AMERICAN MUSEUM NOVITATES

Number 204 Published by THE AMERICAN MUSEUM OF NATURAL HISTORY New York City Dec. 24, 1925

56.39,1(77.2)

THE CRINOID OCCURRENCE AT CRAWFORDSVILLE, INDIANA

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The Department of Geology and Invertebrate Palæontology of The American Museum of Natural History possesses a great slab measuring 30×42 inches (Fig. 1) and some smaller ones, from the well-known crinoid locality at Crawfordsville, Indiana.[2] These slabs show a great number of specimens and species mingled together but preserved in an excellent manner. As is to be seen from the photographs (Figs. 1 and 2), the crinoids do not lie in a single plane, but some lie higher, some deeper, the latter, by careful preparation, being exposed by cutting off the rock almost vertically. At least four or five layers are distinguishable. A more careful examination shows that all parts of crinoid skeletons are preserved, such as arms, calices, stems, and roots. Crowns and stems are found in abundance, but roots are rare. Concerning the orientation of the crinoids on the slabs, there is no special direction at all. Sometimes it seems that the majority of crowns in one layer have the distal ends in a certain direction, whereas in another layer they lie in a different direction. But it is almost impossible to determine this exactly. This is due to the fact that it is difficult to determine to what layer a specimen belongs.

As stated above, the crinoids belong to many different species. On the larger slab we find the following species[3]:

Barycrinus lyoni Hall.
Cyathocrinus multibrachiatus Lyon and Casseday.
Decadocrinus depressus Meek and Worthen.
Dichocrinus ficus Lyon and Casseday.
" *polydactylus.*
Dizygocrinus indianus Lyon and Casseday.
Gilbertsocrinus (*Goniasteroidocrinus*) *tuberosus* Hall.

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[2]It gives the author great pleasure to thank the officials of The American Museum of Natural History for the opportunity to study the excellent collections of Palæontology in that institution. He is especially indebted to the late Dr. E. O. Hovey, to Dr. C. A. Reeds, and to Assistant Mr. E. J. Foyles, who kindly helped him during his stay at the Museum.

[3]Unfortunately when studying these slabs, especially from a biological viewpoint, I had no chance to verify the determinations or to rectify them according to newer systematic researches.

Fig. 1. Great Keokuk limestone slab (30 × 42 inches), from Crawfordsville, Indiana, containing, in different layers, mostly crinoids which are beautifully preserved.

Original in The American Museum of Natural History.

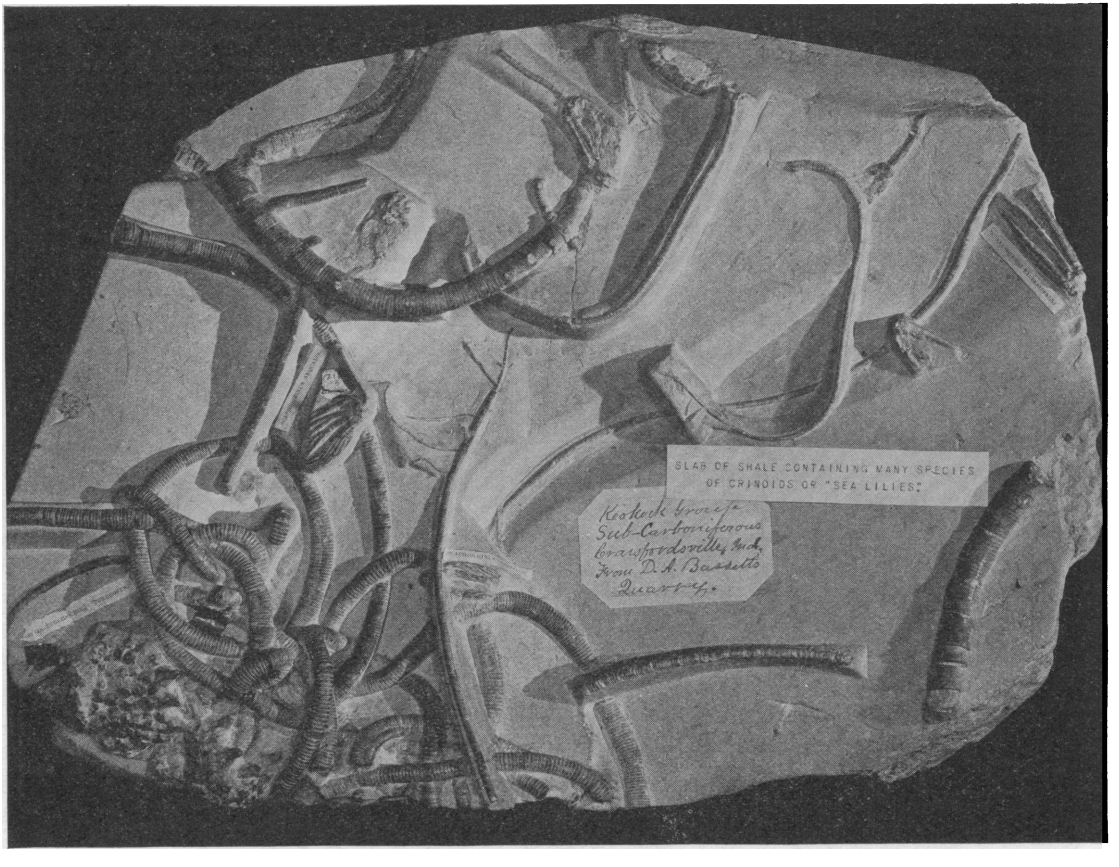

Fig. 2. Another slab from Crawfordsville, Indiana. About $\frac{2}{5}$ natural size.
Original in The American Museum of Natural History

Onychocrinus sp.
Platycrinus hemisphericus.
Scaphiocrinus æqualis Hall.
" *coneyi* Hall.
" *unicus* Hall.
Scytalocrinus decadactylus Lyon and Casseday.
Taxocrinus exsculptus Lyon.
" *meeki* Hall.
" *ramulosus* Hall.

Besides these and some undetermined fragments, *Protaster gregarius*, *Archimedes terebriformis*, and *Platyceras* sp. appear on this slab. These forms, however, are represented by only one or two specimens.

Similar circumstances were observed in the collections from the same locality in the Peabody Museum at New Haven, Conn., and also in the beautiful Springer collection in the U. S. National Museum at Washington, D. C. In New Haven,[1] about forty different species of crinoids were found, belonging to different groups, such as Camerata, Flexibilia, etc. A few other fossils, such as blastoids, asteroids, edrioasteroids, bryozoans, brachiopods, and gastropods, also appeared, but they were always represented by single specimens.

The question arises as to how to explain the remarkable accumulation of crinoid remains on the slabs. And this question leads naturally to the further one concerning the explanation of the occurrence of crinoids at Crawfordsville.

This question is, of course, not a new one, and it has been answered long since. But so far as I can see, it has been answered always in only one way. The common idea seems to be that which Springer has expressed twice in recent years. Once he dealt with that problem in 1917 on the occasion of examining the occurrence of the genus *Scyphocrinus*,[2] and again in 1924 in his paper, 'A remarkable fossil Echinoderm fauna in the East Indies.[3] There he expressed the opinion that the crinoids lived at Crawfordsville in colonies, and that therefore the place where they were found represents also their living-place.[4]

Is the above explanation the only possible one, and if not, is it the most probable one?

[1]The author is indebted to Prof. R. S. Lull, Prof. Charles Schuchert and Prof. C. O. Dunbar for their courtesy in permitting him to examine the specimens from Crawfordsville, Ind., in the Peabody Museum of Yale University.

[2]Springer, Frank, 1917, 'On the Crinoid genus *Scyphocrinus* and its bulbous root *Camarocrinus*,' Smithsonian Institution Publ. 2440, LXXIV, p. 9.

[3]Springer, Frank, 1924, 'A remarkable fossil Echinoderm fauna in the East Indies,' Amer. Journ. Sci., Ser. 5, VIII, p. 328.

[4]Compare also: Wachsmuth, C., and Springer, F., 1897, 'North American Crinoidea Camerata, Mem. Mus. Comp. Zool., XX, XXI, Cambridge.

As O. Abel stated for the first time in 1911,[1] and discussed further in his 'Lehrbuch der Paläozoologie,'[2] we have, in the case of finding a fossil in the rocks, always to examine whether the finding-place coincides with the living-place and also with the place where the animal died, or if it coincides with only one or with none of these places. In the latter case the finding-place represents only the imbedding-place.

The question we have to deal with is, therefore: Did the crinoids, found at Crawfordsville, really live in this place? Is the occurrence in this locality, therefore, "autochthon" or "allochthon"?[3]

The first thing to discuss in this connection is the fact that the crinoids do not occur in a single layer but in a number of layers; each layer, at least in all examined slabs, appears only a little higher or deeper than its neighbors. Keeping this in mind, we can now imagine that all crinoids found in the slab lived there at the same time, or that those of the different layers lived one after another, at first those of the deepest layer, then those of the second layer, and so on. In the first case, we must suppose that the sedimentation of all layers took place at the same time; that means that the crinoids were killed by a single event. The supposition that the sedimentation was not a sudden but a continuous process seems untenable because crinoids could hardly live in a place where masses of mud were coming on or falling down without interruption (see page 9). The first supposition also seems not highly probable, because the sediment itself shows no trace of a sudden deposition. Similar difficulties also arise, of course, when we think of a successive life of the crinoids in the different layers.

But there are yet other things demanding consideration. As mentioned above, we find on the figures and also on other slabs many arms, calices, and stems in beautiful preservation, but roots seldom occur. Among the many individuals of the great slab, only two root-regions are to be observed. That is remarkable indeed, for in the case of a colony we should expect a higher proportion.

But something else is worthy of notice. All the roots I found on different slabs from the Crawfordsville locality are of the same type.

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[1]Abel, O., 1912, 'Über die verschiedenen Ursachen des gehäuften Vorkommens von Tierleichen in Gesteinen,' Verh. zool.-bot. Ges. Wien, LXII, pp. 57–60.

[2]Abel. O., 1924, 'Lehrbuch der Paläozoologie,' 2d edition, Jena. That fossil animals did not always live in the place where we find their remains, was called to attention in the nineteenth century (see Boué, A., 1873, 'Über die aus ihren Lagerstätten entfernten und in anderen Formationen gefundenen Petrefacten,' Sitzungsber Akad. Wissen. Wien, LXVII, I Abt., pp. 375–390), but the importance of this fact had not become recognized at that time.

[3]In a previous paper (Ehrenberg, K., 1924, 'Über das Vorkommen von Fossilresten, ein Beitrag zur Paläobiologischen Terminologie, Naturwissenschaften,' 12. Jahrg., pp. 593–596), I proposed to distinguish the cases where living-place, dying-place, and imbedding-place are represented by the same locality as autochthon occurrences, and to consider occurrences where these three places are not represented by one locality, as allochthons.

Always the stem tapers gradually distally and ends generally in a few cirrus-like branches which in turn give off some smaller branchlets. Just above that most distal region there are some more or less slender cirri, functioning doubtless as means for fixations on the bottom. No traces of any secondary calcareous deposit are to be seen in the root region. As I intend to state more in detail in another paper, dealing with the different types of pelmatozoan roots, this above-mentioned root-form does not represent a real root. It is rather a somewhat modified distal end of the stem, and therefore I would place this root-form among the stem-roots and call it cirrus-root. The fact that all the roots are cirrus-roots is somewhat surprising, because we should expect to find in a colony more compact root-forms with secondary calcareous deposits at least, inasmuch as we think of a permanent fixation.

Coiled stems are also frequent at this locality. Some are to be seen on the slabs, and I observed them very often in other cases. As I pointed out in 1922, two types of coiled pelmatozoan stems are distinguishable.[1] In the one case the coiling is restricted to the distal end, and this means a semi-sessile life, as I called it in the paper referred to. Most of the coiled stems found at Crawfordsville belong to this type. In the second case, however, nearly the whole stem is coiled, and the crown lies on the middle of this coiling, protected by the cirri and covered when the coil is closed. The latter type was recognized by me in connection with a non-sessile life.[2] This second type has now become known from Crawfordsville in the form of *Camptocrinus crawfordsvillensis*, described by Springer in a paper soon to appear.[3] Such forms, of course, can hardly be taken, in the usual sense, for members of a colony.

Where organisms live together in great numbers we usually find individuals of different ages, young, adult, and some having traces of senility. Indeed, a colony can continue to grow only if some of the offspring remain or settle again in the same place. The slabs in question, however, show only a few very young specimens. It is possible, of course, that the young, very delicate skeletal elements have been destroyed. But where we see the crinoids in general so beautifully preserved, we must infer that the conditions were very favorable, and the small skeletal

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[1]Ehrenberg, K., 1922, 'Über eingerollte Pelmatozoenstille und ihre Bezichungen zur Sessilität,' Acta Zoologica, III, pp. 271–305.

[2]Ehrenberg, K., 1922, 'Bau und Lebensweise von Herpetocrinus,' Pal. Zeitschr., V, 2, pp. 182–208.

[3]Springer, F., ——. 'Unusual forms of fossil Crinoids.' Here the author wishes to express his thanks to Mr. F. Springer, who permitted him not only to study his beautiful crinoid collection but to see the manuscript of his new and interesting paper.

The author likewise is indebted to Dr. R. S. Bassler and to Dr. E. O. Ulrich, both of the U. S. National Museum.

pieces of young specimens are hardly less capable of preservation than the cirrus joints or outermost arm-branchlets of the adults.

FURTHER CONSIDERATIONS.—Among pelecypods, for example, we can easily distinguish forms living in fresh water from those living in sea water. Among the latter we know that some live in the shallow, moving water of the shore region, while others live in the quiet depths of the ocean. We further know that all these different groups are marked by some general features characteristic for each of these groups. So, for instance, the fresh-water mussels all have a peculiar shell, and in most cases we are able to recognize them at sight. Although only very little work has yet been done along this line of investigation among crinoids and among Pelmatozoa in general, some similar distinctions may be made. I recall forms such as *Eugeniacrinites*, *Torynocrinus*, *Cyathidium*, etc., which Jaekel[1] marked as reef-dwellers or the carpoids *Cothurnocystis*,[2] etc., which are considered to have lived on the surface of the bottom.

When the crinoids found at Crawfordsville are compared from this point of view, we can observe many different types. Great and heavy forms, such as *Gilbertsocrinus tuberosus*, are associated with the much smaller *Decadocrinus depressus* and other species with slender arms and delicate pinnulæ. *Platycrinus hemisphericus*, one of the most frequent forms at this locality, represents a further type. There are also other types that are easy to distinguish. After all, we must infer that these diversified types are adapted to different modes of life and are therefore representatives of different life-regions.

Summarizing the previous discussions, it is hardly necessary to emphasize that the occurrence in different layers, the relative rareness of roots and their peculiar shape, the coiled stems, the comparatively small number of young specimens, and the different types of shape of the body, do not harmonize very well with what we should expect in the case of a colony.

Let us turn now to the locality itself, to the sediment and to the process of fossilization. So far as I can see, only two papers deal especially with the locality. The first is a little note by Professor E. O. Hovey (1801-1877), published in 1867[3]; the second was written by F. Braun in 1873. The latter being a private paper, I was unfortunately not able

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[1]Jaekel, O., 1918, 'Phylogenie und System der Pelmatozoen,' Pal. Zeitschr., III, pp. 1–128.

[2]Bather, F. A., 1913, 'Caradocian Cystidea from Girvan,' Trans. Roy. Soc. Edinburgh, XLIX, II, No. 6, and 'Cothurnocystis: a Study in Adaptation,' Pal. Z., VII, 1925. (Compare Jaekel, O., 1918.)

[3]Hovey, E. O., 1867, 'The crinoidal banks of Crawfordsville, Indiana,' Amer. Naturalist, I, pp. 554, 555.

to see it. According to Hovey, the subcarboniferous rocks outcrop abundantly along the Rock (or Sugar Creek) River and its tributaries: "Along the banks of this river are strata of limestone, made up almost entirely of the broken stems and arms of crinoids, cemented by carbonate of lime, and occasionally containing heads finely preserved. But *the geological horizon in which the heads of crinoids are mostly found, is a calcareous shale or sandstone, of quite limited vertical extent,* not much exceeding two feet in thickness, and often but six or eight inches. *In this the crinoids are abundant, and in great perfection,* the arms and basal plates being well preserved, with stems attached, and not infrequently even the finest tentacles." [Italics by the present author.]

This report, of course, is of great interest in many respects. First, it shows that the slabs represent only a part of the horizon characterized by the beautiful preservation of the fossil remains, for each slab with a thickness of only a few inches is of much less thickness than that reported above. Bearing in mind also the beautiful preservation throughout all this horizon, we can infer that the different slabs in the various museums came from different parts of this horizon. This means that the different layers observable on each slab, one always a little above the other, are not in all slabs exactly the same. In other words, we are, in my opinion, entitled to infer that this whole horizon was composed of many layers, which were arranged in the above-mentioned manner. This means that the difficulties for the colony explanation, represented by the few layers of a single slab (see page 5), must become multiplied under such circumstances.

But there is still something else to be taken into consideration. Despite its being composed of many layers, the horizon with which we are dealing is only a small part of the crinoid strata at Crawfordsville. The fact that in the one case we find the fossils fragmentary and imbedded in limestone, in the other case beautiful and always almost completely preserved and imbedded in a gray, finely granulated shale or sandstone, indicates a change of conditions both as to lithology and to fossil preservation.

What were the conditions under which the sediments were deposited and the fossils imbedded therein?

According to Schuchert,[1] three sea regions are distinguishable in North America during the Mississippian period: the Central Interior sea, the Appalachian basin, and the Cordilleric sea. In the first one,

[1]Pirsson and Schuchert, 1924, 'Textbook of Geology,' Part 2, Historical Geology, 2d edition, New York and London.

with which we have to deal, the invasion began in the Chattanoogan with black mud deposits. Then, in the Kinderhookian, the water became clearer, and in the Osagian the Burlington limestone became deposited. That was the time of the greatest transgression, and after that a regression of the sea began in the Keokuk, the highest division of the Waverlian. There we find the limestones, which are not so clear as before in the south, while in the northern part shales and sandstones prevailed. The Crawfordsville locality is included in this horizon. A glance at a paleogeographical map of that time further shows[1] that there was not an open sea, but only small seaways where the Keokuk sediments became deposited, and the locality at Crawfordsville may, therefore, not have been far from the coast. From all this we may further conclude that the water of these seaways was not deep and that the sediments, therefore, must be taken as deposits of relatively shallow water.

As to the process of the fossilization, we have little more to say. The fossils in the slabs show a beautiful preservation in contrast to the greater part of the strata at Crawfordsville. Hardly any traces of destruction are observable. The only change which occurs, and that frequently, is a pyrite pseudomorphosis.

Now we return to the question whether it is probable that the Crawfordsville crinoids really lived where they were found. The occurrence on the slabs having been noted in this regard, the task remains to see if the local conditions we have just dealt with admit the possibility of crinoidal life. This question, of course, is to be answered only by comparison with the present life conditions of crinoids. Unfortunately not much is known about the latter. Let us see, therefore, if this knowledge is sufficient for any decision in this matter.

In his important work on living crinoids, A. H. Clark[2] made the following statement concerning crinoid habitats: "Except on sandy and exposed muddy shores, littoral crinoids occur in all possible situations. Their one essential requirement is pure, well-aërated water having a relatively high minimum salt content and well provided with minute plankton organisms."[3] This and further statements in other parts of his work belong before all to littoral crinoids and especially to comatulids. But, so far as the essential requirement, pure, well-aërated water, is concerned, we are entitled to suppose that it was also a "conditio sine qua non"

[1]Schuchert, C., 1910, 'Paleogeography of North America,' Bull. Geol. Soc. Am., XX, pp. 427–606, Pls. XLVI–CI.

[2]Clark, A. H., 1921, 'A Monograph of the existing Crinoids,' I, Part 2, Bull. U. S. Nat. Mus., No. 82, Washington.

[3]Clark, A. H., *op. cit.*, p. 593.

for our crinoids from Crawfordsville. For, so far as we know, a pure and well-aërated water is a life-essential for echinoderms in general. This is also proved by the various specializations in the different groups which serve to retain infection from the madreporite and the ambulacral system. That is the probable function of the anal tube among crinoids. It also seems to be the cause for the removal of the anus among echinoids.[1] Another example of it is given by the curious respiration channel of *Echinocardium cordatum*.[2]

Bearing all this in mind, we have to deal with the question: Was the water at Crawfordsville such that crinoids could live therein?

In this connection we have to consider first the sediments. In agreement with the above statements, a muddy and sandy bottom,—and such a one we have doubtless to reconstruct,—is not at all an ideal living place for crinoids. However, under the supposition that there was pure, well-aërated water, it would be perhaps going too far to exclude the possibility of crinoidal life. Perhaps a somewhat greater obstacle to the colony explanation could be seen in the color of the sediment, for this may point to the presence of organic substances resulting from the remains of dead organisms. The latter, however, we must infer, would have caused an infection of the water.

Considering the mode of occurrence on the slab and those arising from the local conditions, the colony explanation seems at least somewhat improbable. However, the evidence is not sufficient for a definite decision.

But that decision may be reached, I believe, by another fact already mentioned but not yet presented, namely: the pyrite pseudomorphoses. The latter depend, as we know, on the presence of sulphur gases. And, judging from the fact that such pyrite pseudomorphoses are rather frequently observable at Crawfordsville,—as was also confirmed by the kindness of E. Kirk,—we must further conclude that these gases were present to a large extent. We know from our present experience that in the depths of the Black Sea no animal life is possible on account of the sulphur combinations.[3] We must suppose that animals such as crinoids, so sensitive to the infection of water, could not have lived under such conditions.

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[1]Abel, O., 1924, Lehrbuch der Paläozoologie,' 2d edition, Jena, pp. 268, 307.

[2]Von Uexkuell, S., 1909, 'Umwelt und Innenwelt der Tiere,' Berlin (cited by Hesse-Doflein, 1914, 'Tierbau und Tierleben,' II, Leipzig-Berlin).

[3]Compare Pompeckj, J. F., 1901, 'Die Juraablagerungen zwischen Regensburg und Regenstauf,' Geognost. Jahreshefte, XIV (cited by Abel, O., 1922, 'Lebensbilder aus der Tierwelt der Vorzeit,' Jena).

With regard to the statement that the occurrence at Crawfordsville does not represent a fossil colony, the question now arises as to how this accumulation may be explained.

The first thing we can state in this regard is that the occurrence is not an autochthon but an allochthon one (see page 5). The crinoids, if they did not live at this place, must have been brought there in some way. Can we now say anything more in detail as to how this may have been done?

Just above we referred to the Black Sea and its peculiar conditions. Of course it is impossible to compare directly our crinoid occurrence with the Black Sea, for the latter reaches a considerable depth, while the Keokuk sea about Crawfordsville was probably shallow. The Norwegian "Poller" does not seem to me to be exactly comparable, for the latter represents shallow shore basins, and the water contains sulphur combinations near the surface. To the latter the fossiliferous lower Jurassic strata near Holzmaden of South Germany have been compared by Abel[1]. As he pointed out in 1922, the famous ichthyosaurs and all the other fossils of this locality may not have lived in this place, but may have been brought by currents into the bay as carcasses, or partly alive. There they sank into the muddy ground, and have been preserved in a beautiful manner.

Although not exactly the same, somewhat similar conditions must have existed for the crinoids at Crawfordsville. During the period when the shales and sandstones of our special horizon were being deposited, the crinoids may have lived somewhere outside of the finding-place. They may have lived in different localities, the heavy ones in somewhat moving water, the others in more quiet places. The forms with coiled stems may have been loosened from their temporary fixation and may have been brought by moderate currents to the site of Crawfordsville, where perhaps also a little bay may have existed. Reaching the sulphur-gas-filled water, they died; their skeletons sank to the bottom and became covered with sediment before any destruction was possible. Others, the more or less permanently fixed forms, may have been brought there after a voluntary or an involuntary detachment in a similar way. So quite different forms of different life regions came together. They did not come from a great distance, of course, and have not been brought by heavy currents, for otherwise such a beautiful preservation would be impossible. So the different layers containing the specimens became deposited within a short time, geologically speaking.

[1]Abel, O., 1922, 'Lebensbilder aus der Tierwelt der Vorzeit,' Jena.

It is, I think, hardly necessary to emphasize that other circumstances, difficult to explain in the case of a colony, become easy to comprehend under the above supposition. The relative rareness of roots and the few young specimens remain no longer a problem. That only cirrus roots are found is explained by the fact that this root-type can be detached, whereas in the case of a secondary calcareous deposit any detachment seems possible only by a breaking off above the root. So only roots of the first type could have been brought to this locality.

If we are correct in our interpretation, the occurrence at Crawfordsville seems to represent nothing else than a great burial ground where, during the time of the deposition of the shales and sandstones, many crinoids were buried, accompanied by only a few other fossils. Before and after that time the circumstances were, of course, quite different, as is clearly shown by the different sediments and the different states of preservation.