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^{230}TH AND ^{231}PA DATING OF UNRECRYSTALLIZED FOSSIL MOLLUSKS FROM MARINE TERRACE DEPOSITS IN WEST-CENTRAL CALIFORNIA

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Prominent marine terraces occupy the seaward slopes of Ben Lomond Mountain between Santa Cruz and Año Nuevo Point in west-central California. The most extensive platform of the lowest marine terrace (the Santa Cruz terrace) is the Highway 1 platform; a poorly preserved lower platform, the Davenport platform, is also recognized in sea-cliff exposures (Bradley and Griggs, 1976).

Previous dating by Bradley and Addicott (1968) of three mollusks from the Davenport level near Santa Cruz yielded ^{230}Th ages between 76,000 and 100,000 years B.P. and two samples from localities near Año Nuevo Point yielded ^{230}Th ages of 68,000 (Cal-F2) and 16,000 (Cal-F4). Pleistocene marine sequences in California have recently been assigned ages using the amino acid racemization technique, that is calibrated by reliable uranium-series ages of coral samples (Wehmiller and others, 1977). Amino acid ratios indicate an age for the Davenport platform deposit, near Santa Cruz, of 80,000 to 100,000 years and for the main Santa Cruz terrace deposit, near Año Nuevo Point, of 90,000 to 140,000 years.

Age assignments of the Davenport platform deposit using these two methods are in reasonable agreement. However, the ^{230}Th ages for mollusks from the Santa Cruz terrace deposit, near Año Nuevo Point, are unacceptably too young when compared to the age assignment by amino acid racemization method. Furthermore, sample Cal-F4, yielding an apparent ^{230}Th age of only 16,000 years (Bradley and Addicott, 1968), was dated by the radiocarbon method to be older than 43,000 years (Kelley and others, 1978).

The purpose of this study was to date fossil mollusks from the Santa Cruz terrace deposits using both ^{230}Th and ^{231}Pa methods in order to assess the reliability of the obtained ages (Szabo and Rosholt, 1969; Szabo and Vedder, 1971). (See also Szabo, 1969, for a general description of the uranium-series methods.)

The samples for this study were cleaned by hand scraping and ultrasonic scrubbing in water, and then were crushed to a fine powder. Uranium and thorium concentrations were determined on a solid-source mass spectrometer by the isotope dilution technique using enriched ^{235}U and ^{230}Th spikes. The ^{234}U/^{238}U and ^{230}Th/^{234}U activity ratios were determined by alpha spectrometry (Szabo and Rosholt, 1969). The activity ratios of ^{231}Pa/^{235}U were determined by neutron activation and alpha spectrometry (Rosholt and Szabo, 1969). The relative abundance of aragonite in the powder was determined by X-ray diffraction.

Results of the analyses and calculated ^{230}Th and ^{231}Pa ages of mollusk samples are shown in table 1. Sample S-1 is from the Davenport level of the Santa Cruz terrace, near Santa Cruz, samples S-2 and S-3 are from the main Santa Cruz terrace, near Año Nuevo Point, and samples R-1 and R-2 are recent shells collected on Pismo Beach, near Point Conception. The amount of aragonite is 97% in all but sample R-2, indicating that no significant recrystallization has occurred during their geologic history. Sample R-2 is a recent mollusk species, *Haliotis cracherodii*, that apparently secreted a mixed aragonitic and calcitic shell.

The uranium content is low in the recent shell samples; samples R-1 and R-2 show 0.048 and 0.061 ppm, respectively. The uranium content is a factor of 10 to 20 higher in the fossil shells (S-1, S-2, and S-3), indicating that the uranium entered the shell after the death of the organism. The common thorium concentration (^{232}Th) is low in both recent and fossil shells, therefore no initial ^{230}Th correction is required.

For sample S-1 from the marine deposit on the Davenport level, the ^{230}Th age of 95,000±12,000 years and the ^{231}Pa age of $132{,}000^{+50{,}000}_{-25{,}000}$ years are concordant within the limits of experimental errors. The average uranium-series age of sample S-1 is 114,000±20,000 years; this age and the amino acid racemization age are in agreement.

Samples S-2 and S-3 from the deposit of the main Santa Cruz platform, near Año Nuevo Point, yield concordant ^{230}Th and ^{231}Pa ages. The average uranium-series ages of these samples are 22,000±3,000 and 19,000±2,000 years, respectively; or somewhat older than the age of 16,000±2,000 years reported for sample Cal-F4 by Bradley and Addicott (1968). These ages pose a dilemma because they are geologically too young; yet the analytical data do not indicate any problem. The ^{234}U/^{238}U ratios are low, uranium concentrations appear normal. The ^{232}Th concentration is low and there is no evidence of crystallographic alteration. The reasons for these anomalous results are not evident at this time. It is concluded, however, that U-series ages for mollusks should be checked by other methods, such as radiocarbon dating or amino acid racemization ratios, whenever possible.

Bradley and Griggs (1976) correlated the cutting of the Santa Cruz terrace with the high interglacial sea level stand at about 125,000 years ago, during which time the well dated coral reef was forming on terrace III of the Barbados Island. These data also correspond to the oxygen isotope stage 5e of Fairbanks and Matthews (1978). This "125,000 B.P. high sea stand" is now believed to be a double event with a major transgression at about 135,000 years ago, followed by a minor regression and subsequent readvance at about 120,000 years ago (Chappell and Veeh, 1978). A likely scenario for the formation of the main and lower

platforms of the Santa Cruz terrace is that the main platform, Highway 1 level, was cut about 135,000 years ago during the major transgression of the sea and that the lower platform, Davenport level, was cut during the readvance of the sea at about 120,000 years ago when the marine sediment bearing sample S-1, dated at 114,000 years, was deposited.

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TABLE 1. Analytical data and calculated ages of California mollusks.

Sample no.	Material	Percent aragonite	Uranium (ppm)	Thorium (ppm)	$\frac{^{234}U}{^{238}U}$[1]	$\frac{^{230}Th}{^{234}U}$[1]	^{230}Th Age[2] (years)	$\frac{^{231}Pa}{^{235}U}$[1]	^{231}Pa Age[3] (years)	Average U-Series age (years)
Santa Cruz Terrace, Santa Cruz										
S-1	S. sp.	97	+0.99 −0.01	+0.011 −0.003	+1.28 −0.03	+0.60 −0.04	95,000±12,000	+0.94 −0.04	132,000 +50,000 −25,000	114,000±20,000
Santa Cruz Terrace, Ano Nuevo Point										
S-2	M. sp.	97	+0.43 −0.01	+0.04 −0.01	+1.14 −0.02	+0.20 −0.02	24,000±3,000	+0.33 −0.02	19,000±2,000	22,000±3,000
S-3	Tr. sp.	97	+0.83 −0.01	<0.02	+1.18 −0.03	+0.17 −0.01	20,000±1,500	+0.32 −0.03	18,000±2,000	19,000±2,000
Pismo Beach, Point Conception										
R-1	Ti. sp.	97	+0.048 −0.002	+0.012 −0.002	+1.30 −0.05	ND	ND	ND	ND	
R-2	H. sp.	55	+0.061 −0.002	<0.02	ND	ND	ND	ND	ND	

1. Isotopic activity ratio.
2. Calculated using half-lives of ^{230}Th and ^{234}U of 75,200 and 244,000 years, respectively.
3. Calculated using half-lives of ^{231}Pa of 32,500 years.

S. sp. = *Saxidomus* species
M. sp. = *Marcoma* species
Tr. sp. = *Tresus* species
Ti. sp. = *Tivela* species
H. sp. = *Haliotis* species
ND = not determined