structure is slowly settling, thus changing the image size. If we exclude the possibility that the settling began when our radius measures started, we can set some limits on the magnitude of this effect. The 150-foot Tower Telescope is actually two towers (*13*); one holds the optics and the other, on completely separate piers, holds the dome. Over the 70-year life of the tower, a differential settling of as much as 20 mm would easily have been noticed. This is 0.3 mm per year, which would result in a change of only 0.006 arc second per year, or 0.6 arc second per century, as an upper limit.

Solar magnetic regions at the limb should affect the measured radius because the intensity near the limb is changed by the presence of dark sunspots or bright faculae. Based on our observations of magnetic regions near the limb, this effect is $\lesssim 0.01$ arc second and can be disregarded for this study.

Results. Figure 2 shows the radius residuals obtained after correcting the raw radius measures for the effects listed in Table 1. The standard deviation of a single residual is about 1/4 arc second. The residuals do not have a Gaussian distribution; the dominant error is not random, but systematic. Two problems are apparent: (i) residuals tend to clump for periods of about 40 days (determined by autocorrelation), with larger variation between clumps than within a single clump, and (ii) there is an annual pattern, dominated by episodes of large negative residuals in the spring. Because the systematic variations of the residuals have abrupt onsets and the largest variations repeat annually, we are convinced these systematic errors originate in the instrument or observing procedure, but have been unable to identify the specific causes.

In a 40-day interval we have about 25 observations. The formal error of any parameter measured from the residuals should thus be increased by $\sqrt{25}$ because we do not have independent samples. Including this factor, we fit the residuals separately for a secular trend and an 11-year sinusoid. The results were a trend of 0.2 ± 1.6 arc second per century, or a sinusoid of 0.1 ± 0.1 arc second (errors are ± 1 standard deviation). Both results are consistent with zero radius variation over the past 7 years.

Discussion. It is unfortunate that the systematic effects remaining in our data are so large. The limits on radius variations that we are able to set are not improvements over previous results (*3, 5, 7*) and thus do not resolve discrepancies among those results. The program of observations at Mount Wilson is continuing, and we may be able to find and eliminate the sources of systematic error. The random errors of measurement appear to be about 1/5 or 1/6 arc second per observation; a data set of several years duration with errors of that magnitude would be a significant improvement over previous radius measurements.

When one considers that the instrument, the observing procedure, and the standard radius reduction were not optimized for this purpose, the size of our residual errors is encouraging. A ground-based instrument designed for this specific observation should be capable of extremely high precision.

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Growth Rate of a Vesicomyid Clam from the Galápagos Spreading Center

Abstract. *The shell of a 19-centimeter-long vesicomyid clam, collected live at the Galápagos spreading center hydrothermal field, was sampled along growth lines and analyzed for members of the* ^{238}U *and* ^{232}Th *decay series. The growth rate, determined from the* $^{210}Po/^{210}Pb$ *and* $^{228}Th/^{228}Ra$ *couples, is about 4 centimeters per year along the axis of maximum growth, which is 12 centimeters long. This yields an age of 3 to 4 years for this clam.*

After the discovery of large white clams associated with the Galápagos spreading center by Lonsdale (*1*), a series of exploratory dives were made at the site by the submersible *Alvin*. The shell of a dead vesicomyid clam, collected during the first series of dives in February and March 1977 (*2*) from the site designated Clambake I, was sent to us, and we made a preliminary estimation of the growth rate on the basis of a whole shell analysis for the natural radionuclides (*3*). We first set upper limits of age and then used the $^{228}Th/^{228}Ra$ activi-

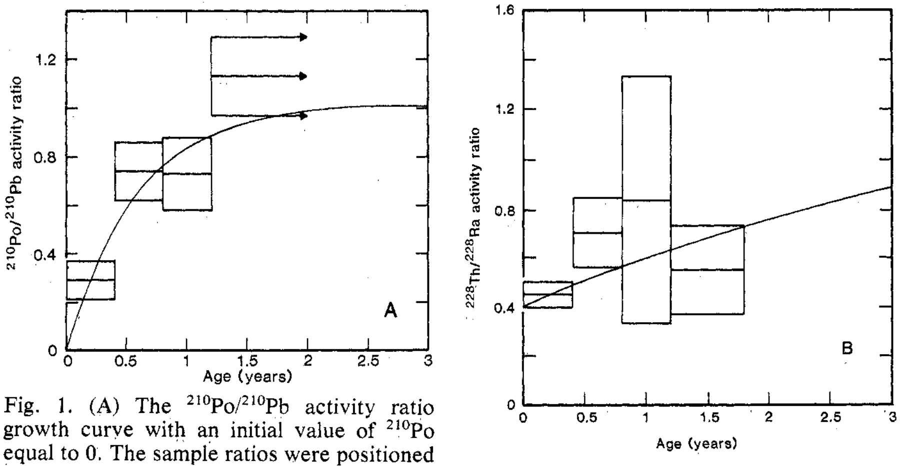

Fig. 1. (A) The $^{210}Po/^{210}Pb$ activity ratio growth curve with an initial value of ^{210}Po equal to 0. The sample ratios were positioned along the curve by eye to obtain the age of the clam; continuous deposition is assumed. The last sample is in equilibrium and therefore could be about 2 years old or older. Its age is constrained by the $^{228}Th/^{228}Ra$ data. (B) The $^{228}Th/^{228}Ra$ activity ratio plotted as a function of age (determined from the $^{210}Po/^{210}Pb$ data) for sequential layers in the clam shell. The best fit curve for $^{228}Th/^{228}Ra$ growth with time requires an initial $^{228}Th/^{228}Ra$ activity ratio of 0.4. The oldest sample is less than 2 years old.

ty ratio to set the "best" age at time of collection of 6.5 years with an analytical level of uncertainty of −3, +5 years (at 1 standard deviation). Such a whole shell age was based on four assumptions, all probably not completely valid. They are: (i) the mass growth rate was constant, (ii) the initial ^{228}Ra specific activity was constant, (iii) there was no initial ^{228}Th, and (iv) no loss of shell by dissolution had occurred.

In order to determine growth rates independent of these constraints, we planned to analyze serial incremental growth layers in the shell of a freshly collected live clam. The opportunity to do this arose during the 1979 winter expedition to the Galápagos spreading center (*4*). We obtained a specimen (895-74), collected live at the site designated Mussel Bed. The specimen has been described by Boss and Turner (*5*) as belonging to the new species *Calyptogena magnifica*. Specimen 895-74 is 188.5 mm long.

One valve of the specimen was available for sampling. After the shell was cut, the inner layer was completely removed from the section to be analyzed by a series of washings with dilute HCl. Removal of this layer was necessary because it represents a range of ages that cannot be resolved during sampling and thus would confound the serial information sought from the outer shell layer if not excluded. Sampling of the outer layers was done with a dental drill. The lengths refer to the distance along the axis of maximum growth as measured from the growing edge. Although each sampled interval was weighed, this gives only a crude estimate of shell mass because of significant losses during the sampling process. Chips of each sample were cleaned in 30 percent H_2O_2 to eliminate the periostracum. Appreciable periostracum was visible only in the sample layer from 0 to 2 cm (the growing edge).

Each layer was analyzed for ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Th, ^{232}Th, and ^{228}Ra. The ^{210}Po, ^{228}Th (and ^{232}Th), and ^{226}Ra were determined immediately and the appropriate separates for ^{210}Pb and ^{228}Ra measurements were set aside for about a year to allow for ingrowth of ^{210}Po and ^{228}Th, respectively, which were then determined to obtain ^{210}Pb and ^{228}Ra concentrations. The methods of analysis are described in (*6*). The results are shown in Table 1.

Table 1. Radiochemical activities measured in serial growth layers of a vesicomyid shell (895-74) from Mussel Bed at the Galápagos spreading center. Reported errors represent 1 standard deviation counting errors.

Interval along traverse (cm)*	Mass (g)	Specific activity at time of collection (dpm/g of CaCo$_3$)						Activity ratios			
		^{210}Po	^{210}Pb	^{226}Ra†	^{228}Th$_{xs}$‡	^{232}Th	^{228}Ra	^{228}Th/^{228}Ra	^{228}Ra/^{226}Ra	^{210}Po/^{210}Pb	^{210}Pb/^{226}Ra
0 to 2	10.50	0.122 ± 0.032	0.423 ± 0.032	0.10	0.0105 ± 0.0010	0.0006 ± 0.0002	0.0232 ± 0.0018	0.45 ± 0.05	0.23 ± 0.03	0.29 ± 0.08	4.23 ± 0.50
2 to 4	7.58	0.325 ± 0.042	0.440 ± 0.039	0.092	0.00718 ± 0.00082	0.0010 ± 0.0002	0.0103 ± 0.0019	0.70 ± 0.14	0.11 ± 0.02	0.74 ± 0.12	4.78 ± 0.64
4 to 6	3.99	0.295 ± 0.051	0.402 ± 0.039	0.084	0.00208 ± 0.00096	0.0011 ± 0.0003	0.00252 ± 0.00097	0.83 ± 0.50	0.03 ± 0.01	0.73 ± 0.15	4.37 ± 0.61
6 to 8	4.16	0.295 ± 0.016	0.262 ± 0.034	0.087	0.00427 ± 0.00082	0.0011 ± 0.0003	0.00772 ± 0.00211	0.55 ± 0.18	0.09 ± 0.03	1.13 ± 0.16	2.85 ± 0.47

*Traverse is along the axis of maximum growth; the total length from umbo to growing edge along this line is 12 cm. †The counting error is about 10 percent of the value listed. ‡Subscript "xs" indicates that the values are corrected for ^{228}Th supported by ^{232}Th.

The growth rate for the clam we analyzed is constrained by two radionuclide couples, ^{210}Po/^{210}Pb and ^{228}Th/^{228}Ra. As calcium carbonate is deposited by molluscs the shell excludes ^{210}Po and incorporates ^{210}Pb. After the shell layer is deposited, ^{210}Pb (22-year half-life) produces ^{210}Po (138-day half-life) by radioactive decay so that the ^{210}Po/^{210}Pb activity ratio changes in a definite time-dependent manner from an initial value of 0 to a secular equilibrium value of 1, which is effectively attained after 2 years (*7*). This growth curve is shown in Fig. 1A, and the ^{210}Po/^{210}Pb ratios of the individual layers sampled (Table 1) are conformed to the curve, thus setting the age at time of collection of each layer. The sample from 6 to 8 cm is not constrained by the ^{210}Po/^{210}Pb value since it is at secular equilibrium and can be any age equal to or greater than 2 years. However, the low ^{228}Th/^{228}Ra activity ratio of the sample constrains it to a young age.

With the ages obtained from Fig. 1A, the ^{228}Th/^{228}Ra activity ratio can be plotted as a function of age (Fig. 1B). The best fit ^{228}Th/^{228}Ra activity ratio evolution curve, drawn through the sampling-error boxes, requires an initial ^{228}Th/^{228}Ra activity ratio of 0.4. This is a surprising result. There is virtually no periostracum preserved for most of the shell. This indicates that ^{228}Th is either trapped in the lattice site of the growing aragonite or is associated with organic matrices within the shell and is therefore not removed by the H_2O_2 cleaning procedure. It should be noted that any secondary adsorption of ^{228}Th would make the ages appear older. Only by accepting an initial ^{228}Th incorporation in the shell with ^{228}Ra can we conform the ^{210}Po/^{210}Pb and ^{228}Th/^{228}Ra ages.

The growth rate of clam 895-74 along the axis of maximum growth is 5 cm per year for the first 6 cm, and about 2 to 3 cm for the next 2 cm, with an average growth rate for the entire 8-cm section of about 4 cm per year. If we assume that the 12 cm from the umbo to the growing edge along the axis of maximum growth were deposited at this average rate, then the age of this specimen of *Calyptogena magnifica* is about 3 years. If we use the growth rate of the layer from 6 and 8 cm for the remainder of the older part of the shell, we obtain an age of 4 years for the clam. These ages are compatible with the whole shell determination made earlier (*3*). Thus the young ages and fast growth rates of the large vesicomyid clams of the Galápagos spreading center hydrothermal field are established within these reasonable limits.

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Growth of Bivalves at Deep-Sea Hydrothermal Vents Along the Galápagos Rift

Abstract. *Direct measurements of shell growth of an unclassified mussel from active hydrothermal vents along the Galápagos Rift reveal growth rates of approximately 1 centimeter per year for mature specimens. The largest mussel collected (with shell length of 18.4 centimeters) was estimated to be 19 ± 7 years old at the time of sampling. Recorded growth rates are among the highest documented for deep-sea species.*

Most communities of abyssal benthic organisms from soft, bottom sediment habitats are characterized by low densities of small deposit feeders. In these communities biological processes, such as metabolism, growth, colonization, and birth, are known to be slow in comparison with processes in shallow-water ecosystems (*1*, *2*). The faunal assemblages discovered in 1977 around deep-sea hydrothermal vents along the Galápagos Rift are different from all earlier studied deep-sea communities; they are dominated by dense aggregations of large epifaunal suspension-feeding organisms that live on hardened lava around active thermal springs. Many of the organisms encounter temperatures of 12° to 17°C and apparently feed on dense suspensions of chemosynthetic bacteria that obtain energy from the earth's interior through oxidation of metal sulfides which emanate from the vents (*3*, *4*).

A major goal of the Galápagos Rift research program is to compare rates of biological processes at the vents with rates in other deep-sea and shallow-water ecosystems. In this report, we summarize results of the first direct measurements of growth of an organism from the hydrothermal vent areas. The studied organism is a presently unclassified mussel (Bivalvia; Mytilidae), a species which dominates the vent fauna in both numbers and biomass (*5*, *6*).

Two techniques exist for obtaining growth rates in skeletonized deep-sea benthos: radiochemical dating (*2*, *7*) and mark-recapture. For this study we employed the mark-recapture technique for the first time in the deep sea. The shells of living mussels at the vent area known as Mussel Bed (*6*) were abraded with a file along their posterior margins on 12 February 1979 with the use of the manipulator arm of the deep-sea research vessel *Alvin* (dive 887). All file-marked specimens were located within a single clump of mussels that was identified with a cube-shaped wire marker and recovered by *Alvin* on 3 December 1979 (dive 986) after 294 days. The filing resulted in different degrees of marking success. Some mussels showed definite evidence of rasp grooves on the abraded region of the shell, and these are identified in Fig. 1A as clearly marked specimens. Mussels with an abraded shell edge but without evidence of grooves cut by the file are labeled as probably marked specimens (Fig. 1A). Mussels from the

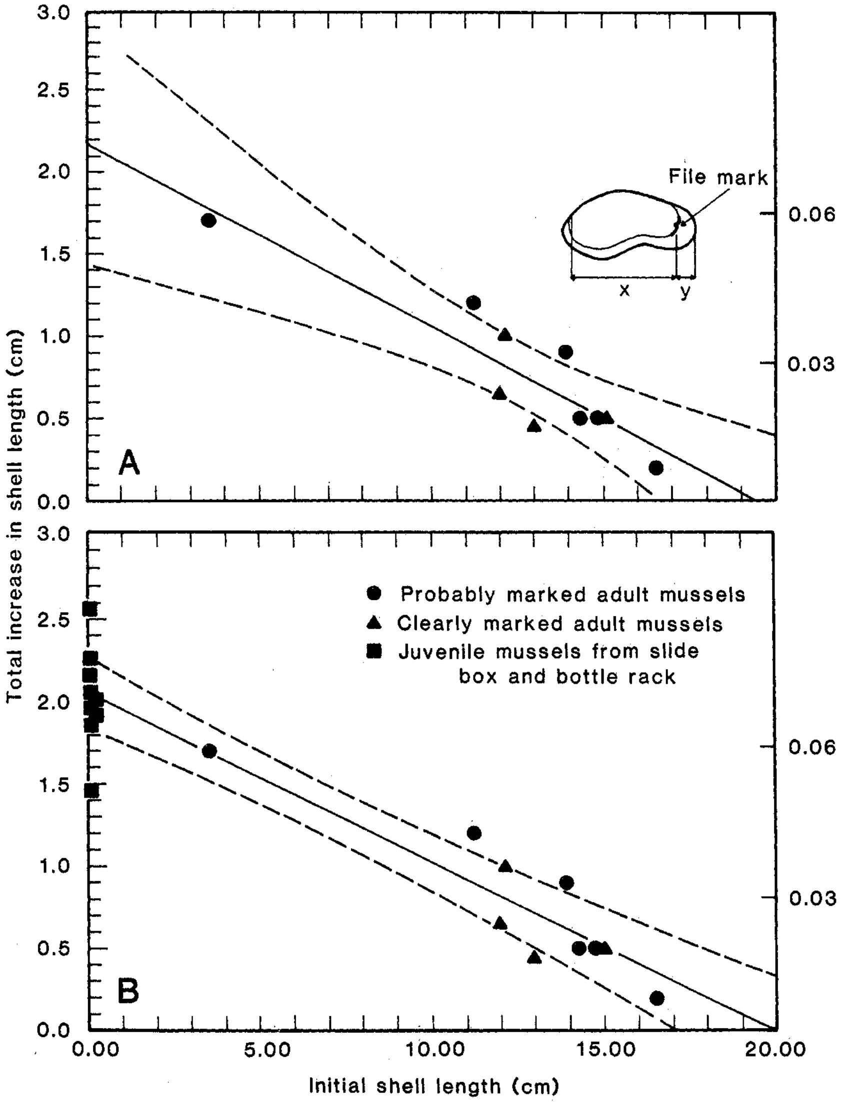

Fig. 1. Total and mean daily increase in shell length for mussels of different sizes. (A) Growth of adult mussels: a plot of the relation of shell length at the time of marking (abscissa) and the increase in shell length after 294 days (N = 10). Inset drawing defines the measurements for the x and y coordinates. Dashed lines are the 95 percent confidence limits for the regression line. (B) Increase in shell length of adult mussels (as above) and juvenile mussels (N = 9) recovered from microbiological sampling equipment deployed for 297 days. An initial settling size of 400 μm is assigned for the juvenile specimens. Dashed lines are the 95 percent confidence limits for the regression.

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