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SOME NEW TINTINNIDAE FROM THE PLANKTON OF THE SAN DIEGO REGION

(From the San Diego Marine Biological Laboratory of the University of California.)

BY

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The following Ciliates belonging to the family *Tintinnidae* have occurred in the collections made at the San Diego Marine Biological Laboratory in 1903-1905. They appear to be as yet undescribed and are of considerable interest in several instances owing to the highly specialized nature of the external shells or loricae which these simple unicellular animals have formed in adaptation to a pelagic life.

I am indebted to Mr. R. D. Williams and Mr. John F. Bovard, assistants at the San Diego Laboratory, for some of the observations recorded and several of the sketches utilized in this paper.

Tintinnus serratus sp. nov.

Pl. XXVI. Fig. 1.

The lorica of this species is tubular, with slightly flaring ends. Its length is about twelve times its least diameter which is near the aboral end. It gradually enlarges anteriorly, attaining just behind the anterior flare a diameter one and one half times that in front of the posterior flare. Both ends are open, the diameter of the aboral aperture being three-fifths of the oral. Within a short distance of each the wall of the lorica flares gradually in a regular curve, approximately 30° from the axis, increasing the diameter about 20%. The aboral margin is perfectly smooth but the oral is deeply and regularly incised, forming a serrate margin of twenty erect, acute teeth.

The wall is unusually thin and hyaline even for this thin-walled genus and shows only the faintest traces of structure.

The animal has not been found in the lorica.

The number of adoral ciliary plates in the genus Tintinnus is stated by Daday ('87) to be 18-20. There are 20 circumoral teeth in the lorica of this species, a fact which indicates that there is some correlation between the structure of the adoral apparatus and the formation of the serrate oral margin of the lorica.

This species belongs to the form-cycle of *T. fraknoi* Daday, differing from it in the possession of the serrated circumoral margin of the lorica, and in attaining less than one half its size. As figured by Daday ('87) the ends in *T. fraknoi* flare more gradually and are less differentiated than in *T. serratus.* In the Pacific plankton, however, I find that *T. fraknoi* generally has the flare better developed than it is in Daday's figures of the species from the Mediterranean.

Dimensions:—Length, 150 μ; diameter inside of flare, anteriorly 18 μ, posteriorly 12 μ; of oral opening, 25 μ; of aboral, 15 μ; length of teeth, 4 μ.

Taken in the plankton at the surface inside the kelp belt off San Diego in June. The structure of the lorica indicates a eupelagic distribution.

Tintinnopsis reflexa sp. nov.

Pl. XXVI. Fig. 2.

The lorica of this organism is cylindrical, finger-shaped, its length two and one-half times its diameter, with rounded fundus and reflexed oral rim. The sides are straight and at the mouth the wall is reflexed, forming a broadly rounded oral perimeter, and continues aborally parallel to and outside of the cylinder for one-tenth of its length, terminating in a smooth unmodified edge. The wall is thin, translucent and has the primary reticulations described by Biedermann ('93) and Brandt ('96) but no secondary fenestration. The outer surface of the wall is sparsely strewn with numerous, small, irregular particles of a more highly refractive character than its own structure.

The animal has the form and structure usual in *Tintinnopsis.* There are two ellipsoidal nuclei centrally located and in the posterior end a single vacuole whose diameter at diastole equals half that of the lorica.

A reflexed oral margin is not found in any other species of *Tintinnidae.* The nearest approach to it appears in the flaring rims of such species as *Amphorella steenstrupi, A. acuta, Petalotricha ampulla, Tintinnopsis mortenseni, T. bütschlii,* and *T. campanula.* In none of these forms has this flaring rim much greater relative proportions than has the reflexed rim of *Tintinnopsis reflexa.* An exception to this limitation in extent appears to be presented in the problematical organism described by Cleve ('99) as *Fungella arctica* and referred by him to the *Tintinnidae.* The significance of this limitation in proportions lies, it seems, in the dependence of this projecting portion of the shell upon the *length of the cilia and intercalary cirri of the adoral ciliary plates.* In *T. reflexa* the distal edge of the lorica is located approximately at the line where the ends of the cirri of the adoral plates would fall when reflexed.

The general form of the lorica of this species approaches most nearly to that of *T. nitida,* described by Brandt ('96) from Karajak-Fjord in Greenland waters. It differs, however, from this species in the posterior reflexion of its more extended rim, in the minuteness and sparseness of the attached particles and in its smaller size.

Dimensions:—Length, 50 μ; diameter, 20 μ.

Taken in a vertical haul from 70 fathoms to surface off San Diego in July. The structure of the shell is indicative of a eupelagic distribution.

Tintinnopsis dadayi sp. nov.

Pl. XXVI. Figs. 3-5.

Lorica campanulate with expanded fundus, spreading margin and cylindrical central portion. Its length from apex to primary oral rim is 2 to 2.5 times its central diameter, 1.3 to 1.8

times that of the fundus and 1.1 to 1.35 times that of the oral margin. In some individuals the lorica is continued beyond the primary oral rim by a cylindrical extension whose diameter is the same as that of the body behind the oral rim as seen in Pl. XXVI, Figs. 4 and 5. A secondary oral rim may appear on the cylindrical extension. No trace of annulation was found in the lorica.

The wall of the lorica is formed by a single hyaline lamella to whose outer surface numerous highly refractive angular particles adhere.

This species is most nearly related to *T. bütschlii* Daday but differs from it in its smaller size, in the absence of annulations, in the more sharply differentiated and sometimes repeated oral rim and in the swollen fundus.

Dimensions.—Length, 80-108 μ; diameter of fundus, 55-65 μ, of the cylindrical part, 40-48 μ, of the oral rim 60-80 μ.

This species was taken frequently in the summer months in shoal waters near shore and evidently belongs to the coastal plankton.

Cyttarocylis quadridens sp. nov.

Pl. XXVII, Figs. 8-11. Pl. XXVIII, Fig. 18.

The lorica is elongated, vase-shaped, tapering abruptly one-third of the distance from the aboral end to a slender attenuately pointed pedicel which bears in its aboral half an expansion armed with four more or less salient tooth-like projections. The oral opening is about one-fifth of the total length in diameter, is squarely truncate, with a thick, very slightly flaring rim. From the mouth the body of the lorica tapers slightly to the sloping shoulders which contract to the slender sub-cylindrical pedicel whose greatest diameter is about one-sixth that of the mouth. The pedicel tapers gradually to about one-half its initial diameter and then spreads into a quadrangular skirt-like expansion which bears the four posteriorly spreading spines on its angles. The diagonal width is here about equal to the initial diameter of the pedicel. From the recessed posterior face of this expansion arises an attenuate terminal spine. The cavity of the lorica is constricted abruptly in the expanded region of the pedicel and is continued as a slender tube nearly to the tip of the terminal spine.

The wall of the lorica is relatively thick, especially toward the oral margin where it measures 5 μ. It grows slightly thinner posteriorly especially in the expanded region of the pedicel and the terminal spine, where it measures only 2-3 μ in thickness.

The wall is composed of minute subregular prisms mainly hexagonal with occasional pentagonal or irregular ones, placed so that their ends form the inner and outer surfaces of the lorica. Their sides form the coarse subregular hexagonal meshwork which Brandt ('96) has designated as the secondary reticulum. The slightly rounded ends of the prisms form the whole, or at least a part, of the inner and outer lamellae of the wall. Under high magnification (Pl. XXVIII. Fig. 18) the outer lamella exhibits a very minute faint reticulation which Brandt has called the primary one. The diameter of the meshes of this primary reticulum is less than 1 μ, and that of the secondary about 5 μ. In the pedicel the secondary reticulum becomes indistinct and on the expansion and terminal spine it disappears altogether, apparently as a result of the greater thickness in the walls of the prisms.

Well preserved specimens of the inhabitant have not been observed within the lorica, though moribund individuals have been found there in a few instances.

This species varies considerably in the prominence and angle of divergence of the four salient spines on the pedicel and in the length of the terminal spine. The four spines are usually symmetrical with respect to each other but instances of asymmetry are occasionally seen (Pl. XXVII. Fig. 9). It belongs unquestionably to the form-cycle of *Cyttarocylis treforti*, described by Daday ('87) from Naples, which, however, has two lateral apophyses in place of a quadrangular expansion of the pedicel. Similar lateral apophyses also occur on the spirally striate form described by Cleve ('99*a*) as *C. hebe* var. *apophysata*. *C. treforti* occurs occasionally in the plankton of the Pacific off San Diego, but it does not appear to intergrade with the form here described as *C. quadridens*.

Observations on the method of formation of the lorica in *Cyttarocylis* are not to be found in literature and I have been unable to keep this species alive for prolonged examination in a microaquarium. It seems probable from the form of the lorica that this is built up from the terminal spine anteriorly, and that the quadrangular expansion on the pedicel with its four spines may in some way result from the presence of the four spiral lines of cilia on the body of the animal which pass from the adoral circlet toward the posterior end. They would form the natural lines of transit of substances gathered by the adoral circlet or extruded from the body and utilized in the formation of the lorica. The posterior ends of these lines of cilia may be regions where the shell-forming substances gather in the form of this quadrangular expansion with its more or less prominent spines. Anterior to this region the spiral course of the cilia and the greater freedom of movement on the part of the body of the animal would tend to facilitate the more regular distribution of the material and to bring about a transition from the quadrangular to the circular cross section of the shell.

Dimensions.—Total length, 430-450 μ; diameter of oral end, 90-100 μ; length of terminal spine, 35-50 μ; diagonal diameter at the expanded region of the pedicel, 12-18 μ.

This species is found generally, though rarely in large numbers, in the summer plankton of the Pacific off San Diego. It has been taken in vertical hauls from 185-35 fathoms to the surface very generally, and less frequently in surface catches. It appears to be a eupelagic species.

Cyttarocylis pulchra sp. nov.

Pl. XXVIII. Figs. 19-23.

This differs from the preceding in its proportions, in the possession of one to three rings about the anterior part of the lorica and in its very stout pedicel with a four-sided posterior portion. The lorica is vase-shaped, being cylindrical in its anterior third with a very slightly flaring mouth whose lip diminishes to a sharp edge. This section of the lorica bears one, or two, but more generally three external annulations which result from a symmetrical increase of the wall to from 2 to 2.5 times its thickness in adjacent regions. The anterior ring is about one-fourth of the diameter of the mouth behind the rim, the second ring three-fourths, and the third a little less than five-fourths. The second and third are thus slightly nearer together than the first and second. The total length of the lorica is seven times its diameter between the rings and five times that on the rings.

The lorica tapers very gradually near its middle to the stout pedicel which with its terminal spine forms the posterior half of the total length. This pedicel is about one-third of the diameter of the anterior part measured between the rings, and changes in the posterior third of its length from a cylinder to a rectangular prism from whose flaring end arises the stout terminal spine. The four angles of the pedicel are carried out (on the skirt-like expansion) in projecting points like those of *C. quadridens* and in addition one similar point is intercalated on each margin of the overhanging ledge midway between the two corners of each face. The width of the faces is about one-fourth the diameter of the mouth of the lorica.

The cylindrical spine projects from the center of the recessed region at the base of the pedicel and ends in an acute tip. Its length is nearly one-half the diameter of the mouth, and its diameter less than one-fifth of its own length.

The cavity of the lorica conforms to the external contour with the exception that there are only very slight annular expansions beneath the rings, and that in the prismatic portion of the pedicel the lumen contracts suddenly to a slender canal which extends as a straight tube nearly to the end of the terminal spine.

The structure of the lorica is essentially similar to that of *C. quadridens.* It is composed of similar elements having a similar arrangement in all parts but the rings. In *C. quadridens* the wall is everywhere composed of a single layer of prisms but in *C. pulchra* the rings, as shown in Pl. XXVIII, Fig. 20, are formed by 2-3 layers of prismatic elements, which pass over into the single layer on either side. In the quadrangular section of the pedicel the prisms which are thin-walled elsewhere become very thick-walled so that their central cavities are almost obliterated, giving a pitted appearance to the wall in this region. This wall is, as before stated, much thickened, but I have found only a single layer of prisms in it. It has a yellowish brown color which is in strong contrast with the hyaline character of the rest of the lorica. The presence of rings on the lorica of this species and the occurrence of loricae having only one or two rings raises an interesting question as to the method and significance of their formation. It seems probable that there occurs during the period of lorica formation a temporary suspension in the factors leading to its elongation without concurrent diminution in the supply of the materials from which the hexagonal prisms are formed, resulting in a local aggregation of the prisms in a ring. This process may, it seems, occur two or three times and at an approximately uniform interval. The structure in these particulars is probably correlated with some phase of activity of profound importance in the animal's economy which is subject to rhythmic repetition. Naturally the suggestion arises that division or possibly conjugation may afford the basis on which these features of shell structure rest. Observations on this point are lacking because of the great difficulty of keeping these most delicate pelagic organisms under laboratory conditions.

The animal has not been seen in a normal condition. Moribund individuals have three or more ellipsoidal nuclei.

Dimensions.—Total length, 405 μ; diameter of oral end, 70 μ; length of terminal spine, 35 μ; width of face of pedicel, 20 μ; diameter of rings 82 μ; thickness of wall, 6-8 μ; diameter of prisms, 2-4 μ.

This species has been found generally in the plankton of the Pacific off San Diego at all seasons of the year but more frequently in the summer. It is never very common and is more frequent in vertical catches than in those taken at the surface. It appears to be a eupelagic species.

Cyttarocylis torta sp. nov.

Pl. XXVII, Figs. 12-15. Pl. XXVIII, Figs. 16, 17.

This species has many points in common with the preceding. In proportions and form of the lorica, the relations of cylindrical portion and pedicel, and in the form of the expansion and terminal spine the two species are counterparts. *C. torta* differs from *C. pulchra*, however, in two prominent details of structure which have been constant in all of the numerous individuals of the species which have come under my observation. In the first place the annulation is not formed by 1-3 distinct rings as in *C. pulchra* but by a very broad thickened band whose anterior and posterior margins are somewhat enlarged, a condition which might arise by the thickening of the region between the first and second rings in *C. pulchra*. The anterior thickening is usually less prominent than the posterior and the intermediate belt is not uniformly or symmetrically thickened on all sides, thus presenting a variety of margins as the lorica is rolled about. A second narrowed ring is found in some individuals behind the broad band, and as in the two ridges in front of it, its anterior face is less abrupt than the posterior one, differing in this particular from the evenly rounded rings on *C. pulchra*.

The second structural feature differentiating this species from *C. pulchra* is the marked torsion of the quadrangular portion of the pedicel, which makes a turn of 90°-180° from right over to left (*cf.* Figs. 14 and 15). The torsion appears in the prominent lines which form the angles of this part of the pedicel and also in the several—usually three—fainter lines distributed on each face between the angles. These lines in common with those upon the angles, terminate in projecting points along the margin of the skirt-like expansion. There is some irregularity among different individuals in the number and distribution of these intermediate lines. The direction of the torsion is uniform in all loricae examined.

The finer structure of the lorica is essentially similar to that of *C. pulchra* as shown in the figures. The quadrangular portion of the pedicel is thick-walled occluding the lumen to a slender tube which has, however, an ovoidal expansion just before it enters the terminal spine (Pl. XXVII, Fig. 12).

This species belongs to the form-cycle of *C. pulchra* to which species it is evidently closely related. The existence of two constantly present differential characters in the individuals of this species under my observation leads me, however, to regard it as distinct from *C. pulchra*. The nearest approach to intergrades appears in one individual of *C. pulchra* (Fig. 23) in which the second ring is slightly widened.

The formation of the twisted end of the pedicel in this species may be due to the rotation of the animal during the early period of shell formation. If so, the rotation must be in one direction constantly, or at least nearly so, during this period of formation. In locomotion the *Tintinnidae*, in common with other free-swimming ciliates, rotate about the long axis. I have not observed *C. pulchra* in activity, but in other species which I have seen in motion reversals in the direction of this rotation are not infrequent. It is difficult to find an explanation of the difference between the broad anterior band and the smaller posterior ring in *C. torta* on the supposition made in the case of the rings in *C. pulchra*, that they are attendant upon the repetition of some phase such as division or conjugation in the life history of the organism.

The structure of the lorica is similar to that of *C. pulchra* with the exception that there are 2-3, and sometimes as many as 5 layers of prismatic elements in the rings and collar and that the thickened region of the pedicel is relatively longer.

The animal has not been seen in normal condition.

Dimensions.—Total length, 450 μ; diameter of mouth, 65 μ, on rings, 90 μ; of pedicel, 18-25 μ; diagonal of pedicel expansion, 30 μ; thickness of wall, 2 to 4 μ; length of terminal spine, 40 μ.

This species has been taken sparingly in both summer and winter plankton of the Pacific at San Diego, but more abundantly in vertical than surface catches. It is apparently eupelagic in its distribution.

Cyttarocylis fasciata sp. nov.

Pl. XXVI. Figs. 6, 7.

Lorica elongated, subconical, its length five times its oral diameter. The posterior third contracts more rapidly than the anterior to a blunt, somewhat irregular, apex. The terminal third is curved slightly to one side so that the apex is asymmetrical. Near the mouth the lorica widens a little to a partially and irregularly everted lip.

The wall of the lorica is formed by a band of substance laid in a spiral of about 17 turns from right over to left (leiotropic) from the apex toward the mouth. The width of this band is not uniform; it varies from 0.2 to 0.6 of the oral diameter, being widest in the fourth and fifth turns from the apex, the region of most rapid diminution in calibre, and narrowing abruptly in the three apical turns, and more gradually toward the mouth. The band is placed somewhat obliquely to the trend of the side so that the posterior margin of each turn is set on the inner face of the anterior margin of the turn behind it (Pl. XXVI, Fig. 7). In the last turn at the oral end the width of the band diminishes gradually so that the mouth is squarely truncate.

The wall is composed of minute prismatic elements of very irregular form, with a varying number (3-6) of sides of irregular and unequal length. As with other species of *Cyttarocylis* here described, the ends of the prismatic elements form the inner and outer faces of the lorica. The irregularity of the pattern which they form in this species stands in strong contrast with the regular hexagonal type seen in species previously described in this paper.

The inhabitant of the lorica has not been observed.

This form belongs to that group of species of *Cyttarocylis* in which the material of the shell is laid down in bands as a result of intermittent activity of secretion or of spiral rotation or torsion of the body. Intermittent deposition yields the annulated type of lorica. When the process of extrusion of the prismatic elements or other lorica-forming substances is intermittent only during the latter part of shell formation, such loricae are produced as that of *C. annulata* of Ostenfeld and Schmidt ('01) where the rings are limited to the anterior end. When intermittent deposition continues throughout the whole of shell formation, the entire lorica is composed of superposed rings of equal or unequal width as in *C. annulata* of Daday ('87) and *C. fistularis* [*Tintinnus fistularis* of Moebius('87)]. Jörgensen is probably correct in regarding the latter species as identical with *C. helix* (Clap. et Lach.) Jörg. in which the structure of the lorica is imperfectly known, but appears from the figure of Claparède and Lachmann ('58-'59) and the discussion of Jörgensen ('99) to consist of an apical portion, which is formed by a broad band spirally wound, and a superposed oral portion made up of a number of narrower transverse rings.

When the deposition of shell material is continuous and attended by torsion we may have the spiral type of banded lorica in the anterior end as in *C. claparedi* of Daday ('87) and the nearly related if not identical *C. ehrenbergi* var. *subannulata* of Jörgensen ('99), or throughout the whole lorica as in *C. pseudannulata* of Jörgensen ('00) and in the species here described.

The type of shell structure in *C. fasciata* suggests the slow rotation of the animal in a constant direction during the deposition of the shell-forming substance (from which the prismatic elements are formed) and the localization and limitation of the region of its extrusion to a single place upon the animal. It seems desirable that all annulate forms of the *Tintinnidae* should be reinspected carefully for spiral structure.

It is evident that the spiral structure of the shell is of great importance in assisting in the rotation of this structure during active locomotion of the animal and maintaining it during passive movement through the water, as for example during its sinking, and that with the rotation there comes a corresponding increase in the molecular friction and that the flotation of the organism is thus facilitated.

This species is most nearly related to *C. helix* (Clap. et Lach.) Jörg., from which it differs in its much greater size (length 520μ to 150-200μ in *C. helix*), and in the greater width of the anterior bands which are also plainly spiral, while in *C. helix* they are probably transverse and are very narrow. The proportions of the two species are also different. *C. fasciata* is conical, while *C. helix* is cylindrical with more or less pronounced curvature of the tapering apex.

Dimensions—length, 520μ; diameter of mouth, 100μ; at apex, 20μ; width of spiral band, 20-60μ.

This species was taken but once, in a vertical haul from 35 fathoms to surface, 8 miles off Pt. Loma in June.

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EXPLANATION OF PLATE XXVI.

Fig. 1.—Lateral view of lorica of *Tintinnus serratus*, ×615.

Fig. 2.—Lateral view of lorica of *Tintinnopsis reflexa*, ×600.

Fig. 3.—Lateral view of lorica of *Tintinnopsis dadayi*, ×375. Individual with primary oral rim only.

Fig. 4.—The same of a second lorica, showing both primary and secondary oral rims, ×190.

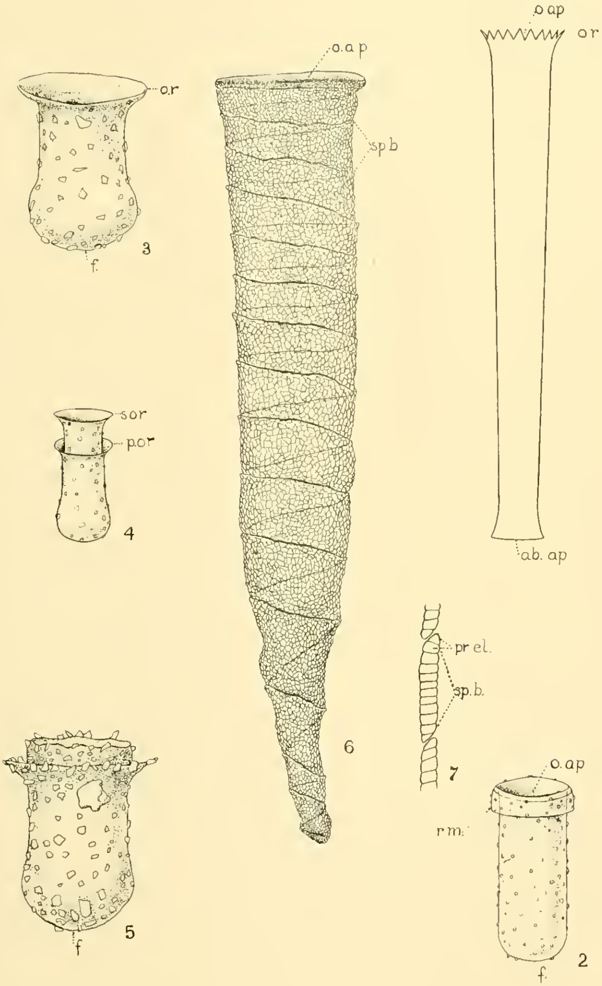
Fig. 5.—The same of a third lorica, in which the secondary oral rim is only partially developed, ×375.

Fig. 6.—Lateral view of lorica of *Cyttarocylis fasciata*, ×490.

Fig. 7.—Longitudinal optical section through wall of lorica of *C. fasciata*, ×1225.

ABBREVIATIONS.

ab. ap.—aboral aperture.
f.—fundus.
o. *ap.*—oral aperture.
o. *r.*—oral rim.
p. o. *r.*—primary oral rim.
pr. cl.—prismatic elements.
r. m.—reflexed margin.
s. o. *r.*—secondary oral rim.
sp. b.—spiral band.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EXPLANATION OF PLATE XXVII.

Fig. 8.—Lateral view of lorica of *Cyttarocylis quadridens*, ×250.

Fig. 9.—Lateral view of posterior ends of lorica of *C. quadridens*, showing asymmetry and degrees in development of the lateral spines, ×250.

Fig. 10.—Lateral view of posterior end of lorica of *C. quadridens*, showing lumen, ×1200.

Fig. 11.—Optical section of wall of lorica of *C. quadridens*, showing prismatic elements, ×1200.

Fig. 12.—Optical section through posterior end of lorica of *Cyttarocylis torta*, showing lumen, ×600.

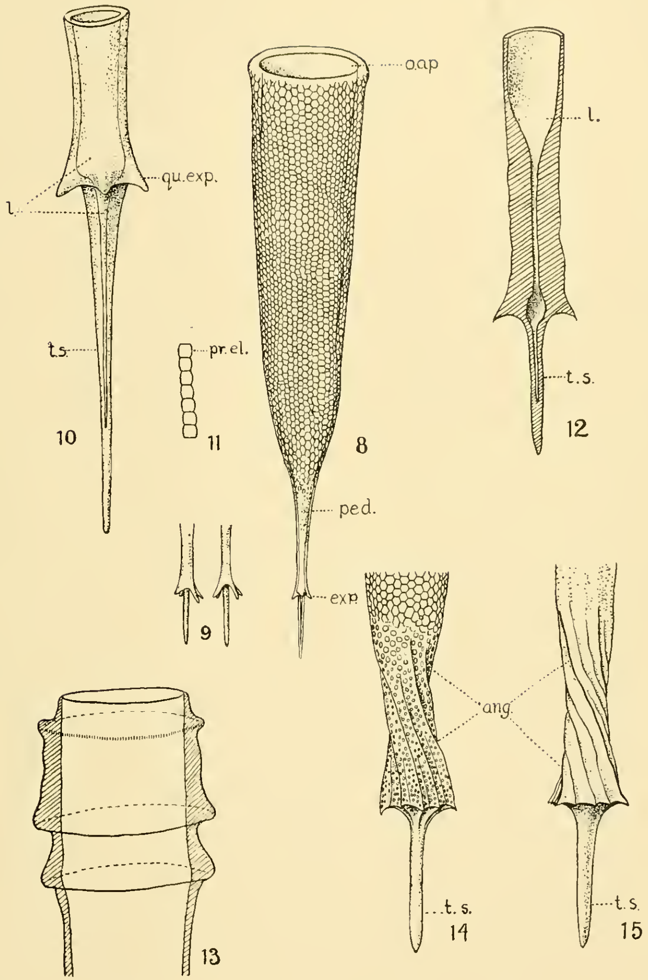
Fig. 13.—Anterior end of lorica of *C. torta*, viewed as a transparency. Lorica with additional posterior ring, ×320.

Fig. 14.—Posterior end of lorica of *C. torta*, showing 90° of torsion, ×600.

Fig. 15.—Another lorica of the same, showing 180°, ×600.

ABBREVIATIONS.

ang.—angles of quadrangular pedicel.
exp.—expansion of pedicel.
l.—lumen of lorica.
o. ap.—oral aperture.
ped.—pedicel.
pr. el.—prismatic elements.
qu. exp.—quadrangular expansion of lorica.
t. s.—terminal spine.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EXPLANATION OF PLATE XXVIII.

Fig. 16.—Lateral view of lorica of *Cyttarocylis torta*, having no additional ring, ×250.

Fig. 17.—Optical section and inner surface of anterior end of lorica of *C. torta*, showing prismatic structure, ×375.

Fig. 18.—Surface of lorica of *C. quadridens*, showing primary and secondary reticulations, ×1100.

Fig. 19.—Lateral view of lorica of *Cyttarocylis pulchra*, having three rings, ×250.

Fig. 20.—Optical section and inner surface of lorica of *C. pulchra*, showing prismatic structure, ×500.

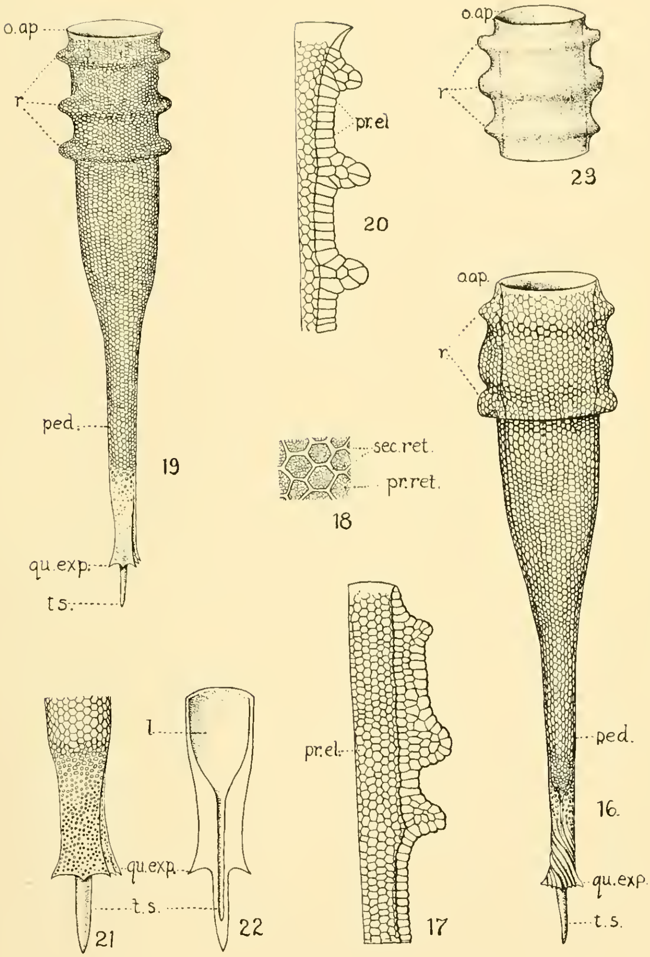
Fig. 21.—Posterior end of lorica of *C. pulchra*, ×500.

Fig. 22.—Optical section of same, showing lumen, ×500.

Fig. 23.—Anterior end of lorica of *C. pulchra*, viewed as a transparency. Lorica with modified central ring, ×250.

ABBREVIATIONS.

o. ap.—oral aperture.
ped.—pedicel.
pr. el.—prismatic elements.
pr. ret.—primary reticulation.
qu. ex.—quadrangular expansion.
r.—rings.
t. s.—terminal spine.
sec. ret.—secondary reticulation.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