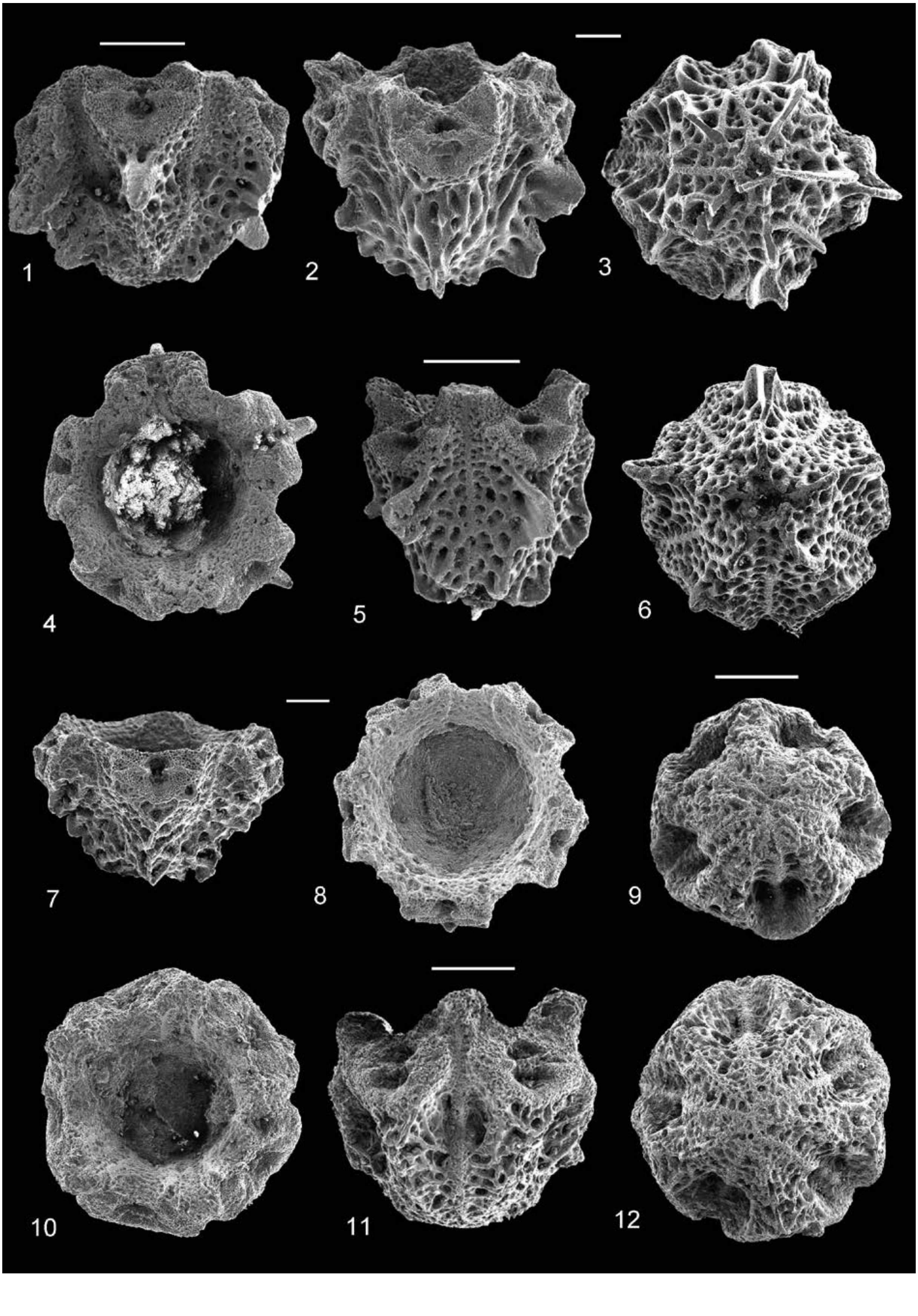
# PLATE 8

**1-8** – *Plotocrinus primitivus* Peck, 1943. 1 – cup bearing single, blunt radial spine, in lateral view (NHMUK PI EE 17782); 2, 3 – cup with bladed radial processes, in lateral radial and aboral views, respectively (NHMUK PI EE 17783); 4-6 – cup in adoral, lateral and aboral views, respectively (NHMUK PI EE 17784); 7, 8 – immature cup in lateral and adoral views, respectively (NHMUK PI EE 17785).

**9-12** – *Plotocrinus rashallae* sp. nov. 9 – paratype cup in aboral view (NHMUK PI EE 17786); 10-12 – holotype cup in adoral, lateral interradial and aboral views, respectively (NHMUK PI EE 17787).

All specimens are from the middle Albian, basal Marys Creek Marl Member, Goodland Formation, Marys Creek, Fort Worth, Tarrant County, Texas (sample MC2; Text-fig. 3).

Scale bars equal 0.5 mm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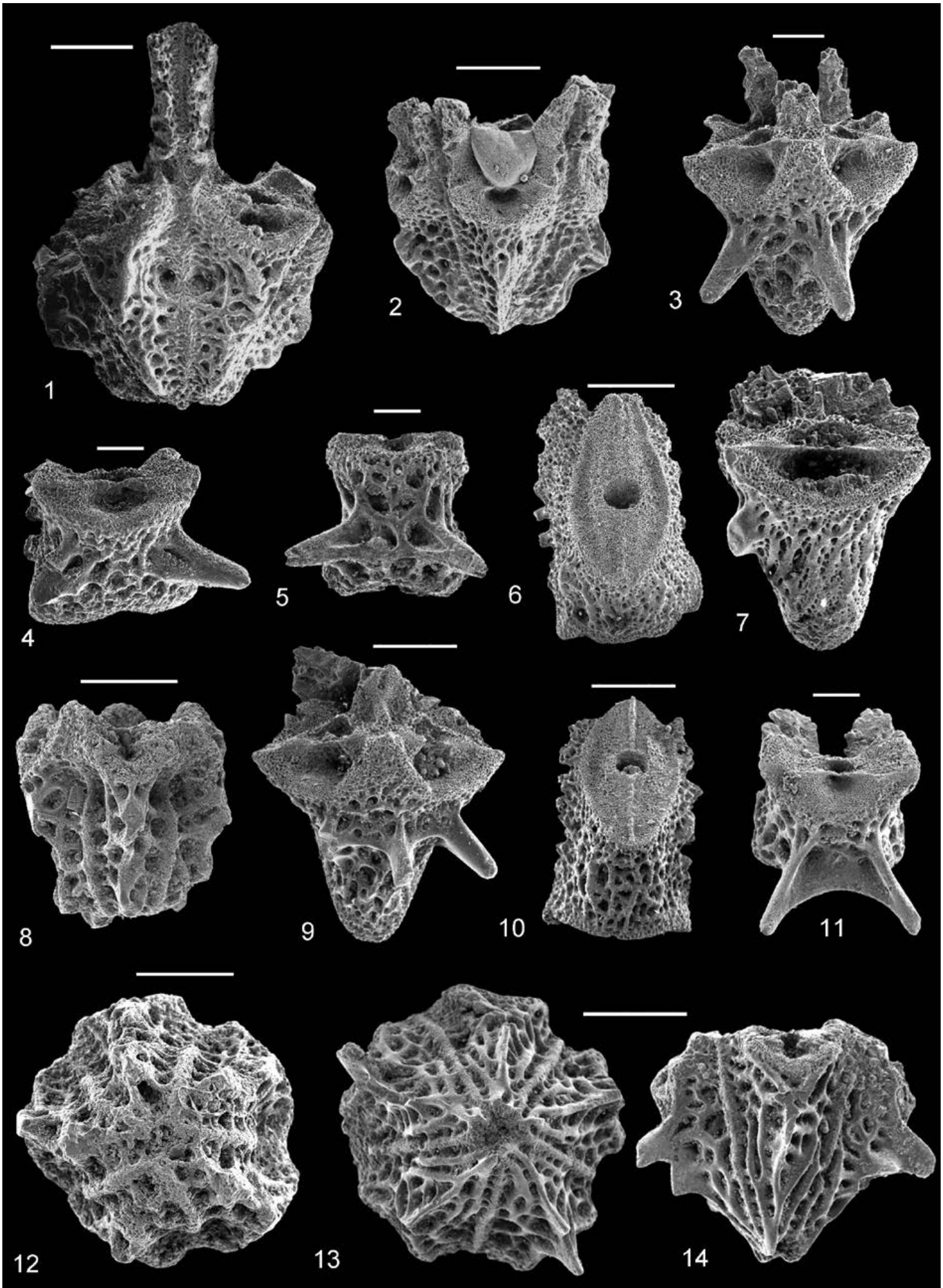
# PLATE 9

**1, 12** – *Plotocrinus rashallae* sp. nov. 1 – paratype cup preserving tall interradial process, in lateral view (NHMUK PI EE 17798); 12 – cup in aboral view (NHMUK PI EE 17799).

**2-11**, **13**, **14** – *Plotocrinus primitivus* Peck, 1943. 2 – cup in lateral view (NHMUK PI EE 17788); 3, 9 – IBr2 in external views (NHMUK PI EE 17789, 17790); 4, 5, 11 – distal brachials in external view (NHMUK PI EE 17793–17795); 6 – IIBr1 in external view (NHMUK PI EE 17791); 7 – IIBr2 in external view (NHMUK PI EE 17797); 10 – IBr1 in external view (NHMUK PI EE 17792); 13, 14 – cup in aboral and lateral views, respectively (NHMUK PI EE 17796).

Figures 1-7, 9-11, 13, 14 are from the middle Albian, basal Marys Creek Marl Member, Goodland Formation, Marys Creek, Fort Worth, Tarrant County, Texas (sample MC2). Figures 8, 12 are from the middle Albian, *Anahoplites intermedius* Subzone, Argiles à Tegulines, Aube, France.

Scale bars equal 0.2 mm (3-7, 9-11) and 0.5 mm for all others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# PLATE 10

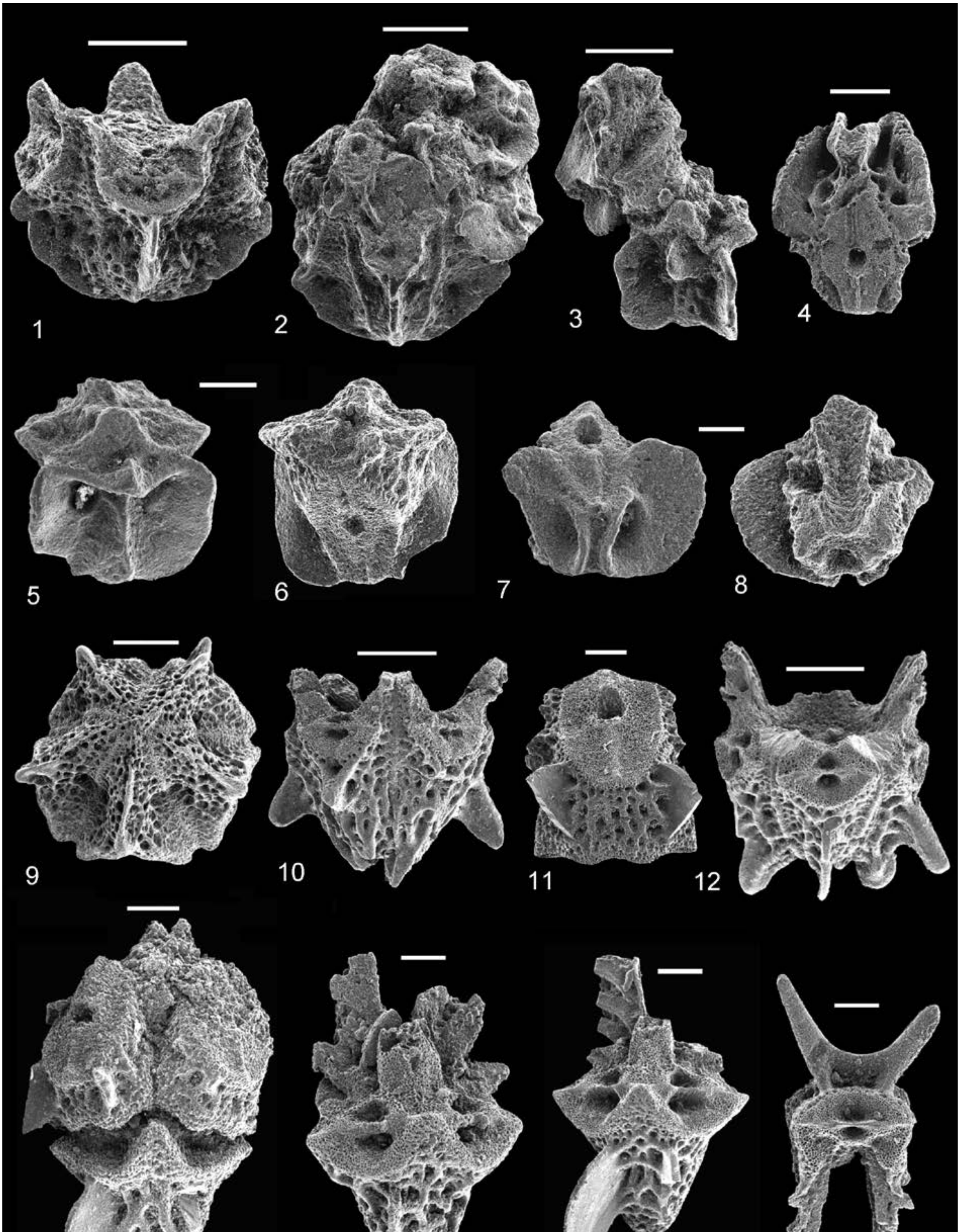
**1-8** – *Plotocrinus molineuxae* sp. nov. 1 – paratype cup in lateral view (NHMUK PI EE 17800); 2 – paratype cup with articulated primibrachial, in lateral view (NHMUK PI EE 17801); 3 – articulated paratype with IBr2, IIBr1 and IIBr2 (NHMUK PI EE 17802); 4 – IBr2 in interior view (NHMUK PI EE 17803); 5, 6 – IBr2 in external and internal views, respectively (NHMUK PI EE 17804); 7, 8 – IBr1 in external and internal views, respectively (NHMUK PI EE 17805).

**9** – *Plotocrinus rashallae* sp. nov., paratype cup in aboral view (NHMUK PI EE 17806).

**10-16** – *Plotocrinus primitivus* Peck, 1943. 10 – cup in lateral view (NHMUK PI EE 17807); 11 – primibrachial IBr1 in external view (NHMUK PI EE 17808); 12 – cup in lateral view (NHMUK PI EE 17809); 13 – articulated IBr2 and IIBr1 (NHMUK PI EE 17810); 14, 15 – IBr2 in external views (NHMUK PI EE 17811, 17812); 16 – brachial from mid- to distal arm portion in distal view (NHMUK PI EE 17813).

Figures 1-8 are from the middle Albian, Benbrook Limestone Member of Goodland Formation, Benbrook dam spillway, Fort Worth, Tarrant County, Texas (sample Ben1). Figures 9-16 are from the middle Albian, basal Marys Creek Marl Member, Goodland Formation, Marys Creek, Fort Worth, Tarrant County, Texas (sample MC1, 2).

Scale bars equal 0.2 mm (5-8, 13-16) and 0.5 mm for all others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# PLATE 11

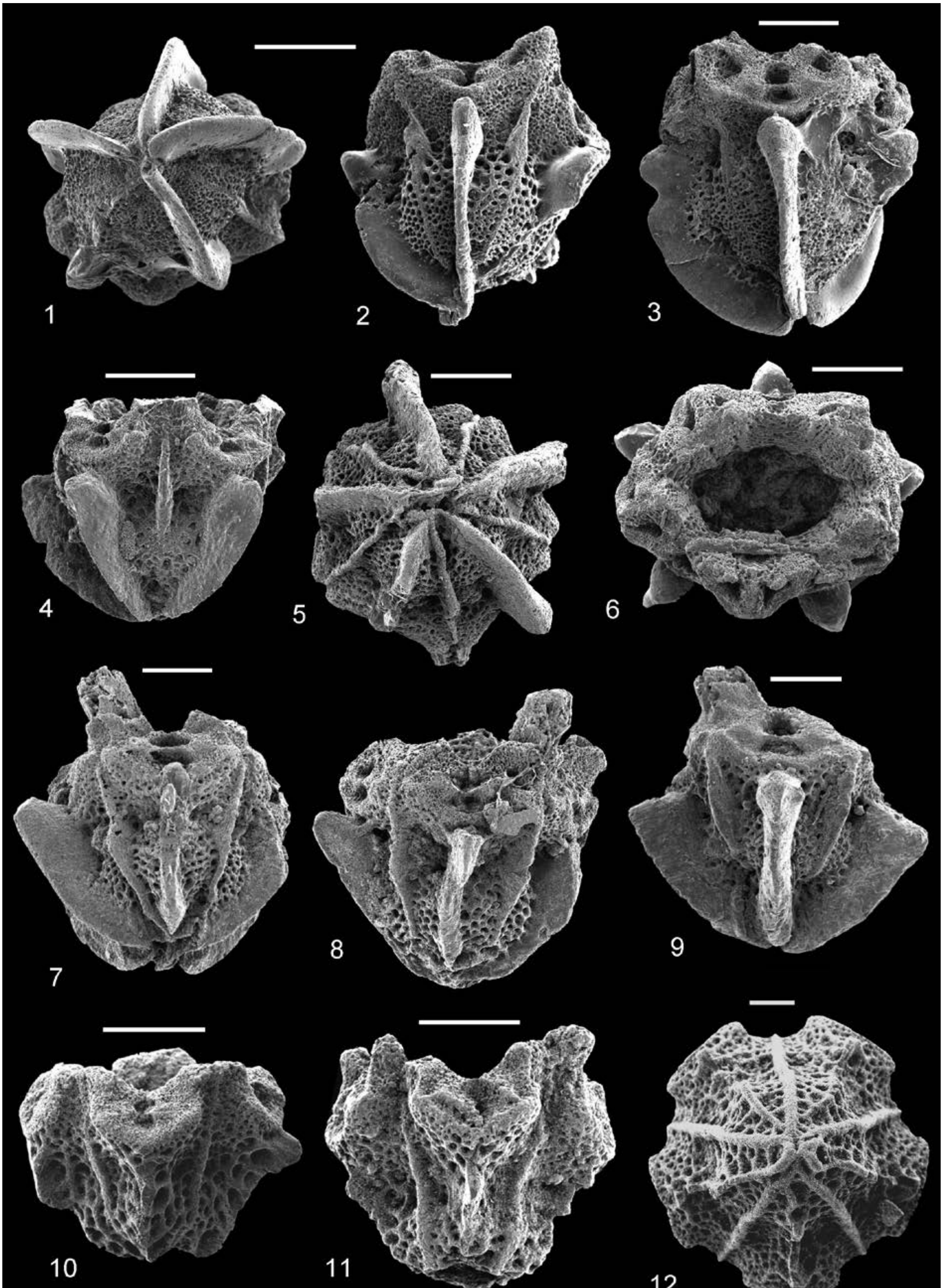
**1-3**, **6** – *Plotocrinus reidi* sp. nov. 1, 2 – holotype cup in aboral and lateral views, respectively (USNM 128561); 3, 6 – paratype cup in lateral and adoral views, respectively (USNM 128361.3).

**4**, **5**, **7-9** – *Plotocrinus distinctus* Peck, 1953. 4, 7, 9 – cups in lateral view (NHMUK PI EE 17814); 5, 8 – cup in aboral and lateral views, respectively (NHMUK PI EE 17815).

**10-12** – *Plotocrinus molineuxae* sp. nov. 10 – paratype cup in lateral view (NHMUK PI EE 17818); 11 – holotype cup in lateral view (NHMUK PI EE 17819); 12 – paratype cup in lateral view (NHMUK PI EE 17820).

Figures 1-3, 6 are from the upper Albian, *Pervinquieria* (*Pervinquieria*) *pricei* Zone, Kiamichi Formation, slope and bank of Red River, north of Denison, Grayson County, Texas. Figures 10-12 are from the middle Albian, Benbrook Limestone Member of Goodland Formation, Benbrook dam spillway, Fort Worth, Tarrant County, Texas (sample Ben1). Figures 4, 5, 7-9 are from the upper Albian, probably the *Dipoloceras cristatum* Zone, uppermost Benbrook Limestone Member of Goodland Formation, Cragin Knobs, Fort Worth, Tarrant County, Texas (see Perkins 1960, pl. 8, fig. 2).

Scale bars equal 0.5 mm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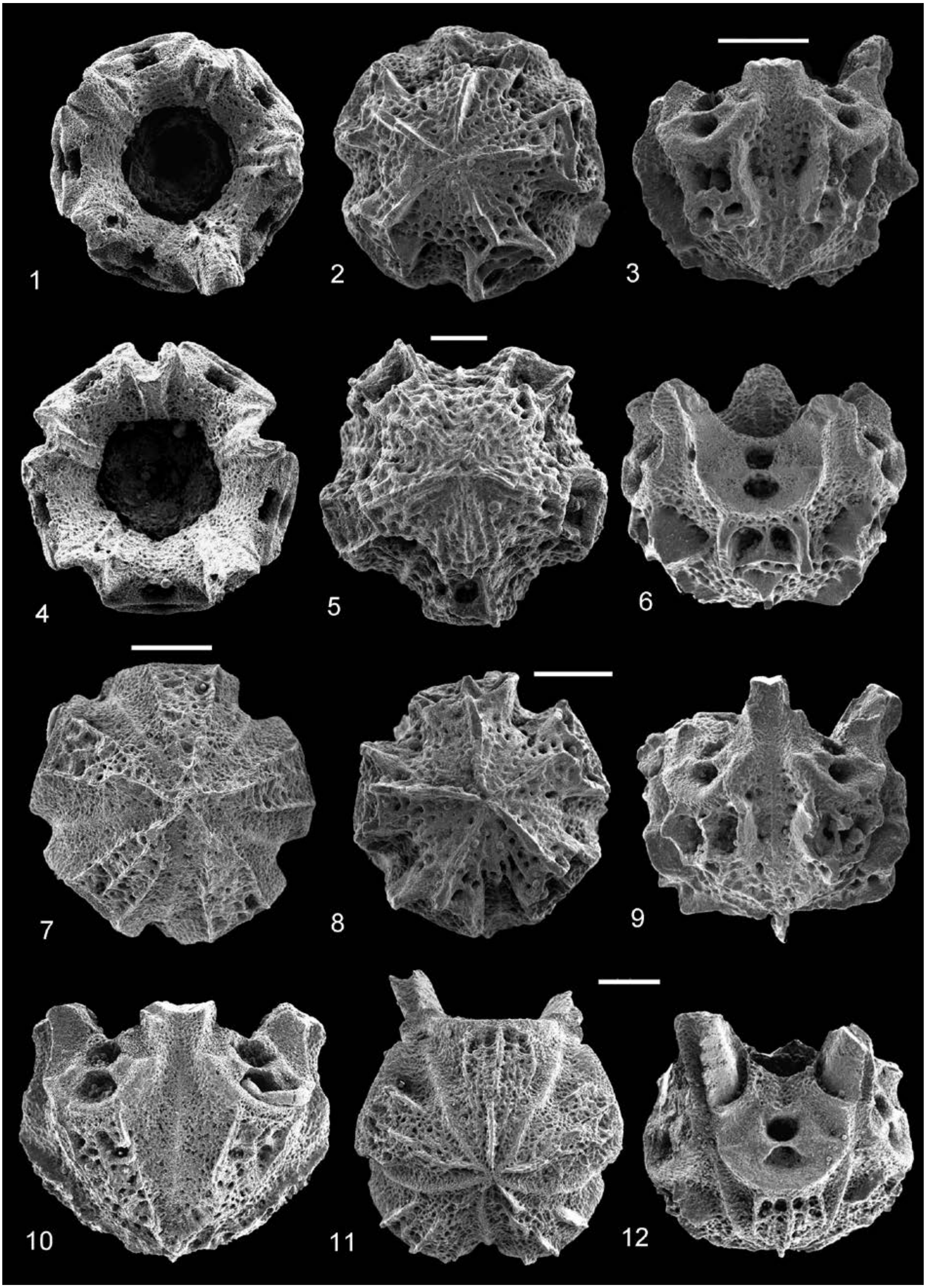
# PLATE 12

**1-6**, **8**, **9** – *Plotocrinus modulatus* Peck, 1943. 1-3 – paratype cup in adoral, aboral and lateral views, respectively (USNM 128359); 4-6 – paratype cup in adoral, aboral and lateral views, respectively (USNM 128359b); 8, 9 – paratype cup in aboral and lateral views, respectively (USNM 128359c).

**7**, **10-12** – *Plotocrinus hemisphericus* Peck, 1943. 7, 10 – cup in aboral and lateral views, respectively (NHMUK PI EE 17821); 11, 12 – cup in aboral and lateral views, respectively (NHMUK PI EE 17822).

Figures 1-6, 8, 9 are from the upper Albian, Duck Creek Formation, deep road cut on east side of US Highway 77, south of Red River Bridge, Cook County, Texas. Figures 7, 10-12 are from the upper Albian, lower Duck Creek Formation, Horseshoe Bend of Red River, Love County, Oklahoma (sample HB6).

Scale bars equal 0.5 mm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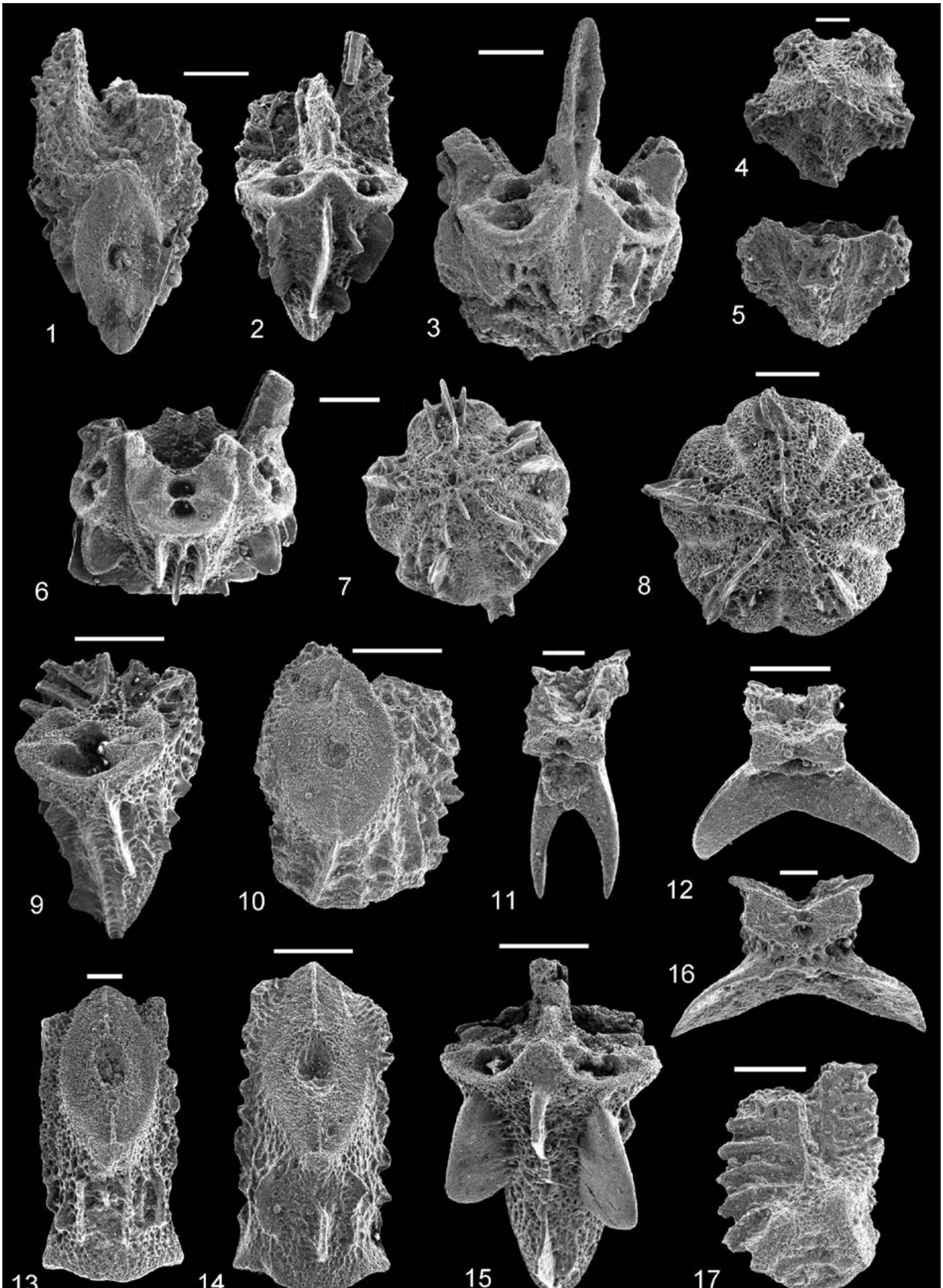
# PLATE 13

*Plotocrinus hemisphericus* Peck, 1943

1, 2 – paratype primibrachial IBr2 in internal and external views, respectively (USNM 128357b); 3 – cup bearing tall interradial process, in lateral view (NHMUK PI EE 17823); 4, 5 – small cup in aboral and lateral views, respectively (NHMUK PI EE 17824); 6, 7 – cup in lateral and aboral views, respectively (NHMUK PI EE 17825); 8 – cup in aboral view (NHMUK PI EE 17826); 9 – IIBr2 in external view (NHMUK PI EE 17827); 10 – IIBr1 in external view (NHMUK PI EE 17828); 11, 12, 16 – distal brachials possibly belonging to this species in distal view (NHMUK PI EE 17829, 17830, 17835); 13, 14 – IBr1 in external view (NHMUK PI EE 17831, 17833); 15 – IBr2 in external view (NHMUK PI EE 17834); 17 – IIBr1 in internal view (NHMUK PI EE 17836).

Figure 1 is from the upper Albian, Duck Creek Formation, deep road cut on east side of US Highway 77, south of Red River Bridge, Cook County, Texas. Figures 2-17 are from the upper Albian, lower Duck Creek Formation, Horseshoe Bend of Red River, Love County, Oklahoma (sample HB6).

Scale bars equal 0.2 mm (4, 5, 11, 16) and 0.5 mm for all others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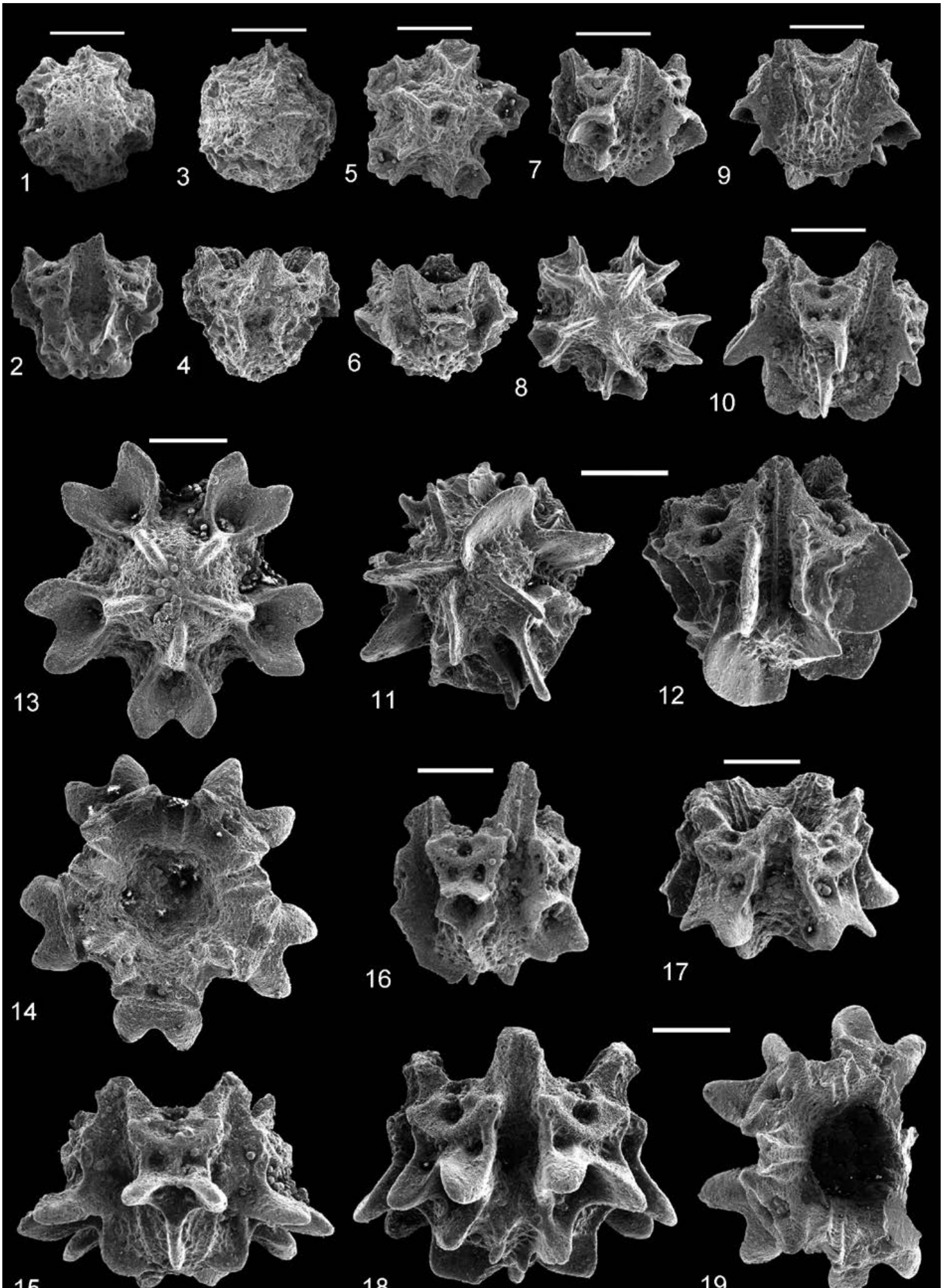
# PLATE 14

*Poecilocrinus spiculatus* Peck, 1943

1-8 – growth series of cups (NHMUK PI EE 17837–11840) in aboral (1, 3, 5, 7) and lateral views (2, 4, 6, 8); 9, 10 – cups in lateral view (NHMUK PI EE 17841, 17842); 11, 12 – form with strong aboral radial blades, possibly belonging to this species, in aboral and lateral views, respectively (NHMUK PI EE 17843); 13-15 – large cup in aboral, adoral and lateral views, respectively (NHMUK PI EE 17844); 16, 17 – cups in lateral view (NHMUK PI EE 17845, 17846); 18, 19 – large cup in lateral and adoral views, respectively (NHMUK PI EE 17847).

Figures 1-9 are from the upper Albian, lower Duck Creek Formation, Horseshoe Bend of Red River, Love County, Oklahoma (sample RR 1). Figures 10-19 are from the same locality (sample HB2).

Scale bars equal 0.5 mm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# PLATE 15

**1-6** – *Peckicrinus porcatus* (Peck, 1943). 1-3 – paratype cup in aboral, adoral and lateral views, respectively (USNM 128349a); 4 – cup in aboral view (USNM 128349b); 5, 6 – cups in lateral view (NHMUK PI EE 17848, 17849).

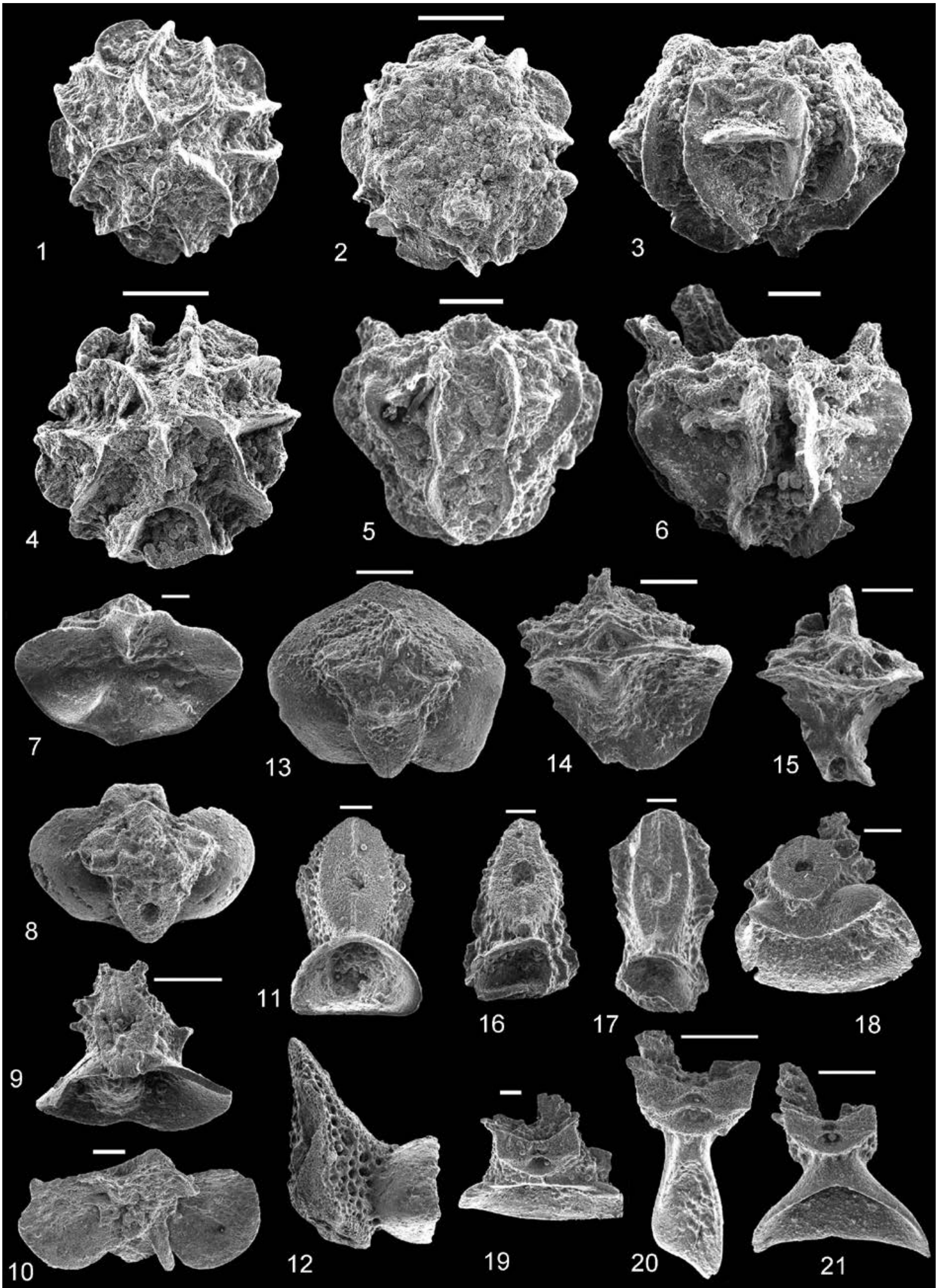
**7-12** – brachials of *Poecilocrinus spiculatus* Peck, 1943. 7, 8 – IBr2 in external and internal views (NHMUK PI EE 17850); 9 – IIBr2 in distal view (NHMUK PI EE 17851); 10 – IBr2 in lateral view (NHMUK PI EE 17852); 11, 12 – IBr1 in external and lateral views (NHMUK PI EE 17853).

**13-20** – brachials of *Poecilocrinus pendulus* Peck, 1943. 13, 14 – IBr2 of A type in internal and external views, respectively (NHMUK PI EE 11854, 11855); 15 – IBr2 of B type in external view (NHMUK PI EE 11856); 16, 17 – IBr1 in external and internal view, respectively (NHMUK PI EE 17857, 17858); 18 – IIBr2 in proximal view (NHMUK PI EE 17859); 19, 20 – brachials from midarm portion in distal view (NHMUK PI EE 17860, 17861).

**21** – distal brachial of unknown affinity in distal view (NHMUK PI EE 17862).

Figures 1-4, recorded as coming from the 'Fort Worth Formation, cutting on Highway US 77, Cooke County, Texas', but the remainder of the fauna from this locality is indicative of the lower Duck Creek Formation. Figures 5, 6, 7 are from the upper Albian, lower Duck Creek Formation, Red River, Horseshoe Bend, Love County, Oklahoma (sample RR1). Figures 8-12 are from the same locality (sample HB2). Figures 14-21 are from the upper Albian, middle Duck Creek Formation, river bank on north side of Red River, east of bridge for US Highway 75, locality no. HTL 28 (Peck 1943). Again, this is actually middle Duck Creek rather than Fort Worth Formation (sample RRFW).

Scale bars equal 0.2 mm (5-8, 10-12, 16-19) and 0.5 mm for all others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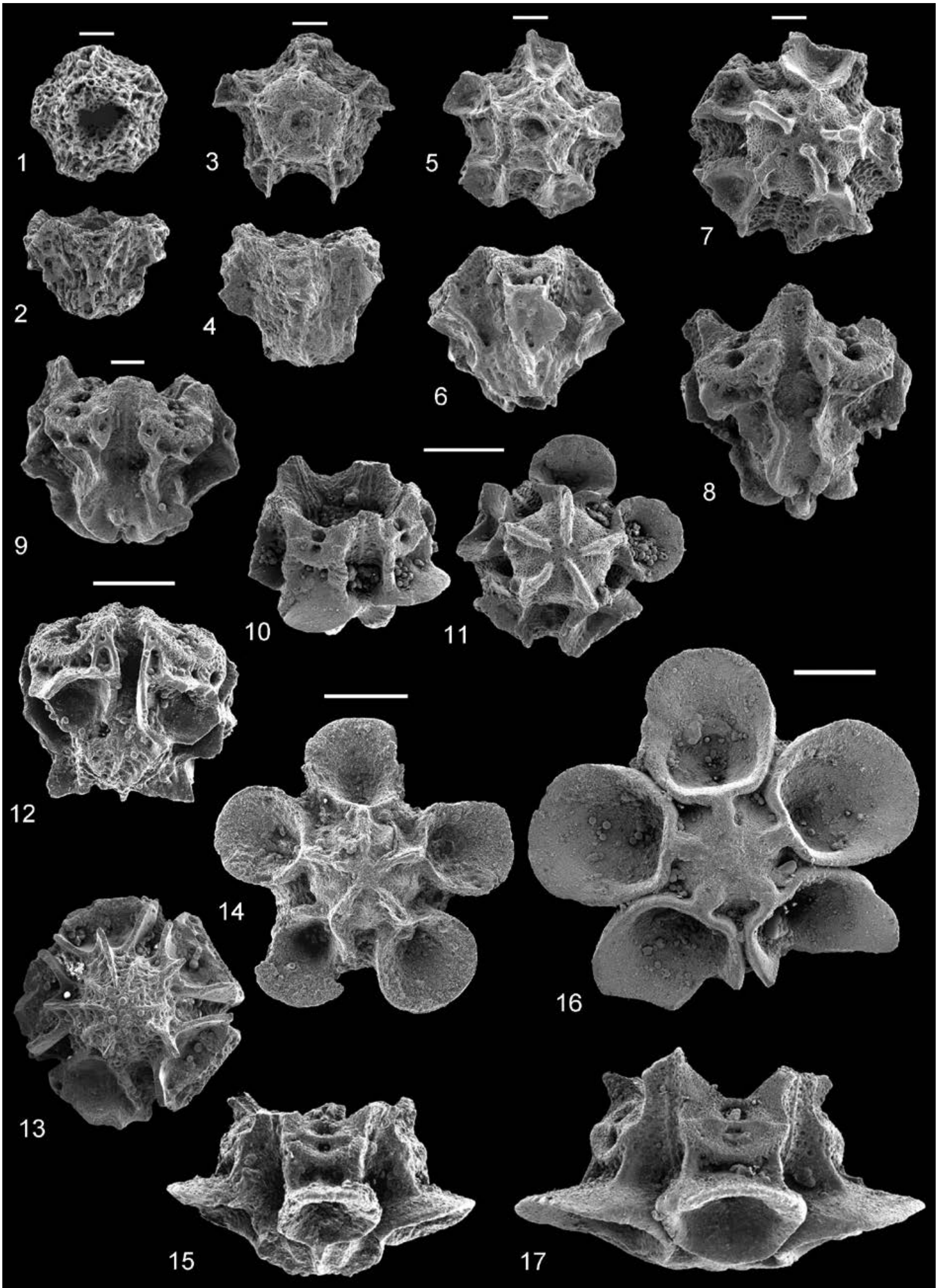
# PLATE 16

*Poecilocrinus pendulus* Peck, 1943

1-8 – growth series of cups (NHMUK PI EE 17863–17866) in aboral (1, 3, 5, 7) and lateral views (2, 4, 6, 8); 9 – cup in lateral view (NHMUK PI EE 17867); 10, 11 – cups in which the rounded, horizontal flanges are present, in oblique lateral and aboral views, respectively (NHMUK PI EE 17868, 17869); 12, 13 – cup in which the concave flanges are nearly vertical, in lateral and aboral views, respectively (NHMUK PI EE 17870); 14-17 – two cups of maximum size in aboral (14, 16) and lateral (15, 17) views (NHM UK PI EE 17871, 17872).

Figures 1-8, 12, 13, 16, 17 are from the upper Albian, middle Duck Creek Formation, river bank on north side of Red River, east of bridge for US Highway 75, locality no. HTL 28 (Peck 1943). Again, this is actually middle Duck Creek rather than Fort Worth Formation (sample RRFW). Figures 11, 14, 15 are from the upper Albian, middle Duck Creek Formation, Red River, Horseshoe Bend, Love County, Oklahoma (sample RR1).

Scale bars equal 0.2 mm (1-8) and 0.5 mm for all others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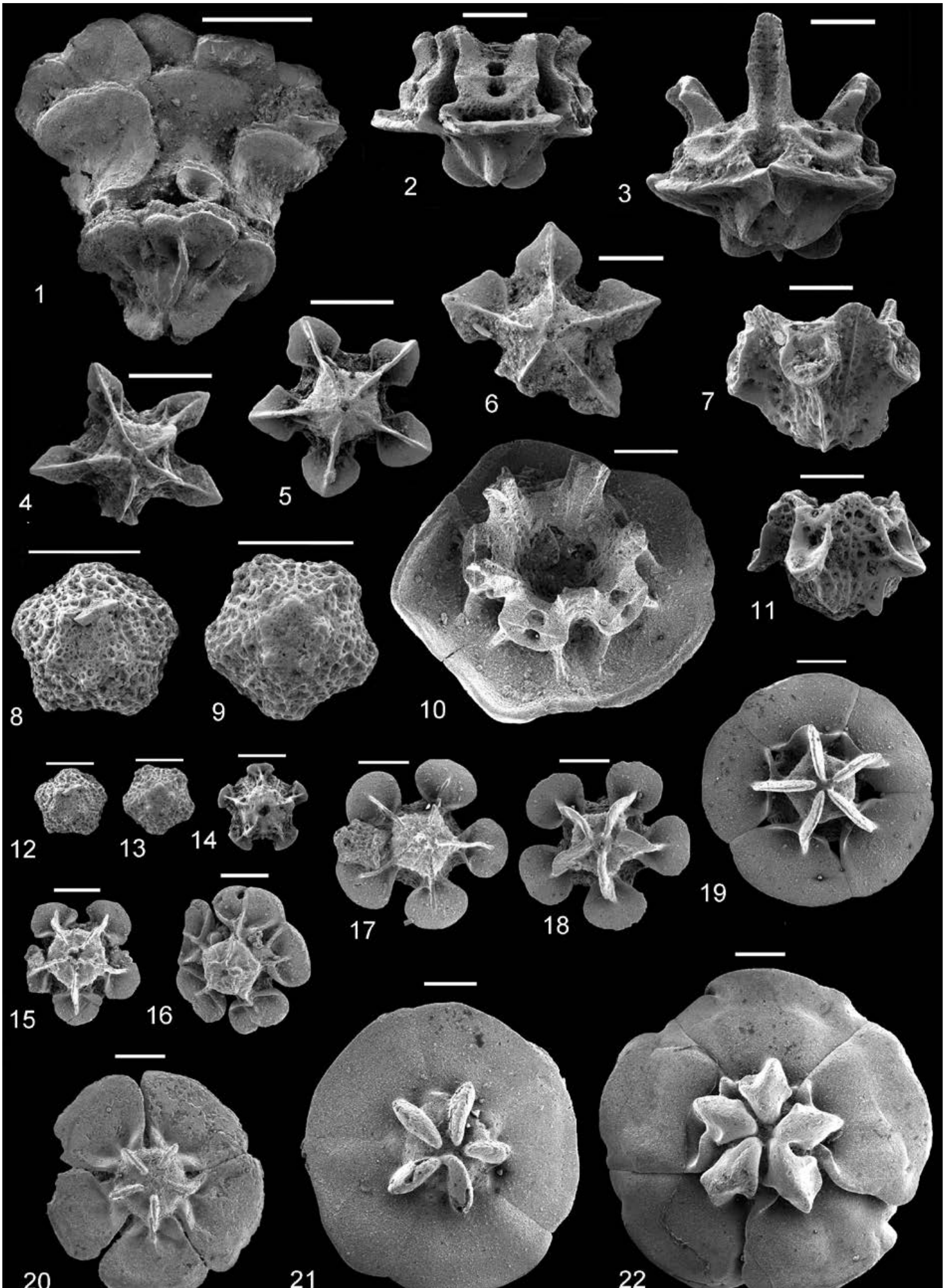
# PLATE 17

*Poecilocrinus latealatus* (Peck, 1943)

1 – cup with proximal brachials, up to IIBr2, in lateral view, original of Hess (2015, fig. 6a; NMB M11522); 2, 3 – cups in lateral view, originals of Hess (2015, fig. 6i, j; NMB M11535, NMB M11534); 4-6, 14 – small individuals of a form with pointed terminations on the radial flanges; originals of Hess (2015, fig. 4c, e, f, i; NMB M11548, NMB M11560, NMB M11544, NMB M11555); 7, 11 – small cups in lateral view; originals of Hess (2015 fig. 5l, j; NMB M11581, NMB M11540); 8, 9, 12, 13 – the smallest cups found, originals of Hess (2015 fig. 4a, b; NMB M11564, NMB M11561); note basals and centrale in 8; 10 – large cup in adoral view (NHMUK PI EE 17873); 15-22 – growth series of cups of a form with rounded flanges, in aboral view (NHMUK PI EE 17874–17881).

Figures 1-9, 11, 12-14 are from the upper Albian, upper Duck Creek Formation, Saginaw Quarry, Fort Worth, Tarrant County, Texas (sample Sag.h). Figures 10, 15-21 are from the upper Albian, upper Duck Creek Formation, Fort Worth, Tarrant County, Texas.

Scale bars equal 0.5 mm (10, 15-20) and 1 mm for all others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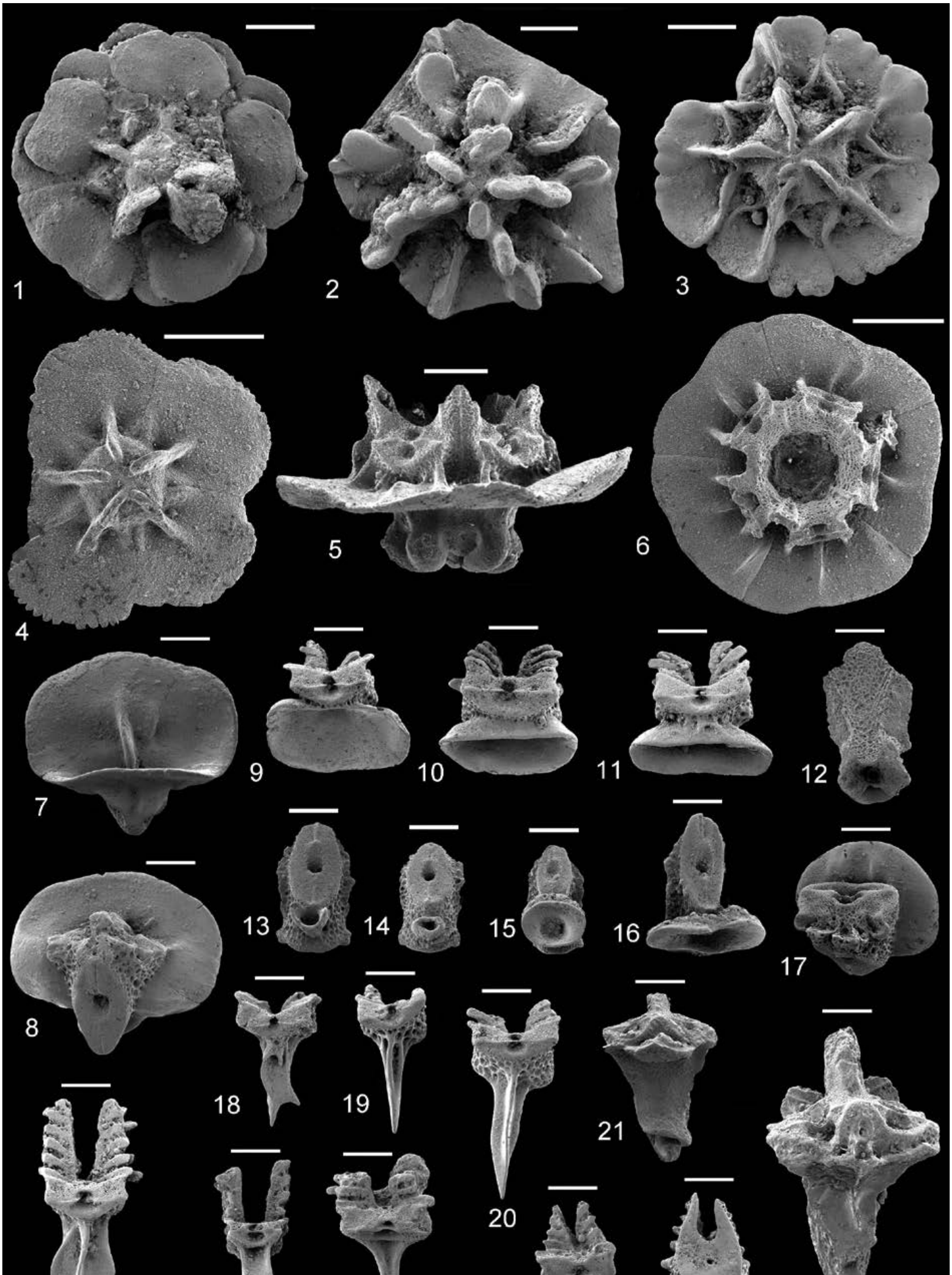
# PLATE 18

*Poecilocrinus latealatus* (Peck, 1943)

1-3 – cups in aboral view, to show double lateral radial flanges (1 – original of Hess 2015, fig. 4m; NMB M11536); irregular growths on aboral surface (2 – original of Hess 2015, fig. 4p; NMB M11552) and an embayed, irregular outline (3 – original of Hess 2015, fig. 4k; NMB M11537); 4-6 – cups in aboral (4; NHMUK PI EE 17882), lateral (5; NHM UK PI EE 17883) and adoral views (6; NHM UK PI EE 17884); 7, 8 – IBr2 in external and internal views, respectively; originals of Hess (2015, fig. 7a1, a2; NMB M11608); 9-11 – proximal secundibrachials in distal view, originals of Hess (2015, fig. 8a–c; NMB M11661, NMB M11655, NMB M11665); 12 – IBr1 in interior view, original of Hess (2015, fig. 7n; NMB M11610); 13-16 – IBr1 in external views, originals of Hess (2015, fig. 7g–i; NMB M11612, NMB M11615, NMB M11613; and fig. 7r; NMB M11647); 17 – IIBr2 in internal view, original of Hess (2015, fig. 8g; NMB M11662); 18-20, 22-24 – distal brachials, in distal view, originals of Hess (2015, fig. 8r–w; NMB M11664, NMB M11672, NMB M11677, NMB M11629, NMB M11671, NMB M11669); 21, 22 – IBr2 of type B in external view, originals of Hess (2015, fig. 13g, h; NMB M11680, NMB M11631; figured as possible brachials of *Orthogonocrinus apertus* Peck, 1943); 25, 26 – small distal brachials in distal/proximal view, originals of Hess (2015, fig. 8n, o; NMB M11658, NMB M11656).

Figures 1-3, 7-27 are from the upper Albian, upper Duck Creek Formation, Saginaw Quarry, Fort Worth, Tarrant County, Texas (sample Sag.h). Figures 4-6 are from the upper Albian, upper Duck Creek Formation, Fort Worth, Tarrant County, Texas.

Scale bars equal 0.5 mm (5, 21, 27) and 1 mm for all others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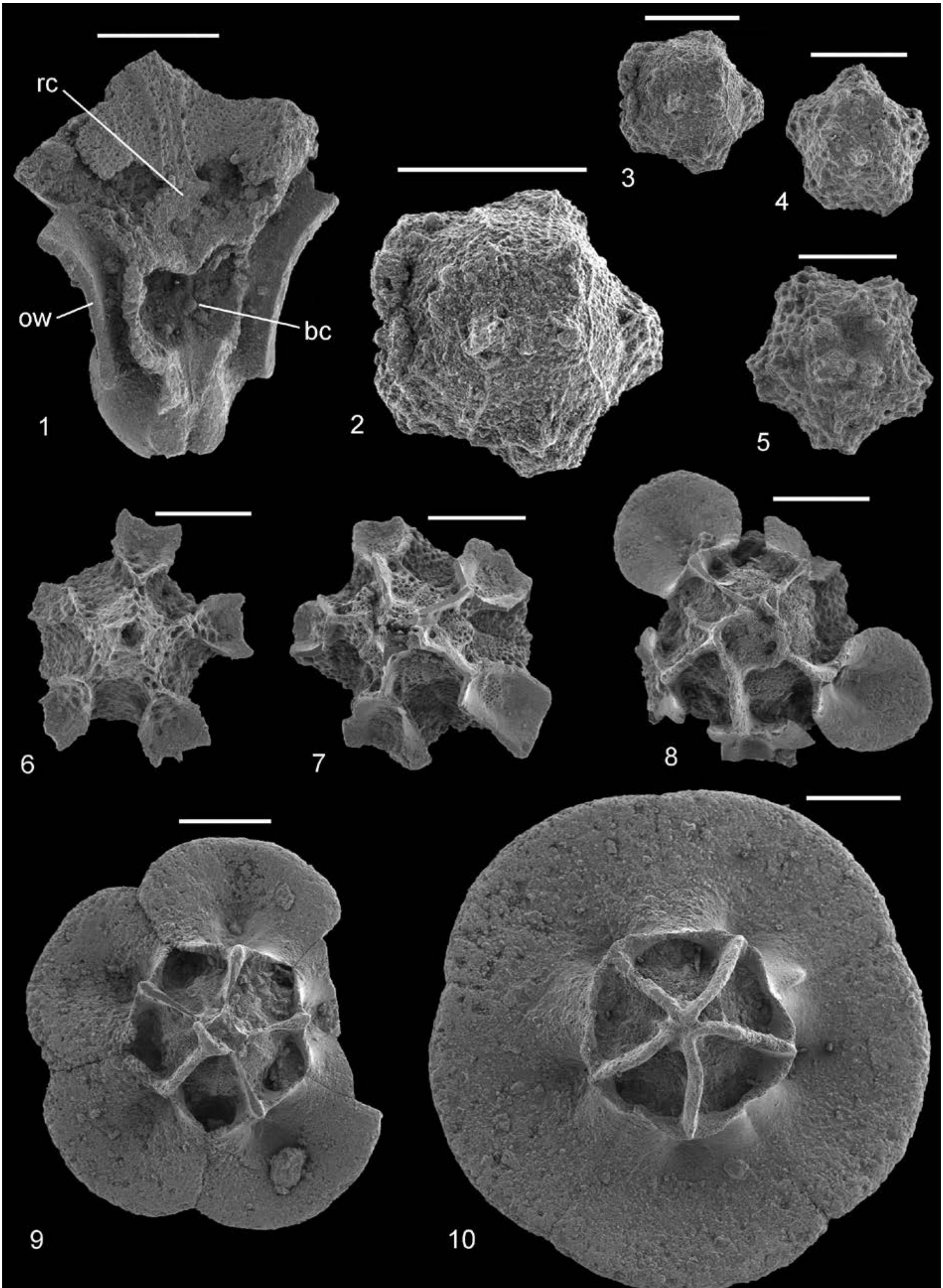
# PLATE 19

**1** – *Poecilocrinus dispandus* forma *elongatus* Peck, 1943. Cup broken longitudinally to show internal structure; note **bc**, basal cavity and **rc**, radial cavity, separated by shelf of basal plates; the radial flanges have fused to form a cylindrical outer wall (**ow**) around the cup, separated from the inner wall by tubes which exit around the aboral pole. Original of Gale (2020, pl. 20, fig. 1; NHMUK PI EE 17554).

**2-10** – *Poecilocrinus dispandus* forma *discus* nov., to show growth series. 2, 3 – the smallest cup found, aboral view, enlarged in 2, to show the presence of basals and a centrale (NHMUK PI EE 17855); 4, 5 – with a simple conical cup (originals of Gale 2020, pl. 20, figs 3, 4; NHMUK PI EE 17576, 17577), but developing increased size radial flanges, aborally concave; 6 and 7 – originals of Gale (2019, pl. 20, figs 5, 6; NHMUK PI EE 17556, 17557). Eventually, these become spoon-shaped (8; original of Gale 2020, pl. 20, fig. 7; NHMUK PI EE 17558), then fuse to form a peripheral shelf (9, 10; originals of Gale 2020, figs 8, 9; NHMUK PI EE 17559, 17560) (modified from Gale 2020, pl. 19).

All specimens are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, middle to upper Weno Formation. Figures 1-5 are from a roadcut in Cleburne, Johnson County, Texas. Figures 6-10 are from sample HTN1, Heritage Trace Parkway, Fort Worth, Tarrant County, Texas.

Scale bars equal 0.5 mm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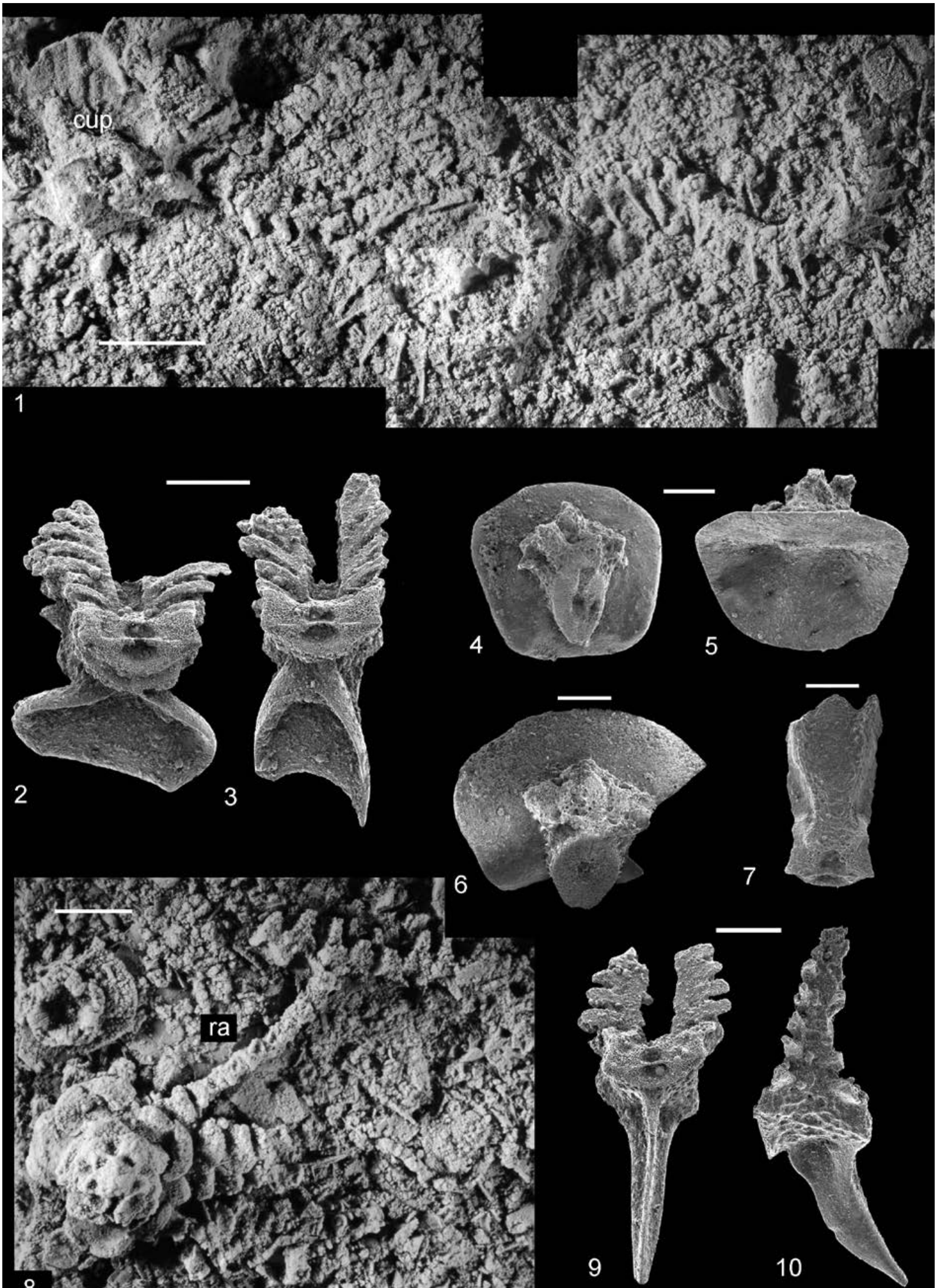
# PLATE 20

*Poecilocrinus dispandus* Peck, 1943

1 – cup and arms in aboral view, original of Scott *et al.* (1977, pl. 1, fig. 3; USNM 220401); 2, 3 – proximal secundibrachials in distal view (NHMUK PI EE 17886, 17887); 4-6 – IBr2 in internal (4, 6) and external (5) views (NHMUK PI EE 17888–17890); 7 – IBr1 in internal view (NHMUK PI EE 17891); 8 – cup and proximal arm in aboral view; original of Scott *et al.* (1977, pl. 1, fig. 7; USNM 220400); note that the arm marked **ra** is regenerated and not typical of the species; 9, 10 – distal secundibrachials in transverse and lateral views, respectively (NHMUK PI EE 17893, 17894).

Figures 1, 8 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, middle Weno Formation, junction of East Berry and Old Mansfield Roads, Fort Worth, Tarrant County, Texas. Figures 2-7, 9, 10 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, middle–upper Weno Formation, roadcut in Cleburne, Johnson County, Texas.

Scale bars equal 0.5 mm (2-7, 9, 10) and 2 mm (1, 8)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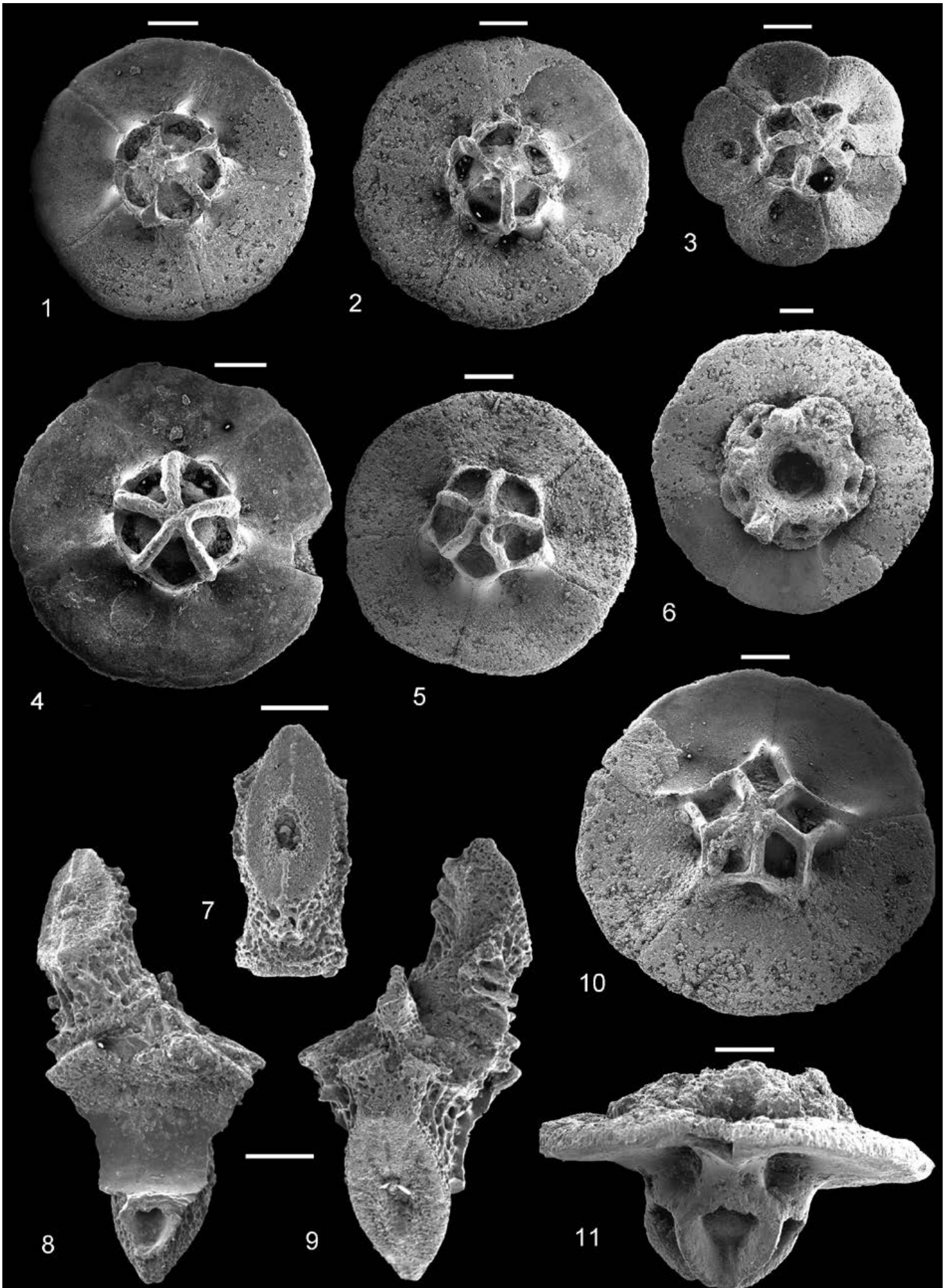
# PLATE 21

**1-6**, **10**, **11** – *Poecilocrinus dispandus* forma *discus* nov. 1-5, 10 – cups in aboral view (NHMUK PI EE 17895–17900); 1 is the holotype; 2-5 are paratypes; 6 – cup in adoral view (NHMUK PI EE 17901); 11 – cup in lateral view (NHMUK PI EE 17902).

**7-9** – *Poecilocrinus dispandus*, proximal brachials. 7 – IBr1 in external view (NHMUK PI EE 17903); 8, 9 – articulated IBr2 and IIBr1 of form B, in external and internal views, respectively (NHMUK PI EE 17904).

Figures 1-6, 10, 11 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, lower Weno Formation, Motorola site, Fossil Creek Boulevard, Fort Worth, Tarrant County, Texas (sample MO). Figures 8, 9 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, lower Weno Formation, Creasote Drive, off Heritage Trace Parkway, Tarrant County, Texas (sample HT0). Figure 7 is from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, middle-upper Weno Formation, roadcut in Cleburne, Johnson County, Texas.

Scale bars equal 0.5 mm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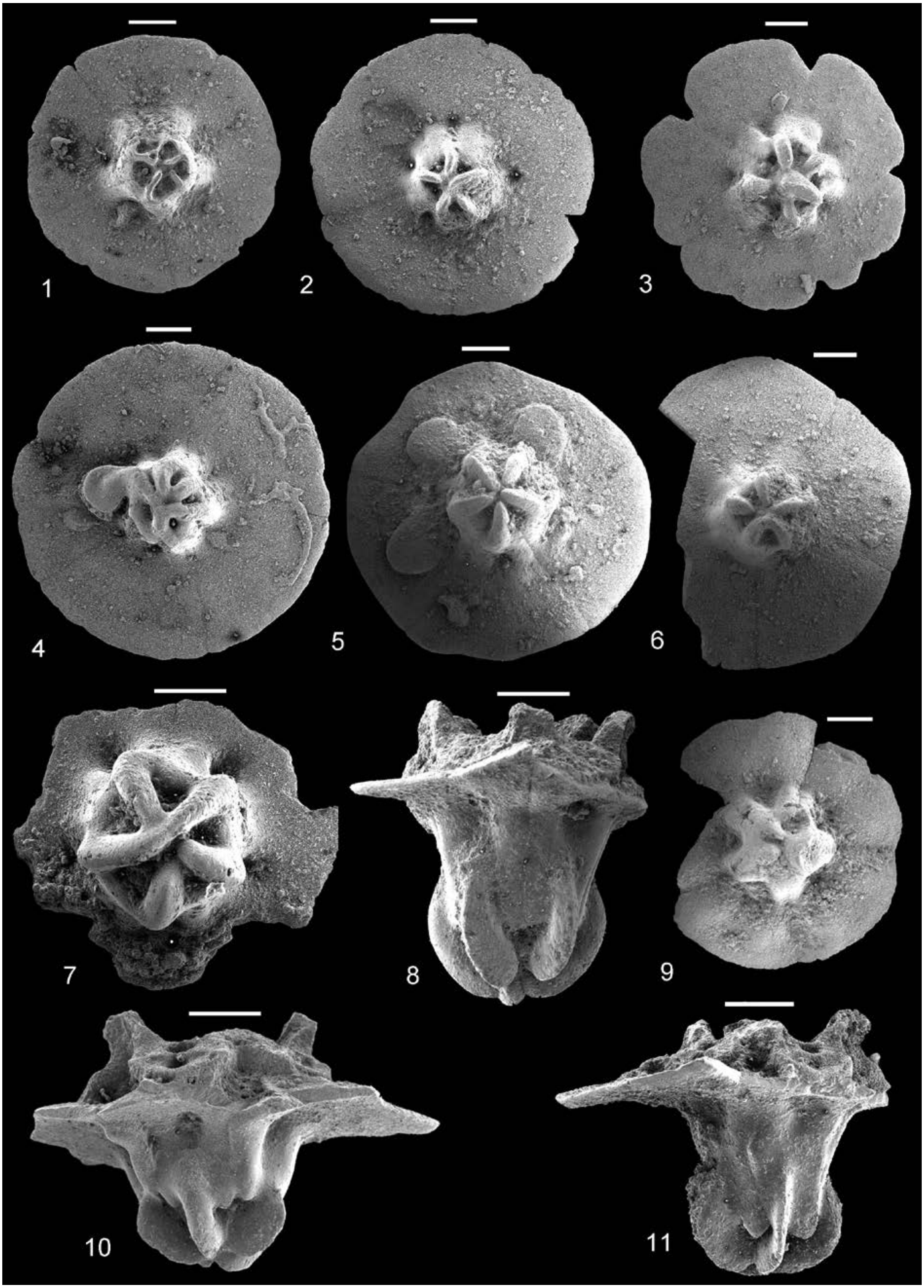
# PLATE 22

**1-6**, **9** – *Poecilocrinus dispandus* forma *discus* nov. Cups in aboral view (NHMUK PI EE 17905–17910, 17913).

**7**, **8**, **10**, **11** – *Poecilocrinus dispandus* forma *elongatus* Peck, 1943. 7 – cup in aboral view (NHMUK PI EE 17911); 10, 11 – cups in lateral view (NHMUK PI EE 17914, 17915).

All specimens are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, middle–upper Weno Formation, roadcut on US Highway 67, in Cleburne, Johnson County, Texas.

Scale bars equal 0.5 mm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## PLATE 23

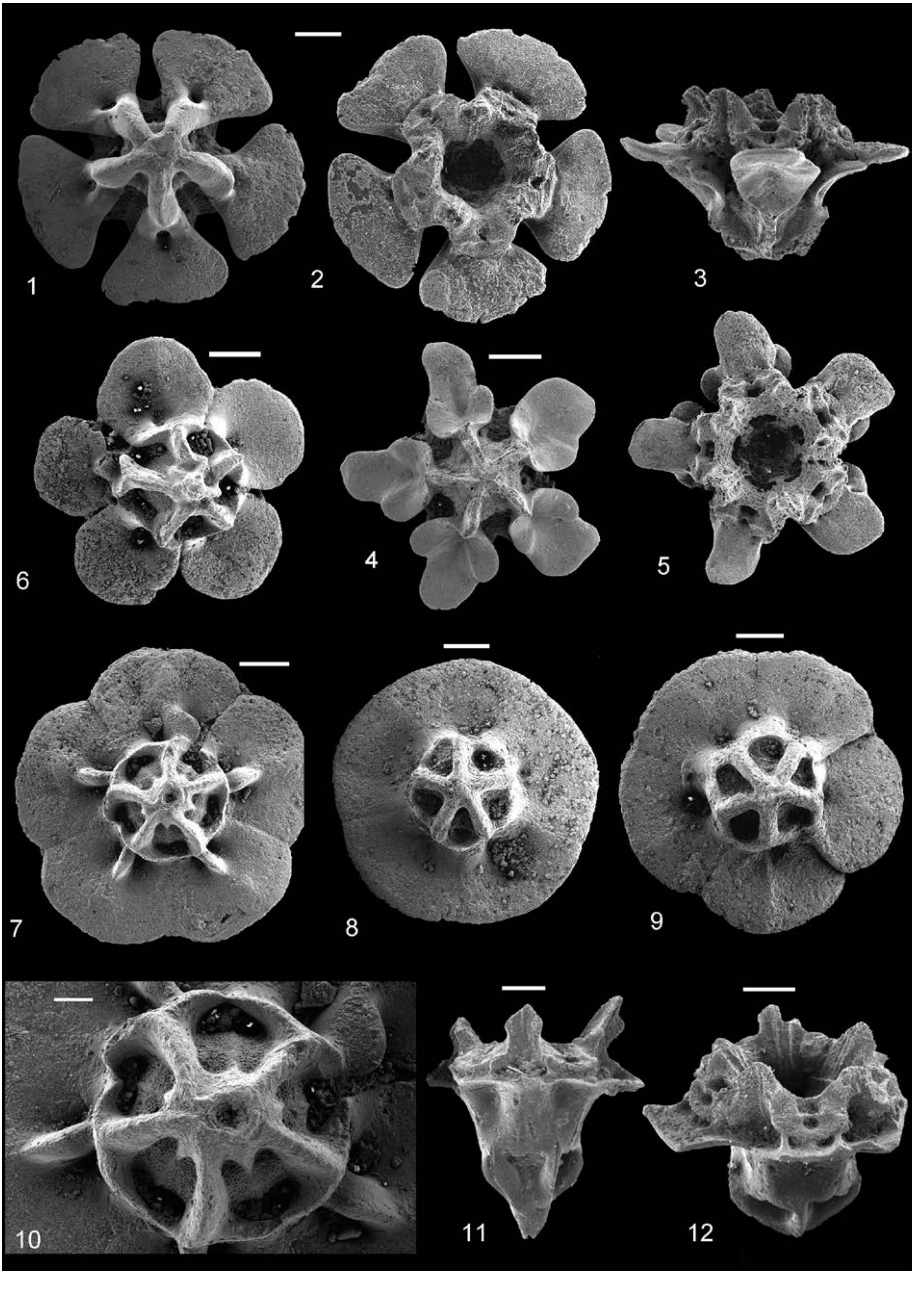
**1-5** – *Poecilocrinus dispandus* forma *floriformis* nov. 1, 2 – paratype cup in aboral and adoral views, respectively (NHMUK PI EE 17916); 3-5 – holotype cup in lateral, aboral and adoral views, respectively (NHMUK PI EE 17917).

**6-10** – *Poecilocrinus dispandus* forma *discus* nov. Cups in aboral view; 10 is an enlargement of the central region of 7 (NHMUK PI EE 17918–17921).

**11**, **12** – *Poecilocrinus dispandus* forma *elongatus* Peck, 1943. 11 – cup in lateral view (NHMUK PI EE 17922); 12 – cup in oblique adoral view (NHMUK PI EE 17923).

All specimens are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, uppermost Weno Formation, Salvation Army locality, Seminary Drive, Sycamore Creek, Fort Worth, Tarrant County, Texas (sample SA2).

Scale bars equal 0.2 mm (10) and 0.5 mm for all others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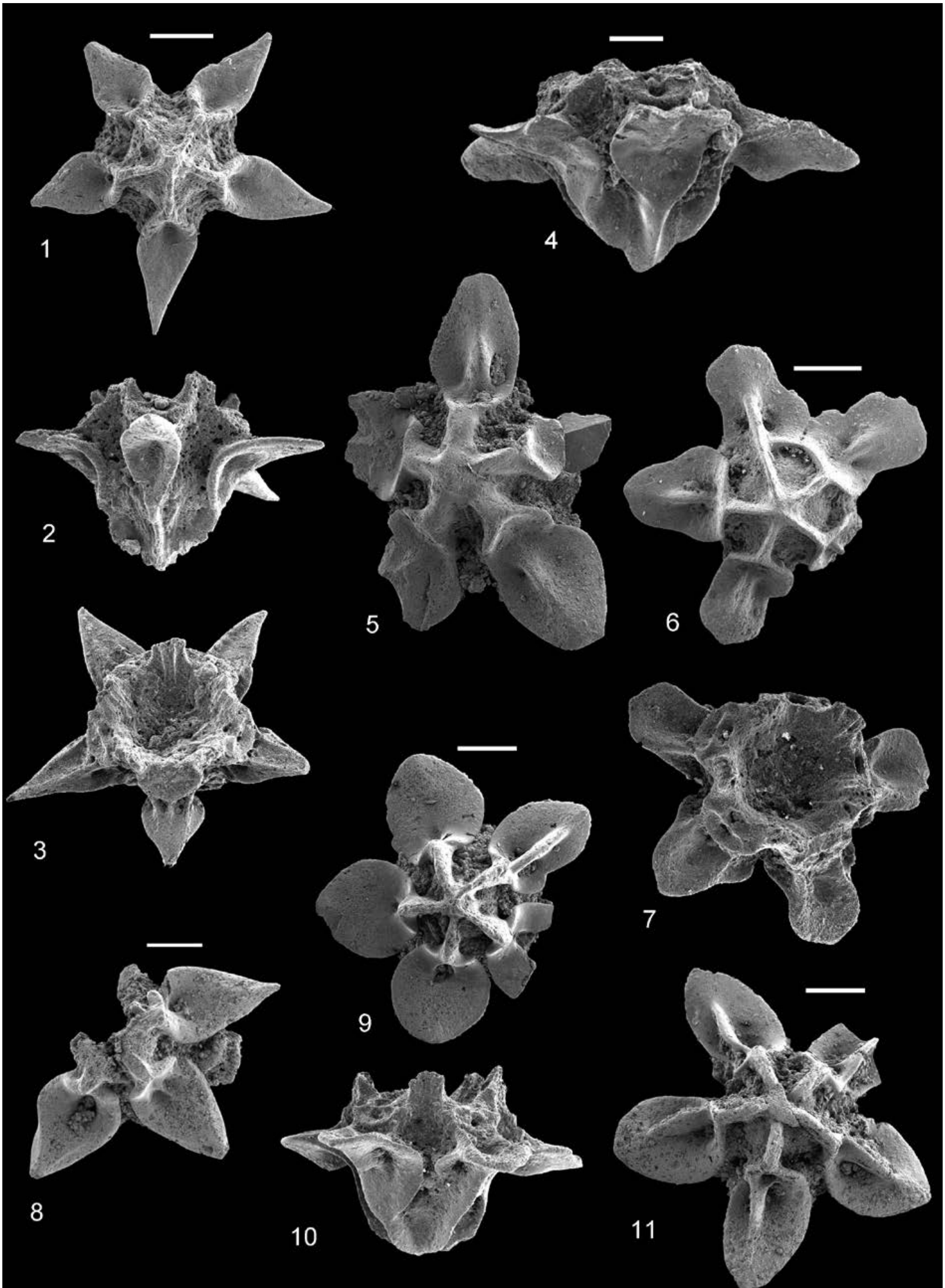
# PLATE 24

**1-11** – *Poecilocrinus dispandus* forma *floriformis* nov., paratypes. 1-3 – cup in aboral, lateral and adoral views, respectively (NHMUK PI EE 17924); 4, 5 – cup in lateral and aboral views, respectively (NHMUK PI EE 17925); 6, 7 – cup in aboral and adoral views, respectively (NHMUK PI EE 17926); 8 – partial cup in adoral view (NHMUK PI EE 17927); 9, 10 – cup in aboral and lateral views, respectively (NHMUK PI EE 17928); 11 – cup in aboral view (NHMUK PI EE 17929).

All specimens are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, upper Weno Formation (sample SA2), Salvation Army locality, Seminary Drive, Fort Worth, Tarrant County, Texas.

Scale bars equal 0.5 mm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# PLATE 25

**1**, **2** – *Poecilcrinus dispandus* forma *floriformis* nov.; cups in aboral views (NHMUK PI EE 17930, 17931).

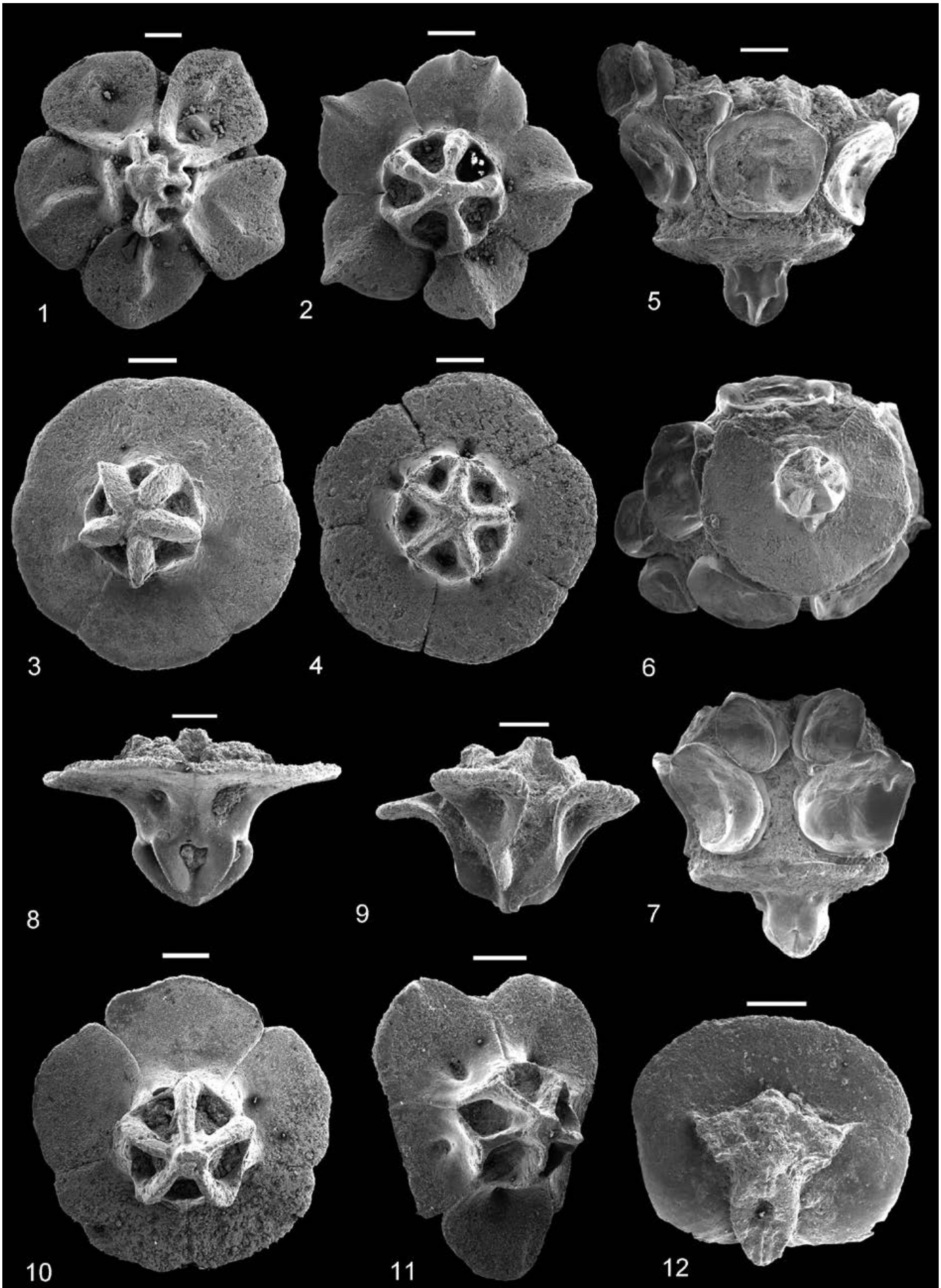
**3-7**, **10** – *Poecilocrinus dispandus* forma *discus* nov. 3, 4, 10 – cups in aboral view (NHMUK PI EE 17932, 17933, 17937); 5-7 – cup with articulated brachials up to IIBr2 in lateral (5, 7) and aboral (6) views (NHMUK PI EE 17934).

**8**, **9**, **11** – *Poecilocrinus dispandus* cf. forma *explicatus* Peck, 1943. 8, 9 – cups in lateral views (NHMUK PI EE 17935, 17936); 11 – cup in aboral view (NHMUK PI EE 17938).

**12** – *Poecilocrinus dispandus* Peck, 1943. IBr2 in interior view (NHMUK PI EE 17939).

Figures 1-4, 8-12 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, Pawpaw Formation, Salvation Army locality, Seminary Drive, Sycamore Creek, Fort Worth, Tarrant County, Texas (sample SA3). Figures 5-7 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, Pawpaw Formation, intersection of I-35 and I-20, Fort Worth, Tarrant County, Texas.

Scale bars equal 1 mm (5-7) and 0.5 mm for all others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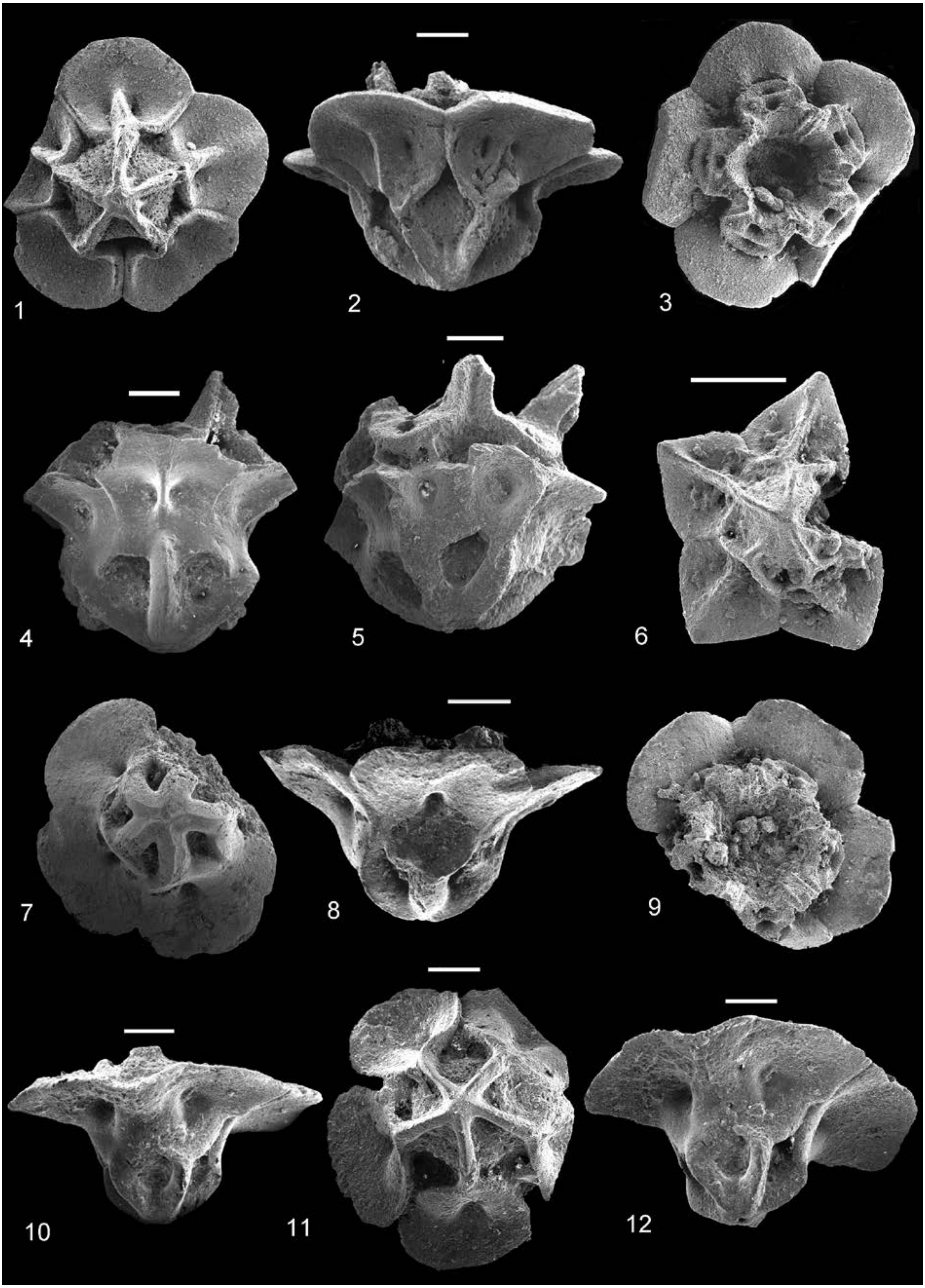
# PLATE 26

**1-6** – *Poecilocrinus molestus* Peck, 1943. 1-3 – cup in aboral, lateral and adoral views, respectively; original of Gale (2020, pl. 22, figs 1–3; NHMUK PI EE 17566); 4-6 – cups in lateral (4, 5) and aboral (6) views (NHMUK PI EE 17940–17942).

**7-12** – *Poecilocrinus dispandus* forma *explicatus* Peck, 1943. 7-9 – paratype cup in aboral, lateral and adoral views, respectively; original of Gale (2020, pl. 21, figs 1–3; USNM 128348a); 10-12 – cups in lateral (10, 12) and aboral (11) views (NHMUK PI EE 17943–17945).

Figures 1-6 are from the upper Albian, Main Street Limestone Formation, Sunset Oak Drive, Fort Worth, Tarrant County, Texas (sample SD4). Figures 7-9 are from the upper Albian, Main Street Limestone, southeast of Fort Worth, Tarrant County, Texas. Figures 10-12 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, Main Street Limestone Formation, Sunset Oak Drive, Fort Worth, Tarrant County, Texas (sample SD1A).

Scale bars equal 1 mm (6) and 0.5 mm for all others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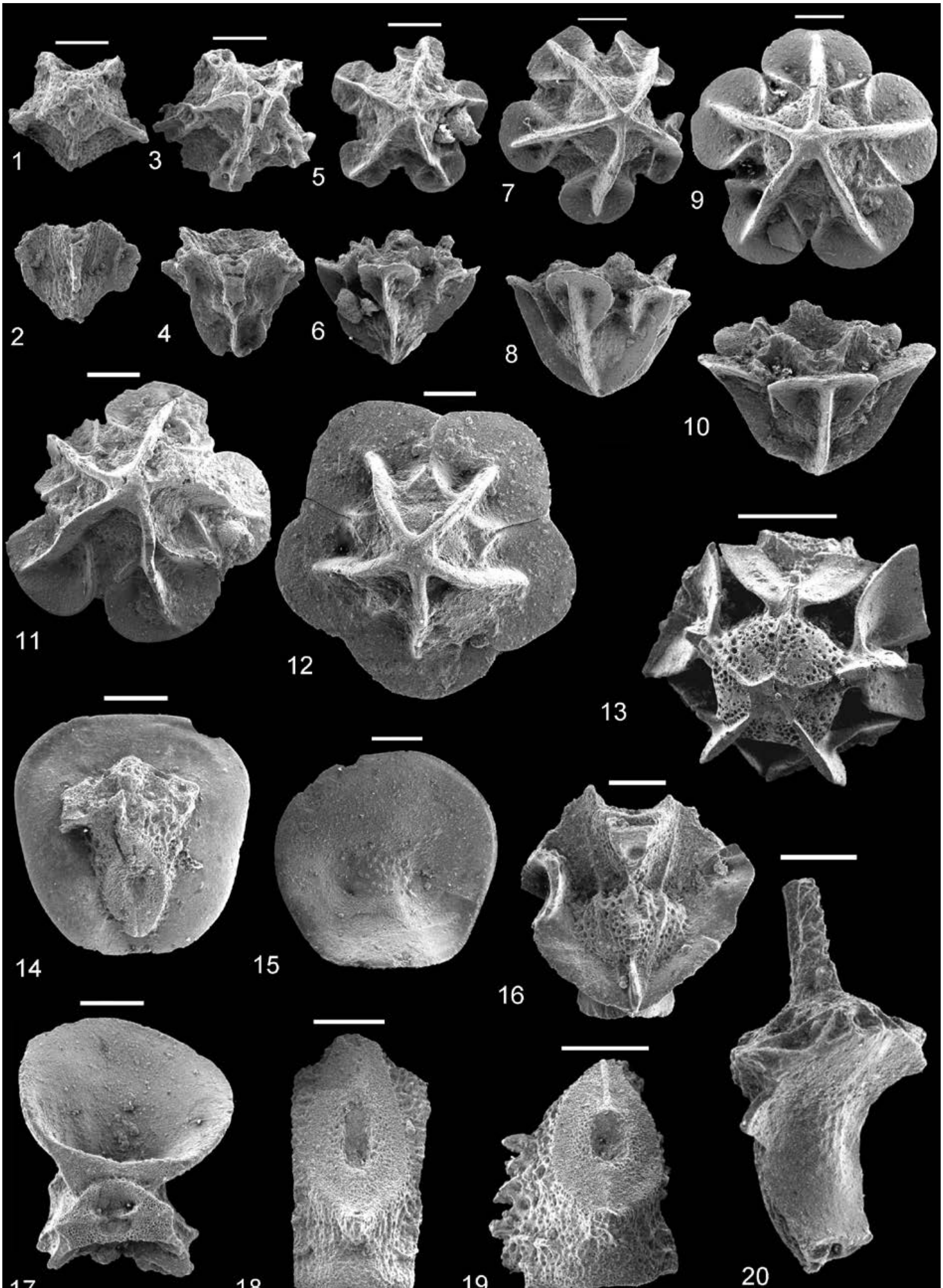
# PLATE 27

**1-15**, **17-20** – *Poecilocrinus signatus* (Peck, 1943). 1-10 – growth series of cups (NHMUK PI EE 17946–17950) in paired aboral (upper row) and lateral views (lower row); 11, 12 – large cups in aboral view (NHMUK PI EE 17951, 17952); 13 – well-preserved cup in aboral view (NHMUK PI EE 17953); 14, 15 – IIBr2 in internal and external views (NHMUK PI EE 17954, 17955); 17 – IIBr2 in external view (NHMUK PI EE 17957); 18 – IBr1 in external view (NHMUK PI EE 17958); 19 – IIBr1 in external view (NHMUK PI EE 17959); 20 – IIBr2 of 'B form' in oblique external view (NHMUK PI EE 17960).

**16** – *Roveacrinus bifidus* Gale, 2019. Cup in lateral view (NHMUK PI EE 17956).

Figures 1-12, 14-20 are from the lower Cenomanian, *Graysonites wacoense* Zone, Grayson Formation, Rayzor Ranch temporary section, Denton, Denton County, Texas (sample RR3). Figure 13 is from the lower Cenomanian, Grayson Formation, Grayson Bluff, Roanoke, Denton County, Texas (sample G3).

Scale bars equal 0.5 mm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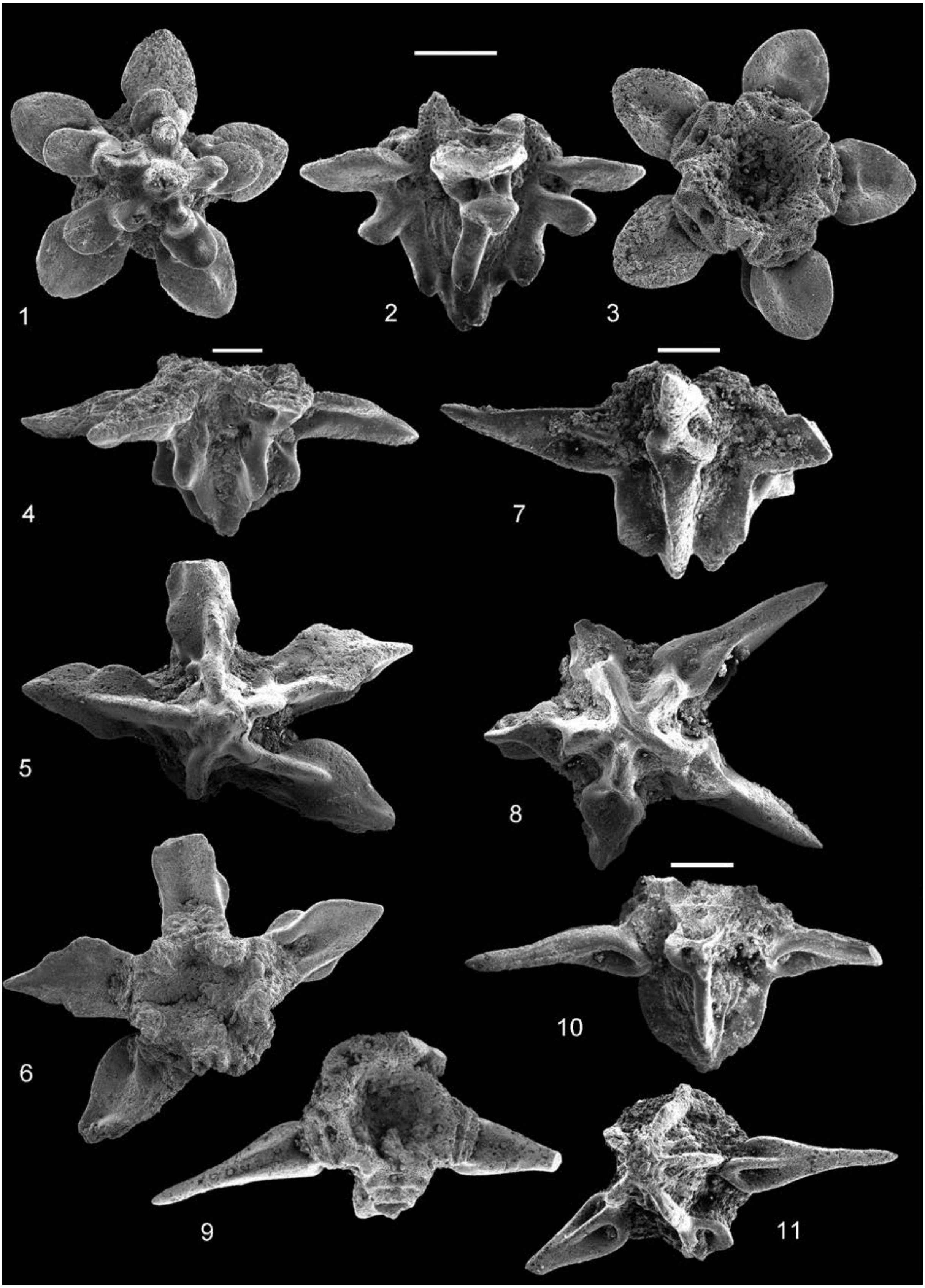
# PLATE 28

**1-3** – *Roveacrinus morganae* sp. nov. Holotype cup in aboral, lateral and adoral views, respectively (NHMUK PI EE 17961).

**4-11** – *Roveacrinus proteus* sp. nov. 4-6 – paratype cup in lateral, aboral and adoral views, respectively (NHMUK PI EE 17962); 7, 8 – paratype cup in lateral and aboral views, respectively (NHMUK PI EE 17963); 9-11 – paratype cup in lateral, adoral and aboral views, respectively (NHMUK PI EE 17964).

Figure 1 is from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, Pawpaw Formation, roadcut at intersection of I-35 and I-20, Fort Worth, Tarrant County, Texas. Figures 4-11 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, Pawpaw Formation, Salvation Army locality, Seminary Drive, Sycamore Creek, Fort Worth, Tarrant County, Texas (sample SA3).

Scale bars equal 1 mm (1-3) and 0.5 mm for all others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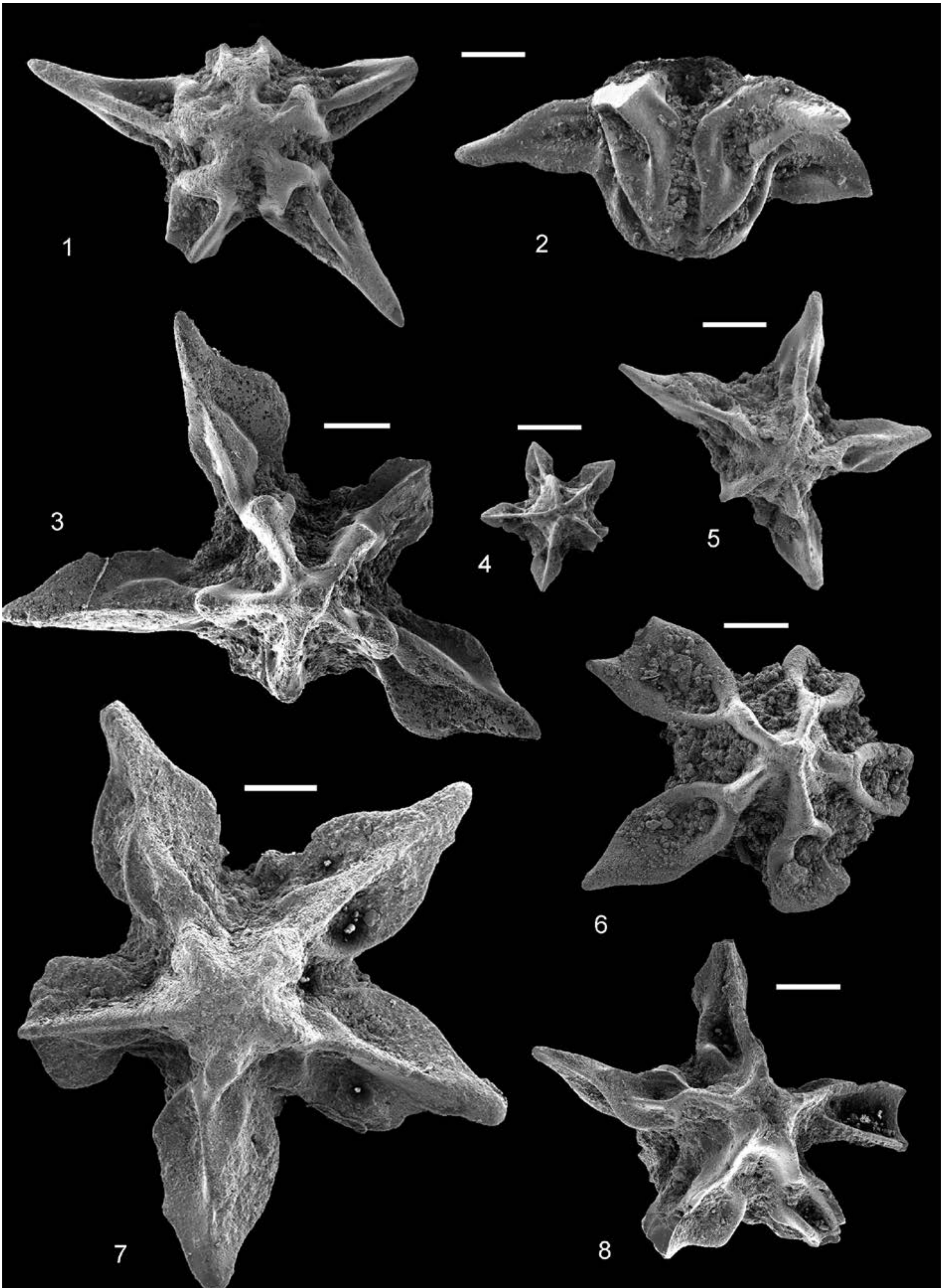
# PLATE 29

**1-3**, **5-8** – *Roveacrinus proteus* sp. nov. 1, 2 – holotype cup in aboral and lateral views, respectively (NHMUK PI EE 17965); 3, 5-8 – paratype cups in aboral view, to show variation (NHMUK PI EE 17966–17970).

**4** – *Poecilocrinus latealatus* (Peck, 1943). Immature individual in aboral view, to show similarity to early *Roveacrinus*; original of Hess (2015, fig. 4e; NMB M11560).

Figures 1-3, 5-8 are from the upper Albian, *Pervinqueiria* (*Subschloenbachia*) *rostrata* Zone, Pawpaw Formation, Seminary Drive, Salvation Army section, Fort Worth, Tarrant County, Texas (sample SA3a, SA3). Figure 4 is from the upper Duck Creek Formation, Saginaw Quarry, Fort Worth, Tarrant County, Texas (Text-fig. 4; sample Sag.h).

Scale bars equal 1 mm (4) and 0.5 mm for all others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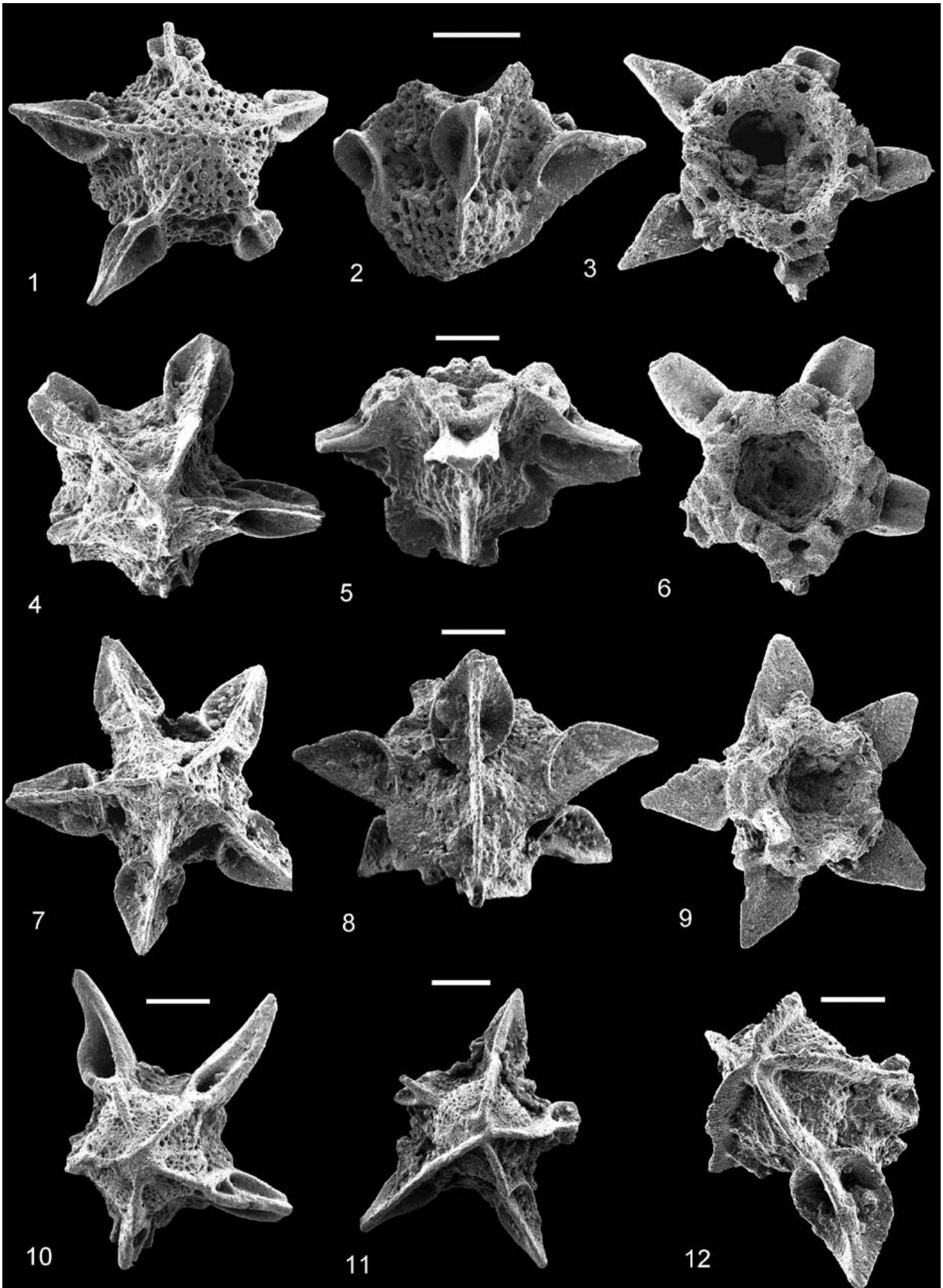
# PLATE 30

*Roveacrinus solisoccasum* Gale, 2020

1-3 – holotype cup in aboral, lateral and adoral views, respectively; original of Gale (2020, pl. 11, figs 1-3; NHMUK PI EE 17456); 4-6 – cup in aboral, lateral and adoral views, respectively (NHMUK PI EE 17971); 7-9 – cup in aboral, lateral and adoral views, respectively (NHMUK PI EE 17972); 10-12 – three cups in aboral view (NHMUK PI EE 17973–17975).

All specimens are from the upper Albian, Main Street Limestone, Sunset Oaks Drive, Hurst, Fort Worth, Tarrant County, Texas (sample SD3).

Scale bars equal 0.5 mm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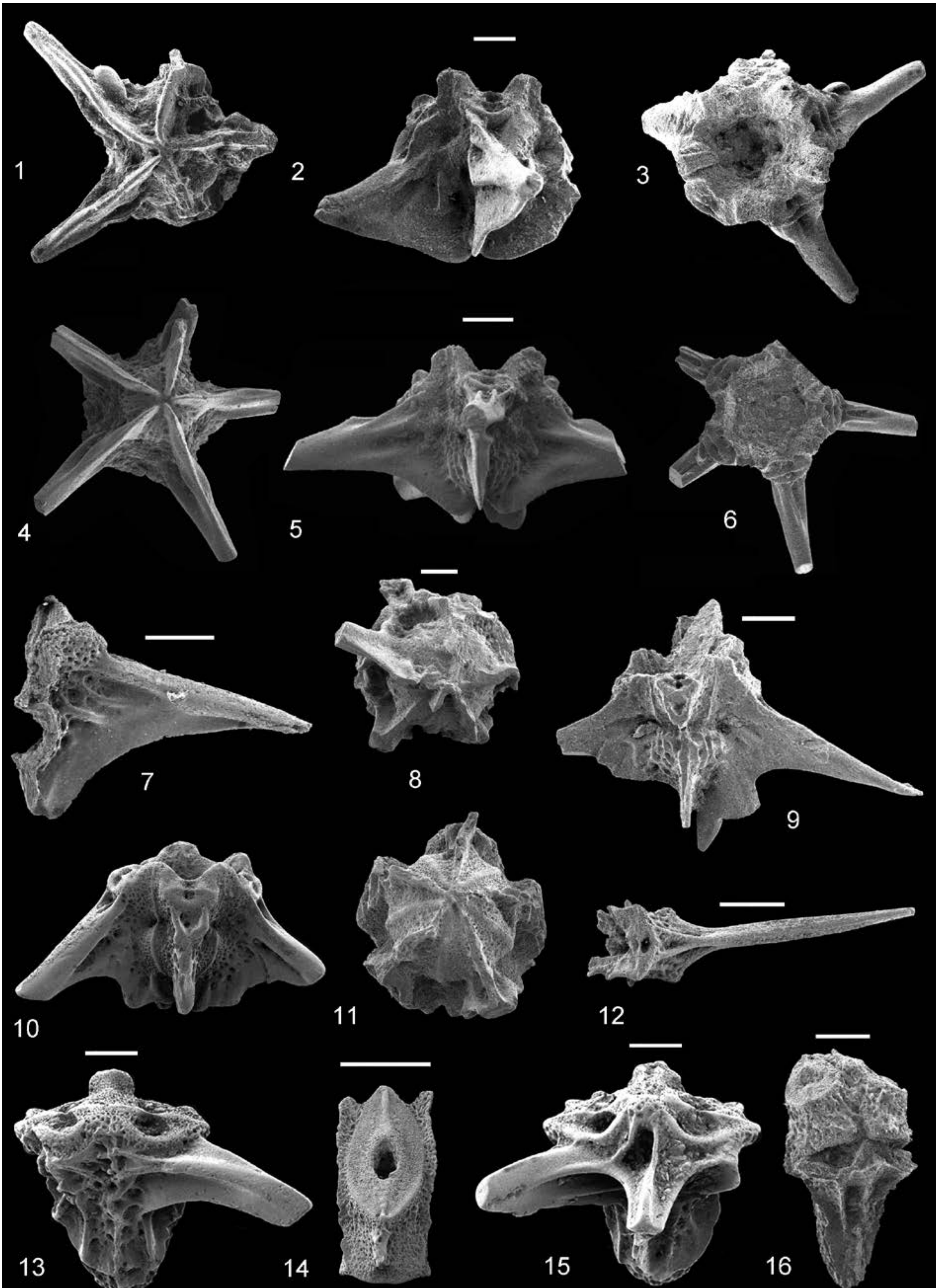
# PLATE 31

*Roveacrinus spinosus* Peck, 1943

1-3 – cup in aboral, lateral and adoral views, respectively; original of Gale (2020, pl. 11, figs 11–13; NHMUK PI EE 17463); 4-6 – cup in aboral, lateral and adoral views, respectively; original of Gale (2020, pl. 11, figs 14–16; NHMUK PI EE 17464); 7 – isolated radial in lateral view, to show form of radial spine and flange (NHMUK PI EE 17976); 8 – cup in aboral view, paratype of *Roveacrinus spinalatus* Peck, 1943 (USNM 128336); 9 – cup in lateral view (NHMUK PI EE 17977); 10 – cup in lateral view, original of Hess (2015, fig. 14r; NMB M11716); 11 – cup in aboral view, paratype of *Roveacrinus spinosus* (USNM 128342); 12 – distal brachial in distal view (NHMUK PI EE 17978); 13, 15 – IBr2 in external view, originals of Hess (2015, fig. 15i, j; NMB M11746, 11747); 14 – IBr1 in external view (NHMUK PI EE 11979); 16 – IBr2 with IIBr1 attached in external view; original of Gale (2020, pl. 11, fig. 8; NHMUK PI EE 17460).

Figures 1-7, 10, 12-15 are from the lower Cenomanian, *Graysonites wacoense* Zone, Grayson Formation, Dottie Lynn Lane, Fort Worth, Tarrant County, Texas (sample level DL1). Figure 8 is from the lower Cenomanian, Grayson Formation (horizon unknown), Grayson Bluff, Roanoke, Denton County, Texas. Figure 9 is from the lower Cenomanian, *Graysonites wacoense* Zone, Grayson Formation, Waco Shale pit, Waco, McLennan County, Texas (sample Waco 2). Figure 11 is from the lower Cenomanian, Grayson Formation (horizon unknown), tributary to Little Mineral Creek, near Fink, Grayson County, Texas (HTL locality 5; see Peck 1943, p. 457). Figure 16 is from the lower Cenomanian, Aït Lamine Formation, Abouda Plage roadcut, Morocco (Gale 2020, sample TA31).

Scale bars equal 0.2 mm (16) and 0.5 mm for all others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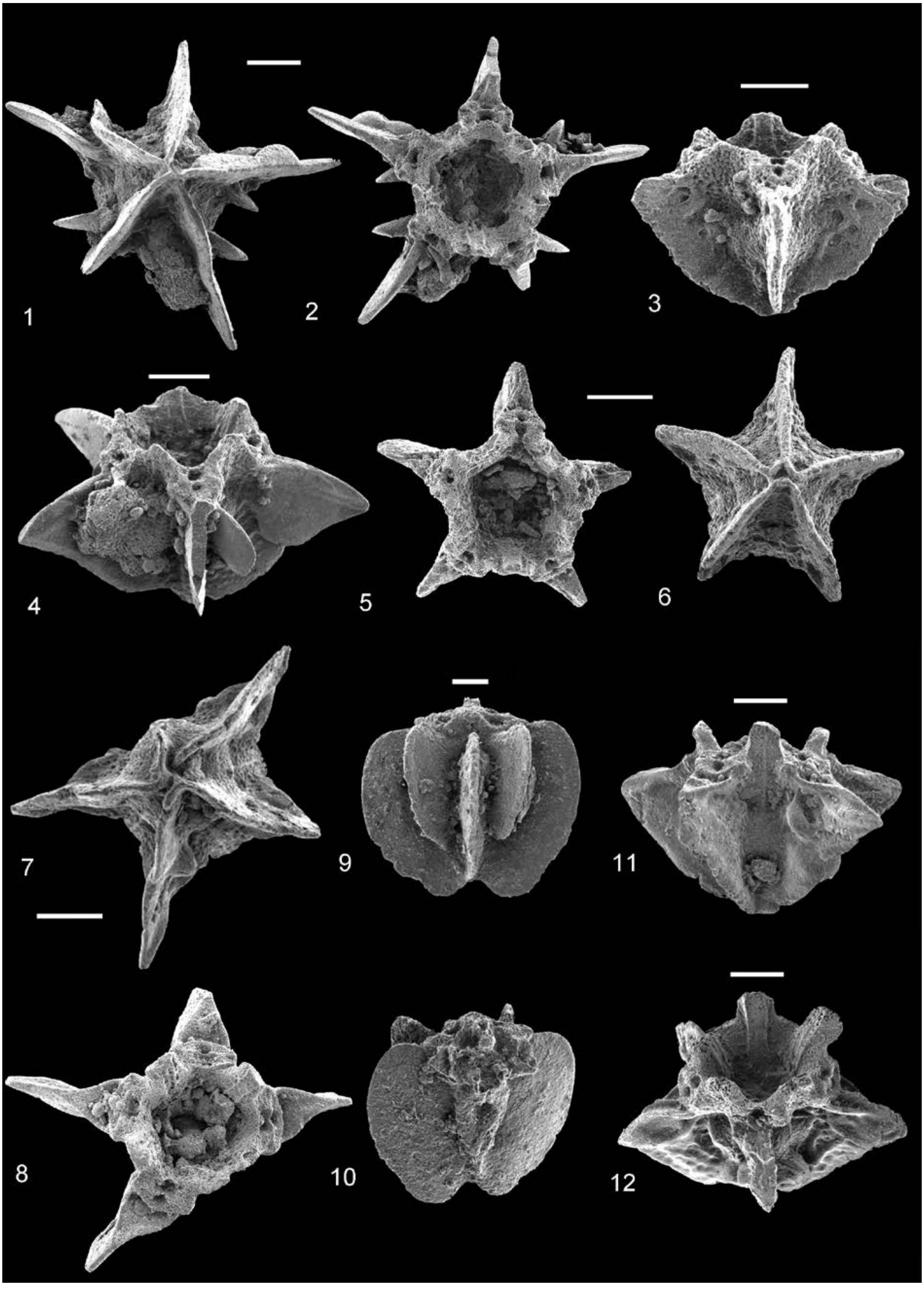
# PLATE 32

*Roveacrinus pentagonus* Peck, 1943

1, 2, 4 – cup in aboral, adoral and oblique adoral views, respectively (USNM 128341b); 3, 5, 6 – cup in lateral, adoral and aboral views, respectively (USNM 128341d); 7, 8, 11 – cup in aboral, adoral and lateral views, respectively (USNM 128341a); 9, 10 – IBr2 in external and internal views, respectively (NHMUK PI EE 17980); 12 – cup in oblique adoral view (NHMUK PI EE 17981).

Figures 1-8, 11 are from the lower Cenomanian, Grayson Formation (horizon unknown), tributary to Little Mineral Creek, near Fink, Grayson County, Texas (HTL locality 5; see Peck 1943, p. 457). Figures 9, 10 are from the lower Cenomanian, *Graysonites wacoense* Zone, Grayson Formation, Waco Shale pit, Waco, McLennan County, Texas (sample Waco 3). Figure 12 is from the lower Cenomanian, upper part of Grayson Formation, Handley, near Fort Worth, Tarrant County, Texas.

Scale bars equal 0.2 mm (9, 10) and 0.5 mm for all others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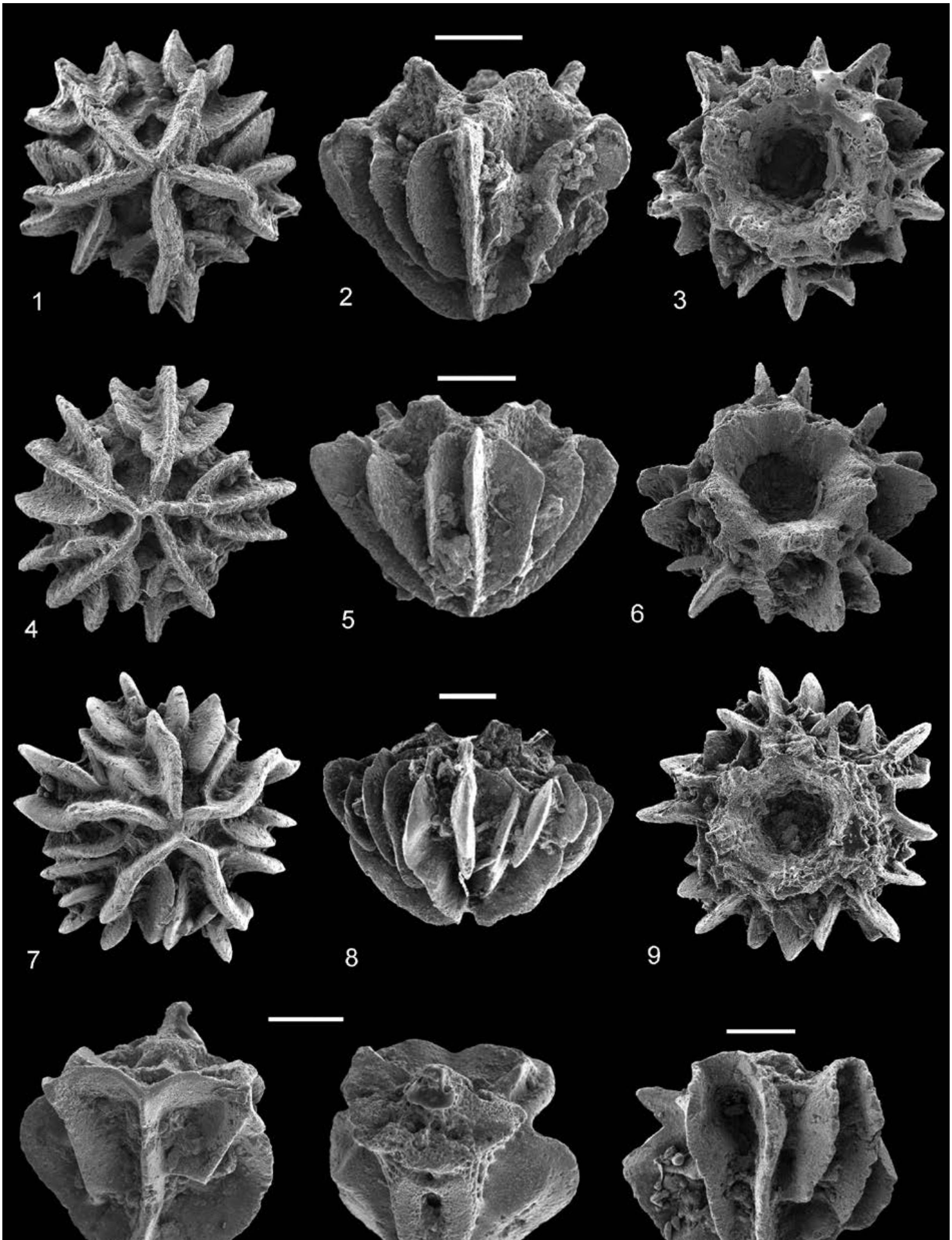
# PLATE 33

*Roveacrinus multisinuatus* Peck, 1943

1-3, 4-6 – two paratype cups in aboral, lateral and adoral views, respectively (USNM 128343b, 128343c); 7-9 – cup in aboral, lateral and adoral views, respectively (NHMUK PI EE 17982); 10-12 – primibrachials IBr2 in external (10, 12) and internal (11) views (USNM 128343d, 128343d).

Figures 1-6, 10-12 are from the lower Cenomanian, Grayson Formation (horizon unknown), tributary to Little Mineral Creek, near Fink, Grayson County, Texas (HTL locality 5; see Peck 1943, p. 457). Figures 7-9 are from the lower Cenomanian, upper part of Grayson Formation, Handley, near Fort Worth, Tarrant County, Texas.

Scale bars equal 0.5 mm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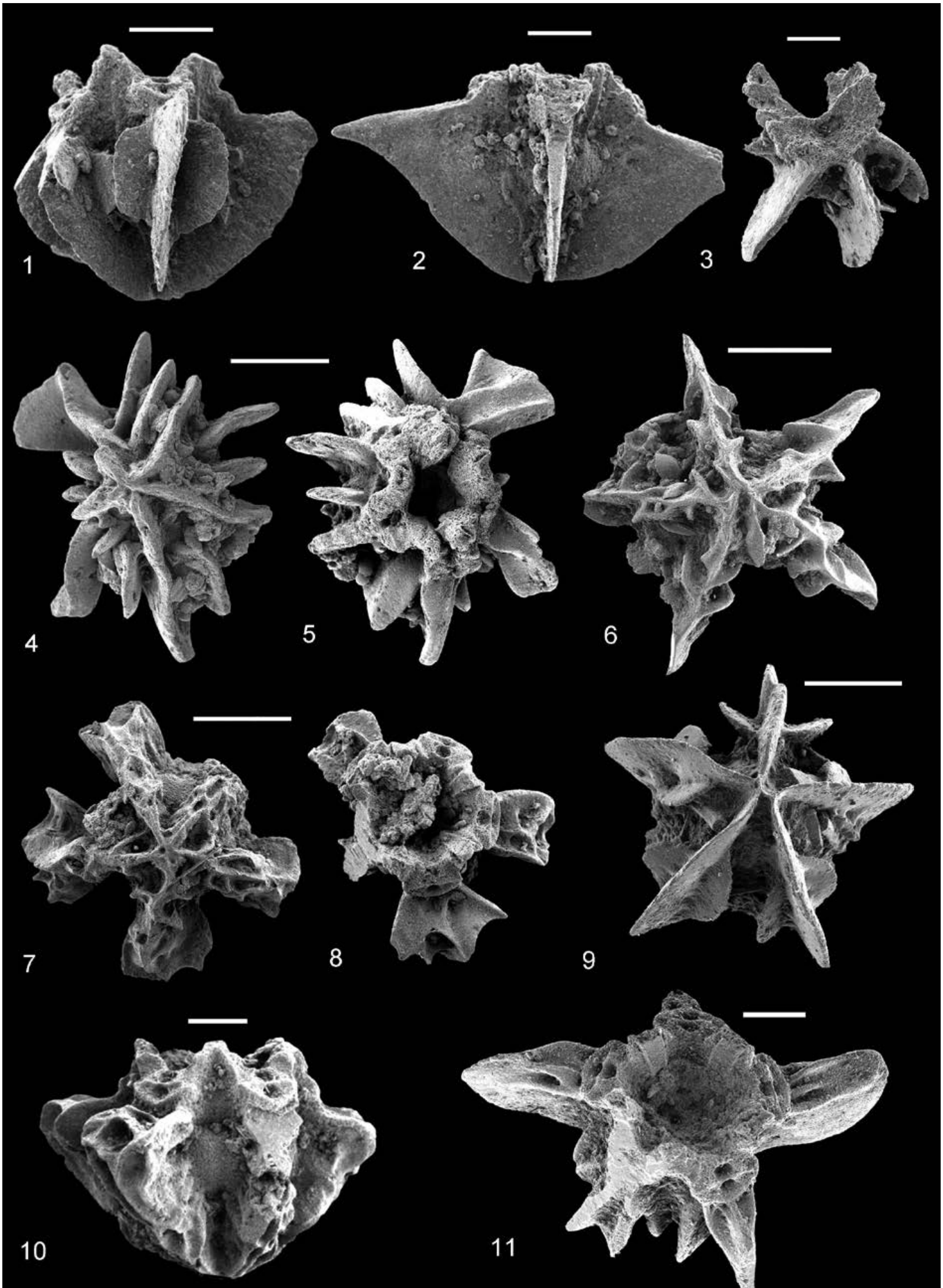
# PLATE 34

**1-3**, **6-11** – *Roveacrinus pentagonus* Peck, 1943. 1 – cup in lateral view (USNM 140176a); 2 – cup in lateral view (USNM 140177a); 3 – distal brachial in distal view (NHMUK PI EE 17983); 6 – cup in aboral view (NHMUK PI EE 17984); 7, 8 – deformed cup in aboral and adoral view, respectively (USNM 140176c); 9 – cup in aboral view (NHMUK PI EE 17985); 10 – cup in lateral view (NHMUK PI EE 17986); 11 – cup in adoral view (NHMUK PI EE 17987).

**4**, **5** – *Roveacrinus multisinuatus* Peck, 1943. Deformed cup in aboral and adoral views, respectively (USNM 140176f).

Figures 1, 2, 4, 5, 7, 8 are from the lower Cenomanian, Grayson Formation (horizon unknown), tributary to Little Mineral Creek, near Fink, Grayson County, Texas (HTL locality 5; see Peck 1943, p. 457). Figures 6, 10, 11 are from the lower Cenomanian, upper part of Grayson Formation, Handley, near Fort Worth, Tarrant County, Texas. Figures 3, 9 are from the lower Cenomanian, *Graysonites wacoense* Zone, Grayson Formation, Waco Shale pit, Waco, McLennan County, Texas (sample Waco 3a). Figure 12 is from the lower Cenomanian, upper part of Grayson Formation, Handley, near Fort Worth, Tarrant County, Texas.

Scale bars equal 0.2 mm (3) and 0.5 mm for all others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