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New Information on the *Holocystites* Fauna (Diploporita) of the Middle Silurian of Wisconsin, Illinois, and Indiana

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INTRODUCTION

Since publishing a revision of the *Holocystites* fauna of North America (Paul, 1971) additional information on specimens, localities, stratigraphic correlation, etc. has become available which we feel should be put on record. First, on a visit to the American Museum of Natural History, New York (AMNH), in September, 1972, Paul relocated the missing holotype of *Holocystites ovatus* Hall, thus allowing the taxonomic position of this form to be interpreted for the first time. He also discovered 14 specimens of *Trematocystis*, *Pentacystis*, and *Triamara* among material collected last century by G. K. Greene (of Indiana) from a previously unrecorded locality (Ryker's Ridge) in Jefferson County, Indiana.

Frest presents additional information on localities and the occurrence of holocystitids in the Middle Silurian of southern Indiana, including details of the section exposed along Big Creek within the Jefferson Proving Grounds, which historically was the richest source of holocystitids from Indiana. Mikulic presents new facts on

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the occurrence of cystoids in, and the correlation of, the Niagaran dolomites of Wisconsin and Illinois. He has also traced the exact sources of many specimens in old collections, largely using the correspondence of T. A. Greene (of Wisconsin). Field work has helped to establish the preservational history of the cystoids and their relationship to the well-known Niagaran bioherms.

In addition to fieldwork, extensive use has been made of the large collections of relevant Silurian material, catalogued and uncatalogued, repositied in Field Museum to supplement the data presented in Paul (1971). In particular the sizeable collections of Osgood cystoid types and Niagaran dolomite fossils from Wisconsin and Illinois, and lesser amounts of Laurel limestone (Indiana) material, have been of considerable value in formulating a paleoecologic framework for the *Holocystites* fauna. Many of the fossils accumulated in the course of fieldwork have been donated to Field Museum. Finally, Dr. Hertha Sieverts-Doreck has kindly drawn our attention to her interpretation (Sieverts, 1934; Sieverts-Doreck, 1963) of hemispherical pits in fossil echinoderms as borings of parasitic gastropods.

ACKNOWLEDGEMENTS

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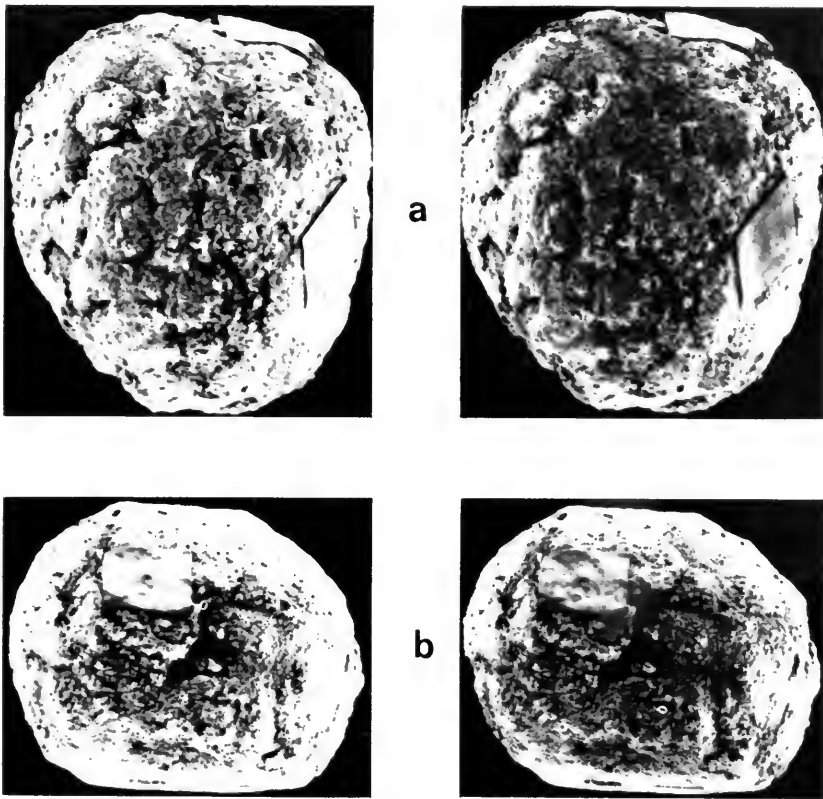


FIG. 1. *Holocystites ovatus* Hall, 1864. Stereophotos of the holotype, AMNH 2021. a, Lateral view to show thecal outline. b, Oral view. Both $\times 1.3$. Both whitened with ammonium chloride sublimate.

***Holocystites ovatus* Hall, 1864. Figure 1.**

For synonymy see Paul, 1971, p. 149.

Type — Holotype (monotype), AMNH 2021, original of Hall, 1868, pl. 12, fig. 2.

Horizon and Locality. — “In the limestone of the Niagara Group at Waukesha, Wisconsin.” Hall, 1864, p. 10. See pp. 95-97 for details of this locality.

Description. —

Theca: ovoid, probably originally pyriform, now slightly crushed and with the base missing. Internal mold 45 mm. high and 40 mm. maximum width.

Plates: probably two generations but not well preserved. Arranged in at least 10 poorly defined circlets of more than eight plates each. Primary plates reach 8-9 mm. in maximum dimension.

Pore-structures: dipores present but on an internal mold it is impossible to confirm that they were originally humatipores.

Mouth: preserved as a tubercle 5 mm. in diameter at the oral pole.

Anus: similarly a 5 mm. diameter tubercle close to the mouth.

Hydropore and gonopore: not detectable with certainty.

Internal structures: ill-defined ridges on the internal mold pass to the right from the positions where the gonopore and hydropore might be expected by analogy with other holocystitids. These ridges mark the positions of channels on the inner surface of the theca which could have housed the gonoduct and stone canal.

Attachment: unknown, base of theca missing.

Remarks.—This specimen is almost certainly conspecific with *H. scutellatus* Hall, 1864. Two forms of *H. scutellatus* were recognized (Paul, 1971, p. 99) and the type of *H. ovatus* agrees better with the larger, more globular form which has larger plates. Evidence is insufficient to determine whether the two forms represent distinct species or not, and so for the present *H. ovatus* is included in the synonymy of *H. scutellatus*. Although the former name has page priority, the name *H. scutellatus* is retained for three reasons. First, it maintains consistency with the original revision (Paul, 1971); secondly, there is a possibility that both names may be validated if the two forms can be shown to represent distinct species; and finally, the ICZN rules do not demand the recognition of page priority; the decision is left to the first revisor.

Localities.—INDIANA: 17 (for Indiana localities 1-16 see Paul, 1971, pp. 163-164). Ryker's Ridge, Jefferson County, Indiana (probably locality 49 of Foerste, 1897, p. 251). In the G. K. Greene collection (AMNH) are 14 cystoids labelled "Rocker's Ridge, Jefferson County, Indiana." No locality with precisely this name occurs on any map of Jefferson County that we have seen. However, Foerste's map (Foerste, 1897, pl. 15) shows a Riker's Ridge (Sections 18, 19, 20, and 29, T4N, R11E, on the current Canaan 7½' quadrangle where it is spelled "Ryker's Ridge") and "Racket Ridge" (sections 8 and 9, T3N, R12E, Carrollton 7½' quadrangle). Racket Ridge lies about 4 miles beyond the easternmost

limit of the Silurian outcrop in southern Jefferson County and extends into Switzerland County. No Silurian strata remain in this area of the Cincinnati Arch and Racket Ridge cannot be Greene's locality. It seems that "Rocker's Ridge" is a misspelling of "Ryker's Ridge" or alternatively that the name has "evolved" since Greene's day.

The Brassfield Limestone and Basal Osgood crop out on the south side of the road 0.2 miles east of Ryker's Ridge Church in the headwaters of Wolf Run (NW¼, SW¼, section 20, T4N, R11E, 7½' quadrangle). This is Foerste's locality 49. Paul visited this spot (July 2, 1968) and recorded 2 ft., 2 in. of tan, yellow, and brown cherty Brassfield underlying 8-9 in. of Basal Osgood, but the rest of the section was largely overgrown. Foerste (1897, p. 251) recorded the following section on the opposite side (i.e., north) of the stream:

"Upper Osgood Clay"	no thickness stated
"Osgood Limestone"	4 ft.
"Lower Osgood Clay"	14 ft.
"Basal Niagara Limestone"	8 in.
"Clinton" (=Brassfield)	34 in.

Most likely this is the section from which Greene collected his material. The cystoids include 11 complete or partial thecae of *Trematocystis*, two complete thecae of *Pentacystis*, and the base of a *Triamara ventricosa* (Miller). Specific identification of the *Trematocystis* and *Pentacystis* will require some cleaning of the specimens; nevertheless, from the known stratigraphic distribution of these genera a fairly complete section is suggested. *Trematocystis* is only known from the *Trematocystis* bed (Paul, 1971, p. 37) below the lower limestone band, *Pentacystis* from the lower limestone band, and *Triamara ventricosa* from the Upper Osgood Shales, above both limestone bands.

Hitherto all known specimens of *Pentacystis* came from Big Creek (localities 3-5 of Paul, 1971) or Osgood (locality 11 of Paul, 1971). This locality represents a southern extension of the range of the genus. Frest has also found a possible *Pentacystis* from the road cut at New Marion (locality 10 of Paul, 1971). Even with these new localities the total known geographic range of *Pentacystis* is remarkably small.

St. Paul, Indiana (locality 16, Paul, 1971, p. 164).

Frest has been actively investigating the biostratigraphy and

paleoecology of Middle Silurian sedimentary rocks of southern Indiana (see Frest, 1975, pp. 81-84). The most probable source of most of Springer's crinoids from the Laurel Limestone of St. Paul (Springer, 1926, pp. 6-7) is the old Adams Quarry (SW¼, SW¼, SE¼, section 3, T11N, R8E, Adams 7½' quadrangle). A summary section is given in Frest (1975, fig. 1). *Holocystites* occurs here and in the active quarry of the St. Paul Stone Co. (NE¼, section 9, T11N, R8E, Shelby County, Indiana, Waldron 7½' quadrangle). The *Holocystites* occur only in the lower part of unit 1, a 52-in. thick pure white, fine-grained partly dolomitized biomicrite which weathers to give a vuggy surface and exhibits indistinct bedding. In this unit cylindrical *Holocystites alternatus* and *Triamara* sp. occur in life position: the *Holocystites* lie on bedding surfaces or mounds of coarser debris with the oral surface directed upward (cf. Paul, 1971, p. 75, fig. 33, p. 90). Their preservational history would seem to have been simple. Only loss of the ambulacral appendages and the oral and anal cover plates plus the growth of some epifauna intervened between death and burial *in situ*.

Big Creek (localities 3-5 of Paul, 1971, p. 163; localities 74-76 of Foerste, 1897). Figures 2-3.

Foerste's localities 74-76 lie along a 2 mile stretch of Big Creek entirely within the Jefferson Proving Grounds (fig. 2). Access is difficult and dangerous due to the large number of unexploded shells which litter the outcrop. Approximately 1½ miles of section were explored and a composite section measured (fig. 3). This section differs little from the details published by Foerste (1897, p. 257) and the section measured by Paul (1971, fig. 12) about 1½ miles further east-northeast.

Just upstream of Foerste's locality 74 the Basal Osgood (unit 7, fig. 3) is exposed in the creek bed. About 6 in. of white silty, unfossiliferous limestone are visible. These are followed by the Lower Osgood Shales (unit 6, fig. 3), about 7 ft. thick with *Trematocystis* near the top. Above this lies the lower limestone band of the Middle Osgood Limestone (unit 5c, fig. 3), which is a 1 ft., 10 in.-thick argillaceous fossil fragmental calcarenite. The proportion of clastic material increases from bottom to top and is especially high in the uppermost 4 in., which are hard to distinguish from the overlying shale beds when deeply weathered. The lower limestone band is not as resistant as the upper and the bedding is

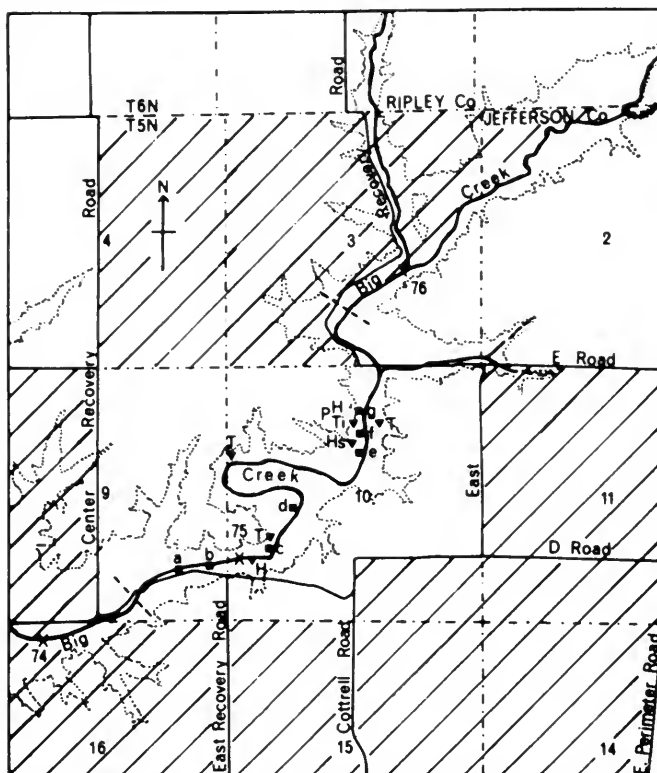


FIG. 2. Outline map of the area along Big Creek within the Jefferson Proving Grounds surveyed by Frest, i.e., between the diagonal broken lines across the creek. X = Foerste's localities 74-76, sites where section (fig. 3) was measured. The Lower Osgood Shales were measured at a and b, the Upper Osgood Shales at c-g. Cystoid occurrences as follows: H = *Holocystites scutellatus*, Hs = *Holocystites spangleri*, P = *Pustulocystis ornatissimus* (found in float), T = *Trematocystis* spp., Ti = *Triamara*. 500 ft. contour dotted, diagonal shading indicates restricted areas. The area of this figure corresponds to the SE corner of the San Jacinto 7½' quadrangle.

more distinct. The usual sequence of beds is: 1½ in. (bottom), 1½ in., 4 in., 3 in., 8 in., 4 in. *H. spangleri* and *Triamara tumida* occur on the underside of the lowest two beds.

Between the two limestone bands is a muddy silty bed called the middle shale (unit 5b, fig. 3). It is about 1 ft. thick and contains many highly fossiliferous nodules or lenses in the lower 4-6 in. Most of the fauna of the Osgood occurs in these beds. The upper limestone band (unit 5a, fig. 3) is approximately 1 ft., 6 in. thick and is a resistant fine-grained unfossiliferous limestone with indistinct bedding. *H. scutellatus* occurs on the upper surface.

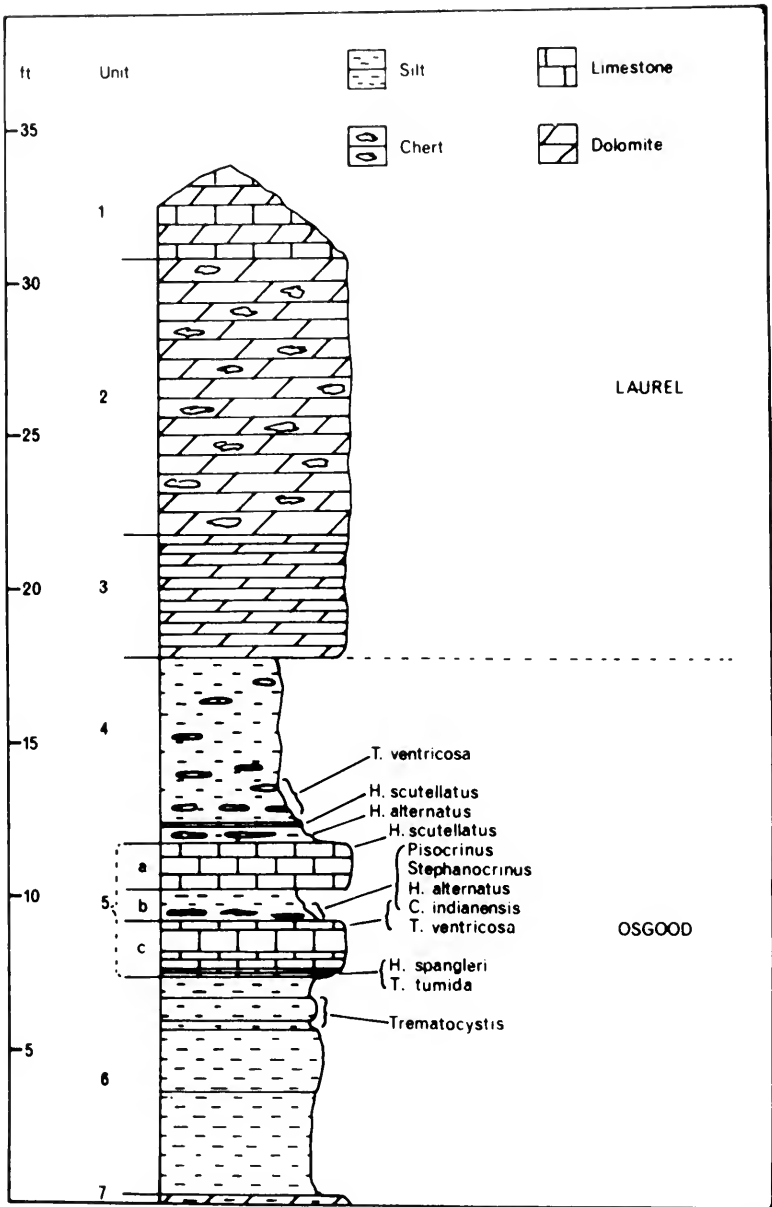


FIG. 3. Composite section through the Osgood and Laurel Formations as exposed along Big Creek within the Jefferson Proving Grounds to show the stratigraphic occurrence of cystoids and some other echinoderms.

The Upper Osgood Shales (unit 4, fig. 3) are best exposed about halfway between Foerste's localities 75 and 76 where the contact with the underlying limestone is sharp but apparently conformable. The upper shales are 6 ft., 1 in. thick and the lower 2 ft. are highly fossiliferous with limestone lenses scattered throughout but most commonly in the basal 1 ft. 7 in. A fairly persistent 1-2 in. limestone band with *H. scutellatus* occurs 7 in. above the base. *T. ventricosa* occurs in 10 in. of shale and nodular limestone above this. *H. alternatus* has also been found in the basal 7 in. Most fossils are echinoderms but other members of the Osgood fauna occur. This precise lithology is not now exposed anywhere else, although it may be inferred to occur below the floor of the old quarry at Osgood (locality 11 of Paul, 1971).

The transition from the upper shales to the Laurel Dolomite is sharp. The lowest 3-5 ft. of the Laurel (unit 3, fig. 3) are usually silty dolomite with indistinct bedding and contain *Flexicalymene celebra* and other trilobites and occasional patches of *Atrypa* and crinoid stems lying on bedding planes. Above this comes 8-10 ft. of highly cherty unfossiliferous limestone in thin (1-3 in.) beds (unit 2, fig. 3). Capping the hills are 2-3 ft. of dolomitic limestone (unit 1, fig. 3) which is deeply weathered and eroded. Quite likely this was in turn originally overlain by more cherty limestone beds.

WISCONSIN.

For more than a century southeastern Wisconsin has been known as a source of a large variety of Silurian fossils, including a diverse fauna of pelmatozoans.

Most of these specimens were collected during the late 1800's when there were numerous stone pits and small quarries in many communities throughout the area. Since locality data given with most of the museum specimens is vague, an attempt has been made to determine the exact collecting localities and stratigraphic positions of these specimens, with emphasis on cystoids. At present very few of the old exposures are accessible or productive and some reference must be made to earlier descriptions of these localities. The correspondence and specimens of some of the nineteenth-century collectors, particularly Thomas A. Greene, were checked for useful information. Research is also being done on the Silurian stratigraphy in southeastern Wisconsin since early work was found to be inaccurate in some of the areas.

Four significant *Holocystites* localities (Grafton, Racine, Waukesha, and Sussex) will be described in this section of the paper, and a list is given of major bioherms and other localities in Wisconsin and Illinois which have produced or may produce cystoids. A general description of bioherms in the area is included since cystoids are commonly associated with these structures.

Grafton (Wisconsin, locality 1 of Paul, 1971).

The quarries at Grafton, Wis. (N½, sec. 25, T10N, R21E, Ozaukee Co., Wis.) are listed as the type locality for *Holocystites cylindricus* by Hall (Paul, 1971, pp. 81, 165). The rock exposed at the quarries contains very few, if any, pelmatozoans, and the study of old collections shows no other cystoids have been found there. It is felt that the specimen was incorrectly labelled and probably came from Racine. Edgar Teller (1911, p. 202), a prominent collector of the late nineteenth century, was also of the opinion that the specimen was not from Grafton.

The Groth's Quarry at Cedarburg (center W½, sec. 35, T10N, R21E, Ozaukee Co., Wis.), 1¼ miles southwest of Grafton, has produced rare and poorly preserved specimens of *Holocystites* and *Gomphocystites*. A large bioherm which is thought to be younger in age than those at Racine is present in the north corner of the quarry.

Racine (locality 2 of Paul, 1971). Figure 4.

Fossiliferous dolomite is exposed in two areas near Racine. The largest area is the type locality for the Racine Dolomite. It consists of several small outcrops and quarries which extend for approximately three-fourths mile south of the rapids on the Root River, northwest of the city of Racine (SW¼, NE¼, sec. 6, T3N, R23E, Racine Co., Wis.). Presently there is a large water-filled quarry on the east side of the river known as Horlick's Quarry which is now a public park. Adjacent to it, on the west side of the river, is a small abandoned quarry which was once known as Beswick's Quarry.

One of the best exposures of a bioherm in southeastern Wisconsin can be found in the Horlick's Quarry. A small exposure of the core is present in the southeast corner of the quarry with the flank beds dipping to the north and west. To the southwest small satellite reefs are partially exposed on both sides of the river.

The second area consists of several quarries on the north side of Racine (SE¼, sec. 29, T4N, R23E, Racine Co., Wis.), approximately

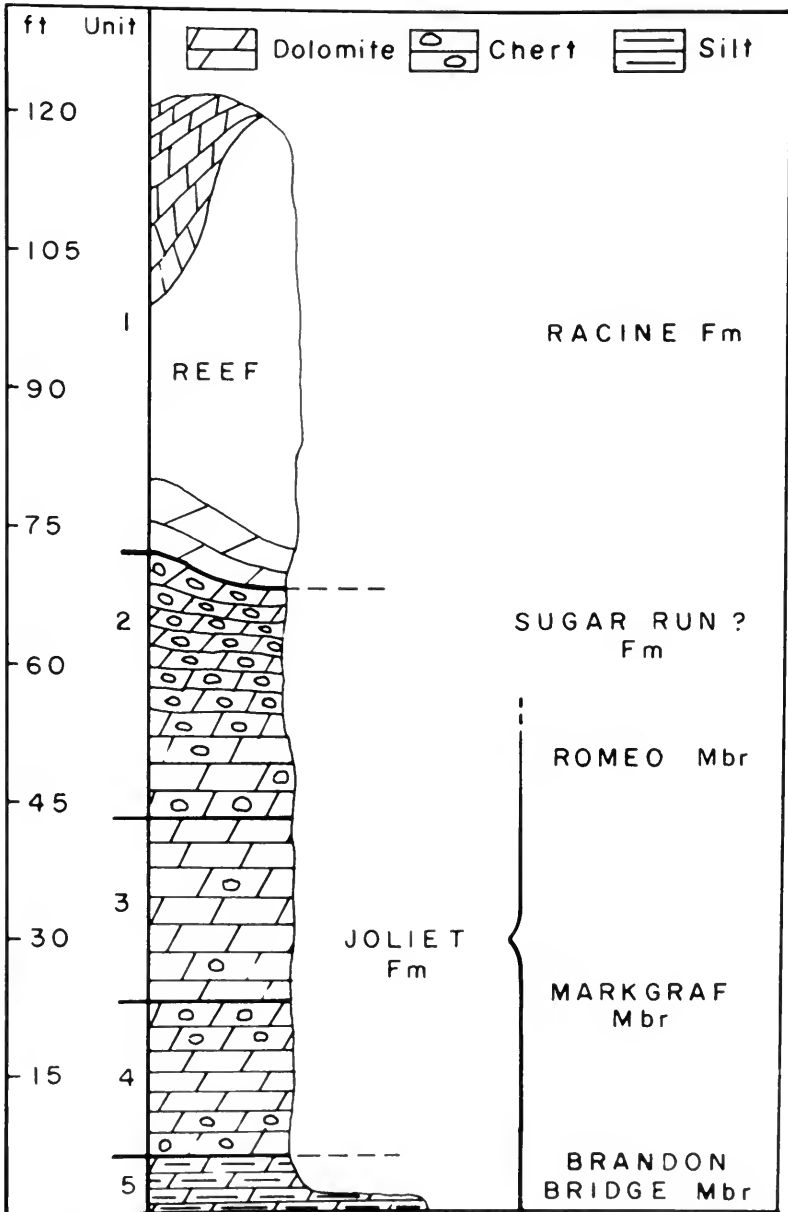


FIG. 4. Section exposed at the Vulcan Materials quarry, Ives, Wis. 1973 to show the probable correlation of NE Illinois and Wisconsin stratigraphic units. Illinois terminology follows that of Willman, 1973.

1¾ mile northeast of the type locality. These quarries are referred to as the Ives' quarries after the small community at that place which has since been incorporated into Racine. A large quarry is presently being run by the Vulcan Materials Company, but the others are completely water-filled.

The correspondence of T. A. Greene indicates that the vast majority of the nineteenth-century fossils labeled "Racine" came from the Horlick's and Beswick's quarries, and that the quarries at Ives were then in somewhat unfossiliferous inter-reef rock. This information agrees with T. C. Chamberlin's (1877, pp. 361-362) description of the area. Greene also indicated that most of the pelmatozoans came from excavations close to the river at the Horlick's and Beswick's quarries; recent field work has verified this information. Expansion of the Ives' quarry in the 1940's and 1950's exposed several bioherms which have the same fauna as the Horlick Bioherm.

The Racine Dolomite is Late Wenlock-Ludlow in age (Berry and Boucot, 1970, pp. 200-201). The exposures around Racine are in the lower part of the Racine Dolomite, which is Upper Wenlockian in age as indicated by the presence of the Silurian trilobites *Stauropcephalus* and *Trochurus*, neither of which is known from younger rocks.

Since no more than 30 ft. of the Racine Dolomite are now exposed at the type section, the following section (fig. 4) of the deep quarry at the Vulcan Materials Company at Ives is given to clarify the stratigraphy.

Unit 1. The Racine Dolomite is the highest unit exposed in the quarry. It consists of 50 or more feet of crystalline, porous, thick-bedded, gray dolomite. Fossiliferous debris consisting of small disarticulated pelmatozoans, brachiopods, and rugose corals is common throughout the unit occasionally forming small lenses. Several large bioherms are found in this unit. They have a massive structureless core with stromatoporoids as prominent framebuilders. The flank beds are highly fossiliferous with disarticulated pelmatozoans being the most common fossils.

Unit 2. Consists of 26 ft. of thin-bedded, fine-grained, light gray dolomite. Chert nodules are abundant throughout most of the unit although they occasionally grade laterally into non-cherty beds. Fossils are locally common and include small disarticulated crinoids, trilobites, bryozoans, and brachiopods. The lower 8 ft. is

thicker bedded and more uniform. Where chert nodules are abundant the unit is irregular-bedded and highly fractured and very conspicuous in the quarry wall.

Unit 3. Twenty feet of thick-bedded, light gray dolomite with stylolitic bedding planes. It is nearly chert-free and poorly fossiliferous.

Unit 4. Seventeen feet of thick-bedded, cherty gray dolomite. The center 5 ft. of the unit is chert-free. This unit correlates with the Markgraf Member of the Joliet Dolomite. Specimens of the trilobite *Stenopareia* are found in the lower cherty layers which indicates it is Early Wenlock or Llandovery in age.

Unit 5. Consists of 6 ft. of thin-bedded, argillaceous, red and brown dolomite. These layers become greenish toward the top. This unit forms the floor of the quarry and correlates with the Brandon Bridge Member of the Joliet Dolomite.

The presence of bioherms in the Racine Dolomite has resulted in much sagging in the underlying units directly beneath the bioherms, extending through the Brandon Bridge beds.

Waukesha (locality 3 of Paul, 1971).

The second major source of Silurian cystoids in Wisconsin was the area around Waukesha. The Silurian stratigraphy in the Waukesha area is still poorly understood although in 1955 Gilbert Raasch solved many of the problems in an unpublished manuscript. There were two areas in which the bedrock has been quarried around Waukesha. The first was Cook's Quarry which was located at the present site of the Carroll College Athletic Field (SE $\frac{1}{4}$, sec. 3, T6N, R19E, Waukesha Co., Wis.). Only a small outcrop of the Waukesha Dolomite remains on the east side.

The second area was a group of quarries, originally Hadfield's, on both sides of the Fox River in the northern part of Waukesha (center S $\frac{1}{2}$, sec. 26, T7N, R19E, Waukesha Co., Wis.). There are now two large quarries of the Waukesha Lime and Stone Company occupying this site. Many of the cystoids and other echinoderms found in Waukesha were found in a unit which was described as "Racine beds" by early authors. The most productive exposure of these beds was Cook's Quarry. Chamberlin (1877, pp. 357-358) gives a general description of the exposure. These beds do show some lithologic similarities to some of the biostromal beds of the Racine Dolomite, but

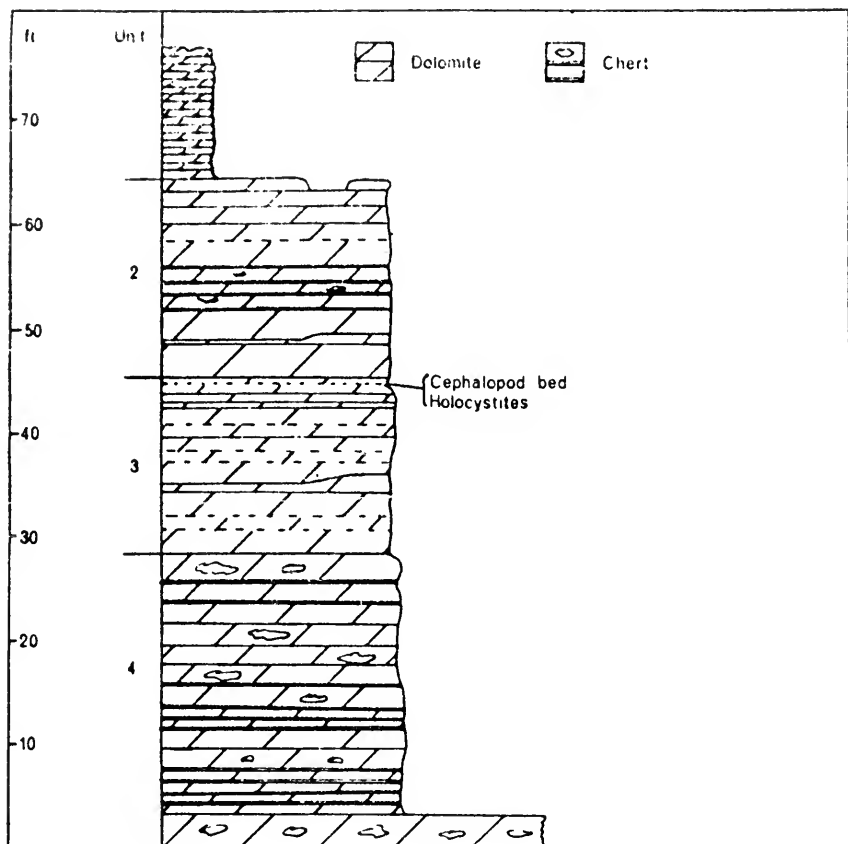


FIG. 5. Section exposed in the Halquist Lannon Stone Company quarry, Sussex, Wis. to show the occurrence of *Holocystites*.

the faunas of the two units are distinct. The "Racine" unit in Waukesha is equivalent to the Romeo Member of the Joliet Dolomite (Raasch, personal communication, 1970).

Beneath the "Romeo beds" is the Waukesha Dolomite. The erroneous identification of the "Racine beds" in the area by many authors has resulted in confusion as to the exact stratigraphic position of the Waukesha Dolomite and miscorrelation with other areas. According to Raasch, the true Waukesha Dolomite is equivalent to the Markgraf Member of the Joliet Dolomite, which would mean it is far below the true Racine Dolomite (Raasch, personal communica-

tion, 1969). The Waukesha Dolomite contains mostly poorly preserved cephalopods, but rare and poorly preserved *Holocystites* have been found.

Sussex. Figure 5.

Approximately 5½ miles north of Waukesha a large quarry has recently been developed by the Halquist Lannon Stone Company (E½, NW½, sec. 35, T8N, R19E, Waukesha Co., Wis.).

A few specimens of *Holocystites* have been collected from a micritic dolomite layer about 18 in. thick and of almost lithographic stone quality which forms a prominent layer in the upper part of the quarry. This layer is referred to as the cephalopod layer because of the abundance of the cephalopods *Dawsonoceras*, *Kionoceras*, and cyrtocones. Also commonly associated with the cephalopods is the trilobite *Bumastus graftonensis*, with rare specimens of *Illaenoides*, *Dalmanites*, *Calymene*, *Scutellum*, and *Cheirurus*. *Eucalyptocrinites* is the only other echinoderm found in the layer besides *Holocystites*, and they are both rare.

Paul infers the preservational history of *Holocystites* as follows: death was followed rapidly (or caused) by detachment from substrata. Build-up of decomposition gases caused the thecae to become buoyant and to drift (together with the nautiloids) perhaps over considerable distances. During this phase the ambulacral appendages and cover plates were lost. Escape of gases, possibly caused by loss of the cover plates, allowed the thecae to sink or they simply grounded on shallow lime-mud flats. Thecae became partly or completely filled with sediment and partly buried. It is inferred the cystoids drifted in because of their association with nautiloids, which are known to have been buoyant, and the absence of benthonic fauna.

During burial the sediment was contemporaneously dolomitized and the upper parts of many fossils were lost, possibly by solution. This is suggested by the cavity-free micritic texture of the dolomite and the fact that only the lower part of most nautiloids is preserved. In turn the contemporaneous dolomitization implies very shallow or emergent conditions, and hence that the drifting shells were stranded on lime-mud flats. Finally the sediments were lithified, by which time much of the original shell material was lost.

A general section of the quarry is given in Figure 5.

Unit 1. Approximately 15 ft. of fine-grained, flaggy dolomite with stylolitic bedding planes, locally known as "Lannon" stone. *Dawsonoceras* and *Phragmoceras* are present in these layers.

Unit 2. Twenty feet of massive-bedded, gray dolomite which is moderately fossiliferous. The lower part contains disarticulated pelmatozoans (including *Caryocrinites*), rhynchonellid brachiopods, and other fossils. Toward the middle of the unit the beds become thinner, brown in color and contain numerous small solution cavities. Above this there is approximately 3 ft. of fine-grained dolomite lithologically similar to the cephalopod layer but lacking cephalopods and cystoids. The trilobites *Bumastus ioxus* and *Dalmanites* are preserved along with strophonellid brachiopods. The lower part of Unit 2 is equivalent to the Romeo Member of the Joliet Dolomite.

Unit 3. The cephalopod layer is considered the top of this unit. Beneath this are 20 ft. of thick-bedded, coarse-grained, white dolomite with poorly preserved cephalopods.

Unit 4. Consists of approximately 30 ft. of thick-bedded gray dolomite with several prominent layers of chert nodules. A noticeable layer or layers of pentamerid brachiopods are found in this unit. The only other fossils are a few poorly preserved *Favosites*.

BIOHERMS IN THE RACINE DOLOMITE

There was extensive biohermal development in southeastern Wisconsin and northeastern Illinois which is primarily confined to the Racine Dolomite. These bioherms, or reefs, had a prolific fauna of crinoids, cystoids, rare blastoids, and other invertebrates. They had a vertical thickness of up to 350 ft., and some have been found with an area of over 1 sq. mile. All have the same general structure, although there are some significant faunal differences.

There is a distinct core which consists of fossiliferous, massive, and cavernous dolomite surrounded by steeply dipping thick beds of coarse bioclastic flank rock. The dip of the flank rock decreases and grades into horizontal thin-bedded and fine-grained dolomite at the boundary of the bioherm.

The framebuilders and binders of the core were predominantly stromatoporoids with corals, algae, and some bryozoans being locally important.

The interstices between the framebuilders were filled with bioclastic debris. Large crevices and cavities were occasionally filled with disarticulated molts of trilobites (*Bumastus*, *Kosovopeltis*, *Arc-*

tinurus) and small orthoconic and cyrtoconic cephalopods. These crevice fillings have also been noted in flank beds close to the core.

The flank beds consist of fragments of both core-dwelling organisms and those which lived on the flank itself. It is in this area that pelmatozoan remains are abundantly found; again they are usually found in the form of disarticulated skeletal elements, but occasionally large concentrations of crinoid cups and cystoid thecae occur. These beds are the source of the prolific pelmatozoan fauna of the Racine Dolomite.

It appears that most of the pelmatozoans lived in the flank area, since they are only common in small areas of the core. Because of their fragile nature they probably could survive only in areas sheltered by wave-resistant structures, such as the coral and stromatoporeid ridges in the Thornton Bioherm of Illinois (Ingels, 1963, p. 419). Also, few holdfasts or root systems are found in the core area, but they are found in the flank beds. The crinoids *Eucalyptocrinites*, *Lampterocrinus*, *Ochlerocrinus*, and *Siphonocrinus* are common. Of the cystoids, only *Caryocrinites* is common but occasional specimens of *Gomphocystites*, *Hallicystis*, and *Holocystites* are also present.

Associated with a small satellite reef a fair number of *Gomphocystites* and *Holocystites* thecae have been found in the old Beswick's Quarry in Racine. This satellite reef is located on the west side of the larger bioherm. The inter-reef rock contains few fossils with the exception of large orthoconic cephalopods and fine bioclastic debris from the bioherm.

Most of the echinoderms are preserved as internal and external molds in the dolomite, the original calcite having been dissolved away. Despite complete and well preserved, the thecae of *Caryocrinites* are not *in situ*. Most lie on their sides and are largely filled with matrix which now forms the dolomitic internal mold. Paul infers their preservational history to have been as follows: death was followed (or caused) by separation from the stem. The detached thecae lost the arms and anal cover plates but were otherwise deposited intact. Sediment filled most of the thecae but usually a small part at the top was left unfilled: the resulting cavity may have been filled with drusy calcite subsequently. The sediment was then lithified. Post-lithification dolomitization affected the sediment within and outside the thecae and produced a cavernous texture. The original organic calcite was dissolved away contempo-

TABLE 1. Significant exposures of Racine Dolomite in southeastern Wisconsin and northeastern Illinois.

<u>Localities</u>	<u>Formation</u>	<u>Pelmatozoans</u>
<p>1. Horlick Reef Complex: Horlick's Quarry (water-filled) Beswick's Quarry (abandoned) SW$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 6, T3N, R23E, Mt. Pleasant Twp. Racine, Racine Co., Wis. South Milwaukee and Racine, Wis. quadrangles.</p>	Racine Dolomite type locality	<i>Holocystites</i> , <i>Halticystis</i> , <i>Gomphocystites</i> ; large variety of crinoids; blastoid <i>Troosticrinus</i>
<p>2. Ives Reef Complex: Vulcan Materials Company Quarry (active) SE$\frac{1}{4}$, sec. 29, T4N, R23E, Caledonia Twp. Racine, Racine Co., Wis. South Milwaukee, Wis. quadrangle</p>	Racine Dolomite	<i>Caryocrinites</i> , <i>Holocystites</i> , <i>Gomphocystites</i> ; large variety of crinoids.
<p>3. Wind Point Reef: lake shore exposures in Shoop Park NE$\frac{1}{4}$, sec. 27, T4N, R23E, Wind Point, Racine Co., Wis. South Milwaukee, Wis. quadrangle</p>	Racine Dolomite	Crinoidal flank rock
<p>4. Franklin Reef: Franklin Stone Products Quarry (active) Vulcan Materials Quarry (active) SE$\frac{1}{4}$, NE$\frac{1}{4}$, sec. 10 and SW$\frac{1}{4}$, NW$\frac{1}{4}$, sec. 11, T5N, R21E, Franklin, Milwaukee Co., Wis. South Milwaukee, Wis. quadrangle</p>	Racine Dolomite	<i>Caryocrinites</i> , <i>Holocystites</i> , variety of crinoids
<p>5. Trimbone Reef Complex: abandoned quarry SW$\frac{1}{4}$, sec. 28, T6N, R21E, Greendale, Milwaukee Co., Wis. Hales Corners, Wis. quadrangle</p>	Racine Dolomite	<i>Caryocrinites</i> , <i>Gomphocystites</i> , <i>Holocystites</i>

TABLE 1. *continued*

<u>Localities</u>	<u>Formation</u>	<u>Pelmatozoans</u>
6. Whitnall Park Reef: sewer tunnel excavation, 1971 running east-west along College Ave. on S. boundary, sec. 32, T6N, R21E, Hales Corners, Milwaukee Co., Wis., Hales Corners quadrangle	Racine Dolomite	<i>Caryocrinites</i> ; large variety of crinoids
7. Schoonmaker Reef: Francy Quarry (filled) SW $\frac{1}{4}$, SE $\frac{1}{4}$, sec. 22, T7N, R21E, Wauwatosa, Mil- waukee Co., Wis. Milwaukee, Wis. quadrangle	Racine Dolomite?	rare pelmatozoans: F. H. Day (in Chamberlin, 1877) lists <i>Holocystites</i>
8. Moody Reef: 26th Street Quarry (filled) SW $\frac{1}{4}$, sec. 30, T7N, R22E, Milwaukee, Milwaukee Co., Wis. Milwaukee, Wis. quadrangle	Racine Dolomite?	rare pelmatozoans
9. Soldier's Home Reef: outcrop NW $\frac{1}{4}$, NE $\frac{1}{4}$, sec. 35, T7N, R21E, Milwaukee, Mil- waukee Co., Wis. Milwaukee, Wis. quadrangle	Racine Dolomite?	no pelmatozoans
10. Brown Deer Reef: tunnel excavation S. boundary of SW $\frac{1}{4}$, SE $\frac{1}{4}$, sec. 3, T8N, R21E, Brown Deer, Milwaukee Co., Wis. Milwaukee, Wis. quadrangle	Racine Dolomite?	no pelmatozoans

TABLE 1. *continued*

<u>Localities</u>	<u>Formation</u>	<u>Pelmatozoans</u>
11. Menomonee Falls Reef: road excavation NE $\frac{1}{4}$, NW $\frac{1}{4}$, sec. 10, T8N, R20E, Menomonee Falls, Waukesha Co., Wis. Waukesha, Wis. quadrangle	Racine Dolomite	crinoidal flank rock; abundant pelmatozoans; <i>Caryocrinites</i> , <i>Holocystites</i>
12. Germantown Reef Complex: abandoned quarries N $\frac{1}{2}$, sec. 22, T9N, R20E, Germantown, Washington Co., Wis. Waukesha, Wis. quadrangle	Racine Dolomite	several small bioherms exposed with crinoidal flank rock
13. Rockfield Reef: water-filled quarry NE $\frac{1}{4}$, SE $\frac{1}{4}$, sec. 9, T9N, R20E, Rockfield, Washington Co., Wis. West Bend, Wis. quadrangle	Racine Dolomite	large bioherm exposed with crinoidal flank rock
14. Mequon Road Reef: abandoned quarry SE $\frac{1}{4}$, sec. 19, T9N, R21E, Mequon, Ozaukee, Wis. Waukesha, Wis. quadrangle	Upper Racine Dolomite	small bioherm exposed with crinoidal flank rock
15. Cedarburg Reef: Groth's Quarry (water-filled) center of W $\frac{1}{2}$, sec. 35, T10N, R21E, Cedarburg, Washington Co., Wis. Port Washington, Wis. quadrangle	Upper Racine Dolomite	bioherm with rare, poorly preserved <i>Holocystites</i> and <i>Gomphocystites</i>

TABLE 1. *continued*

<u>Localities</u>	<u>Formation</u>	<u>Pelmatozoans</u>
16. Grafton: abandoned quarries N½, sec. 25, T10N, R21E, Grafton, Washington Co., Wis. Port Washington, Wis. quadrangle	Upper Racine Dolomite	pelmatozoans very rare
17. Waukesha-Carroll College: Cook's Quarry (filled) SE¼, sec. 3, T6N, R19E, Waukesha, Waukesha Co., Wis. Waukesha, Wis. quadrangle	"Romeo beds"	abundant pelmatozoans, <i>Caryocrinites</i> and <i>Holocystites</i> , non-reef beds
18. Waukesha-Hadfield: Waukesha Lime and Stone Company Quarry (ac- tive) center S½, sec. 26, T7N, R19E, Waukesha, Wau- kesha Co., Wis. Waukesha, Wis. quadrangle	"Romeo beds"	pelmatozoans present, non-reef beds
19. Sussex: Halquist Lannon Stone Company (active) E½, NW¼, sec. 35, T8N, R19E, Sussex, Wauke- sha Co., Wis. Waukesha, Wis. quadrangle	Waukesha Dolomite ?	<i>Holocystites</i> rare, non-reef beds
20. Genessee: active quarry SW¼, sec. 24, T6N, R18E, Genessee Twp. Wau- kesha Co., Wis. Eagle, Wis. quadrangle	Waukesha Dolomite	<i>Holocystites</i> rare, non-reef beds

TABLE I. *continued*

<u>Localities</u>	<u>Formation</u>	<u>Pelmatozoans</u>
ILLINOIS		
21. Bridgeport Reef: abandoned quarry SE $\frac{1}{4}$, sec. 29, T39N, R14E, Chicago, Cook Co., Ill. Englewood, Ill. quadrangle	Racine Dolomite	<i>Halicystis</i> , <i>Gomphocystites</i> , <i>Holocystites</i> , <i>Coelocystis</i> , <i>Caryocrinites</i> , <i>Lampterocrinus</i> , <i>Siphonocrinus</i> , <i>Periechocrinites</i> , <i>Eucalyptocrinites</i> (Greacen and Ball, 1946)
22. Hawthorne Reef: filled quarry NW $\frac{1}{4}$, sec. 34, T39N, R13E, Cicero, Cook Co., Ill. Englewood, Ill. quadrangle	Racine Dolomite	<i>Gomphocystites</i> , <i>Coelocystis</i> , <i>Caryocrinites</i> , <i>Crotalocrinus</i> , <i>Periechocrinites</i> , <i>Eucalyptocrinites</i> (Greacen and Ball, 1946)
23. Cheltenham Reef: filled quarry SE $\frac{1}{4}$, sec. 30, T38N, R15E, Chicago, Cook Co., Ill. Jackson Park, Ill. quadrangle	Racine Dolomite	<i>Caryocrinites</i> , <i>Periechocrinites</i> , <i>Eucalyptocrinites</i>
24. Thornton Reef: Material Service Corporation Quarry (active) S $\frac{1}{2}$, sec. 28 and E $\frac{1}{2}$, sec. 33, T36N, R14E Thornton, Cook Co., Ill. Harvey and Calumet City, Ill. quadrangle	Upper Racine Dolomite	pelmatozoans present

raneously with or prior to dolomitization, thus forming molds which are frequently covered with small dolomite rhombs. Often the internal molds are slightly incomplete and the missing portion is always uppermost in undisturbed thecae. In some holocystids from the Niagaran of Illinois and Wisconsin the inner parts of the thecal plates are partly dolomitized (e.g., Paul, 1971, figs. 19b, 37b). This suggests very early onset of dolomitization, certainly before solution of the test material. Equally, however, other examples, like the *Caryocrinites* from Racine, have both the internal and external molds covered with small dolomite crystals which must have formed after solution of the test was complete. Both types of preservation occur together. The *Holocystites* from Racine probably had a similar preservational history to that inferred for *Caryocrinites*.

Racine Dolomite bioherms have been found in many places in southeastern Wisconsin and northeastern Illinois and a list of significant exposures is given in Table 1.

It should be noted that in the northern half of Milwaukee County several prominent bioherms (Schoonmaker, Moody, Soldier's Home, Brown Deer) have little or no pelmatozoan remains present in the core or flank rock. The cores are typical stromatoporoid-coral mounds with many small branching bryozoans present. The flank rock is primarily made of fragments of small branching corals, flat stromatoporoids and tabulate corals, brachiopods, trilobites, and bryozoans. These bioherms may be slightly younger than those at Racine, but the absence of pelmatozoans at these localities is probably due to presently unknown ecological factors.

PARASITES

Many holocystids have hemispherical pits excavated in their surfaces which Paul (1971, p. 41), arguing from first principles, interpreted as the attacks of parasites. Paul could not positively identify the nature of the parasites involved. Published accounts of parasites (Hyman, 1955, pp. 115-119; Clark, 1921, p. 645) do not describe in sufficient detail injuries caused to the hosts. Dr. Hertha Sieverts-Doreck kindly drew attention to her earlier interpretation (Sieverts, 1934; Sieverts-Doreck, 1963) of very similar but smaller pits in the Devonian crinoid *Cupressocrinites* Goldfuss as borings of ectoparasitic predatory snails. In *Cupressocrinites*, as in holocystitids, none of the pits penetrated through the calyx wall into the coelomic cavity. Many occurred on arm ossicles and even stems were attacked

(Sieverts-Doreck, 1963, pl. 1). This morphology does not agree well with descriptions of the biology and feeding of recent parasitic gastropods found on crinoids and other echinoderms. In an attempt to settle the matter the spirit collections of recent crinoids in the British Museum, Natural History were searched. A single specimen of *Rhizocrinus lofotensis* (Reg. No. 85-3-30 No. 122G, from 400 fathoms at lat. $9^{\circ}10$ S, long. $34^{\circ}49$ W) was located with two pits, one with the remains of a gastropod attached (fig. 6). The crinoid is extremely small: the cup is 1.75 mm. high and 1.50 mm. wide. The two pits are in a radial plate and are surrounded by a raised area of thickened plate which grew in response to the attack. The exposed pit (i.e., the one without the remains of the gastropod still attached) is 0.42 mm. in diameter, penetrates right through the plate (which is, of course, very thin) and has a small central tubular hole 0.13 mm. in diameter which passes deep into the interior of the crinoid. The other pit has a soft tissue cover across the surface emerging from the center of which is the proboscis of the snail (fig. 6).

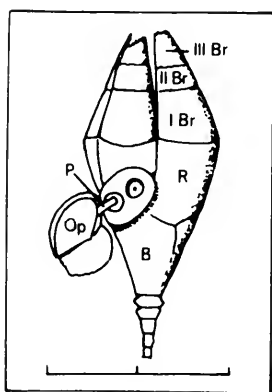


FIG. 6. Sketch of *Rhizocrinus lofotensis* parasitized by a snail (BMNH 85-3-30 no. 122G). B = basal plate; IBr, IIBr, IIIBr, first three brachial plates of arms; Op, operculum of snail; P, proboscis of snail; R, radial plate. Scale in mm.

The pits are similar to those of fossils except for one important detail. The modern example reaches into the interior of the cup and has a deep tubular hole where the proboscis of the snail penetrated the soft tissue. This morphology agrees very well with descriptions of feeding methods of modern parasitic snails (Fretter and Graham, 1949; Clark, 1921, pp. 645-647).

Nevertheless, the fossil pits are very similar to the recent borings (except that they do not penetrate the thecal cavity) and are unlike the galls produced by other parasites such as myzostomid worms and various copepods. Also it may be unwise to place too much reliance on a single example in a very thin-plated recent crinoid al-

though Clark (1921, pp. 645-647) consistently uses the word "holes" to describe the injuries to recent crinoids. It seems most likely that Sieverts-Doreck is correct in her interpretation. This still leaves the puzzling fact that the fossil snails apparently never managed to penetrate into the interior of the cup. Perhaps they received adequate nourishment from tissues within the plates. Clark (1921, pl. 57, fig. 1362) illustrates a *Stilifer* attached to the arm of *Bathymetra* sp.

One final point: although these pits are known in echinoderms from at least the Middle Ordovician (Benbolt Formation of Tennessee and Virginia) to the Triassic, none is as large as the examples in holocystitids. Holocystitid pits are usually 4 mm. in diameter as opposed to 1.4-1.7 mm. in *Cupressocrinus* (Sieverts-Doreck, 1963, p. 241) and not more than 2 mm. in any other examples. Plausibly the Osgood snails were also much larger than normal. As far as we are aware, no snails with suitable shells (see Clark, 1921, pl. 57, figs. 1359-1361) have been found in the Osgood Formation, but they should certainly be sought.

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