# The Role of Burrowing Sponges in Bioerosion*

## Klaus Rützler

Department of Invertebrate Zoology, National Museum of Natural History,
Smithsonian Institution, Washington, D.C. 20560

*Summary.* Among the large number of limestone-eroding organisms, sponges, mainly of the family Clionidae are of special interest because of their efficient means of substratum penetration by cellular etching and because they release characteristically shaped calcium carbonate chips which can be detected in the mud-size fraction of many sediments. Identifiable trace fossils and sediments are of great ecological and paleoecological significance.

As new data on the excavating mechanism have become available, the questions of burrowing rates and sediment production have gained importance. Extrapolation from short-term experiments (under 6 months) on substrate invasion are inconclusive because of high initial penetration rates resulting from mechanical stimulation and lack of competition. New experiments show that the rate curve flattens after 6 months and that optimum long-term erosion of $CaCO_3$ does not exceed 700 mg m$^{-2}$ year$^{-1}$ (*Cliona lampa* and *C. aprica*). Substrate limitations and competition will further reduce this rate.

By monitoring the production of $CaCO_3$ chips by *Cliona lampa*, it was possible to link activity patterns to certain environmental factors. Mechanical stimuli, high light intensity, strong currents and, possibly, low temperature seem to accelerate the burrowing process. Sponge-generated chips can make up over 40% of coral mud when deposited in the current shadow of the reef framework.

Using transect counts and sponge area-biomass conversion factors, the mean abundance of burrowing sponges on the Bermuda platform could be calculated. On suitable hard bottom substrates it averages 16 g dry weight per m$^2$. From this value the burrowing potential of sponges can be estimated as 256 g $CaCO_3$ per m$^2$ substrate per year. Since 97–98% of the eroded limestone remains in particulate form, the contribution of fine sediments can amount to 250 g m$^{-2}$ year$^{-1}$.

Attention is called to the fact that erosion rates by burrowers can not directly be compared with those of borers or scrapers. The former are intermittent and their activities are affected by environmental and biological interactions, while activities of the latter are rather constant and guided by the need for food.

## Introduction

Sponges of the family Clionidae have long been known for the ecological impact they cause by riddling limestome objects which they inhabit in most marine environments.

Damage to oyster cultures by clionids has been publicized since the early part of the Nineteenth Century (references in: Clapp and Kenk, 1963) and is still stimulating surveys and experimental research (Hopkins, 1956; Hartman, 1958; Hoese and Durant, 1968).

Ecological requirements of *Cliona*, particularly salinity and temperature tolerances, competition for food and substrata and depth distribution were studied and discussed by Volz (1939), Hartman (1957, 1958), Driscoll (1967), Bromley and Tendal (1973) and Pang (1973). Possible use of these data for paleoecological analyses and for life and post mortem histories of shell bearing invertebrate fossils was proposed by Lawrence (1969) and Bromley (1970).

The burrowing mechanism used by sponges, an old controversy between advocates of chemical and of mechanical means has been restudied by Warburton (1958), Cobb (1969) and Rützler and Rieger (1973). It is now accepted that the excavation is performed by cellular etching of the substratum, which results in freeing of characteristically shaped calcium carbonates chips (Fig. 1b and c). These chips are expelled through the oscula and are carried away by water currents. Although the nature of the etching agent (possibly carbonic anhydrase) is still under investigation (Hatch, 1972), it has been calculated that only 2–3% of the eroded substratum is removed in dissolved form (Rützler and Rieger, 1973).

Otter (1973) and Ginsburg (1957) pointed to the fact that sponge burrowing plays an important part in weakening of the coral reef framework, thus accelerating erosion by wave action in shallow water. Goreau and Hartman (1963) demonstrated much more obvious destructive effects caused by sponge burrowing on the fore-reef slope in Jamaica, below 30 m. They also suggested that these sponges contribute to the large mud fraction of sediments produced in reef communities. This latter assumption was further supported by Neumann (1965, 1966) at Bermuda and by S. V. Smith (personal communication, 1972) at Fanning Island. Fütterer (1974) determined and counted clionid-produced particles by scanning electron microscopy. He calculated that sponge-generated fine sediments can amount to 2–3% (Northern Adriatic Sea, Persian Gulf) or even to 30% (Fanning Island) of the total sediment.

Rates of bioerosion caused by *Cliona lampa* were determined by Neumann (1966) by measuring weight loss of limestone blocks which had been attached to sponge bearing material for up to 100 days. From this data he calculated that *Cliona* infested substrata can lose as much as 1.4 cm per year, or 6–7 kg per m$^2$ per 100 days, producing nearly 6 kg fine sediments per m$^2$ per 100 days (assuming 10% removal in solution, as proposed by Warburton, 1958).

During a recent study on the burrowing mechanism of *Cliona lampa* (Rützler and Rieger, 1973), I initiated similar experiments to obtain new growth of this sponge in blocks of Iceland spar. I calculated comparably high penetration rates but was puzzled by the fact that labeled and measured "old" *Cliona*-infested substrata (mollusk shells, small coral heads and limestone rock) had not shown significant shape or size changes during 16 months of *in situ* observation. My conclusion, that a stimulation effect would cause exceptionally high rates during the invasion of new substrata had also been suggested by Neumann (1966).

Measurements of long-term excavation rates are, therefore, important for realistic estimates of sponge participation in erosion and sediment production. For this purpose I left calcite blocks attached to *Cliona lampa* in Bermuda for up to 10 months during 1972–1974. A 16-month experiment with particularly large blocks to offer ample new substratum was unfortunately lost by storm

or vandalism. A similar 12-month experiment, however, conducted with conch shells attached to *Cliona aprica* at the Belize (British Honduras) barrier reef (1972/1973) was successful. To monitor weight loss of materials already infested by sponges, weighed and labeled bivalve shells containing *Cliona lampa* were returned to their previous habitats for 7 months (1973).

Short term burrowing activity patterns and possible influence of temperature and water movement were also investigated. For this part of the study, a dense population of *Cliona lampa* growing on isolated concrete pillars in the center of Ferry Reach Entrance (North Shore, Bermuda) was used. The sponges infest extensive accumulations of the bivalve *Chama macerophylla* (Fig. 1a) which fouls the pillars. The tides cause a directional flow of water in the narrow channel. Thus, the characteristically shaped chips produced by the sponges could be trapped in sediment jars during periods of observation in January and August, 1973. They were measured and counted in comparison with controls outside the influence of the *Cliona* population.

To evaluate the ecological consequences of the burrowing activity, it is necessary to relate the rates of erosion and sediment production to sponge abundance in a given area. For this purpose, the relative abundance of excavating sponge species hitherto known from Bermuda (Rützler, 1974) was determined by a series of representative transect counts.

## Materials and Methods

For the excavation experiments in Bermuda pre-weighed Iceland spar blocks were attached to *Cliona lampa* Laubenfels (forma *lampa*) under water (1–3 m) using plastic coated wire. The procedures followed those outlined by Rützler and Rieger (1973). The blocks selected had a size close to $3 \times 2 \times 1.5$ cm. In the reef crest area of Carrie Bow Cay, Belize, slabs chiseled from fresh shells of *Strombus gigas* Linnaeus were weighed and wired to *Cliona aprica* Pang (forma *aprica*) which burrowed the coral *Acropora palmata* (Lamarck) in about 1–2 m depth. The conch slabs ranged in size $6 \times 4 \times 0.5$ cm to $12 \times 10 \times 1.8$ cm. After the experiments the area of initial penetration by the sponge (= contract area) and the area of total sponge coverage (new growth) were measured using planimetry on paper tracings. Then the sponge material was removed by soaking in commercial sodium hypochloride. Calcified fouling organisms were removed by careful scraping. After rinsing and removing spicules and debris with a jet of water, the blocks were dried and weighed.

To record burrowing activity patterns 8 sediment traps were placed between 4 large concrete pillars in Ferry Reach Entrance (Bermuda). The pillars are fouled by a dense population of the bivalve *Chama macerophylla* Gmelin, which is infested by *Cliona lampa*. The *Cliona* population present above and surrounding the traps was calculated to cover 62 m², within a 5 m radius.

A fair portion of chips produced by these sponges could, therefore, be trapped using 500 ml glass jars with 60 mm diameter openings. To avoid too much contamination with resuspended sediments the jars were mounted on PVC rods, with their openings 70 cm above the sea floor. Two controls were installed in a similar manner, but approximately 40 m away from the sponge population. Each series of jars was removed after 48–149 hrs exposure. Those affected by sudden weather changes were discarded. In the laboratory the sediments were washed through a 200 μm sieve to remove large particles, mostly plant material. All samples were resuspended in 40 ml seawater to take a representative 2 ml subsample, the rest was allowed to settle and dry for weighing after a short rinse in freshwater. The subsample was membrane filtered, dried and mounted for light microscope or scanning electron microscope observation. It turned out that the freshly excavated chips from dense *Chama* shell could easily by recognized under the light microscope. SEM photomicrographs were
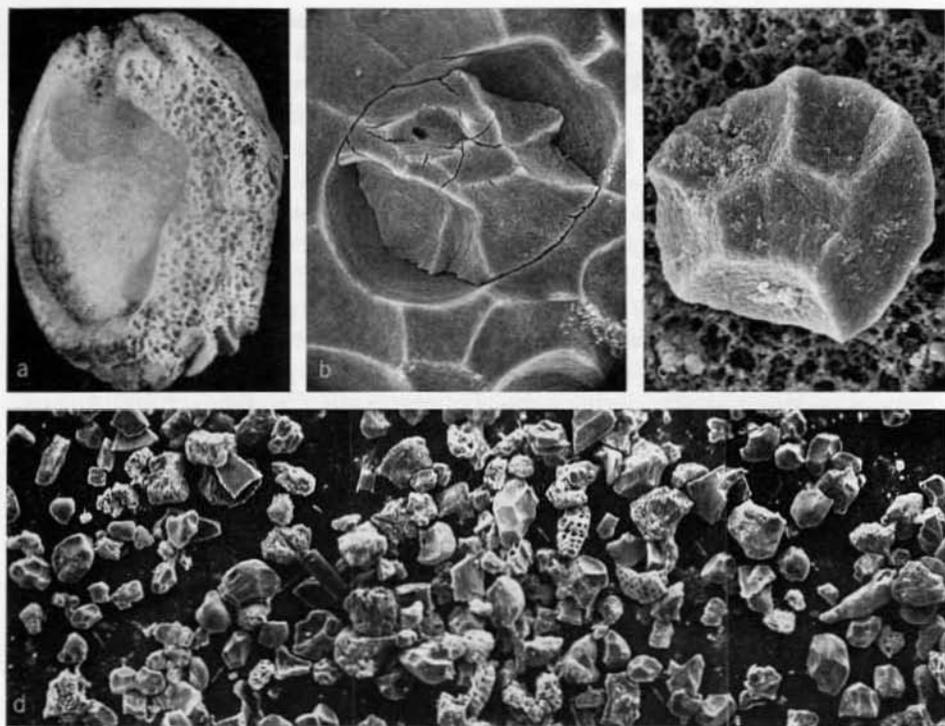
Fig. 1 a—d. Burrowing and sediment production by *Cliona lampa*. (a) Sponge riddled *Chama macerophylla* shell (× 0.8); (b) etchings on substratum surface and partly removed chip (× 500); (c) excavated limestone chip on cellulose filter (× 1000); (d) sediment sample containing sponge chips, with characteristically scalloped surface (arrows) (× 100)

only used for the confirmation of counts (Fig. 1 c and d). Sponge chips and other particles were recorded separately by point counting using a Weigel graticule and a measuring scale in the microscope ocular.

Assessment of burrowing sponge abundance in Bermuda was accomplished by frame counting along transect lines. Each transect was 20 m long. In patch reefs and other rocky areas offshore, their starting point and direction were chosen at random. On rocky coasts the direction of transects was perpendicular to the shore line. Using SCUBA a $^1/_4$ m² frame with 100 cm² line grid was positioned every 2 m on the transect and the bottom underneath was carefully searched for crusts or papillae of clionid sponges. The extent of the papillary fields was estimated to the closest $^1/_4$ of each grid frame (5 × 5 cm) and recorded for each species (as defined by Rützler, 1974). Of the only non-clionid burrower, *Spheciospongia othella* none but the young excavating stages were noted.

Biomass estimates for the different species and forms are based on 4 subsamples each. After measuring the surface area of the papillae fields or of the ectosomal crusts, the sponges were treated with changes of dilute hydrochloric acid until they were completely decalcified. Care was taken not to lose any tissue fragments by enclosing the samples in bolting cloth. Endolithic algae and other organisms were removed after decalcification while the tissues were suspended in water under a dissecting microscope. Wet weight was taken after quick blotting, dry weight after drying to constant weight of 105° C. Determination of ash-free dry-weight was not considered significant because of the fairly consistent spicule to soft tissue ratio in all species.

## Results

### Long Term Excavation Rates and Substrate Availability

The Iceland spar blocks used in the Bermuda experiments have the advantage of being dense, pure and homogenous calcite. The well defined crystal surfaces provide maximum contact area for attachment to sponges and can be easily cleaned from unwanted fouling organisms (e.g. crustose coralline algae). Neumann's (1966) observation that the substrate mineralogy has little effect on burrowing rate could be confirmed by comparing rates in Iceland spar with those in *Chama* shells. Porosity of the substrate aids quicker and deeper penetration but no more material is removed per unit time. Porous calcarenite also poses experimental problems because of mechanical crumbling and invasion by other organisms. Since calcite blocks could not be obtained in large sizes, slabs of fresh conch shells were used in Belize. These are an important naturally occurring substrate for clionid sponges.

Both species of sponge studied have an incrusting habit which facilitates quantitative assessment and prevents most secondary invaders from settling. Only some algal felts, crustose Corallinacea, Foraminifera (*Homotrema*), hydroids and tunicates (*Clavellina*) settled on parts of the substrate blocks, and some blue-green algae penetrated superficial layers. The competitive advantage of the incrusting habit is demonstrated by the large surface areas (in the order of square meters) these sponges can occupy. Large coral heads have probably been killed by spreading *Cliona lampa* because the delicate surface structure of the corals (e.g. *Siderastrea, Diploria, Montastrea*) is still distinct under the sponge crust (Rützler and Rieger, 1974). When the corals had been dead and exposed for only a few weeks filamentous algae had taken over and obscured the structure. This is supported by labeled and photographed live specimens of *Montastrea annularis* bordering *Cliona lampa* in Harrington Sound, Bermuda. During a 9 month observation period (August 1973–May 1974), the sponges advanced 0.9–2.1 cm at the expense of the coral (Rützler, unpublished). Glynn (1973) arrived at similar results (2 cm per 9-month period) by transplanting *Cliona* sections to injured but uninfested sites of *Siderastrea*. Large coral specimens, mainly *Acropora palmata* can be entirely covered by *Cliona aprica* near the Carrie Bow Cay reef crest.

Table 1 lists the results of field experiments ranging from 33 to 350 days, including the data of Neumann (1966). The area of contact (attachment) with the "mother" sponge is the only measure of biomass available for the experiments up to 4–5 months. If this contact is broken, the wound heals forming ectosomal tissue with ostia and oscula undistinguishable from naturally grown specimens. On substrata older than 5 months ectosomal tissue has already spread from the sides and from points where the sponge has penetrated through the upper substrate surface. This growth can be considered a new sponge specimen with its own independent aquiferous system. To its measured surface area the burrowing rates can be related. Rates related to the initial contact area *only*, reflect the growth potential of the mother sponge but have no bearing on the sponge biomass involved (Fig. 2a). The means follow a power regression model ($y = 63.8x^{1.4}$) with a coefficient value $r^2 = 0.93$. Related to actual surface coverage values the