Influence of Climate on the Formation and Isotopic Composition of Calcretes

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The control exerted by climate on calcrete formation throughout the Caribbean region is expressed as a change in the oxygen isotopic composition of calcretes along the climatic gradient between south Florida and the Turks and Caicos Islands, British West Indies. Along this gradient, an oxygen isotopic trend is documented as an increase in δ18O from south Florida to the Turks and Caicos. This is attributed mainly to higher temperatures and faster evaporation rates in the Turks and Caicos Islands. Isotopic compositions of meteoric waters have not been measured directly, but may play a secondary role in the observed isotopic trend in calcretes.

INTRODUCTION

Numerous past studies have focused on the influence of climate on different aspects of calcrete formation. In a most general sense, formation of calcretes depends on the presence of a seasonal climate which alternates between wet and dry conditions [Goudie, 1973; Harrison, 1977; Boucot et al., 1982]. Morphologies and physical make-up of calcretes have been studied along climatic gradients (mostly rainfall and evaporation), and differences documented [Harrison, 1977; Semeniuk and Searle, 1985; Semeniuk, 1986] in terms of degree of development and completeness (presence of diagnostic horizons) of the calcrete profile [Semeniuk and Searle, 1985]

Rainfall is one of the most commonly cited climatic parameters which governs calcrete formation [Harrison, 1977; Semeniuk and Searle, 1985], however, calcretes have been reported from areas with rainfall as little as 300 mm/year [Goudie, 1973]. Furthermore, soil scientists believe that CaCO3 precipitation is an ongoing process in desert soils [Schlesinger, 1985]. On the other hand, Semeniuk and Searle (1985) suggested, based on field observations, that calcrete development in southwestern Australia is restricted to areas with rainfall exceeding 800 mm/year. This discrepancy can be partly explained by invoking evaporation, which is another climatic parameter instrumental in calcrete formation. A balance between rainfall and evaporation is crucial for calcretes to form so that absolute amounts of rainfall per se are not as important as the interplay between the two [Harrison, 1977].

In the last ten years or so, numerous studies have related carbon and oxygen isotopic signatures of calcretes to climatic conditions [Cerling et al., 1977; Talma and Neterberg, 1983; Cerling, 1984; Cerling and Hay, 1986; Amundson et al., 1988]. A good correlation exists between the type of flora (C-3 or C-4) present during calcrete formation and the δ13C of calcrete [Cerling, 1984]. A correlation between oxygen isotopic signatures of calcretes and meteoric waters and evaporation has been shown to exist to a certain degree [Salomons et al., 1978; Cerling, 1984].

Precipitation of calcretes are controlled three processes: 1) degassing of CO2 from precipitating waters, 2) evaporation, and 3) evapotranspiration [Salomons and Mook, 1976; Salomons et al., 1978; Cerling, 1984]. The original carbon isotopic composition of the fluid is determined by the relative CO2 contributions of various components which are: 1) atmospheric (-6 ‰) [Cerling and Hay, 1986], 2) dissolved carbon from preexisting limestone, 3) the ratio of C-3 (-24 to -34 ‰ PDB) [Smith and Epstein, 1971] and C-4 plants (-6 to -19 ‰) [Salomons et al., 1978], and 4) plant root respiration rates [Cerling, 1984]. During inorganic precipitation, degassing of CO2 commonly only affects the δ13C signature because 12CO2 is preferentially lost during molecular diffusion [Cerling, 1984]. As CO2 equilibrates rapidly with water relative to the rate of calcium carbonate precipitation, CO2 degassing does not affect the oxygen isotopic composition of calcretes which primarily depends on the δ18O of the precipitating fluid and its temperature. Therefore, 3 main variables affect the ultimate δ18O of calcretes: 1) the original δ18O of meteoric waters (rainfall, groundwater), 2) δ18O enrichment of waters during evaporation prior to calcium carbonate precipitation, and 3) temperature. The major problems in interpreting oxygen isotopic compositions of calcretes can be summed up by the lack of knowledge of 1) rainfall isotopic composition, 2) amount of evaporation prior to calcrete precipitation and 3) process of calcium carbonate precipitation (CO2 degassing or H2O evaporation).

The purpose of this study is to (1) document isotopic variations in
calcretes from different settings, (2) investigate any correlations with climatic gradients, and (3) identify specific climatic parameters which can be singled out as the main causal variables for $\delta^{18}O$ variability.

**Settings**

Pedogenic surficial calcretes were studied from six localities spanning across a gradient from south Florida to the Turks and Caicos Islands. Below are brief descriptions of the individual localities:

**Caicos**

The Caicos Platform comprises the southernmost platform of the Bahamian chain of platforms (Fig. 1). The northern margin is rimmed by a continuous chain of Pleistocene islands [Wanless et al., 1989]. The western and eastern margins are rimmed by fewer islands. The platform itself measures about 70 km by 100 km end is, thus, relatively small compared to Bahamian standards. Based on morphostratigraphic principles [Garret and Gould, 1984], the islands on Caicos Platform record several stages of island growth during the Pleistocene by ridge accretion which continued during the Holocene [Wanless and Rossinsky, 1986; Wanless et al. 1989]. The southern portions of the northward facing islands consist of tidal flats [Wanless et al., 1989].

Calcretes occurring on topographic highs are petrographically and geochemically different from those occurring in topographic lows [Rossinsky and Wanless, 1992]. In both cases, the parent limestone is primarily an oolitic grainstone with minor amounts of skeletal allochems.

**Bahamas**

**Great Exuma.** Great Exuma island is located at the southwestern extent of Exuma Sound. The island is mainly comprised of colian ridges which dip bankward in a westerly direction [Ball, 1967].

**Gun Key.** Gun Key is located just south of Bimini at the western margin of Great Bahama Bank (Fig. 1). The island consists of sets of ridges comprised of oolitic and skeletal grainstones. These ridges seem to be of colian origin, based on the presence of Cerion sp., gastropod molds, and detrital gypsum grains within ridge sequences. Calcretes occur on the Pleistocene limestone surface as discontinuous patches because of dissolution and karst development.

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**Figure 1:** Map of south Florida and the Bahamas showing the location of the areas studied. Areas studied are south Florida, and the more arid Turks and Caicos Islands with stations of intermediate climate, Key Largo, Big Pine Key, Gun Key, Bahamas, Great Exuma, Bahamas, Bahamas, and Abraham Bay, Bahamas.
South Florida. South Florida is readily divisible into two separate climatological areas based on annual precipitation; the wetter mainland and the drier Florida Keys [Schomer and Drew, 1982]. Peninsular south Florida is a partly inundated carbonate platform. Continental influences are minor and consist of terrigenous influx of quartz sand via longshore drift [Wanless, 1976], and minor clays. The south Florida carbonate platform is separated from the Bahamas by the Straits of Florida. Calcretes from the mainland of south Florida were sampled from the Anastasia formation which occurs approximately 100 km north of Miami (Fig. 1).

The Florida Keys are an arcuate chain of islands at the southern tip of south Florida extending from Soldier Key to Key West, a distance of approximately 150 miles. They are divided into the upper keys which consist of the coraline Key Largo Limestone and the lower keys whose bedrock is comprised of the oolitic Miami limestone [Coniglio and Harrison, 1983]. The calcretes investigated in this study have been collected from Key Largo (upper keys) and Big Pine Key (lower keys) (Fig. 1).

CHARACTERIZATION OF CLIMATE

In order to characterize various climatic parameters along the Florida - Caicos climatic gradient, four stations have been selected for which climatic records are available. They are: 1) Miami (25° 48' N; 80° 16' W), 2) Key West (24° 33' N; 81° 45' W), 3) Abraham Bay (22° 22' N; 75° 28' W), and 4) Grand Turk (21° 26' N; 71° 08' W) (Fig. 1). Precipitation and rainfall have been compiled for the above stations over a period of 10 years from 1951 to 1960 (U.S. Dept. of Commerce, World Weather Records 1951-1960). Temperature and rainfall data for Grand Turk were compiled from World Wide Airfield Summaries conducted by the Naval Weather Service, a defunct government agency. The duration of the Airfield Summaries spanned 11 years, however, the exact years of the compilation are not known. Compilations from Grand Turk and the other three stations, thus, probably overlap to some degree and are comparable. No other climatic records from the Turks and Caicos Islands (except 1951 and 1952) seem to be published.

Winds, wind steadiness, specific humidity, and cloudiness data were taken from Hastenrath and Lamb (1961). These records span the period from 1911 to 1970. A comparison of those parameters is only made between Florida and Turks and Caicos Islands.

CLIMATIC PARAMETERS

Four aspects of climate, wind speed, wind steadiness, temperature, and precipitation are summarized in Figure 2 A-D. The data is presented as monthly averages over a 10 year period. Miami and Caicos are the only two stations taken into account for the first four parameters. For temperature and precipitation, Abraham Bay (Mayaguana Island, Bahamas) and Key West are considered in

Figure 2: (A) Plot of average monthly wind speed in m/sec for Miami and Caicos compiled between 1911 and 1970 [Hastenrath and Lamb, 1977]. (B) Plot of average quarterly wind steadiness in per cent for Miami and Caicos compiled between 1911 and 1970 [Hastenrath and Lamb, 1977]. (C) Plot of monthly average temperature in degrees Celsius compiled between 1951 and 1960 for Miami, Key West, Abraham Bay, and Caicos. Total averages for that time period are given in parentheses below station names (World Weather Records). (D) Plot of monthly average precipitation in mm compiled between 1951 and 1960 for Miami, Key West, Abraham Bay, and Caicos. Total averages for that time period are given in the upper left hand corner (World Weather Records).
addition to Miami and Caicos. Little variation exists in total cloudiness between Miami and Caicos averaging approximately 5 tenths for both locations. Specific humidity is recorded during January, April, July, and October with slightly higher humidities occurring in Caicos, except for July.

The climatic gradient between Caicos and South Florida manifests itself most dramatically in terms of wind regime, temperature, and precipitation (Figs. 2A, B, C, and D). These factors result in a higher evaporation rate in Caicos compared to South Florida. Wind speed, on a monthly basis (Fig. 2A), and wind steadiness (Fig. 2B), on a quarterly basis, are significantly higher in Caicos than in Miami. Monthly temperatures are shown in Figure 2C for all four stations. During the summer months there are minor differences, while during the winter months Caicos and Abraham Bay have significantly higher temperatures than South Florida. Key West has consistently higher temperatures than Miami all year. Extreme differences can be seen in precipitation among all four stations (Fig. 2D). By far the highest precipitation occurs in Miami except for November and December. Lowest rainfall occurs in Caicos; 605 mm/year, which amounts to 40% of Miami's average annual rainfall (1512.9 mm/year). Key West and Abraham Bay are intermediate at 970.4 and 951.0 mm/year, respectively. During the time that these measurements were taken, South Florida as well as the Caribbean Sea were affected by tropical cyclones below normal frequency [Dunn et al., 1967].

Methods

Isotopic Analysis

Carbon and oxygen isotopic analyses were measured on CO₂ extracted from powdered calcrite samples after digestion in H₃PO₄ at 90°C [Swart et al., 1991]. All samples were analyzed using a

A) ANASTASIA FORMATION
SOUTH FLORIDA

Δ²⁰C = -7.99 σ = 2.62
Δ¹⁸O = -3.82 σ = 0.20

B) KEY LARGO
FLORIDA KEYS

Δ²⁰C = -6.72 σ = 1.96
Δ¹⁸O = -3.07 σ = 0.97

C) BIG PINE KEY
SOUTH FLORIDA

Δ²⁰C = -6.99 σ = 1.20
Δ¹⁸O = -2.83 σ = 0.81

D) GUN KEY
BAHAMAS

Δ²⁰C = -6.40 σ = 1.69
Δ¹⁸O = -2.64 σ = 0.45

E) GREAT EXUMA

Δ²⁰C = -6.40 σ = 2.70
Δ¹⁸O = -2.42 σ = 0.54

F) CAICOS ISLANDS
BRITISH WEST INDIES

Δ²⁰C = -7.26 σ = 2.04
Δ¹⁸O = -1.76 σ = 0.70

Figure 3: Plots of carbon and oxygen isotopic data for (A) Anastasia Formation, South Florida, (B) Key Largo, Florida Keys, (C) Big Pine Key, South Florida (D) Gun Key, Bahamas, (E) Great Exuma, Bahamas, and (F) Caicos. The Δ²⁰C and Δ¹⁸O means and standard deviations are given below each graph.
Finnigan-MAT 251 mass spectrometer at the Stable Isotope Laboratory of the University of Miami. All data are corrected for conventional contributions to mass 45 and 46 following the procedure of Craig (1957), modified for a triple collector instrument and are reported relative to PDB. The external reproducibility determined by the analysis of 20 replicate samples of laboratory standard is 0.03 ‰ for oxygen and 0.02 per mil for carbon.

RESULTS

Carbon and Oxygen Isotopic Signatures in Calcretes

Approximately 400 calcrete samples were analyzed for their stable carbon and oxygen isotopic compositions. Crossplots of oxygen and carbon isotopic compositions of calcretes from individual stations are shown in Figure 3 A-F. In general, calcretes from all locations exhibit a wide range of δ13C and a narrower range of δ18O. The standard deviation of δ18O from different sites, however, varies significantly. The average calcrete composition from the Anastasia Formation (Fig. 3A) is most depleted in δ13C by at least 1 ‰ compared to all other stations (except Caicos). Oxygen isotopic compositions of calcretes from the Anastasia formation show the greatest depletion in δ18O, a mean value of -3.82 ‰, compared to calcretes from Caicos at the other end point of the climatic spectrum, with an average δ18O composition of -1.76.

Calcretes from Key Largo, which occur predominantly in coraline limestone of the upper Florida Keys (Fig. 3B), exhibit large variations in both carbon (δ13C = -6.72 ‰) and oxygen (δ18O = -3.07; σ = 0.97) isotopes. These values are similar to those obtained from Big Pine Key calcretes (δ13C = -6.99; σ = 1.20 and δ18O = -2.83; σ = 0.81) occurring on oolitic limestone (Fig. 3C).

Isotopic data from Gun Key (Fig. 3D) are similar to those of Great Exuma (Fig. 3E). Both sites have calcretes with a mean δ13C of -6.40 ‰ although the standard deviation is considerably greater at

![Figure 4](image_url)  
Figure 4: Plot of carbon and oxygen isotopic data of Valley Calcretes and Ridge Calcretes on Caicos islands. δ13C and δ18O means and standard deviations for both calcrete types are given in the upper right hand corner of the graph.

![Figure 5](image_url)  
Figure 5: Plot of mean δ13C and δ18O and standard deviations for calcretes from Anastasia formation, Big Pine Key, Caicos, Key Largo, and Great Exuma. Great Exuma (σ = 2.70 ‰) than at Gun Key (σ = 1.69 ‰). Oxygen isotopic data from these two sites are also similar (δ18O = -2.64 ‰; σ = 0.45 ‰ and δ18O = -2.42 ‰; σ = 0.54 ‰) for Gun Key and Great Exuma, respectively. The calcretes from Caicos are the least depleted in δ18O (δ18O = -1.76 ‰; σ = 0.70) (Fig. 3F). Valley calcretes and ridge calcretes [Rossinsky and Wanless, 1992] have been plotted separately in Figure 4. Whereas δ13C is similar, δ18O shows a significant difference of 0.86 ‰ in mean δ18O-values between the two calcrete types.

Mean carbon and oxygen isotopic values for all stations with their respective standard deviations are shown in Figure 5. The average carbon and oxygen isotopic signatures for all sites have been plotted with respect to the climatic gradient which exists between Caicos and

![Figure 6](image_url)  
Figure 6: Plot of average δ13C and δ18O of calcretes from sites along climatic gradient between Caicos and the Anastasia formation in south Florida. A general depletion in δ18O occurs along this climatic gradient from Caicos to south Florida and agrees generally with compositional trends observed in meteoric waters from this area. δ13C shows no trend between Caicos and south Florida.
south Florida (Fig. 6). Although there is no correlation between the carbon isotopic signature and geographic location, the $\delta^{18}O$ shows a variation of approximately 2 $^\circ$/oo between Caicos and south Florida.

**Discussion**

**Origins of Isotopic Variations**

The absolute and relative variation in the oxygen isotopic composition from Caicos to S. Florida is a function of at least four parameters: 1) Mechanism of precipitation, 2) composition of precipitating fluids (evaporative waters), 3) temperature of precipitating fluids, 4) composition of rainfall.

**Mechanism of Precipitation**

The mechanism of precipitation (CO$_2$ loss, evapotranspiration, evaporation) will determine whether the calcretes are $\delta^{18}O$ enriched, or if they reflect values of the local meteoric waters. If calcretes precipitate as a result of evaporation rather than CO$_2$-degassing or evapotranspiration, the precipitating fluids will become enriched in $^{18}O$ through fractionation. If calcretes precipitate as a result of CO$_2$ degassing or evapotranspiration, processes which aren't accompanied by oxygen fractionation [Cerling, 1984], $\delta^{18}O$ of the waters will remain relatively constant, and compositional differences may be attributable to variations in rainfall $\delta^{18}O$, temperature, or the composition of the precipitating fluids.

**Composition of Precipitating Fluids**

Evaporation can be clearly demonstrated to take place during or prior to calcrete precipitation in the Caicos Islands. Much of the $\delta^{18}O$ variation displayed in the Caicos calcretes can be explained by differences between evaporative processes which take place in fluids precipitating calcretes in topographically low versus topographically high areas. Calcretes forming in these varied topographic settings have been termed valley calcretes and ridge calcretes, respectively [Rossinsky and Wanless, 1992]. Figure 4 shows that valley calcretes are distinguishable from ridge calcretes based on their $\delta^{18}O$ signature. The impermeable nature of ridge surface calcretes inhibits meteoric waters from penetrating into the underlying, porous grainstone, enhancing rapid surface runoff. On ridges, therefore, calcretes precipitate from fluids which evaporate significantly less than in valleys. Meteoric waters tend to accumulate in the valleys where they are subject to evaporation and, thus, become enriched in $^{18}O$. Consequently, valley calcretes are 0.86 per mil heavier than ridge calcretes. This enrichment, however, can also be the result of a temperature difference of 3.5 °C between the precipitating fluids (Fig. 7). Although temperature differences between ridge and valley waters are to be expected, a difference of 3.5 °C in vadose water seems excessive. Therefore, evaporation must at least in part be responsible for the isotopic difference of 0.85 per mil between fluids precipitating valley and ridge calcretes.

Evaporation may be variable in response to local phenomena as is the case in Caicos where valley calcretes are enriched in $\delta^{18}O$ by 0.86 per mil relative to ridge calcretes (Fig. 4). However, even within valley calcretes and ridge calcretes the variability is considerable ($\sigma = 0.6$ and 0.54 respectively). This variability is probably a result of variations in the oxygen composition of rainfall. Variability of individual rainfall compositions are probably faithfully retained in the vadose zone, whereas calcretes precipitating in phreatic waters will have a more average composition. The $\delta^{18}O$ variability in calcretes between Key Largo and Big Pine Key (0.24 per mil) is for the most part a result of rain variability as local differences in evaporation are unlikely to be significant in the absence of topography. As calcretes probably precipitate in response to individual rainfall events, the entire calcrete deposit should reflect an average oxygen isotopic composition of the precipitating fluids.

**Temperature**

The oxygen isotopic composition of precipitated calcium carbonate is temperature dependent. Average temperatures at the different sites (Fig. 2E) are well constrained, and it is reasonable to assume that temperatures of soil and vadose waters are comparable to those of the atmosphere. However, it is not known whether the annual average temperature can be assumed to be representative of periods of calcrete precipitation. If calcretes precipitate as a result of CO$_2$ partial pressure, precipitation may occur preferentially during winter months and at night, when plant respiration rates and temperature are at their lowest. Calcrete precipitation favored during annual temperature maxima or minima can significantly influence the oxygen isotopic composition of the precipitated phase.

**Oxygen Isotopic Compositions of Meteoric Waters**

Mean annual $\delta^{18}O$ values of precipitation worldwide have been compiled by Yurtsever and Gat (1981) (Fig. 8). As a result of station sparsity on the globe, many values have to be extrapolated. In this study, average annual rainfall for south Florida and the northern Bahamas has been assumed to be -2.7 $^\circ$/oo SMOW [Swart et al., 1989], -2.5 $^\circ$/oo SMOW for the southern Bahamas, and -2.3 $^\circ$/oo SMOW for Caicos. Salomons et al. (1978) argued that the $\delta^{18}O$ composition of the infiltrated waters from which calcretes precipitate depends on the average precipitation. However, in south Florida,
groundwater has been measured to be as much as 3 \%o heavier than rainfall [Meyers, 1990], depending on the infiltration rate of rainwater into the ground.

Meteoric water can also vary in its isotopic composition depending on its origin. In south Florida, precipitation can be derived locally from the ocean or the Everglades. Rain can also be derived from larger storm systems when south Florida happens to lie in their migratory path. The oxygen isotopic composition in all of the above cases varies significantly. Rain water in Miami has been shown to be of a highly variable nature (Swart, unpublished data). At any one locality, however, it can be assumed that waters in the phreatic zone have a fairly constant oxygen isotopic (not necessarily the same as an individual rainfall) composition which represents the average meteoric composition. In contrast, waters in the vadose zone can be highly variable, reflecting compositions of individual rainfalls. Vadose water isotopic composition can also be expected to evolve rapidly if conditions are favorable for evaporation. As calcrites precipitate in the vadose zone, they are apt to incorporate the oxygen isotopic variability of individual rainfalls reflected in the vadose waters, which may help explain the observed variability at any one locality.

INTER-STATION VARIABILITY

A gradual but consistent depletion in the average $\delta^{18}O$ of calcrites occurs from Caicos to south Florida. Average oxygen isotopic compositions of calcrites have been plotted as solid triangles in Figure 9. Plotting almost parallel above, are the calculated average oxygen isotopic compositions of the precipitating fluids (solid circles). These have been calculated using known documented annual average temperatures and average calcrite compositions from corresponding locations. Thus, the vertical offset between the calculated values of the precipitating fluids and the measured composition of the calcrites in Figure 9 is a function of temperature.

A third line, plotted as solid squares (Fig. 9), defines the estimated average $\delta^{18}O$ of rain at each location. These estimates are based on extrapolations from Yurtsever's and Gat's (1981) compilations on average world-wide meteoric water compositions. The line defining the estimated average composition of rain can be seen to converge sharply with the line defining the calculated average of the precipitating fluids towards south Florida (Fig. 9). The oxygen isotopic difference between these two lines represents the amount of compositional change which rainwater has to undergo to reach the isotopic composition of the precipitating fluids. The degree of compositional change can be seen to diminish from Caicos to south Florida and suggests that evaporation plays a primary role in the evolution of the precipitating fluids. At each station, the composition rain evolves by evaporation along the cross-hatched pattern (Fig. 9) and becomes enriched in heavy oxygen. Higher evaporation, necessary to achieve a larger compositional change in Caicos, is consistent with the observed climatic data.

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Age constraints on calcrites in a climatic framework, are among the most fundamental prerequisites for a successful study. Corling
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contemporaneous. Any geochemical differences would therefore be related, at least in part, to climatic differences.

**Suggestions for Future Isotopic Work in Relation to Climate**

The above is a simplistic model which relies only on two more or less well known parameters - temperature and calcite δ¹⁸O. Three parameters need further study to be able to relate diagenetic products to waters of δ¹⁸O and climatic conditions in general. These are: 1) the actual temperature during calcite precipitation (as discussed above diurnal or even seasonal preference for calcite precipitation can change oxygen compositions by several per mil); 2) amount of evaporation at individual sites; and 3) a demonstrable mechanism for calcite precipitation (evaporation or CO₂-degassing). With these parameters constrained, the average meteoric water composition can be determined quite easily from the isotopic composition of the precipitating fluid by back calculating evaporation.

In the rock record these parameters are more difficult to determine. However, petrographic, mineralogic, and paleontologic (especially palynology) evidence may be used to quantify evaporation, temperature, and perhaps even mechanisms of precipitation. Of great interest would be the establishment of meteoric water compositions during cycles of glaciation in the Pleistocene, a time period for which the quantification of the above mentioned critical parameters may be possible.

The primary and foremost objective, however, should be to test out this model by measuring meteoric waters directly. Because calcretes are demonstrably forming in Caicos today, this would be the good place to start acquiring quantitative measurements on critical parameters outlined above and testing results of the model against actual meteoric water oxygen compositions.

**Conclusions**

Isotopic differences between calcretes from the two climatic endpoints (Caicos and south Florida) in this study can be attributed to differences in climatic conditions. This conclusion is tentative, and more work is needed for additional supporting evidence.

A gradual enrichment in δ¹⁸O along the climatic gradient between south Florida and Caicos is likely to be related to warmer and drier climatic conditions and thus higher evaporation rates in the Turks and Caicos Islands. Differences in the isotopic composition of meteoric waters are not established but probably play a secondary role.

Variations in climatic parameters considered of primary importance in determining the oxygen isotopic composition of precipitated calcretes can occur over short periods of time. To establish paleoclimatic gradients based on the oxygen composition of calcretes, care must be taken to compare signatures in calcretes of same ages.

Topography can play a key role in the oxygen isotopic signature of calcretes. On Caicos, valley calcretes have been shown to be enriched in δ¹⁸O relative to ridge calcretes due to differing evaporation regimes within the two settings. When comparing calcretes from different climatic settings with regard to their oxygen isotopic composition, great care must be taken to compare calcretes from the same topographic setting.

Although the carbon isotopic signatures in calcretes have been shown to be climate-dependent based on the distribution of C-3 versus C-4 plants [Cerling, 1984], the following discussion will be

(1984) cites the work of Salomons et al. (1978) as being only partially successful in showing a correlation between calcite δ¹⁸O and meteoric water δ¹⁸O because of a lack of age constraints on calcretes. He argued that present-day isotopic compositions of meteoric water may not reflect past compositions from which the calcretes may have precipitated. The time in question spanned 1 million years. In another study, Cerling and Hay (1986) have shown that at Olduvai near the African East Rift Valley for any given temperature of formation, the total range in calculated δ¹⁸O (SMOW) values has had a range of 8 ½oo over the last 2 million years. In this study, the time span in which calcretes may have formed is much narrower. Within this time frame it is assumed that meteoric waters did not vary to a great extent. Rossinsky and Wanless (1992) and Rossinsky et al. (1992) documented that the Caicos calcretes are young, perhaps forming at the present time. Comparable field criteria in the Florida keys are also present in mottled calcrete which exhibit unequivocal present-day vegetative associations. Comparisons between isotopic signatures in Caicos calcretes and south Florida calcretes only then have value if the calcretes in question are of the same ages.

Robbin and Stipp (1979) have obtained radiocarbon dates from laminated calcretes on Key Largo and Big Pine Key and concluded that their formation occurred during the last 5000 to 6000 years. The youngest dates obtained were 400 ± 70 and 270 ± 80 ybp for Key Largo and Big Pine Key respectively. This would indicate that modern Caicos calcretes and south Florida calcretes are
restricted mainly to $^{18}$O. Too little is known about the photosynthetic pathways of indigenous flora at the different sites as well as rates of respiration and organic decomposition, in order to relate carbon isotopic signatures to climate in a sensible way.

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