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Front Cover: Lee-side exposure of a fossil parabolic dune viewed from the Grahams Harbour side (west) of North Point, San Salvador, Bahamas. These Holocene carbonate eolianites have been assigned to the North Point Member of the Rice Bay Formation (Carew and Mylroie, 1995). The eolian cross-stratification dips below present sea level, proving that late Holocene sea-level rise is real. Top of the dune is about 7 meters above the sea surface. Photo by Al Curran.

Back Cover: Dr. Noel P. James of Queen's University, Kingston, Ontario, Canada, keynote speaker for this symposium. Noel is holding a carving of a tropical fish created by a local artist and presented to him at the end of the symposium. Photo by Al Curran.

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GEOLOGIC INVESTIGATION OF THE LATE PLEISTOCENE JAIMANITAS FORMATION: SCIENCE AND SOCIETY IN CASTRO'S CUBA

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ABSTRACT

The late Pleistocene Jaimanitas Formation, consisting of marine coastal, lagoonal and reefal carbonates and eolianites, forms much of the north coast of Cuba, and is the foundation for the city of Havana. The Terraza de Seboruco, the emergent fossil reef terrace of the Jaimanitas, borders the present coast, with paleo-lagoonal facies extending inland one or more kilometers. Exposures through the reef in a working quarry and in a canal produced three coral samples which have been TIMS U-Th dated, indicating a Substage 5e age (140-120 kyrs) for the reef. One *Montastrea* sp. sample provided a 26.5 coral-year stable isotopic profile for paleoclimatic reconstruction. The present reef elevation of +2 to +3 m MSL is consistent with elevations of correlative Substage 5e reefal deposits along tectonically stable margins in the wider Caribbean. The north coast of Cuba lies along the presently inactive convergence zone between the North American and Caribbean plates; the most recent tectonic activity predated the emplacement of the Jaimanitas reef. Thus the +6 m MSL sea level standard for Substage 5e is applicable to northwest Cuba.

Although a scientific trip, a long and difficult bureaucratic process to obtain travel permits took place in the US, and an even more pervasive bureaucracy obstructed and curtailed our activities while in Cuba. Attempting scientific work in Cuba constituted a unique learning experience in how a communist society conducts its daily business, and how Americans, who are viewed with suspicion, are dealt with.

Along with our Cuban colleagues, we experienced typical aspects of life in Castro's Cuba. Although we stayed at a "good" hotel in Havana, we were not immune to water and power outages, food shortages, and the general conditions endured by Cubans over the last seven post-Soviet years. Cubans love to talk to foreigners about their plight, and, not suspecting we were Americans, regaled us with stories of unethical covert US activities against Cuba.

Most of these tales were "corroborated" in the official communist (government issued) daily newspaper, *Granma.*

We brought our Cuban colleagues up to speed on recent scientific and technical developments, and were given the necessary permits to take home our samples, along with classic geologic articles, geologic maps, and a letter detailing the Cuban scientists' desire for a formal collaborative relationship. We also left with admiration for our colleagues' love for geology and dedication to their work despite restrictions and hardships that have driven other Cubans to abandon their professional vocations.

INTRODUCTION

Our plans to explore the northwest coast of Cuba developed over two years. An initial meeting with Cuban scientists Nancy Revilla Urra, Consuelo Diaz Otero and Manuel Iturralde Vinent occurred during the 1995 SEPM meeting. Iturralde Vinent's (1995) field guide to the geology of Cuba introduced us to the coastal terraces of north west Cuba (Figure 1). Nancy Revilla returned to St. Petersburg in 1996 to conduct remote sensing work, at which time we discussed the possibility of conducting paleosea level and climate research on the coastal terraces. She arranged for a letter of invitation to conduct the work in Cuba from the sub-director if the Ministry of Fisheries in Havana. Since the 1995 SEPM meeting, relations between Cuba and the US deteriorated owing to an incident wherein an American plane flown by Cuban exiles (*Brothers to the Rescue*) was shot down by the Cuban government. Direct flights from the US were discontinued and severe restrictions were imposed on travel to Cuba by US citizens. A long and difficult process ensued with the U.S. Treasury Department, Division of Foreign Assets Control, to obtain a License to travel to Cuba legally within the restrictions of the embargo and the lack of diplomatic relations between our two countries. Permission from Cuba for work visas was not forthcoming, so we obtained tourist visas, then faced bureaucratic problems in Havana in order to do field work. When our permits and visa problems eventually resolved themselves, we were able to do three days of field work and to see a significant cross section of the island and its Quaternary stratigraphy. We were permitted to take samples back to the US, despite that many other scientists have been waiting years to have their samples released.

State of Science

Cubans who remain dedicated to their careers in science, i.e. those who have not reverted to the lucrative tourist industry, do so at great financial and professional cost. Scientists are paid in pesos, not dollars (required to purchase necessities), they have no resources, no equipment or supplies, no gasoline, vehicles, boats, recent computers or instruments, no means to repair old equipment, and no access to current literature. Faxing is available when the phone system is operating, and email is available, although erratic, unreliable, and monitored. Cubans depend heavily on infrequent opportunities to go abroad to utilize foreign labs to complete their projects, or they wait for opportunities to come to them. We provided such an opportunity to our hosts via the reams of current literature we brought to them, money for gasoline to get out to the field, and the possibility of procuring costly sample analyses.

Misconceptions

Cubans are convinced that American universities and research facilities are all equally endowed with a wide range of equipment, instrumentation, and facilities. They were surprised to learn that relatively few sites have specialized equipment (e.g. mass spec capability to perform TIMS U-Th and radiocarbon dating, among many others), and that radiocarbon is the only dating method available as a commercial service. Cubans think Americans have unlim-

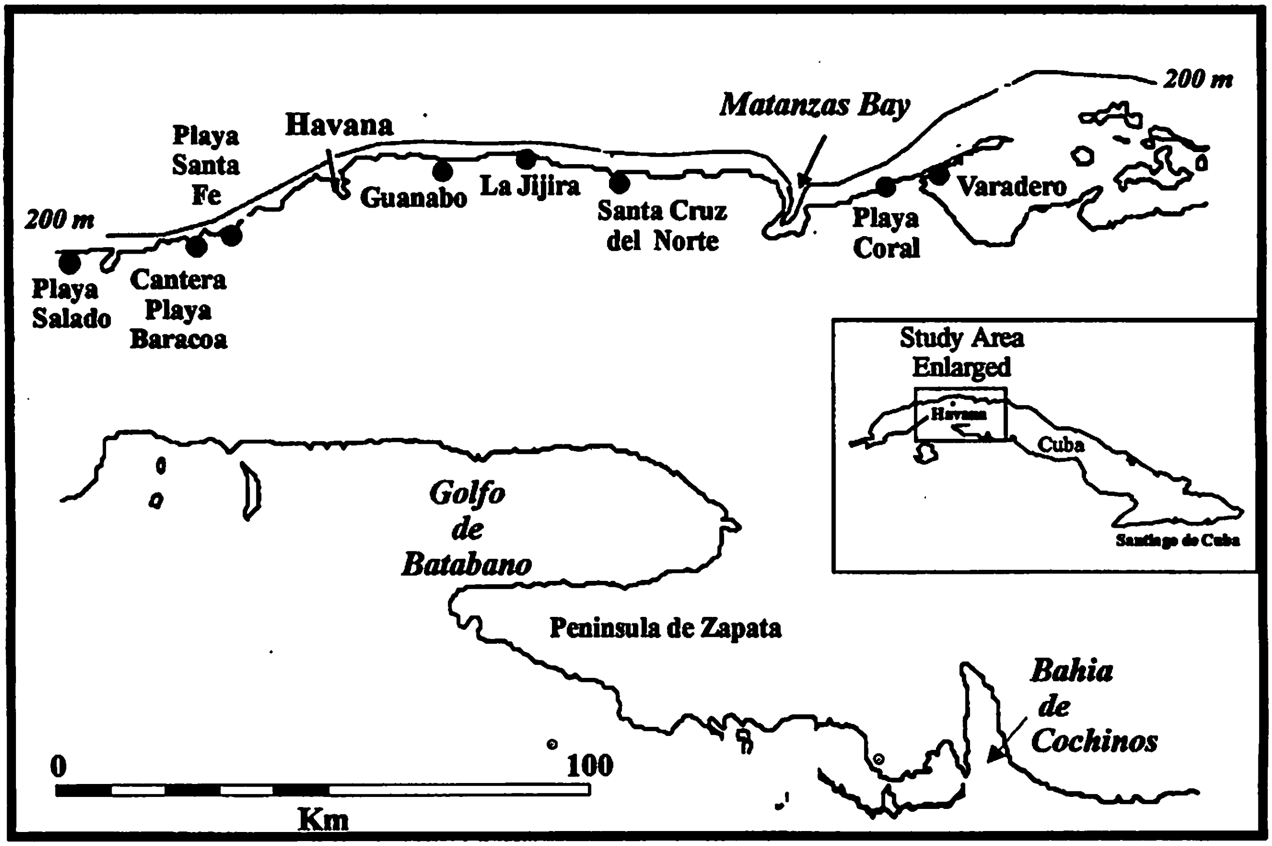

Figure 1. Location Map, North-west Cuba, in the Havana-Matanzas region. All field and sample sites are plotted. After Iturralde Vinent (1995).

ited funding, not realizing that we face increasing competition for ever-diminishing resources. We attempted to explain that we were paying our expenses with personal funds as a gamble towards getting eventual funding for further analyses, and that some of the data would be produced by colleagues. Collaborations surprised them as being a necessary means towards getting a project funded and completed.

Geochronology was the most important issue for resolving several Cuban Quaternary scenarios, however the topic was fraught with misconceptions and unlimited expectations. Owing to their isolation from current (the last 30 years) literature, Cubans believe that many geologic materials (eolianite, paleosol, weathered material, re-crystallized material) can be radiometrically dated, or accurately dated by some quantitative method. A great deal of discussion ensued and eventually we were able to differentiate various sample types and their geochrologic potential, as well as the dating methods appropriate to each.

Scientific Objectives

While considerable research into late Pleistocene reef terrace stratigraphy, sea levels, tectonics, geochronology and paleoclimatology is available and ongoing for the wider Caribbean region, including the Florida Keys, the Bahamas, Barbados and Bermuda, no comparable work had been known from Cuba. Long isolated from mainstream scientific interaction and international publication, the few pre-Soviet, and later Soviet sponsored, Cuban publications dealing with coastal studies have remained available only by going to Cuba or as gifts from traveling Cuban scientists. Thus a large geographic gap in knowledge of the Pleistocene of the Caribbean was noted by these authors and others. This preliminary project to document the late Pleistocene of a small area near Havana barely scratches the surface of the Quaternary of Cuba.

Our objectives were to sample one or more generations of Quaternary reefs, to conduct radiometric dating of reef corals and assess the timing of reef initiation and duration, to assess tectonic activity, reconstruct paleo sea surface temperatures using coral-derived stable isotope data, and to correlate Cuban stratigraphy and sea level interpretations to those of the wider Caribbean.

PREVIOUS WORK

Most of the classic Cuban literature dealing with coastal formations and sediments is contained in Bermudez (1961) and Ducloz (1963), and is descriptive (geomorphologic) and sedimentologic or petrologic in nature. Quaternary geology in these studies is extremely limited, with more emphasis on coastal sediments and on older strata with economic potential. Shanzer et al. (1975) and Kartashov et al. (1976) described Quaternary strata of north west Cuba, including the Jaimanitas formation. Peñalver Hernandez et al. (1982) reviewed the literature on the Quaternary of western Cuba, with little emphasis on the Jaimanitas. Later studies on the late Quaternary coastal formations and reef terraces incorporate structural foundations and seismic data (Ionin et al., 1972), and aerial photography of submarine geology (Ramirez Cruz et al., 1989). A portion of recent Cuban geologic literature is available only in Russian. Apart from the lack of extra copies, those studies could neither be translated nor referred to herein.

The indurated, subaerially exposed late Quaternary Terraza de Seboruco (literally "terrace of reefs;" Ducloz, 1963; Figure 2) borders much of the north coast of Cuba and its lagoonal facies extend several kilometers inland. *Terraza de Seboruco* is a local term used to designate the porous or cavernous limestone making up the terrace and "responsible for" the sharp-peaked weathering surface known as "diente de perros" (dog's teeth). Although an older, higher terrace (Terraza de Yucayo) was indicated by Iturralde Vinent's (1995) and Ducloz's (1963) cross sections (Figure 2), it was not visible near the coast, with the exception of stack remnants (Peñon del Fraile) near Playa Jibacoa (Iturralde Vinent, 1995). Submerged terraces have been reported between 9-18 m deep (Bermudez, 1961; Ramirez Cruz et al., 1989; Figure 2).

Portions of the Caribbean basin are tectonically active (Mann et al., 1995), and the southeast area of Cuba near Guantanamo and Santiago de Cuba is known for violent uplift resulting in steep flights of raised coastal terraces (Fairbanks and Dodge, 1979; Dodge et al., 1983; Fairbanks, pers. com., Dodge, pers. com). Although Cuba is not specifically addressed, Mann et al. (1995) describe the currently *inactive* convergence zone between the North American and Caribbean plates bordering the north Cuban coast. Some differential uplift along the Terraza de Seboruco has been interpreted by Shanzer et al. (1975), because north Matanzas (Figure 1) at +4 to +5 m MSL, is elevated slightly higher than Havana at +3.5 to +3 m MSL. If tectonic uplift had occurred along the north coast since the building of the Terraza, the dating of the reef and comparison of its age and elevation to existing Caribbean sea level models would allow for an estimation of the extent and rate of that uplift.

FIELD ACTIVITIES

Leandro Peñalver and Miguel Cabrera of the Geological Institute provided an excellent overview of the Quaternary stratigraphy of northwest Cuba and guided us to definitive outcrops and exposures. Jaimanitas rocks are the foundation of Havana (Figure 1). The Malecon (waterfront) of Havana consists of a seawall and boulevard built on the elevated reef terrace, with eolianite outcrops on the landward side of the boulevard. The reef terrace seaward of the seawall serves as an oil and tar-coated "beach." No samples were collected there.

Good exposures of the Terraza de Seboruco along the coast included those at Punta La Jijira (Figure 1), where the weathered Jaimanitas forms the wide shoreline with the characteristic "diente de perro" karst surface, and patches of red paleosol. The terrace edge is 1-2 m above the water line. No datable coral samples could be obtained from the heavily weathered and cemented surface. Good exposures were found along the walls of a 10-year old canal cut through the Terraza at Santa Cruz del Norte (Figure 1). Three corals, including two very large *Montastrea* sp. and one *Acropora palmata*, were sampled. Playa Coral (Figure 1) had geomorphology similar to that at Punta la Jijira, however the facies is lagoonal rather than reefal. No corals could be sampled at Playa Coral, again due to induration and weathering.

At Playa Salado (Figure 1), the Jaimanitas outcrops at sea level, 2 m lower in elevation than the above localities, flooring the swash zone and covered with patches of sand. Kartashov et al. (1976) promoted the idea that the Jaimanitas resulted from not one but two transgressions, resulting in upper and lower Jaimanitas members. Only the lower Jaimanitas is observed at Playa Salado. Approximately 10 m from the shoreline is a 1.5-2 m high, slightly indurated pile of red-coated corals, distinct from an *in situ* reef deposit, termed the Salado Formation. Kartashov et al. (1976) define the Salado as a particular, not *in situ*, deposit consisting of a carbonate clay matrix with redeposited megafossils (corals, mollusks) and diagnostic iron-staining. They correlate the Salado Formation to the Upper Jaimanitas and do not consider it a storm deposit, but the result of a "very local transgression." The Upper Jaimanitas, which is is geomorphically and stratigraphically identical to the Terraza de Seboruco, is apparently missing. Salado fossils are said to be derived locally from the lower Jaimanitas. The provenence of the clays are nearby terrigenous Quaternary red clays. Other authors (Peñalver Hernàndez, pers. com.) do not give formation status to the Salado, preferring to call it the Salado Breccia. Unfortunately, these stained, transported corals were unsuitable candidates for TIMS dating and/or stratigraphic analysis. The heavily weathered Lower Jaimanitas could not be sampled.

The back reef, and associated lagoonal facies of the Jaimanitas, were viewed inland of the coast, at ~+5 m MSL elevation, in a working quarry (Cantera Playa Baracoa; Figure 1). A high (>50% visual estimate) matrix to framework ratio invoked comparisons with the Key Largo Limestone (Stanley, 1966), which similarly contains multiple genera of small head and branching corals (e.g. *Porites* sp.) "floating" in fine-grained matrix. The Jaimanitas differs from the Key Largo due to the iron-rich terrestrial

Table 1. TIMS U-Th dates on corals from the Terraza de Seboruco, north-west Cuban coast. U-Th dating was carried out by Joyce Lundberg.

Site	Location	Elevation (m MSL)	age (kyrs)	2σ (kyrs)	U/U_{init}	U/U_{init} error/ kyrs	Corrected age
Baracoa Quarry	open face	+2 to +3	126,684	±0.62	1.175	0.03/6.0	~120
Baracoa Quarry	spoil	+2 to +3	148,654	±1.17	1.175	0.03/6.0	~142
Santa Cruz del Norte	canal wall	+1 to +3	132,400	±0.49	1.176	0.03/6.0	~126

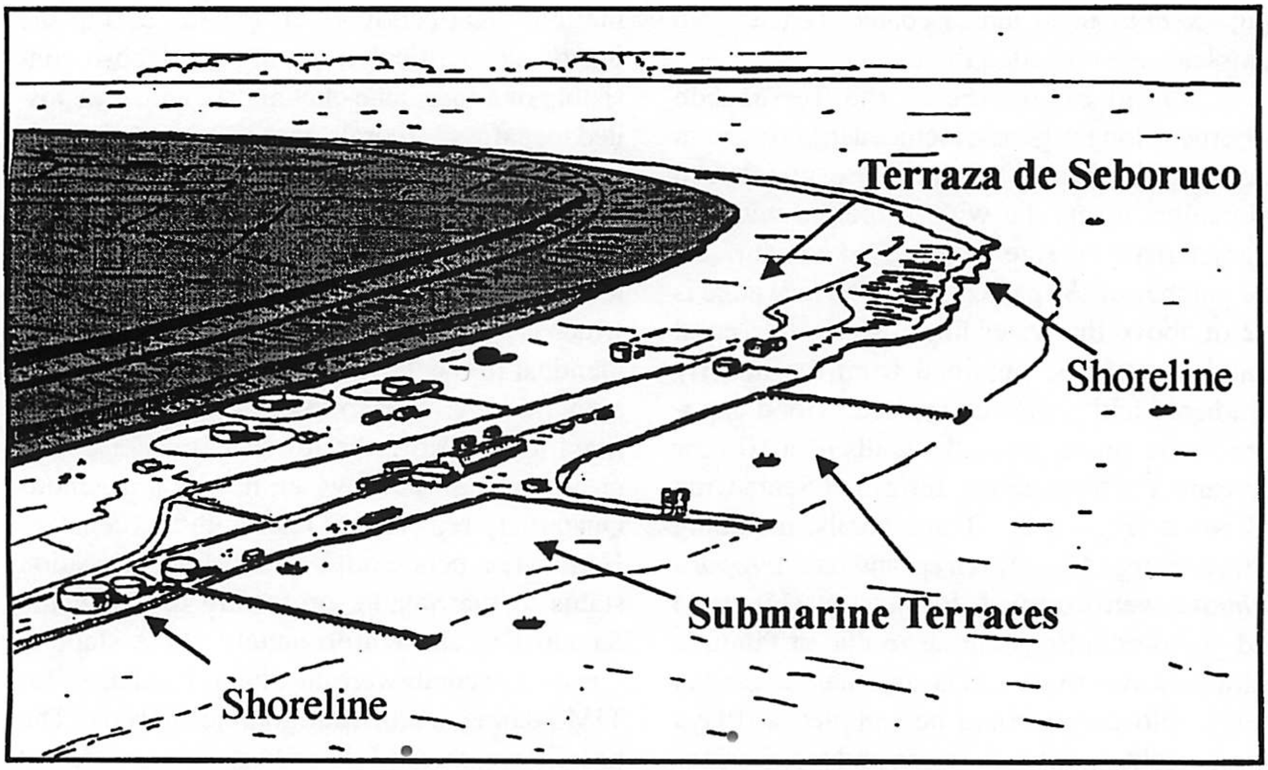

Figure 2. Representative profile of marine terraces on the west side of Matanzas Bay (after Ducloz, 1963 and Iturralde Vinent, 1995). The Terraza de Seboruco is a wide platform forming the rocky north shore of Cuba in the study area. The shaded area represents the older terraces described in Ducloz (1963). Submarine terraces are also indicated (Bermudez, 1961; Ramirez Cruz, 1989).

clays derived from older volcanic rock from the interior of Cuba, giving the Jaimanitas matrix a terracotta color and forming the dark red paleosols on the top of the unit. A small *Siderastrea* head was cut from the working face, and two small head corals were sampled from the adjacent spoil.

A church in Matanzas (Figure 1) sits on top of a sheer wall of coralline limestone, which forms the only outcrop of the Matanzas Formation. The Matanzas, which tops at +7-+8 m MSL, has been interpreted (Shanzer et al., 1975) as having been deposited during the peak of the Jaimanitas transgression. The Matanzas Formation has never been dated, but has been interpreted as similar in age to the Jaimanitas (Cabrera, pers. com.) Stratigraphic relationships are unclear; connections to the Jaimanitas proper along the coast have been severed by distance and development. Because the entire outcrop had been subjected to extensive meteoric diagenesis, resulting in re-crystallization throughout, useful dates could not be obtained.

METHODS

Coral Processing

Coral Head Sampling.

Large corals were cut on outdoor saws at the Geological Institute in Havana, then washed. Thick slabs were wrapped and taken back to the US. Further slabbing was done using a water-cooled lapidary saw at the USGS Center for Coastal Geology in St. Petersburg, Florida.

Coral X-radiography.

One large coral slab slated for isotopic analysis was X-rayed at Nova University, Dania, Florida.

Coral Microsampling.

Very small samples of coral carbonate were drilled using a system developed by Peter K. Swart, Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami (Leder et al., 1991; 1996). The coral X-ray was first used to measure the widths of annual bands across the area to be sampled. An average band width (approximating yearly growth rate) was calculated, then divided by the number of samples to be drilled per coral year. This drilling increment was keyed into a computer program that propelled the drill along the coral skeleton to produce a powdered carbonate sample. Samples were drilled continuously along the slab, stopping to collect each individual sample in a copper boat, dust the coral slab, then continuing where the previous sample ended.

One large *Montastrea* sp. slab was continuously sampled as described, at the rate of four per average coral year over a 30-year portion of the slab. A smaller, two-year area was sampled at the rate of 50/year to account for the full amplitude of isotopic variability preserved in the coral skeleton.

Mass spec analyses were completed at the RSMAS lab in 1998, following the procedures described by Leder et al. (1996). Carbonate samples were processed by an automated carbonate device (Common Acid Bath @ 90°C) attached to a Finnigan-MAT 251 gas ratio mass spectrometer. External precision was calculated from replicate analyses of the internal laboratory calcite standard and was 0.03 $^{o}/_{oo}$ for $\delta^{18}O$. Data were corrected for usual isobaric influences and expressed relative to SMOW.

Coral Dating

U-Th Dating.

After detailed examination of the sample (via microscope and/or X-ray diffraction completed by J. Lundberg) to rule out re-crystallization of the skeletal aragonite to calcite, subsamples of three corals were analyzed via Thermal Ionization Mass Spectrometric Uranium series methods (described in Li et al. (1989), Lundberg and Ford (1994), and Toscano (1996)).

RESULTS

Samples and Dates

Three coral samples provided consistent age data for the Terraza de Seboruco. Two from the Baracoa Quarry (Table 1) document a wide age range for the reef, recognizing that the older coral from the spoil pile may incorporate dating errors due to diagenesis, despite mineralogic analysis. The third coral, from the canal at Santa Cruz del Norte, produced a date that has been regarded as the timing of Substage 5e reef initiation in other parts of the Caribbean, notably the Bahamas (Chen et al., 1991) and Barbados (Edwards et al., 1987; Gallup et al., 1994). Any date older than 128 ka can be regarded as having pre-dated the insolation maximum near the Substage 5e peak (e.g. Martinson et al., 1987; Chen et al., 1991).

In Cuba, where the reef apparently grew as a mainland-attached fringing reef, terrestrial input, diagenesis in a humid, tropical environment, subaerial exposure and meteoric diagenesis might have affected the dates, but the care taken to collect samples from fresh quarry faces and canal walls minimized problems ascribed to exposure and meteoric diagenesis. Terrestrial contamination did not appear as low $^{230}Th/^{232}Th$ ratios (Blackwell, 1990), hence the dates are considered accurate to correlate the reef to isotopic Substage 5e and to assess the amount

Table 2. Stable isotope data. Cuba: Santa Cruz Del Norte fossil coral. Elevation +1 to +3 m MSL, 132.4 +/- 0.49 ka. 30 coral years sampled at 4/year. One year analyzed at 50/year for high-resolution data. Note: Samples 1-39 do not represent the same coral year among the low- and high-resolution data sets.

**Montastrea annularis* temperature equation ($t°C = 5.18 - 4.523 * (\delta_c - \delta_W)$) of Leder et al. (1996).

Sample No.	**4/yr $\delta^{18}O$ $\delta_{(c)}$**	**$\delta^{18}O$ $\delta_{(c)}$**	**+6m δ_W**	**Paleotemp. Leder eq.***	**Paleotemp.**	**50/yr $\delta^{18}O$ $\delta_{(c)}$**	**^{18}O $\delta_{(c)}$**	**Paleotemp. Leder eq.***	**Paleotemp.**
1	-3.67	***max***	1.034	26.416192	***max***	-6.15	***max***	37.633232	***max***
2	-3.42	-2.99	1.034	25.285442	43.241752	-5.76	-3.38	35.869262	61.288522
3	-4.12	***min***	1.034	28.451542	***min***	-4.73	***min***	31.210572	***min***
4	-3.76	-7.39	1.034	26.823262	23.340552	-4.73	-11.38	31.210572	25.104522
5	-3.57	***range***	1.034	25.963892	***range***	-9.19	***range***	51.383152	***range***
6	-4.64	4.4	1.034	30.803502	19.9012	-6.29	8	38.266452	36.184
7	-3.92	***average***	1.034	27.546942	***average***	-6.71	***average***	40.166112	***average***
8	-4.23	-4.38	1.034	28.949072	29.617767	-6.56	-5.99	39.487662	36.503487
9	-4.61		1.034	30.667812		-6.09		37.361852	
10	-4.6		1.034	30.622582		-6.02		37.045242	
11	-5.48		1.034	34.602822		-4.88		31.889022	
12						-6.13		32.86599	
13						-6.63		35.12749	
14	-4.21		1.034	28.858612		-8.09		46.407852	
15	-4.38		1.034	29.627522		-5.52		34.783742	
16	-4.76		1.034	31.346262		-6.69		40.075652	
17	-3.66		1.034	26.370962		-7.63		44.327272	
18	-4.53		1.034	30.305972		-5.98		36.864322	
19						-8.02		41.41446	
20	-4.58		1.034	30.532122		-7.19		42.337152	
21	-3.03		1.034	23.521472		-4.53		30.305972	
22	-4.24		1.034	28.994302		-4.33		29.401372	
23	-3.79		1.034	26.958952		-5.45		34.467132	
24	-4.05		1.034	28.134932		-4.15		28.587232	
25	-3.07		1.034	23.702392		-11.38		61.288522	
26	-3.25		1.034	24.516532		-3.53		25.782972	
27	-4.02		1.034	27.999242		-6.2		37.859382	
28	-3.55		1.034	25.873432		-3.56		25.918662	
29	-4.71		1.034	31.120112		-8.62		48.805042	
30	-3.42		1.034	25.285442		-3.38		25.104522	
31	-3.16		1.034	24.109462		-5.69		35.552652	
32	-3.75		1.034	26.778032					
33	-4.58		1.034	30.532122					
34	-4.12		1.034	28.451542		-5.26		33.607762	
35	-3.9		1.034	27.456482		-5.53		34.828972	
36	-4.5		1.034	30.170282		-3.5		25.647282	
37	-3.01		1.034	23.431012					
38	-2.99		1.034	23.340552		-6.04		37.135702	
39	-5.64		1.034	35.326502		-5.37		34.105292	
40	-4.69		1.034	31.029652					
41	-4.51		1.034	30.215512					
42	-4.89		1.034	31.934252					
43	-6.2		1.034	37.859382					
44	-4.57		1.034	30.486892					

Sample No.	4/yr $\delta^{18}O$ $\delta_{(c)}$	$\delta^{18}O$ $\delta_{(c)}$	+6m δ_w	Paleotemp. Leder eq.*
45	-5.37		1.034	34.105292
46	-5.66		1.034	35.416962
47	-4.3		1.034	29.265682
48	-4.51		1.034	30.215512
49	-4.36		1.034	29.537062
50	-4.17		1.034	28.677692
51	-4.24		1.034	28.994302
52	-6.33		1.034	38.447372
53	-5.18		1.034	33.245922
54	-7.39		1.034	43.241752
55	-5.37		1.034	34.105292
56				
57	-5.4		1.034	34.240982
58	-3.37		1.034	25.059292
59	-3.34		1.034	24.923602
60	-3.6		1.034	26.099582
61	-4.39		1.034	29.672752
62	-5.55		1.034	34.919432
63	-4.66		1.034	30.893962
64	-3.92		1.034	27.546942
65	-4.6		1.034	30.622582
66	-4.39		1.034	29.672752
67	-4.69		1.034	31.029652
68	-4.11		1.034	28.406312
69	-3.95		1.034	27.682632
70	-3.33		1.034	24.878372
71	-3.51		1.034	25.692512
72	-3.69		1.034	26.506652
73	-5.34		1.034	33.969602
74	-3.65		1.034	26.325732
75	-3.63		1.034	26.235272
76	-5.39		1.034	34.195752
77	-4.01		1.034	27.954012
78	-3.78		1.034	26.913722
79	-3.67		1.034	26.416192
80	-4.87		1.034	31.843792
81	-5.1		1.034	32.884082
82	-6.22		1.034	37.949842
83	-3.86		1.034	27.275562
84	-3.86		1.034	27.275562
85	-3.77		1.034	26.868492
86	-3.63		1.034	26.235272
87	-6.71		1.034	40.166112
88	-3.84		1.034	27.185102
89	-3.47		1.034	25.511592
90	-3.31		1.034	24.787912
91	-3.42		1.034	25.285442
92	-4.59		1.034	30.577352
93	-4.91		1.034	32.024712
94	-5.1		1.034	32.884082
95	-6.57		1.034	39.532892
96	-5.85		1.034	36.276332
97	-5.71		1.034	35.643112
98	-3.76		1.034	26.823262
99	-3.75		1.034	26.778032
100	-3.48		1.034	25.556822
101	-3.61		1.034	26.144812
102	-4.97		1.034	32.296092
103	-6.6		1.034	39.668582
104				
105	-3.78		1.034	26.913722
106	-3.54		1.034	25.828202
107	-5.63		1.034	35.281272

and direction of tectonic activity in the study area.

Stable Isotopic Data and Temperature Estimates

One large coral from Santa Cruz del Norte was X-rayed and micro-sampled at the rate of 4/yr over 30 coral years to produce a low resolution stable $\delta^{18}O$ record for Substage 5e. Samples taken at weekly resolution (50 samples per coral year) allow documentation of the full amplitude of variability retained in the coral aragonite (Halley et al., 1994; Leder et al., 1991; 1996; Swart et al., 1996). Two coral years were sampled at the rate of 50/year, with one of these years analyzed for $\delta^{18}O$ to produce a high-resolution record of variability to interpret the long-term, low-resolution record more fully.

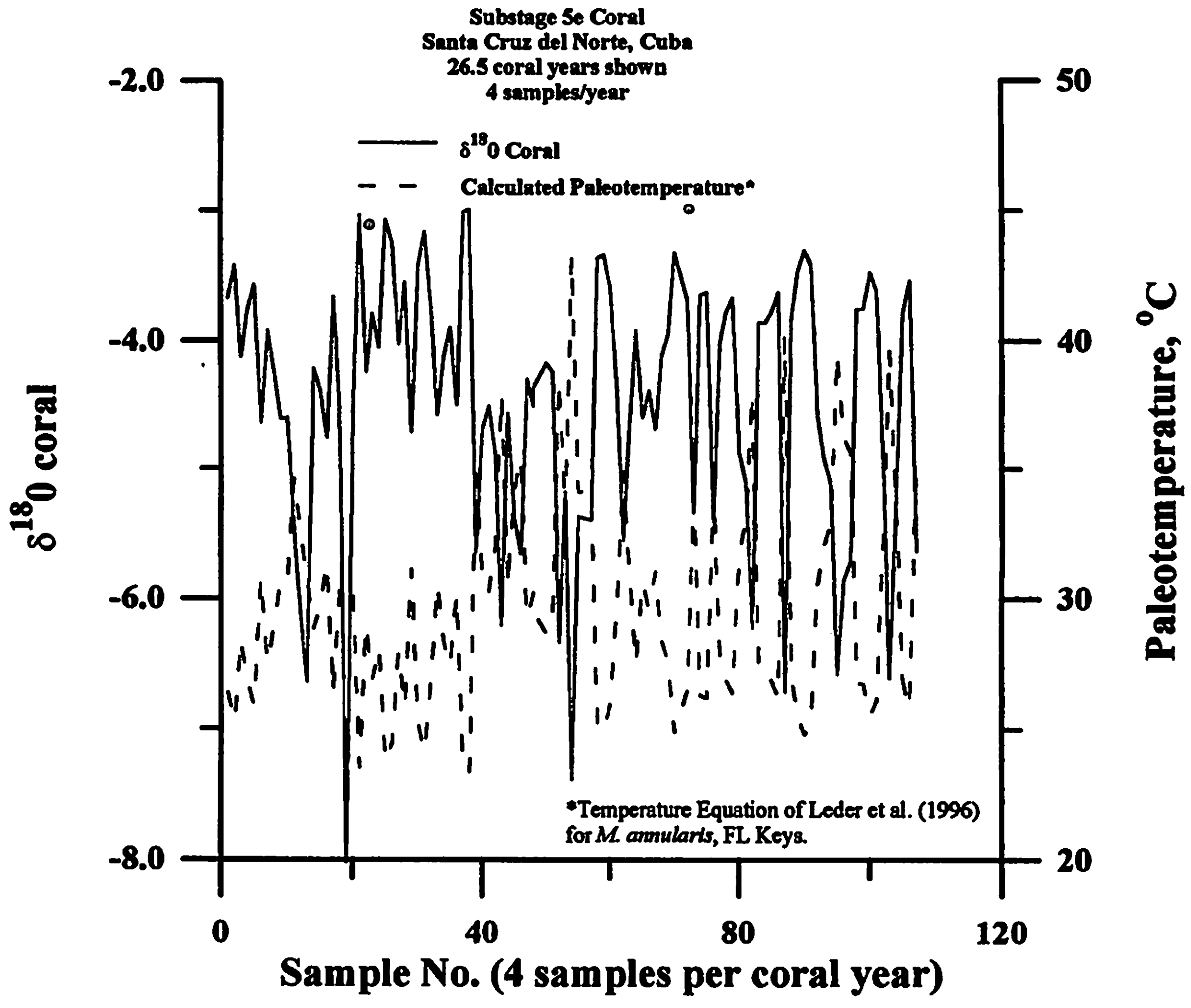

Figure 3. *Low resolution stable isotope record from Substage 5e coral (126 ka U-Th -corrected age- see Table 1), Santa Cruz del Norte. The Montastrea sp. was sampled continuously to produce four sample increments per coral year, based on an average growth rate measured and calculated from the coral X-radiograph. 26.5 years analyzed are shown. The $\delta^{18}O$ record shows well-defined seasonality and overall warmer than present temperatures. Two highly depleted δ_c values (<-6.5‰; Table 2) produced peak temperatures of 40-43 °C.*

Calculation of Paleotemperature from Coral $\delta^{18}O$

Calibrated Equation Approach.

Using $\delta^{18}O$ to calculate paleotemperatures is best accomplished with a species-specific, locality- calibrated temperature equation (McConnaughy, 1989a,b; Aharon, 1991; Halley et al., 1994; Leder et al., 1996) based on regression analysis between coral $\delta^{18}O$, *in situ* temperatures and oxygen isotopic composition of seawater. Equation 1 (Leder et al., 1996) is the only one available for *M. annularis*, in the Florida Keys or the Caribbean:

$$t°C = 5.18 - 4.523 * (\delta_C - \delta_W). \quad (1).$$

Because this equation was developed for Florida Keys waters, the constants may not apply to Cuban waters. It has been used successfully to reconstruct reasonable late Pleistocene and early Holocene sea surface temperatures from fossil corals in Florida (Toscano, 1996; 1998; Toscano and Lundberg, 1996; in prep.), hence it is used here to further test its usefulness outside its im-

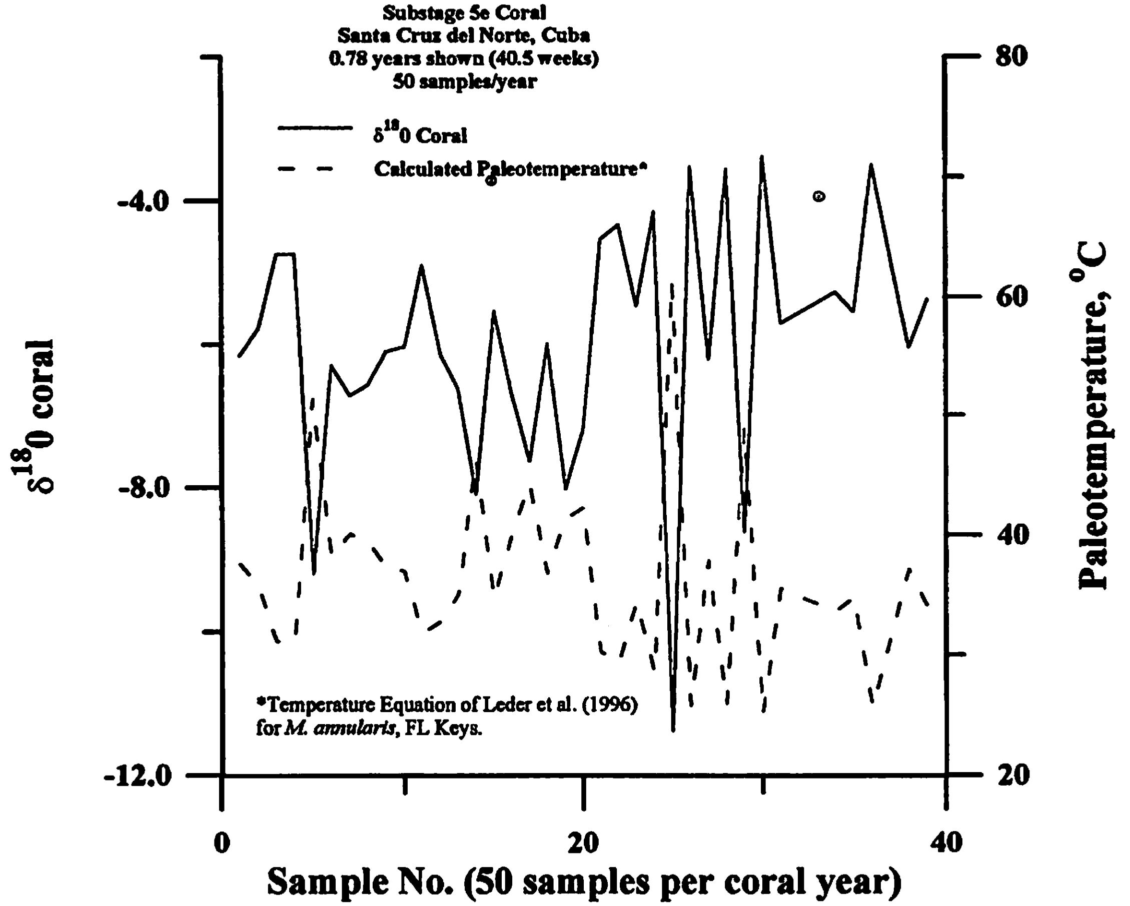

Figure 4. High resolution stable isotope record from Substage 5e coral (126 ka U-Th - corrected age- see Table 1), Santa Cruz del Norte. The Montastrea sp. was sampled continuously to produce 50 sample increments per coral year, based on an average growth rate measured and calculated from the coral X-radiograph. Approximately 40.5 weeks are shown. The δ_C *record exhibits monthly fluctuations including nine extreme high temperature peaks of >40°C (maximum 61°C) resulting from 9 highly-depleted* δ_C *values (<-6.5‰). While high-resolution data are designed to reproduce the full range of variability in temperature, the extremes noted via the calibrated temperature equation for Florida would result in coral death and may actually reflect fluctuations in salinity.*

mediate calibration area.

Determination of δ_c.

δ_c is determined from CO_2 evolved from solid carbonate by reaction with 100% H_3PO_4. The δ_c obtained from coral skeletons results from a combination of environmental parameters including *in situ* water temperature, δ_w (which incorporates salinity fluctuations), and the effects of vital fractionation (McConnaughy, 1989a). These parameters have been accounted for in *Montastrea annularis* within the Florida Keys by Equation 1 (Leder et al., 1996).

Determination of Paleo δ_w.

The paleo δ_w is essential for distinguishing ancient paleotemperatures from modern, especially if the fossil isotopic ranges are the same as for modern corals. For paleo-oceans, δ_w is an estimate representative of modern reef waters, corrected for the ice volume effect due to differences in paleo sea level from modern sea level. Using a corrected δ_w, paleotemperatures should be reproducible from fossil coral isotopes using Equation 1.

Deriving reasonable working estimates for the δ_w of Substage 5e requires use of the sea level estimate of +6 m MSL and the δ_w calibration of -0.11‰ per 10 m sea level difference from present (Fairbanks and Matthews, 1978). This coral isotope/sea level calibration can be multiplied by the paleo sea level to give the *change in δ_w from present values.* This relationship continues to be a standard in $\delta^{18}O$-based paleoclimate and sea-level studies in the Caribbean (e.g. Fairbanks, 1989; Bard et al.,1990a; b; Guilderson et al.,1994).

For Cuba, the present δ_w in the study area is not known. The present δ_w in Florida Keys Reef tract waters, representing an area 20 km SW to 50 km NE offshore of Hen and Chickens Reef, falls between 0.9‰ and 1.5‰ (1.5‰, 0.9‰, 1.0‰ (Lloyd, 1964); 1.2‰ (DaSilveira et al.,1987)) and between 0.8‰ - 1.4‰ in Biscayne Bay (Leder et al., 1996). A value of 1.1‰ averaged from these sources is used as the modern value from which paleo δ_w was calculated in Florida (Toscano, 1996; 1998; Toscano and Lundberg, in prep.) and is used as an arbitrary value for modern Cuban waters, recognizing the error likely to be introduced. Paleo δ_w is calculated as follows:

$$\text{Paleo } \delta_w = (-0.011‰/\text{m})*(Z) + 1.1‰ \qquad (2)$$

where Z is the sea level elevation relative to present, with the appropriate sign. Sea levels above present, with positive Z values, produce depletion (negative shift) in δ_w.

Possible errors in paleo δ_w values stem from their dependence on the accuracy of the sea-level estimates, as well on the general accuracy of the modern seawater $\delta^{18}O$. Any offset from the actual sea level decreases the accuracy of the paleo δ_w estimate by 0.011‰ of δ_w for every meter which the sea-level estimate is in error. Each meter of estimated sea level change results in a ±0.05°C difference in the calculated temperatures. The error becomes climatically significant (i.e. >0.5°C) for sea-level elevation estimates which are incorrect by more than 10 meters. For Susbtage 5e, the almost universally accepted benchmark sea level estimate of +6 m MSL (e.g. Bard et al,. 1990b; Chen et al., 1991; Mylroie and Carew, 1988, Neumann and Moore, 1975; Richards et al.,1994) is used and should not introduce large errors. A maximum sea level of +6 m MSL results in a calculated difference in δ_w from modern of -0.066‰ (±0.0033‰). From Equation 2, Substage 5e paleo δ_w is 1.034‰ (±0.0033‰).

DISCUSSION

Geochronology of the Jaimanitas Reef

All dates in Table 1 are indicative of reef growth during Substage 5e. All three Jaimanitas dates have U/U_{init} values which are elevated slightly over the modern seawater standard of 1.14 (Gallup et al., 1994). Each 0.01 increase over 1.14 is likely indicative of a 2 kyr apparent increase in age, thus each of the dates appear to be up to 6 kyrs older than the samples actually are (Gallup et al., 1994). If so, the Jaimanitas age range should be corrected to 142 - 120 kyrs, shifting it further into the range (132-120) generally describing that of Substage 5e from isotopic and other reef records (Martinson et al., 1987; Chen et al., 1991). The Jaimanitas reef is correlative to its TIMS U-Th dated Caribbean counterparts in the Bahamas (Cockburntown reef) (Chen et al., 1991), Barbados (Barbados III) (Gallup et al., 1994), and Florida (Key Largo Limestone) (Broecker and Thurber, 1965; Osmond et al., 1965).

Sea level Interpretation and Implications for Tectonic Activity

Visual estimates in the field placed the Jaimanitas reef surface at +2 to +3 m MSL at the shoreline of north Cuba. Given the age of ~125 ka for the reef, some physical erosion due to subaerial exposure probably occurred from ~120 to ~5 ka. Marine physical and bio-erosion, occurring from about 5 ka to the present when the Holocene transgression reached the top of the platform, probably accounts for additional loss of the reef surface (Hallock, 1988). Remnants of a red paleosol on the reef suggest erosion of at least that portion of the terrace surface. The actual amount of erosion is probably unquantifiable; however the present reef surface is still 2-3 m above present sea level, i.e. it remains at or slightly below the elevation range consistent with a shallow water depth over a reef crest growing in a +6 m sea level. Thus no obvious tectonic uplift is indicated for this time frame along the northern margin of Cuba (Mann et al., 1995). The higher-elevated sections observed at Matanzas (Shanzer et al., 1975) have not been dated and therefore may not be Jaimanitas-related.

Paleoclimatology and SST Estimates

Stable isotopic data are shown graphically in Figures 3 (low resolution 26.5-year record) and 4 (high-resolution 1-year record), with calculated paleotemperatures superimposed. Both records show pronounced seasonality and 19-36°C paleotemperature ranges (calculated in Table 2). Several δ_c (Table 2) are extremely depleted (<-6 ‰), and produce extremely high (and unlikely) paleotemperatures for Caribbean waters (Carriquiry et al., 1994; Winter et al., 1991; Hudson et al., 1994) using Equation 1. Low-resolution data produced two values of 40-43°C (Table 2). High-resolution data contain at least 9 extremely depleted δ_c values that produced calculated paleotemperatures between 40°C to 61°C (Table 2). Temperatures exceeding 30°C for long periods result in coral bleaching, attenuated growth rates (Leder et al., 1991), and probable mortality, yet these corals survived. While the overall temperatures are slightly high, averaging 29.6°C, they occur consistently within a time frame of concurrent peak insolation, obliquity, eccentricity, and sea level (Berger, 1992; Berger and Loutre, 1991; Crowley and Kim, 1994).

Because a number of δ_c are so depleted, it is difficult to determine which constants in Equation 1 may have artificially amplified the calculated temperatures. The paleo δ_w used from Florida data, due to a lack of *in situ* δ_w measurements in Cuba, is a likely source of (unquantifiable) error. In addition, the equation of Leder et al. (1996), calibrated for the Florida Keys, may not account for environmental factors in north Cuba. The sea level estimate is not considered to have introduced error, as discussed above. Depleted δ_c in high-resolution data may actually reflect large salinity fluctuations within the reef (Halley et al., 1994). Low resolution data therefore produce a more realistic temperature history by masking non- temperature related environmental effects on δ_c.

FUTURE WORK

We have been invited to return to Cuba and continue reef studies along the north coast and in the south coast near Santiago de Cuba. We would like to target good sections like Santa Cruz del Norte and fully describe the section in the canal, as well as to sample and core the reef. Funding will be difficult to obtain and logistics will be problematic, but the work can be done with sufficient planning and assistance from our Cuban colleagues. The Geological Institute has the information necessary to expedite our work visas for future trips, which we hope to make when diplomatic relations improve.

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