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PALEOGEOGRAPHIC PERSPECTIVES ON THE FIRST LANDFALL OF COLUMBUS[1]

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Paleogeographic evaluation supports the Samana Cay Columbus landfall theory. Despite traditional efforts based on navigational criteria, the identity of the Bahamian island on which Columbus first made landfall in the New World, and of the others visited by him before reaching Cuba, remains enigmatic. Beyond commemorative considerations, the inability to determine wherein the ethnographic and environmental observations made by Columbus apply significantly hinder our ability to fully utilize this early American historical record. Paleogeographic reconstructions have not been adequately pursued in connection with the landfall debate. Comparisons between current physical and ecological features and those described by Columbus have been used to argue between the two leading landfall candidates: San Salvador (Watling Island), the most popular prospect, and Samana Cay. Such comparisons rest on the implicit assumption that the present characteristics of the islands have remained unchanged during the past 500 years. Evidence is presented in this paper, based on integration of paleoclimatic, geological, archeological, and historical data of hemispheric, regional, and local scale, which indicates that environmental conditions on the islands have changed substantially since 1492. Attempts to identify the first landfall of Columbus should consider the implications of these changes.

The first encounter of the Old World with the New World occurred on October 12, 1492, on an island called *Guanahani* by its native inhabitants and christened *San Salvador* by Christopher Columbus. Columbus described it as "quite large, and very flat, and with very green trees and many waters and a very large *laguna* in the middle."[2] No other landfall in recorded history compares in importance, as it was here that unprecedented global changes were set in motion. It is thus truly ironic, as we mark the passage of the quincentennial of Columbus's voyage, that the identity of this landfall is an enduring enigma. Beyond commemorative considerations, other academic shortfalls result from this enigma. The observations recorded by Columbus of the inhabitants, settlements, and environments he first encountered in the New World, although cursory, provide a unique historical source of information. Our ability to fully utilize this information to reconstruct the past is curtailed by not knowing with exactitude wherein they apply.

Transatlantic crossing reconstructions based on the navigational information in Columbus's log make it clear that the island is to be found among those of the greater Bahama Archipelago (Richardson and Goldsmith, 1987) (Fig. 1). Within this archipelago, however, nine different islands along a 750-km arc have been proposed over the past four centuries as the first landfall. In conjunction with each

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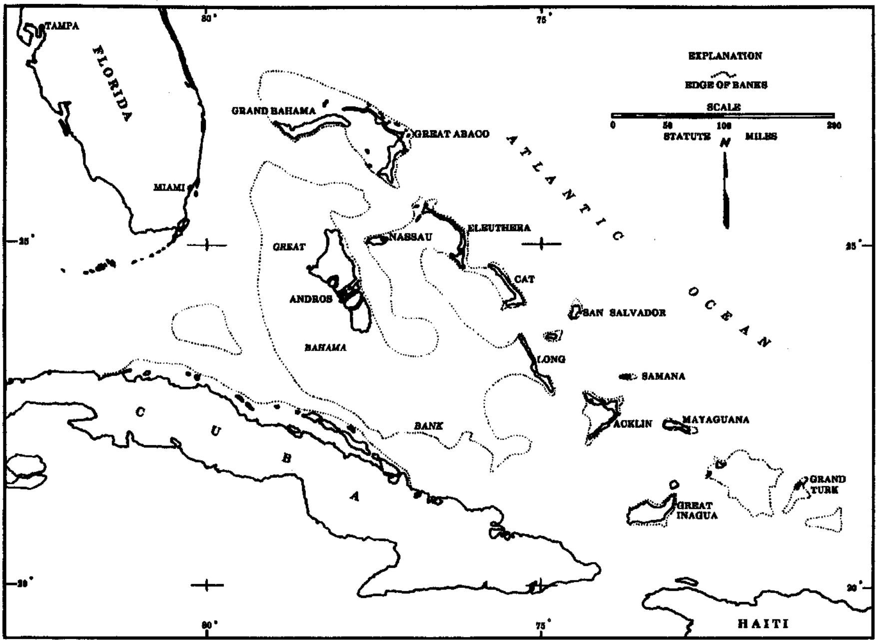

Fig. 1. The Bahama Archipelago.

first landfall candidate, several other islands are proposed as those subsequently encountered by Columbus before reaching Cuba. The historical development of the landfall question has been reviewed by Fuson (1987) and Parker (1985). A critical analysis of the history and historiography of Columbus's first voyage has more recently been attempted by Henige (1991). The landfall debate at present focuses primarily on two leading candidates, both in the central Bahamas: San Salvador (Fig. 2) (previously called Watling Island and renamed in 1926) and Samana Cay (also known as Atwood Cay) (Fig. 3) (Dor-Ner and Scheller, 1991; Keegan, 1992a). The San Salvador/Watling Island theory, which currently is generally favored, rests primarily on the work of Morison (1942), with modifications offered by Keegan and Mitchell (1987), Mitchell and Keegan (1987) and Keegan (1992b). The Samana Cay theory is mainly based on the work of Fox (1882) and Judge (1986). Fuson (1987) and Perez (1987) have further elaborated some points of the Samana Cay theory.

The proposed landfall theories have focused primarily on navigational criteria, which have proven insufficient to resolve the problem, while ignoring important paleogeographic aspects. Various arguments for and against each of the theories have assumed that the environments of the islands have remained largely unchanged during the past 500 years. The present study is an attempt to

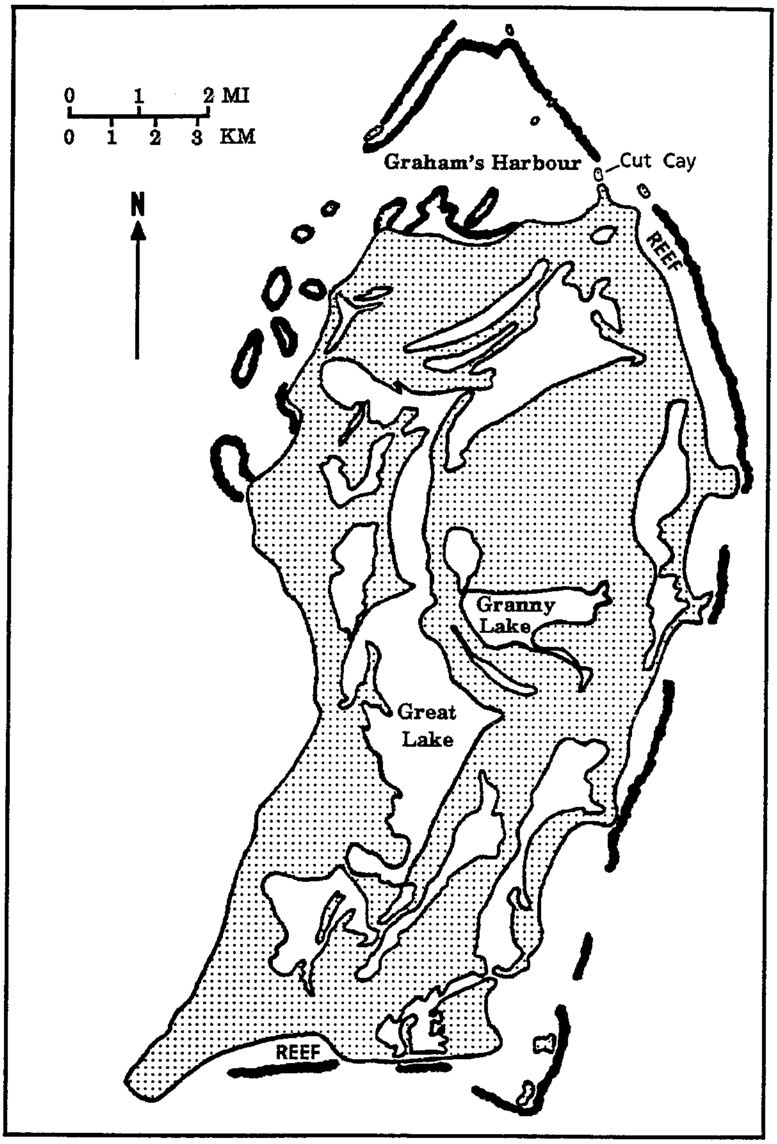

Fig. 2. Map of the present physical features of San Salvador (Watling) Island.

decipher the geographic characteristics of the Bahamas in 1492 by reference to regional and hemispheric conditions at the time. Evidence is presented which indicates that environmental conditions on the islands have changed substantially during the last 500 years.

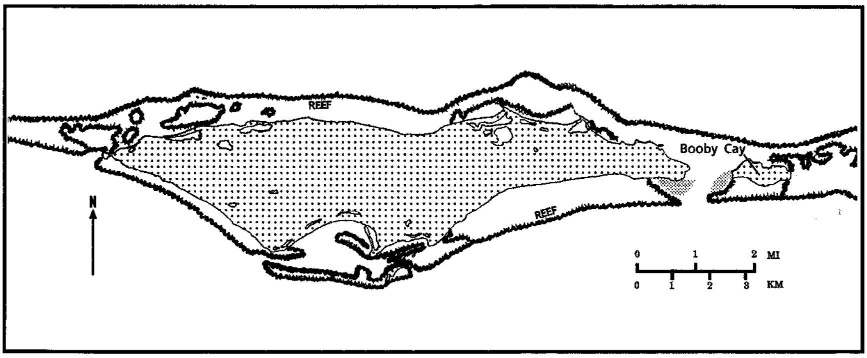

Fig. 3. Map of the present physical features of Samana Cay.

HEMISPHERIC CLIMATIC AND SEA LEVEL CONDITIONS. The period from about A.D. 1430 to 1850 is commonly and collectively known as the Little Ice Age (NRC 1975, p. 151). During this period many glaciers in Alaska and Europe advanced close to their maximum positions since the last major ice age some 18,000 years ago. Expansion of the Arctic pack ice into North Atlantic waters also occurred, causing the isolation and demise of the Norse colony in southwest Greenland.

However, the change toward the colder climate associated with the Little Ice Age was not geographically synchronous (Jones and Bradley, 1992; Williams and Wigley, 1983). While there was a mid-to-late 15th century cold episode in parts of Europe and western North America, summers were relatively warm in the eastern Canadian Arctic and southern Greenland (Camuffo and Enzi, 1992; Williams and Wigley, 1983). In the eastern Canadian Arctic, the Devon Island ice cap meltwater record is in good agreement with proxy climatic data from Baffin Island in showing warming from the 13th-14th to the 15th-early 16th centuries. Additionally, organic matter dated to A.D. 1490 has been sampled from the bottom of an ice wedge on Baffin Island (Miller, 1973; Williams and Wigley, 1983), also suggesting seasonal thawing of ground that is now perennially frozen. In southern Greenland, material from Norse burials dating up to the late 15th century has been recovered from ground that apparently became perennially frozen soon after burial (see Porter and Denton, 1967).

The warm period of the late Middle Ages identified in the Arctic region of eastern North America coincides with a relative sea level rise (submergence) during the late 14th and 15th centuries. A sea level stand for this period on the order of 0.5 m above present sea level has been identified on Cat Island, Bahamas, based on study of coastal terrace deposits (Lind, 1969a, 1969b). A submergence is also evidenced in Europe during this period, although sea level there may not have stood higher than at present (Bloch, 1965; Ters, 1987). The coincidence of this submergence with a warm period in the eastern Canadian Arctic and southern Greenland suggests that sea levels rose eustatically as a result of glacial melting in that region.

In the area of the Caribbean, detailed proxy climatic data from Haiti indicate a long-term trend over the past millennium of increasing aridity and decreasing temperature (Curtis and Hodell, 1993). This general trend is commensurate with changes in orbitally induced variations in seasonal insolation (Hodell et al., 1991). Superimposed upon this long-term trend, however, are abrupt climatic events decades to centuries in duration for which the causes are indeterminate.

Geologic evidence from the central Mexican highland indicates that a glaciation corresponding to the Little Ice Age occurred from the 17th through the 19th centuries (Heine, 1984). Ship-based measurements from the late 18th and early 19th centuries indicate lowered sea surface temperatures over large areas of North Atlantic subtropical ocean (Wendland, 1977). An indirect indication of colder conditions in the Bahamas during this time is the historically unique occurrence of snowflake precipitation in 1798 (Craton, 1968, p. 12). In summary, the available hemispheric evidence indicates that significant macroscale climatic changes have occurred in the past 500 years and suggests that sea level in the Bahamas *circa* A.D. 1492 was 0.5 m higher than at present.

RAINFALL AND VEGETATION. The occurrence of wetter climatic conditions in the Bahamas during aboriginal times is initially suggested by the contrast between the existing xerophytic, low coppice-thicket growth (Byrne, 1980; Coker, 1905) and the lush vegetation described by Columbus in his log.

Byrne (1980) has indicated that rainfall is the most important climatic factor controlling vegetation growth on the islands, where summer droughts are currently common. This is especially true on the more arid islands in the central and southern parts of the archipelago. The current plant species found on the islands are essentially the same as those found in Central America and the rest of the West Indies, but their generally stunted nature is strikingly distinct. In terms of Whittaker's pattern of plant formation-types in relation to mean annual rainfall and temperature (Bolin, 1980; Whittaker, 1970), the current formations of the central Bahamas are of the thorn forest type (Fig. 4). This formation-type is optimally characterized by open growth of trees less than 9 to 12 m high with grassy undergrowth. Actual canopy heights in the central Bahamas region are in the range of 2 to 3 m (Keegan, 1992b, p. 32).

Contrastingly, upon his exploration of the islands, Columbus repeatedly mentions features such as "many very green and very large trees" and "many groves, very thick and very large." The historical accounts of English colonists arriving on the islands in the late 17th and 18th centuries indicate the presence of forested lands consisting of mahogany, mastic, lignum vitae, cedar, and braziletto

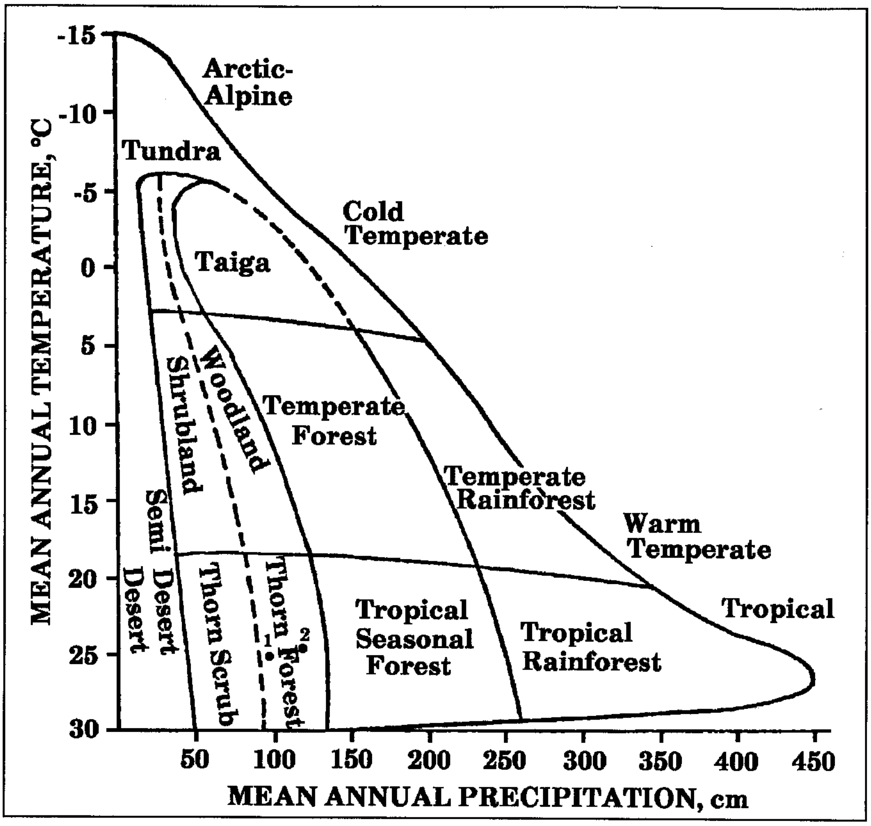

Fig. 4. World plant formation-type pattern in relation to rainfall and temperature (after Whittaker, 1970 and Bolin, 1970). The present positions of the Samana Cay (1) and San Salvador (2) formations within the pattern are shown.

(Campbell, 1978; Winter, 1987). The present scarcity of significant forest growth on the islands, especially that of the central and southern Bahamas, has been generally attributed to the deforestation undertaken by these settlers (Byrne, 1980; Morison, 1942, p. 234; Winter, 1987). However, this argument by itself does not appear to adequately explain the lack of greater arboreal growth on islands like Samana Cay, which has remained uncultivated and largely uninhabited in post-aboriginal times (Judge, 1986).

Keegan (1992b) has argued that, in contrast to the present environment, the prehistoric Bahamas must have provided an attractive location for aboriginal population expansion. Archeological evidence indicates that the migration of the Lucayan Indians occurred from the southern to the central islands and that settlement densities are weighted toward the latter (Keegan, 1992b). This pattern supports Keegan's conclusion that the prehistoric vegetation of the central and southern Bahama archipelago consisted of climax tropical seasonal forest and thorn forest (or tropical woodland), respectively. It may be conservatively estimated that the canopy of the tropical seasonal forest would have reached at least 18 m in height (Whittaker, 1970).

The former existence of a higher tree canopy may at least partially explain the apparent discrepancies between the longer distances of island sightings stated or implied in the Columbus log and present-day distances of visibility (see Henige, 1991; Parker, 1985). Superimposition of an 18-meter high tree canopy on the topography of islands along or near the Morison (1942)-, Fox (1882)-, and Judge (1986)-theorized tracks through the east-central Bahamas increases the maximum island sighting distances by 8 to 19%. These values are relative to present-day sighting distances for a sightline height of 19 m (estimated for the lookout on the flagship *Santa Maria,* based on Pastor, 1992) and a maximum canopy height of 3 m under conditions of atmospherically unlimited visibility.

If, as suggested, a tropical seasonal forest existed in the central Bahamas, it may be estimated from Figure 4 that the mean annual precipitation was between 140 and 250 cm, with the smaller values of the range being more likely.

Palynological studies to assess vegetational changes on the islands are generally lacking. This is due to the low pollen concentrations characteristic of calcareous sediments such as those found in lakes of the Bahamas (Pacheco and Foradas, 1987). Pacheco and Foradas have studied the pollen record of Granny Lake, San Salvador/Watling Island, and have attempted to generate absolute pollen frequencies from the low pollen content of the sediments in a 31-cm deep core. These authors tentatively conclude that the present coppice-thicket plant community has dominated the interior of the island throughout the Holocene and that only "minor environmental fluctuations" have occurred during this time. However, this conclusion is suspect given that pollen from mahogany and other forest trees historically documented on the islands is absent from the samples collected. The authors attempt to account for the absence of mahogany tree pollen, specifically, by suggesting that mahogany forests were restricted to the coast. This explanation is unsatisfactory because mahogany as well as the other native-forest trees are known to favor the more fertile and less exposed blacklands of the island interiors (Campbell, 1978, p. 41). These discrepancies, and the unfavorable conditions of alkalinity and shallow water depth (maximum 2.5 m) that characterize Granny Lake (Pacheco and Foradas, 1987), suggest that preferential destruction of certain arboreal pollen has occurred and that accurate ecological interpretation is not possible from the palynological data available (Dimbleby, 1985, p. 31; Fægri and Iversen, 1989, p. 146).

GEOCHEMICAL PALEOENVIRONMENTAL INDICATORS. The occurrence of significant climatic changes in the Bahamas and other regions of the American tropics/subtropics within the last 500 years is further indicated by lacustrine geochemical data.

Paleosalinity fluctuations have been identified in sediment cores from Watling's Blue Hole (San Salvador/Watling Island) (Teeter and Quick, 1990), Salt Pond (San Salvador/Watling Island) (Teeter et al., 1987a), and Nixon's Blue Hole (Great Inagua) (Teeter et al., 1987b) by interpretation of the magnesium content of *Cyprideis americana* ostracode shells. Curtis and Hodell (1993) and Hodell et al. (1991) have obtained a proxy climatic record from Lake Miragoane, Haiti, by analyses of the stable isotopic and trace element composition of *Candona* sp. ostracode shells in sediment cores. Especially revealing are the high-resolution $\delta^{18}O$ data obtained by sampling the cores at 1-cm intervals. Given that Lake Miragoane loses a substantial fraction of its water through evaporation, changes in the $^{18}O/^{16}O$ ratio of lake water and shell calcite should mainly reflect changes in the ratio of evaporation to precipitation (E/P) (Curtis and Hodell, 1993; Hodell et al., 1991). Decreases in E/P would result in decreased $\delta^{18}O$ values and vice versa.

Because radiocarbon dates are available for discrete intervals within the Watling's Blue Hole and Lake Miragoane cores, generation of time series profiles of the paleosalinity data for the former and $\delta^{18}O$ data for the latter was undertaken to allow cross comparisons.

Radiocarbon Dating Analysis. Since both Watling's Blue Hole and Lake Miragoane are hard water lakes, radiocarbon dates of shells are susceptible to a reservoir effect error resulting from the incorporation of "dead" carbon from the limestone bedrock (Curtis and Hodell, 1993; Teeter, 1989a). For a system in contact with the atmosphere, the theoretical limiting factor is 50% "dead" carbon which would produce a constant dating error of one ^{14}C half-life (5568 or 5730 years) (Rubin and Taylor, 1963). Although ^{14}C fractionation effects in shell specimens are taken into account by use of measured $\delta^{13}C$ values, an offset must also be deducted from the resulting radiocarbon age to correct for the reservoir deficiency (Stuiver and Polach, 1977).

Three radiocarbon dates are reported for Watling's Blue Hole corresponding to mollusc shell samples from depths of 38, 104, and 168 cm, respectively (Teeter, 1989a; 1990). These dates were derived by deducting a correction of 2080 radiocarbon years before present (RCYBP) from the conventional radiocarbon ages obtained from the samples (J. W. Teeter, personal communication, February 1994; Teeter, 1989a). The age correction was determined by dating a live mollusc specimen collected from a depth of one to two meters below the water surface. However, due to the post-1945 artificial enhancement of atmospheric ^{14}C activity (Faure, 1986, p. 391), the fictitious age of the modern shell specimen dated probably does not fully reflect the reservoir effect on fossil shells. As an alternative way of determining the reservoir correction, the measured ages of the shell

TABLE 1
MEASURED RADIOMETRIC DATES OF SAMPLES FROM CORES TAKEN IN WATLING'S BLUE HOLE (SAN SALVADOR ISLAND, BAHAMAS) AND LAKE MIRAGOANE (HAITI)

Cored Depth (cm)	Sample Type	Measured Age (^{14}C yr BP)
	Watling's Blue Hole[a]	
—	Pelecypod (modern)	2,080 ± 50
38	Pelecypod	3,470 ± 80
104	Pelecypod	4,010 ± 60
168	Gastropod	4,790 ± 60
	Lake Miragoane[b]	
8	^{210}Pb	129 ± 40
22	Ostracode	1,085 ± 60
216	Ostracode	2,780 ± 55
233	Ostracode	2,680 ± 60
233	Wood	1,655 ± 60

[a] Data from J. W. Teeter, University of Akron, personal communication, February 1994, and Teeter (1989a).
[b] Data from Curtis and Hodell (1993).

samples (Table 1) were plotted against their corresponding depths in accordance to the method outlined by M. Stuiver (personal communication, February 1994; 1975). The regression line through these points, labelled A in Figure 5, has a coefficient of determination (R^2) of 0.99 and a y-intercept (corresponding to the extrapolated apparent age at the surface) of 3040 RCYBP. The slope of the regression line (10.14) was used in conjunction with the 3040 RCYBP correction to derive the time series for the Watling's Blue Hole paleosalinity data shown in Figure 6.

The radiometric data for Lake Miragoane consists of radiocarbon dates for eight ostracode shell samples from depths ranging from 22 cm to 718 cm, an estimated age at 8 cm of 129 RCYBP based on a ^{210}Pb profile, and radiocarbon dates of 1,655 RCYBP for wood at 233 cm and 10,230 RCYBP for bulk organic carbon at 753 cm, respectively (Curtis and Hodell, 1993). The three nonshell data points and the datum of zero age at the top of the core were used by Curtis and Hodell (1993) to define a second-degree polynomial equation describing the age-depth relationship for the entire 767-cm interval sampled. Because the Watling's Blue Hole data only encompasses the period from approximately 2000 RCYBP to the present, the accuracy of this age-depth relationship within the corresponding upper third of the Lake Miragoane cored interval is of paramount importance for time series comparison. Analysis of the data indicates that, for the interval in question, a linear relationship provides a better estimator of age as a function of depth than the overall polynomial fit defined by Curtis and Hodell (1993).

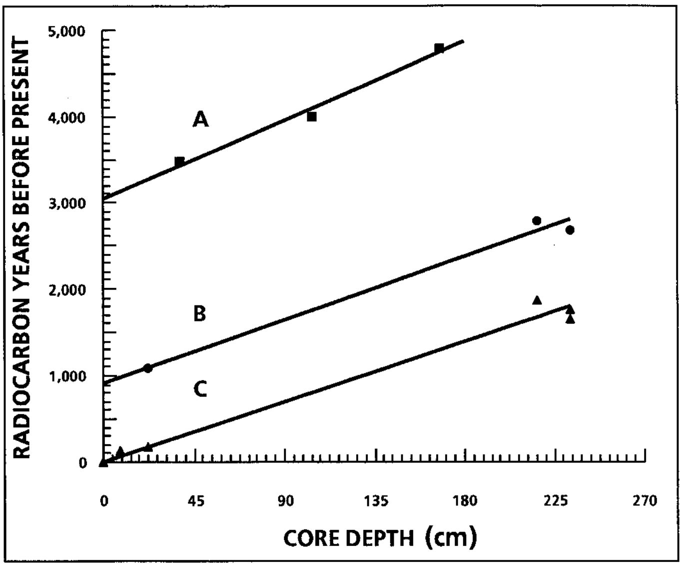

Fig. 5. Regression of radiocarbon dates against depths below lake bottom: (A) radiocarbon dates for mollusc shells from Watling's Blue Hole (San Salvador Island, Bahamas) uncorrected for reservoir effect error (see Table 1); (B) radiocarbon dates for ostracode shells from Lake Miragoane (Haiti) uncorrected for reservoir effect error (see Table 1); and (C) corrected shell and other radiocarbon dates from Lake Miragoane.

The uncorrected ages of the three Lake Miragoane ostracode shell samples from depths down to 233 cm were plotted against their corresponding datum levels (Table 1). The regression line through these points (labelled B in Fig. 5), has a coefficient of determination (R^2) of 0.98 and a y-intercept (corresponding to the extrapolated apparent age at the surface) of 920 RCYBP. This reservoir correction compares favorably with the difference of 1,030 radiocarbon years between the ages measured for paired wood and ostracode samples from the same 233-cm deep horizon (Table 1). A linear regression through all the data points corresponding to depths down to 233 cm (i.e., the three reservoir-corrected ostracode ages, the two nonshell ages, and zero age at the top of the core) yields the line-of-best-fit labelled C in Figure 6. This regression line, which essentially parallels line B, has a slope of 7.72 and a coefficient of determination (R^2) of 0.98. The standard error of the age estimate from this linear regression (100 RCYBP) is smaller than that from the Curtis and Hodell (1993) second-order polynomial relationship (160 RCYBP) for this section of the cored interval. The equation for line C was used to derive the time series for the Lake Miragoane $\delta^{18}O$ data (Fig. 6). Following Curtis and Hodell (1993), a five-point running mean was applied to the isotopic data to dampen variability on time scales of less than about a century.

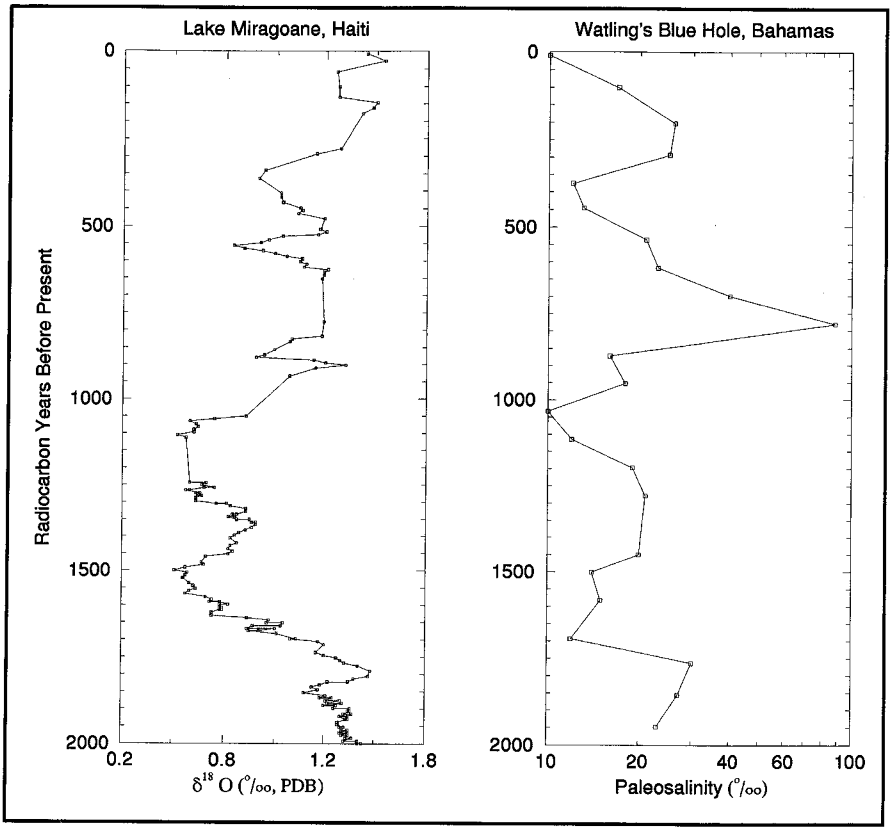

Fig. 6. Time series of geochemical paleoenvironmental indicators from sediment cores of Lake Miragoane (Haiti) and Watling's Blue Hole (San Salvador Island, Bahamas). The Lake Miragoane data are oxygen isotope measurements of *Candona* sp. ostracode shells (Curtis and Hodell, 1993). The ratio of evaporation to precipitation is low to the left of the figure, high to the right. The Watling's Blue Hole data are paleosalinities interpreted from the magnesium content of *Cyprideis americana* ostracode shells (Teeter and Quick, 1990). The time series were generated by the author using the age-depth regression lines (A and C) in Figure 5.

Time Series Comparisons. Despite the differences in resolution between the $\delta^{18}O$ and the paleosalinity time series shown in Figure 6, it appears evident that the fluctuations observed in both series are generally coincident in time. Moreover, low $\delta^{18}O$ values, indicative of times of low E/P ratios (i.e., reduced evaporation and/or increased precipitation) in Lake Miragoane, correspond to low salinity values in Watling's Blue Hole.

Conversions of radiocarbon ages to calendar years in the following discussion were performed using the calibration curves of Stuiver and Pearson (1993). By reference to Figure 6, it appears that the date A.D. 1490 (380 RCYBP) approximately corresponds to a minimum within a protracted period of decreased $\delta^{18}O$ values in Lake Miragoane and decreased salinity in Watling's Blue Hole. A similar preceding event occurred around A.D. 980 (1080 RCYBP). In Salt Pond, two correlative horizons of salinity minima are reported by Teeter and Quick (1990). The lake core data available for Salt Pond also include a vertical profile of aluminum concentrations within insoluble inorganic residue (Teeter et al., 1987a). Aluminum is a good indicator of soil erosion (or, more directly, of the sediment influx into the pond) given that it is chiefly associated with the clay fraction of residual soils and is relatively immobile chemically. Both correlative horizons of salinity minima are also characterized by maxima in aluminum concentrations, indicating increased erosion at these times (Teeter et al., 1987a). All of this evidence suggests that regional increases in precipitation, rather than merely decreases in evaporation, were associated with the periods of reduced aridity during the 10th and 15th-16th centuries A.D.

Since about A.D. 1680 (180 RCYBP), the $\delta^{18}O$ trends in Lake Miragoane and the salinity trend in Watling's Blue Hole appear to become more divergent. While the salinity of Watling's Blue Hole appears to have decreased systematically from about 1680 to the present, the data for Lake Miragoane indicates generally arid conditions during this time. Salinity has steadily increased in Salt Pond since the last correlative salinity minimum (Teeter et al., 1987a). These observations suggest that, during the last 300 years, precipitation has decreased and become less of a regional overriding factor in controlling lake salinity. Other factors influencing a lake's salinity, such as elevation with respect to sea level and the degree of interconnection with the open ocean (Teeter, 1989b), appear to have become locally important. The data from Nixon's Blue Hole (Teeter et al., 1987b) is somewhat problematical relative to this scenario in that only subtle paleosalinity fluctuations are indicated throughout an 82-cm core. However, the salinity distribution from this site is qualitatively similar to that observed on San Salvador/Watling Island. Teeter et al. (1987b) suggest that the likely reason for the small salinity range observed is the moderating effect of fresh water seepage from the adjacent dune into the conduit bringing salt water into Nixon's Blue Hole.

Anthropomorphic effects may have contributed to increased aridity in some areas. However, as previously noted, a general trend toward greater aridity over the past millennium is commensurate with changes in orbitally induced isolation variations (Curtis and Hodell, 1993; Hodell et al., 1991). The regional, climatic nature of increased aridity in historical times is supported by documentary evidence from Isla Mona (Kaye, 1959). Discovered by Columbus in 1494, Isla Mona is a small, historically sparsely populated island located about 73 km west of Puerto Rico. The great fertility of the island reported during the late 15th, 16th, and early 17th centuries is at variance with its present semiarid climate and sparse vegetation, indicating more humid conditions during the earlier times. Also, during this early period, the island was a provisioning and watering station, although in modern times no springs capable of providing an ample and reliable source of water are known. The increased aridity in Isla Mona over the last three centuries in the absence of significant human alteration supports the contention that regional rainfall changes have occurred. Analysis of the climatic history of other places in the southern portion of the North Atlantic Ocean would be useful in further assessing this pattern. Especially worthy of attention would be small, low-lying islands where the impact of climatic shifts may be most pronounced.

THE LAGUNA ON GUANAHANI/SAN SALVADOR. Much debate regarding the identity of Columbus's first landfall has focused on the identification of the water feature he described as "a very large *laguna*" located "in the middle" of the island. One point of debate has been whether Columbus was referring to a central, interior body of water, or lake, such as that which exists on San Salvador/Watling Island (Fig. 2) (as advocated by Keegan, 1992b, p. 187; Morison, 1942, p. 233; Obregón, 1987; Taviani, 1987), or whether his description refers to a lagoonal embayment midway along a coast, as is found on the south side of Samana Cay (Fig. 3) (as advocated by Fuson, 1987, pp. 78-79, 201). There is no doubt that the term as generally used by Columbus was not restricted to salt water bodies. On October 22 he mentions taking water for the ships from a *laguna* on one of the other islands. Also, on November 24, he specifically distinguishes a sheltered stretch of sea between two islands as a "sea *laguna*" ("*laguna de mar*").

An important clue regarding the type of *laguna* Columbus observed on *Guanahani/San Salvador* is the statement by Las Casas (1951, Vol. I, p. 200) (presumably based on information from Columbus's complete log or some collateral source) that "in the middle" of the island "was good fresh water that [the Indians] drank." However, a fresh water *laguna* is not only irreconcilable with the littoral lagoon interpretation for Samana Cay but also with the present-day saline character of Great Lake and the other interior surface waters on San Salvador/Watling Island. Davis and Johnson (1988) report an average chloride concentration for Great Lake waters of approximately 41,000 mg/l, i.e., hypersaline relative to ocean water, which has a chloride concentration of about 20,000 mg/l. Average chloride concentrations for other lakes on the island range from about 21,000 to 139,000 mg/l.

The lake core data and the climatic interpretations previously discussed suggest that, indeed, hydrochemical and hydrological conditions on the islands may have been quite different 500 years ago. On San Salvador/Watling Island, increased precipitation appears to have resulted in lake waters of low salinity and probably greater areal extent. On Samana Cay, presently devoid of any sizable inland surface water body, a numerical hydrogeologic computer model suggests the past existence of such a feature (Valdés, n.d.).

COASTAL RECONSTRUCTIONS. To test the route theorized by Morison (1942) for Columbus's voyage through the Bahamas, Mitchell and Keegan (1987) have attempted to reconstruct the 1492 coastline of specific Bahamian islands. On the basis of these reconstructions, the authors concluded that "unique" coastal features and Lucayan Indian settlements described by Columbus are found on the islands along Morison's proposed track.

The reconstructive approach used by these investigators was to identify areas that were tidal creeks and bays in 1492 and which have since been closed off by depositional processes to form lakes. Many of the relict tidal creeks and bays were found to be associated with Lucayan occupation sites ostensibly matching the location of coastal settlements described by Columbus. However, the crucial dates of the tidal creek-lake transitions were interpreted from lake sediment cores by assuming a regional, average depositional rate of 0.1 cm/yr. This assumption, which is the key to the entire reconstruction exercise, is highly questionable. The significant environmental changes that are herein inferred to have occurred on the islands during the last 500 years make it very unlikely that an average depositional rate, even if it could be rigorously established, would provide a meaningful dating criterion. Because the Lucayans occupied the Bahamas since at least A.D. 1200 (Keegan, 1992b), Lucayan settlements located on relict tidal creeks may not necessarily date to 1492 and the significance of the alleged "correlations" with coastal settlements mentioned in the Columbus log is equivocal.

Another shortcoming of the coastal reconstructions by Mitchell and Keegan is the failure to consider that sea level in the Bahamas 500 years ago apparently stood 0.5 m above present mean sea level (Lind, 1969a, 1969b). Instead, it was assumed by the authors that sea level in the region in 1492 was a few centimeters below its present level. This assumption was based on the generalized submergence curve for southwestern Florida prepared by Scholl et al. (1969), which suggests that eustatic sea level has risen continuously during at least the last several millennia. Contrastingly, more recent sea-level studies in western Florida (Tanner, 1992) indicate a number of late Holocene fluctuations (although specific dates on these are tentative). Moreover, as Scholl et al. (1969) note, even their smooth submergence curve should not be construed to mean the absence of small scale (0.3 to 0.5 m) oscillations in sea level.

Mitchell and Keegan (1987) have also compared the distribution of reefs around the islands with the descriptions given by Columbus. The distribution of Bahamian reefs is presumably no less extensive at present than it was 500 years ago. Coral reefs are relatively resistant to erosion and are characterized by growth rates of as much as 1 cm/yr (Milliman, 1993), with sea level as a main controlling factor (Selley, 1978, pp. 216-217).

The most explicit description given by Columbus of reef characteristics are for the island of *Guanahani/San Salvador.* In his log entry for October 14, narrating what he found as he reconnoitered the island from a boat, Columbus states that:

"Many men and many women came [to the beach] ... [and] called to us in loud voices to go ashore; but I was fearful, seeing a great reef of rocks that *encircles that island all around*; and *in between*, it becomes deep and a port for as many ships as there are in all of Christendom, and the entrance to it very narrow. It is true that *within this band* there are some shallows, but the sea does not move any more than inside a well" (emphases added). Mitchell and Keegan (1987), as well as Morison (1942), propose that this description accurately corresponds to the nearly continuous reef bounding Graham's Harbour (Fig. 2). However, this interpretation ignores the explicit depiction by Columbus of a reef that totally encircled the *entire island* itself and was separated from it by a *band* of sheltered water (i.e., a back-reef lagoon) that he compared to a port. A comparison of the reef distribution around the whole of San Salvador/Watling Island (Fig. 2) and Samana Cay (Fig. 3) clearly indicates that the latter conforms much more accurately to the literal representations made by Columbus. Indeed, a modern boating guide to the Bahamas (Ministry of Tourism, 1985, p. 355) advises boaters that venturing ashore at Samana without local knowledge can be treacherous because the cay is "completely surrounded" by coral reefs.

As he explored *Guanahani/San Salvador* on October 14, Columbus relates that he was also searching for a location "where a fortress could be made. And I saw a piece of land that forms like an island, although it is not, on which there were six houses. It could be cut into an island in two days .... [A]djoining said islet there are groves of trees which are the most beautiful that I saw, so green ..., and much water." Morison (1942, pp. 227, 236) identifies Columbus's pseudo-island as Cut Cay, located on the southeastern part of Graham's Harbor (Fig. 2), and postulates that in the intervening 500 years the sea has eroded the narrow channel that separates it from San Salvador/Watling Island. Mitchell and Keegan (1987) endorse this identification, although they also note that the well-cemented Pleistocene eolianites making up the feature would be expected to have undergone little erosion during the past 500 years.

In the Samana Cay landfall theory, Columbus's pseudo-island is generally identified as the islet, referred to as Booby Cay, located approximately 1 km east of Samana (Fig. 3) (Fox, 1882; R. H. Fuson, personal communication, October 1991; J. Judge, personal communication, May 1992). As Booby Cay is not presently subaerially connected to Samana, this identification, like the Cut Cay one, must postulate that the islet was separated from the main island during the centuries since Columbus's description. In this case, however, such a postulation is not entirely ad hoc. Inferences can be made from the paleoenvironmental conditions previously outlined to suggest that a tombolo-type beach may have tied Booby Cay to Samana Cay 500 years ago.

As shown in Figure 3, sandbanks are presently located on the extreme southeastern end of Samana and on the western end of Booby Cay. These sandbanks are the result of sediment transport and deposition under the influence of prevalent northeasterly to southeasterly swell (Lind, 1969a). The sands deposited in the banks derive from the insular shelf, due to wave erosion of the reefs, and from localized shoreline erosion. The work of Lind (1969a) in the Bahamas suggests that an increase in wave energy over the shelf, such as may occur under conditions of higher sea level than at present, would enhance the mass transport of shelf sands toward shore. The youngest beach-ridge terrace accretionary feature on Cat Island (Bahamas) dates to the 15th century and is thought to correspond to the inferred +0.5 m sea level stand for this period (Lind, 1969a, 1969b). On the north coast of San Salvador/Watling Island, accretionary sediments are found dating to 420 ± 70 years BP (Carew and Mylroie, 1987). A substantial increase in sediment influx during this time could have also lead to the development of island-linking between Samana and Booby Cays by a tombolo-type feature. The formation of double or forked tombolos enclosing lagoonal and mangrove areas is not uncommon, especially where wave incidence angles differ on each flank of the tied island (De Saint Marc and Vincent, 1968; Farquhar, 1972). Although speculative, the existence of such a feature would be commensurate with Columbus's description and, at least qualitatively, with the sea level scenario herein outlined. A shift from mainly depositional to mainly erosional conditions, leading to the disruption of the tombolo, would have occurred during the last 500 years as sea level fell.

CONCLUSIONS. Attempts to identify the first landfall of Columbus have made little or no effort to consider the paleogeography of the Bahama Islands in a comprehensive, physical context. The evidence presented here indicates that integration of paleoclimatic, geological, archeological, and historical information of hemispheric, regional, and local scale is necessary to properly elucidate environmental conditions on the islands during the past 500 years. It is recognized that the conclusions of this study stem largely from interpretation of fairly limited data for the late Holocene period of the region. However, it is hoped that future studies will enable further testing of their validity.

The available data suggests that, upon Columbus's arrival in 1492, the following conditions existed in the central Bahamas: (1) the climate was significantly wetter; (2) a tropical seasonal forest existed with trees reaching heights on the order of 18 m; (3) ponds or lakes containing fresh water were prevalent; and (4) sea level was about 0.5 m higher than at present.

Previous hypothetical inferences regarding the environment and appearance of the islands in aboriginal times have generally assumed that historical anthropogenic impacts have been the single, or at least the most important, cause of interim change. The present study suggests that non-anthropogenic physical factors may have been even more important in altering the environment of the Bahamas. Paleogeographic evaluation appears to enhance the possibility that Samana Cay was the first landfall of Columbus in the New World.

NOTES

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[2] This and subsequent quotes of the words of Christopher Columbus are translated from the Dunn and Kelley (1989) transcription of Columbus's onboard log as abstracted by Bartolomé de las Casas. Neither the original log nor any complete copy of it is known to survive.

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ERRATA

Page 78, caption for Figure 4: "Bolin, 1970" should read "Bolin, 1980."

Page 83, Figure 6, Lake Miragoane graph: the horizontal-axis tic marks labeled "0.2," "0.8," "1.2," and "1.8" should read "0.25," "0.75," "1.25," and "1.75," respectively.

Page 84, 7th line from bottom: "isolation" should read "insolation."

Page 84, 9th line from bottom: "Anthropomorphic" should read "Anthropogenic."

Page 89, 19th line from bottom should read: "physical Union), pp. 135-152."