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PRELIMINARY NOTE ON THE NATURE OF TAONURUS

BY

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ARTHROPHYCUS AND DÆDALUS OF BURROW ORIGIN*

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The conclusion reached by the writer regarding the nature of the problematic genera *Arthrophycus* Hall and *Dædalus* (Rouault) is the result of a study of *Arthrophycus alleghaniensis* (Harlan) [*A. harlani* (Conrad), *Harlania halli* Goeppert] and *Dædalus archimedes* (Ringueberg), as they occur in the outcrop of the Medina (basal Silurian), in the Genesee gorge at Rochester, N. Y.

A. alleghaniensis is known as simple or branching vermiform ridges having numerous transverse corrugations and a median longitudinal depression. The form here called *D. archimedes* occurs as rugose plates which may be flat, vertical, and roughly U- or tongue-shaped in outline, or crimped into irregular shapes, or may form inverted archimedean spirals. One of the spirals was described by Dr. Ringueberg as *Spirophyton archimedes.* In Europe the genus is known as *Vexillum*, but finding this name preoccupied, I have adopted the name *Dædalus*, which was used by Rouault, the founder of the genus *Vexillum*, for some forms which he at first regarded as generically distinct from it.

Arthrophycus has been considered as the cast of a seaweed, a worm, the trail of various animals, branched passages, and as the result of purely mechanical forces. Its appearance has even suggested the arms of an ophiuroid. *Dædalus* has been considered as a seaweed, a sponge, and as the result of mechanical forces, for example, eddying water and rills.

The writer finds that *Arthrophycus* has a structure very similar to that of *Dædalus*, and has concluded that both are the result of the burrowing of animals.

*This is an abstract of a paper forming part of a thesis accepted by the faculty of Yale Graduate School for the degree of Doctor of Philosophy. It was read before Section E of the American Association for the Advancement of Science, at Syracuse, July 21, 1905. The published paper will be fully illustrated.

In the Genesee gorge, *D. archimedes* occurs through the upper 30 feet of the Medina ; *A. alleghaniensis* is restricted to the lower 14 feet of this zone. The rock is a sandstone. The upper portion is argillaceous and homogeneous. The bedding planes are not pro-

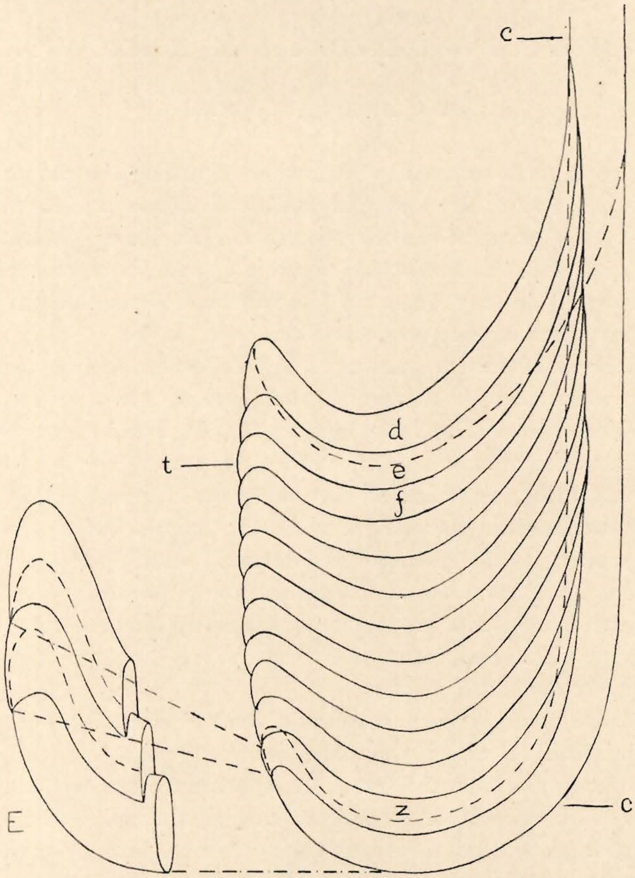

Fig. 1.—Diagram showing the general mode of formation of *Dædalus*.
The upper dotted line represents the lower side of the burrow in its first position ; the lower dotted line, the upper side of the cylinder, or burrow, in its last position ; *d*, *e*, *z*, the strips, or packings made as the burrow was shifted ; *t*, the thin edge ; E, lower portion of the last two packings and the cylinder, enlarged, showing the caplike terminations of the strips, one fitting up into another and the last ensheathing the end of the cylinder.

nounced and weathering carries the ledge back with an even face. In the lower portion, the rock is purer sandstone and the layers are separated by seams of shale which are more or less arenaceous. This portion exhibits such features as bars, cross-lamination, oblique layering, current-crests, current-channels, erosional, ripple-marked, and

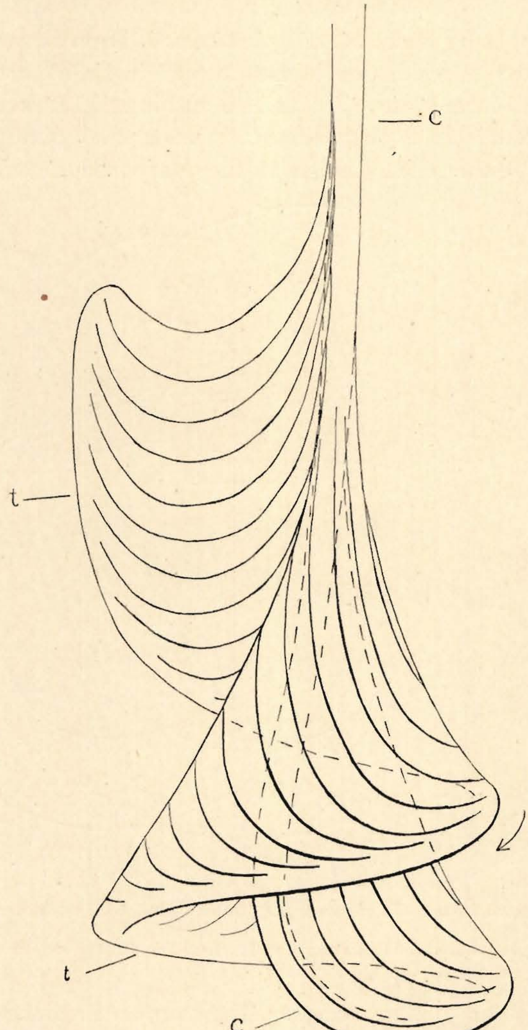

Fig. 2.—Diagram showing gradation from the vertical form of *Dædalus* to the spiral. *c*, cylinder; *t*, thin edge.

sun-cracked surfaces, and occasionally surfaces covered with brecciated matter or rolled balls of clay, indicating shallow water of fluctuating depth, in which the conditions were probably virtually estuarine. Remains of the characteristic life of the Paleozoic are completely absent.

The ridges by which *A. alleghaniensis* is known are found on the under surface of sandstone layers resting in shaly partings. They vary in width from $\frac{1}{16}$ to $\frac{3}{4}$ of an inch and in relief from almost nothing to as much as 2 or 3 inches. Usually they disappear into the sandstone at either end. In length they vary from an average of 5 or

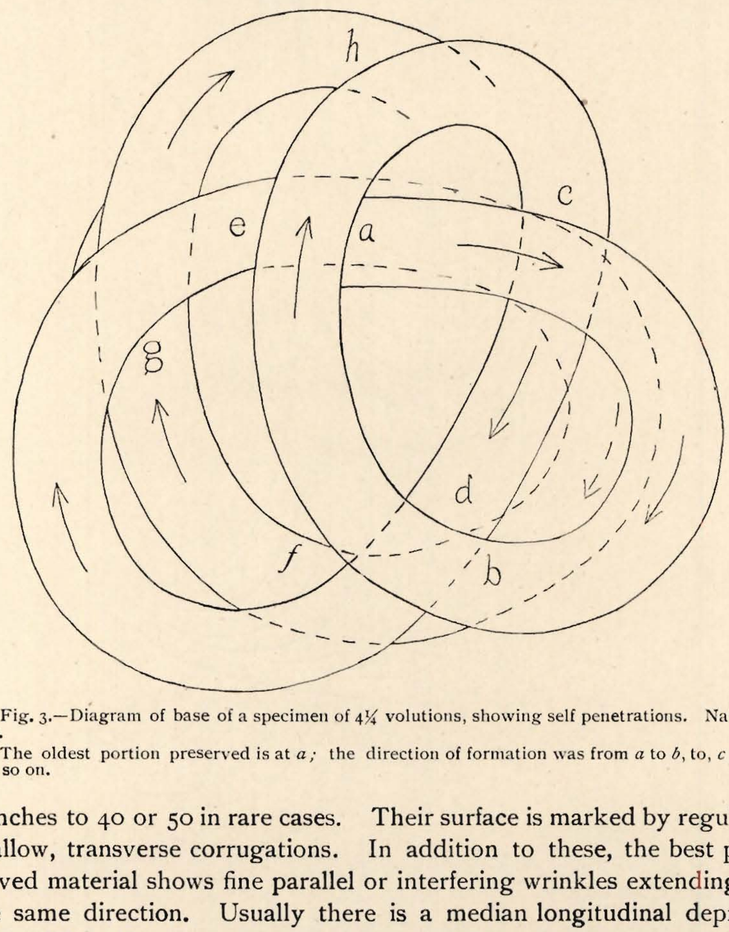

Fig. 3.—Diagram of base of a specimen of 4¼ volutions, showing self penetrations. Natural size.

The oldest portion preserved is at *a*; the direction of formation was from *a* to *b*, to, *c* to *d*, and so on.

6 inches to 40 or 50 in rare cases. Their surface is marked by regular, shallow, transverse corrugations. In addition to these, the best preserved material shows fine parallel or interfering wrinkles extending in the same direction. Usually there is a median longitudinal depression. The ridges cross and cut one another at every conceivable angle, sometimes forming flabellations.

When ridges in higher relief are examined from the side the edges of many closely appressed curved elements may be seen bearing traces of the same transverse corrugations as the base and ascending obliquely from it. Sometimes these elements can be traced some distance into the sandstone. In well weathered specimens they are found to be distinct and separable, lunate in section, the under side the convex, and generally bearing the transverse corrugations and longitudinal groove. They usually appear as branches from the upper side of the basal ridge. This ridge, however, is not a one-piece cast, but is formed of the overlapping lower ends of the elements as they thin out successively. In many instances the elements do not lie regularly one above the other, but a little to one side, so that two or

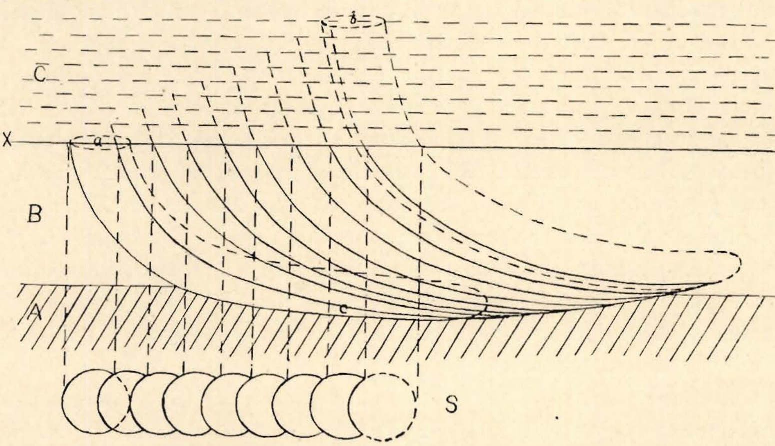

Fig. 4—Diagram showing the general mode of formation in *Arthrophycus*.
A, clay stratum; B, layer of sand in which burrowing began; C, sand deposited while the burrow was occupied. In this, the structure is more or less completely obliterated, probably because of the less stable nature of the sand near the surface, *a* and *b*, first and last positions of the burrow. The curving lines between indicate the edges of the strips, or packings, made as the burrow was shifted. S, transverse section along the line XY, showing the form and arrangement of the packings and their relation to the burrow; *c*, ridge on the under surface of a sandy layer, formed when the burrow penetrates an underlying clay stratum.

more may be at almost the same level, thus producing a thickening. Again, the displacement may be so pronounced toward the upper end as to produce flaring fascicles. These structures are found as frequently in the sandstone as projecting on its under surface. The upper parts are very rarely preserved and then, but poorly.

Frequently the study of these compound structures is complicated by their cutting through one another. Sometimes the cuttings take place in such a way that the ridges made by the bases appear to branch, and it is not unusual to find a number of them closely approximated and radiating from their intercepting ends. The casts can be separated, showing one continuous through the other. The cuttings afford the means of determining the relative ages of the structures, for the one cut had to exist before the other could cut it.

D. archimedes occurs in the sandstone and sometimes in the more arenaceous partings. The flat forms stand vertically in the rock, the rounded end down (see Figure 1). They are frequently 12 to 14 inches in depth, and at the same time rarely exceed 4 inches in breadth and ½ inch in thickness. Both faces are crossed by a series of sagging ridges ascending higher at one end than the other. The edge at which the upper ends terminate is the thicker. The ridges are the edges of curved strips, lunate in section, which saddle one upon the other. At their upper ends they thin out and lap upon a marginal cylinder so as to partially enclose it. The cylinder extends around the base, terminating in a blunt point at the thin edge. At this edge the end of each strip forms a conical cap which partially ensheathes the one beneath, the lowest capping the tip of the cylinder. In many specimens traces of corrugations like those of *Arthrophycus* occur upon the cylinder and the edges of the strips. Sometimes they are so well defined as to impart a crenulated appearance to the surface of the plate. They do not, however, occur upon the contiguous surfaces. Where a base projects into an underlying shale, it may show even the fine wrinkles.

Although many of the plates are practically flat, others are crimped and contorted into an infinite variety of shapes. Many specimens which are flat in the upper portion, have in the lower, the form of an inverted archimedean spiral (see Figure 2), either dextral or sinistral, each volution having from the side the appearance of an oblique cone with its apex in the cavity of the one above. The margin of the spiral is formed by the thin edge. At the base the cylinder appears as the continuation of this edge, rounds upward, and passes through the center of the structure. The curving strips, which in the flat plates have a general transverse direction, turn upward from the margin.

As in *Arthrophycus*, penetration of one structure by another is of constant occurrence. In the spirals the cutting of one portion by another portion is also very common. One specimen preserving 4¼ volutions in nearly the same plane, cuts itself 9 times. Several of these cuttings are represented in Figure 3 of its base.

The self-penetrations by giving the relative ages of different parts of the spirals, enable us to determine the direction of formation in *Dædalus.* Examination of specimens showing such cuttings establishes the cylinder as the terminal element and shows the direction to be a general downward one. In the flat plates the descent is direct, but in the flexuous and spiral forms it is more or less gradual or there may be none.

The cylinder is always present, but the number of component strips varies with the length. If we should in imagination trace the development of a plate back to its beginning, we should expect a continually lessening number of strips as it became shorter and shorter, until at last only the cylinder would remain. Such isolated cylinders are found. They are roughly J-shaped and at the lower end taper to a blunt point. The corrugations are limited to the under half of the surface.

In *Arthrophycus*, the direction of formation was just the reverse of that of *Dædalus*, and the last strip fitted to an overlying cylinder. Isolated cylinders having a more open curvature than those referred to *Dædalus* are sometimes associated with them.

The clue to the nature of *Arthrophycus* and *Dædalus* is given by the penetrations. They show that these objects were not organisms. The structures or portions of structures cut were in all cases casts. The spirals which penetrate themselves were already casts as far down at least as the point of penetration, while still in process of formation. Casts, of course, could exist only in the sediment.

In my opinion the isolated cylinders are the casts of simple burrows. The plates of *Dædalus* were formed by repeated packings of sediment in the upper side of the lower portion of a J-shaped burrow while it was being shifted. Each of the curved lamellæ represents a packing. The cylinder represents the burrow in its final position (see Diagram 1). The packings were made largely in disposing of sediment sifted into the burrow by tidal currents and other agencies. The direction which the shifting took adjusted the length of the burrow to the growth of the occupant. The most rapid increase in length was effected by the direct descent seen in the flat plates. The lateral shifting which generated the flexuous plates, and when uniform in direction, the spirals, became less and less effective in lengthening the burrow as the rate of descent diminished. For example, in one specimen collected, in which there are between 8 and 9 volutions and probably in the neighborhood of 800 packings, the descent is only 3½ inches. The directness of descent was undoubtedly affected to some degree by the conditions at the surface. If denudation was going on, the destruction of the upper portion of the burrow would need to be offset; if on the other hand, sediment was accumulating over the spot, the aperture would be raised and the rate of descent would be retarded according to the rapidity of deposition. Variations in the factors governing the direction of shifting resulted in the formation of plates which are flat in one portion and flexuous or spiral in another. Deviations in the direction often led to the burrow's cutting through some portion of the earlier packings which it could do just as it could through the surrounding sediment or a neighboring cast.

In *Arthrophycus* the insifting sediment, instead of being packed against the upper side of the lower portion of the burrow, appears to have been distributed along the entire under side, thus producing a progressive shifting of the whole burrow (see Figure 4).

With each shifting the lower end was extended, and this tended to keep the burrow at about the same depth and inclination; it maintained the length or increased it, the amount needed, as in *Dædalus*, depending upon the amount of sedimentation. In many cases the animal is seen to have shifted laterally, first one way then the other. From the flabellations it appears that it sometimes drew out from a burrow and made a new one beside it; for usually the cuttings show that the different series of packings comprising a flabellation were formed successively from one side of the group to the other.

The packings in *Arthrophycus* and *Dædalus* were probably made by pressure exerted by the animal's body. From their distinctness it seems likely that they were separated by some secretion, like a film of tenacious, quick-hardening mucus, added to make the material packed more cohesive. By the same pressure by which the creature compacted the insifting material on one side, it crowded itself into the sediment on the other. When this was silt, it took an impression of the minutest details of the body.

The animals which formed these burrows were probably sedentary Polychæta.

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PRELIMINARY NOTE ON THE NATURE OF TAONURUS.

BY CLIFTON J. SARLE.

Read before the Academy December 11, 1905.

Among problematic genera probably none has aroused more general interest and discussion than *Taonurus*. This genus was created in 1858 by Fischer-Ooster for fossils from the Flysch of Switzerland. To it are referable the fossils known under the names *Spirophyton* Hall, *Alectorurus* Schimper, *Physophycus* Schimp., *Cancellophycus* Saporta, and *Glossophycus* Saporta and Marion. It should also include some of the forms placed under *Taonichnites* (*Medusichnites*) Matthew, as well as those under the older genus *Zoophycos* Massalongo which do not agree with the type species *Z. caput-medusæ* in being cespitose.

As thus comprehended, *Taonurus* ranges from early Cambrian to late Tertiary and appears to be world-wide in its occurrence. It is found in both shallow and deep water deposits. Often it is so abundant as literally to make up great thicknesses of strata which may otherwise be practically barren.

The prevailing opinion among writers regarding the nature of *Taonurus* has been that it is a plant, the majority referring it to the algae, a few to the aquatic hepaticæ. It has also been regarded as an anthozoan, as the coprolite of a mud-eating animal, possibly of a holothurian, and as a mere surface marking produced by the tentacles of some creature. Other views are that it is of purely mechanical origin, produced by running or swirling water and by forces acting during or after solidification of the beds. One writer is of the opinion that different forms may have originated in different ways, namely, by the action of swirling water, by the action of waves upon attached plants, and by the movements of worms upon the surface of the sediment. Another has advanced the view, first, that it was formed by the filling of a system of branched passages, later, that it represents a spiral cavity, which he is inclined to think served as a repository for eggs rather than as a dwelling. In this connection he points out a resemblance between the form of *Taonurus* and that of the spirally enrolled spawn bands of certain gastropods. More recently he has attempted to show by experiments in blowing through a slender tube upon fluid clay, that structures analogous to *Taonurus* might be produced by various physiological movements.

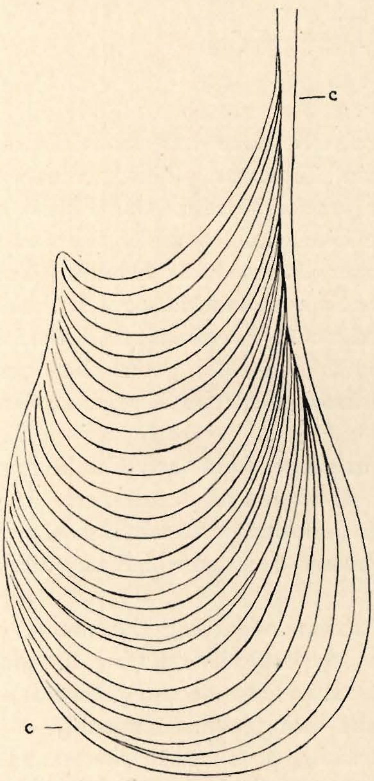

Fig. 1.—U-shaped form of *Taonurus*; *c*, cylinder.

The explanation of the nature of *Taonurus*, presented here in brief, was suggested in a recent study of *Dædalus* (Rouault)* by the general resemblance of *Taonurus* to that form. The material upon which this explanation is based is from the Esopus and Hamilton formations of the middle Devonian in New York. In collecting it special pains were taken to note the position of the fossil in the beds.

Taonurus may be described as thin plates occurring nearly horizontally in the rock, from which they are frequently separable. These may be roughly U-shaped or suboval in outline (see Figure 1) or irregularly lobate, or may form inverted archimedean spirals, either dextral or sinistral, in which the successive volutions increase in size downward (see Figure 2). An individual volution has the appearance of a flat cone with the apex directed upward. Many of the spirals are more or less lobed in outline. Both faces of these plates are marked by a series of curving lines or ridges. In the U-shaped

* "*Arthrophycus* and *Dædalus* of Burrow Origin"; Proc. Rochester Acad. of Sci. vol. 4; 1906, pp. 203-210.

or oval plates, beginning at one side they cross with a curvature nearly the same as that of the base and ascend along the other. The edge of the plate is formed by a narrow border, usually flat, but sometimes in better preserved specimens, distinctly cylindric. In the spirals the ridges radiate outward from the apex in sickle-shaped curves to meet the margin at a low angle, recalling the lines of sparks given off from a pin-wheel. In many spirals, however, at the upper end of the top volution, they are arranged in such a way as to suggest the form and appearance of one of the U-shaped plates. The free edge of the spiral is formed by the marginal cylinder, which at the base of the structure rounds in and upward and passes through the center. In some well-weathered specimens preserved in sandstone, the curved ridges are seen to be the edges of strips which are

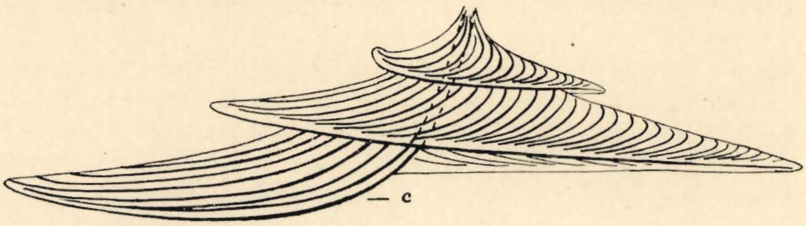

Fig. 2.—Spiral form of *Taonurus*; *c*, cylinder.

lunate in section and saddle one upon the other, the last of the series partially enclosing the cylinder.

Frequently these structures are found passing through others, or one part of a spiral may pass through another part. These penetrations could not have occurred had these structures been organic. The self-penetrations are always the cutting of an upper volution by a lower. This indicates downward formation. It also shows that these structures originated in the sediment, for the portions cut were casts, and as such could exist only in the sediment.

As intimated above the key to the nature of *Taonurus* was given by a study of *Dædalus*. That genus comprises simple J-shaped cylinders and U-shaped, irregularly flexed, and spiral plates, much thicker than those of *Taonurus* (see Figures 1 and 2, pages 204, 205 of this volume.) The U-shaped plates stand vertically in the rock instead of reclining, and the volutions of the spirals generally form acute cones, instead of depressed, and are practically uniform in size in the same spiral. These plates have essentially the same structure seen in *Taonurus*,—a series of curved lamellæ, lunate in section, and a marginal cylinder. They also penetrate one another and themselves, and like it were formed downward. A comparison of the two genera makes unavoidable the conclusion that they originated in the same way, that is, that *Taonurus* like *Dædalus* was formed by successive packings of sediment along the radial side of a curved burrow which was shifted with each packing, the aperture as a rule remaining stationary. The packings are represented by the lamellæ, the burrow by the marginal cylinder. The distal end of the cylinder was formed by successive fillings in the blind end of the burrow, the ascending portion, by the filling finally of the burrow itself. The burrow extended nearly horizontally in the sediment instead of nearly vertically, as in *Dædalus*. When the packing was principally in the lower portion, an elongated plate, U-shaped in outline was formed, the burrow gradually lengthening with each shifting. When the material was distributed along the side of the burrow for the greater part of its length, the displacement became lateral as well as longitudinal and resulted in the formation of a spiral plate of increasing dimensions, the burrow rounding in at the base being the generatrix of the volutions and axis of the structure. Variations in the way in which the sediment was disposed of produced corresponding variations in outline. Sometimes in the spirals the deviations in direction led to the burrow's passing through some portion of its former path, producing the self-penetrations described.

It seems likely, as in *Dædalus*, that the animal which produced these structures was a sedentary polychætous annelid.

Dictyodora liebeana Weiss, which has been compared to, *Taonurus* (*Spirophyton*) and *Dædalus*, is probably of the same nature as these.

The forms included under *Taonurus* by Saporta and others, and now recognized as belonging to the genus *Rhizocorallium* Zenker (*Glossifungites* Lomnicki), were produced by the packing of sediment along the radial side of a reclining U-shaped burrow of two openings, as it was repeatedly shifted and lengthened. The species described as *Arenicolites duplex* Williams was produced in the same way, instead of by the filling of grooves in the surface of the mud.