ULTRASTRUCTURE AND CHEMISTRY OF THE SKELETON OF *TUBIPORA MUSICA* LINNÉ

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Tubipora musica Linné, 1785 is the only known hard, calcitic, reef-building alcyonarian coral. Its skeleton consists of calcite spicules in different modes of organisation. The spicules are built of two parts: a central column consisting of elongate calcite needes arranged in concentric layers coaxial with the axis of the spicule, and of a cover of shorter calcite needles in an imbricated arrangement. The calcite has a Mg-content of about 3.5 % weight. The highly unstable Mg-rich calcite skeleton readily explains the poor fossil record of the species.

The present study is based on samples of *Tubipora musica* Linné from a reef complex situated about 20 km south of Eilat, Israel. Samples of living colonies had a size of 10–25 cm, while debris collected from the dry beach were only a few millimeters in size.

Specimens studied with the scanning electron microscope were treated with sodiumhypochlorite and ultrasonic vibrations in order to remove the organic material. By this method, however, the organic material was only partly removed and by further treatment the clean areas were submitted to etching, which affected the shape of the crystals. Treatment with the enzyme Alkalase during 24 hours under conditions of pH higher than 7 and temperature of 25–30° C, followed by ultrasonic vibrations, resulted in uncorroded surfaces free of organic material, (B. B. Andersen, personal communication).

The study of ultrastructures was made in a scanning electron microscope.

Chemical analyses were made in an electron microprobe with standards analysed by atomic absorption.

Morphology

Bayer (1956) gave a description of *Tubipora musica* Linné, 1758, the only representative of the family Tubiporidae Ehrenberg, 1828.

In order to clarify the termonology applied in the following ultrastructural investigation, a morphological description of *T. musica* Linné is given below.

The colonies of *T. musica* are generally dome-shaped and may reach the size of several metres.

The skeleton is built of radial tubes and concentric stolons (pl. 1, fig. 1). The tubes are radially orientated and are either continuous through the colony or arise from the concentric stolons. In the specimens studied, the diameter of the tubes varies between 1.3 and 1.8 mm. The stolons are built of two layers connected by pillars (pl. 1, fig. 2). The thickness of the stolon is about 0.4 mm and the distance between them 3–10 mm. In places tabulae part the tubes. The tabulae are prolongations of the stolons, and like these, built of two layers. The tubes and stolons are perforated. The perforations have a diameter of 10–20 μ and widen towards the surface. Larger passages connect the stolon interlayer cavity with that of the tube (pl. 1, fig. 3).

Outside the rigid skeleton loose, elongate, spinose spicules are found, which are sometimes fused into clusters (pl. 2, fig. 1).

The terms stolon and platform, as well as spicule and sclerite applied by Bayer (1956) in the description of *T. musica* seem to be respectively synonymous. In the following description the terms spicule and stolon will be used.

Ultrastructure

All the elements mentioned above are built of spicules, which may be loose, in clusters, in delicate network (tabulae), or cemented (tubes and stolons).

In the electron miscroscope a spicule is seen to be built of a central column formed of concentric layers of needles (pl. 2, fig. 2) each of which is 0.4–1.0 μ in diameter. They are arranged parallel to the axis of the spicule. This central column continues into irregular protrusions, and is divided into tubular segments by organic membranes. A thin cover of shorter needles in an imbricated arrangement coats the spicule (pl. 2, fig. 3). The latter generally have well developed crystal faces in contrast to those building the central column.

Spicules of the same kind are found to build the tabulae, the thickness of which is generally of the order of size of the diameter of a spicule. The thickness of the stolons and the tubes is several times that of a spicule. Both skeletal elements are built of a framework of spicules, cemented by needles similar to those forming the spicule. The cementation needles are radiating from the central column to the surface of the tubes or stolons. In places tabulae are cemented in the same way as tubes or stolons are.

In pl. 2, fig. 4, the structural relationship between the central column, the cementation needles and the covering imbricated layer is shown.

The spicules would seem to be primarily secreted as isolated bodies. The isolated spicules are cemented to form the rigid skeleton, which is then covered by the imbricated layer. The perforations are either spaces where cementation did not take place or sites of dissolution. Locally the central part of a spicule is seen to be interrupted by a perforation.

Chemical analysis

Chemical analysis for the elements Sr and Mg in the skeleton of *T. musica* was made with the electron microprobe.

The Mg-content was found to be about 3.5 % weight (corresponding to 14,5 % mol $MgCO_3$). This corroborates the observations within the alcyonarians from environments with identical temperatures published by Chave (1954) and Clarke & Wheeler (1922). Lowenstam (1964) reported values of the same order of size as those by the present author, while Glover & Sippel (1967) found a slightly higher value (17 % mol $MgCO_3$).

As the Mg-content is higher than that found in stable solid solution of Mg in natural nonbiogenic calcite (Goldsmith, Graf & Joensuu, 1955) an X-ray diffraction investigation was made in order to detect a possible presence of Mg-rich minerals besides calcite. Both diffractometer and Guinier-camera results showed the presence of calcite only. The smaller d-values obtained indicate that the Mg is incorporated in the calcite lattice. The uniform distribution of this element is furthermore indicated by scan-pictures made with the microprobe.

The Sr-content was found to be about 0.30 % (corresponding to 0.37 % mol $SrCO_3$). This is in the range of the values published by Thompson & Chaw (1955) and by Odum (1957), in contrast to the results by Lowenstam (1963) which are somewhat higher (0.7–1.0 % mol $SrCO_3$).

The Mg and Sr-contents of the samples collected from the dry beach were found to be identical to those of living colonies.

Colour

The skeleton of *Tubipora musica* has a prominent dark red colour. The intensity of the colour diminishes from the surface of the tubes and stolons towards their centres. With regard to loose spicules, some were found to be coloured while others were not.

The colour is not due to the soft body of the coral nor to symbiontic algae, as the colour does not change when skeletal parts are immersed in sodiumhypochlorite. No red remains were observed after solution in hydrochloric acid. No structural difference was found between the coloured and the uncoloured parts. Consequently the red medium must be incorporated in the skeleton. This corroborates the statement by Nicol (1967) that the red colour is due to pigmentation.

Conclusions

The interest in T. *musica*, especially in respect of its behaviour under diagenetic processes, arose from the observation that the species is a rather common constituent of living reefs, while it is lacking a fossil record.

The skeleton which is built of high-magnesium calcite, is stable within the environment of the living body, but becomes unstable when exposed to marine or subaerial conditions, therefore recrystallisation is to be expected. However, recrystallisation does not occur which may be explained considering the large surface relative to weight, and its porous structure. On the other hand, however, the fragile and delicate skeletal structure faciliting a mechanical breakdown may carry a part of the responsibility for its missing fossil history.

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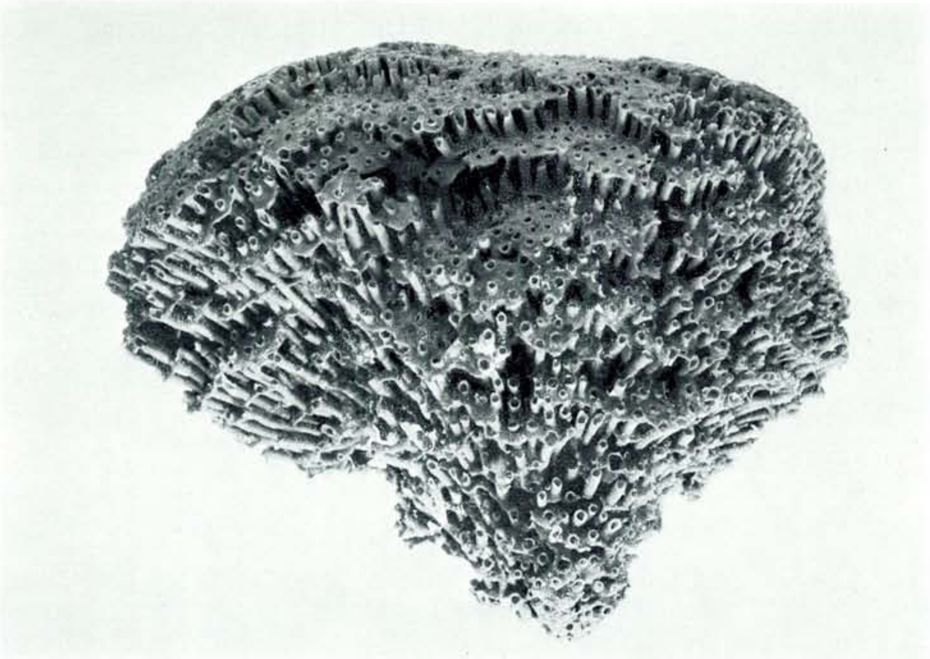
Plate 1

Fig. 1. Skeleton of *Tubipora musica* Linné built of radial tubes and concentric stolons.
Fig. 2. Fractured stolon showing the two perforate layers connected by pillars.
Fig. 3. Right-angle view of tube surface with fractured stolon. The older part of the tube, A, is more heavily cemented than the younger part, B. The cavity of the stolon is connected to that of the tube by larger passages.

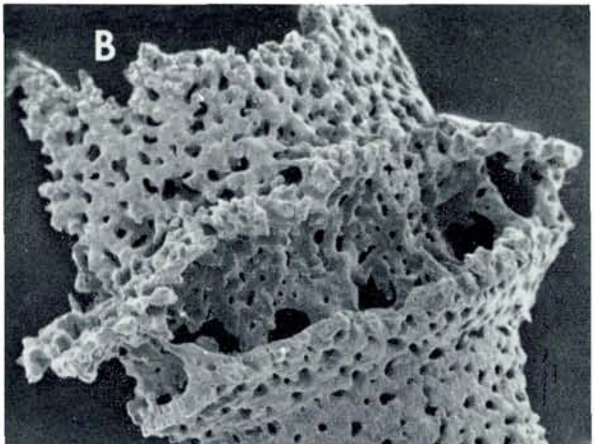


1

1 cm

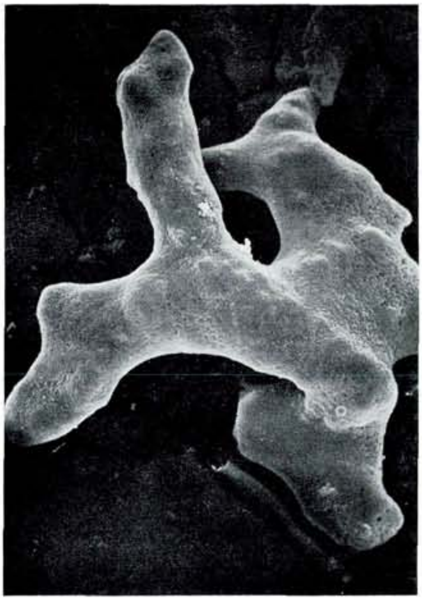
2

300μ

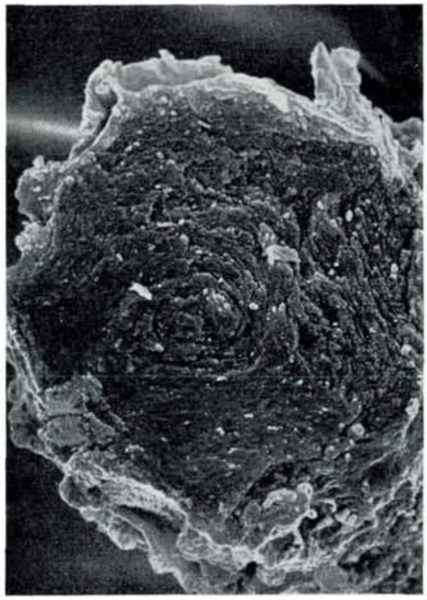


3

300μ



1 75μ



2 15μ

3 4μ

4 20μ

Dansk sammendrag

Orgelkorallen *Tubipora musica* Linné, 1785 er den eneste hidtil beskrevne revdannende calcitiske alcyonarie-koral. Dens skelet består af calcit-spikler. Spiklerne består af to dele: En central søjle som er bygget af aflange calcit-nåle arrangerede i concentriske skaller, hvor nålenes længde-akse er parallel med den centrale søjle, samt af et dæklag af kortere nåle, der er arrangeret som mursten i en væg. Skelettets calcit har et magnesium-indhold på ca. 3.5 vægtprocent. Denne calcit er ustabil, og er en mulig grund til at slægten *Tubipora* ikke kendes fossilt, idet skelettet opløses, før det rekrystalliserer.

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Plate 2

Fig. 1. A loose cluster of spicules, formed by fusion of a number of elongate spicules.
Fig. 2. Fractured loose spicule showing the central column formed of concentric layers of needles arranged parallel to the axis of the spicule, (perpendicular to the fracture plane).
Fig. 3. Outer layer of a spicule showing imbricated arrangement of the crystals.
Fig. 4. Fracture surface of a tube. A: central column of an incorporated spicule. B: cementation needles. C: outer layer.

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