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Growth Rate of Giant Clam Tridacna gigas at Bikini Atoll as Revealed by Radioautography

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Reprinted from Science, July 16, 1965, Vol. 149, No. 3681, pages 300-302

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Abstract. *At Bikini Atoll, radioactivity from strontium-90 deposited in the growing shell of a giant clam, presumably during the testing of nuclear weapons in 1956 and 1958, produced unmistakable lines on radioautographs made from transverse sections of the shell. The regular banding seen in the sections is interpreted as annular in nature. One annulus precedes the 1956 layer of radioactivity, two intervene in 1958, and six follow to the time of collection, so that this clam (length, 52 centimeters) was in its 9th year of life.*

Written records of the giant clam *Tridacna gigas* Linné have existed for centuries. Considered remarkable at first simply because of its large size (2 m in greatest length and several hundred kilograms in weight), the clam was later (*1*) found to contain symbiotic algae within its tissues. Yonge proposed that the clam attained such size by "farming" the zooxanthellae within the greatly expanded tissues of the siphons, and by utilizing the photosynthetic products in nutrition (*2–4*). However, in spite of an almost universal curiosity about the age of these giants of the coral reefs, no studies on their rate of growth have been reported. The rate of growth of *T. gigas* over a period of several years can now be estimated by reading the annulations in the shell and relating them to marks introduced by radioactivity from nuclear detonations.

Although the ability of *T. gigas* to concentrate Co^{60} in its soft parts has been emphasized (*5*), little is known concerning the uptake of radionuclides by the shell, which is shown here to contain Sr^{90}. To elucidate the pattern of deposition of nuclides in the shell after nuclear detonations, one valve of a specimen 52 cm in length (*6*) from Bikini Atoll was transversely sectioned with a 51-cm circular diamond saw. Figure 1 shows a section, 6 mm in thickness, from the region immediately anterior to the umbo. Figure 2 shows a radioautograph resulting from exposing the section to "No Screen" x-ray film for a period of 3 months. Two lines each about 2 mm wide, representing layers of radioactive material, appeared on the film. Other sections farther from the umbo also showed these marks. Records (*7*) reveal that tests of nuclear devices were conducted at Bikini Atoll only in 1946, 1954, 1956, and 1958. It is reasonable to attribute the layers of radioactivity to the two most recent test series. The 1956 Redwing series at Bikini extended from 20 May through 20 July, and the 1958 Hardtack series from 11 May through 22 July.

The positions of the layers containing radioactivity were determined by superimposing the radioautograph on the shell section, and are shown as stippled lines in Fig. 1, top. This view by transmitted light accentuates the conspicuous alternating dark, relatively opaque, layers, as contrasted with the lighter, more translucent bands, clearly indicating apparent years of age. Up to the 1956 line the clam was in its first year of life. Two years intervene between the two stippled lines, to 1958, and then six more years to the inner surface of the shell representing 1964, so that the clam was in its 9th year. The 1956 line corresponds to a shell length of about 10 cm, and the 1958 line, to about 24 cm.

It is of special interest that a tropical organism living in water with a mean monthly temperature varying less than 3°C (*8*) throughout the year should display distinct annulations. Seasonally varying environmental factors other than temperature, such as winds, currents, weather, light, and the abundance of planktonic food, could influence growth. At Bikini Atoll the relatively constant winter trade winds from the east are frequently interrupted in summer by other winds, particularly from the south (*9*), and surface currents would be similarly influenced.

Spawning is probably of a seasonal nature and thus may influence shell growth. Yonge (*2*) cites the spawning of the closely related genus *Hippopus* in January of the Australian summer and gives 30°C as the minimum temperature for spawning of the giant clam (*3*). Wada (*10*) reported that *Tridacna* collected in the Palau Islands in April, May, and June of 1938, 1940, and 1941 frequently discharged sperm and eggs when brought into the laboratory, although he said nothing of those collected in other seasons.

During growth, new shell material is added exclusively on the inside. Although the mantle is attached only at the pallial sinus, it contacts and deposits new material (aragonite) upon the entire inner surface of the shell. The extrapallial portion of the shell, distal to the pallial sinus and comprising about half of the total inner surface, is prismatic, while the central basal part of the shell is nacreous. In macroscopic views of sections (Fig. 1, bottom) the distal, prismatic part is relatively opaque and shows only faint layering; the central, nacreous part is more translucent and distinctly layered. The two areas are clearly demarcated by a boundary layer leading from the basal edge of the existing pallial sinus obliquely through the shell toward the umbo at the base (Fig. 1, *P*).

Figure 3 shows a low-power photomicrograph obtained by using crossed polaroid discs of a thin (15 to 20 μ) shell section at the position indicated by the dashed lines of Fig. 1 (top). Although Fig. 3 shows the outer border of the shell at the upper left, it does not extend to the inner border. The prismatic outer layer occupies the first and most of the second column of photographs down to the sloping light area which is the pallial layer marked *P*, while the rest of column 2 and all of columns 3 and 4 consist of nacre. The prismatic layer is composed of vertical columns about 45 μ in thickness disposed normally to the outer surface of the shell. The nacreous layers below are more irregular, with only slight or localized indications of vertical striae, but with both primary, coarse layering and fine striations oriented approximately parallel to the inner shell surface. The degree of separation of the fine striations seems to affect the differentiation of the dark and light annular bands revealing age; the striations are finer and more closely packed (about 15 μ between centers) in the dark, relatively opaque areas of Fig. 1 than in the lighter, more translucent regions (25 μ). Probably the light areas are deposited during seasons of warmest water temperature, 29° to 30°C, which occur at Bikini Atoll from August to October, inclusive (*8*). Possibly a cool summer accounts for the lack of a distinct light area on the inside of the shell in Fig. 1 even though it was collected on 22 August.

Tridacna gigas grows fast compared to other molluscs. Wilbur and Jodrey (*11*) estimated from uptake of Ca^{45} that the shell of the oyster, a relatively fast-growing mollusc, increased in weight about 1 g per 70 cm^2 of surface per month. The annual increment in thickness of the giant clam shell under consideration was approximately 1 cm. With a shell density of 2.75 this would yield

$$(1.0)(70)(2.75)/12 \doteq 16$$

grams per 70 cm^2 per month, or 16 times the growth rate of the oyster. Annular bands on the only other specimen (*12*) of *T. gigas* sectioned to date in this laboratory indicate growth approximately 1.5 times as fast, to a length of 55 cm in only 6 years. Such rapid growth, where length increased by 5 to 8 cm per year, or by 50 cm or more in from 6 to 9 years, probably gives the giant clam the distinction of being the fastest growing of bivalves.

In order to identify the radionuclides responsibile for the lines on the radioautographs, a strip about 7 mm wide along the 1958 line of radioactivity was bandsawed and chipped from the shell section shown in Fig. 1, top. The broken pieces of this excised strip, weighing 14 g, yielded 8 net counts per minute in a low-level, anticoincidence gross beta counter of 0.4 geometry with a background of 0.8 count per minute. There was no detectable peak above background even after 3900 minutes of counting on a 256-channel gamma spectrometer with a 7.6-cm sodium iodide crystal detector. The material was finally analyzed for Sr^{90}-Y^{90}, considered the most likely radionuclides

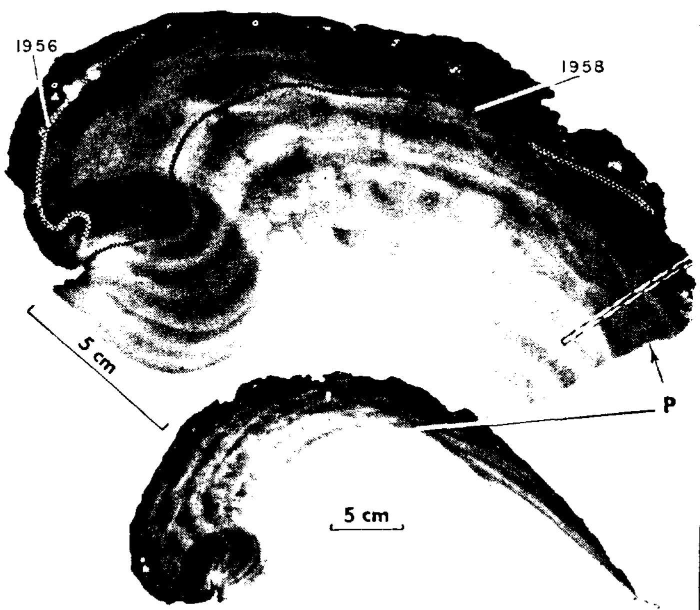

Fig. 1 (above). Transverse section, 6 mm in thickness, of *Tridacna gigas* shell near the umbo. (Top) Basal portion to a scale 2.5 times the lower figure, showing by stippled lines the positions of the layers of radioactivity traced from the radioautograph (*P*, indicates the pallial mark). (Bottom) Entire section.

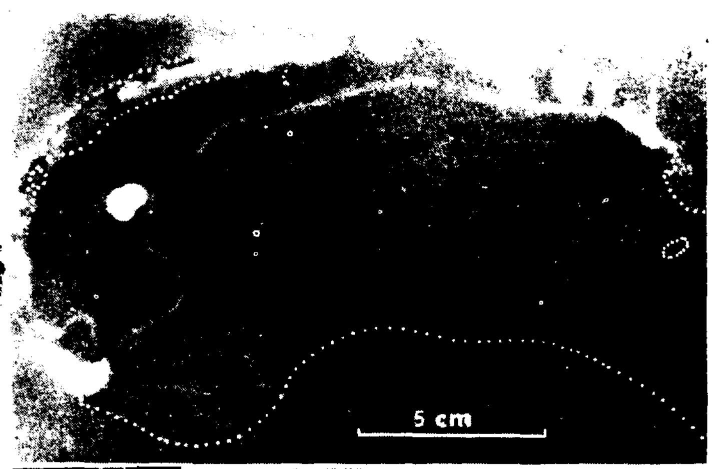

Fig. 2 (above right). Radioautograph of basal portion of section of shell of *Tridacna gigas* shown in Fig. 1. Retouching was limited to the dotted lines indicating the outlines of shell and eroded areas. The two light undulating lines originating near the umbo resulted from the beta activity of Sr^{90} presumed to have been deposited in 1956 and 1958, respectively. Radioactivity is also evident in the umbonal cleft and elsewhere on the outer surface as well as in the eroded spaces. The white spot left of center resulted from Ca^{45} mixed with the ink used to label the section *5b* (see Fig. 1).

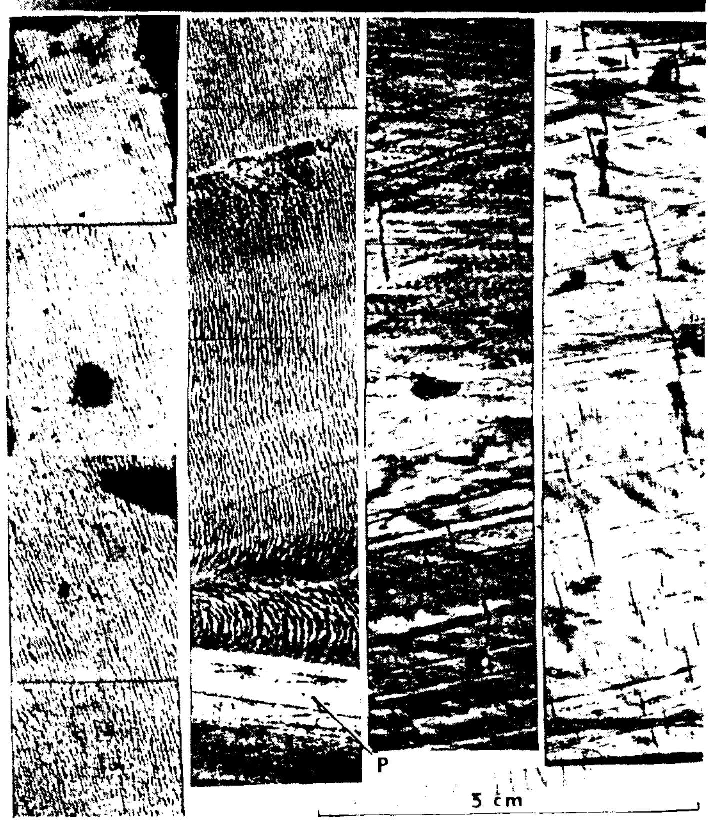

Fig. 3 (right). Composite photomicrograph of thin transverse section ground to a thickness of 15 to 20 μ. Removed from the position indicated by dashes on the right side of Fig 1, (top). Length and width of section, 41 by 2 mm. The continuous strip is divided for convenience into four columns starting with the outside of the shell at the upper left (*P* indicates the pallial mark).

because of the absence of gamma activity and because of the association of Sr with Ca. Beta-counting of the Y^{90} daughter of the Sr^{90} gave 16 disintegrations per minute per gram of shell material, and the decay rate was appropriate for Y^{90}. Thus, although there were undoubtedly other radionuclides in the shell shortly after the detonations, physical decay left detectable amounts of only Sr^{90}.

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References and Notes

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6. Specimen 302 was the smallest of six ranging to 73 cm in length collected between 2 and 4 p.m. on 22 August 1964 about 100 m off the north point of Airukiiji Island in water 1 to 3 m deep. On the following day the soft tissues were removed for radioassay. The dry half-shell, brought to Seattle, was sectioned on 21 September 1964.
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12. Dr. A. D. Welander found specimen 128 about 11 a.m. on 12 August 1964 in water less than 1 m deep within 20 m of the north shore of Engebi Island, Eniwetok Atoll.
13. Work done under contract AT(45-1)1385 with the AEC. I thank also Mr. Egil Oas for preparing the thick and thin sections of the shell, Miss Lorna Matson for the radioautographs, and Dr. Grant Gross for identification by x-ray diffraction of aragonite in the shell.

7 June 1965

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