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Upper Ordovician of the Cincinnati, Ohio, Area, USA

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THE 'PUBLISHING AMATEURS'

The Upper Ordovician of North America is the Cincinnatian Series, named for the richly fossiliferous beds in the Ohio–Indiana–Kentucky tri-state area surrounding Cincinnati, Ohio. This area is near or beyond the southern extent of Pleistocene glaciation, so bedrock is exposed or covered only thinly with glacial sediments. Hillsides, stream beds and road cuts expose the interbedded shale and limestone Cincinnatian strata, and fossils virtually tumble from rocks into collecting bags. This physical backdrop of abundant fossils and layered strata has been an intellectual seed for more than a century and a half. Many now-famous palaeontologists grew up in Cincinnati, including R. S. Bassler, J. M. Nickles, C. Schuchert and E. O. Ulrich. Caster (1981) referred to early Cincinnati geologists as the 'publishing amateurs' or in the case of those just listed as the 'amateurs-turned-professionals'.

Bryozoans and brachiopods are the most prolific Cincinnatian fossils, but trilobites and echinoderms are the prizes of these strata. Crinoids are the most abundant echinoderms of the Cincinnatian, but asteroids, cyclocystoids, edrioasteroids, rhombiferans and stylophorans are also known from these beds.

STRATIGRAPHIC CYCLES

At an estimated 20°S palaeolatitude, Cincinnatian sediments were deposited in a tropical, shallow-water epicontinental setting, approximately 440 million years before present. The composite outcrop section in Ohio consists of more than 300 m of interbedded fossiliferous limestones and shales. Eustatic sea level fluctuations and storms were apparently the dominant physical factors controlling sedimentation, and this produced a hierarchy of cyclical strata.

Upper Ordovician strata (Cincinnatian) are dominated by four shallowing-upward sequences (Fox 1962; Holland 1993; Davis & Cuffey in press). The base of the Cincinnatian begins with the Kope Formation (Edenian Stage) and facies shallow upward to the Bellevue Formation in the Middle of the Maysvillian Stage (Fig. 85). The deepest Kope facies still appears to have been within storm wave base. Deposits of a second short cycle comprise the remainder of the Maysvillian, and a third cycle results in the lowest part of the Richmondian Stage. The sequence is capped by the remainder of the Richmondian, the fourth cycle. It begins with the deep-water Waynesville Formation, which gradually shallows to the unfossiliferous, mud-cracked Elkhorn Formation.

Hans Hess, William I. Ausich, Carlton E. Brett, and Michael J. Simms, eds., *Fossil Crinoids*.

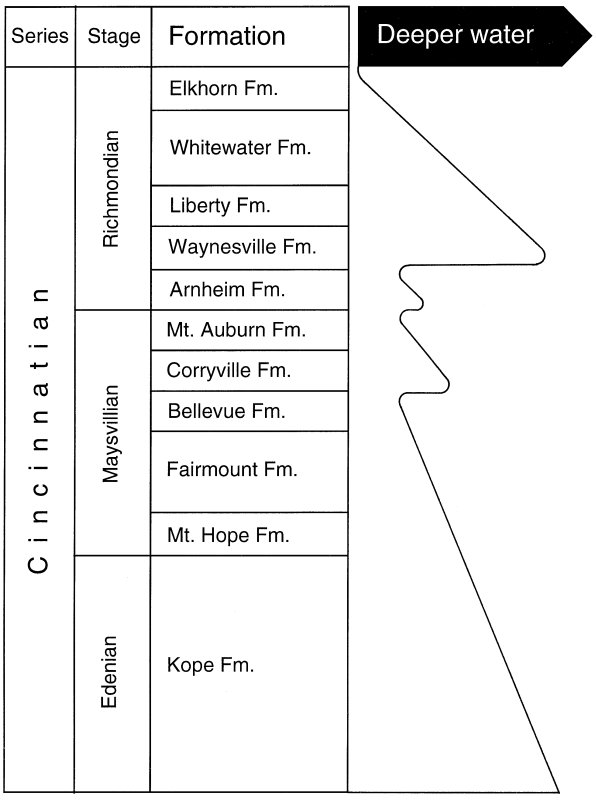

Fig. 85. Representative stratigraphy of the Cincinnatian (Upper Ordovician) outcrop belt in southwestern Ohio, with interpreted relative changes in sea level. (Modified from Davis & Cuffey in press.)

The termination of Cincinnatian deposition resulted from a global regression of sea level due to the latest Ordovician continental glaciations.

The Cincinnatian sequence is dominated by tempestites, fewer in the deep-water settings and many more in the shallow-water environments. Furthermore, tempestites are bundled into repeated packages, producing cyclic stratigraphic patterns (Tobin 1986; Jeanette & Pryor 1993).

CINCINNATIAN CRINOIDS

In comparison with many Middle Ordovician echinoderm assemblages, the Upper Ordovician Cincinnatian is a rather odd fauna. In the Cincinnatian, blastozoans are very rare. Furthermore, some of the characteristic Middle Ordovician crinoids, such as calceocrinids and hybocrinids, are absent and the generic diversity of diplobathrid camerates is much reduced. In total, approximately 37 species assigned to 20 genera are currently recognized from Cincinnatian strata. The most common crinoids are the diplobathrid *Gaurocrinus*; the monobathrids *Glyptocrinus*, *Pycnocrinus* (Figs. 90, 94, 95) and *Xenocrinus* (Fig. 25, 92); the disparids *Cincinnaticrinus* (Figs. 86, 89), *Ectenocrinus* (Fig. 26) and *Iocrinus* (Fig. 74); and the cladids *Cupulocrinus* (Fig. 93) and *Plicodendrocrinus*. The multi-plated disparid lichenocrinid-type holdfast, which cements to shells and hardgrounds, is also quite common (Figs. 87–89).

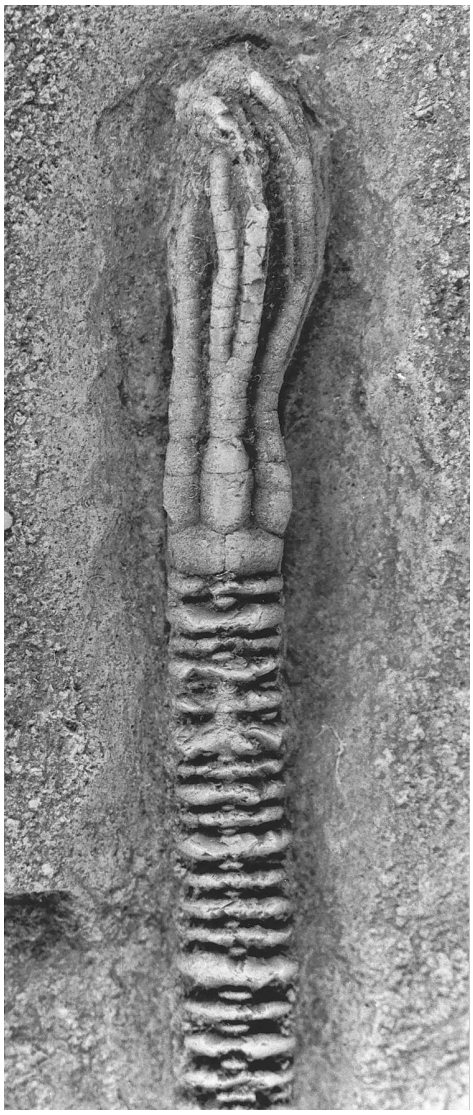

Fig. 86. *Cincinnaticrinus pentagonus*. Richmondian from southwestern Ohio. (From Ausich 1996b.) ×4.

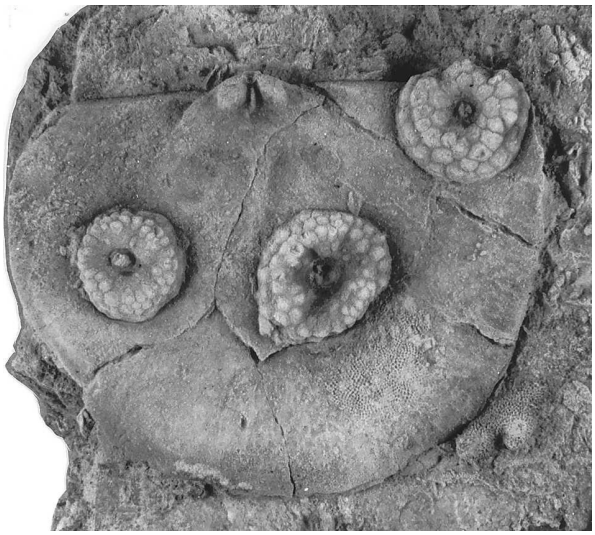

Fig. 87. Lichenocrinid-type holdfasts cemented on a brachiopod shell. Cincinnatian, southwestern Ohio. (From Ausich 1996b.) ×2.

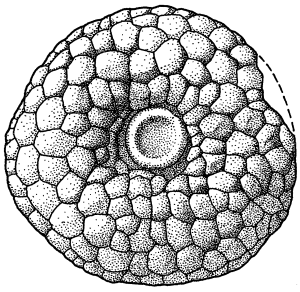

Fig. 88. Lichenocrinid-type holdfast with stem insertion, based on a specimen from the Cincinnatian, southwestern Ohio. ×4.

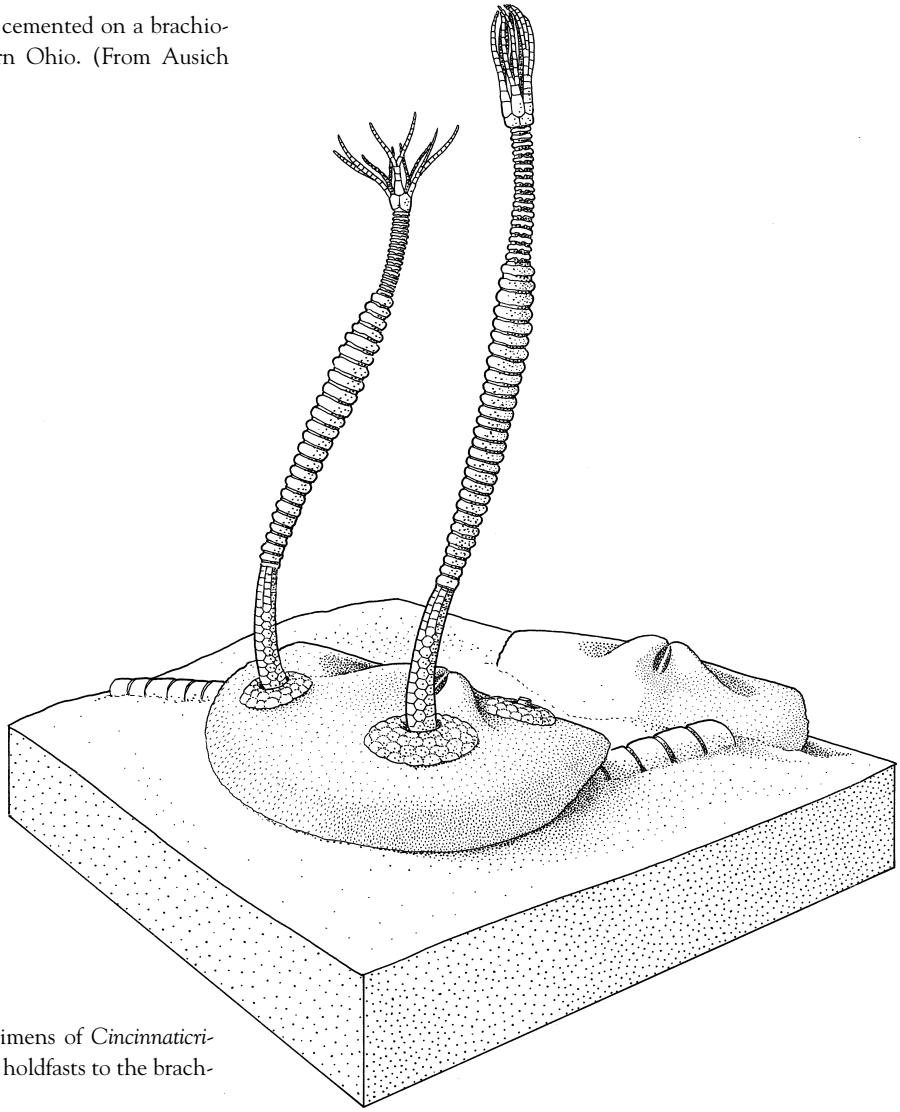

Fig. 89. Reconstructions of two specimens of *Cincinnaticrinus*, attached with their lichenocrinid holdfasts to the brachiopod *Rafinesquina*. ×1.

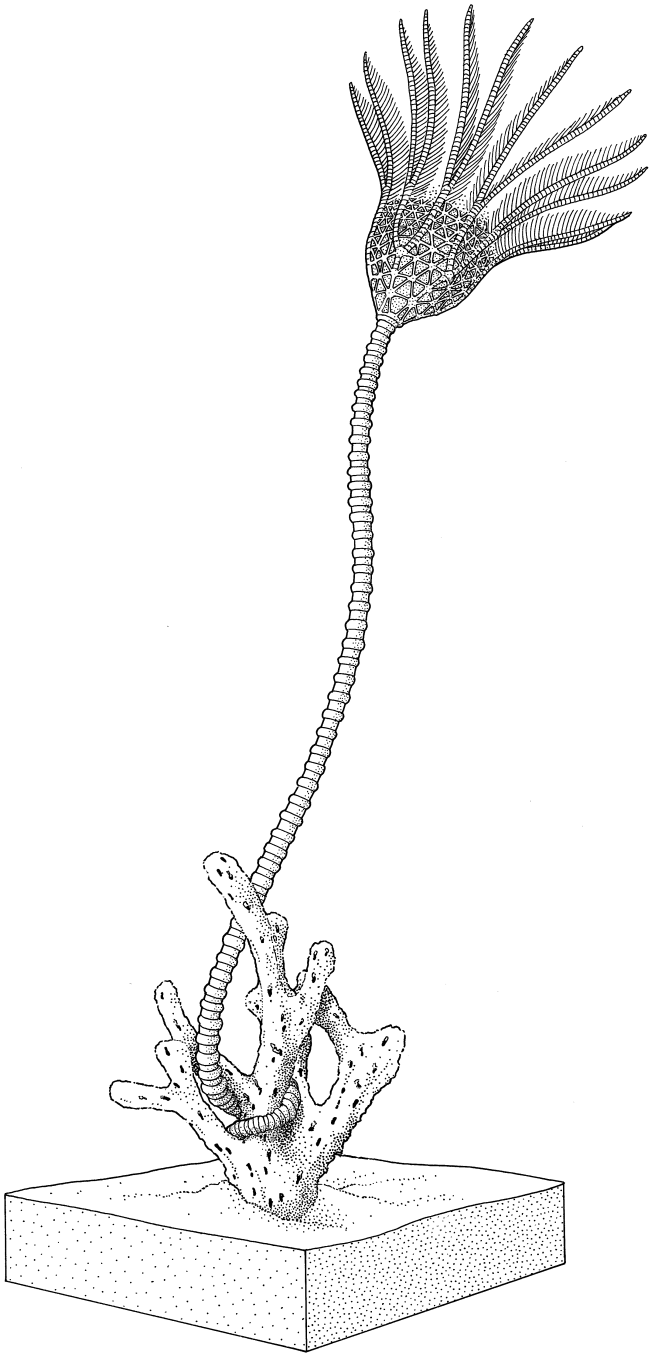

Fig. 90. Reconstruction of *Pycnocrinus* attached to a bryozoan. ×0.75.

Stalked echinoderms tend to be more common in the intermediate-depth facies, such as the shallower parts of the Kope, Fairmount, Corryville, Waynesville and Liberty Formations. Crinoid crowns were typically preserved on smothered bottoms, as transported elements of turbidites (Meyer 1981; Schumacher & Ausich 1985; Schumacher & Meyer 1986) or as large log jams of crinoid stems and crowns that were presumably swept into channels. These preservational modes were probably the result of episodic, catastrophic storm deposition (Meyer 1981). Cincinnatian crinoid assemblages are typically rather low in diversity. It is not unusual for monospecific stands to occur, and assemblages with more than five species are rare. Crinoids may occur in densities as high as 400 per square metre.

INTERESTING DISPARIDS

Two Cincinnatian disparids, *Cincinnaticrinus* and *Ohiocrinus*, are morphologically fascinating. *Cincinnaticrinus* (formerly *Heterocrinus*; see Warn & Strimple 1977) is a very common Cincinnatian crinoid, so it is very well known. It has an exceedingly small crown. In fact, the crown seems to be an afterthought on the stem rather than the focal point of the animal. Cincinnatian species of *Cincinnaticrinus* are *C. varibrachialus* (Edenian to Maysvillian) and *C. pentagonus* (Maysvillian to Richmondian) (Fig. 86).

Cincinnaticrinus has a lichenocrinid-type holdfast (Fig. 89). This holdfast is a low, convex, multi-plated structure with a central depression for stem attachment (Fig. 88). It commonly cemented to brachiopod shells, but it also attached to other skeletal debris, including crinoid columns, hardgrounds and lithified nodules. A progression of morphologically dissimilar columnals comprise the *Cincinnaticrinus* stem. The oldest (attached to the holdfast) columnals are pentameric with vertical ranges of pentameres offset laterally and joined along a zig-zag suture (Fig. 89). This arrangement gradually changes to one with offset pentameres and straight sutures, and then to one with pentameres aligned laterally with straight sutures. After the crown was mature, growth of the column was complex and is only partially understood. Apparently, pentagonal, pentameric columnals were added. Each of these enlarged in height and width and became circular. Subsequently pentagonal, pentameric columnals may have been added between these larger circular columnals; and these intercalated columnals also grew, becoming indistinguishable from the other, larger columnals.

With the arms closed, the crown, including the aboral cup with its high radial circlet, may be narrower than

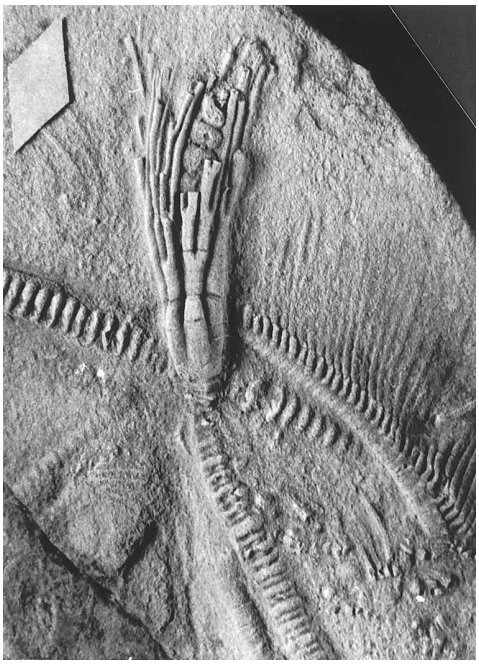

Fig. 91. *Ohiocrinus brauni.* Cincinnatian, southwestern Ohio. Note spiral anal sac. (Reprinted by permission of the National Museum of Natural History, Washington, D.C.) ×3.

the stem (Fig. 86). The anal sac in *Cincinnaticrinus* is short, narrow and arm-like in appearance. The arms divide isotomously on the fourth or fifth primibrachial and then heterotomously several times. Adult *Cincinnaticrinus* crowns attached to the holdfast are unknown. This has suggested to some authors that the adult *Cincinnaticrinus* broke free from the holdfast (Warn & Strimple 1977), but it is difficult to envisage how this crinoid survived without attachment, because it lacked cirri and shows no evidence of being distally coiled as in *Pycnocrinus dyeri*, discussed in the next section.

In total, the crown seems disproportionately small for the stem, the filtration fan was quite small and the body cavity in the cup was minute, yet this was a highly successful Cincinnatian crinoid. Perhaps its small size and encrusting habit arose paedomorphically, enabling it to adapt to an opportunistic mode of life.

Ohiocrinus, another Cincinnatian disparid, is very rare. The aboral cup and crown are more normally proportioned than in *Cincinnaticrinus*, but *Ohiocrinus* has a unique anal sac. This structure is composed of small plates arranged into a spiral structure (Fig. 91). Presumably this housed a greatly enlarged digestive system, but the reason for such an adaptation remains a mystery.

CAMERATES AND PLATYCERATID GASTROPODS

Pycnocrinus and *Glyptocrinus*, especially *Pycnocrinus dyeri*, are the most common Cincinnatian camerates. With a high calyx, many fixed brachials, many interradial plates and several biserially pinnulate arms, these are typical Ordovician camerates.

Pycnocrinus dyeri has a distally coiled stem that was used as an attachment around bryozoans or other erect crinoid stems (Fig. 90). The column is composed of circular columnals with nodals separated by varying numbers of internodals. The calyx has a high bowl shape and is distinguished by a median ridge along each ray and a star-shaped ridge pattern on interradial plates (Figs. 94, 95). The second primibrachial is axillary, but the fixed brachials do not divide again. The arms become free after six or seven secundibrachials, and after another three or four free secundibrachials the arms divide again. Fixed pinnules are incorporated into the interradial areas, and the free arms are biserial with long, delicate pinnules.

These crinoids provide one of the best early glimpses at the special biotic interaction between crinoids and platyceratid gastropods, a relationship that lasted throughout the Palaeozoic. Platyceratids are a morphologically diverse group of archaeogastropods that are most commonly preserved attached to a crinoid tegmen. Because these gastropods attach directly over the anus, platyceratids have traditionally been considered to be

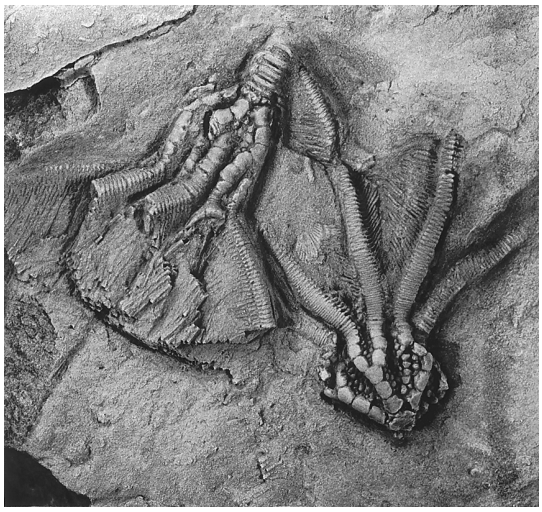

Fig. 92. *Xenocrinus baeri.* Richmondian, southwestern Ohio. (From Ausich 1996b.) ×1.5.

Fig. 93. *Cupulocrinus polydactylus*. Richmondian, southwestern Ohio. (From Ausich 1996b.) ×1.

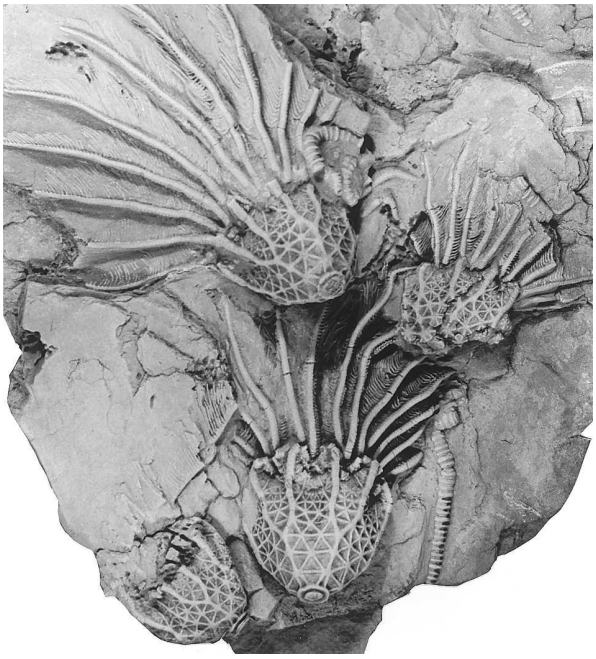

Fig. 94. *Pycnocrinus dyeri*. Maysvillian, southwestern Ohio. (From Ausich 1996b.) ×0.85.

coprophagous commensals (Bowsher 1955; Breimer & Lane 1978). In some Mississippian examples, it is clear that the gastropods were permanently attached over the anus. Alternative explanations of this association, such as active drilling by the gastropods, are now under consideration (Baumiller 1990b; Morris & Felton 1993). Perhaps different platyceratids fed in different ways.

Cyclonema and *Naticonema* are the two Cincinnatian platyceratids, with *Cyclonema* (Fig. 95) the most common (Morris & Felton 1993). Unlike younger platyceratids, these gastropods were not permanently affixed to the tegmen, but apparently moved about (Bowsher 1955), so the crinoid–platyceratid relationship was less specialized during the Ordovician than later.

IMPORTANT COLLECTIONS IN THE UNITED STATES

Cincinnati Museum of Natural History, Cincinnati, Ohio
Field Museum of Natural History, Chicago, Illinois
Miami University, Oxford, Ohio
National Museum of Natural History, Smithsonian Institution, Washington, D.C.

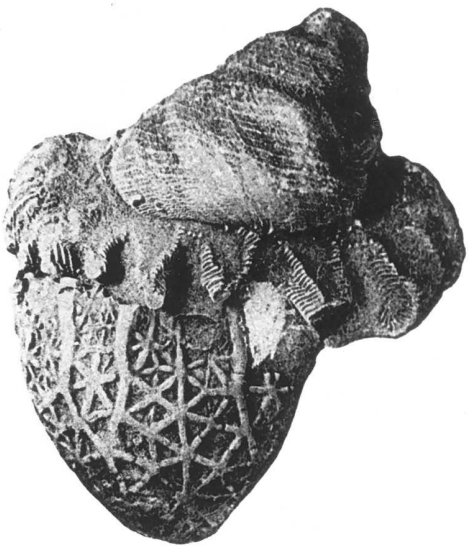

Fig. 95. *Pycnocrinus dyeri* with the platyceratid gastropod *Cyclonema* sp. positioned on the tegmen. Cincinnatian, southwestern Ohio. (From Bowsher 1955; reprinted by permission.) ×1.5.