QUATERNARY RESEARCH 3, 142–146 (1973)

Helium–Uranium Dating of Corals from Middle Pleistocene Barbados Reef Tracts[1]

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Received January 18, 1973

By He–U dating of corals from elevated Pleistocene reef tracts on Barbados, we have extended back to the Middle Pleistocene the high sea stand chronology previously deduced by Th^{230}–U dating. Six samples from the first major reef tract complex older than the 200,000-yr complex gave ages of 350,000 ± 25,000 yr B.P. Two corals from the crest of Second High Cliff, an unusually large escarpment occurring approximately midway in the terrace sequence, gave concordant ages of 480,000 and 500,000 yr. Unrecrystallized corals from older reefs gave ages ranging back to 650,000 yr.

The results date episodes of high sea stands at 350,000 and 500,000 yr B.P.

INTRODUCTION

Previous field and geochronologic studies of Barbados stratigraphy (Broecker *et al.*, 1968; Mesolella, 1968; Mesolella *et al.*, 1969) have established that the island is composed of a Tertiary sedimentary core which is mantled by a series of concentric coral reef tracts. Work done on upper Pleistocene reef tracts has established that at least for the past 200,000 yr the island is being uplifted at the rate of about one foot per thousand years. Coral reefs fringing the island form at times when local sea level is stable for several thousand years. Reef tracts may form during stadial periods but since such features will probably be overgrown during a subsequent interglacial, it is believed that all currently emergent reef tracts were probably formed during high sea stands.

A map of Barbados, W. I. showing the principle mapable uplifted reef tracts is presented in Fig. 1. Features 200,000 yr and younger have been dated by applying the Th^{230} growth method (Broecker *et al.*, 1968; Mesolella *et al.*, 1969; James *et al.*, 1971); the results are summarized on the figure. The helium–uranium dating method (Fanale and Schaeffer, 1965; Bender, 1970, 1973) affords the opportunity to determine the ages of older reef tracts and thus to date the high sea stands they record. We have completed a preliminary geochronologic study, and the results are reported here. We have also extended the stratigraphic studies of Mesolella *et al.* (1969) and Mesolella (1968), and aspects of this work bearing on sea level studies will be briefly presented.

HE–U DATING STUDIES

Fanale and Schaeffer (1965) and Bender (1970, 1973) have shown that He–U ages of unrecrystallized fossil corals are reliable age indicators provided (a) there is no evidence of U gain or loss; (b) there is no

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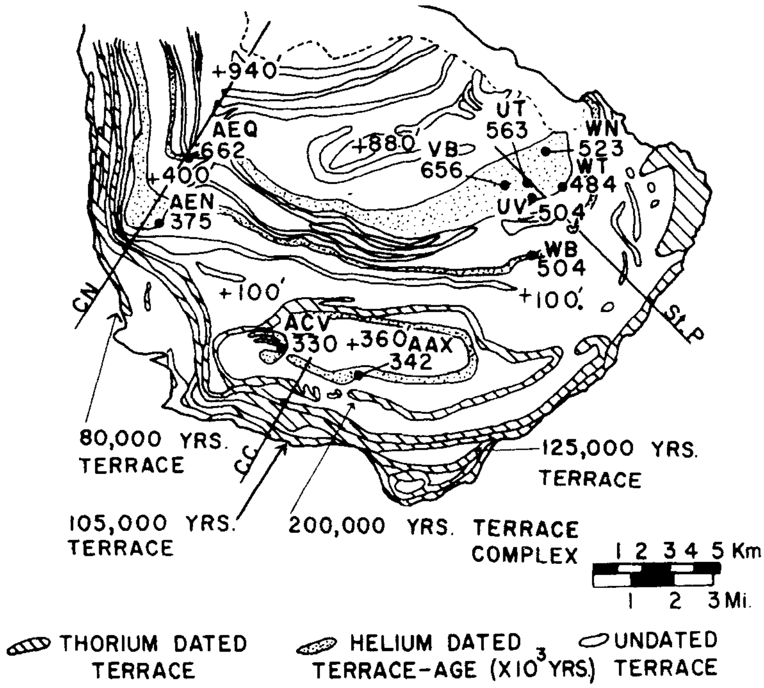

FIG. 1. Map summarizing results to date of the geochronology of southern and central Barbados coral reefs. Numbers next to pulses are elevations; numbers next to heavy dots are He–U dates. Results of thorium-230 growth method dating are summarized.

anomalous disequilibrium of the uranium daughters; (c) a correction is made for inherited helium; (d) a correction is made for "shot out" helium. All work on Barbados corals indicates that conditions a and b are always satisfied (Mesolella *et al.*, 1969, Bender, 1970, 1973). Correction c is made by assuming a value of $0.6 \pm 0.4 \times 10^{-8}$ scc He^4/g (Bender, 1973); correction d is not necessary since Barbados corals have resided in the vadose environment throughout most of their history.

Fourteen specimens from ten different localities were dated (Table 1). Helium concentrations were determined by isotope dilution as described previously (Bender, 1973). The precision for duplicates of samples listed here was $\pm$ 2%. The He^3 spike was calibrated against the known He^4 content of air; the uncertainty in the spike calibration increases the uncertainty in He^4 analyses by $\pm$ 1%. Uranium analyses were very graciously performed by Roy Spalding at Texas A & M University using delayed neutron activation analysis (Amiel, 1962; Mo, 1971); uncertainties are $\pm$ 4%. All results are given in Table 1. Due to the variance in the value of inherited helium, the uncertainties in the ages are somewhat larger than the analytical uncertainties; they are about $\pm$9% for samples about 300,000 yr old, and decreases to $\pm$6% for samples 600,000 yr old.

He–U ages of stratigraphically equivalent samples dated in this work are in good agreement, giving a standard deviation from the mean of $\pm$5%.

DISCUSSION OF THE RESULTS

In previous studies of the absolute chronology of Barbados terraces (Broecker *et al.*, 1968; Mesolella *et al.*, 1969), we have only dated samples from reef tracts which were distinct morphostratigraphic units with facies relationships sufficiently well defined that the relation of the dated sample to paleo-sea level was clear (Mesolella, 1967). In sampling the older terraces we

TABLE 1

HELIUM CONCENTRATIONS, URANIUM CONCENTRATIONS, AND He–U AGES OBTAINED ON THE SAMPLES IN THIS STUDY[a]

Locality	Sample	Genus and species	[U] (ppm)	[He^4] ($\times 10^7$ scc/g)	[He^4] (-5.9×10^{-9})	[He^4]^{corr}/[U]	Age (yr)
AAX	L1258A	M.A.	2.48	.955	.896	.353	348,000
	D	A.p.	2.62	.938	.879	.335	333,000
	F	S.s.	2.51	.937	.878	.350	346,000
ACV	L1263C	S.s.	2.70	1.04	0.98	.363	357,000
	F	D.	1.98	0.682	0.593	.299	303,000
AEN-1		S.s.	2.53	1.04	0.98	.387	375,000
WT-1	L1166F	M.a.	2.43	1.33	1.27	.523	484,000
UV	L1255E	D.	2.55	1.45	1.39	.546	504,000
VB	L1260F	M.a.	3.08	2.33	2.27	.736	656,000
WN-2		A.p.	4.06	2.38	2.32	.572	523,000
UT-2		A.p.	3.14	2.01	1.95	.621	563,000
AEQ	L1144D	M.a.	2.73	2.10	2.04	.748	662,000
WB	L1267A	M.a.	2.49	1.46	1.40	.563	517,000
	C	Meand.	2.34	1.25	1.19	.508	490,000

[a] Uncertainties in the He–U ages are ±9% for the oldest samples and ±6% for the youngest, including the uncertainties in analyses, diagenesis, and inherited helium correction. Different species and genera are designated as follows: *Montastrea annularis*, M.a.; *Acropora palmata*, A.p.; *Siderastrea siderea*, S.s. *Diploria*, D.; *Meandrina*, Meand. Standard deviation of computed ages of samples of the same age from the mean = 5%.

tried to adhere to this general policy, but as we rarely found unrecrystallized samples during our early reconnaissance we tended to collect them whenever we found them. Specifically samples from WB and AEQ were considered quite lucky finds in our early collecting. By the time we collected the other samples we understood the terrane better, and succeeded in finding unrecrystallized specimens in localities where morphostratigraphic relationships are clear. In as much as we had previously attempted to date reconnaissance samples from AEQ and WB by the thorium-230 method, we included them in the helium dating program. We report their ages here for completeness, even though the stratigraphic significance is less clear than that of the rest of the dates.

Helium–uranium dates for the various localities studied are listed in Table 1 and shown in Fig. 1. At localities where different fossils were dated, the average age is given, with the number of samples analyzed in parentheses.

Six samples from a major reef tract complex at a higher elevation than the 200,000-yr complex were dated from localities AAX, ACV, and AEN. The three samples from AAX gave ages ranging from 333,000 to 348,000 yr; the one sample from AEN was dated at 375,000 yr. It is clear that these samples formed at about the same time, but there is no compelling evidence from the stratigraphy or geochronology to indicate whether these localities record one or two episodes of high sea level. The two samples we dated from ACV were taken from a coral head zone at the very top of the Christchurch region which we originally believed represented the highest and oldest part of the reef tract complex correlated with AEN and AAX. The geochronology and stratigraphy of ACV is somewhat ambiguous. The samples gave ages of 315,000 and 357,000 yr. Their ages may truly be younger than the ones from ACV and AAX; in this case ACV must represent a sea stand about fifty feet higher than that represented by AEN and AAX. This interpretation meets with a stratigraphic inconsistency, however; if these samples were, in fact, formed by a younger high stand, why weren't the surrounding areas blanketed by coral reef overgrowth? The alternative is that ACV represents the oldest reef on Christchurch and the date of 315,000 yr obtained on Diploria is anomalously low due to the uncertainty in the inherited helium correction. In fact, because of the young age and low U content of this sample, the radiogenic helium content is the lowest of any sample analyzed in this work, and as a result of this the assumed value of inherited helium (0.6×10^{-8} scc/g) comprises a higher fraction of the total (9%) than in any other sample. Although there are uncertainties in the interpretation of He–U ages at the different localities, the results date an episode of reef tract formation on Barbados at about 350,000 yr B.P.

The next oldest reef tract was dated at locality W. B.; two samples gave concordant ages of 490,000 and 520,000 yr. These results are not easily reconciled with the other ages of this study. As the reef is only slightly higher than the 350,000 yr complex, we expected the age to be no older than about 400,000 yr. There are three possible explanations for the result. First, it may be that the reef was formed during a low stand. As dating indicates that the tract is roughly the same age as localities UV and WT, which are about 200 ft higher in elevation, sea level at its formation can be estimated at about —200 ft relative to the level when Second High Cliff formed. As indicated earlier, it is unlikely, though not impossible, that such a low stand would be preserved uncovered until the present. The second possibility is that the corals formed in deep water during a high sea stand and cannot be precisely related to any sea level datum; the ecological variability of these species (Mesolella, 1967) is consistent with this interpretation. The third possibility is that the corals are contaminated by a small amount of the much older Tertiary basement immediately underlying the coral cap at this locality. About 2% contamination would probably suffice to raise the apparent ages of the samples by 100,000 yr. We are currently studying these possibilities by analyzing samples of the basement and by dating the westward extension of this reef.

Barbados topography is marked by two unusually high escarpments running parallel to the western and southern shores. The first of the features (first high cliff) is a depositional feature formed by extensive coral reef growth 125,000 yr B.P. The second feature (second high cliff) is a partly depositional and partly erosional feature further landward and much higher than first high cliff. We have dated specimens from localities UV and WT at about 500,000 yr and these results fix the age of the construction of second high cliff, at least in this area. Samples from other areas will be difficult or impossible to obtain because they are recrystallized.

Finally, we have dated four samples that are older than second high cliff by stratigraphic considerations: VB, WN, UT and AEQ. The AEQ sample was taken at the base of a high cliff in a quarry. We have not been able to examine the stratigraphy of the overlying sediments, and thus cannot now make any conclusions about the implications of the age of the sample for paleosea level. On the other hand, He–U ages of 520, 560, and 660×10^3 yr for WN, VT, and VB, respectively, are consistent with the stratigraphic relationships and roughly date periods of high sea stands. Future stratigraphic and geochronologic work will be aimed at precise dating of the high stands these reefs record.

DISCUSSIONS AND CONCLUSIONS

Previous work on Barbados chronostratigraphy has revealed evidence of reef complex formation at about 125,000 yrs B.P. (with lesser episodes at 80,000 and 105,000 yrs B. P.) and 200,000 yrs B. P. This work dates major episodes of reef tract formation and high sea stands at 350,000 and 500,000 yr B. P. The 350,000-yr complex probably records the same warm climatic event recorded as an O^{18} minimum following glacial termination V of Broecker and Van Donk (1970) whose age they estimated as 380,000 ± 25,000 yr B.P. The date of 500,000 yr for the construction of Second High Cliff can be correlated with the conspicuous absence of ice drafted detritus found at this time in North Pacific cores (Kent *et al.*, 1971).

We recently mapped one newly defined terrace stratigraphically related to the 200,000-yr B.P. complex, and several terraces lying within the 300,000–500,000-yr range. These terraces, along with those dated by the Th^{230} growth and He–U methods, comprise a more or less continuous series of Barbados terraces recording episodes of high sea stands back to at least 650,000 yr B.P.

ACKNOWLEDGMENTS

This research was supported by NSF contract AT (30-1) 3139 to the Lamont-Doherty Geological Observatory, NSF contracts GA 306, GA 4028 and GA 26103 to Brown University, and an AEC contract to the State University of New York at Stony Brook.

We are very grateful to Professor Oliver Schaffer of SUNY-Stony Brook for making available to us his mass spectrometry facilities, and to Roy Spalding for performing the U analyses. Parts of this work were done in the laboratory of Professor Wallace Broecker of Columbia University, and MLB gladly acknowledges his support and help.

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