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13 November 1978; revised 26 March 1979

Giant Larvacean Houses: Observations from Deep Submersibles

Abstract. *The abundance of large, previously unknown larvacean feeding structures in the deep ocean is a striking contrast to the rarity of such forms taken in net hauls. In some areas, abandoned houses and their disintegrated parts provide a substrate for other organisms and contribute to organic aggregates.*

Our concepts of oceanic mesopelagic life are mainly based on samples taken with trawls, nets, and pumps. However, new insights have been gained by underwater scuba divers in shallow oceanic waters; these observers report that several planktonic forms secrete mucoid feeding structures that are generally destroyed by our usual collecting methods (*1*).

The most elaborate of these structures are produced by larvaceans, urochordates that retain the larval tunicate "tadpole" anatomy. Minute (3 to 6 mm), shallow-dwelling species secrete cocoonlike mucous "houses" that are an order of magnitude larger than the animals and are equipped with intake screens and complex internal filters. Protectively situated in its house, the animal filter-feeds by creating a flow of water through the apparatus with its undulating tail. When the sieves clog, the larvacean evacuates the house and rapidly secretes another, a process that can be repeated at 2- to 4-hour intervals (*2*). Larvacean houses were studied by an earlier generation of biologists who carefully ladled these fragile structures from surface waters (*3*), but the abundance and importance of the abandoned houses as a substrate for microcrustaceans and bacteria and as a source of organic aggregates have only recently been revealed by modern diving techniques (*2, 4*).

Some 70 years ago, rare catches from deep net tows of *Bathochordaeus charon*, a larvacean more than ten times larger than shallow-dwelling forms, were reported (*5*). Recent examination of midwater-trawl catches off the southern California coast has increased the known number of specimens of this giant form to 13 and extended their range to the eastern Pacific (*6*). Because the houses of *B. charon* have never been described [Chun (*3*) theorized that they must be the size of pumpkins], I report here on observations made more than 10 years ago from deep submersibles (*7*).

My observations indicated that there are several types of large larvacean houses, ranging in size from 30 to 100 cm, that are widely distributed in pelagic waters adjacent to the continental shelves of the western middle American coast (Fig. 1). Their abundance varies from an occasional individual to one per cubic meter, a density observed above thermoclines at depths of 25 to 50 m. Some of my observations suggest that abandoned giant larvacean houses provide a substrate for microcrustaceans and contribute to organic particulate material in deep waters as do smaller forms at surface levels (*2, 4*).

During early dives, certain large mucous structures seen from submersibles were an engima to me. The evidence which eventually led me to conclude that these were extremely large larvacean houses follows. With the exception of their size, the structures were roughly similar to textbook descriptions of minute larvacean houses, and intact structures contained a double-lobed nucleus which resembled the internal filter of smaller forms. In some cases, a slow rhythmic beating by an organism adjacent to the nucleus appeared identical in position and motion to that described for minute larvacean forms. Once, a pollywog-shaped organism, about 6 to 8 cm in length, was seen leaving and swimming rapidly away from a disintegrating mucous structure that had been hit by the submersible. Finally, after several futile attempts, a structure containing an occupant was captured in a suction device attached to the front of the submersible (*7*). The collecting process reduced the structure to mucus-like scum; the organism, however, was recovered intact and examined in its fresh state by Donald P. Abbott (Stanford University) who identified it as a larvacean. (Unfortunately, this specimen was subsequently lost.)

While I recall seeing at least five types of large larvacean houses, by recourse to photographs and motion-picture films I can give general descriptions of three types. Type 1 house (Fig. 2A) is approximately 70 to 100 cm in its greatest dimension. The form of the house differs, but it is essentially a flimsy sac that appears to be at least partially open at the bottom. One or two mucous strings usually trail

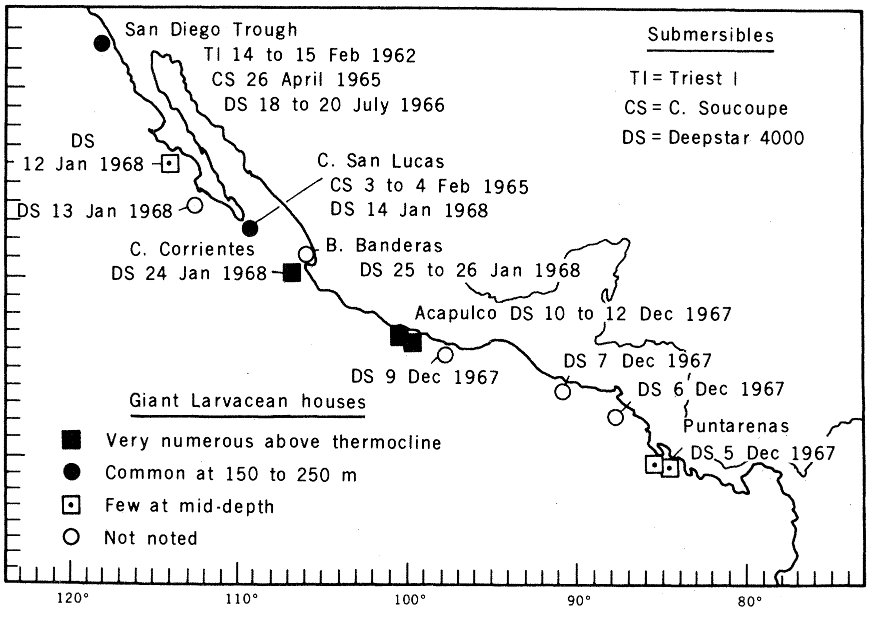

Fig. 1. Locations and dates of submersible dives and the observed relative abundance of large larvacean houses.

out of the bottom. The thin outer skin is covered with small particles. An internal filter, suspended by mucous strands, is situated in the upper region of the envelope. This filter is double-lobed, with a system of transverse ridges. When hit by the superstructure of a submersible, the house slowly disintegrates into ropy mucus. The type 2 house approximates an ovoid, about 20 to 26 cm in length. A double-lobed internal filter, larger in size relative to the envelope than that of type 1, is situated approximately in the middle of the house. The skin of the house appears firmer and is covered with fewer and larger particles than is type 1. What appears to be an external filter can be made out in one photograph (Fig. 2B). Type 3 house (Fig. 2C) is approximately a spheroid of about 30 to 40 cm in diameter. The outer skin is very flimsy, but strongly reflects light, apparently due to small adhered particles. The double-lobed internal filter is relatively large and centrally located. This type of house shatters into small pieces and fine particulate matter at the first contact with a submersible superstructure.

The type 1 house was noted on many dives off San Diego, California, the most detailed observations being made from *Deepstar 4000* (18 to 20 July 1966). During a four-dive series in the San Diego trough (Fig. 1) to depths of 600 to 700 m, some 60 type 1 houses were observed: 48 were seen at depths between 150 to 250 m; seven were above this level, the most shallow at 120 m; and five were below 250 m, the deepest at 375 m. Some houses were in various stages of disintegration, and on these houses small crustaceans (probably copepods) were resting on the outside and swimming around them. In another case, crustaceans were seen swimming away from a house and then returning to it. Crustaceans were also observed inside a disintegrating house clinging to and moving around on the internal filter. These observations were only possible when the submersible was motionless and the house was directly in front of the viewing port and sightlighted with a movable motion-picture light.

The type 2 house was observed and photographed from the *Cousteau Soucoupe* at about 120 m off Cabo San Lucas, Baja California, 4 February 1965 (Fig. 1). I cannot determine from my notes whether this specific type of house was observed on other dives.

In turbid, shallow water off Cabo Corrientes, Mexico (Fig. 1), type 3 larvacean houses were so concentrated at 25 to 45 m that in some areas they were in contact with one another, but, on the average, there was about one house per cubic meter. Just below this concentration in a thin layer about 5 m deep, disintegrating houses formed what looked like a gelatinous matrix. Below this level to a depth of 70 m, there were about three internal filters per cubic meter. The houses and their disintegrating parts had apparently separated out on a strong thermal density gradient (the ocean temperature decreased some 9°C in the interval between 50 to 75 m). Below 75 m, I noticed only pieces of disintegrated houses, and these seemed to be smaller as we descended. At 130 m, small odd-shaped fragments could still be recognized as parts of houses. These were mixed with still smaller, spheroidal organic masses, 5 to 8 cm in diameter, considerably larger than the organic aggregates that are normally seen on submersible dives. Below 170 m, recognizable pieces of houses were no longer seen, but the relatively large organic masses were common. At greater depths, to 670 m, these masses appeared to have thinned, but still dominated the "marine snow." Deeper, when the submersible's lights were switched off, objects the size of these masses glowed with a bioluminescence suggestive of that produced by bacteria. Because of the observed orderly vertical transition, the masses may have been decomposing fragments of the houses.

On the ascent phase of the dive, I noted the same stratification of larvacean houses and their disintegrating parts. The isolated internal filters then appeared yellowish green in the increased ambient light, and I assumed that this was caused by phytoplankton that had clogged the filters. At 35 to 45 m I closely inspected a number of intact houses. In only about one out of eight cases could I detect signs of a live occupant, a ratio similar to that reported for small, shallow forms (*2*).

In two dives off Acapulco (Fig. 1), I had seen slightly fewer larvacean houses of the same type and the vertical stratification of disintegrating parts below their level of concentration was essentially the same. The Cape Corrientes and Acapulco dives were the only locations where so many houses were noted, and these aggregations are perhaps limited to productive nearshore tropical waters where currents and strong thermoclines interact as a concentrating mechanism. However, along a great expanse of the eastern Pacific, large larvaceans are much more common than is to be in-

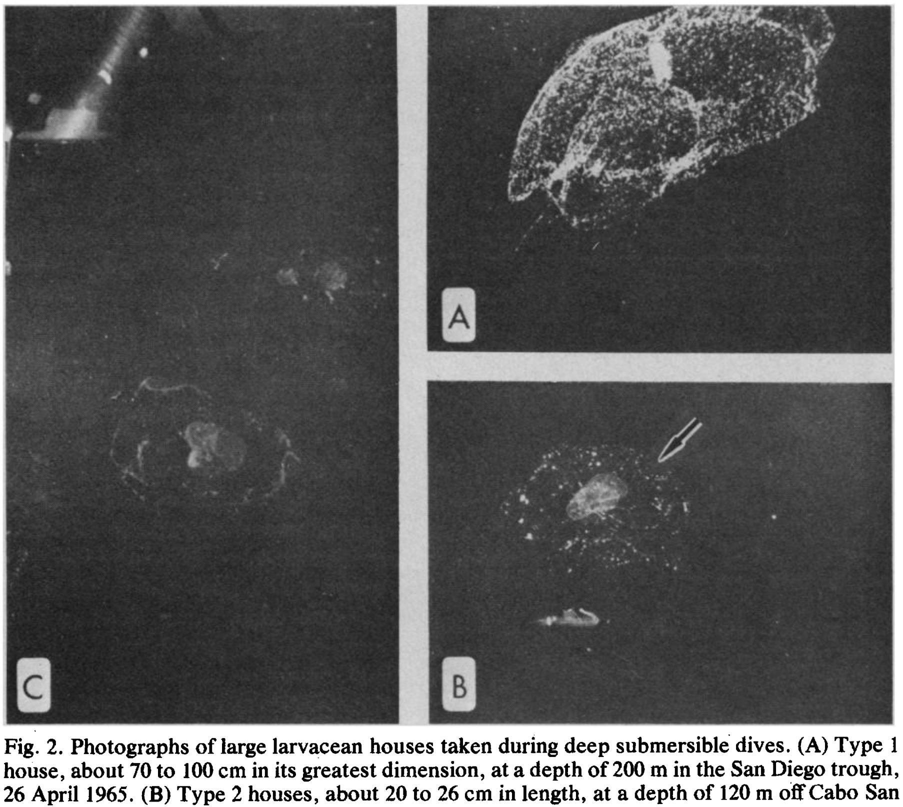

Fig. 2. Photographs of large larvacean houses taken during deep submersible dives. (A) Type 1 house, about 70 to 100 cm in its greatest dimension, at a depth of 200 m in the San Diego trough, 26 April 1965. (B) Type 2 houses, about 20 to 26 cm in length, at a depth of 120 m off Cabo San Lucas, Baja California, 4 February 1965. The arrow marks the probable intake filter. The organism below the house is a pelagic gastropod, probably *Pterotrachea coronata*. (C) The type 3 house at a depth of 40 m off Cape Corrientes, Mexico, 24 January 1968. The houses are about 30 to 40 cm in diameter and were disintegrating in the vortex caused by the submersible's movements. The bottom of the intake funnel of the collecting device (upper left) is 27 cm across. In all the houses the internal filters show clearly. The larvaceans, if present, should be closely associated with these structures although they cannot be made out in the pictures.

ferred from the few net-captured specimens. The obvious reason for this discrepancy between observations in situ and results from net hauls is the fragility of the houses (*6*), and perhaps that the unimposing preserved larvacean specimens are unrecognized in the gelatinous residues of net-haul samples.

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7. As part of the U.S. Navy Electronics Laboratory deep submersible program, the major objective of my dives was acoustic scattering studies. Observations were also made when there was the opportunity, and some of these and early attempts to collect large larvacean houses have been discussed [E. G. Barham, *Oceans Mag.* **1**, 55 (1968)]. The submersible vehicles have been described [R. F. Busby, *Manned Submersibles* (Office of Oceanographer of the Navy, Washington, D.C., 1976)].
8. I thank I. E. Davies, a fellow observer on many dives, who first pointed out the similarity between textbook figures and the then unidentified structures. The work from *Deepstar 4000* was aided by pilots R. P. Bradley and R. Church, both now deceased. Discussions with C. P. Galt, A. L. Shanks, and J. D. Trent have been helpful. In late 1966, N. B. Marshall suggested in correspondence that the largest type house could be that of *Bathochordaeus charon*.

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The Viscous Sublayer at the Sea Floor

Abstract. *A 0.6-centimeter-thick sublayer was found in horizontal flow profiles obtained by traversing a heated thermistor from 19 centimeters above to 2 centimeters below the water-sediment interface in 200-meter-deep water on the Oregon continental shelf. In this sublayer the speed of the current varies linearly with distance above the sediment. Estimates of viscous stress from this sublayer and turbulent stress from the profile agree within 5 percent. Stress calculated from a current-meter spectrum agrees within its 95 percent confidence limits.*

Measurements of currents near the sea floor have been made for some years (*1*) but never within 1 cm of the bottom.

We present results from an experiment in which a heated thermistor was traversed over a 21-cm vertical travel, from 19 cm above the sediment-water interface to 2 cm below it. The site for the experiment lay in 199 m of water at 45°20.29′N, 124°20.34′W on the Oregon continental shelf. Grain size analysis of sediment in the area (*2*) indicates that the surface sediment is a silty sand (61 percent sand, 28 percent silt, and 10 percent clay). The mean diameter of a grain [computed by the method of Inman (*3*)] is 0.0042 cm. Time-lapse photographs taken by the motion-picture camera mounted on the instrument platform revealed no bedforms likely to significantly influence the flow.

The heated thermistor was tranversed by a crank-and-piston mechanism, which completed one cycle per minute. The signal was sampled every 1.5 seconds, together with the signal from an electrical potentiometer which indicated the position of the sensor. Because the drive was not linear, observations were not evenly spaced vertically, but the spacing was approximately 1.0 cm except near the top and bottom of the travel where it was less. The traversing velocity does not affect the results more than a few percent, because of the slowing of the drive near the boundary where the current is slow and because of the properties of the vector addition process. The thermistor was connected in a half-bridge configuration. Sufficient current was supplied to heat it to approximately 20°C above ambient temperature in typical flows. The sensing area of the thermistor was about 0.02 cm. Calibrations were performed by mounting the transducer on a whirling arm in a bath chilled to bottom-water temperatures. We have observed that the effect of pressure on these thermistors is negligible for these purposes at this depth; the effect of salinity also is not significant.

To construct a detailed profile from measurements spaced vertically 1 cm apart, a number of traverses had to be used to make up one profile. Sampling period and rotation period were incommensurate so samples eventually occurred at all vertical positions. This was an advantage in this case because waves (3.5 cm/sec orbital velocities, 15-second period) affected each profile so severely that averaging would have been required in any case; this way the wave motion was not coherent from one sample at a given height to the next nearby sample. The relative orientation of waves and the mean flow is not deducible from any of our measurements. The averages were calculated by averaging all measurements within each 1-mm-thick slice of the water column. The wave motion was undiminished at the top of the sublayer, but was not visible nearer the sediments.

To make up the profiles shown (Fig. 1) a steady current was observed for 1 hour. To minimize the effects of waves, the period of highest currents was selected for detailed analysis. At this time the direction of current flow, indicated by a vane, was such that the platform and mounts caused no interference with the flow past the sensors. The averaged full-height profile shows that most of the shear occurred in the lowest centimeter. In the inset of Fig. 1, means of the samples in the 1.2-cm area just above the sediment are shown. The lowest 0.6 cm of these are well fitted by a straight line, indicating viscous flow. The location of the sediment-water interface with respect to the profiles is taken from the zero-velocity height of this line. The shear given by this least-squares fit is 11.9 ± 0.7 sec^{-1} (all error limits are 95 percent confidence estimates). Multiplying this shear by viscosity, $\nu = 0.0150$ g/cm-sec, the value 0.18 ± 0.01 dyne/cm^2 is obtained for the viscous stress. The friction velocity, $u_* \equiv (\text{stress/density})^{1/2}$, is then 0.42 ± 0.012 cm/sec. Above the sublayer the profile is well fitted by a logarithmic form. The drag coefficient, C_D, referred to the (logarithmically) extrapolated 100-cm velocity (12.4 cm/sec) is 0.0011 ± 0.0001, well within the range of previous estimates (*4*), and a little less than the predicted value of 0.0015 for hydrodynamically smooth flow of this speed. The dimensionless height of the sublayer, taken as the height where linear and logarithmic fitted lines meet (Fig. 2) divided by ν/u_*, is 17 ± 1, somewhat larger than the value traditionally given for channel and pipe flow (*5*). One might speculate that these last two effects, that is, the drag coefficient being lower than expected and the dimensionless sublayer thickness being greater, may be a result of the sediment load. In laboratory experiments, sediment added to water has been seen to cause even greater drag reduction and sublayer thickening (*6*).

The energy dissipation in the sublayer, calculated for viscous flow, is 2.12 ± 0.25 erg/cm^3, which becomes 1.27 ± 0.15 erg/cm^2-sec when integrated over the sublayer thickness. Dissipation in the turbulent boundary layer is usually taken to be $C_D \rho U^3$, where ρ is density and U is mean current (taken at 100 cm), so the dissipation in this case is 2.1 erg/