

The Late Maastrichtian bourgueticrinid crinoid *Dunnocrinus aequalis* (D'ORBIGNY, 1841) from The Netherlands and Belgium

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Abstract

The bourgueticrinid "*Bourgueticrinus*" *aequalis* D'ORBIGNY, 1841 is by far the commonest Late Cretaceous crinoid species in the type area of the Maastrichtian Stage (NE Belgium, SE Netherlands). Many hundreds of thousands of dissociated ossicles, of crowns and columns alike, have been collected during recent years. Based on the structure of the crown (number of arms and brachial articulation types), the species is best reclassified in the otherwise exclusively North American genus *Dunnocrinus* MOORE, 1967. It is particularly well represented in the Lanaye (Gulpen Formation), Valkenburg and Grönsveld (Maastricht Formation) Members, of Late Maastrichtian age. Rare occurrences of more or less completely preserved specimens, the result of obrution, have been given special attention. Material from one such crinoid "lagerstätte" from the base of the Grönsveld Member as exposed at the ENCI Nederland BV quarry, which includes attachment structures of unusual complexity with stereom overgrowths, is here described. This particular lagerstätte closely resembles that which yielded the Late Maastrichtian type species of the genus *Dunnocrinus*, *D. mississippiensis* MOORE, 1967, from the southern U.S.A.

Key-words: Crinoidea, Bourgueticrinidae, lagerstätte, Late Maastrichtian, The Netherlands, Belgium.

Résumé

Le bourgueticrinidé "*Bourgueticrinus*" *aequalis* D'ORBIGNY, 1841 est de loin l'espèce de crinoïde du Crétacé supérieur la plus commune dans la région-type de l'étage maastrichtien (NE de la Belgique, SE des Pays-Bas). Plusieurs centaines de milliers d'ossicules dissociés, de calices et de tiges ont été récoltés au cours des dernières années. Sur base de la structure du calice (nombre de bras et types d'articulation brachiale), l'espèce est attribuée de façon plus appropriée à *Dunnocrinus* MOORE, 1967, un genre par ailleurs exclusivement nord-américain. L'espèce est particulièrement bien représentée dans les Membres de Lanaye (Formation de Gulpen), de Valkenburg et de Grönsveld (Formation de Maastricht), d'âge maastrichtien supérieur.

De rares occurrences de spécimens plus ou moins complètement préservés, résultat d'obrution, ont fait l'objet d'une attention particulière. Le matériel provenant d'un tel "lagerstätte" à crinoïdes de la base du Membre de Grönsveld tel qu'il est exposé à la carrière ENCI Nederland BV, est décrit; il comprend des structures d'attachement d'une complexité inhabituelle avec surcroissance du stéréome. Ce "lagerstätte" particulier ressemble étroitement à celui d'où provient l'espèce-type du genre *Dunnocrinus*, *D. mississippiensis* MOORE, 1967, du sud est des U.S.A.

Mots-clefs: Crinoidea, Bourgueticrinidae, lagerstätte, Maastrichtien supérieur, Pays-Bas, Belgique.

Introduction

GOLDFUSS (1826-1844) appears to have been the first author to record crinoids from what was later to become the type area of the Maastrichtian Stage (Fig. 1). That author described and illustrated (1831, p. 186, pl. 57, fig. 3R), amongst other specimens, a dorsal cup of a bourgueticrinid crinoid under the name *Apiocrinites ellipticus* MILLER.

When erecting the genus *Bourgueticrinus*, D'ORBIGNY (1841, pp. 95-98) referred to a number of species of that genus, amongst which, "... les B. [*sic*] *ellipticus* et *aequalis*, se trouvent exclusivement dans la craie blanche supérieure de Paris, d'Angleterre, de la Touraine et de Maëstrich [*sic*]". Of the latter species, D'ORBIGNY (pp. 96, 97) noted that, "De là il n'en fut plus question jusqu'en 1811, ou Parkinson (4) la donna ainsi qu'une autre (B. *aequalis*), sous les noms de *Botle Encrinite* et de *Strait*

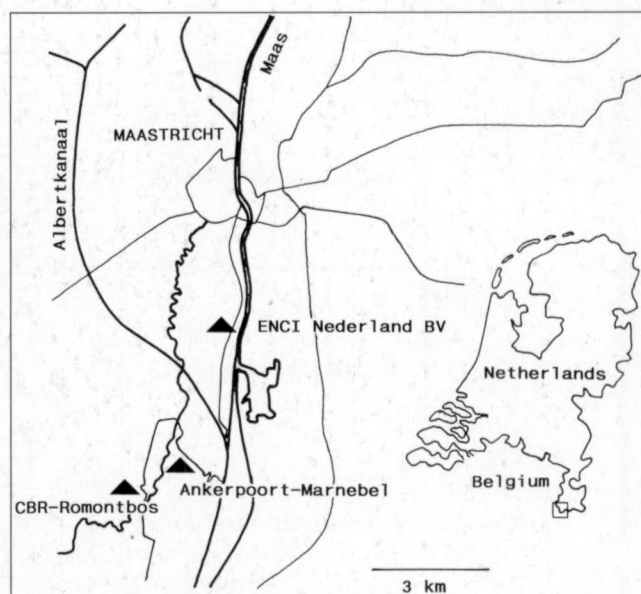


Fig. 1 – Map showing the location of the ENCI Nederland BV, CBR-Romontbos and Ankerpoort-Marnebel quarries in southern Limburg (The Netherlands) and Liège province (Belgium).

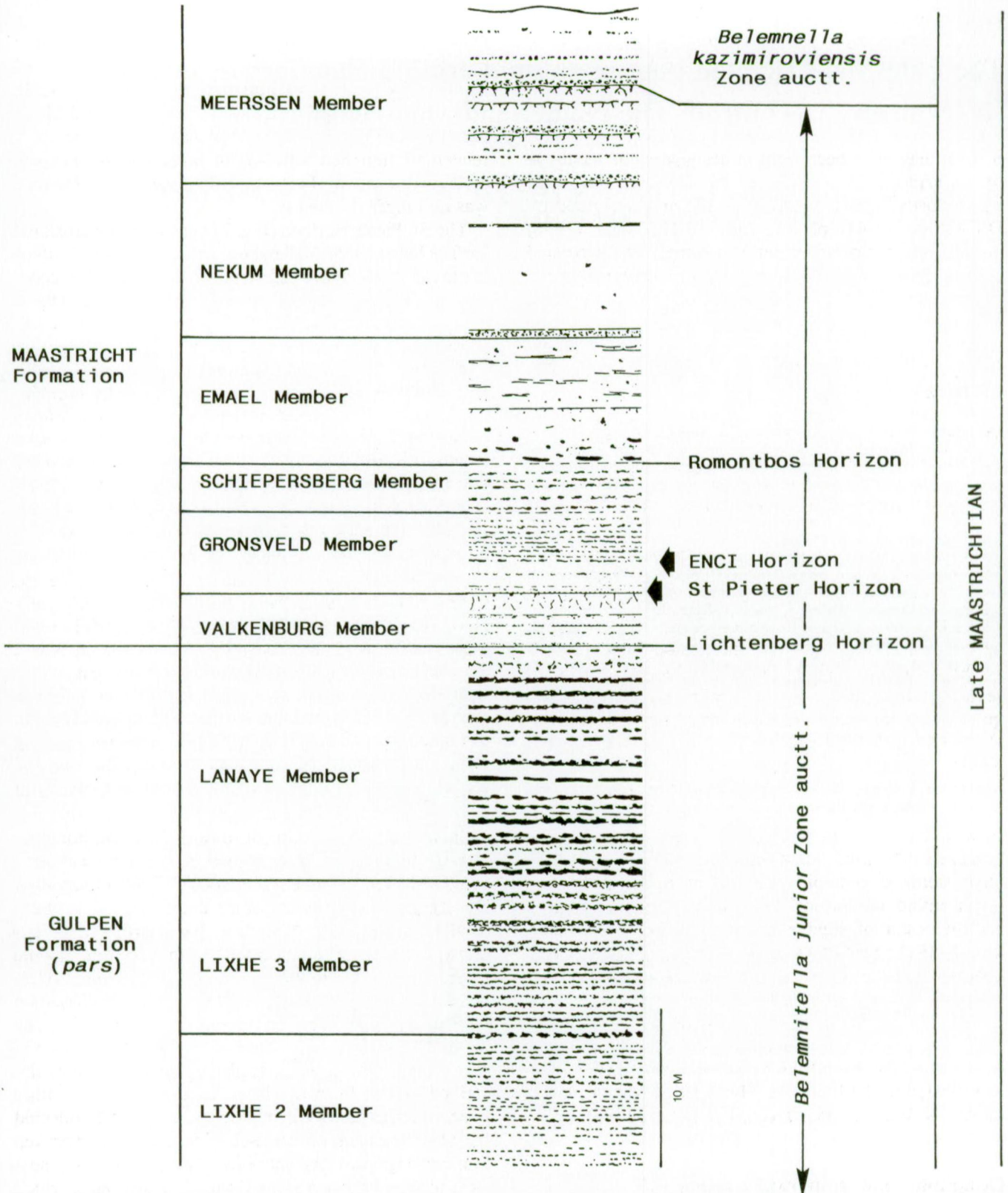


Fig. 2 – Lithostratigraphy (modified after FELDER *et al.*, 1978), coleoid cephalopod biozones and chronostratigraphy of the section exposed at the ENCI Nederland BV quarry (Maastricht); the arrows mark the provenance of the material of *Dunnicrinus aequalis* (D'ORBIGNY, 1841) described in the present paper.

Encrinite. L'auteur distinguant avec sagacité ces deux formes et leur attribuant des fragmens de tiges à articulations alternativement oblongues et comprimées laté-

ralement." He also remarked (p. 97) that, "Enfin Goldfuss (4) adoptant le genre de Miller dans toute son étendue, y laissa régner la même confusion, et ne distingua

même pas les deux espèces si nettement désignées par Parkinson. (3) *Organic Remains*, t. II, pl. XIII, f. 75 et 34. (4) Goldfuss, *Petrificata Germaniae*, t. I, p. 186, pl. 57, f. 3.'

Careful reading of this text shows that RASMUSSEN (1961, p. 170) may have been right in designating as lectotype of "*Bourgueticrinus*" *aequalis* the specimen illustrated by GOLDFUSS (1831, pl. 57, fig. 3R) and re-figured by D'ORBIGNY (1841, pl. 17, figs. 10-12). JAGT (1998) pointed out that preservation of a sample of dissociated columnals and a single dorsal cup (= lectotype) in the GOLDFUSS type collection suggests these ossicles to have been collected from the base of the Valkenburg Member (Maastricht Formation), directly above the Lichtenberg Horizon (Fig. 2), as exposed in the Maastricht area.

The introduction of a formal lithostratigraphy for Upper Cretaceous and Lower Palaeocene strata in the Maastrichtian type area (FELDER, 1975a, b; ALBERS & FELDER, 1979) made it possible to determine the spatial and temporal distribution of this and other species of crinoid. In recent years, many hundreds of thousands of dissociated ossicles have been collected, making *Dunnocrinus aequalis* the commonest crinoid species known to date from the area. More or less complete specimens, however, are rare and occur only in a few places. BLESS *et al.* (1987, pl. 3, fig. 1) illustrated a specimen from the upper Lanaye Member of the Ankerpoort-Marnebel quarry (Eben Emael, Belgium). Comparable finds have subsequently been made at the nearby CBR-Romontbos quarry (Fig. 1), from the same stratigraphic level, and at the ENCI Nederland BV quarry, from a higher level, namely from the base of the Gronsveld Member (Maastricht Formation) (JAGT *et al.*, 1994). The latter "crinoid lagerstätte" is of special importance, not only on account of the large number of well-preserved specimens, but also because of the association with pterocomid comatulids, phymosomatid echinoids as well as ophiolipidid and ophiacanthid ophiuroids. Obviously, such occurrences are the result of sudden burial (obration, see ROSENKRANZ, 1971; SEILACHER *et al.*, 1985; DONOVAN, 1991; LAWRENCE, 1996) of live animals, which may have been triggered by active synsedimentary tectonic movements (inversion) in the area (BLESS, 1991; BLESS *et al.*, 1987, 1993; GRAS, 1995). The present ENCI crinoid/ophiuroid occurrence thus rivals other echinoderm "lagerstätten" as recorded in the literature (HESS, 1975; MEYER, 1984; MOORE & VOKES, 1953; TAYLOR & BRETT, 1996).

Geographic and stratigraphic setting

The material described in the present paper was collected from the basal 0.5 m of the Gronsveld Member (Maastricht Formation) as exposed at the ENCI Nederland BV quarry, south of Maastricht (Figs. 1, 2), between 1993 and 1997.

FELDER (1975a) originally distinguished two "horizons" in that part of his zone VIII^w which was later

referred to as "Gransveld Member", namely the St. Pieter and ENCI horizons. Both levels were defined at the ENCI Nederland BV quarry. FELDER noted the overall similarity between these horizons, one of which, the St. Pieter Horizon, defines the base of the Gronsveld Member. He assumed the ENCI Horizon to be genetically related to flint bed VIII^w-3. In other papers (FELDER, 1975b; ALBERS & FELDER, 1979) the ENCI Horizon was no longer referred to.

The St. Pieter Horizon (Fig. 2) constitutes an erosional surface between the Valkenburg and Gronsveld members (ZIJLSTRA *et al.*, 1988; ZIJLSTRA, 1994), held to be recognisable over distances of several kilometres (ALBERS & FELDER, 1979). LIEBAU (1978) assumed the Gronsveld Member to have been deposited in a middle sublittoral setting with seagrass communities under tropical conditions. VILLAIN (1977) considered the "gravelly intrabiomicrosparite" of this member (= fine- to medium-grained packstones and grainstones; BLESS *et al.*, 1987) to have been deposited at palaeodepths of 20 to 40 m, without oceanic influence. In fact, some authors (BLESS, 1991; BLESS *et al.*, 1993) have provided arguments for interpreting the entire Late Cretaceous (Early Campanian-Late Maastrichtian) sequence in the type area of the Maastrichtian Stage to represent shallow nearshore environments only. Seagrass of protozosteroid and cymodoceoid affinity (BRASIER, 1975) is comparatively common at this level, occasionally silicified and in places associated with (silicified) angiosperm driftwood.

For the lower part of the Gronsveld Member, ZIJLSTRA (1994) described fining-upward cycles with a phosphatic, glauconitic/pyritic bioclastic sand at their bases, the sand of the lowermost cycle being characterised by well-developed wavy lamination. Wavy laminated sediment at the base of these cycles changes upwards via (sub)horizontally laminated sediment towards lithified, homogeneously bioturbated, fine-grained, purer carbonate sediment at the top. Of note is ZIJLSTRA's (1994) observation that the glauconitic cycles of the underlying Valkenburg Member at the ENCI Nederland BV quarry change laterally towards the south into cycles with flint nodule layers very similar to those of the Lanaye Member (Gulpen Formation), thus corroborating correlations based on bioclast analyses (see JAGT, 1988). The same holds true for the St. Pieter and ENCI horizons. The latter horizon in particular has recently yielded the crinoid faunules described herein. In most places, accessibility was rather poor, which explains why most specimens were collected from bedding planes of large-sized blocks that had broken loose during quarrying activities. Only rarely was it possible to remove larger slabs from the quarry face, which means that an analysis of a larger area has not been carried out as yet. In many cases, a thin cream to (greyish) brown clayey film was noted to cover the articulated echinoderm fossils. Attempts are currently made to analyse the mineral content of this clayey layer, in order to determine its provenance. For the moment, it may safely be assumed that deposition of this layer was the result of clastic input during a storm; subsequent bioturbation

appears to have been negligible (JAGT, 1995a). Preliminary observations suggest that in certain places, concurrent crinoids grew closely together, but their exact position and the distances between individual specimens can only be determined on the basis of large slabs, such as the ones illustrated herein (Pl. 1, Figs. 1, 7; Pl. 2, Figs. 2, 3, 7; Figs. 3, 4). On these slabs the radicular attachment structures represent or approximate the original site of anchorage of the crinoids. In comparison with the many thousands of isolated dorsal cups, some of them preserving proximal brachials (Fig. 5A, B, D; Pl. 3, Figs. 1-3, 7), basal and radial rings, and proximale columnals (Fig. 5C), mostly found concentrated in shell hash layers (Pl. 2, Fig. 5), more or less complete specimens are rare. These may represent animals that lived in a more protected environment, such as a channel-like depression on the seafloor. Not until a large area can be excavated will it be possible to assess their areal distribution in detail. Coupled with this, the direction of the clastic sediment influx may then be determined. Specimens probably collapsed as a result of the increased turbulence coupled with such an event, which caused the crinoid's ability to lift the crown to decrease rapidly and then collapse onto the substrate. Two specimens (Pl. 1, Fig. 3; Pl. 2, Figs. 1, 6) show this substrate to have been a kind of "soup-ground", since the crowns sank deeply into the substrate, causing the arms to spread out (Pl. 2, Fig. 6) or to become dislodged (Pl. 4, Fig. 10).

ZIJLSTRA (1994) assumed the coarse-grained cycles to have been deposited in higher energy and deeper water settings than the correlative flint beds to the southwest of the basin. The depth of storm reworking was held to have been stronger in the north (ENCI Nederland BV), thus explaining why the storm sequence was thicker than the zone of bioturbation and thus preserved lamination and fining-upwards in the lower part of fining-upwards cycles.

The present occurrence appears to confirm the correlation of the base of the Gronsvelt Member at ENCI Nederland BV with the top of the Lanaye Member in the Emael area (BLESS *et al.*, 1987) as based on the crinoid percentage in bioclast assemblages and the total number of ornamented ostracods. Comparably well-preserved specimens of *D. aequalis* have been recorded from between flint beds 20 and 21 of the Lanaye Member in the Emael area (BLESS *et al.*, 1987, pl. 3, fig. 1; CBR-Romontbos and Ankerpoort-Marnebel quarries). DUFFIN & REYNDERS (1995) favoured a direct correlation of the Gronsvelt Member between the CBR-Romontbos and ENCI Nederland BV quarries, noting that the absence of *D. aequalis* from this member at the former locality could be explained by accepting shallower conditions there. These authors noted that the fossil hash resting directly on the ENCI Horizon at the CBR-Romontbos quarry was identical in thickness and fossil content to that at the base of the overlying Emael Member. This is certainly not the case at the ENCI Nederland BV quarry, which means that BLESS *et al.*'s (1987) interpretation is here favoured, at least for the time being.

With the exception of the coleoid cephalopod *Belemnitella* gr. *junior* NOWAK, 1913, which traditionally has been interpreted as a Late Maastrichtian index, the base of the Gronsvelt Member has so far not yielded any other age-diagnostic macrobiota. Despite this lack of stratigraphic detail, *D. mississippiensis* and *D. aequalis* appear to be almost age equivalent (COBBAN & KENNEDY, 1995).

Systematic description

The terminology of the crinoid endoskeleton used herein follows MOORE *et al.* (1968, 1978) and UBAGHS (1978). The classification of articulate crinoids follows SIMMS & SEVASTOPULO (1993) and SIMMS *et al.* (1993). Specimens documented herein are deposited in the Institut Royal des Sciences Naturelles de Belgique, Brussels (IRScNB) and the Natuurhistorisch Museum Maastricht (NHMM). The following abbreviations refer to individual collections at NHMM:

JJ - J.W.M. JAGT;
K - M.M.M. KUYPERS;
MD - M.J.M. DECKERS;
RD - R.W. DORTANGS;
RN - R. VAN NEER.

Class Crinoidea MILLER, 1821, p. 7

Subclass Cladida MOORE & LAUDON, 1943, p. 32

Infraclass Articulata MILLER, 1821, p. 13

Order Comatulidina CLARK, 1908, p. 135

Suborder Bourgueticrinina SIEVERTS-DORECK *in* UBAGHS, 1953, p. 762

Family Bourgueticrinidae DE LORIOL, 1882, p. 64

REMARK

RASMUSSEN (1978, pp. T841-T847) distinguished four families of bourgueticrinine. At least some of these were considered to be paraphyletic by SIMMS *et al.* (1993, p. 503), who recognised the single family Bourgueticrinidae. Although the latter classification scheme is followed herein, for completeness it is considered constructive to mention that MOORE (1967, p. 7) placed *Dunnicrinus* MOORE in the Bourgueticrinidae (but did not recognise other families of bourgueticrinine; see also MOORE *et al.*, 1968, p. 49), whereas RASMUSSEN (1978, pp. T844-T846) classified this genus within the family Bathycrinidae BATHER, 1899.

Genus *Dunnicrinus* MOORE, 1967, p. 8

Type species - *Dunnicrinus mississippiensis* MOORE, 1967, p. 8, pls. 1-7, pl. 8, figs. 3-8; text-figs. 1-8, by monotypy.

Included species - *Dunnicrinus aequalis* (D'ORBIGNY, 1841) and possibly "*Bourgueticrinus*" *suedicus* (CARPENTER, 1881). JAGT (1998, pl. 31, figs. 2, 3, 5, 9, 11;? Pl. 36, figs. 5, 6;? Pl. 38, figs. 8, 9) recorded material referred to the latter species from the Late Campanian of

the extended Maastrichtian type area. The structure of associated proximal brachials is very similar to that of *D. aequalis*, and suggests that "*B. suedicus*" may be closely related to that species, and perhaps be a member of the same phylogenetic lineage. Moreover, in addition to representatives of the *Bourgueticrinus constrictus* stock which occur commonly in the late Early to early Late Maastrichtian Vijlen and Lixhe members (Gulpen Formation) (see JAGT, 1998, pl. 32, figs. 5-9, 11;? pl. 33, figs. 7-10; pl. 36, fig. 7), there are dissociated columnals and articulated brachials which are indistinguishable from those here assigned to *D. aequalis*.

***Dunnocrinus aequalis* (D'ORBIGNY, 1841)**
(Plates 1-9; Figs. 3-7)

- 1831 *Apiocrinites ellipticus* MILLER - GOLDFUSS, p. 186, pl. 57, fig. 3R only.
- *1841 *Bourgueticrinus aequalis* D'ORBIGNY, p. 96, pl. 17, figs. 10-12.
- 1961 *Bourgueticrinus aequalis* ORBIGNY, 1841 - RASMUSSEN, p. 170, pl. 28, figs. 11-14.
- ?1980 *Bourgueticrinus suedicus* (CARPENTER) - KLIKUSHIN, p. 83, pl. 1, fig. 4.
- ?1982a *Bourgueticrinus aequalis* ORBIGNY - KLIKUSHIN, text-fig. 1.
- ?1982b *Bourgueticrinus aequalis* D'ORBIGNY, 1840 - KLIKUSHIN, p. 812, pl. 1, figs. 1-5, text-fig. 1a-i, table 1.
- ?1983 *Bourgueticrinus aequalis* ORBIGNY - KLIKUSHIN, table 1.
- 1986 *Bourgueticrinus aequalis* D'ORBIGNY, 1841 - JAGT, p. 232, figs. 1, 4c, d, 10.
- 1989 *Bourgueticrinus aequalis* [sic] ORBIGNY - LEE, text-fig. 3I.
- 1989 *Bourgueticrinus aequalis* ORBIGNY - LEE, p. 95.
- 1994 *Bourgueticrinus aequalis* D'ORBIGNY, 1841 - JAGT *et al.*, p. 221, fig. 1.
- 1995b *Dunnocrinus? aequalis* - JAGT, p. 192, figs. 5, 7.
- 1998 *Dunnocrinus aequalis* (D'ORBIGNY, 1841) - JAGT, pl. 34, figs. 3, 6; pl. 35, figs. 2, 3, 5-11; pl. 36, figs. 1, 3, 9; pl. 37, figs. 1-3; pl. 38, figs. 1-4; text-figs. 28, 29.

REMARK

KLIKUSHIN's (1982a, b, 1983) records of *Bourgueticrinus aequalis* from the Lower Maastrichtian of the Volga Basin may indeed refer to this species, but as long as the structure of the (proximal) brachials remains unknown there can be no certainty.

TYPE

Lectotype, designated by RASMUSSEN (1961, p. 170), is specimen no. 396a in the GOLDFUSS Collection at the Institut für Paläontologie, Rheinische Friedrich-Wilhelms-Universität (Bonn, Germany), illustrated by GOLDFUSS (1831, pl. 57, fig. 3R) and D'ORBIGNY (1841, pl. 17, figs. 10-12). As JAGT (1998) remarked, the state of preservation suggests that this specimen, and associated columnals, were collected from the basal Valkenburg

Member (Maastricht Formation) in the type area of the Maastrichtian Stage.

LOCUS TYPICUS AND STRATUM TYPICUM

RASMUSSEN (1961, p. 170) noted that there was some confusion concerning the type area. GOLDFUSS (1831) recorded this species from the Cretaceous of the Maastricht region as well as from Lemförde, near Osnabrück, Germany. D'ORBIGNY (1850) considered that this species was from Maastricht, which opinion is here accepted.

MATERIAL STUDIED

IRScNB 10747, IRScNB 10748, NHMM 1996132/1-8, NHMM 1997100/1-4, NHMM 1997101/1-4, NHMM 1997102/1-9, NHMM MD 0101, NHMM MD 0166, NHMM MD 0406, NHMM MD 0438, NHMM MD 0957, NHMM MD 0964, NHMM MD 1486, NHMM MD 1642, NHMM MD 2133, NHMM MD 2135/1-12, NHMM MD 2842, NHMM MD 2894, NHMM MD 3369-3370, NHMM MD 3376-3380, NHMM MD 3385a/b, NHMM MD 3396, NHMM MD 3445, NHMM MD 3466, NHMM MD 3469, NHMM MD 3520-3522, NHMM MD 3528, NHMM RN 1213, NHMM RD 163, NHMM JJ 9653a, NHMM JJ 9655, NHMM K 2502-2503, NHMM K 3385-3387, NHMM K 3389-3390 and NHMM K 3396, all from the base of the Grönsveld Member (Maastricht Formation) of the ENCI Nederland BV quarry.

DESCRIPTION

Stem: Column slender, elongate and narrow (Pl. 1, Figs. 4, 6, 9; Pl. 2, Figs. 1-4; Figs. 3, 4A). Column about same width as the dorsal cup (Pl. 1, Figs. 2, 9; Pl. 3, Figs. 1, 2), changing in diameter little throughout its length. Long, but incomplete, columns include 62 (Pl. 1, Fig. 6) to 72 (Pl. 2, Fig. 1) to 79 columnals (Pl. 1, Fig. 9). Column divided into short proxistele, long mesistele and a short dististele (= attachment structure), although these regions intergrade. Except in attachment structure, latus smooth and unsculptured throughout, varying from planar to slightly concave proximally (Pl. 3, Figs. 1, 2; Pl. 4, Figs. 1-6) to more convex (Pl. 5, Fig. 8; Pl. 6, Fig. 2; Pl. 7, Fig. 5). Attachment by a strongly branched, radicular (= root-like) holdfast (*sensu* BRETT, 1981), either terminal or as a short runner (Pl. 1, Figs. 1, 5, 8; Pl. 2, Figs. 3, 4, 7; Pl. 7, Figs. 1-8; Figs. 3, 4).

Proximal columnals cylindrical. Articulation between proximale and basals syzygial (Pl. 3, Figs. 1, 2). Proximal articular facet of proximale circular, scalloped (Pl. 3, Fig. 4), divided into five equal, trapezoid, gently concave regions, separated by radially-positioned ridges; each trapezoid region supports a basal plate. Lumen central, small and rounded pentagonal in outline. Distal articular facet of proximale circular to slightly elliptical in outline (Pl. 3, Figs. 6, 8), with a central, circular to elliptical lumen. Incipient fulcral ridge may be developed (Pl. 3, Fig. 6), although articulation between the proximale and second columnal appears essentially synostosal; functional synarthral articulations apparent just distal of this region, although columnals are still cylindrical (Pl. 1, Fig. 2).



Fig. 3 – Two pluricolumnals with radicular attachment structures of *Dunnicrinus aequalis* (D'ORBIGNY, 1841) on a slab (NHMM RD 229) from the base of the Gronsvelde Member, ENCI Nederland BV quarry (Maas-tricht); scale bar equals 10 mm.

Functional synarthrial articulations on elliptical articular facets that are more or less divergent on each columnal, occur slightly more distally and persist throughout the mesistele (Pl. 1, Figs. 4, 6, 9). These columnals are broader, and thus relatively lower, in the more distal mesistele. They are grouped in pairs, articular facets at either end of each pair of columnals being approximately parallel. Articular facets are divergent at between $c. 60^\circ$ and 90° (compare, for example, Pl. 6, Fig. 2 and Pl. 5, Fig. 7, respectively). More distal columnals of the mesistele strongly elliptical with strongly divergent articular facets (Pl. 5, Figs. 5–8). Lumen central, small and elliptical to tetragonal elliptical to “diamond”-like in outline. Fulcrum corresponds to long axis of articular facet. Fulcrum moderately broad, with central groove and fine crenulae on either side of, and orientated perpendicular to, groove (Pl. 6, Figs. 5, 7, 9). Fulcrum flanks elongate, elliptical, slightly depressed areolae.

Most distal part of stem (= dististele; Pl. 6, Figs. 4, 5, 7,

9) forms a radicular attachment. Most such attachments are essentially terminal (= dendritic radices *sensu* BRETT, 1981) (Pl. 1, Figs. 1, 5, 7, 8; Pl. 2, Figs. 3, 4, 7; Pl. 7, Figs. 1, 3, 6–8). Others bear an attachment that is a radicular runner (*sensu* DONOVAN, 1997), with radices concentrated on one side of stem (Pl. 7, Figs. 2, 4, 5; Pl. 8, Fig. 1). Radicles are elongate, slender, densely clumped together, with unsculptured latera and may show at least three episodes of dichotomous to trichotomous branching. Articulations between radicular ossicles synostosomal. Branches become progressively more slender at each branching episode without obviously tapering (see, for example, Pl. 7, Fig. 6).

Radicles arise from radice scars situated, at least in more proximal part of attachment, at either end of fulcrum on the more proximal articular facets of columnals. Distal columnals of the mesistele have radice nodes (*sensu* DONOVAN, 1997) situated on the latus and positioned, particularly, at the ends of fulcrum of the more proximal facet in each columnal (Pl. 6, Fig. 2). These develop into circular radice scars, bearing radices, in the dististele, situated, at least in the more proximal mesistele, only at the ends of the proximal facets of each columnal (that is, two on each columnal), although encroaching onto the latus of adjacent, more proximal columnal (Pl. 5, Fig. 1; Pl. 8, Fig. 8). Radice scars in these regions circular, planar structures with central, circular to elliptical lumen (Pl. 5, Figs. 1, 3; Pl. 8, Fig. 8), articulating synostosomally with the attached radice. Radice canals in this region are connected to axial canal of stem through canals situated beneath synarthrial fulcrum of proximal columnal facet (Pl. 5, Fig. 6). More distally, radice scars occur in other positions, often with outlines other than circular due to close packing (Pl. 5, Figs. 1–4; Pl. 8, Figs. 1–6; Pl. 9, Figs. 1–8). More proximal radice scars are orientated perpendicular to the stem; more distally, they are arrayed in various directions, most notably distalwards and parallel to the axis of the stem (Pl. 9, Figs. 1, 2, 5–8). Terminal regions of radicular holdfasts generally irregular in outline, although some are tetragonal to elliptical (Pl. 6, Figs. 6 and 8, respectively), the axial canal being sealed and the actual terminal region commonly being multiplated (Pl. 5, Figs. 1, 4; Pl. 8, Figs. 3, 4). One specimen preserves a probable juvenile attachment, which is small, circular in outline and truncated conical in shape, with circular, synostosomal articular facet and small, central, circular lumen (Pl. 8, Fig. 7).

Many fragments of stem overgrown by secondary stereom calcite; fewer show complementary resorption of columnal calcite to facilitate growth of radices. One notable pluricolumnal (Pl. 3, Fig. 5), possibly from the mesistele, consists of three columnals incompletely overgrown by a secondary stereom layer, producing one robust, rigid, but fused multi-element, ossicle (thus reducing stem flexibility in this region). However, most overgrowths are obviously from dististele (= attachment structure). Overgrowths take a variety of forms, being most apparent where secondary calcite forms a stereom “cur-

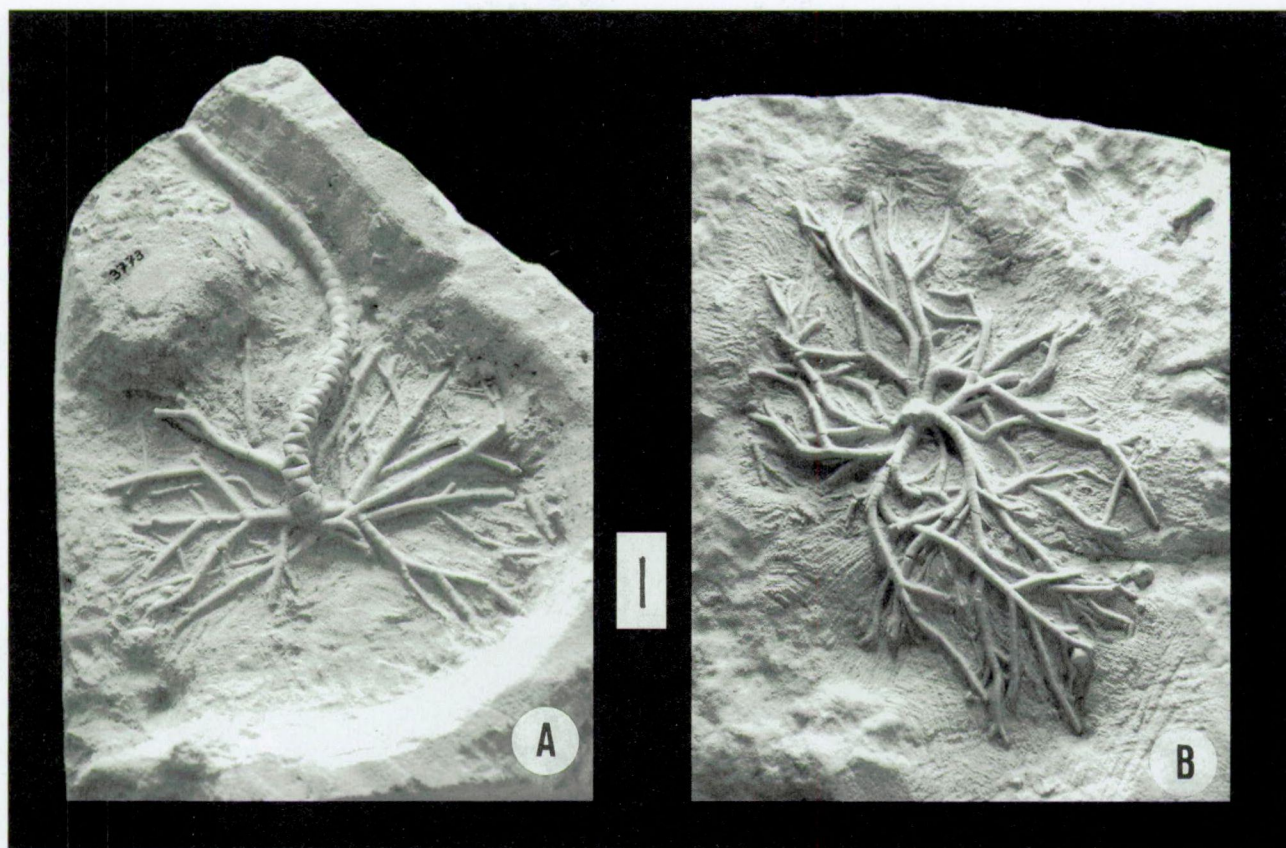


Fig. 4 – Radicular attachment structures, one specimen (A) preserving a considerable portion of column, of *Dunnicrinus aequalis* (D'ORBIGNY, 1841) on two slabs (NHMM MD 3773 and MD 3743, respectively) from the base of the Gronsveld Member, ENCI Nederland BV quarry (Maastricht); scale bar equals 10 mm.

tain'' on the latus (Pl. 5, Figs. 2, 3; Pl. 6, Figs. 1, 3; Pl. 9, Figs. 2, 3). Stereom overgrowths do not occlude radice scars (Pl. 9, Fig. 2). New radices secreted by secondary stereom are mainly orientated distally and parallel to sub-parallel to the stem. Growth of these secondary radices was associated with resorption and/or overgrowth around the circumferences of columnal facets, modifying their original elliptical outlines (Pl. 5, Fig. 2; Pl. 6, Fig. 3; Pl. 8, Figs. 5, 7; Pl. 9, Figs. 5, 7, 8).

Crown: The present material comprises a number of crowns in various states of preservation (Pl. 1, Figs. 2, 3, 9; Pl. 2, Figs. 1, 2, 6; Pl. 4, Figs. 1-7, 9, 10), but, as preserved, all are slender and comparatively high, with unbranched arms. The best preserved crown measures *c.* 29 mm in height (Pl. 4, Fig. 1), but the total height of a complete crown may be estimated to have reached up to twice this value. Depending on the way the specimens were entombed, arms are either held close together (Pl. 1, Fig. 2; Pl. 4, Figs. 2, 3), outspread to varying degrees (Pl. 2, Figs. 1, 6; Pl. 4, Fig. 1) or slightly disarticulated and/or displaced (Pl. 4, Figs. 5, 6, 10). Proximal arm portions diverge outwards so that their diameter exceeds that of the radial ring, except in specimens in the process of regenerating arms (Pl. 1, Fig. 2; Pl. 4, Fig. 2). Brachials are strongly wedge shaped and bear pinnules from Br₂ onwards (Fig. 6B, D).

The dorsal cup (Pl. 3, Figs. 1, 2; Fig. 5A, D) is (sub-)cylindrical to slightly conical in profile, with a proximale columnal of varying height, often constricted at half its height. The ratio of height basal/height radial varies during ontogeny, but in typical adult specimens is 1/2-2.5. JAGT (1998, pl. 35, figs. 6-11) illustrated a near-complete juvenile crown, as well as dorsal cups showing traces of predation, displaying various stages of regeneration and deviation in the number of radials and basals.

Like *D. mississippiensis*, *D. aequalis* invariably has but five arms. MOORE (1967, p. 14) considered this to be a significant generic attribute of the genus *Dunnicrinus*, but it may be that more Late Cretaceous bourgueticrinine taxa had such an arm arrangement (see JAGT, 1998). This would indicate that, in a food-rich environment, a lower filtration capacity (see ROUX, 1987) was sufficient. The arms are slender, almost of uniform width, but with a slight taper distally. Proximal portions of arms abut (Pl. 4, Figs. 1, 3). Pinnules are borne by brachials (except the proximal brachial in syzygially paired brachials, Fig. 6A, C) on alternate sides of the arm, and reach overall lengths of up to 0.5-0.7 mm, consisting of, as preserved, at least ten to fifteen pinnular ossicles (Pl. 1, Fig. 2; Pl. 2, Figs. 1, 6; Pl. 4, Figs. 1, 2, 7). Pinnules taper gradually, and the articulation between individual ossicles is straight muscular.

MOORE (1967, p. 19) noted that the abundance of syzygies in the arms, coupled with their random distribution, was a distinctive feature of his new genus. In *D. aequalis*, this appears also to be the case, but in contrast to *D. mississippiensis*, the first syzygy does not occur until Br_5 (Fig. 7).

DISCUSSION

JAGT (1988, 1995b, 1998) favoured re-assignment of "*Bourgueticrinus*" *aequalis* to *Dunnicrinus*. In diagnosing this new genus, MOORE (1967, p. 8) observed that, "... the first brachial [is] quadrangular, equal in width and height to radial, invariably nonpinnulate, muscular articulation between radial and first brachial and between all brachials except between lower and upper elements of syzygial brachial". On p. 15 in the same paper, he stated, "Articulations of the brachials, excepting that

between the first and second and counting syzygially paired brachials as units, are all oblique muscular." The ossicle illustrated in his pl. 7, fig. 14a-e, and interpreted to be "... brachial (possibly second) ..." indeed appears to have a muscular articulation proximally. The specimen illustrated in his pl. 8, fig. 8b shows "... first brachial (above), both showing distal articula of muscular type", but this is not entirely convincing.

In *D. aequalis*, the articulation between the radial and first brachial is muscular, that between the first and second brachial cryptosynarthrial (Fig. 5B), and that between all other brachials obliquely muscular (Fig. 6A, B, D) or cryptosyzygial (Fig. 6C). Despite the degree of uncertainty outlined above, the similarities between both species are such that they may be considered closely related. MOORE (1967) stressed that, in his material, "genuine" proximale columnals were rare; in contrast,

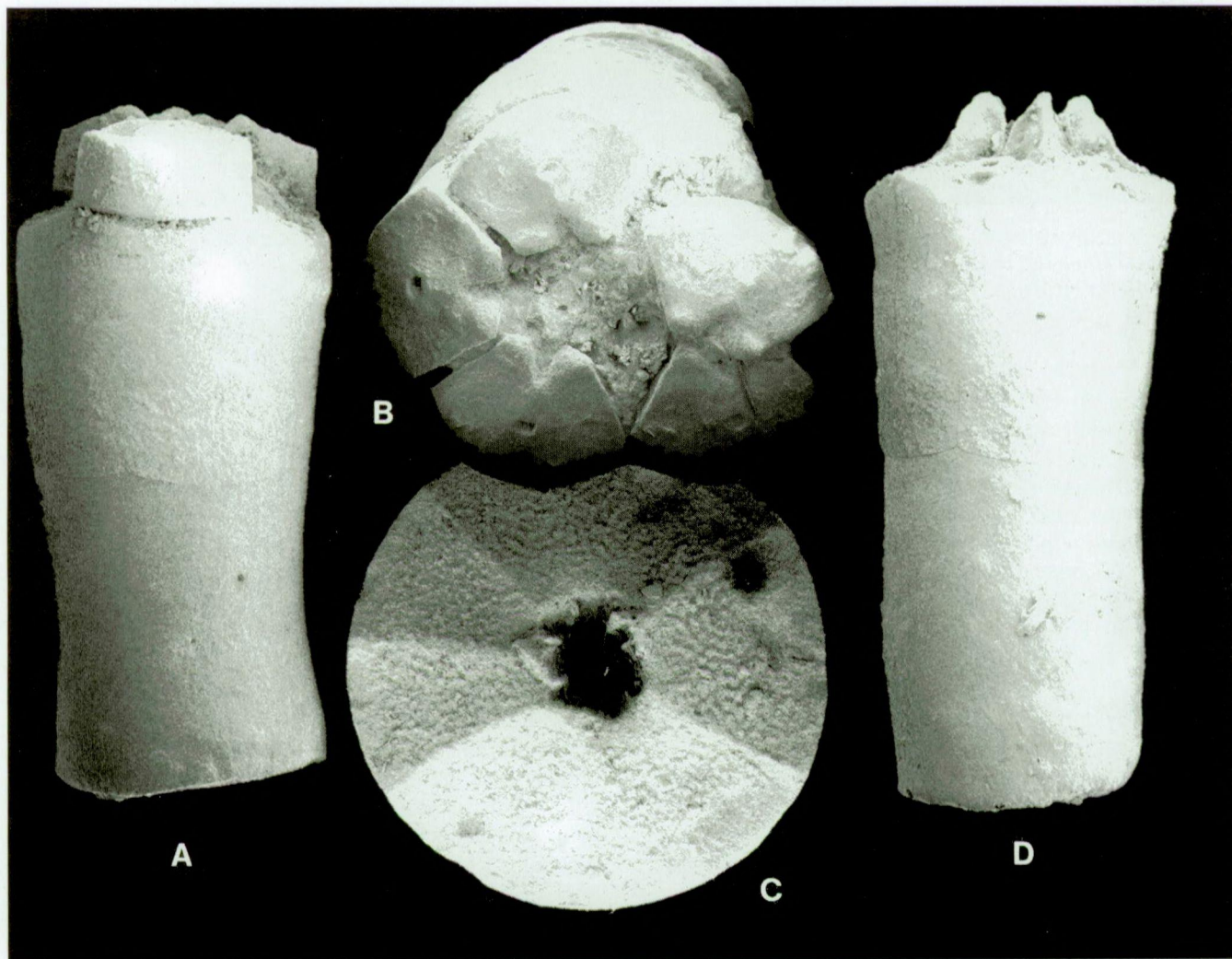


Fig. 5 – *Dunnicrinus aequalis* (D'ORBIGNY, 1841), ENCI Nederland BV quarry (Maastricht), base Gronsveld Member (Maastricht Formation, late Maastrichtian); A - NHMM MD 0965.3, lateral view of dorsal cup and attached proximale columnal and three proximal brachials (Br_1), x 10; B - NHMM MD 2188, distal articular facet of slightly displaced proximal brachials (Br_1), x 15; C - NHMM MD 0849, proximal articular facet of atypical proximale columnal, x 15; D - NHMM MD 3340, lateral view of dorsal cup and attached proximale columnal, x 11. All scanning electron micrographs of gold-coated specimens.



Fig. 6 – *Dunnocrinus aequalis* (D'ORBIGNY, 1841), dissociated brachials, ENCI Nederland BV quarry (Maastricht), base Gronsveld Member (Maastricht Formation, late Maastrichtian); A - NHMM 1997100-1, proximal articular facet of syzygial brachial, x 30; B - NHMM 1997100-2, distal articular facet of muscular brachial with pinnular articulum, x 40; C - NHMM 1997100-3, distal articular facet of syzygial brachial, x 30; D - NHMM 1997100-4, latus of proximal brachial Br₁, x 35. All scanning electron micrographs of gold-coated specimens.

none of the numerous specimens from the Maastrichtian type area lack such a structure. In addition, syzygially paired proximal brachials appear to be distributed (Fig. 7) rather randomly along the arms in *D. aequalis*, and in a less regular pattern than in its relative *D. mississippiensis* (MOORE, 1967, figs. 4, 5; table 3).

A certain number of specimens have regenerating arms, arm loss being the result either of sublethal predation (MEYER & AUSICH, 1983; LAWRENCE & VASQUEZ, 1996) or of autotomy.

Associated with the specimens of *D. aequalis* are phymosomatid echinoids preserving lanterns and spines [*Gauthieria pseudoradiata* (SCHLÜTER, 1883)] as well as ophiolpidid [*Ophiomusium* gr. *subcylindricum* (VON HAGENOW, 1840); see Pl. 2, Fig. 4] and ophiacanthid

[*Ophiacantha? danica* RASMUSSEN, 1952; see Pl. 7, Fig. 4] ophiuroids. The brittlestar material will be described in detail elsewhere (JAGT, in press). A few isolated centrodorsals, dissociated brachials and the cluster of arms here illustrated in Pl. 4, Fig. 8, belong to the pterocomid comatulid *Placometra* gr. *laticirra* (CARPENTER, 1880) (see JAGT, 1998, pl. 14, figs. 1-13; pl. 24, fig. 5). Sieve residues have yielded more ophiuroid species, but these have not yet been recognised as articulated remains, nor have asteroids, of which at least three species are known from dissociated ossicles (*Chomataster acules* SPENCER, 1913, astropectinid and goniasterid indet.).

By comparison with extant bourgueticrinids (see, for example, DONOVAN & PAWSON, 1994; DONOVAN, 1997,

and references therein), it is apparent that the gross stem morphology of *D. aequalis* is essentially similar to that of other members of this group. While there are obvious advantages in studying the stems of unfossilised crinoids, such as the ease of disarticulation which permits detailed, columnal-by-columnal description of changes in articular facet morphology, the numerous articulated and (particularly) disarticulated specimens of *D. aequalis* have permitted analysis of both gross morphology and details of columnal-scale architecture. This is particularly true of the attachment structures, which possess highly distinctive ossicles.

Crinoid attachment structures, otherwise called hold-fasts or roots, occur in a broad range of morphologies (BRETT, 1981), although within any given taxon this range is limited. The bourgueticrinids show two forms of distal attachment (RASMUSSEN, 1978, p. T841; DONOVAN & PAWSON, 1994, p. 1341), either by cementation of

an irregular, encrusting terminal “disc” (see, for example, MATSUMOTO, 1913; MCKNIGHT, 1979; JAGT, 1998) or by branched radices (see, for example, DÖDERLEIN, 1912; MOORE, 1967; GRIMMER *et al.*, 1984), although only one of these modes is followed by any given species. The latter form of attachment is seen in the type species of *Dunnicrinus*, *D. mississippiensis* MOORE, 1967, but without the secondary stereom overgrowths seen in *D. aequalis*. Typical examples of each of these forms of attachment in selected, extant bourgueticrinid species were recently described by DONOVAN & PAWSON (1994) and DONOVAN (1997), respectively. The latter paper described the columns and attachment structures of two species of the gracile taxon *Democrinus* PERRIER, 1883. These are typical of radicular bourgueticrinid attachments. However, the morphology of at least some of the radicular attachments of *D. aequalis* show unusual features compared to those of *Democrinus*.

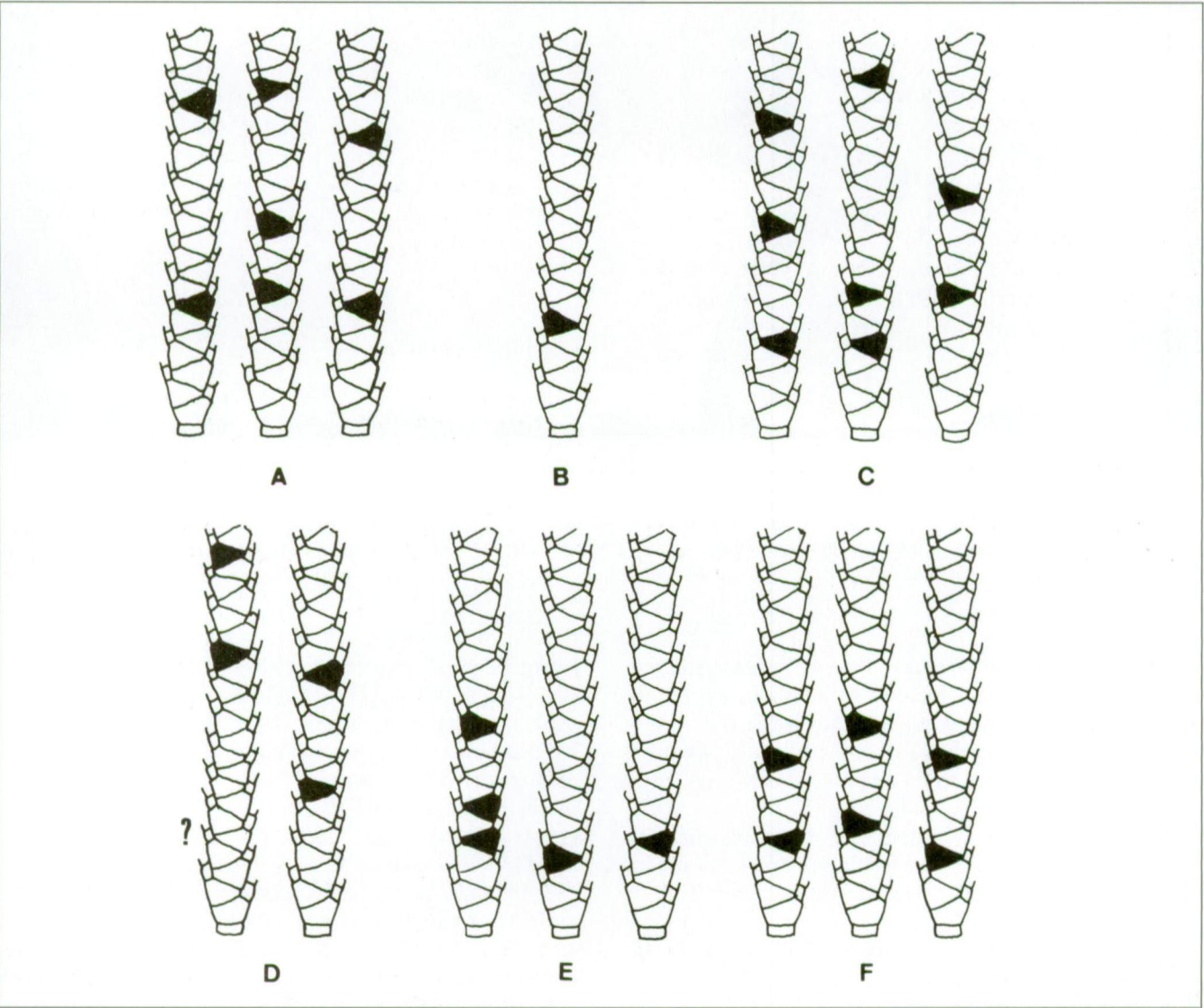


Fig. 7 – Distribution of syzygial brachial articulations in *Dunnicrinus aequalis* (D’ORBIGNY, 1841) as based on: A - NHMM MD 3378; B - NHMM MD 3385a; C - NHMM MD 3385b; D - NHMM JJ 9653a; E - NHMM RN 1213; F - NHMM RD 163.

As in *Democrinus* spp., *D. aequalis* is anchored by radicular holdfasts (see also KLIKUSHIN, 1982b, fig. 1G-I). Note that these are radices *sensu stricto* and not cirri; they articulate synostosially, were inflexible in life (DONOVAN, 1990, 1993) and do not include contractile tissues (GRIMMER *et al.*, 1984). As noted by MOORE *et al.* (1968, p. 49), bourgueticrinids lack "...cirri, but [have] branching root-like distal bifurcations." In contrast, the true cirri of isocrinids and comatulids articulate synarthrially and include possible contractile tissues, permitting re-attachment following locomotion (HOLLAND & GRIMMER, 1981; GRIMMER *et al.*, 1985; DONOVAN, 1993; but see discussion in WILKIE, 1983). Thus, attachment in *D. aequalis* was permanent, although it is probable that, if detached from its holdfast, a bourgueticrinid could regenerate a radicular attachment (see DONOVAN & PAWSON, 1997); although the bourgueticrinid column is poorly adapted for autotomy, such dislodgement may have been the result of predation. Such attachments, seen in many pelmatozoan groups, are considered to be adapted for deep penetration of an unlithified sediment (HALLECK, 1973, fig. 3) and, indeed, the circular sections of *D. aequalis* radices examined in this study do suggest that they grew without "interference" from an underlying, firm or hard substrate.

What is particularly notable about the attachment of *D. aequalis* is the complexity of the densely branched radicular holdfasts and, perhaps more significantly, the occurrence of stereom overgrowths encircling fragments of the distal stem. As noted by DONOVAN (1997), crinoid columns which articulate synarthrially are assumed to have been particularly flexible (DONOVAN, 1988), under the control of mutable collagenous tissues (WILKIE *et al.*, 1993). This flexibility would be prevented by overgrowths between columnals, such as encrusting epibionts (DONOVAN, 1993, 1997) or, in this case, secondary stereom. Such secondary stereomic secretions are known in many pelmatozoan groups (see, for example, FRANZÉN, 1977, fig. 4; BRETT, 1978, 1981; LE MENN, 1989) and are considered to form in those regions of the stem in contact with the substrate; the encircling development of this stereom in the dististele of specimens of *D. aequalis* is considered to be suggestive supporting evidence that they were buried in an unlithified substrate. These overgrowths have the affect of reducing the flexibility of the overgrown area to zero, presumably an advantage in the buried(?) attachment structure of a sessile benthic organ-

ism. These overgrowths are reminiscent of the cemented attachments seen in some bourgueticrinids (see, for example, DONOVAN & PAWSON, 1994, figs. 2.2, 2.4) and suggest that *D. aequalis* was using elements of both modes of attachment to produce a particularly rigid structure. That these overgrowths are continuous with the stereom of the stem is indicated by the occurrence of radice scars formed on this secondary stereom overgrowth. The distal orientation of these radices presumably further reduced stem flexibility. The juvenile attachment (Pl. 8, Fig. 7) is of significance in this discussion, indicating that, in at least in the early part of its life history, *D. aequalis* was able to produce a cemented attachment. KLIKUSHIN (1982b, p. 815) considered what are called secondary stereomic overgrowths herein to be regions of regeneration in broken radices; however, there is no indication of such regeneration following breakage in at least some of the overgrown specimens figured herein (for example, Pl. 3, Fig. 5). It is relevant to note that in *Democrinus* spp. and the morphologically similar columns of Palaeozoic platycrinitids, the distal stem reverts to a synostosis or symplexy, respectively, in the region of the attachment (DONOVAN, 1997). The attachment structure is rigid, that is, it does not require the degree of flexibility found in most of the column. Symplexies and, particularly, synostoses are less flexible than synarthries, and are thus better suited for intercolumnal articulations in the region of the attachment. The secondary stereom of *D. aequalis* served a similar function in reducing flexibility.

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PLATE 1

Dunnicrinus aequalis (D'ORBIGNY, 1841), ENCI Nederland BV quarry (Maastricht),
base Gronsveld Member (Maastricht Formation), late Maastrichtian.

- Figs. 1, 8 – NHMM MD 0406, 1 - slab showing three complete and one incomplete attachment structures (see also Pl. 7, figs. 3, 8), x 0.45; 8 - radicular attachment structure, x 0.68.
 Fig. 2 – NHMM JJ 9653a, crown and proximal column (see also Pl. 4, fig. 2), x 1.5.
 Figs. 3 – IRScNB 10747 (*ex* DECKERS Colln, no. 3466), partly disarticulated pluricolumnal and crown (top, see also Pl. 4, fig. 10), x 0.95.
 Fig. 4 – NHMM MD 3379, pluricolumnal and dorsal cup, x 1.2.
 Fig. 5 – NHMM MD 3445, radicular attachment structure, x 1.1.
 Fig. 6 – NHMM MD 1642, long pluricolumnal from the mesistele, x 0.55.
 Fig. 7 – NHMM MD 0166, slab showing attachment structures and pluricolumnals in association with brissid echinoids of the genus *Diplodetus* SCHLÜTER, 1900 (see also Pl. 7, fig. 1), x 0.15.
 Fig. 9 – NHMM MD 3369, partial crown (top right) and curved, near-complete column (not preserving attachment structure), x 0.6.

PLATE 2

Dunnicrinus aequalis (D'ORBIGNY, 1841), ENCI Nederland BV quarry (Maastricht),
base Gronsveld Member (Maastricht Formation), late Maastrichtian.

- Figs. 1, 6 – NHMM K 3396, 1 - crown and elongate column (attachment structure not retained), x 0.45; 6 - detail of crown, with arms open and directed down into surface of substrate, x 1.1.
 Fig. 2 – NHMM MD 3380, two pluricolumnals, plus a crown (see also Pl. 4, fig. 5) and attached pluricolumnals, x 0.85.
 Figs. 3, 4 – NHMM MD 3370, 3 - two distal stems, showing the mesistele to dististele transition and their closely associated attachment structures, x 0.46; 4 - view of whole slab, showing associated ophirolepidid ophiuroid *Ophiomusium* gr. *subcylindricum* (VON HAGENOW, 1840), x 0.3.
 Fig. 5 – NHMM MD 0964, a hash of columnals and pluricolumnals, x 0.66.
 Fig. 7 – NHMM K 2502, detail of slab showing two attachment structures and a pluricolumnal preserved in close association with brissid echinoids preserved in both life and inverted orientations, x 0.6.

PLATE 3

Dunnicrinus aequalis (D'ORBIGNY, 1841), ENCI Nederland BV quarry (Maastricht),
base Gronsveld Member (Maastricht Formation), late Maastrichtian.

- Figs. 1, 3, 6, 7 – NHMM 1997101-1, 1 - lateral view of dorsal cup and attached proximale columnal, x 10; 3 - brachial facet of radial, adoral surface towards bottom of page, x 25; 6 - distal articular facet of proximale columnal, x 17; 7 - oral surface of dorsal cup, x 15.
 Figs. 2, 8 – NHMM 1997101-2, 2 - lateral view of dorsal cup and attached proximale columnal, x 10; 8 - distal articular facet of proximale columnal, x 15.
 Fig. 4 – NHMM 1997101-3, proximal articular facet of proximale columnal, x 18.
 Fig. 5 – NHMM 1997101-4, lateral view of three sequential columnals viewed through an oval hole in a stereom overgrowth that encloses all three, x 10.

All scanning electron micrographs of specimens coated with 60% gold-palladium.

PLATE 4

Dunnicrinus aequalis (D'ORBIGNY, 1841), ENCI Nederland BV quarry (Maastricht),
base Gronsveld Member (Maastricht Formation), late Maastrichtian.

- Fig. 1 – NHMM MD 3385a/b, pair of crowns preserved both parallel and in the same orientation, pinnules particularly apparent on the right specimen, x 2.1.

- Fig. 2 – NHMM JJ 9653a, crown with some arms slightly disarticulated (see also Pl. 1, fig. 2), x 2.7.
 Fig. 3 – NHMM MD 3378, crown with well-preserved arms, x 2.5.
 Fig. 4 – NHMM K 3389, detail of proximal column, dorsal cup and proximal arms, x 4.6.
 Fig. 5 – NHMM MD 3380, crown with partly disarticulated arms (see also Pl. 2, fig. 2), x 2.6.
 Fig. 6 – NHMM K 3390, detail of proxistele, dorsal cup and proximal, disarticulated arms, x 4.
 Fig. 7 – NHMM RN 1213, detail of an arm and attached pinnules, x 5.
 Fig. 9 – NHMM JJ 9655, oral view of dorsal cup, showing proximal brachials, x 5.
 Fig. 10 – IRScNB 10747 (*ex* DECKERS Colln, no. 3466), cluster of arm fragments preserved adjacent to dorsal cup (right) and proxistele (see also Pl. 1, fig. 3), x 3.

Cluster of well-preserved arms of the associated comatulid crinoid *Placometra* gr. *laticirra* (CARPENTER, 1880).

- Fig. 8 – NHMM RD 164, x 1.7.

PLATE 5

Dunnicrinus aequalis (D'ORBIGNY, 1841), ENCI Nederland BV quarry (Maastricht),
 base Gronsveld Member (Maastricht Formation), late Maastrichtian.

- Figs. 1, 4, 5 – NHMM 1997102-1; 1 - lateral view of pluricolumnal from terminal part of stem, x 10; 4 - distal surface of terminal "columnal", x 11; 5 - proximal articular facet of pluricolumnal, x 10.
 Figs. 2, 3 – NHMM 1997102-2; 2 - distal articular facet, largely overgrown by secondary stereom bearing small, bud-like, radicular facets, x 11; 3 - lateral view of pluricolumnal bearing radicular facets, x 7.
 Fig. 6 – NHMM 1997102-3 (see also Pl. 3, fig. 8), elongate articular facet with blunt extremities (due to presence of large cirral facets), elongate lumen and part of the cirral canals exposed beneath the synarthrial fulcrum, x 9.
 Fig. 7 – NHMM 1997102-4, articular facet, x 14.
 Fig. 8 – NHMM 1997102-5, articular facet, x 14.

All scanning electron micrographs of specimens coated with 60% gold-palladium.

PLATE 6

Dunnicrinus aequalis (D'ORBIGNY, 1841), ENCI Nederland BV quarry (Maastricht),
 base Gronsveld Member (Maastricht Formation), late Maastrichtian.

- Figs. 1, 3 – NHMM MD 2135/1; 1 - lateral view of pluricolumnal with thick, radicular stereom overgrowth, x 11; 3 - distal articular facet, x 10.
 Fig. 2 – NHMM MD 2135/2, columnal of mesistele showing absence of radicular facets, but presence of radice nodes (*sensu* DONOVAN, 1997), best seen in the bottom left and top left, indicating that this columnal is from close to the mesistele to dististele transition, x 10.
 Fig. 4 – NHMM MD 2135/3, proximal circular articular facet of pluricolumnal from dististele, x 20.
 Figs. 5, 7 – NHMM MD 2135/4; 5 - detail of part of the synarthrial fulcrum, x 90; 7 - proximal articular facet of columnal from dististele, x 13.
 Fig. 6 – NHMM MD 2135/5, tetragonal distal "facet" of terminal columnal, x 15.
 Fig. 8 – NHMM MD 2135/6, elliptical distal "facet" of terminal columnal, x 13.
 Fig. 9 – NHMM MD 2135/7, proximal articular facet of columnal from dististele, x 15.

All scanning electron micrographs of specimens coated with 60% gold-palladium.

PLATE 7

Radicular attachment structures of *Dunnicrinus aequalis* (D'ORBIGNY, 1841), ENCI Nederland BV quarry (Maastricht),
 base Gronsveld Member (Maastricht Formation), late Maastrichtian.

- Fig. 1 – NHMM MD 0166 (see also Pl. 1, fig. 7), x 1.
 Fig. 2 – NHMM MD 3376, x 0.64.

- Figs. 3, 8 – NHMM MD 0406, two radicular attachment structures (see also Pl. 1, fig. 1), x 0.95 and x 0.5, respectively.
Fig. 4 – NHMM K 3387, with associated ophiacanthid ophiuroid, an arm of which rests on the pluricolumnal, x 1.
Fig. 5 – NHMM MD 0957, x 1.5.
Fig. 6 – NHMM MD 0166, x 0.8.
Fig. 7 – NHMM MD 0166, x 1.1.

PLATE 8

Dunnicrinus aequalis (D'ORBIGNY, 1841), ENCI Nederland BV quarry (Maastricht),
base Gronsvelt Member (Maastricht Formation), late Maastrichtian.

- Fig. 1 – NHMM 1997102-6, lateral view of radicular pluricolumnal, x 8.
Figs. 2, 5 – NHMM 1997102-7; 2 - lateral view of radicular pluricolumnal, x 10; 5 - distal articular facet, showing scalloping to permit growth of cirri, x 12.
Figs. 3, 4 – NHMM 1997102-8; 3 - basal view of terminal pluricolumnal, x 15; 4 - lateral view, x 12.
Fig. 6 – NHMM 1997102-9, radicular pluricolumnal, x 8.
Fig. 7 – NHMM MD 2133, articular facet, partly overgrown by secondary stereom and a juvenile attachment disc, x 8.
Fig. 8 – NHMM 1997102-3 (see also Pl. 5, fig. 6), radicular pluricolumnal, x 8.

All scanning electron micrographs of specimens coated with 60% gold-palladium.

PLATE 9

Dunnicrinus aequalis (D'ORBIGNY, 1841), ENCI Nederland BV quarry (Maastricht),
base Gronsvelt Member (Maastricht Formation), late Maastrichtian.

- Figs. 1, 8 – NHMM MD 2135/8; 1 - lateral view of pluricolumnal from dististele, x 12; 8 - distal articular facet, x 12.5.
Figs. 2, 7 – NHMM MD 2135/9; 2 - lateral view of pluricolumnal from dististele showing lobate stereom overgrowth continuous with radice scar, x 11.5; 7 - distal articular facet, x 10.
Fig. 3 – NHMM MD 2135/10, lateral view of pluricolumnal from dististele showing uneven overgrowth of stereom, x 10.
Fig. 4 – NHMM MD 2135/11, irregularly scalloped (distal?) articular facet of columnal from dististele, x 12.
Figs. 5, 6 – NHMM MD 2135/12; 5 - distal articular facet of pluricolumnal from dististele, x 10; 6 - lateral view, x 10.

All scanning electron micrographs of specimens coated with 60% gold-palladium.

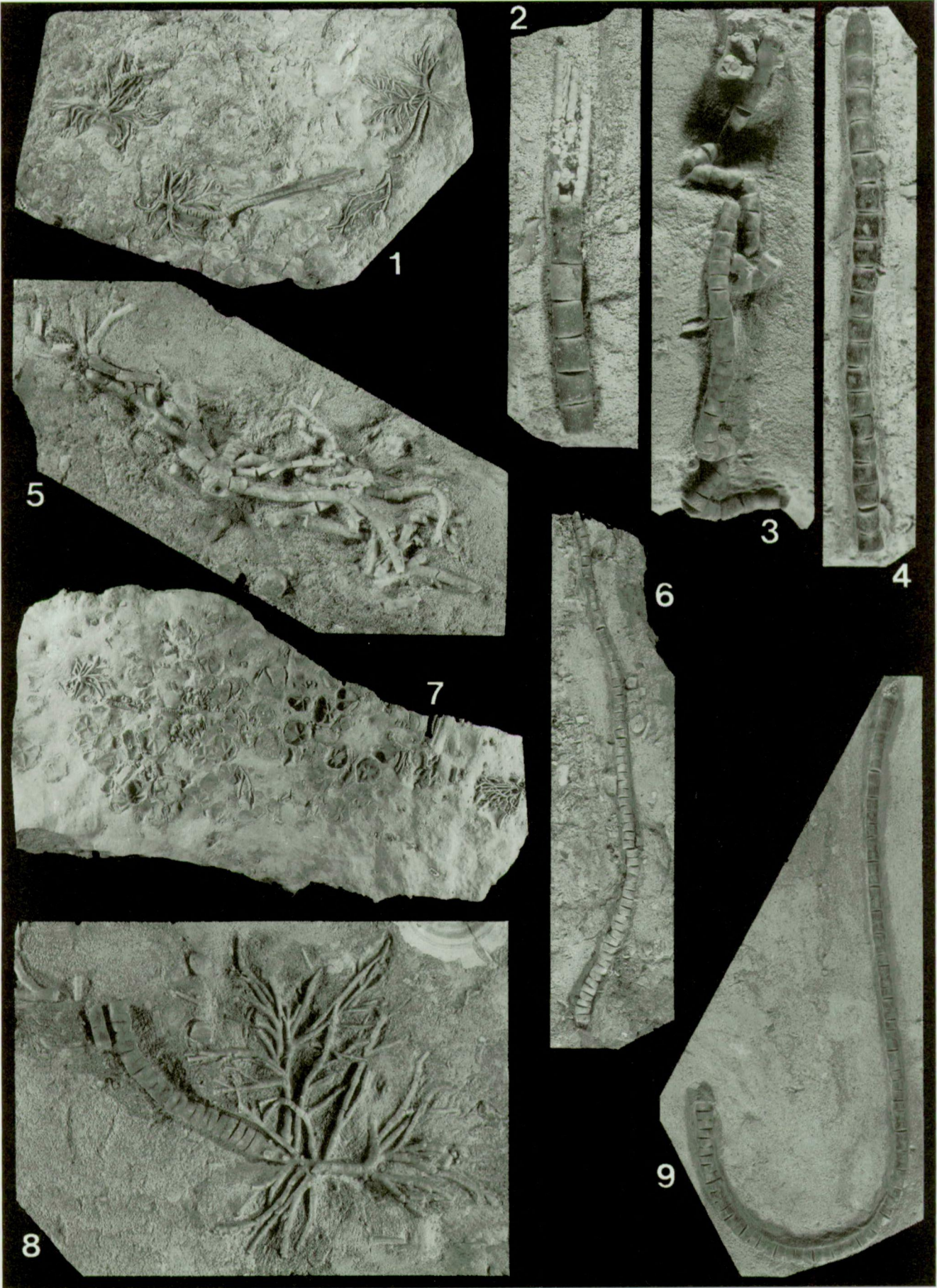


PLATE 1

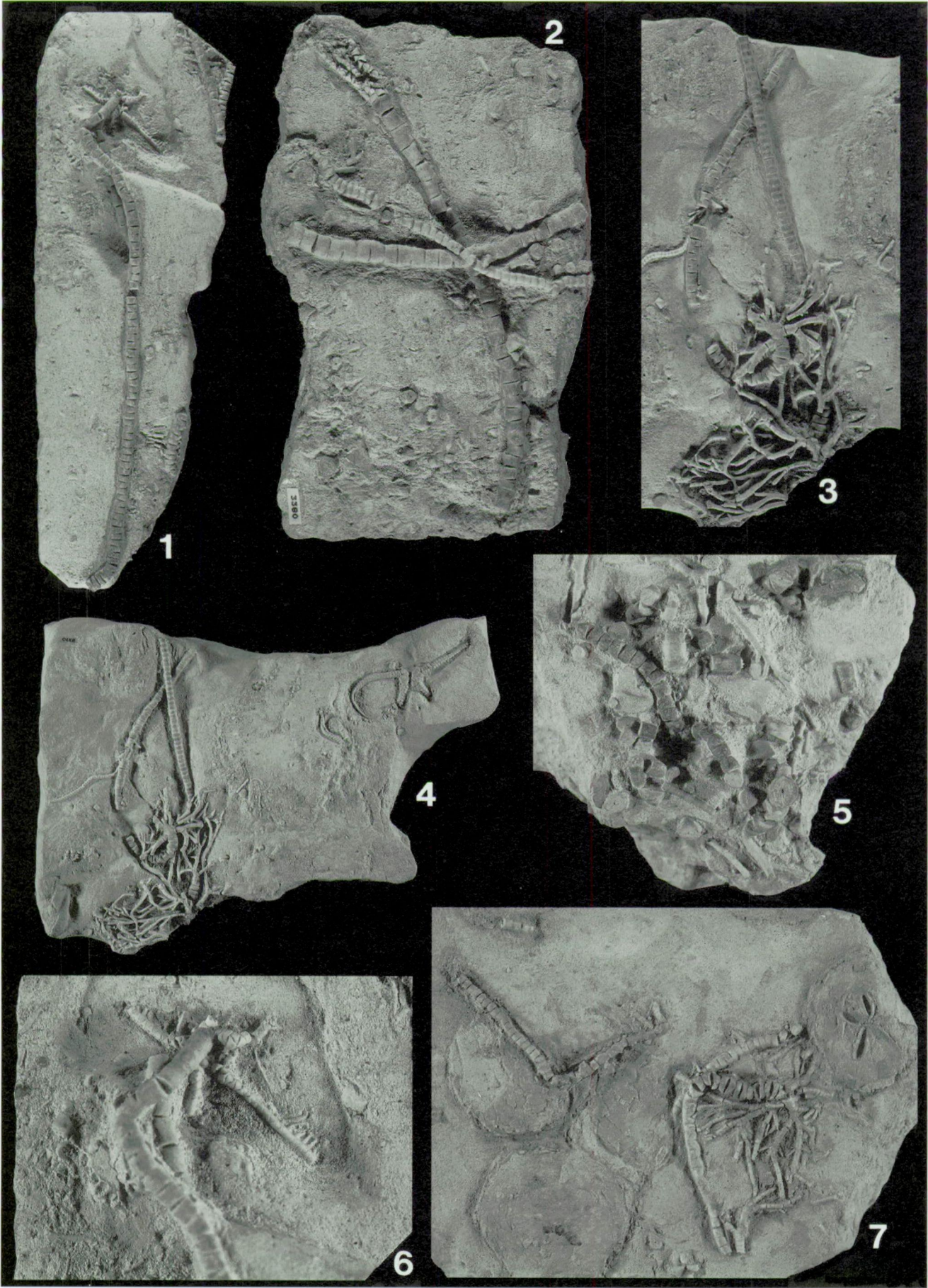


PLATE 2

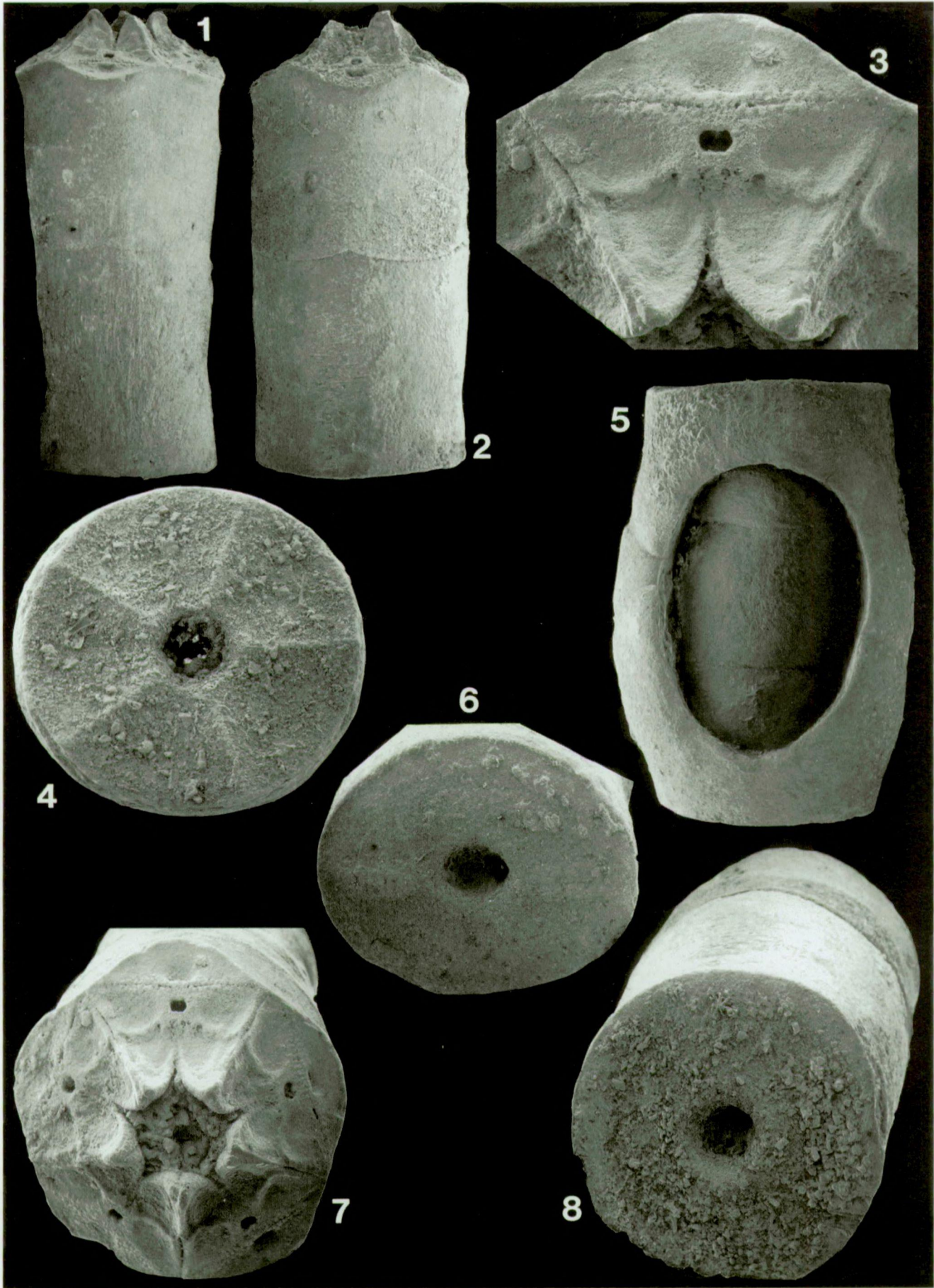


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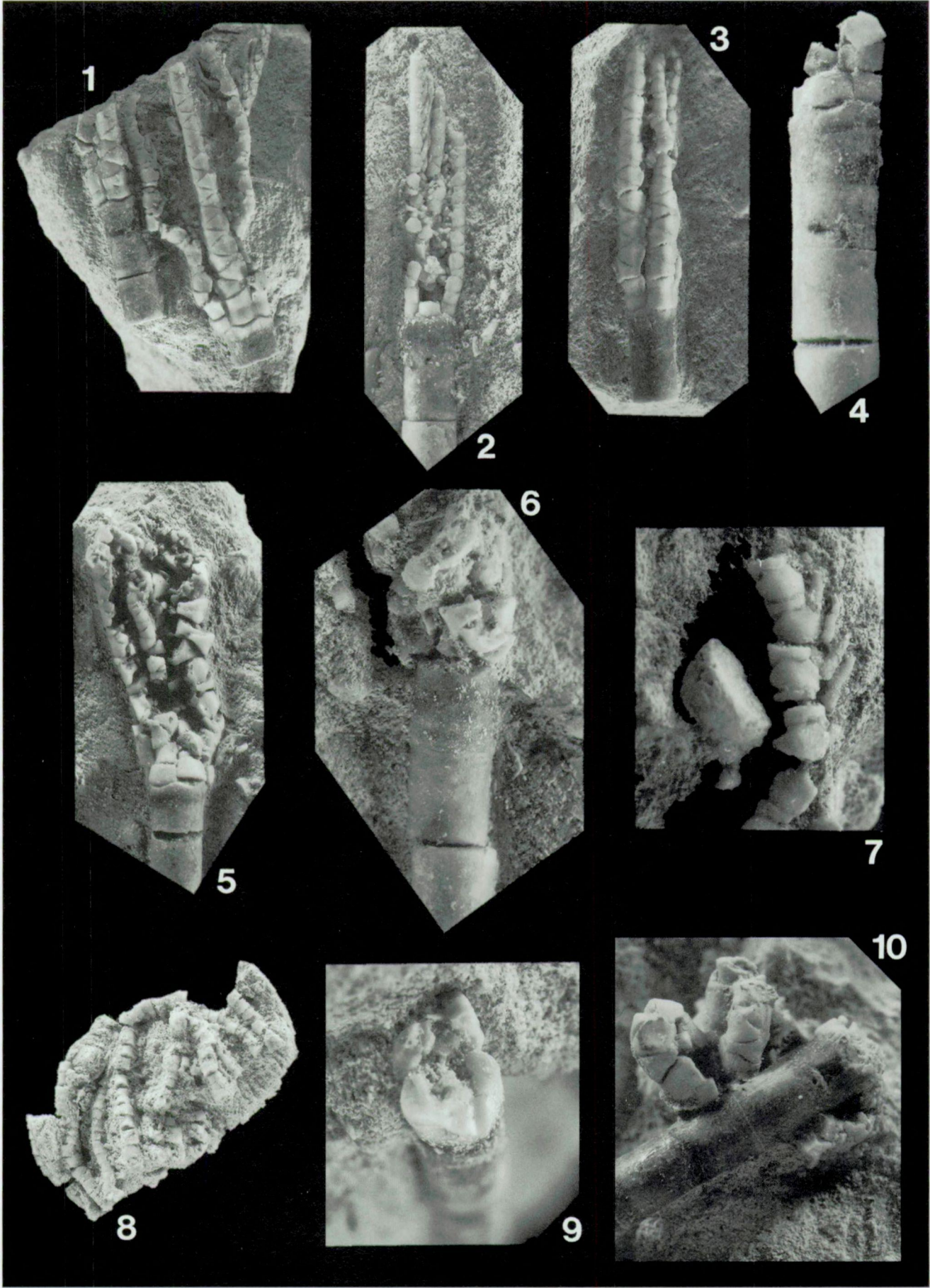


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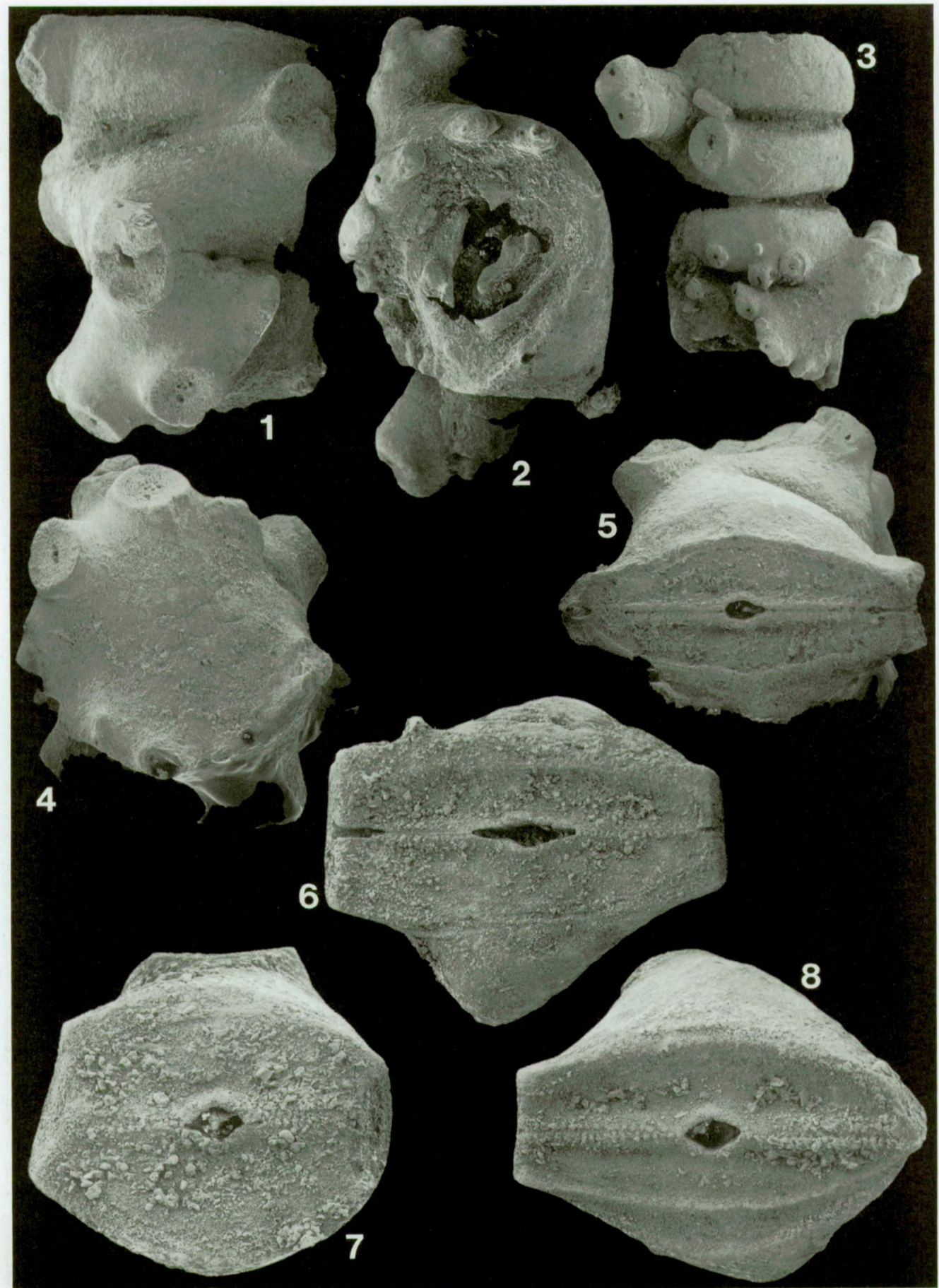


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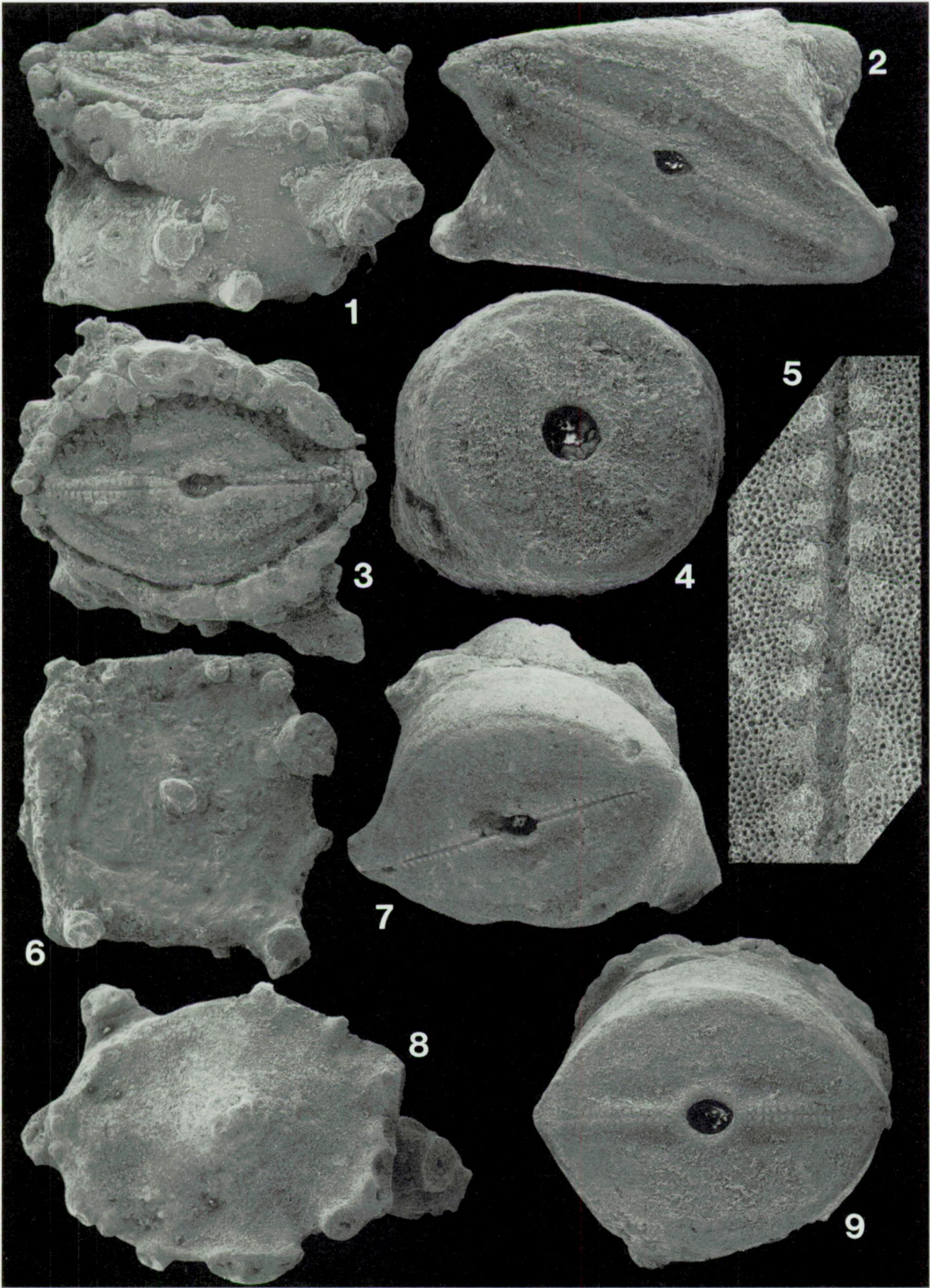


PLATE 6

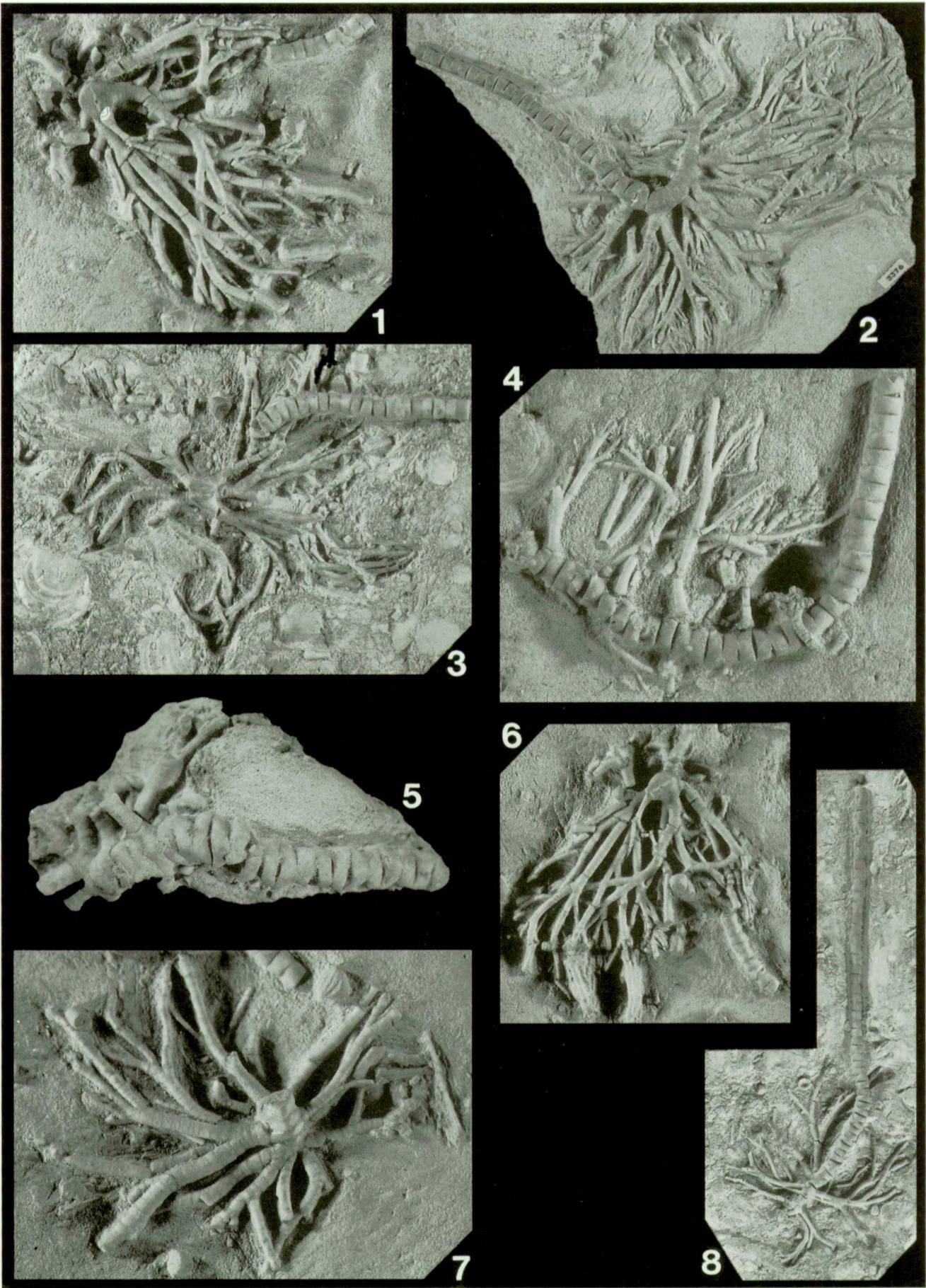


PLATE 7

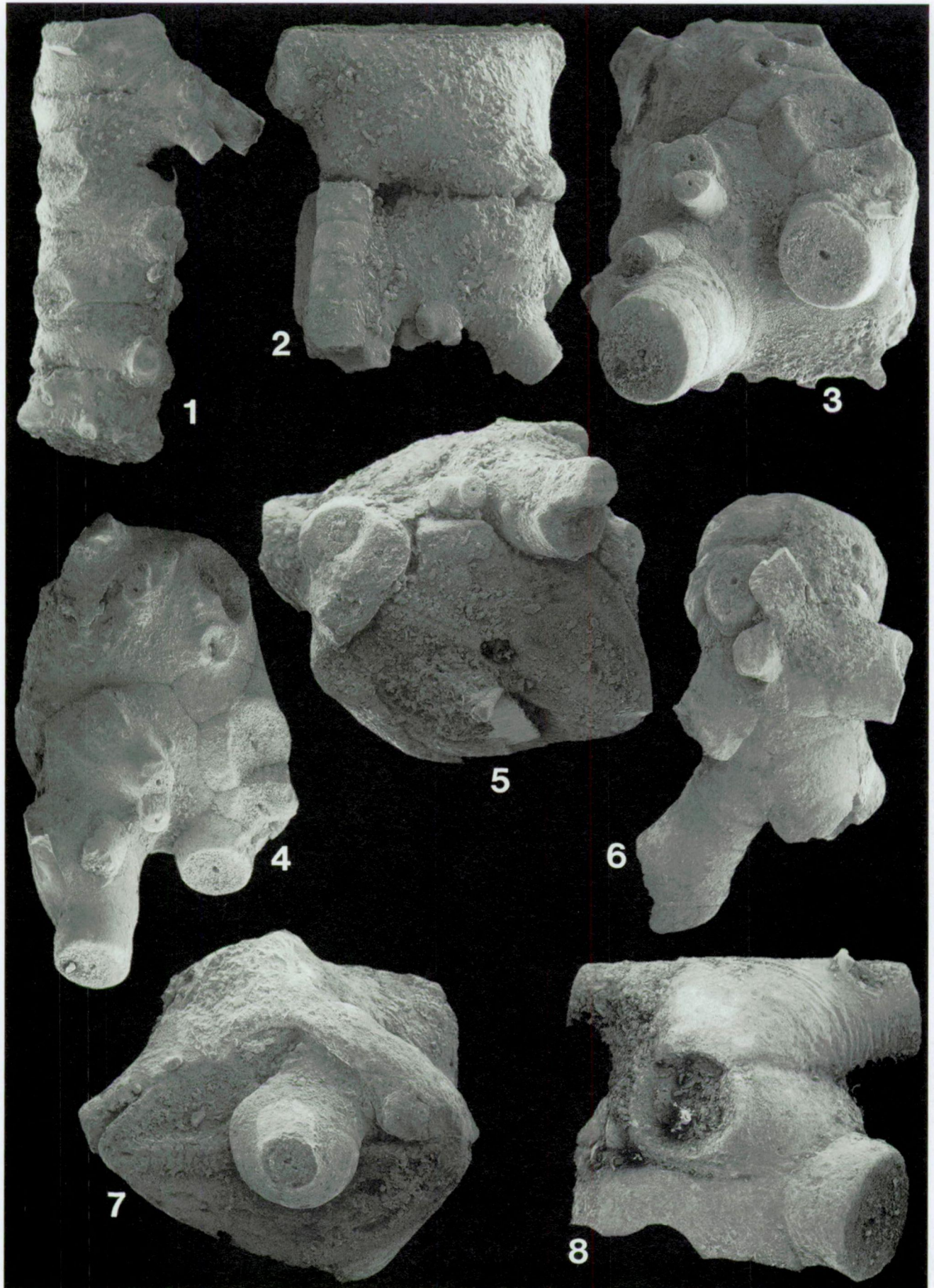


PLATE 8

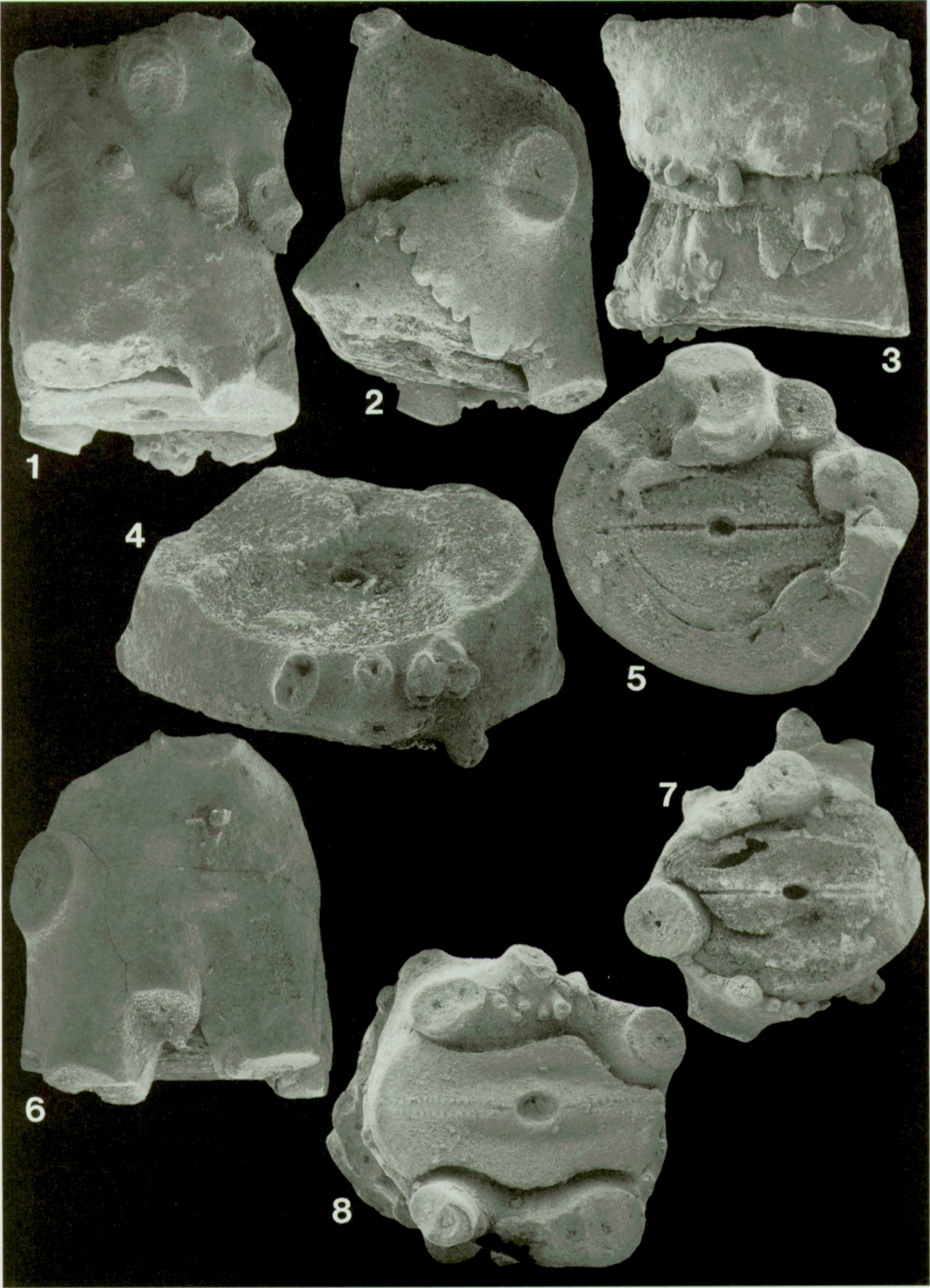


PLATE 9