HIGH-RESOLUTION CARBON AND OXYGEN ISOTOPE AND TAPHONOMY RECORDS FROM DOMINICAN ACROPORA CERVICORNIS CORAL AND IMPLICATIONS FOR MID-HOLOCENE CLIMATE

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INTRODUCTION

The mid-Holocene (5 – 7 kya) is proposed to be a thermal maximum—a warmer geologic time period relative to rest of the Holocene in the northern hemisphere. This estimate is based on astronomical observations of Milenkovitch cycles. While current climatic conditions are not identical to that geologic time-period, understanding the mid-Holocene thermal maximum is helpful for a better understanding of our current period of relative warming.

Paleoclimate of the past 10,500 years has been documented for the island of Hispaniola by isotopic analysis of fresh-water ostracods from Lake Miragoane, Haiti (Curtis and Hodell, 1993), the geographically closest site to this study. Curtis and Hodell (1993) used lake-sediment core data to reconstruct in broad strokes the rough fluctuations of temperature and precipitation patterns.

Unlike Curtis and Hodell, this study concentrates on coral skeletons, which add a component to the paleoclimate picture for a variety of qualities (Swart, 1983, Gagan, 2000). Reefs are generally widespread throughout the tropics in most parts of the world, making it possible to examine similar aspects of various oceans. Calcite and aragonite in recent (<400 ka) corals can be easily and accurately dated via radiocarbon methods. Coral skeletons also contain a variety of geochemical tracers such as stable isotopes and trace elements that can be proxy evidence for such values as past temperature, rainfall, and oceanic circulation (Gagan, 2000).

Acropora cervicornis is a species of branching stony coral that prefer depths of 3 to 18 meters and often form dense thickets as part of a larger reef system (Humann, 1993). Humann (1993) also states that these coral can grow up to 13 to 15 cm per year, though this tends to be a high maximum value. Shinn (1966) cites an average of 10 cm a year for coral in ideal conditions; when conditions become less than perfect, growth rates can slow dramatically. *A. cervicornis* tends to be one of the more fragile members of the reef ecosystem and so is seen as a possible keystone species for the general health of a reef (Hubbard, et al, 2005).

Before coral can be used as climate proxies, it must be established that the outcrop is *in situ*. Taphonomy, or degradation in skeletal architecture, has been used to determine ancient reef settings (Greenstein and Moffat, 1996, Pandolfi and Greenstein, 1997). In general a higher mean taphonomy value corresponds to a more degraded coral and a higher energy environment. More pristine coral are an indicator of a lower-energy environment.

Stable isotope ratios signal the isotope ratios that were present in the ancient seas. Typically, when the oxygen ratio favors the lighter isotopes, the temperature was higher during formation or the evaporation-to-precipitation (E/P) ratio was lower (more rainfall). The reverse is also true. While carbon isotopes are less straightforward, the generally accepted hypothesis holds that when the carbon isotopes are lighter, more terrestrial input existed.

In this study, taphonomy data and $\delta^{13}C$ and $\delta^{18}O$ stable isotope ratios of *A. cervicornis* coral from the Lago Enriquillo region of the Dominican Republic are used to reconstruct time-specific paleotemperatures as well as general climatic trends for the early to mid-Holocene. In this contribution, I show that the Las Clavellinas outcrop examined is *in situ*, that paleoseasonality did not vary during the mid-Holocene, and that climate was warming, indicating a northward shift of the ITCZ.

METHODS

Coral, shell, and echinoderm (mainly *A. cervicornis* staghorn coral) samples were taken in the gully near Las Clavellinas and at the road-cut known as Coral Graveyard, both in the Lago Enriquillo area of southwest Dominican Republic. Three simple stratigraphic sections were sampled in the Las Clavellinas gully and one section was sampled in the Coral Graveyard area. For each section, coral samples were removed, along with a random volume sampling of all material present for geochemical and taphonomy studies.

Taphonomy numbers were assigned for all coral specimens based on an adapted taphonomy scale of 1 (pristine) to 5 (degraded) (Fig. 1). These were then organized by percentage of each taphonomy grid per section and subsection.

Radiocarbon dates were run at Lawrence Livermore National Laboratory for samples taken from all four sections. Dates for Section DR-C were run every half meter. Two samples were dated for Section DR-L and one for Section DR-K. One radiocarbon date was gathered for the Coral Graveyard *in situ* section.

Figure 1: Taphonomy Grades. Taphonomy grades are listed below each ideal sample. Grades are as follows: 1) Pristine, 2) Slightly Weathered, 3) Moderately Weathered, 4) Weathered, and 5) Heavily Degraded.

Samples from all four sections were analyzed with XRD to determine percentage aragonite and calcite content. Once a few samples from each section were determined to contain only trace amounts of calcite, micromilling for isotope analysis could commence.

Thin sections were cut from corals along the length with a rock saw and mounted on glass slides. These slides were then mounted in the micromill framework so as to be able to move with computer-guided controls. Samples were drilled with a stationary dentistry drill in 1-mm increments up both the thecal wall and corallite on the coral samples (Fig. 2). Samples were then loaded into a Kiel (MAT 253) mass spectrometer.

Statistical t-tests were run for the taphonomy grade values recorded for all corals. The test compared the taphonomy of the population that appears to be *in situ* (Las Clavellinas) with the population that appears to be transported (Coral Graveyard).

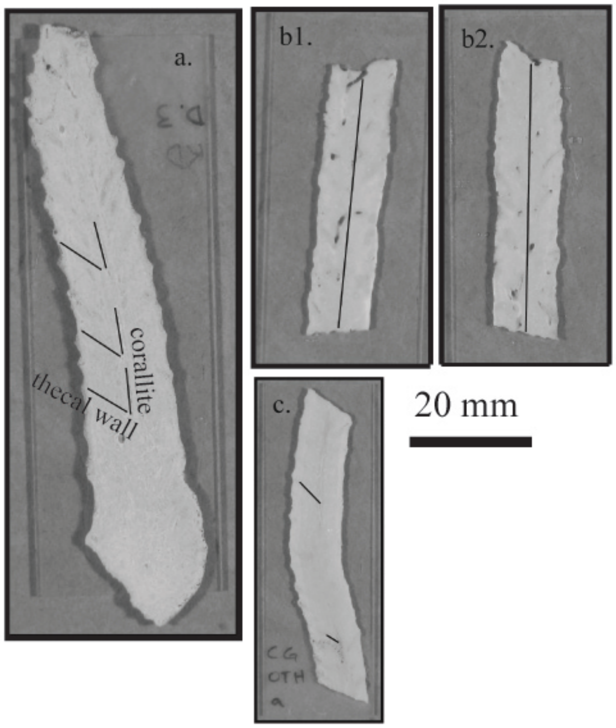


Figure 2: Milled Samples. (a.) Sample KD from Section DR-K. (b1, b2) Sample CG 1 from the in situ section of Coral Graveyard. (c.) Sample CG 2 from Coral Graveyard.

RESULTS

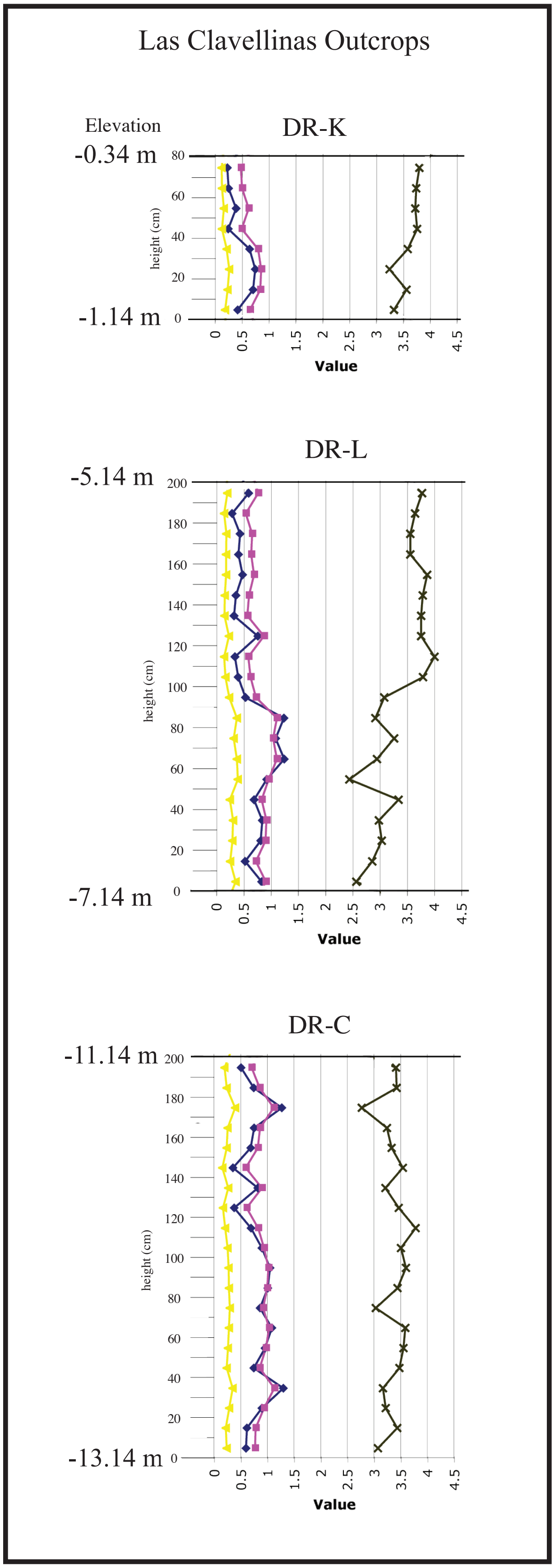
Mean taphonomy values varied over space and time (Fig. 3). In section DR-C, average taphonomy varied between 2.78 and 3.80. In section DR-L average taphonomy showed a dramatic shift in numerical value between 90 and 100 cm in height. Before 90 cm, the average varied between 2.44 and 3.35. After 100 cm, though, average taphonomy was significantly higher and never dipped below 3.5 again, staying between 3.56 and 4.00. The standard deviation showed a similar value change. Before 100 cm, it experienced similar values to section DR-C, and after 100 cm it falls off, with only 1 value greater than 1.15 and 5 out of 11 values lower than a normal distribution curve. DR-K, the shortest section of the three, yielded average subsection values between 3.25 and 3.81 while standard deviation values ranged between 1.31 and 0.75. In the Coral Graveyard Taphonomy Section, average subsection taphonomy was slightly higher and more consistent than the Las Clavellinas sections. All average values were above 3.95 and ranged as high as 4.27. Standard deviations never varied far above 1, with the highest at 1.16 and were often lower than 1, that is, lower than a normal distribution. In fact, not one taphonomy value of "pristine" was recorded for any coral gathered at Coral Graveyard.

For section DR-K, carbon and oxygen isotope ratios positively correlate in both the thecal wall and in the corallites. The $\delta^{13}C$ value for this sample ranged from –0.28 to –2.14 ‰ in the thecal wall and 0.65 and –2.25 ‰ in the corallite, and $\delta^{18}O$ ranged from –1.86 to –3.07 ‰ in the thecal wall and –1.82 and –3.08 in the corallite. However, the isotope values for the corallite and corresponding thecal wall do not seem to covary in any way. $\delta^{13}C$ from Coral Graveyard (CG 1) ranged from –1.66 to –4.39 ‰ while $\delta^{18}O$ ranged from –2.36 to –3.51 ‰.

For the data that was gathered on two corallites from section CG-2, $\delta^{13}C$ ranged from –0.90 to –3.76 ‰ while $\delta^{18}O$ ranged from –2.31 to –3.28 ‰. However, for many (65%) of the expected data points, values were recorded; not enough powder was present to generate the minimum required gas for analysis so it will be excluded from future discussion.

DISCUSSION

The results of the sample t-tests indicate a significant difference between the coral populations found at Coral Graveyard and Las Clavellinas. The population (P) two-tailed result is -3.7×10^{-202} while for statistically similar populations this value would be greater than 0.05. This analysis indicates that parts of the Coral Graveyard outcrop were transported rather than deposited *in situ*.



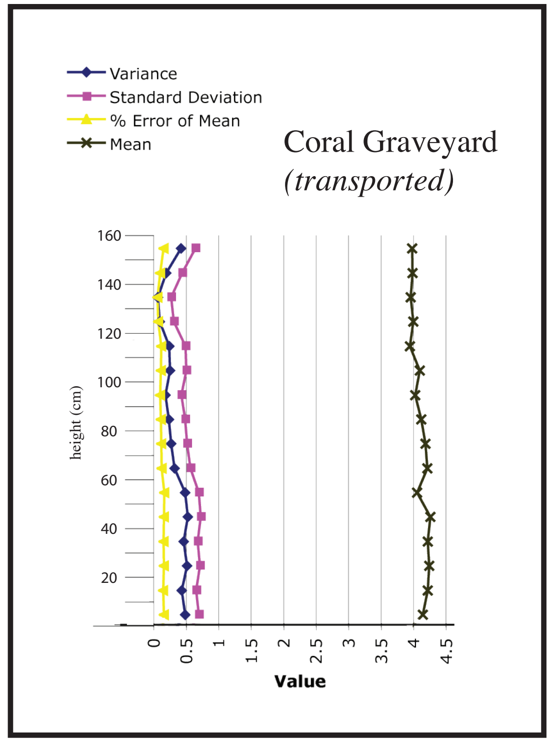
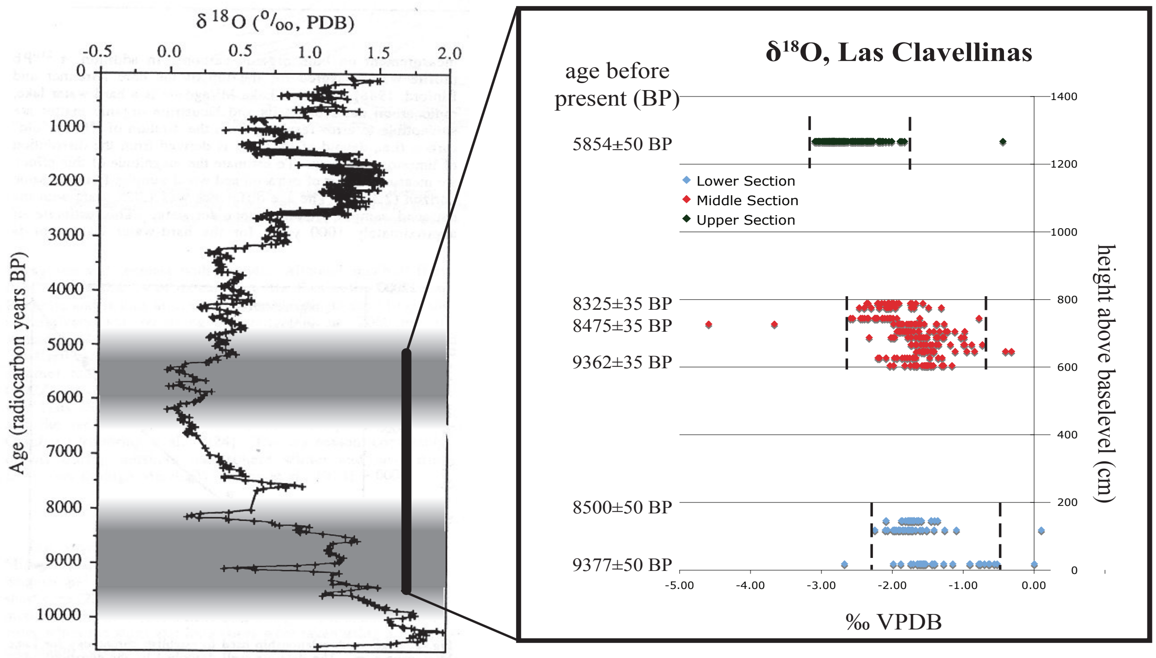


Figure 3. Taphonomy results for Las Clavellinas and Coral Graveyard. On avarage, Las Clavellinas sections show lower mean taphonomy, higher standard deviations, and are more variable. Coral Graveyard has higher means, lower standard deviations, and less variability.

In terms of $\delta^{18}O$ values for Las Clavellinas coral, values covary with the $\delta^{18}O$ from ostracods of Lake Miragoane, Haiti (Curtis and Hodell, 1993) in Figure 4. The average $\delta^{18}O$ value for each section in Las Clavellinas corresponds to the approximate relative value in the grey-banded areas for the Miragoane $\delta^{18}O$ curve. Variability is also a factor for paleoseasonality determinations. Ignoring some outliers (<2%) we can get a general sense the magnitude of annual temperature fluctuations. Throughout much of the early to mid-Holocene it would appear that $\delta^{18}O$ values varied by about 2.0 ‰. Oxygen isotopes from the upper section



From Curtis and Hodell, 1993.

Figure 4: δ18O values from Las Clavellinas A. cervicornis (Jackson, 2006; Teneva, 2006) compared to δ18O calcitic shell data from Lake Miragoane, Haiti (Curtis and Hodell 1993).

population showed no significantly higher or or lower variability.

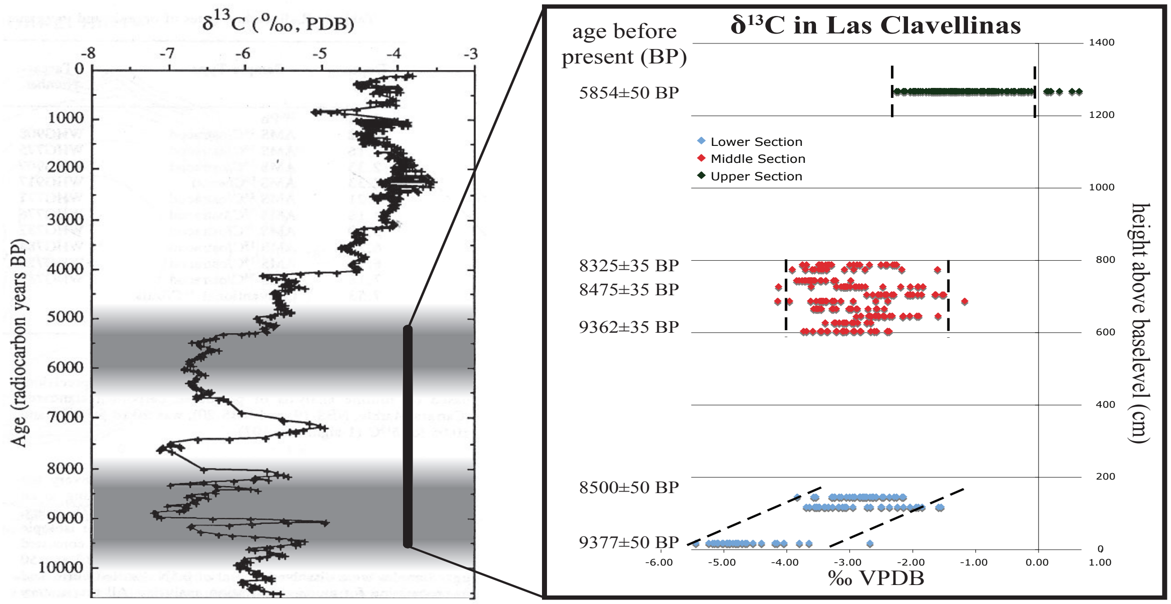
In terms of $\delta^{13}C$ values, co-variation with previous data from the area is less evident (Fig. 5). The upper section shows a more enriched average $\delta^{13}C$ value than the other two sections, while previous data suggest it should stay fairly similar (Curtis and Hodell, 1993). Again, the data in Figure 2 roughly approximates the shaded grey areas of the calcitic shell data. Here the data is also of similar variability (about 2.3 ‰), suggesting a fairly constant seasonality effect throughout this time period.

The oxygen depletion we see in the upper section when contrasted with the other two sections is indicative of a change in paleoenvironment between these two time periods. Lighter isotopes in the upper section indicate a warmer period, a wetter period (decrease in the E/P ratio), or both.

Oxygen istope data suggest that the atmospheric weather phenomena did migrate northward during the mid-Holocene thermal maximum.

CONCLUSIONS

The five-step taphonomy scale can be used in conjunction with mean and standard deviation analysis to determine general degradation of fossil coral, and when used in combination with statistical tests can even help to determine whether an outcrop is in situ or transported. Taphonomy analysis and field observations from the environmental sections of the two locations show that while parts of Coral Graveyard have been transported, Las Clavellinas outcrops are likely *in situ*. Annual variability paleoseasonality was fairly constant throughout the time period (~9380 to ~5850 BP). Mean $\delta^{18}O$ values from *A. cervicornis* support previous data and indicate a warmer period about 5.85 kya. These proxies indicate warming of surface-water temperatures, increased precipitation, or a combination of the two factors caused by northward migration of the ITCZ.



From Curtis and Hodell, 1993.

Figure 5: $\delta^{13}C$ values from Las Clavellinas A. cervicornis (Jackson, 2006; Teneva, 2006) compared to $\delta^{13}C$ calcitic shell data from Lake Miragoane, Haiti (Curtis and Hodell 1993).

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