Procedures for Preparing Acetate Peels and Evidence Validating the Annual Periodicity of Growth Lines Formed in the Shells of Ocean Quahogs, *Arctica islandica*

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Introduction

Bivalve mollusks have historically been aged by examining the external valve surface for growth "rings" or "bands" that form as an annual event (Rhoads and Lutz, 1980). Although such surface features are useful for ageing some species, for others the method produces conflicting and incomplete results. This is particularly true for the ocean quahog, *Arctica islandica*, a species with a potential life span of about 225 years (Ropes and Murawski, 1983). Small ocean quahogs (shell length < 60 mm or 2⅜ inches and < 20 years of age) often exhibit definite external rings in the light brown to mahogany colored shell covering, the periostracum. The same rings formed during the earliest years in the life of large, old ocean quahogs may be discernible, but erosion often obliterates some and those near the ventral valve margin are crowded together in the uniformly black periostracum. Microscopic examination fails to reveal definite rings.

In some bivalve species, darker growth lines alternating with lighter growth increment deposits are seen in the broken edges of valves that have continuity with "bands" on the external valve surface. The development of diamond-impregnated saw blade equipment has greatly facilitated cutting bivalve shells in a directed manner for an examination of the accretion of shell layers from the beginning of their formation at the umbo to the ventral margin. Although cutting the valve is a time consuming procedure, it is believed that the internal depositional features tend to be much less affected by destructive external environmental conditions impacting on the valve surfaces and, thus, a record of growth is preserved intact. Annual microstructural deposits may also occur in other parts of the shell that can be prepared for examination by fairly rapid methods, such as was reported for the chondrophore of the surf clam, *Spisula solidissima*, by Ropes and O'Brien (1979) (Fig. 1).

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ABSTRACT—Techniques are described for producing acetate peels of radially sectioned ocean quahog, Arctica islandica, *shells to observe age and growth phenomena. Specimens marked and recovered 1 and 2 years later validated the hypothesis that growth lines are formed annually. Growth functions have been developed for quahogs from off Long Island, N.Y., and Georges Bank. The growth of the species is characterized as being slow. Some geographic and individual specimen variability in growth was observed. Sexual maturity was attained at 5-6 years of age, but varied with size and sex. Ages approaching and exceeding 100 years are not uncommon. One specimen was about 225 years old, an age greater than known longevity estimates of other bivalve species.*

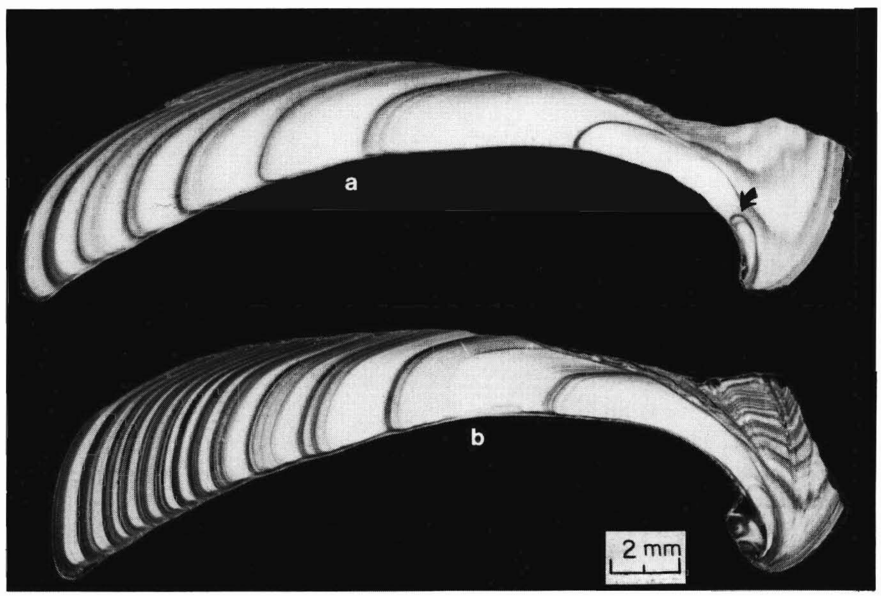

Figure 1.—Enlarged images of thin-sectioned chondrophores from two surf clams: (a) 8 years old, 139 mm (~5½ inches) in shell length, collected 16 December 1975 at lat. 36°32.5′N, long. 75°28.8′W, off False Cape, Va. (b) 13 years old, 137 mm (~5³/₁₆ inches) in shell length, collected 12 December 1975 at lat. 38°03.5′N, long. 75°05.0′W, off Chincoteague, Va. The first annulus formed in the life of a surf clam is sometimes faint (an arrow points to a bold one in the chondrophore of clam (a)). The most recent annulus at the marginal edge of these chondrophores was not completely formed. A millimeter scale is included in this and subsequent figures.

Simply cutting the valves of a bivalve may not expose well defined growth lines, due to variations in the microstructure of the shell deposits. Such is the case for ocean quahogs. Kummel and Raup (1965) included techniques of preparing the cut valve surfaces and transfer of the microstructural details onto sheet acetate for fossil bivalves. The following outlines procedures that have been developed at the Woods Hole Laboratory of the NMFS Northeast Fisheries Center for preparing shells of ocean quahogs, with evidence validating the annual periodicity of annuli and summaries of recent age and growth studies.

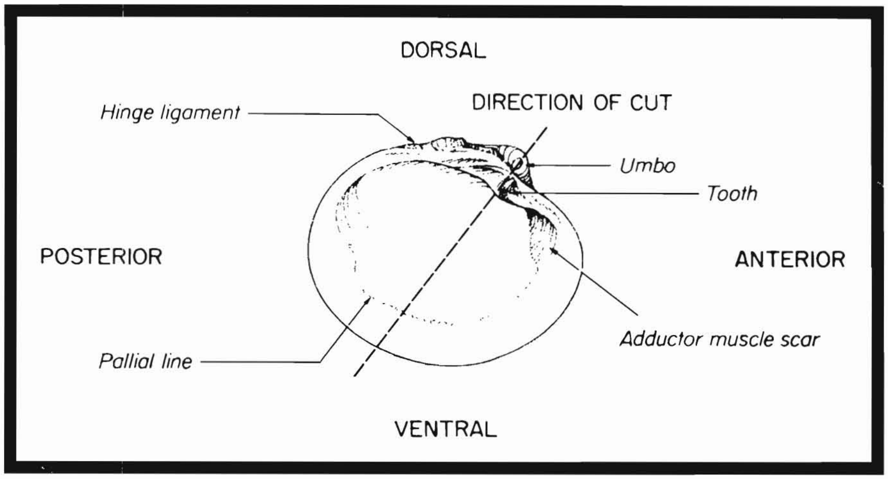

Figure 2.—The internal features of an ocean quahog shell showing the plane of section (dotted line) for orientation purposes during the sectioning operation.

Acetate Peel Method

Before processing the shells for age determinations, records of sample collection information are tabulated with measurements of paired whole valves. Figure 2 shows the internal valve features useful for orientation purposes when using vernier calipers to measure the length (longest anterior-posterior dimension), height (deepest dorsoventral dimension), and width (widest lateral dimension) to the nearest 0.1 mm. Dry shell weights are measured to the nearest 0.1 g.

Internal annuli are exposed by radially sectioning the left valve of a pair, since it is unique and contains a single prominent tooth in the hinge (Fig. 2). This tooth contains annuli useful in confirming counts made in the valve portion. A pencil mark is made at the ventral margin at a point from the posterior end equal to one-third of the valve length. The valve is then fastened with its concave, inner surfaces toward the diamond blade of a saw machine and on its adjustable arm holder with an adhesive putty. Table 1 lists sources of apparatus[1] or materials. The valve is oriented with the tooth toward the front of the saw machine to cut through the middle of the tooth or immediately adjacent to the posterior edge of the tooth and through the pencil mark at the ventral margin. The cut is made completely through the valve and the anterior portion is saved for later treatment. About 7-8 medium-sized (60-70 mm or 2⅜-2¾ inches long) or 3-4 large-sized (100+ mm or 4 inches) quahogs can be cut per hour.

Table 1.—Sources of apparatus and materials used to section, polish, embed, and produce acetate peels of ocean quahog shells.

Apparatus or materials	Source
Isomet low-speed saw machine Diamond wafering blades (High concentration) a) 10.2 cm × 0.3 mm × 12.7 mm b) 12.7 cm × 0.38 mm × 12.7 mm	Buehler, Ltd. 41 Waukegen Road P.O. Box 1 Lake Bluff, IL 60044
Hustler vibrating lap, 15 inches diameter Slab-Stik (adhesive putty) Grind and Shine, gem finishing compounds (#2, silicon carbide 800-F; #3, Syntin)	Raytech Industries P.O. Box 6 Stafford Springs, CT 06076
Epon 815 resin and DTA hardener	Miller-Stevenson Chemical Co., Inc. P.O. Box 950 Danbury, CT 06810
Di-acetate sheets 19″ × 24″ × 0.005″ thick	Commercial Plastics and Supply Corp. 352 McGrath Highway Somerville, MA 02143
Norton, Tufbak, Durite, waterproof, closekote, silicon carbide paper.	Local hardware store
"Freezette" plastic refrigerator containers.	Local hardware store

Calcium carbonate deposits embedded in the inner surfaces of the periostracum react during a later etching step, leaving voids in the peels. These deposits and the periostracum are removed by placing valve specimens in full-strength household bleach (sodium hypochlorite ~5.25 percent) for a few hours.

Pre-embedding grinding of the cut surfaces with wetable carborundum paper (240 and 400 grit) is advisable. Remove obvious saw marks or other blemishes and grind to expose the broadest surface of the tooth. Allow the specimens to dry completely before proceeding with the next step.

The valve specimens are embedded in an epoxy resin at room temperature. Mix

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

carefully, but thoroughly (~1 minute), avoiding the introduction of bubbles, and in small amounts (50-75 ml) to minimize an exothermic reaction. Pour the mixed epoxy into plastic molds to a depth of about ½ cm. Lower the valve into the epoxy with the cut surface toward the bottom of the mold and press down to force bubbles from between the cut surface and mold bottom. Place the whole set-up in a vacuum chamber and subject to low pressure (~25 psi) for about 1 hour. This evacuates bubbles formed in the epoxy. Leave at room temperature overnight to harden.

Three successively finer grits (240, 400, and 600) of wetable carborundum paper are used to obtain a smooth surface on the embedded cut surfaces of the valves. Most of the grinding is done with the 240 grit paper to remove epoxy from the cut surfaces of the valves; the finer grits (400 and 600) are used to minimize scratches from the coarser grit papers.

A blemish-free, high-gloss surface on the cut valve surfaces is produced on a vibrating lap machine in two steps. In step one, the pad in one pan for the machine is flooded with tapwater and drained in a bucket. After clamping the pan on the machine, the pad is charged with medium grit powder (#2), the specimens placed on the pad, and the machine turned on. Lead weights (~200-300 g) can be fastened to the blocks with adhesive putty to hasten polishing. During a 1-hour period the specimens are removed, rinsed in tapwater, damp-dried, and inspected for a moderate sheen. In step two, specimens are transferred to a second pan containing a wet pad, the pad is charged with fine grit powder (#3), and the machine is operated for 1-2 hours. The final high gloss is most evident on the cut valve surface, but less so on the epoxy surface.

The polished cut edges of the valves are then etched by immersing the blocks in a 1 percent HCl solution for 1 minute, followed by rinsing in tapwater. It is essential not to damage the polished or etched surfaces. Allow the etched specimens to dry. Code numbers for each valve specimen can be scribed with a carbide-tipped pen into the polished epoxy surface near the cut surfaces. These numbers are automatically transcribed onto the acetate peel during the next step.

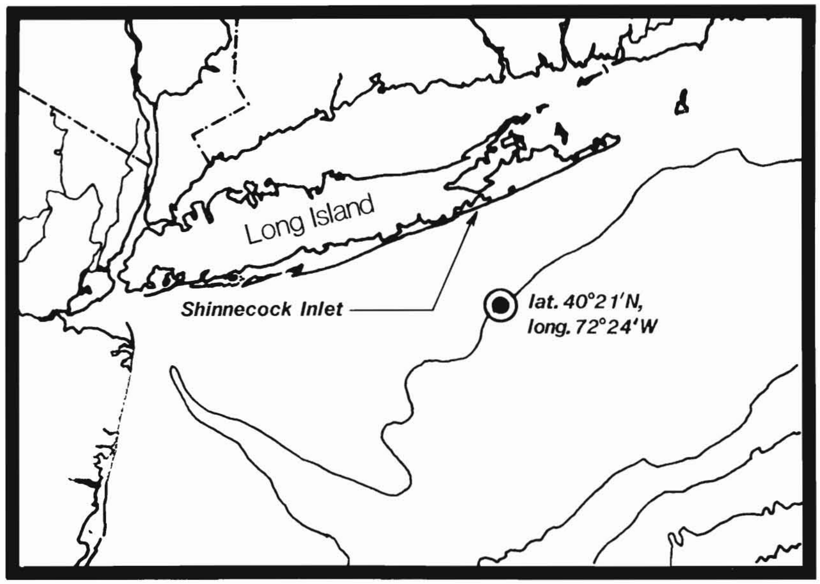

Figure 3.—Location of ocean quahogs dredged for marking and release in late July-early August 1978. Annual recoveries have been made.

Acetate peels are produced by supporting the block with the etched surfaces uppermost and level. A sheet of acetate that extends beyond the edges of the block is applied and held in place with a binder clip. The free end of the acetate is lifted, acetone is flooded onto the block surface, and the acetate sheet is lowered onto the surface. Acetone must occur between the sheet and etched surface without bubbles for a successful peel. The whole block is turned over, excess acetone is drained off, laid on a pad of paper, and pressed for about 1 minute. After a 1-hour drying period, the acetate is peeled off and sandwiched between clean glass slides for examination. Additional peels can be made without repeating the polishing and etching procedures. An acetate sheet left on the block protects the etched surface from damage during storage.

Validation of Annuli

The acetate peel technique has been used by several investigators to supply valuable evidence supporting the hypothesis of an annual periodicity of growth line deposition in ocean quahogs (Thompson et al., 1980a, b; Jones, 1980; Turekian et al., 1982). However, these studies did not include the direct and readily comprehended observations of growth after marking specimens, evidence that was necessary for a general acceptance of the hypothesis.

In 1978, the National Marine Fisheries Service conducted a marking operation at a deep-water (53 m) site 48 km SSE of Shinnecock Inlet, Long Island, N.Y. (lat. 40°25.1′N, long. 72°23.7′W) (Fig. 3). The location was chosen because it is remote from clam dredging practices in the Middle Atlantic Bight, and, from survey results, it was known to contain an abundance of quahogs of a wide size range (Murawski et al., 1982).

A commercial clam dredge vessel, the M/V *Diane Maria*, was chartered for the marking operation. The knife of the hydraulic dredge was 100 inches (2.54 m) wide and the cage was lined with ½-inch (12.7 mm) square-mesh hardware cloth to retain small clams. Ocean quahogs for marking were collected within 9 km of the planting site

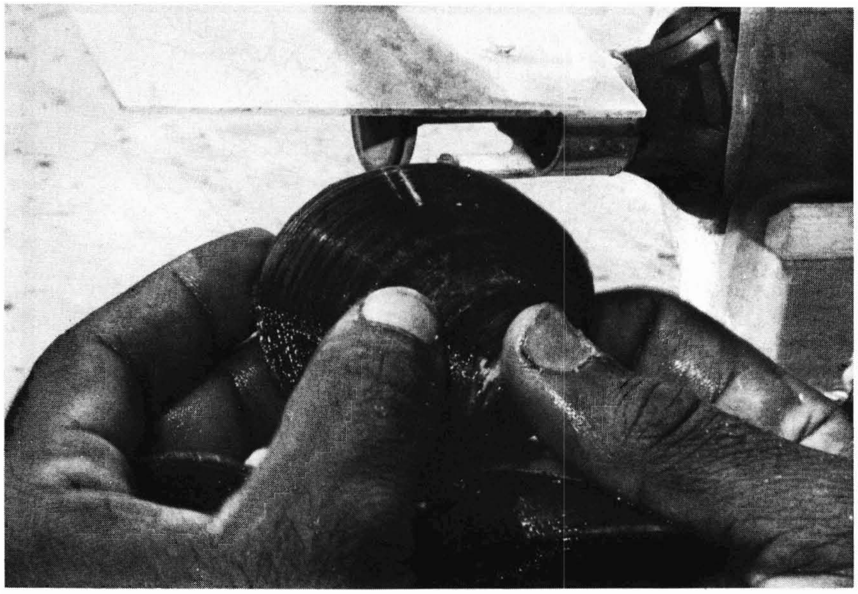

Figure 4.—Marking ocean quahogs for release off Long Island, N.Y., in 1978.

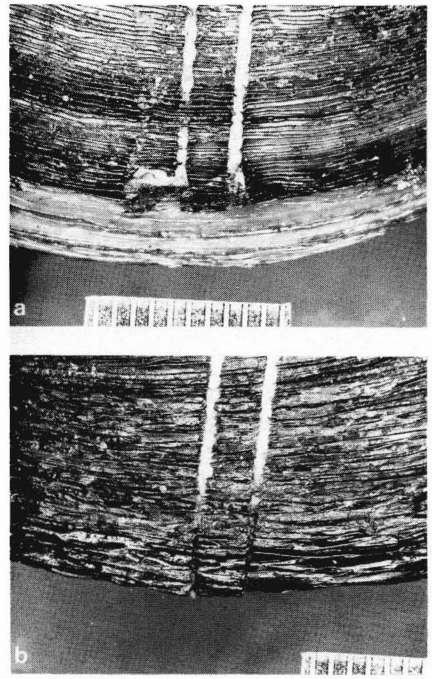

Figure 6.—(a) Enlarged view of the notches and new shell growth in the valve of the ocean quahog in Figure 4. (b) Enlarged view of the notches in the valve of an ocean quahog about 95 years old and 91.7 mm ($\sim 3^9/_{16}$ inches) in shell length recovered on 9 September 1980. The thick periostracum obscured very slight growth ($\sim$0.3 mm or $^1/_{100}$ inch) attained during the 2 years after the notching operation.

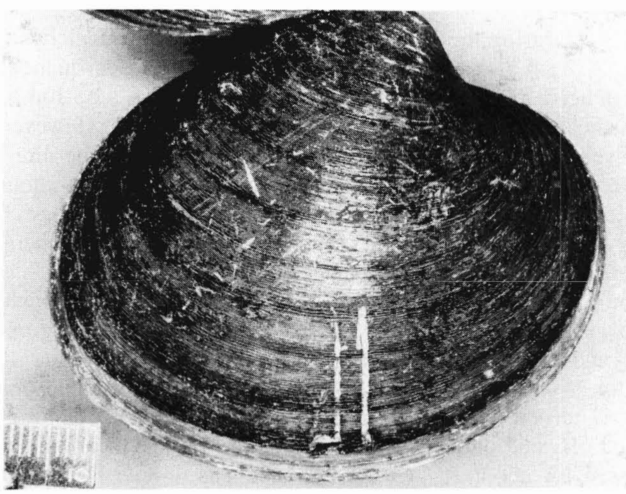

Figure 5.—Left valve of a 15-year-old ocean quahog, 60.0 mm ($\sim 2\frac{1}{3}$ inches) shell length, recovered on 9 September 1980 2 years after marking and release. The notch marks and growth thereafter show clearly at the valve margin. Estimated growth was 3.5 mm ($\sim \frac{1}{8}$ inch).

and released during a 10-day period ($\sim$17,000 on 26 July, 3,000 on 2 August, and 21,000 on 4 August 1978). Two 0.7 mm thick carborundum discs spaced 2 mm apart and mounted in the mandrel of an electric grinder produced distinctive parallel, shallow grooves from the ventral margin up onto the valve surface (Ropes and Merrill, 1970) (Fig. 4). Four operators of grinders marked about 1,600 clams per hour. Groups ($\sim$3,000-8,000) of marked clams were released at Loran C coordinates within a rectangular area of about 3 by 6 microseconds.

Marked clam recoveries were made in conjunction with annual clam resource surveys. During recovery operations, a Northstar 6000 Loran C unit and Epsco Loran C plotter aided in a systematic search of the planting site. Marked clam recoveries were highly variable. On 20 and 21 August 1979 and about 387 days after the marking operation, 43 hydraulic dredge tows at the planting site captured 14,043 ocean quahogs, and 74 (0.5 percent) were marked; on 9 September 1980 and about 773 days after the marking operation, 1,899 ocean quahogs were captured in two dredge tows, and 249 (13.1 percent) were marked. Some marked specimens were damaged, but 67 recovered in 1979 and 200 recovered in 1980 were alive and had intact paired valves.

The parallel groove marks in the wet shells were easily recognized during recovery operations (Fig. 5). New shell was more obvious at the valve margin of smaller, younger clams, since readily

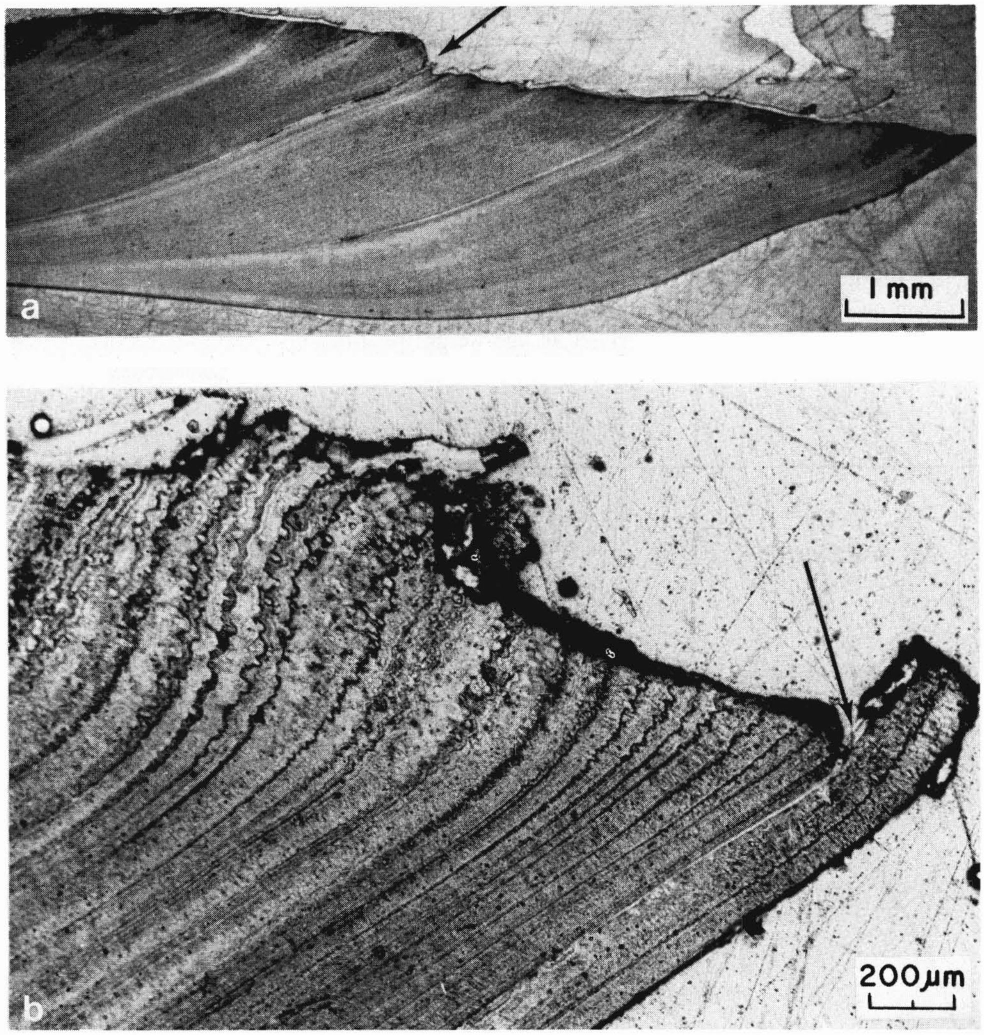

Figure 7.—Photomicrographs of acetate peels showing growth and annuli at the valve margins of the ocean quahogs used in Figures 4 and 5. (a) Three annuli in the younger quahog. An arrow points to the annuli formed soon after marking the clam. (b) Many repetitive annuli in the older quahog. An arrow points to an interruption of growth and annuli formed at or soon after marking the clam. The flattened area was produced by the notching operation. This clearly separated shell growth and annuli formed before and after the notching operation. Note that only one additional annulus was formed by both quahogs during the 2 years they were free in the natural environment, but that two increments of shell growth had been accreted.

visible growth had occurred after marking, as seen by a lighter, yellowish-brown coloration of the periostracum that usually contrasted sharply with the earlier, slightly darker layer (Fig. 5 and 6a). In old ocean quahogs the dark black periostracum obscured new shell growth (Fig. 6b). In all sizes of mark-recaptured quahogs, acetate peels showed definite increments of growth and annuli formed after marking that were consistent with an annual periodicity (Fig. 7a, b). Specific microstructures have been identified and described for the annuli and growth increments (Ropes et al., In press, a).

Application of the Technique

Based on finding an annual periodicity of annuli in marked ocean quahogs, Murawski et al. (1982) generated growth functions for two sources of age data. Internal growth lines in cross-sectioned valves were used to locate external bands on the valves for measurements of growth at each age in 134 unmarked ocean quahogs 19-60 mm (~ ¾-2⅜ inches) in shell length that were collected during the marking operation and the growth of 67 marked quahogs

(59-104 mm or ~2⅜-4⅛ inches) recaptured 1 year after marking. The growth function of backcalculated increments at age was described by $SL = 75.68 - 81.31\ (0.9056)^t$, where SL is shell length in millimeters and t is age in years; the growth function of recaptured marked specimens was described by $SL_{t+1} = 2.0811 + 0.9802\ SL_t$. Figure 8 shows the predicted shell lengths at age for ocean quahogs at the Long Island marking site. Growth was characterized as slow; at age 10 annual increases in shell length were 6.3 percent, at age 50, 0.5 percent, and at age 100, only 0.2 percent.

Age determinations of ocean quahogs by the acetate peel technique have permitted analyses of temporal relationships with growth and comparison of growth between areas inhabited by the clam. Murawski et al. (1982) developed a length-weight (drained meat) equation and derived an age-weight relationship for quahogs from the Long Island marking site. Weight gains were initially greater than length increases at young ages, but were nearly equal at the oldest ages. At age 10 mean weight increased by 18.1 percent, but at age 100 the increase was only 0.2 percent.

Ropes et al. (In press, b) collected small ocean quahogs from the vicinity of the Long Island marking site to determine sex and gonadal condition. Microscopic examination of histologically prepared tissues of clams 19-60 mm (~¾-2⅜ inches) in shell length revealed that 36 were immature and could not be sexed, but that sexual differentiation was evident in 97. Sixty-nine of the latter were in two types of intermediate development: Those with sparse tubule development (20); and those with moderate tubule development (49). Only 28 clams were fully mature. Age and growth were assessed from acetate peels of shell cross sections for a relationship with gonadal conditions. Immature quahogs 8 years old were found, but most averaged 5 years old, and were from 19 to 46 mm (~¾-1 13/16 inches) in shell length and averaged 34 mm (~1⅜ inches). Mature males were 5 or more years old and 36 mm (~1 7/16 inches) in shell length or larger; females were 6 or more years old and 41 mm (~1⅝ inches) or larger. Slightly younger and smaller quahogs were in the intermediate gonad developmental stages. The attainment of sexual maturity at age/size was variable. Determinations of sex of these and specimens 57-103 mm (~2¼-4⅛ inches) in shell length collected from the same area in 1980 indicated that the smallest and youngest ocean quahogs were predominantly male, but the largest and oldest were predominantly female.

Young ocean quahogs typically have a light brown to mahogany colored shell covering that darkens to black with increasing size and age (hence, the common names mahogany and black quahog, respectively). The brown or mahogany coloration persisted in intermediate and some large ocean quahogs collected in 1980 from southern Georges Bank and the condition was immediately recognized as being unlike that seen for ocean quahogs of similar sizes from the Middle Atlantic Bight area (Ropes and

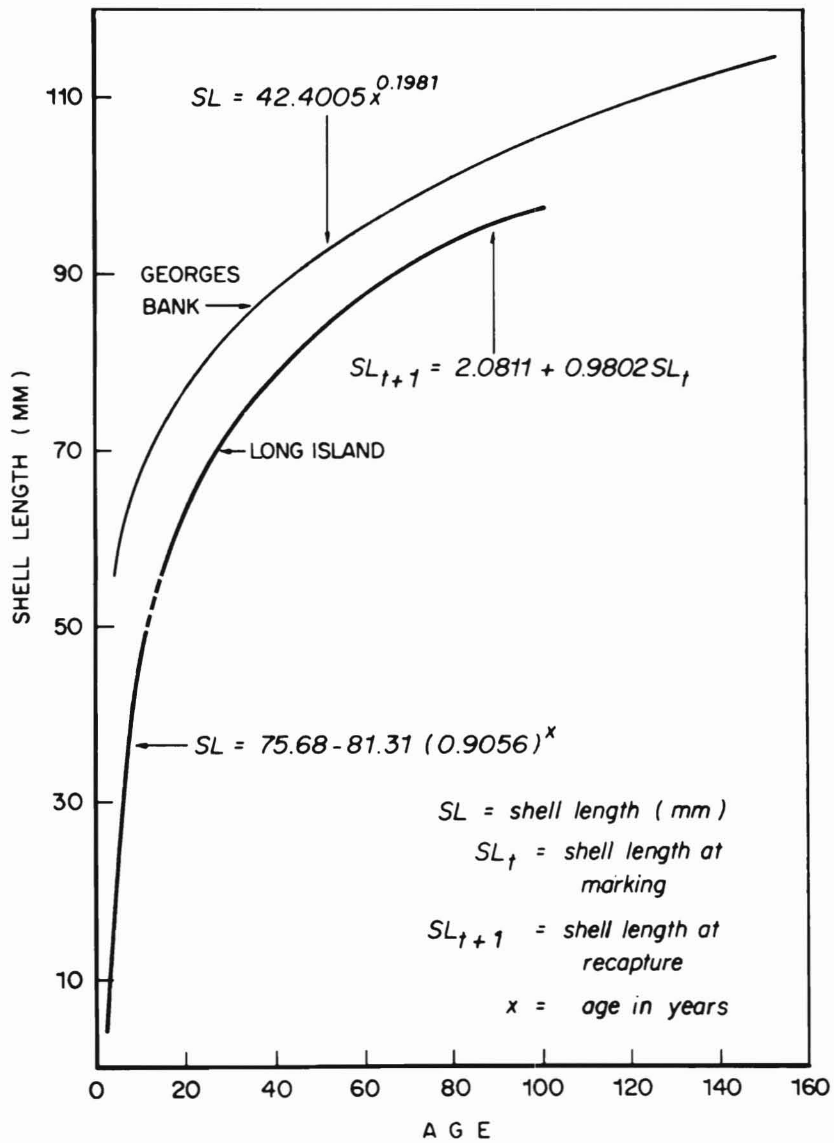

Figure 8.—Age vs. shell length of ocean quahogs off Long Island, N.Y., and from Georges Bank.

Pyoas, 1982). This obvious dissimilarity suggested that age and growth characteristics of ocean quahog populations on Georges Bank may be different from those of other geographic areas.

The shells of 82 ocean quahogs from Georges Bank were prepared for age analysis and the average length at age was compared with similar growth data of quahogs from off Long Island. A growth curve fitted to the Georges Bank data and plotted along with a growth curve of the Long Island data indicated a much slower growth rate for the latter area (Fig. 8). A few shells of ocean quahogs were also available from off Sable Island, Canada. These provided age observations from a third geographic area for comparison with quahogs of the same size from the other two areas, but were too few to construct a growth curve. Georges Bank quahogs were clearly younger than those from off Long Island or Sable Island; Sable Island quahogs were the oldest. For example, an ocean quahog 100 mm (~4 inches) in shell length from Georges Bank and one the same size from off Long Island were 40 and 110 years old; quahogs 52 and 54 mm (~2 inches) in shell length from Georges Bank and Sable Island were 4 and 13 years old; and a Georges Bank quahog 73 mm (~2⅞ inches) in shell length and a Long Island quahog 72 mm (~2¾ inches) in shell length were 16 and 24 years old, respectively (Fig. 9).

A longevity of about 150 years reported for the ocean quahog, *Arctica islandica*, by Thompson et al. (1980a, b) was a startling discovery. Life span estimates of a few invertebrates, including the freshwater mussel, *Margaritana margaritana*, of not over 100 years have been made (Comfort, 1956). Zolotarev (1974), Zolotarev and Ignat'ev (1977), and Zolotarev and Selin (1979) found from examinations of the shell structure, analyses of an oxygen-isotope method, and notching experiments that the Far East mussel, *Crenomytilus graynus*, may exceed 100 years of age; Turekian et al. (1975) found from radiometric analyses and counting internal growth bands that a deep sea nuculoid bivalve, *Tindaria callistiformis*, only 8.4 mm in shell length, may be about 100 years old.

Table 2.—Ages of unusually large ocean quahogs.

Sample date	Location		Depth (m)	Shell dimensions				Valve thickness (mm)	Age (years)
	Latitude	Longitude		Length (mm)	Height (mm)	Width (mm)	Weight (g)		
14 Feb. 1977[1]	39°55′	73°31′	38.4	132.0	121.2	71.5	412.7	7.0	157
7 Dec. 1978[1]	39°30′	73°19′	34.7	130.0	111.5	61.6	244.6	3.2	53
11 Aug. 1982[2]	40°34′	68°56′	69.0	130.0	119.0	63.2	310.8	4.8	93
Fall 1980[3]	41°06′	70°54′	36.6	107.2	95.2	68.3	397.7	12.3	221

[1]The earliest 2-3 annuli in the hinge tooth were missing, but all in the valve were present.
[2]The earliest 2-3 annuli in the hinge tooth were missing and 1-2 of the earliest annuli in the valve were missing.
[3]The earliest 3-5 annuli in the hinge tooth were missing and 2-3 of the earliest annuli in the valve were missing.

The estimate of longevity by Thompson et al. (1980a) was of an ocean quahog 88 mm (~3½ inches) in shell length. Much larger maximum shell lengths are attained. Murawski and Serchuk (1979) analyzed shell length-meat weight relationships of 2,564 ocean quahogs collected during a winter 1978 assessment survey throughout the Middle Atlantic continental shelf. Specimens with a maximum shell length of 131 mm (~5³/₁₆ inches) were found. Although the shells of these quahogs were not saved, three unusually large ocean quahogs were saved from the clam assessment surveys and a fourth was provided by commercial fishermen (Table 2). All were alive when caught. Shell erosion destroyed some of the earliest annuli. Therefore, age determinations are minimum values.

The ages of the three very large ocean quahogs were surprising, because only one slightly exceeded the longevity value reported by Thompson et al. (1980a). It was the 132 mm (~5¼ inches) in shell length quahog from off central New Jersey that was estimated to be 157 years old (Table 2). Another 130 mm (5⅛ inch) quahog from off central New Jersey was only 53 years old and the third from Georges Bank was 130 mm in shell length and 93 years old. The age and growth of ocean quahog populations from off New Jersey have not been investigated. Thus, the observations for the two New Jersey specimens may only represent unusual growth.

The heavily shelled ocean quahog from south of Noman's Land in southern Massachusetts water was smaller than the other three clams, but had a somewhat more globose shape (Table 2). Its shell weight was 397.9 g (~14 ounces), which is nearly equal to the 412.7 g (~14.6-ounce) weight of the largest (132.0 mm) clam examined. Part of the shell weight was due to thickening of the valve, especially beneath the hinge plate which measured 13 mm. This was more than twice as thick as was measured for the youngest (53-year-old) clam caught in 1978. About 90 percent of the thickening was of the inner shell layer. The outer shell layer became increasingly prominent with growth, although ventral to the pallial line it was no more than 4 mm thick. No apparent blunting of the ventral margin was observed, a characteristic sometimes seen in large, old hard-shelled clams, *Mercenaria mercenaria* (Dall, 1903; Belding, 1912). This clam was estimated to be 221 years old.

These observations are largely anecdotal, but they emphasize the potential for considerable variability in the size/age relationship and longevity of ocean quahogs. The variability appears to be most extreme at large size. Specific conditions for fast growth, large size, and very old age of ocean quahogs are unknown. Nevertheless, longevity for the species is substantially greater than reported by Thompson et al. (1980a) and may even be slightly higher than the 221 years given herein, since the earliest annuli were eroded and the clam was alive when captured.

Discussion

The acetate peel technique has proven to be invaluable for providing age determinations of ocean quahogs. However, its application is labor intensive. Nevertheless, segments of the populations have been aged, gaining insight

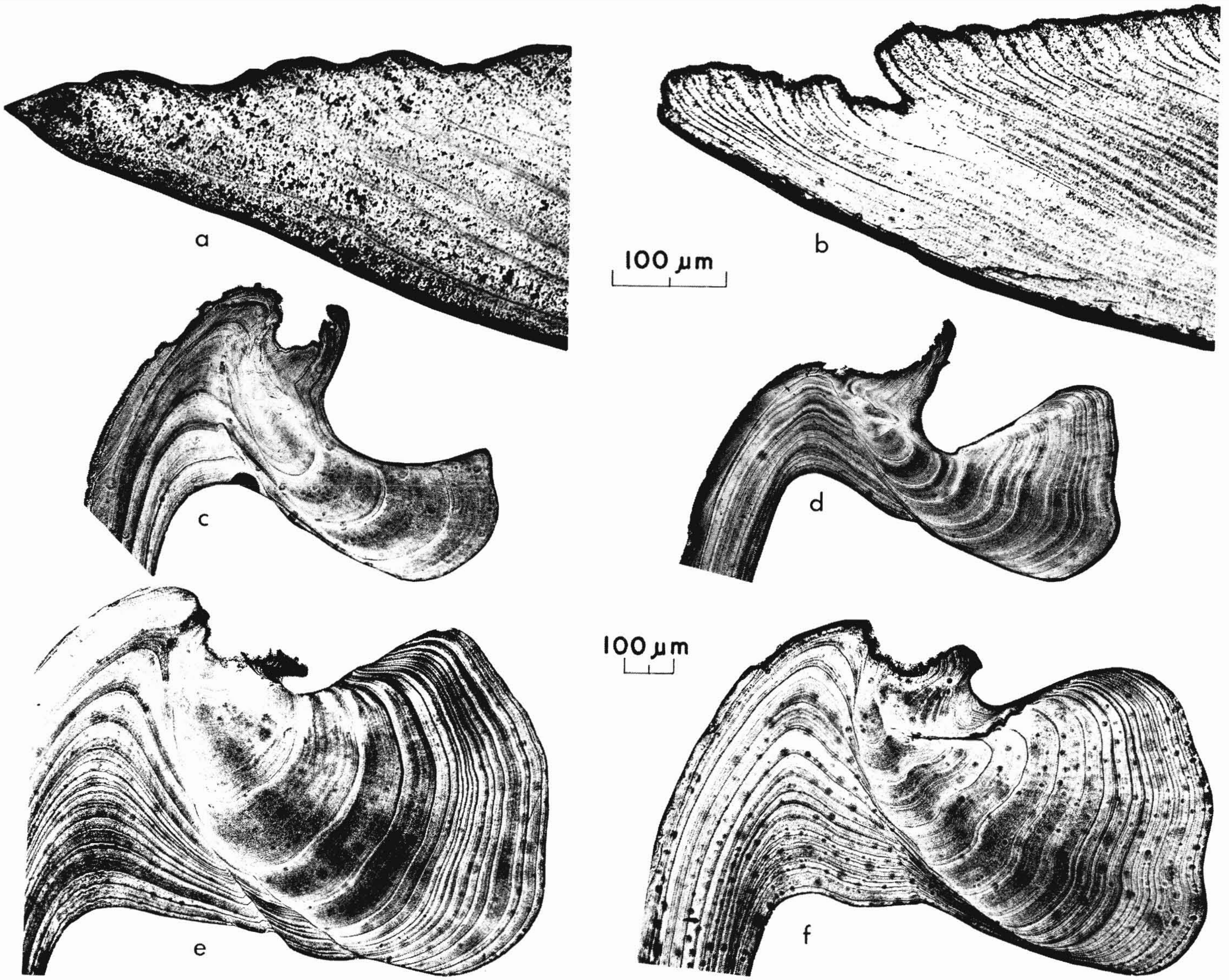

Figure 9.—Valve tip of *Arctica islandica* (a) from Georges Bank, 100.0 mm (~4 inches) in shell length and 40 years old, and (b) from off Long Island, N.Y., 100.3 mm (~$4\,^1/_{16}$ inches) in shell length and 110 years old. Upper scale bar shows enlargement of a and b; lower scale bar is for the remaining photomicrographs. Hinge tooth of *Arctica islandica* (c) from Georges Bank, 53.9 mm (~$2\,^1/_8$ inches) in shell length and 4 years old, and (d) from Sable Island Bank, 52.1 mm (~$2\,^1/_{16}$ inches) in shell length and 13 years old. Hinge tooth of *Arctica islandica* (e) from Georges Bank, 73.2 mm (~$2\,^7/_8$ inches) in shell length and 16 years old, and (f) from off Long Island, New York, 72.1 mm (~$2\,^3/_4$ inches) in shell length and 24 years old.

into age relationships of this important bivalve.

The observed differences in growth rate between geographic areas indicate that a generalized growth curve may not be strictly applicable throughout the extensive range of the species. Along the North American coast, it occurs from off Cape Hatteras, N.C., to off Newfoundland, Canada, and it also occurs off Iceland, the Faroe and Shetland Islands, and along the European coast from off Spain to the White Sea in Russia (Ropes, 1979b).

For population assessment studies, it is desirable to age large numbers of specimens throughout the extensive potential fishing areas in the Middle Atlantic Bight and off southern New England, a goal that is thwarted by the labor-intensive nature of shell preparation and microscopic examination required to age ocean quahogs. Preparation of shells for ageing are in progress for samples taken 1981-83 from marked quahogs off Long Island and samples taken from Georges Bank in 1982. The challenge for future studies is to expand sampling in areas being fished. The U.S. resource is presently regulated by a fishery management plan developed by the Mid-Atlantic Fishery Management Council with annual quotas of 40-60 million pounds of meats (MAFMC, 1981). It has been hypothesized that harvested areas would probably recover slowly due to the slow growth rate of ocean quahogs (Murawski and Serchuk, 1980). Analyses of age composition and growth in such areas may provide a basis for evaluating recovery.

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