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Back Cover: Dr. H. Leonard Vacher, University of South Florida, Keynote Speaker for the 12th Symposium and author of "Keynote Address – Plato, Archimedes, Ghyben Herzberg, and Mylroie", this volume , p. ix. Photograph by Don Seale.

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PALEOSOLS OF THE BAHAMAS AND THE NORTHERN MARIANA ISLANDS: SOURCE AREAS FOR THE INSOLUBLE RESIDUE AND RELATION TO PALEOCLIMATE

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ABSTRACT

Because paleosol formation is closely related to atmospheric circulation patterns and dust load, determining the source areas of insoluble residues (IR) in paleosols from the Bahamas and the Commonwealth of the Northern Mariana Islands (CNMI) may provide paleoclimatic information. The Bahamian samples were collected on a north-south transect from North Andros Island to Great Inagua Island. This transect was long enough to identify any potential differences in source areas, as well as to ascertain any influence on paleosol geochemistry caused by differences in average annual precipitation. The northern Bahamas are relatively wet (~1100-1200 mm·year^{-1}) and the southern Bahamas is relatively arid (~600-700 mm·year^{-1}). Using the Al_2O_3:TiO_2 ratio, which remains relatively constant over time, we compared the Bahamian paleosols with potential sources of IR for this region. The three most likely IR sources are North African dust, Lesser Antilles ash, and North American loess. The data indicate that African dust is the main component of the IR in Bahamian paleosols. However, ~30% of our samples had Al_2O_3:TiO_2 ratios above the range of African dust and below the range of Antilles ash. Unfortunately, because of the geochemical similarities between North American loess and African dust, no identifiable contribution of North American loess could be detected. However, based on other studies of air-borne dust in the North Atlantic region, it is likely that loess is a minimal component in the Bahamian paleosols.

The geochemistry of the paleosols in the CNMI is highly variable. Because there is a maximum 1° of latitudinal difference between the studied islands, it is unlikely that this variability was caused by climatic factors. The Al_2O_3:TiO_2 ratios of the exposed volcanic rocks are significantly higher than that of most carbonate paleosols. This may indicate that a combination of volcanic ash, Asian dust (Gobi and Takla Makan deserts), and sediment eroded from local terrigenous (volcanic) outcrops are probably the major sources of IR in the paleosols.

INTRODUCTION

The present study investigates the source of insoluble insoluble residue (IR) in the carbonate paleosols of the Bahamas and the Commonwealth of the Northern Mariana Islands (CNMI). These islands were chosen because they were close to continental dust sources whose geochemistry is distinctly different from the carbonate bedrock. Hence, at these locations the contribution of atmospheric dust to paleosol formation can potentially be easier to determine, with attendant implications for past atmospheric circulation.

Paleosols are important paleoenvironmental indicators because they represent relatively long intervals (~10^5 years) of erosion and dissolution, whereas the limestones themselves represent relatively short intervals (~10^4 years) of carbonate sediment accumulation. The IR in the paleosols may be related to patterns of past atmospheric circulation as the input of Saharan dust to the Bahamas is well documented and the input of Asian dust to the Northern Mariana Islands is likely. Even though the IR of the Bahamian paleosols were previously investigated (e.g. Muhs et al., 1990; Foos, 1991; Foos, 1995), the present study extends the sampling area.

BAHAMIAN PALEOSOLS

In the Bahamas, there are several potential sources for the IR in the paleosols: accumulation by dissolution of calcarenites, dust from North Africa (mainly western Sahara and Sahel region), volcanic ash from the Lesser Antilles arc, and loess from North America.

The carbonate dissolution model assumes that weathering (dissolution) of the underlying eolian calcarenites results in concentration of impurities and organic matter into a residual soil, which eventually becomes a paleosol (Ruhe et al., 1961). However, the IR in the Bahamian calcarenites are ~0.01 % (Boardman et al., 1995), which would require the dissolution of extremely high volumes of carbonate. Such extreme dissolution rates were not observed anywhere in the Bahamas. The dust models imply an allogenic addition of IR to the soils, directly related to past atmospheric circulation.

The input of Saharan dust to the Bahamas was confirmed by satellite imagery (Figure 1) and dust flux measurements in the Caribbean and Florida (Kalu, 1979; Prospero, 1996). The African dust represents ~65% of the present global dust emissions (Ginoux et al., 2004) and, based on measurements of African dust input in Miami (Florida), Prospero and Nees (1987) calculated modern deposition rates of 0.13 $g \cdot cm^{-2} \cdot ka^{-1}$, which is sufficient to account for the observed IR of the Bahamian paleosols. In fact, the amount of Saharan dust deposited during glacial periods, when Bahamian paleosols are predominantly formed (Carew and Mylroie, 1995), should have been higher than at present. This is suggested by multiple proxies (mineralogical, faunal, palynological etc.) from North Africa, which document increased aridity and higher wind speeds (i.e. higher dust load) during glacial periods (e.g. deMenocal et al., 1993; Leroy and Dupont, 1994).

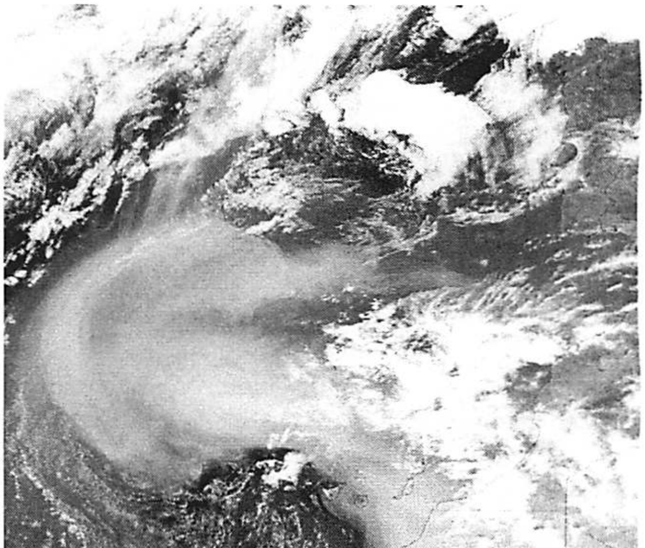

Figure 1. Dust storm over western Africa and the eastern North Atlantic. The dust plume is reaching over 1600 km into the Atlantic (image by OrbView-2 satellite, SeaWiFS sensor; NASA record ID 512).

The volcanic ash from the Lesser Antilles could be transported by winds to the Bahamas (Figure 2). However, Muhs et al. (1990) determined that there is no input of volcanic material from the Lesser Antilles to the island of New Providence, Bahamas.

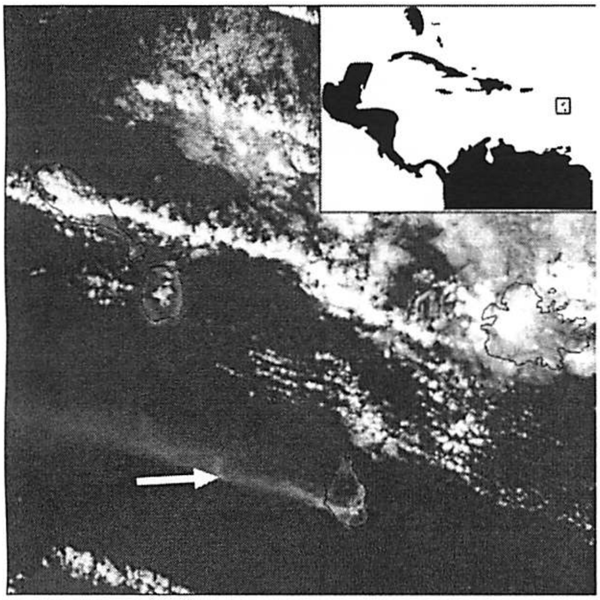

Figure 2. Satellite image of Montserrat Island and the Soufriere Hills Volcano (Lesser Antilles) showing that the path of the volcanic ash (arrow) is towards NW, and thus can reach the Bahamas (image by Aqua satellite, MODIS sensor, NASA record ID 24779). The inset shows the position of the island in the Atlantic.

Another possible source of IR in the Bahamas is loess derived from the North American continent. This is a potential source because the winter climate of the Bahamas is influenced by cold fronts coming from North America, and the physiography of San Salvador shows dune orientations consistent with two main wind directions: the easterly trade winds, and northwesterly storm winds (Figure 3).

NORTHERN MARIANA ISLANDS PALEOSOLS

The paleosols of CNMI are much more complex, and have received less scientific investigation than their Bahamian counterparts. The paleosol samples were collected from the southern part of CNMI (see Methods) from islands that are situated within the same climatic zone (tropical marine), and have a similar geology.

Figure 3. Schematic physiography of San Salvador with arrows pointing to dune orientations consistent with wind directions from the east and northwest.

The sampled islands are located in the tropical Western Pacific (between 14.1°N and 15°N; 145.2°W and 146°W), and are composed of volcanic cores and limestones with terrace levels and fringing coral reefs. The most likely sources of IR in the CNMI paleosols are limestone dissolution, volcanic ash (from the numerous volcanoes of the Mariana archipelago), locally-derived volcanic weathering products, and Asian dust (predominantly from the Gobi and Takla Makan deserts).

The limestones are Eocene or younger, and their residues content is highly variable. Carroll and Hathaway (1963) reported values between 0.1 and 31.2% in Guam (which has a politically separate identity from the CNMI, but is part of the same archipelago and has a similar geologic history and stratigraphic column as the sampled islands).

In addition to the residual component of the paleosols derived from limestone dissolution, the input of volcanic ash from the various volcanoes of the Mariana Ridge is also probable (Figure 4).

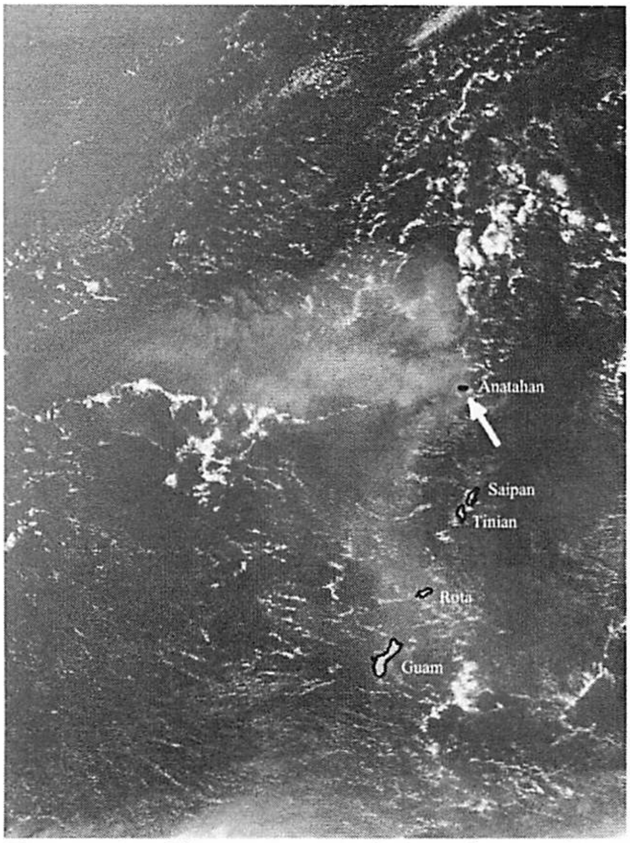

Figure 4. The eruption of Anatahan volcano (arrow) in May 2003. Note that part of the ash plume is reaching the islands situated to the southeast of the eruption site (image by Terra satellite, MODIS sensor; NASA record ID 25329).

Dust from Asia (Figure 5) may also contribute to the IR, because of strong westerly air currents which develop during the dry season at altitudes of ~3000 m that can reach the CNMI. These dust-laden winds extend from the interior of the Asian continent to the central North Pacific. Asian dust was identified at Enewetak Atoll (11°20'N, 162°20'E) of the Marshall Islands (Duce et al., 1980), so it is likely that the dust also reaches the CNMI which are closer to the Asian continent and farther north than the Marshall Islands (Figure 6).

Figure 5. Asian dust (arrow) over Korean Peninsula and Sea of Japan (image by Terra satellite, MODIS sensor; NASA record ID 12349).

METHODS

We collected the samples during the summer of 2003 and detailed sample descriptions are given in Ersek (2004). In the Bahamas the paleosols were collected on a roughly N-S transect, from North Andros and Eleuthera, to New Providence and San Salvador, and ending in Great Inagua. In the CNMI we took paleosol samples from Saipan, Tinian, Rota, and Aguiguan. The sampling regime enabled the determination of both inter- and intra-island variability of paleosol geochemistry, and also the contribution of each possible source of IR to the paleosols. Dr. Bruce Panuska also donated paleosol samples which were previously used for paleomagnetism analyses.

In the field, paleosol samples were selected based on their distinct color and texture. At least 4 grams of IR were extracted from each sample. The paleosols from both island groups were analyzed using X-Ray Fluorescence (XRF) at the College of Charleston, SC. The samples were crushed and screened through a 100 µm sieve and the fine fraction was then used for XRF analysis. Data consistency was verified by analyzing a test sample three consecutive times.

The IR contribution of the potential sources was assessed using the Al_2O_3:TiO_2 ratio. This oxide ratio was chosen because previous investigations showed that Al_2O_3 and TiO_2 are relatively immobile in the tropical carbonate environment and their ratio remains approximately constant over time (Muhs et al., 1990).

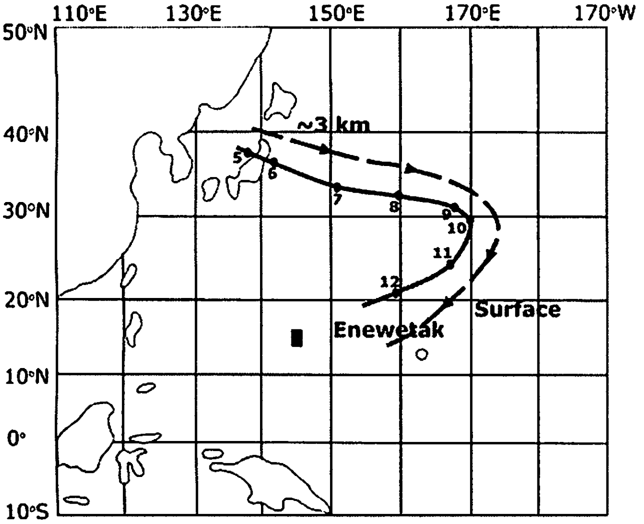

Figure 6. The path of the Asian dust gradually approaching the surface of Enewetak Atoll from an elevation of ~ 3km. The outer line represents an idealized dust trajectory, and the points on the inner line are showing the position of the anticyclone between 5 and 12 May, 1979 (modified from Duce et al., 1980). The approximate position of the islands used in the present study is indicated by a black rectangle.

RESULTS

The Bahamas

The Al_2O_3:TiO_2 ratio of the Bahamian paleosols is laterally consistent within the same paleosol horizon (Ersek, 2004). However, the inter- and intra-island variability is higher than anticipated (Figure 7).

The Al_2O_3:TiO_2 ratio for Lesser Antilles volcanic glass is 67 ± 15 (Carey and Sigurdsson, 1978) and for Saharan dust collected in Barbados this ratio is 15 ± 3 (Glaccum, 1978). The Bahamas data indicate that most samples (52.7%) fall exactly within the range of the African dust, and no samples have ratios in the Antilles ash range. The paleosol values that fall between the African and Antilles ranges may indicate a contribution of volcanic ash during periods of intense volcanic activity in the Lesser Antilles during the Quaternary. The contribution of the North American loess could not be assessed because the Al_2O_3:TiO_2 range of Mississippi Valley loess (13.5 ± 1.5) (Muhs et al., 2001) has values that are overlapping with those of African dust.

Northern Mariana Islands

The only available Al_2O_3:TiO_2 ratios for volcanic rocks exposed in the Mariana Islands are from Saipan: 62.2 for dacites and 27 for andesites (Cloud et al., 1956, p.38). In contrast, the paleosols from Saipan, Tinian and Aguiguan have Al_2O_3:TiO_2 ratios of 17.1 ± 2.7 at 95% confidence (Ersek, 2004). These data appear to indicate that autochthonous volcanics do not contribute to the IR of the carbonate paleosols that are not in close proximity to volcanic exposures. Some of the samples from Rota were collected from areas where volcanic rocks were exposed directly upslope of the sample location. They have higher Al_2O_3:TiO_2 ratios than the other paleosols (Figure 8), suggesting a volcanic contribution to the IR.

Because they have similar mineralogical properties, the North African and the Asian dust probably have similar Al_2O_3:TiO_2 ratios. If so, the data presented here may suggest that Asian dust is an important contributor to the IR of the CNMI carbonate paleosols.

CONCLUSIONS

Saharan dust is the most likely source of residues in the Bahamas, but volcanic ash from the Lesser Antilles may have contributed to the IR at times of intense volcanic activity. The contribution of the North American loess cannot be assessed at this time.

A combination of differences in exposure time, proximity to volcanic outcrops, types of volcanic rocks exposed (e.g. andesite vs. dacites),

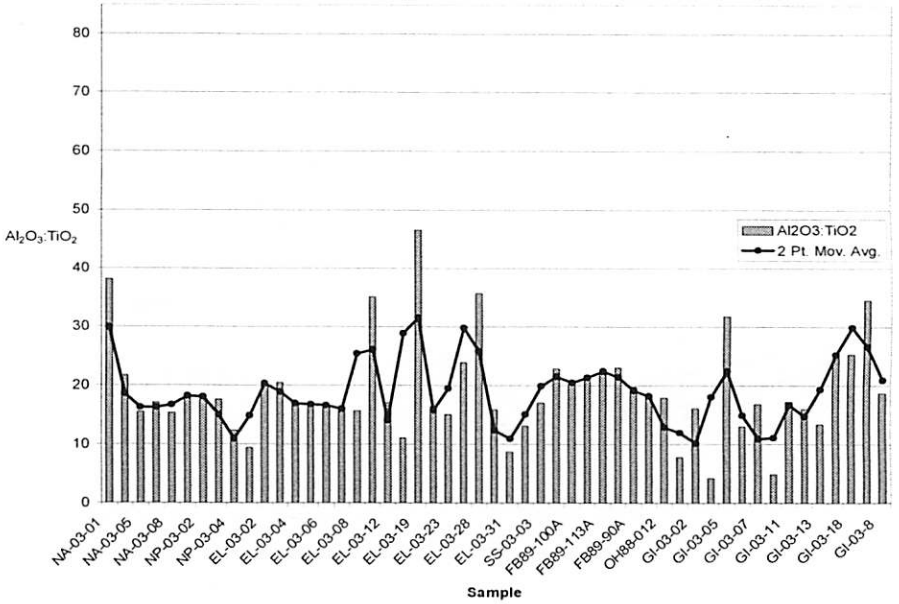

Figure 7. Distribution of the Al_2O_3:TiO_2 ratio in Bahamian paleosols. The data were smoothened by applying a two point moving average (2 Pt. Mov. Avg.) to the data. From left to right the samples represent North Andros (NA), Eleuthera (EL), San Salvador (SS, FB, OH), and Great Inagua (GI).

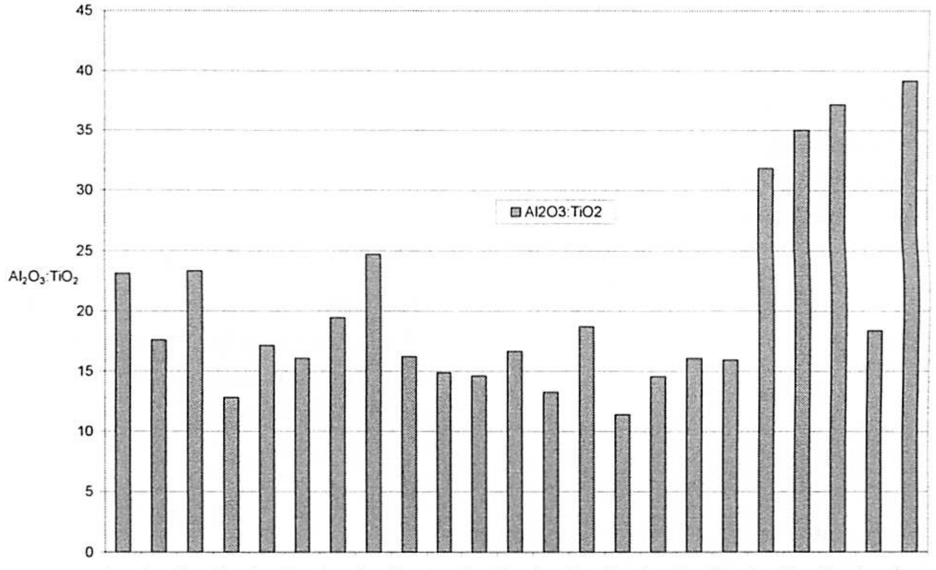

Figure 8. Distribution of Al_2O_3:TiO_2 ratio in the CNMI. From left to right the samples represent Saipan (SP), Tinian (TN), Aguiguan (AG), and Rota (RT). Sample RT-03-17 (Al_2O_3:TiO_2 ratio of 39.1) is a soil sample developed over volcanic rocks; sample RT-03-11 (Al_2O_3:TiO_2 ratio of 31.8) is a volcanic pebble from a stream; paleosol samples RT-03-13 and RT-03-14 were collected in the proximity of volcanic outcrops.

frequency and magnitude of volcanic eruptions and the path of the resulting ash, and topographic position within the island probably contribute to the variability of the geochemical signal of the CNMI paleosols.

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