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Hon. Andrew S. Draper LL.D.
Commissioner of Education

SIR: I have the honor to submit herewith my Fourth Annual Report as Director of the Science Division, for publication as the introductory portion of the 61st Annual Report of the State Museum.

Very respectfully
JOHN M. CLARKE
Director

State of New York
Education Department
COMMISSIONER'S ROOM

Approved for publication this 22d day of January 1908

A. S. Draper

Commissioner of Education

THE BEGINNINGS OF DEPENDENT LIFE

BY JOHN M. CLARKE

For a number of years the writer has endeavored to assemble material from the older faunas which might illuminate the incipient expressions of dependent life. It is through this avenue only that the problem of the origin of the symbiotic conditions which now pervade all nature can ultimately be approached with hope of resolution.

The dependent condition of individual existence is one of the manifold presentments of organic adaptation which is to be comprehended best by comparison of the complicated conditions prevalent today with their simpler expressions in the early life of the earth. Adaptation is in large measure a sociological problem of immediate concern. It is not proper to consider the more serious features of sociological adaptation as merely analogous to organic adaptation. In human society dependence means simplicity, that is, loss of complexity; it reduces moral independence and induces idleness, beggary, misery and crime. Here is no question of analogy, but rather of continuity of mode, of cause and effect, penetrating human society. Such laws as govern its fundamental and primary manifestations are to be sought in the primitive life of the earth.

I am fully aware of what extensive data are essential to adequate conclusions in this inquiry and how far-reaching the bearings of the inquiry must be. At this time I should go no further perhaps than to point out some of the very numerous and most instructive expressions of these conditions which it has been practicable to bring together, abiding in the hope of eventually collating more copious data. I shall not go too far, however, in suggesting certain obvious inferences which seem entirely justified by these data and by the general principles of adaptation.

Dependent life, whether expressed in the often extraordinarily complicated conditions of parasitism, or in more simple symbiotic manifestations such as commensalism or mutualism or still more simply in the merely fixed condition of the individual through the whole or a part of its life, involves conditions of degeneration. These degenerative effects are relative; they may involve an individual in most of its essential organs and functions, a genus, a family or an entire class of organisms. Such effects may be restricted to only a part or certain parts of an organism and special degenerate organs are recognized throughout the higher forms of nature.

Degeneration follows adaptation. It may be primarily the result of special adaptation in the individual for its own protection producing no more than a condition of fixation. This is degeneracy in essence because it involves dependence. Discovered and perfected by the organism as helpful against its enemies or in the winning of food, it continues into atrophy of organs no longer needed; such atrophy once begun extends to other organs as the adaptation and dependence become more complete, till in the end all the organs in succession become involved in accordance with the lessened demand upon them; the alimentary, the locomotive, the sensory, all except those involving the function of reproduction. Nature is permeated with such degeneration. Few, probably no members of the whole vast fauna and flora of the earth are free of the bond of supporting others at the cost of their own effort and vitality. From the protozoa and bacteria to man and the oak every greater or less division of nature is riddled with these dependent organisms.

The path of evolution is specialization, chiefly by adaptation; only occasionally is evolution progress. The upward march of organic nature is before the eye, palpable, pleading and perspicacious, but degeneracy is largely unseen, impalpable, sequestered and ignored. Often though expressed openly, even throughout great natural divisions, it is not apprehended. Progress involves complication of structure; simplicity of structure too often means derivation by degeneration from the complex rather than initiation of upward advance.

The total result of degeneracy in nature and in human society presents itself to us as the outgrowth of a primitive miscarriage in the normal upward trend of nature which has grown in intensity with the passage of time till now it presents to the philosophic mind the appalling condition of a widespread downward impetus throughout the living world whose tendency is to undermine that which still stands upright. Degenerative tendencies in organic and in social life increase and intensify by their own impetus, like a stone rolling down hill. It has not been shown that there is in nature any power to redeem itself when degenerative adaptation has once begun, any hope of salvation within the organism or group of organisms, of turning back, recouping and starting again on the upward path. In the face of the counter evidence here set forth, the conclusion is unavoidable that, for a large part of humanity ethical philosophies are inefficient and illusive.

The lines of progress in organic life have steered wide of these dependent existences or have maintained their charted course in spite of them.

Great groups of organisms, classes, orders and subkingdoms have been so permeated by degeneracy of growth that their life, lasting, it may be, from almost the dawn of existence to the present, has had no other outcome than to perpetuate a depraved race. Such a race, however broad its boundaries and long its perdurance, has been entirely outside the general path of that upward advance which has led to the higher expressions of life. I would cite the mollusks as such a great division of organisms. Created free and independent, their almost universal acquisition of shell protection has kept them down to earth or made them grubbers in the mud of the ocean. Only a few of them, by acquirement rather than by endowment, sail the seas, and the floating habit, says a well known writer, is nearly related to the sessile. They have progressed only within the narrow limitations of their own race. Out of them has come nothing better. No lines of progressive evolution lead from the higher organisms back to them, but all pass them by. We do not even know the real relations of the great subdivision of the Mollusca to the molluscoids — the brachiopods and bryozoans; whether these are not degenerative expressions from the early mollusks rather than stages along the line of development to higher molluscan forms. We do know that all have filled the earth and sea of today with representatives in no substantial degree different from their ancestors of the Silurian.

Were we to begin an investigation of the degenerate condition pervading nature and to start with man and his more than one hundred species of parasites, there would be but one conclusion of our excursion; it was clearly stated long ago:—the whole creation groaneth and travaileth.

In the more innocent expressions of symbiosis termed mutualism and commensalism, where associations of organisms are purely social and apparently harmless or even mutually advantageous to the participants, it is probable that the outcome is infallibly deleterious.

The glass rope sponge (Hyalonema) has its coil of rope, by which it anchors itself to the sea bottom, incrusted and shielded by a coral (Polythoa), which spreads like a thin wrap of felt all about it, while its ally the Venus Flowerbasket (Euplectella) imprisons a crab in its interior behind the bars it throws across its aperture but feeds it with ever changing water currents; worms and anthozoan corals grow together, with the tubes of the former surrounded by the cells of the latter, both sweeping the water currents together for food which may go to either mouth; dead snail shells in which hermit crabs have taken residence are often beset with sea anemones (Sagartia and Adamsia) whose stinging cells may scare away the enemies of the crab, while the crab favors the fixed anemones by moving his establishment from place to place, thus to new feeding grounds.

All these conditions seem on the surface entirely harmless or positively advantageous to all parties involved; that is advantageous in the sense that they make life easier, less arduous, discourage activity and perfect adaptation. Perfect adaptation, however advantageous to the individual concerned, is the very expression of degeneration in symbiotic life. Throughout nature complete adaptation makes for stability and long life, incomplete adaptation for the restless activity which leads to progress.

The general effect then of all symbiotic conditions is degenerative. They themselves arise from degenerate tendencies and could not exist save that degeneration had already set in. They are expressions of this condition and serve to confirm and transmit this tendency. The fact is tremendously evident that even the most innocent of symbiotic, dependent or attached conditions of growth is the leaven of progressive degeneracy.

It is well known that the critical methods of morphology and embryology have been requisite to determine the original ancestral independence of the most debased of parasites. While the doctors of the middle ages wondered over the barnacles and pictured them as growing on trees, dropping thence to the ground transformed into geese, their real nature as debased crustaceans was not unfolded till the life history of the creatures showed that their early stages were free and predatory, and the adult condition one of extreme adaptation by progressive loss of functions and organs. Thus the parasitic and dependent habit is always preceded by a free and predatory condition. Once the dependent habit is established the capacity for reaction grows weaker; degenerative adaptation creeps still further back in the life of successive generations and the degradation of the adult state becomes more profound.

The all pervading conditions of symbiosis and dependence in living creatures are largely beyond the reach of our present inquiry. We are endeavoring to seek some clew to the origin of dependent life from its earliest and simplest expressions. The parasitic conditions of the present organic world are complicated in the extreme as a result of progressive and easy adaptation; often two, three and sometimes four hosts are necessary to the full life course of the dependent. Usually these present extreme conditions are expressed only by soft-bodied terrestrial organisms. The evidences of dependent life presenting themselves to the paleontologist must be chiefly of marine origin and wholly adapted to a single host; they must moreover be wholly simple in their expression or may be easily misconceived. There are certain of these simple expressions of long standing; we find them in existing nature and the ancient faunas show that such associations began far back in the history of life. To some of these we shall make special reference. Besides these a multitude of illustrations of dependent and attached forms of organisms can be drawn from every hand in the ancient as well as the recent faunas. They call for no special illustration but they nevertheless enforce our consideration of the origin of this condition.

So far as our facts go there are but few evidences of true parasitic conditions in the Paleozoic faunas. The oldest and clearest is the well known case of the coalition of the limpetlike snail Platyceras and the crinoids. The snail settles down at an early age on the dome of the crinoid, placing the aperture of the shell over the anal vent of its host and remains attached for an indefinite period of its subsequent life.

It is clear that the snail depends for its food on the waste from the crinoid and the fact that it remains attached for a very considerable period of its existence is shown by specimens of the crinoid dome bearing successive scars made by the enlarging growth of the mouth of the snail shell. Though this is the most extreme expression of ancient parasitism known to us, it was evidently of a very elastic kind and by no means affected all individuals of this genus of shells. This combination makes its first appearance in the early Devonic and seems to have become intensified in the great crinoid plantations of the early Carbonic but in either formation the examples of the actual dependent combination are in very slender proportion to the number of individuals of either snail or crinoid. Some of the snails acquired this habit of parasitic dependence, others evidently did not. Apparently it was in some measure an individual adjustment. Yet the more general dependence of this snail Platyceras on the crinoids is indicated by the fact that quite generally Paleozoic strata carrying an abundance of the one also abound in the other.

Time has not extinguished this affiliation, for the existing seas afford occasional evidence of similar relation between the limpets and the crinoids. Our material seems to throw some light on the inception of this dependent habit. A crinoid, Glyptocrinus, from the Lower Siluric is occasionally found inclosing in its arms a holostomatous snail, Cyclonema, not attached to the dome, for the shell had not the limpet habit of attachment, but lying free in such attitude as to get the full advantage of the crinoid's waste.

True dependence is also indicated by a similar association between the crinoids of the Carbonic rocks and the starfish Onychaster. The starfish adjusts itself, mouth downward over the anal aperture of the crinoid. Our specimens showing this condition have been caught in this act of feeding. The flexible character of the starfish made the attachment easily subject to change. This association too is one that time has not cured.

Much more abundant than these exhibitions of parasitism are those of the commensal habit as indicated by our illustrations of worms and corals, worms and sponges, barnacles and corals.

In the natural and expected course of procedure commensalism is the precursor of parasitism, and commensal associations became established more abundantly and at an earlier date than the other. Such mutual associations among members of the groups here indicated have been continued till today, not in precisely similar manifestation but in like alliances between individuals of the different divisions.

The protected sedentary condition, effected either by the agency of a special organ, as among most of the old brachiopods during a part or all of their life, or by the cementation of the shell to the rocks or some like object, is so widespread as to here command attention as a still simpler expression of dependent life. That the attached condition among organisms involves and expresses degeneration and necessarily promulgates still further decline, biologists are well agreed.[1] An argument therefore to show that groups of attached organisms like the corals, the sponges, the bryozoans, are degenerate and that their apparent simplicity of structure is less a primitive than a derived condition, is not here called for.

As we contemplate the earliest faunas of the earth we find that adherent and attached forms of life are in a notably less proportion than in the faunas succeeding. Bryozoans, crinoids, corals, sponges, attached worms are extremely rare; trilobites and brachiopods enormously predominate. The trilobites were crawlers and swimmers. The brachiopods however were of different habit. The predominating forms were the inarticulate species allied in structure to the living Lingula and, if allied also in habit, burrowed in the mud of the sea bottom with their fleshy pedicles, potentially not actually attached. Some of the genera with long pedicle sheaths may not have had this habit but have been actually attached to solid objects by their arm; this was undoubtedly the habit of the articulate brachiopods also until the time came with the maturity of these creatures when the arm was atrophied and they fell back on the sea bottom, free but still incapable of locomotion. In this condition, like many bivalves (e. g. Mya, the soft-shelled clam, which lies buried in the mud with no power to get any way but further in) they were potentially attached though actually independent.

To the faunas earlier than the Cambric with their probable decrease of attached organisms, we can not appeal. We can, however, still follow the line of our argument into those earlier faunas which still remain unrevealed.

In all shell bearing organisms the shell is not a primitive but a secondary development. Primitive organisms, as all considerations of biology insist, were shell-less throughout their existence — a conclusion not only indicated by ontogeny but by philosophy. The generally accepted conception that the archetype of organic life was a naked free-swimming pelagic creature may be supplemented by the proposition that the primitive condition of all organisms even after departure from the radicle was still naked and free. We must conceive that only as the independent soft-bodied animals of the earliest

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[1] See especially Arnold Lang. Einfluss der festsitzenden Lebensweise.

faunas adapted themselves to life in shallow waters did the necessity for shell protection arise for with this change from a free-swimming to a creeping or stationary littoral habit came the lessened capacity for escape by locomotion. As Lang has said, the coast is full of dangers; the waves beat violently against it, the regularly returning tide keeps the waters ever moving. From these attacks of nature's blind forces the creatures must protect themselves. Some, in times of stress, seek deep water, some scuttle into protected spots or bury themselves in the sand, and others catch hold of stable bodies, attaching themselves by suction or fixation. But all these resorts are inefficient without the addition of shell protection; that once achieved, the animals may rejoice and flourish in the play of the waves which brings them nourishment with decreased exertion on their part. The primary step toward a degeneration which in the lapse of ages has led to the dependent life conditions of today would seem with reason to lie in the forced reduction of this locomotive power and adaptation to a sedentary condition resulting in the necessity for the formation of a protective shell.

ILLUSTRATIONS OF PALEOZOIC SYMBIOTIC ASSOCIATIONS

The instances here given are some of the more instructive occurrences of this sort that have come under my notice. They are not in all cases common though they exemplify consociations which are familiar in like groups of the living world. The record of their number will doubtless be much increased as such objects come under closer observation. The collection of such data from the early periods of the world's life is not likely to be carried too far for it is here, rather than in a profuser and much more complicated later development, that the factors of symbiosis are the more easily legible.

Worms and Corals

The coexistence of the tubicolous worms with the corals is one of the commonest phenomena of present seas. It became established at a very early stage in the earth's history and in the Devonic coral reefs the habitude had already become widespread and varied. It was palpably less frequent in Siluric times, at least our material would so indicate, and when it does present itself, the expression is quite simple. In most cases it is an elementary expression of commensalism. Worm and coral may start to grow together directly on settling down from the free larval state, or conjunction may be formed by attachment of the annelid larva after the growth of the coral has well progressed; in both cases the growth of the latter engulfs the former save at its tentacled aperture.

The coral Zaphrentis or Cystiphyllum and the worm Gitonia corallophila. I give this latter designation to what appear to be chiefly straight worm tubes found in simple cyathophylloids such as those mentioned. The worm has attached itself at any stage of the coral growth and quite often its tubes are found projecting in considerable number from the calyx of the coral disordering the septa by its thickened stereom and taking just the position most advantageous to its feeding with the help of the coral's tentacles [pl. 2, fig. 1]. Often these tubes seem to puncture the thecal walls of the coral where actually they have become overgrown or left behind by the increase of coral substance. It is not usual to find both of these conditions in one corallite. Plate 2, figure 3, shows a Zaphrentis with a series of small worm apertures at its base; figure 2 is an enlargement of the thecal wall of Zaphrentis with two apertures one of which shows distinctly the wall of the tube; figure 4 is a Cystiphyllum with apparently short-lived worm tubes established at different growth stages of the coral. In figures 5, 6 of the same plate are two views of a tube both ends of which seem to open into the calyx of a small Zaphrentis. If I interpret the growth of this worm correctly it started almost concurrently with the coral and like the worm on Pleurodictyum kept both ends up. It will be seen by examination of these figures that the course of the worm tube is singularly erratic; both branches have kept close to the margin of the calyx, one has come pretty straight up, while the other in its late stages made almost a half circuit of the calyx.

All the examples above cited are from the Onondaga limestone of the Lower Devonic.

The corals Monticulipora and Stromatopora and the worm Gitonia sipho. These compact, stony, massive structures covered with thousands of arms reaching out for new supplies of nourishment, seem to have especially invited the settlement of straight tubed worms which, for convenience, are designated as Gitonia sipho.

A very striking example is that illustrated in plate 1, figure 4, where the coral has overgrown the face and eyes of a moulted head shield of the trilobite Dalmanites and a series of worms has started growing obliquely upward from the very beginning of the coral (Monticulipora) growth. This specimen is from the Onondaga limestone.

A very similar combination is shown in figure 3, plate 1, which represents a colony of Favosites sphericus (Helderbergian) with worms of like character. Figures 1, 2 are of a Stromatopora from the Cobleskill (Uppermost Siluric) limestone, one showing the worm apertures on the weathered surface, the other being a polished face of the same specimen with many cross-sections of oblique tubes.

The tabulate coral Pleurodictyum; the worm Hicetes innexus; a sponge, and the gastropod Loxonema (sometimes Pleurotomaria) or the brachiopod Chonetes [*see* plates 3, 4]. This is a very remarkable and most instructive combination and we have illustrated it quite fully on the accompanying plates. The combination of the coral and the worm has long been known and the sandstone casts of the base of Pleurodictyum with the "coiled central body" or "wormlike object" are common in the Lower Devonic (Coblentzian) of Germany and have frequently been illustrated.

Pleurodictyum is a compound coral growing in small lens shaped colonies with large cells and the genus is widely distributed in faunas of Lower and Middle Devonic time. We may mention P. lenticulare Hall of the Helderbergian of New York and its variety laurentinum of the Grande Grève limestone of Gaspé; P. convexum Hall, Onondaga limestone; P. problematicum Goldfuss of the Coblentzian; P. constantinopolitanum Archiac and Verneuil, from the lowest Devonic of the Bosphorus; P. amazonicum Katzer of a similar age in the Amazonas and P. styloporum Eaton from the Middle Devonic Hamilton shales of New York. The concurrence of the coral and its convoluted worm has been noted in several of the species here mentioned but the varying degree of its frequency is instructive. Thus in the earliest species, P. lenticulare, I have seen the worm tube very rarely, after the examination of a considerable number of examples; in the var. laurentinum not at all; never in the large species P. convexum Hall of the Onondaga limestone. The single illustrations of P. amazonicum and P. constantinopolitanum show its presence but enable one to form no conception of its prevalence. The combination is frequent enough in P. problematicum to have given rise to the specific name of the coral. The Middle Devonic P. styloporum has afforded the material for most of the illustrations here given. Of this very common species in the calcareous shales of the Hamilton I have been able to critically examine several hundred individuals and it is safe to say that the worm is present in the majority of examples. It is easy to determine its presence on inspection of the tentacular surface of the coral by the contrast between its round tubes and the angular coral cells. All the specimens here figured to show the convolutions of the worm have been drawn from actual preparations.

The history of the combination in P. styloporum is as follows: At the close of the free-swimming larval stage the coral, in fully eight cases out of ten, selected and attached itself to a dead or living shell of the gastropod Loxonema hamiltoniae. Directly upon fixation or even actually contemporaneous with it was the attachment of the larval worm upon the incipient coral or alongside it. In many cases, such as that illustrated in plate 4, figure 3, the worm tube is directly fixed to the gastropod; again it may be free of the gastropod, and separated from it by the thickened basal theca [*see* pl. 4, fig. 1, 2]. With the multiplication of cell growth and the upward trend of the coral, the worm began its convoluted growth, its tube growing as much at one end as at the other. Some of the existing serpulid worms have their eyes on the hinder end of the body at the tentacular surface; it is fair to presume that at this early period this advanced stage of degeneracy had not been reached and the tube was thus kept open at both ends. In view of the regularity of coiling shown in some of the commensal worm tubes it is interesting to notice that in this case the worm after making a start, gets its double coil into parallelism for a half to an entire turn and then each arm starts off into a direct course following the radial path of the coral cells. These branches often pass in and out between the cells, keeping their extremities always at the tentacular surface and very seldom is there evidence of the worm encroaching on the polypite cells. Still this may occur and the worm tube occasionally becomes encased by a young polypite and holds a position in the center of the cell [pl. 4, fig. 4].

There may be other worms encased in the thickened base of this coral as shown in figures 1, 2, plate 4, but it is not yet clear where their apertures lie as I have never seen but two annelid openings at the surface of the adult coral. It is quite possible that originally opening on the tentacular surface at an early stage of coral growth they have been buried in the later accumulations of stereom. There are long tubular passages between the corallites in early growth stages which have not been described in the structure of this coral genus and in sections these are confounded with worm tubes but in etched specimens such as have here principally served for illustration, their nature is clear.

In this interesting combination there is still another member—a small calcareous sponge. It has come to my notice several times. The one here figured was taken from the tube of the worm but whether that is its usual position or whether it may seat itself in one of the coral calyces or whether indeed it is a usual member of the consociation can not clearly be regarded as established.

I have given (pl. 4) some illustrations which show how readily the dead parts of these organisms become incrusted with serpulid worms. Figure 8 is the surface of a part of a dead Loxonema to which a Pleurodictyum had grown and figure 7 shows the inside of an old tube of the commensal worm Hicetes innexus, itself incrusted with minute worm tubes.

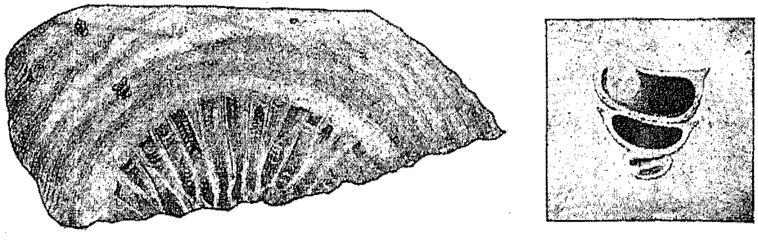
Interesting as is this instance of commensalism, its most extraordinary feature is the amazing evidence of selection by the larval coral of the body to serve as the base on which it is to grow. I have stated above that a very evident majority of the colonies of this coral Pleurodictyum as it occurs in the Hamilton shales are attached to an organic object and that this organic base in approximately 80 per cent of the cases is a shell of Loxonema hamiltoniae. Occasionally the shell may be a Pleurotomaria of one or another species. I have no record of its being any other than one of these gastropods. On the other hand the German Pleurodictyum problematicum fixes itself by decided preference to the brachiopod Chonetes sarcinulatus Schlotheim. I have examined a considerable number of specimens of this Coblentzian species but have seen no other shell used for attachment nor have I found record of any other. Though I can not use percentages with reference to the frequency of this occurrence, this palpable fact remains that as between these two closely allied if not identical corals, one selects a gastropod, the other a brachiopod as its base of attachment. Emphasis is to be put on the word "selects" for among the brilliant examples of selective adaptation none could be more striking than this. The floor of the New York ocean was covered with Chonetes and of the German ocean with gastropods during the life of this coral. Were either wanting in the other fauna, hundreds of other species of organisms lined the sea bottom. The coral was not deprived of its choice.

Taken as a whole this combination is very complicated commensalism from a date so ancient as the Devonic, more extreme than any other yet known from the Paleozoic rocks. But we find a somewhat parallel case in the present described by Bouvier as occurring in the Gulf of Aden — a coral and a worm growing together, and hidden in the coral substance a gastropod on which both settled down when the partnership began; furthermore there appears to be a small bivalve in association with the worm. Other somewhat similar cases might be cited.

The Devonic coral Acervularia and the spiral worm Streptindytes acervulariae; a Siluric Stromatopora with a somewhat similar spiral worm, Streptindytes concoenatus; a Devonic Stromatopora with the spiral worm, Streptindytes compactus. The first of these occurrences was described some years ago by Prof. Samuel Calvin [On a New Genus and Species of Tubicolar Annelida. Am. Geol. 1:24. 1888]. It is the case of a large annelid whose tube measures ⅛ to ¼ inch in diameter growing upward in numbers among the cells of the compound coral Acervularia davidsoni Edw. & H. from the Middle Devonic rocks of Iowa. The species has not before been illustrated and I have to thank Dr Calvin for the privilege of introducing the accompanying cut of this interesting commensal [pl. 1, fig. 7].

Another example of these spiral commensal worms (Streptindytes concoenatus) is afforded by the Stromatopora reefs of the Cobleskill limestone (Upper Siluric). The illustration here given [pl. 1, fig. 5, 6], affords some idea of how a small mass of Stromatopora may be quite riddled with these minute corkscrews. This is taken from a single section across a small colony in which it is apparent that these worms have become sessile at different stages of growth in the coral mass as they start at different levels in the colony. It is also clear that the worm tube made at least one horizontal convolution before starting on its upward spiral growth and it is more than likely that its elongated spiral is due to the requirement of keeping its tentacular end up at the feeding surface of the growing coral. These tubicolous worms have very plastic tubes and readily adjust themselves to surroundings. In the worm of Pleurodictyum (Hicetes innexus) the early spiral form was soon lost, perhaps because the corallites are so large and close that such growth was effectually obstructed. I have given here some illustrations of a worm from the Hamilton group described by Hall as Spirorbis angulatus from closely attached examples showing but one or two entirely horizontal volutions. These silica etchings show how quickly in later growth the tube departs from the horizontal position and draws out into a loose spiral even when not confronted by the necessity of keeping its feeding end on a level with that of some companion organism [pl. 2, fig. 8-11].

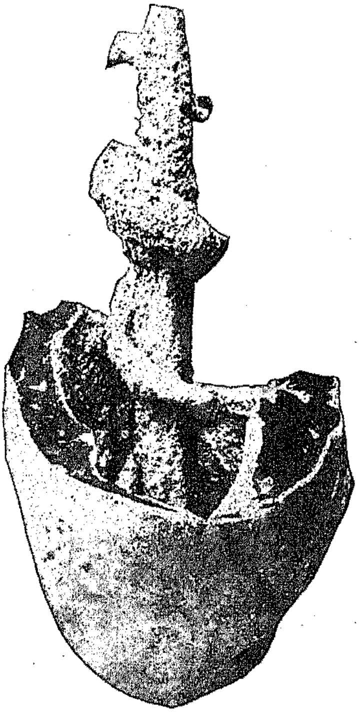
The third of these combinations is illustrated by a specimen for which I am again indebted to Professor Calvin. A little colony of Favosites has had its tentacular surface entirely overgrown with a Stromatopora. Within the substance of the Stromatopora is a multitude of spiral worm tubes not stretched out into loose volutions as in the other instances mentioned, but keeping their two or three volutions in close contact and resembling an Autodetus without its external smoothly sloping surface. The edges of these tubes are apparently always angular. These little worms have started growth anywhere on the substance of the Stromatopora and instead of growing like a Spirorbis with whorls broadly attached for a turn or two, have coiled closely upward and ceased growth in every case very abruptly. This case is singularly instructive as showing that the worm failed to keep pace in growth with the coral and confessed its natural limitations of growth, while in the other cases cited the worm apparently has had the ability to adapt itself to this upward growth by stretching out its tube into loose curves and keeping its aperture always clear at the surface. The little Streptindytes compactus however was not equal to this struggle for existence except as it planted its successors in-



Stromatopora with embedded spiral annelid tubes. Streptindytes compactus, located at various stages of the growth of the coral. The character of the annelid tube is shown in the enlargement at the right (x 5). The Stromatopora has entirely overgrown a small Favosites colony. Middle Devonic, Iowa discriminately over the coral at its various levels of growth. How well it struggled to maintain itself is indicated by the presence of fully 30 individuals on a surface of this coral 2 inches square. The single specimen of this species observed is from the Middle Devonic Cedar Valley beds at Iowa City, Iowa.

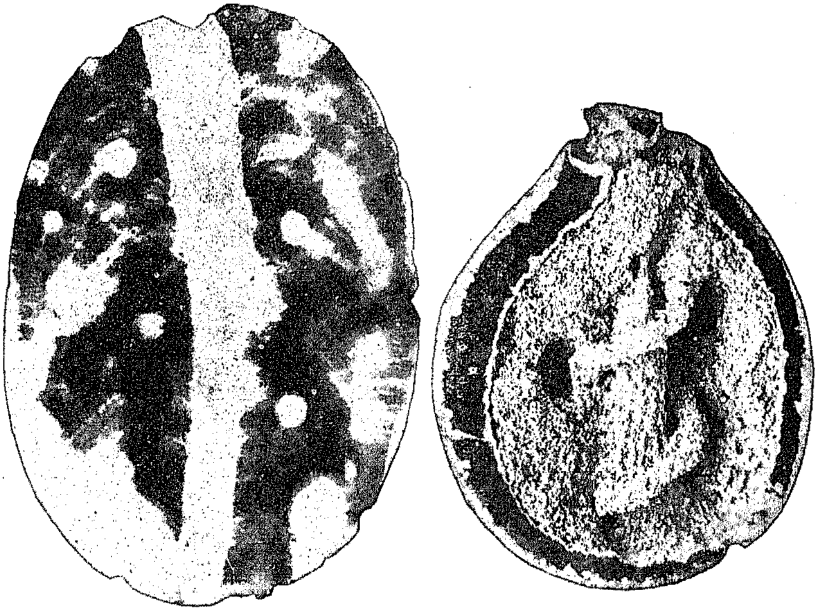
Worms and Sponges

We find in more than a single instance among the fossil hexactinellid sponges of the family Dictyospongidae evidences of worm tubes attached to the inner wall or cloaca of the sponge and living in a condition of commensalism. Such worms have been observed in the species Hydnoceras tuberosum var. glossema and Prismodictya telum Hall & Clarke, from the sponge plantations of the Upper Devonic in western New York [pl. 5, fig. 1, 2]. In a considerable number of individuals of the latter species from the same locality nearly all showed the presence



of the annelid commensal and as the surface of the impression left in the sands by the worm tube is in all cases crossed by the reticulated skeleton of the sponge it is inferred that the position of the former was internal. These are silicious sponges allied to Euplectella and though we find no parallel expression of commensalism in the living glass sponges, yet Euplectella carries a parasite in the form of a crustacean which in youth enters its open cloacal cavity and remains there so that when the sponge has in adult growth built the terminal or sieveplate over its aperture the crustacean is wholly and permanently caged.

A very commanding illustration of the association between the sponges and spiral annelids is afforded by a series of specimens displayed in the British Museum. These I am able to reproduce here by the kindness of the trustees of that Museum from photographs made by permission of the Keeper of the Department of Geology, through the friendly agency of Dr F. A. Bather. In all these specimens it would appear that the worm, which has made a tube of large dimensions, began its commensal existence early in the life of the sponge and has coiled upward in a very loose spiral about and just within the cloacal wall. Of the figures given here two



These and the figure on the preceding page represent silicified sponges with spiral annelid tubes from the English Chalk. In the upper figure (locality unknown) and the lower right-hand figure (Beckhampton), the exposed worm tube is coiled about a vertical tube which appears to be the silicified wall of the cloaca. These spirals are obviously in reversed direction. The lower left-hand figure is a direct print from a thin section of another sponge in which the position of the worm tube, cloaca and concentric structure of the sponge are shown. Prepared by Dr. Bather. Figures about natural size. British Museum (Natural History) Department of Geology: A. 475; 55117 are of specimens so broken as to expose the interior. Solid flint has replaced the outer part of the sponge body, but in the disintegrated silica of the interior the tube of the cloaca stands vertical with hardened walls about which the worm tube seems to coil like a beanstalk on a pole. The transparent section which is reproduced from a direct print, shows with probably more accuracy the actual distance of the tube from the cloaca. It is extremely instructive to note that the direction of coiling is unlike in the two specimens exposing the spiral, while in the section it would be impossible to determine whether the course of the coiling is dextral or sinistral.

Barnacles and Corals

The barnacles of today express to us one of the extreme results of modification through adaptation to a parasitic condition. I have ventured to suggest on a previous occasion that the Siluric barnacles of the genus Lepidocoleus [pl. 5, fig. 3] are an expression of these creatures before such modifications set in. It is regularly segmented throughout its length, its biserial row of plates being open on one side only for the protrusion of the appendages. The forms known as Turrilepas, Plumulites and Strobilepis of the Devonic, are not of greatly different structure. We know however of fully modified acorn barnacles in the Devonic Protobalanus and Palaeocreusia. The latter is parasitic on a Favosite coral of the Onondaga limestone (Lower Devonic), in which it appears to be embedded by the overgrowth of the polypites rather than by burrowing its way into the colony as do sometimes the acorn barnacles of the present [pl. 5, fig. 4, 5].

Crinoids and Cystids with Gastropods

We are here presented with what appear to be instances of genuinely dependent parasitism—where an attached organism relies upon its host for its nutriment and existence. They constitute the earliest instances we can cite of a dependence between organisms that has become essential rather than merely convenient and it is of extraordinary interest because we find some clue here to the origin of the habit. The attachment of the limpetlike gastropod Platyceras to the calyx of the crinoid of the Paleozoic has already been referred to and many instances of it have been cited and illustrated.[1] This attachment is so effected that the mouth of the shell is seated directly over the anal aperture of the crinoid so that the former may catch the digestal waste of the latter. Upon this waste the Platyceras palpably sustains itself. So many instances of this conjunction have passed under examination that no question can arise as to the fact that such attachment is solely for feeding purposes. Suggestions which have been occasionally made that the attachment is rather accidental than otherwise, as attachment to some substantial object is the habit of the gastropod, are not borne out by the evidence afforded by multitudes of these cases. It is quite certain, however, that in the Devonic and Carbonic faunas where this habit became most prevalent, there was always a predominant percentage of the gastropods that did not lend themselves to it; nor have we reason yet to conclude that the habit once inaugurated necessarily continued during the remaining life of the individual. It did continue for a considerable period of the shell's existence as the very instructive figure 6 on plate 6 indicates, the concentric scars being the successive impressions of the lip of the shell as its growth enlarged, while its position relative to the after opening of the crinoid is unaltered.

The history of this form of dependence is extraordinary and illuminating. Throughout the Siluric the crinoids and cystids abounded but mollusks of the limpetlike construction of Platyceras were few. Moreover the crinoids were for the most part built with slender domes well hedged about by delicate arms, and on these domes the mollusk might have found difficulty in securing a footing.

The earliest intimation of the tendency on the part of a mollusk to seek its food from the rejectamenta of the crinoid is afforded by an example of a Lower Siluric Glyptocrinus which holds within its arms and in a feeding posture a shell of the holostomatous gastropod Cyclonema bilix. One might regard the occurrence accidental if it had not been observed more than once.

In the Upper Siluric, Platyceras had become somewhat more abundant but its numerical development did not reach that of the allied mollusk Diaphorostoma and in plate 6, figure 1, we have an illustration of a small shell of this latter genus attached over the after of the cystid Caryocrinus ornatus (Rochester shale). Thus far in time no examples have come to our observation of

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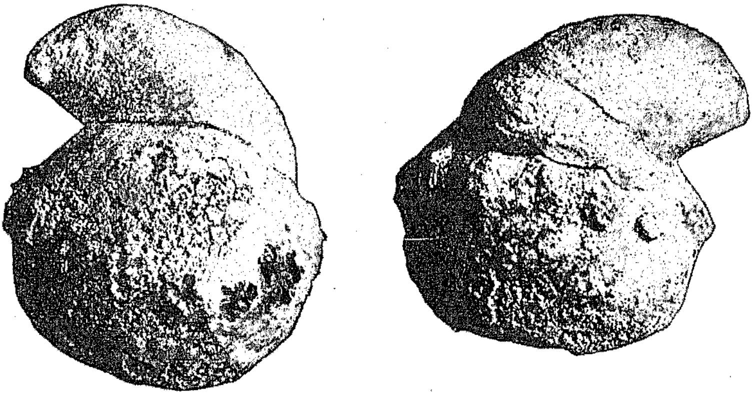
[1] See particularly C. R. Keyes. Synopsis of American Carbonic Calyptraeidae. Acad. Nat. Sci. Phila. Proc. 1890. p. 150. The author here records a long list of these parasitic associations and especially indicates the effect of this condition in modifying the aperture of the gastropod.

attachment between Platyceras and the crinoids. With the opening of the Devonic the development of Platyceras became enormous, so much so that the calcareous phase of the earliest Devonic has been termed the Platyceras stage. The crinoids also were common at this time, but cases of any dependent conjunction of the two are extraordinarily rare; the only instance of this early date known to me is that cited by Drevermann from the Coblentzian. Little by little, however, the habit was assumed and becoming more frequent in the Middle Devonic it seems to have attained a culmination in the faunas of the earlier Carbonic. During all the ages which have intervened between the Paleozoic and the present there is no record which has come to my notice to prove that this ancient habit has had an uninterrupted existence. The crinoids and the limpets have continued and certainly the detailed records of Mesozoic and Cenozoic faunas should have given some account of this habit had it perdured. We have remarked that the consociation was always an easy one to which even at its hight not all the members of the genus Platyceras were compelled. In the absence of demonstration, it may be fair to hold it possible that the descendants of these mollusks really abandoned this form of attachment and rebounded from the degenerative condition which it involved; this would be a fact of profound significance if it indicates that an organism once started on the downward path can take a new hold of life and regain its independence. Yet we are doubtless not justified in such a conclu-



Silicified specimens of Platyceras attached to the dome of Megistocrinus farnsworthi White, from the Middle Devonic of Iowa. The perfect adjustment of the shell to the crinoid is seen in the adaptation of its margin to every irregularity of the surface of the dome. Loaned by Prof. Samuel Calvin sion. In the present seas all gastropods of truly parasitic habit are parasites on the Echinoderma, the class to which the crinoids belong. Crinoids are few today and appear to be relatively free from these attachments, but their allies, the starfish and sea urchins, are still beset by the gastropods, often so reduced by the degeneration of their condition as to be scarcely recognizable. This far-reaching and general condition of depravity would seem a direct inheritance of the ancient conditions we have portrayed.[1]

Crinoids and Starfish

We have some very interesting instances of association between the crinoids and the ophiuran Onychaster flexilis Meek & Worthen. Three of these are here figured, one a copy from Wachsmuth and Springer's figure of Actinocrinus multiramosus W. & Sp., the others drawn from specimens in the possession of Mr Fred Braun. In the first the starfish has encircled with its arms the dome of the crinoid, mouth downward in such an attitude as to suggest though probably not to demonstrate that it was diligently attending to the waste of the crinoid. As the arms of the crinoid have been broken away the act of the starfish is exposed in all its nakedness. In the specimens of the Onychaster with Barycrinus hoveyi Hall, the arms of the two creatures have become completely entangled and fixation for feeding purposes at least is entirely effective. In respect to the end sought and attained this condition is one of parasitism but one still subject to the control of the individual. There seems no reason to assume that the starfish is here endeavoring to suck the life out of the crinoid itself and it would be going further than the facts justify to interpret this demonstration solely as an act of feeding like that of the common starfish of today in its attacks upon the oyster.

I quote here some remarks from Wachsmuth and Springer's *North American Crinoidea Camerata* [1897, p. 566], concerning the relations of Platyceras and Onychaster to the high domed crinoid Actinocrinus multiramosus.

Of this large and beautiful species we obtained at Indian Creek and Canton over forty specimens, most of them in excellent preservation, with the arms attached; and it is very remarkable that nearly one half of them have either a Platyceras attached to the

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[1] The brothers Sarasin have described a very interesting case of the parasitic attachment of a limpetlike Platyceras to a living starfish, in which the former by an extension of its mouth into a snout which penetrates the test of the starfish, sucks out the nutritious fluids *Ergebniss einer Forschungsreise auf Ceylon, v. I*]. While the parasitic condition between the limpets and crinoids of the Paleozic was elastic, this is fixed and beyond repair. Other living snails parasitic on the allies of the crinoids are interestingly described in the *Naturwissenschaftliche Wochenschrift*, January 17, 1904.

tegmen, or a specimen of Onychaster between the arms and coiled around the anal tube. This, so far as we know, is the first instance in which a Platyceras has been found in contact with a Crinoid with a long anal tube; in all cases heretofore noticed the Crinoid had an anal opening directly through the tegmen, and the Gastropod was fastened invariably with the anterior portion of the shell over the opening. This led to the supposition, for which there seemed to be good reasons, that the Mollusk obtained its nourishment, in part at least, from the excrements of the Crinoid. This, however, was impossible in the case before us, where the anal tube, with the anus at the distal end, extends out far beyond the tips of the arms, and, so far as observed, bends abruptly to one side, so that neither the opening nor the refuse matter could have been in contact with the Mollusk.

In more frequent association with this Actinocrinus is the Onychaster, and it is worthy of note that this species of ophiuran is rarely found by itself. Nor has it been observed at Indian Creek on any of the other Crinoids, while at Canton it appears also on most of the specimens of Scytalocrinus robustus (Hall), a species with a large ventral tube, and the anus located far down at the anterior side; but with this exception we have not seen it on any other species. The fact that this Ophiurid is only found associated with certain species, and there always under similar conditions, and the frequency of this occurrence, would seem to indicate that the position between the arms of these crinoids was its favorite resting place, in which it either found protection, or some special facility for obtaining nourishment.

These specimens are from the Crawfordsville limeshale of the Lower Carbonic (Mississippian).

Crinoids and Myzostomum

All the known living species of the minute wormlike creature Myzostomum (60 to 70 in number) are parasitic on the crinoids whereon they form galls or swellings by the overgrowth of the test. Similar galls have been noted on both Mesozoic and Paleozoic species of crinoids by Bather, Shipley, Fraas and other writers, and they are generally ascribed to the Myzostoma.

Coral on a Coral

The case of Caunopora. It is now quite generally conceded that Caunopora which has commonly been regarded as a hydroid coral like Stromatopora, but with sharply defined, definitely walled tubes, is actually a laminate hydroid overgrowing a series of erect tubes like those of Syringopora or Aulopora, carrying oblique dissepiments within. Caunopora placenta Phillips is a Devonic species.

Fistulipora occidens presents a similar coalition of a hydroid coral and the primitive tubulate Aulopora. This species was described from the Upper Devonic Lime Creek shales of Rockford, Iowa, by Hall [N. Y. State Mus. 23d Rep't. 1873. p. 228, pl. 10, p. 9, 10] who recognized the fact that the large pores on the surface of the coral are projecting tubes of Aulopora. An interesting feature of this concurrence is that colonies of the Fistulipora are quite as frequently without the Aulopora as with it.

One may compare with these instances the interesting case mentioned by Whitfield of the recent coral Ctenophyllia, entirely inclosed by a hemispherical growth of Meandrina labyrinthica (described in Am. Mus. Nat. Hist. Bul. 1901. 14: 221).

In addition to the instances given above of actual commensal conditions, I am taking this occasion to append a brief account of certain ancient pseudoparasitic organisms of boring habit. These come frequently under the eye of the paleontologist but very little attention has been given to them, occasional incidental references being for the most part the sum of our knowledge of the Paleozoic expressions. The literature of the later formations contains random accounts of such organic relics but I should be going too far afield in this instance to make definite allusion to these.[1]

These boring bodies infesting the dead shells which form a large part of the material of the paleontologist are very likely to be either minute algae or fungi, or sponges of genera producing similar effects to the living Cliona or Vioa. The work of the former has had some notice [*see* Duncan Quar. Jour. Geol. Soc. 1876. p. 205; Kölliker. Zeitschr. Wiss. Zoolog. 1859, 10: 215; Loomis, N. Y. State Mus. Bul. 39. 1900. p. 223] and their tubules are recognizable by contrast by their microscopic size and the occasional presence of hyphal swellings. The total amount of deterioration and disintegration of skeletons caused by these minute organisms was doubtless great even in Paleozoic times.

The work of boring sponges, however, on ancient organisms has been a far more effective cause of destruction and waste of dead shells. There are certain conditions of preservation in which these borings enforce themselves on the attention, especially when the student has to deal with an arenaceous matrix from which all the calcareous matter of the shells has been dissolved leaving sharp

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[1] Very instructive instances of these later expressions are cited in a recent paper by E. Schütze, Die bohrenden und schmarotzenden Fossilien der schwäbischen Meeresmolasse, Jahresb. d. Ver. f. vaterl. Naturk. in Württ. 63, 1907. p. 81-84; Bericht ueb. 29 Versamml. d. Oberrhein. geolog. Vereins zu Wörth, 1906; Zeitschr. f. Mineral. Geol. u. Palaeont. Jahrg. 1.

and clean casts of the borings; or when these natural conditions are reproduced artificially by removing the calcareous material from a lime shale.

Probably the first attempt to characterize with a definite name these undoubted sponge borings was that of McCoy [Brit. Paleoz. Foss. 1855. p. 260, pl. 1B, fig. 1, 1a] who illustrated under the name Vioa prisca a series of simple straight club-shaped casts of borings occurring in the shell substance of the pelecypod identified as Pterinea demissa Conrad of the Upper Siluric. It is probably safer not to designate these sponge relics by the name of any genus now living and I propose, in speaking of several distinct forms of them, to employ the term Clionolithes.

The straight clavate tubes of Clionolithes priscus (McCoy) usually originate at the edge of a dead shell and expand gently inward; probably the sponge nested at the club-shaped extremity of the hole, drawing the water currents in to itself. It is not always the case that the shell was dead before the work of these borers began. There are several illustrations given here to show that a brachiopod or pelecypod may have been attacked by these sponges at any growth stage and that after the attack had begun the growth of the shell continued. There is a curious simultaneousness in the attacks of these pseudoparasites—all started in at once and frequently one such attack is not followed by others [*see* pl. 8, fig. 2, 4]. This form, C. priscus, was quite common in the late Siluric and very abundant throughout the Devonic.

Clionolithes radicans designates a quite different expression of this boring habit. Here the tubes radiate and branch outward from a center, giving a decided rootlike expression to the resultant very complicated combination of tubes. These branching tubes often unite, fuse or anastomose producing a somewhat irregularly reticulated expression. This sponge particularly infested the living and dead shells of the brachiopods, finding entrance less often at the margin than through the pores on the surface of the shell. The complex of tubules is small in comparison with those of C. priscus and it is not unusual to find both of these forms infesting the same shell. This boring sponge, so far as my observation extends, is restricted to the Devonic.

Clionolithes reptans has threadlike vermiform tubes which wander loosely and at random through the shell substance of both brachiopods and pelecypods.

Clionolithes palmatus, a singular form assuming broad sparsely branched palmate hollow fronds and found only in the pelecypods and gastropods of the Portage group (Upper Devonic).

Among these boring bodies is another, which judging only from the form of its tubes must have been very unlike the rest. I have observed it only in the brachiopods of the Coblentzian sandstone and in order to express its notable difference from the other borings mentioned shall designate it as Caulostrepsis taeniola. In these the borers began at the edge of the shell and the casts of their borings are long, narrow tapelike tongues with an elevated edge all the way around. This corded edge is a continuous tube while the area between is a narrow flat space connecting the tubes of the loop. I hesitate to assign this curious form to the sponges; it has in miniature a resemblance to some of the worm casts found on the surface of old rocks, but the evident open connexion between the tubes of the loop makes it difficult to allot to this boring its probable maker.

Boring pelecypods were not unknown in the early Paleozoic. Instances are rare indeed but a very striking example is the small Modiomorphalike shell Corallidomus concentricus described by Whitfield from the Cincinnati shales of Ohio [*see* Geol. Ohio. 1893. 7: 493, pl. 13]. The figure given by this author shows a colony of the coral Labechia ohioensis Nicholson perforated by scores of burrows in some of which the shell itself is found. Such occurrences have been freely described in Mesozoic faunas and boring insects in the woods of the Tertiary.

EXPLANATION OF PLATES

PLATE 1

1 Part of the weathered surface of a Stromatopora from the Cobleskill limestone, Schoharie, N. Y., showing the openings of the worm tubes Gitonia sipho

2 A section of the same colony permeated with such tubes

3 A colony of Favosites sphericus Hall from the New Scotland beds (Helderbergian) with similar tubes

4 A head of the trilobite Dalmanites overgrown with a colony of Monticulipora in which is embedded a series of Gitonia sipho. Onondaga limestone, Becraft mountain, N. Y.

5 Sections of spiral tubes (Streptindytes concoenatus) in a colony of Stromatopora. The apparent difference in direction of volution in these is due entirely to the different depth and angle at which the tubes are cut. From the Cobleskill limestone (Upper Siluric) Schoharie. x 2

6 An enlarged restoration of the characters of these worm tubes. x 5

7 Streptindytes acervulariae Calvin: two tubes in a colony of Acervularia davidsoni E. and H. x 1.5. From the Middle Devonic of Roberts Ferry, Iowa

PLATE 1.

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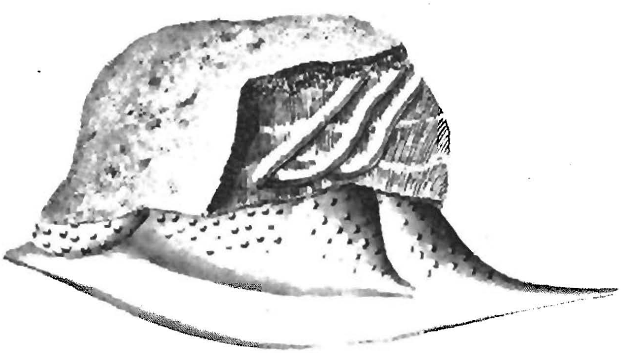

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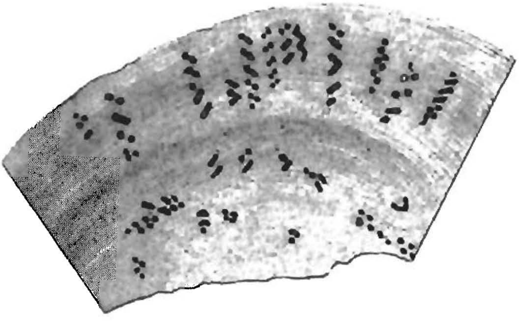

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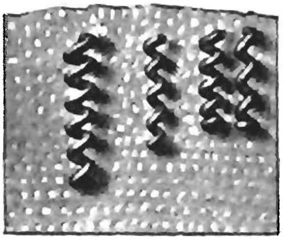

Following p. 172

PLATE 2

1 A calyx of Zaphrentis with a number of tube openings of Gitonia corallophila

2 Tubes of the same character opening outward through the lateral walls of Zaphrentis; much enlarged

3 A Zaphrentis with tube openings at the base

4 A Cystiphyllum with short tubes opening outward through the thecal walls

5, 6 A Zaphrentis from two points of view to show the course of a tube of Gitonia corallophila with both ends opening outward in the calyx

All these specimens are from the Onondaga limestone (Lower Devonic).

7 Caunopora — a schematic section showing the Syringopora- or Auloporalike tubes overgrown by the Stromatopora substance; coral on coral

8-11 Enlarged figures of Spirorbis angulata Hall, a worm tube from the Hamilton group of New York. These specimens are silica replacements etched from limestone (Menteth limestone), and show the tendency of the tube to unwind in a lax spiral as soon as fixation is firmly established.

PLATE 2.

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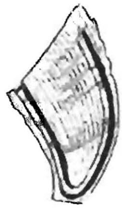

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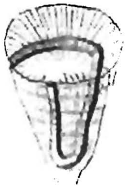

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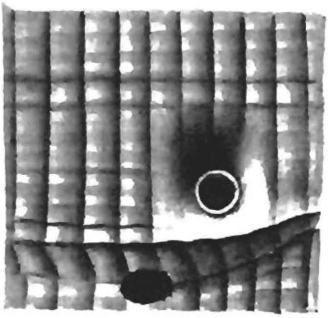

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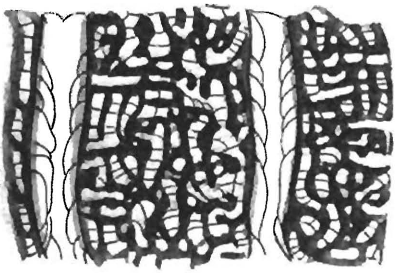

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PLATE 3

A series of drawings to illustrate the commensalism of Pleurodictyum and the worm Hicetes innexus

1, 2 Top and side views of a corallum of Pleurodictyum styloporum Eaton from the Hamilton shales of New York. The worm tubes are clearly seen at x-x on the surface of the colony.

3 Vertical section of a corallum showing sections of the convoluted tube near its base

4 The under side of a corallum with impression of the gastropod Loxonema hamiltoniae to which it is attached

5 An etching which has removed the base of the coral and shows the initial convolutions of the worm tube

6 The form of the entire tube, drawn from an actual specimen

7 The basal surface of Pleurodictyum problematicum attached to the brachiopod Chonetes sarcinulatus Goldfuss. This specimen is from the Coblentzian at Stadtfeld.

8 An etching of the basal part of P. styloporum showing the chief worm and a wormlike extension which appears to arise from the base of a polypite and turn into an upward course between the cells

PLATE 3

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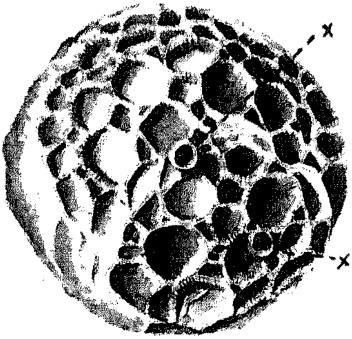

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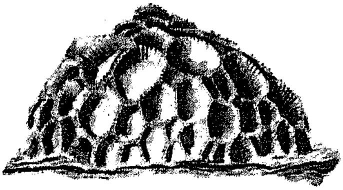

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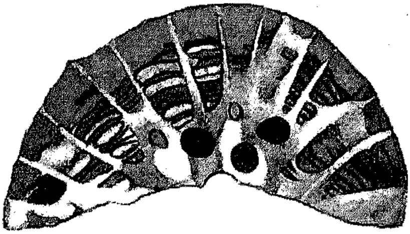

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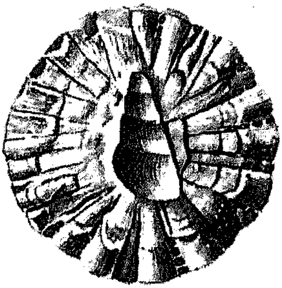

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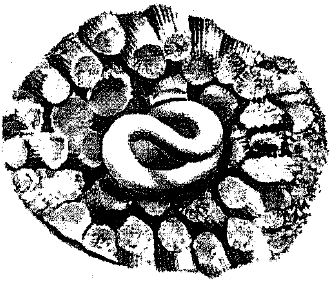

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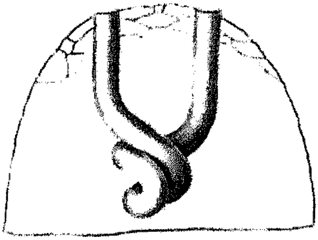

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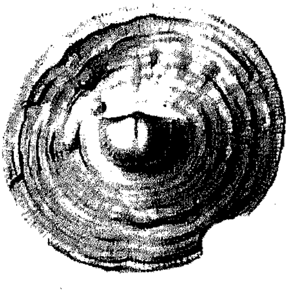

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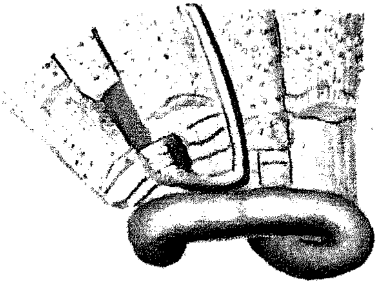

Following p 176

PLATE 4

Continuation of the illustration of Pleurodictyum and Hicetes, etc.

1, 2 Sections of P. styloporum showing not only the large worm but the smaller ones in the thickened base of the coral

3 An etching of P. styloporum showing actual attachment of the worm tube Hicetes to the surface of the gastropod Loxonema

4 The tube Hicetes penetrating one polyp cell and passing thence into another

5 The small sponge found in the tube of the large worm Hicetes

6 Chonetes sarcinulatus Goldfuss, the brachiopod to which P. problematicum usually is attached. (After F. Roemer)

7 The greatly enlarged interior surface of the worm tube Hicetes with slender serpulid worm tubes attached

8 The enlarged surface of part of a Loxonema, covered with small serpulids. This specimen of Loxonema had served as base of attachment for P. styloporum.

9 Loxonema hamiltoniae Hall

PLATE 4.

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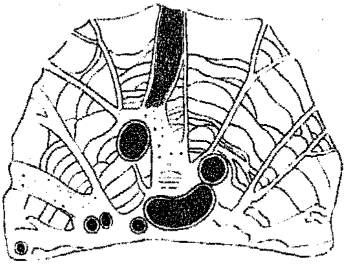

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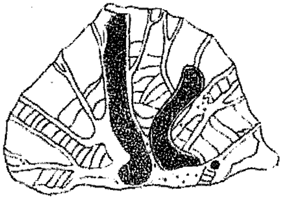

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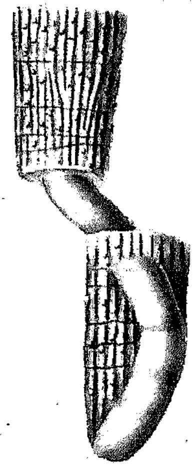

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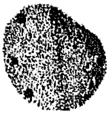

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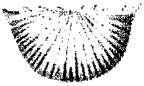

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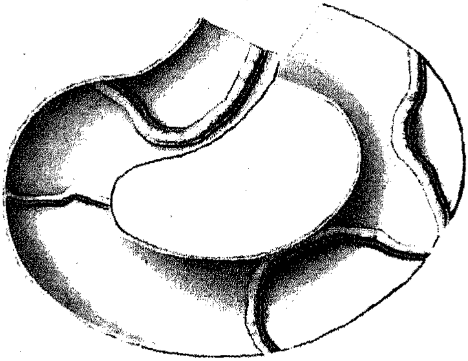

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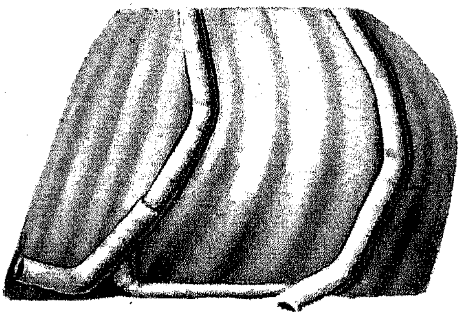

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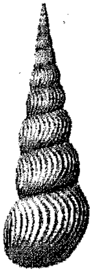


Fallhammer, p. 1 [illegible]

PLATE 5

1 Hydnoceras tuberosum Conrad var. glossema H. & C. A silicious hexactinellid sponge with markings of worm tubes on the inner side of the recticulum. From the Chemung group (Upper Devonic) of southwestern New York

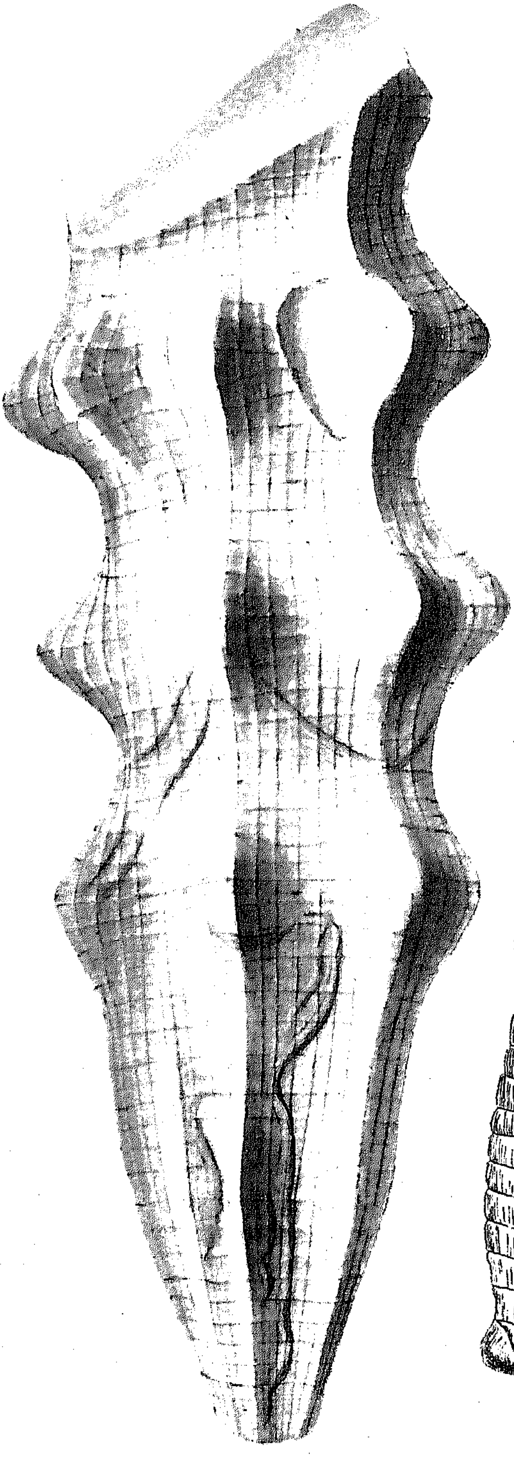
2 Another silicious sponge, Prismodictya telum H. & C. with similar worm tubes also from the Chemung group of New York

3 The barnacle Lepidocoleus jamesi of the Lower Siluric (Cincinnati group) showing the unatrophied condition of the animal whose segmentation may be regarded as represented by the paired valves which meet at the edge allowing room for the protrusion of the appendages

4, 5 Palaeocreusia devonica Clarke, a barnacle buried in a colony of Favosites hemisphericus partly by burrowing and partly by overgrowth of the coral. From the Onondaga limestone, Leroy, N. Y.

PLATE 5

1



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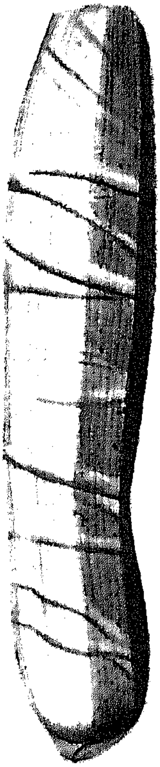

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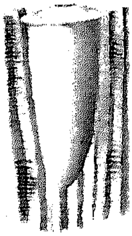

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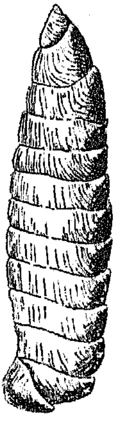

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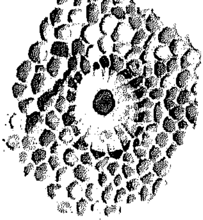


Following p. 150

PLATE 6

1 Caryocrinites ornatus Say, a cystid having a small gastropod (Strophostylus) attached and covering the apertures of the summit. From the Upper Siluric (Rochester) shale of western New York

2 Glyptocrinus (decadactylus Hall) with a holostomatous gastropod, Cyclonema bilix, inclosed within the arms in an attitude of feeding at or near the anal aperture of the crinoid. From the Cincinnati shale

3, 4 Cromyocrinus simplex with attached Platyceras of relatively large size, its anterior portion covering the anal aperture of the crinoid while the rest of the lip of the snail extends over the entire hight of the calyx. Carbonic limestone, Moscow, Russia

5 Platyceras enveloping the dome of Arthracantha punctobrachiata Williams [after Hinde, Ann &. Mag. Nat. Hist. 1885]. From the Hamilton group

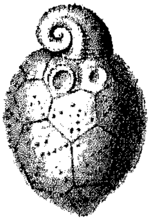
6 A part of the tegmen of Strotocrinus regalis Hall showing the successive growth marks made by an attached Platyceras, always keeping its anterior extremity over the anal aperture of the crinoid [after Keyes, Acad. Nat. Sci. Phila. Proc. 1890. pl. 2, fig. 7]. From the Carbonic (Mississippian) of Crawfordsville, Ind.

7 Platyceras infundibulum Meek & Worthen attached to the anal surface of Platycrinus hemisphericus M. & W. [after Keyes *ut. cit.* fig. 10]

8 Actinocrinus multiramosus Wachsmuth & Springer. The calyx with a starfish (Onychaster) fastened to the anal tube [after Wachmuth & Springer *ut cit.* pl. 55, fig. 3]

PLATE 6

1



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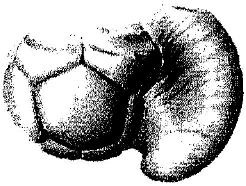

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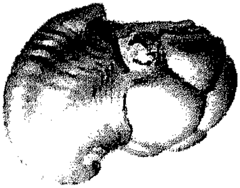

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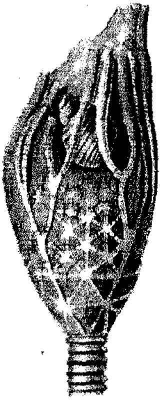

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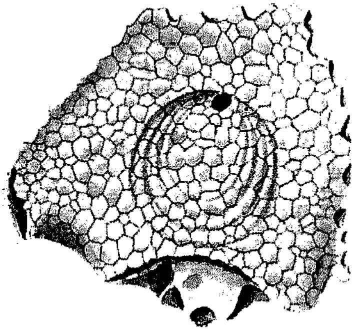

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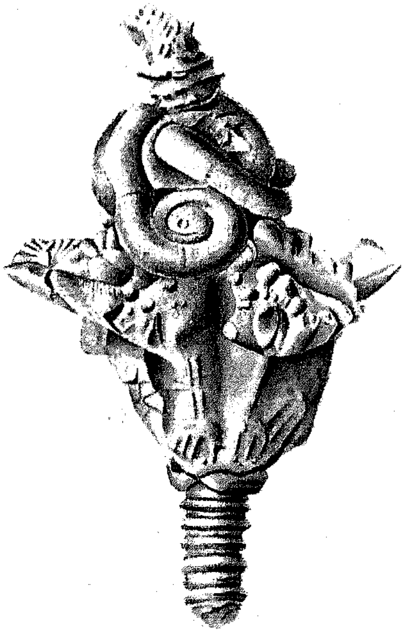

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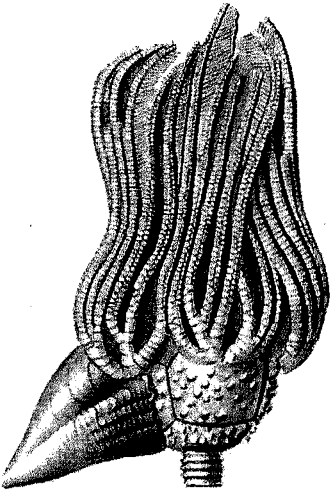


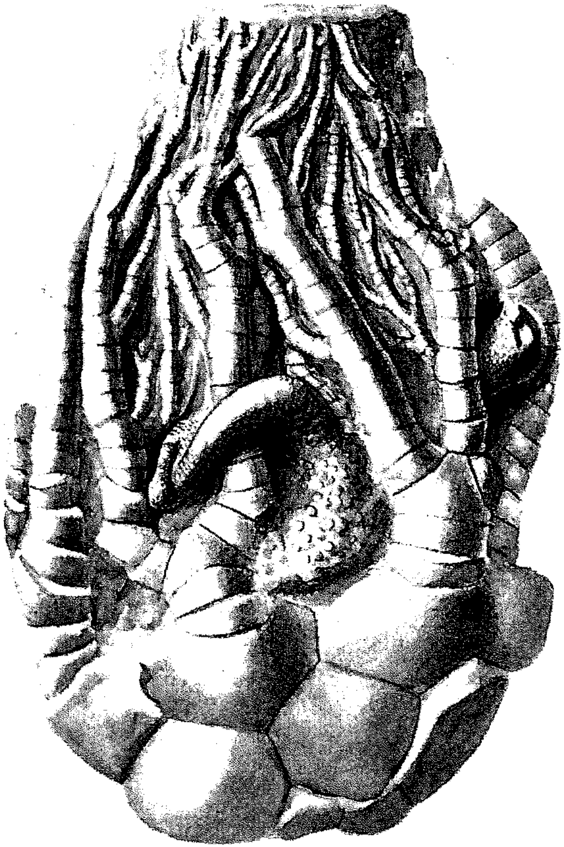
Following p. 182

PLATE 7

1, 2 Two specimens of Barycrinus hoveyi Hall with the starfish Onychaster flexilis intertwined within the arms. (Mississippian) Carbonic. Crawfordsville, Ind. From the collection of F. Braun

PLATE 7

1



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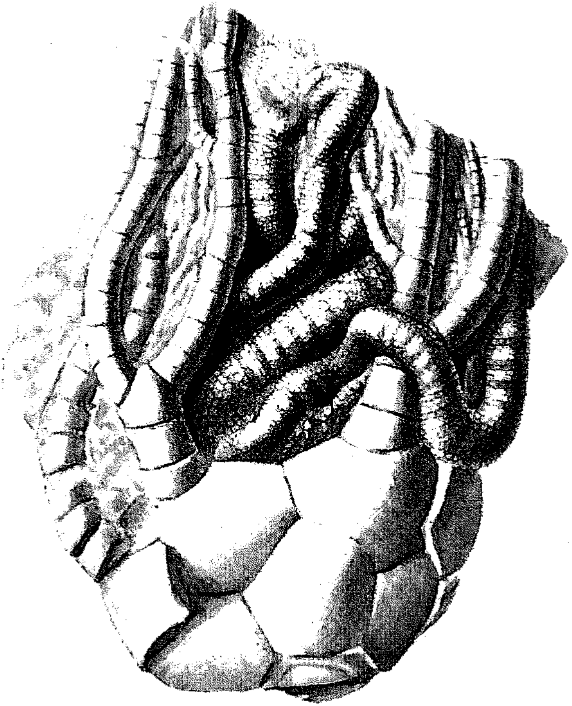

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PLATE 8

1 Clionolithes (Vioa) priscus McCoy, cast of borings in a shell of Pterinea demissa (Conrad) McCoy [after McCoy, Brit. Paleoz. Foss. pl. 1B, fig. 1, 1a]

2 The same. A series of clavate tubes in the shell substance of Leptocoelia flabellites (Conrad) all starting from the margin of the valve at a definite period of growth in the shell. x 2. Oriskany sandstone, Highland Mills, N. Y.

3 The same in a valve of Spirifer from the Chemung group near Sideling hill, Maryland. x 3

4 The same. A valve of Aviculopecten from the Chemung group (Upper Devonic) of Allegany county, N. Y. with a series of borings all beginning at a definite growth stage of the shell beyond which shell growth has continued, indicating that the mollusk was alive when the borings were begun and continued to live while they were making

5 A valve of Spirifer granulosus from the Hamilton shales of New York, with several such borings

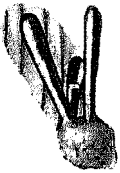
6 A tube cast in the valve of the brachiopod Leptostrophia perplana (Conrad). The sponge started to bore at the thickened cardinal process of the dorsal valve and on account of the thinness of the valve was compelled to make its tube broader than high. At the inner end the tube spreads out and shows a tendency to divide. x 3. From the Hamilton shales of New York

7 Another example of a flattened tube cast on a thin shelled pelecypod of the Hamilton group, N. Y.

8 Clavate borings in a valve of Leptostrophia oriskania, Oriskany limestone, Becraft mountain, N. Y., x 3

PLATE 8.

1



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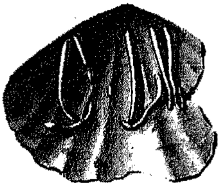

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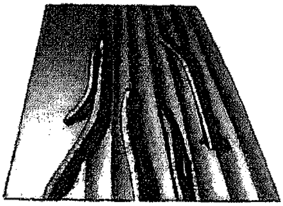

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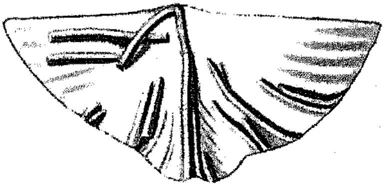

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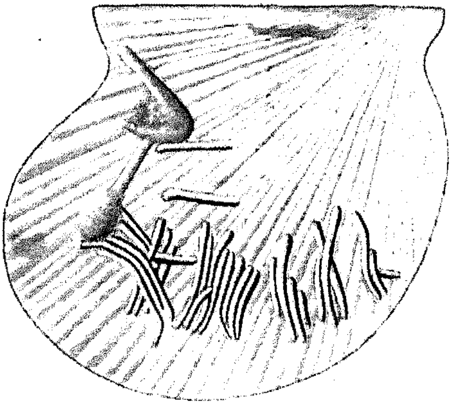

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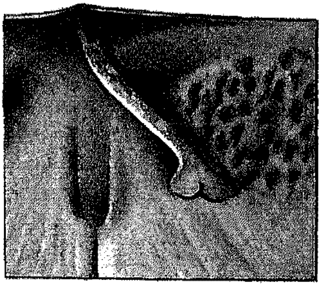

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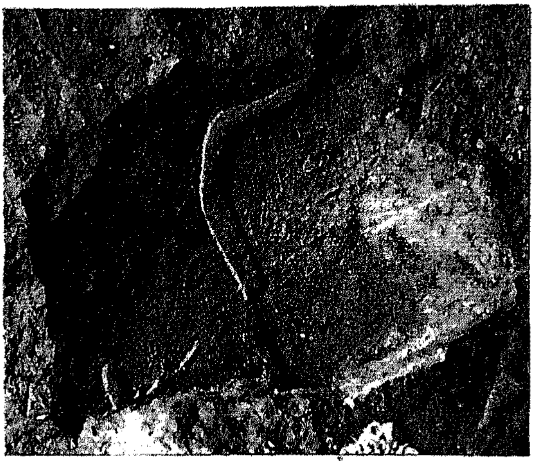

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Following p. 156

PLATE 9

1 Clionolithes priscus (McCoy). A specimen of Leptostrophia magnifica Hall, from the Grande Grève limestone (Lower Devonic) of Gaspé with several straight clavate tubes extending in from the margin of the shell. Where the shell substance has disappeared at the right of the specimen are seen numerous examples of the branched boring, Clionolithes radicans.

2 Clionolithes radicans. An etched specimen of an old shell of the brachiopod Dalmanella superstes H. & C. of the Chemung shales of New York with a multitude of irregularly branching borings riddling the shell and apparently starting inward from the shell margin. x 8

PLATE 9

1

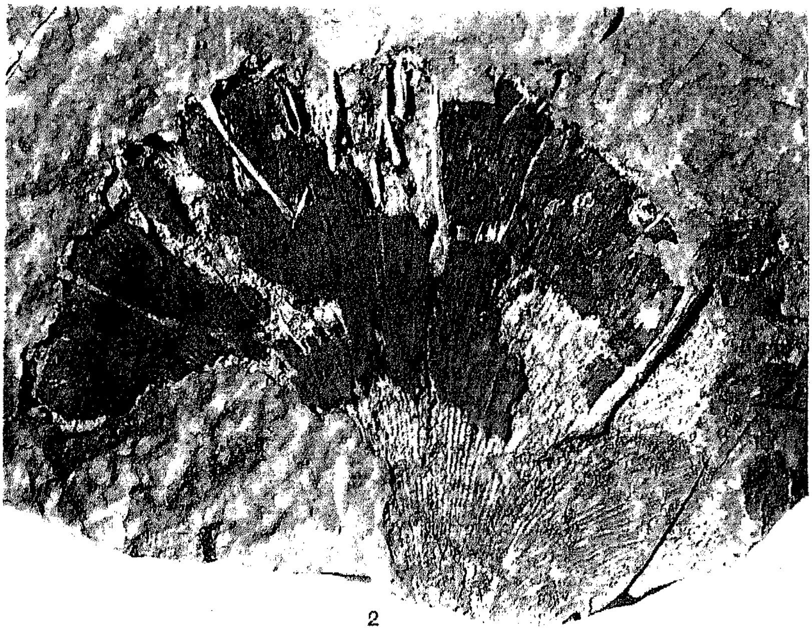

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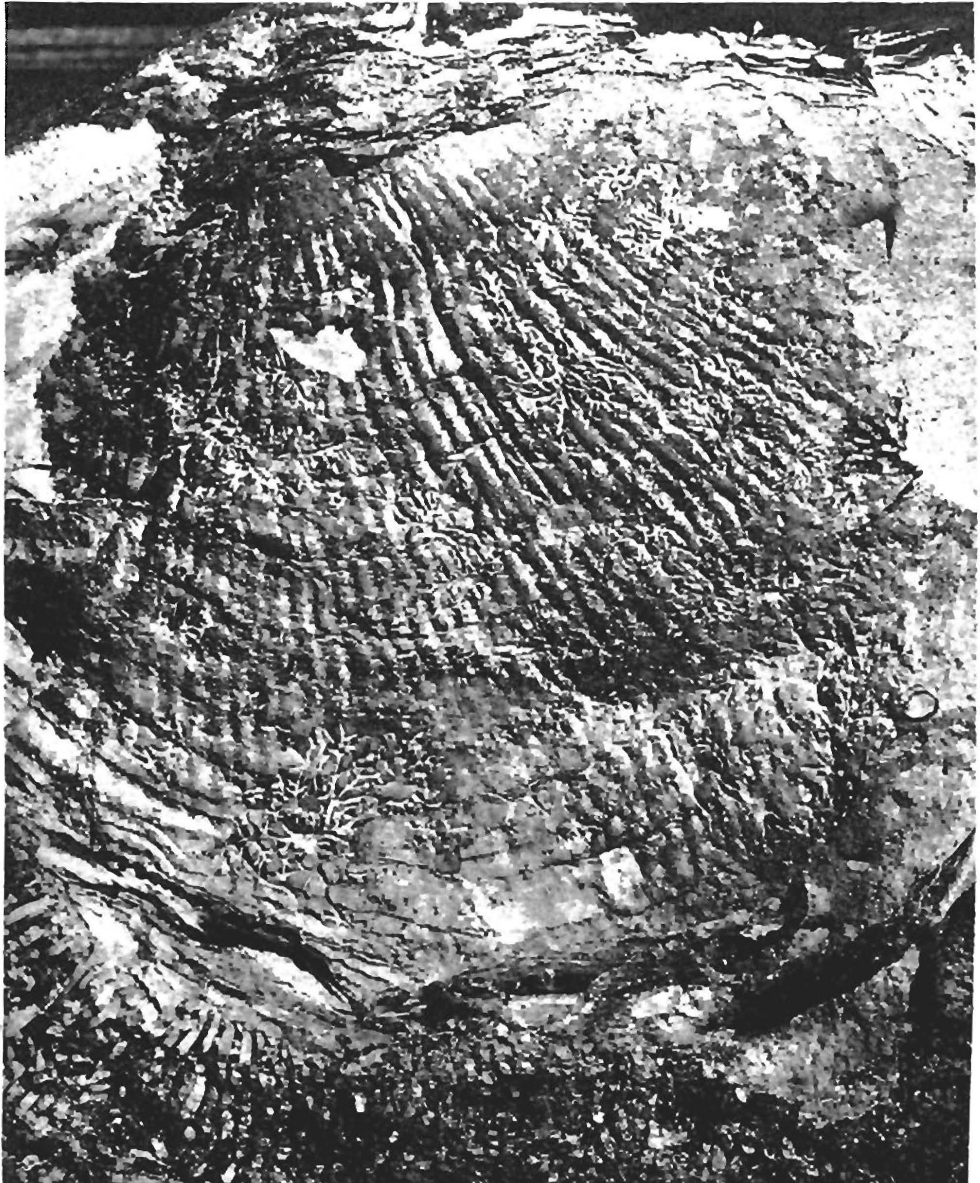
PLATE 10

A greatly enlarged view of an etched specimen of the brachiopod Atrypa reticularis Linné, whose outer surface has been overgrown with a monticuliporoid coral and whose shell substance was perforated with branching clusters of the tubes of Clionolithes radicans. From the Onondaga limestone, Becraft mountain, N. Y.

PLATE 10



following p.196

PLATE 11

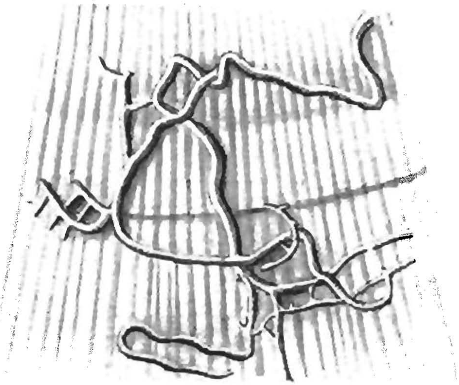
1 Clionolithes radicans, a single cluster of tube casts, x 5 in the substance of the shell of Atrypa reticularis from the Chemung sandstone of Mansfield, Pa.

2 The same. A silicified replacement of a tube cluster within the shell substance of Leptostrophia magnifica Hall, standing in relief on the surface of the valve. From an enlarged photograph, which also shows the casts of the small tubules constituting a proper part of the structure of this shell and through one of which it is probable that the sponge entered. From the Grande Grève limestone (Lower Devonic) Gaspé

3 Clinolithes reptans; sparse, diffuse tubules in the substance of a shell of Leptostrophia oriskania, Oriskany limestone, Becraft mountain, N. Y. Greatly enlarged

PLATE 11.

3



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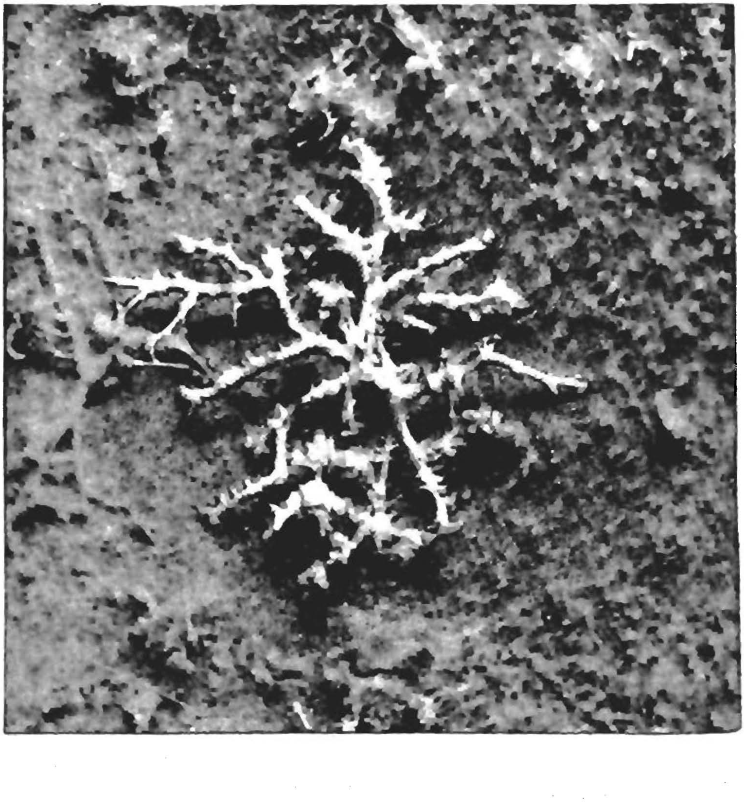

PLATE 12

1 Clionolithes palmatus. A valve of the pelecypod Loxopteria dispar Sandberger; from the Portage beds (Upper Devonic) of Correll's point, N. Y. in the substance of which this cluster of frond-shaped cavities lies. x 2

2 The same. A somewhat more diffuse cluster in the shell substance of Loxonema danai Clarke from the same formation and locality. x 5

3 Caulostrepsis taeniola. Stropheodonta cf. gigas McCoy from the Seigener schichten (Coblentzian) of Seifen. The margin of the brachiopod has been entered on all sides simultaneously by these borers forming loop-shaped tubes which are joined by a thin median cavity. Together with these are simple tube casts of Clionolithes priscus. I owe this specimen to the kindness of Prof. E. Kayser.

4 The same on Stropheodonta protaeniolata Maurer, same locality [after Maurer]

5, 6, 7 Large circular perforations in the valves of brachiopods, probably made by the radula of predatory gastropods. In figure 5 the brachiopod is Spirifer medialis Hall from the Hamilton shales of New York; figure 6, Meristella from the Oriskany limestone of Glenerie, N. Y.; and figure 7 a small Spirifer granulosus Conrad from the Hamilton rocks. In 5 and 7 the hole is on the dorsal valve and has precisely the same position with reference to the shell and the animal within which the gastropod was doubtless seeking. The hole, figure 6, has the same position on the ventral valve of Meristella. It is interesting to observe that the Spirifer in figure 5 and the Meristella in figure 6 succeeded in forestalling the purposes of the enemy by secreting a false floor beneath the hole after it had perforated the shell. Spirifer, figure 7 may have fallen a victim to the attack as the hole is not sealed. These are instructive illustrations of the early acquisition of this perforating mode of attack by the gastropods.

PLATE 12.

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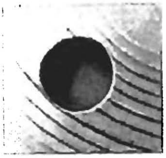

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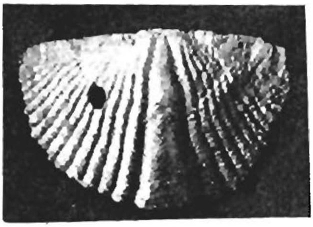


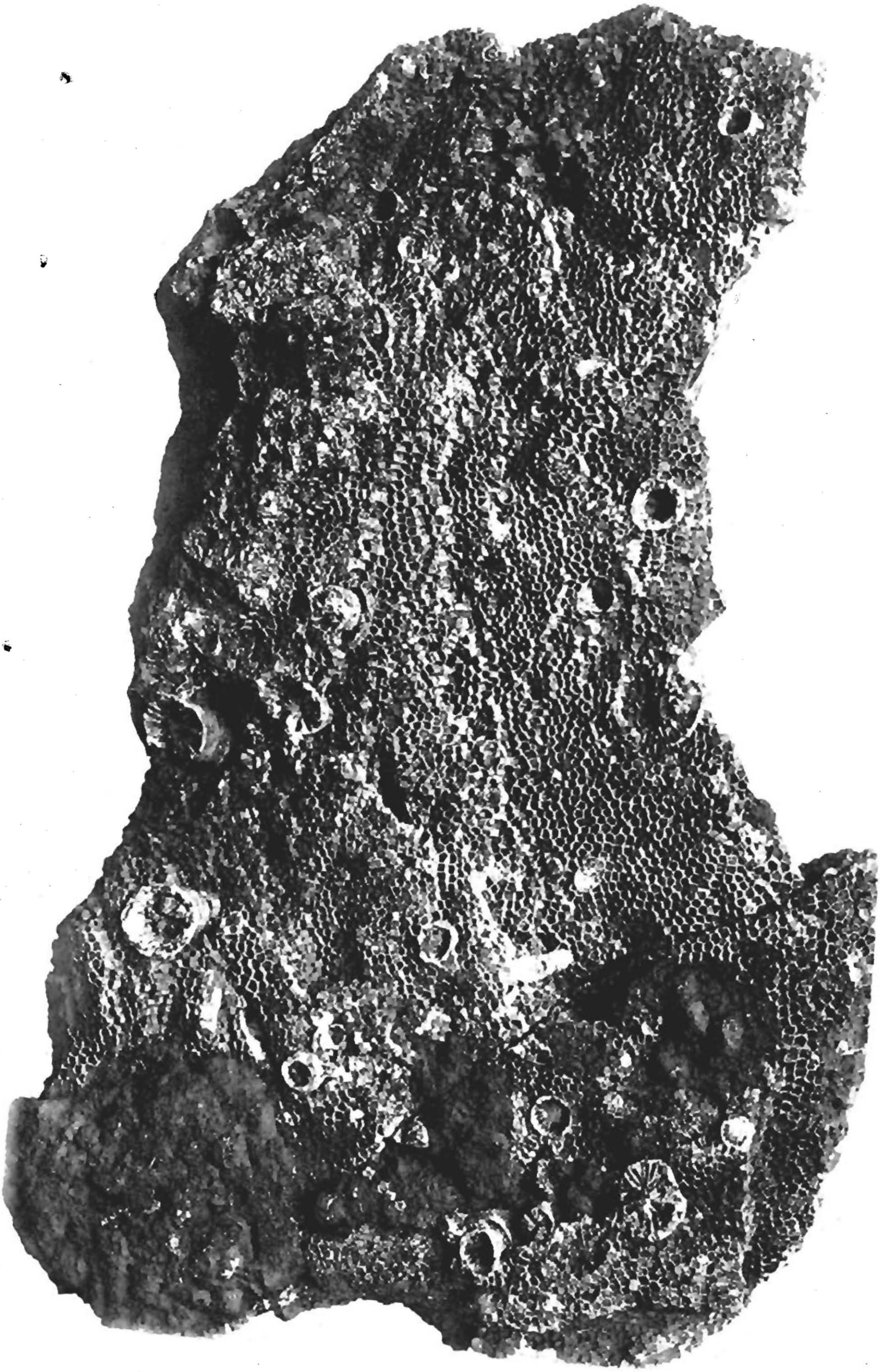
Following p. 194

PLATE 13

A colony of the coral Favosites niagarensis Hall which has partially overgrown a small plantation of the cyathophylloid coral Amplexus, but not to such extent as to interfere with the calyces of the latter

From the Niagaran formation near Monticello, Iowa. The print has been kindly loaned by Dr Samuel Calvin.

PLATE 13



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