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MINERALOGY OF BAHAMIAN SOILS

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ABSTRACT

The mineralogy and chemistry of soils occurring on eolian deposits of San Salvador, Bahamas were investigated. The nonclay minerals include calcite, aragonite, hematite, goethite and quartz. The major clay minerals observed are illite, chlorite, hydroxy-interlayered clay (HIC) and boehmite. The clay mineral assemblages range from a detrital assemblage containing illite and chlorite through a pedogenic assemblage which contains HIC and boehmite. The presence of carbonates results in a relatively high soil pH. The SiO_2/Al_2O_3 ratios are very low indicating leaching of silica and enrichment in aluminum. The surface textures of quartz grains isolated from soils suggest they had an eolian hot desert source which was overprinted by pedogenic silica precipitation.

INTRODUCTION

The mineralogy of soils occurring on Pleistocene eolianites in the Bahamas was investigated. The majority of the samples were collected on the island of San Salvador, however, data from soils collected on Eleuthera are also included in this report. Samples were collected from the following locations on San Salvador; Dixon Hill, Harbour Estate, Reckley Hill, Trial Farm Settlement, the new well field near the Airport, Observation Tower Ridge, Great Lake Cay (the Cay behind Dixon Hill), South Victoria Hill Settlement, East Beach Causeway, Watlings Castle, and Little Fortune Hill. Samples from Governors Harbour were collected on Eleuthera.

Relief in the study area is low and the topography is depositional rather than erosional. The major topographic features are eolian ridges. The climate is characterized by warm rainy summers and cooler dryer winters with an average temperature of 26°C and annual precipitation of 115 cm (Little and others, 1977). The Köppen classification of the climate is humid tropical savanna. The vegetation in the study area is dense mixed broad leaf coppice. The parent material of the soils is carbonate eolianite plus airborne dust from North Africa (Muhs and others, 1990).

RESULTS

Mineralogy

Mineralogical analysis was performed on a Philips APD 3720 X-ray diffraction system. A random mount of the <2 mm fraction was X-rayed for identification of the non-clay minerals. Oriented mounts of the <2μm fraction were prepared before and after removal of carbonates and free iron oxides. Various pretreatments such as saturation with ethylene glycol, saturation with K^+ and heating were used to aid in the identification of the clay minerals.

The nonclay minerals include calcite, aragonite, hematite, goethite and quartz. The carbonate content ranged from 9 to 75%. The major carbonate mineral is low-Mg calcite with minor amounts of aragonite present. The primary source of carbonates in the solum is the break down of carbonate eolianite. The presence of carbonates, which act as a buffer, results in a relatively high pH, ranging from 7.8 to 8.8 (Fig.1).

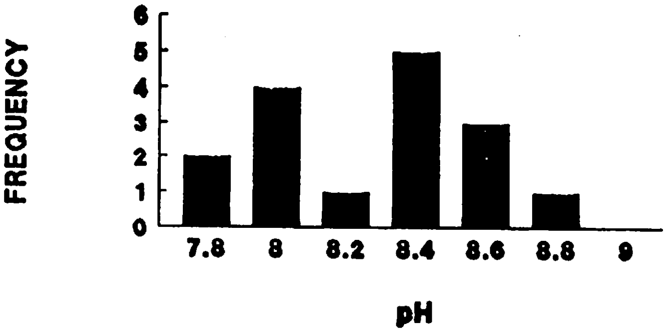

Fig. 1. pH of soil samples from San Salvador.

The iron minerals hematite and goethite have aluminum substituted in their structure. These minerals play an important role in determining the soil color which ranges from 10 YR 6/8 to 2.5 YR 3/4. The bright red colors are due to the presence of hematite and yellow-brown colors are attributed to goethite. Quartz, a minor component of the soils, is inherited from the original detrital material blown in from North Africa.

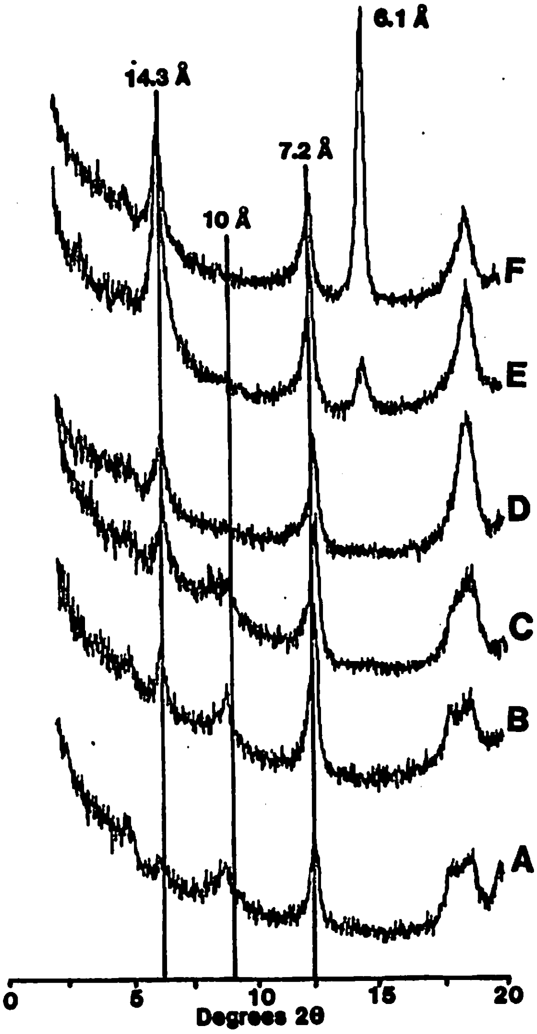

Fig. 2. X-ray diffraction patterns of clays from San Salvador soils, showing detrital clays (A & B), intermediate clays (C & D) and pedogenic clays (E & F). All patterns are of air-dried, oriented mounts of the <2 μm fraction with carbonates and free iron oxides removed. A - Trial Farm Settlement, B - South Victoria Hill Settlement, C - Dixon Hill, D - Reckley Hill, E - Airport well field, F - Observation Tower Ridge.

The clay minerals observed were illite, chlorite, hydroxy-interlayered clay (HIC) and boehmite. The clay mineral assemblages range from a detrital assemblage containing illite and chlorite through a pedogenic assemblage which contains HIC and boehmite (Fig. 2). Detrital assemblages are represented by patterns A and B on Figure 2. Identification of illite and chlorite is based on the presence of 10 Å and 14 Å reflections which do not shift after treatment with ethylene glycol and do not collapse upon heating (Fig. 3). The presence of illite and chlorite is rare in San Salvador soils, the major clay mineral being HIC. HIC are common constituents of soils. They have been referred to in the literature by other names such as dioctahedral vermiculite, dioctahedral chlorite, chlorite-like clay, and intergradient chlorite-vermiculite. They are 2:1 clays with interlayers of incomplete gibbsite sheets, or "islands" of Al-hydroxy polymers (Barnhisel & Bertsch, 1989). An untreated, air dried HIC has XRD basal reflections at 14.1, 7.1, 4.76, 3.57Å. An 060 reflection at 1.50Å indicates this mineral is dioctahedral. The degree of interlayering varies from partly interlayered with a few isolated Al-hydroxy polymers to fully interlayered where all the available sites are occupied by Al-hydroxy polymers. The degree of interlayering can be estimated by saturating the clay with K^+ and measuring the shift in the 14 Å peak after heating. A large shift to 10 Å indicates incomplete interlayering and a small shift to 13 Å indicates complete interlayering (Barnhisel & Bertsch, 1989). Clay assemblages intermediate between detrital and pedogenic contain partly interlayered HIC (Fig. 2, patterns C and D). Upon heating the 14 Å peak of these clays collapsed to 10 Å indicating incomplete interlayering (Fig. 4). The collapse was not complete suggesting there may be some type of mixed layering with chlorite. Soils with a pedogenic clay mineral assemblage of fully interlayered HIC and boehmite are represented by patterns E and F on Figure 2. The partial collapse of the 14 Å peak to 12.3 Å after saturation with K^+ and heating (Fig. 5) indicates a fully interlayered HIC is present. Also illustrated in Figure 5 is the 6.1 Å reflection, characteristic of boehmite. The occurrence of boehmite is restricted to soils which contain fully interlayered HIC, suggesting that boehmite does not precipitate until after all the available sites in the HIC are occupied by Al-hydroxy polymers.

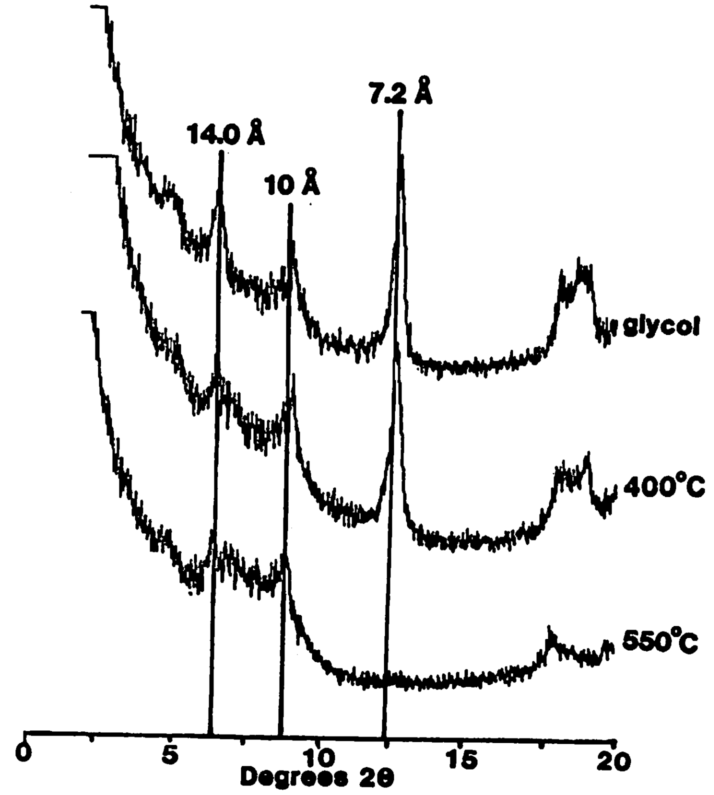

Fig. 3. X-ray diffraction patterns of clay from South Victoria Hill Settlement, representative of a detrital mineral assemblage. 14 Å & 7.2 Å - chlorite, 10 Å - illite.

Chemical Composition

The chemical composition of the <2mm fraction of selected soil samples was determined with Inductively Coupled Plasma Spectrometry (ICP). The results of these analyses are reported in Table 1. Due to the presence of organic matter, carbonate and hydrous phases, the loss on ignition (LOI) values were high. In order to compare variations in the chemical compositions the oxides were normalized to 100%. The CaO concentration is highly variable ranging from 2 to 56%

Table 1: Chemical analyses of selected Bahamian soils. 1. Dixon Hill, 2. Harbour Estate, 3. Reckley Hill, 4. Airport T2, 5. Airport T9, 6. Observation Tower, 7. Governors Harbour, Eleuthera, (Avg. of 21 analyses).

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	TiO_2	SiO_2/Al_2O_3
1.	43.0	31.1	13.1	5.7	2.9	2.2	1.7	1.38
2.	42.2	32.3	14.7	4.7	2.6	1.1	1.9	1.31
3.	26.9	24.2	9.8	34.0	2.4	1.0	1.3	1.11
4.	16.5	17.0	7.1	56.1	1.7	0.4	0.9	0.97
5.	18.7	33.1	12.1	32.4	1.7	0.4	1.6	0.57
6.	25.4	47.2	20.2	2.0	1.8	0.6	2.6	0.54
7.	27.1	33.2	13.7	20.6	2.0	1.1	1.7	0.82
Avg	28.5	31.2	13.0	22.2	2.2	1.0	1.7	0.96

SiO_2/Al_2O_3 ratio. As soils weather, leaching of silica is accompanied with a relative enrichment of Al, Fe and Ti. The soils analyzed all have a very low SiO_2/Al_2O_3 ratio and soils containing boehmite have SiO_2/Al_2O_3 ratios less than one. There is no relationship between the SiO_2/Al_2O_3 ratio and CaO concentration (Fig. 6). This indicates that the carbonate content does not effect the chemical maturity of the soils.

Quartz Grain Surface Textures

The surface texture of quartz grains isolated from Al-rich soils which had a pedogenic mineral assemblage were examined. A summary of the surface features observed and their frequency is given in Table 2 and illustrated in Figure 7. Descriptions of these features can be found in Krinsley & Doornkamp (1973), Higgs, (1979) and Culver and others, (1983). Features formed by precipitation of silica were observed on 93% of the grains. Of these features smooth surfaces of silica precipitation are most common. "Flowers" of silica occur within depressions on the sand grains. The most likely source of silica for precipitation on quartz grains is the breakdown of feldspars and unstable clay minerals. The low SiO_2/Al_2O_3 ratio of the soils indicates that silica has been mobilized with some of the soluble silica precipitating on stable quartz grains.

The most common dissolution feature observed was V-shaped etch pits. Other features observed were solution crevasses, scaling, and rounded appendages. Unlike quartz grains from high energy chemical environments described by Krinsley & Doornkamp (1973) the surface of Bahamian quartz grains were not dominated by large scale decomposition features. Crook (1968) and Cleary & Conolly (1972) observed that weathering in a pedogenic environment results in solution rounding and formation of embayed quartz grains which was not observed in these samples. Previous studies on the effect of pedogenic weathering on quartz grain surface textures focused on acid soils with a high organic concentration. These soils have a relatively high pH which should favor inorganic dissolution of quartz, however, they are depleted in organic matter which also contributes to silica dissolution.

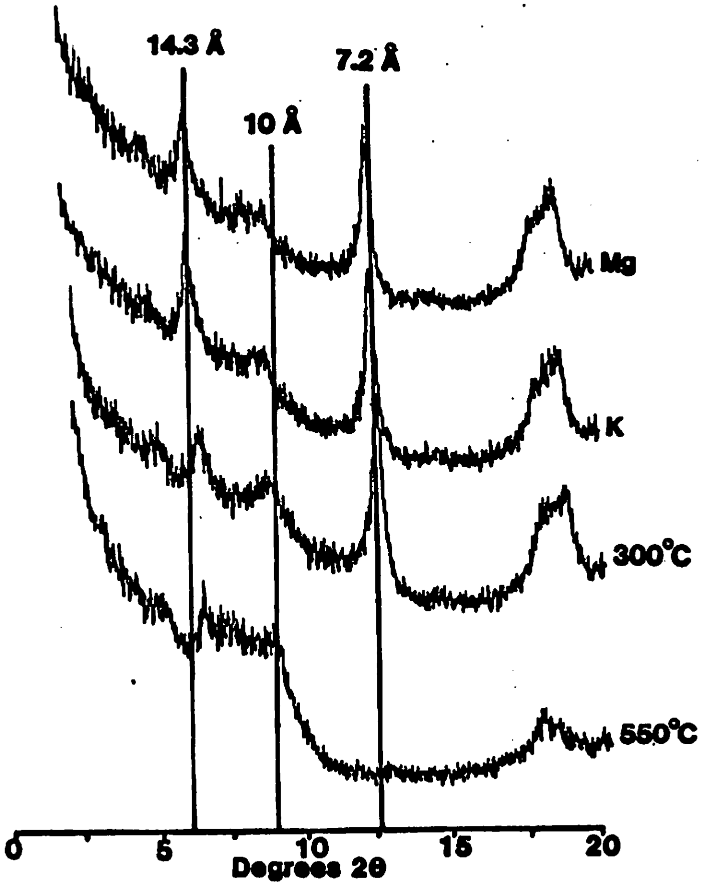

Fig. 4. X-ray diffraction patterns of clay from Dixon Hill, representative of an intermediate assemblage. Collapse of 14.3 Å peak to 10 Å indicates partly interlayered HIC. Mg - saturated with Mg^{+2}, K - saturated with K^+.

Flat cleavage faces, cleavage planes, steps, blocky breakage and upturned plates were the major mechanical breakage features observed. Also observed were dish-shaped concavities, conchoidal fracture, chattermarks, grooves and parallel striations. Mechanical V-pits, which are diagnostic of subaqueous environments (Krinsley & Doornkamp, 1973) were not observed on these grains. Most of the mechanical breakage features were superimposed with a layer of smooth silica precipitation. Upturned plates on the grains were rounded and modified by silica precipitation as described by Margolis & Krinsley (1971). These features were most likely inherited from the North Africa eolian source. However, some of the mechanical

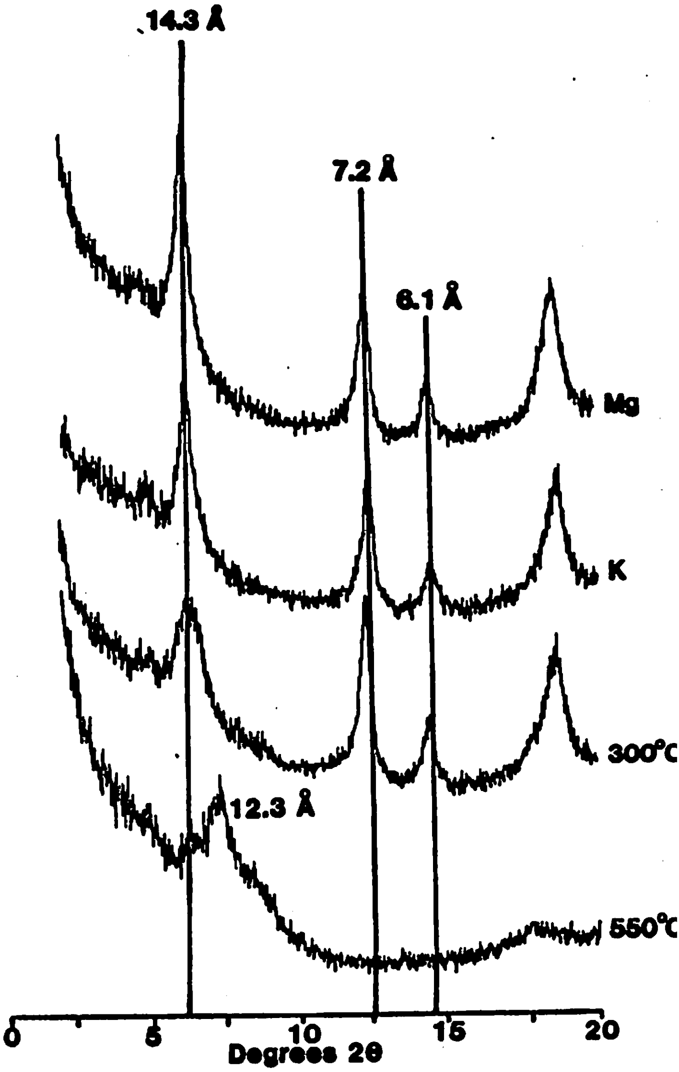

Fig. 5. X-ray diffraction patterns of clay from the Airport well field, representative of a pedogenic assemblage. Partial collapse of 14.3 Å peak to 12.3 Å indicates fully interlayered HIC. 6.1 Å - boehmite, Mg - saturated with Mg^{+2}, K-saturated with K^+.

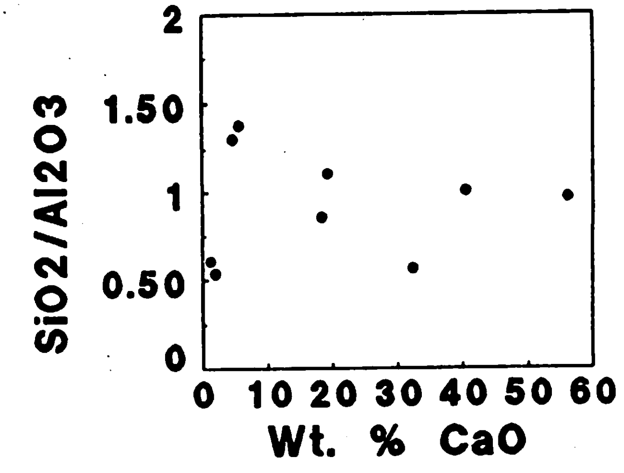

Fig. 6. SiO_2/Al_2O_3 ratio versus weight % CaO of Bahamian soils.

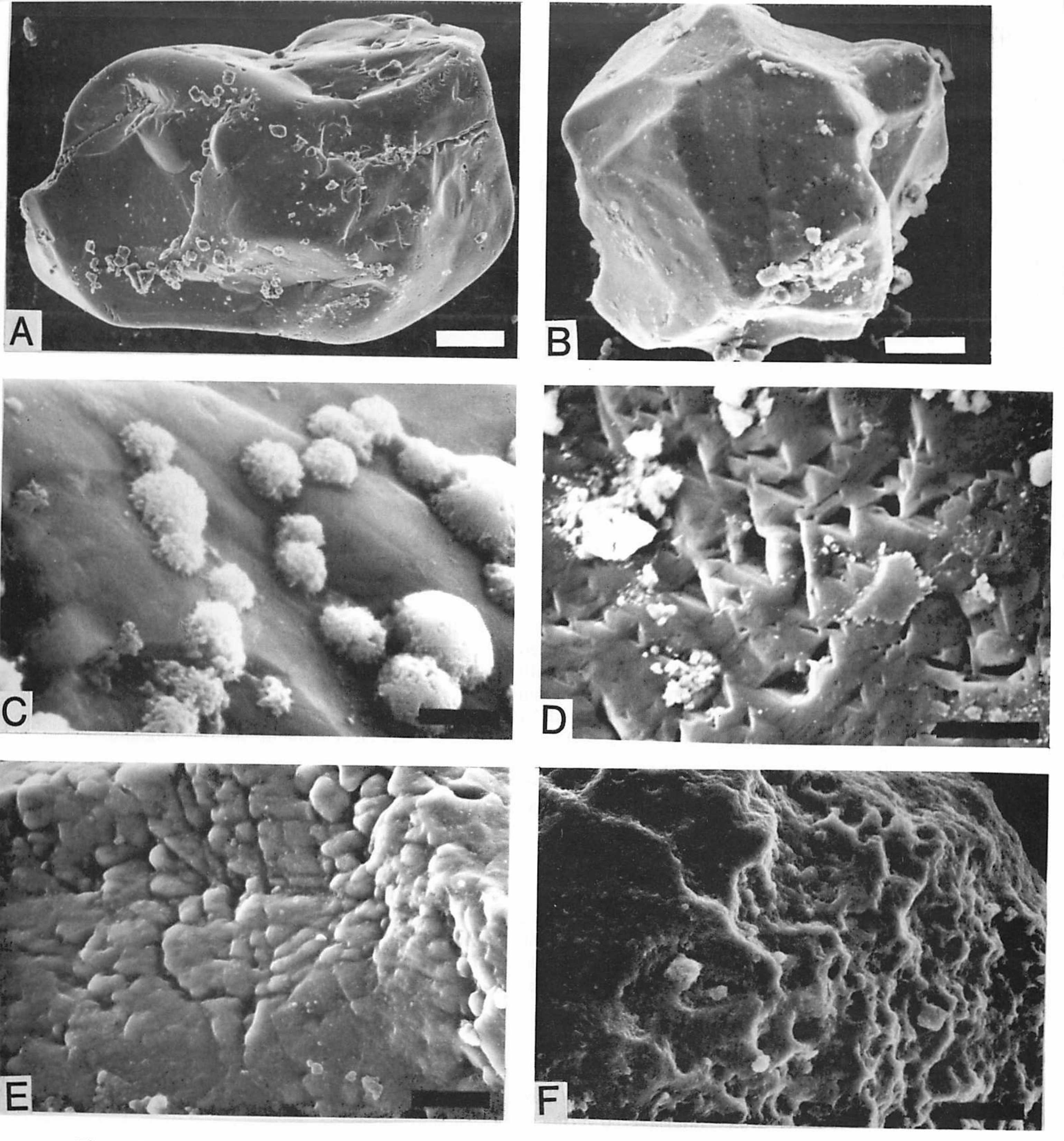

Fig. 7. SEM images of quartz grains from Bahamian aluminous lateritic soils. **A** - Subrounded medium sand sized grain showing low relief, a smooth surface of silica precipitation, dissolution crevasses and scaling (scale bar = 50 μm). **B** - Subangular fine sand sized quartz grain showing medium relief, conchoidal fracture and a flat cleavage face covered by a smooth surface of silica precipitation (scale bar = 30 μm). **C** - "Flowers" of silica precipitated on a subangular fine sand sized grain (scale bar = 3 μm). **D** - V-shaped etch pits on a rounded coarse sand sized grain (scale bar = 10 μm). **E** - Complex surface of solution and precipitation on a subangular medium sand sized grain showing solution crevasses and smooth silica precipitation (scale bar = 10 μm.). **F** - Upturned plates covered with an irregular surface of silica precipitation on a rounded coarse sand sized grain (scale bar = 15 μm).

Table 2. Frequency of surface features observed on quartz grains.

Surface Feature	Frequency (%)
Precipitation Features	
silica precipitation	93
smooth surface	77
irregular surface	20
globules and flowers	32
Dissolution Features	
V-shaped etch pits	47
solution crevasses	23
scaling	23
rounded appendages	13
dull solution surface	17
irregular solution surface	12
deep solution surface	3
Mechanical Features	
flat cleavage faces	52
cleavage planes	43
steps	45
blocky breakage	27
upturned plates	32
dish shaped concavities	20
conchoidal fracture	18
chattermarks	18
grooves	17
parallel striations	5

breakage features could have been produced within the soils. Fresh conchoidal fractures with no evidence of silica solution or precipitation were observed and may have been formed by scaling due to chemical decomposition. Although the surface textures of these quartz grains are not definitive they suggest an eolian hot desert source overprinted by pedogenic silica precipitation.

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REFERENCES CITED

Barnhisel, R. I., and Bertsch, P. M., 1989, Chlorites and hydroxy-interlayered vermiculite and smectite: in Dixon, J. B. and Weed, S. B., eds., Minerals in Soil Environments, 2nd Ed.: Soil Science Society of America, Madison, Wis., p. 729-788.

Cleary, W. J. and Conolly, J. R., 1972, Embayed quartz grains in soils and their significance. Journal of Sedimentary Petrology, v. 42, p. 899-904.

Crook, K. A. W., 1968, Weathering and roundness of quartz sand grains: Sedimentology, v. 11, p. 171-182.

Culver, S. J., Bull, P. A., Campbell, S., Shakesby, R. A. and Whalley, W. B., 1983, Environmental discrimination based on quartz grain surface textures: a statistical investigation: Sedimentology, v. 30, p. 129-136.

Higgs, R., 1979, Quartz-grain surface features of Mesozoic-Cenozoic sands from the Labrador and Western Greenland continental margins: Journal of Sedimentary Petrology, v. 49, p. 599-610.

Krinsley, D. H. and Doornkamp, J. C., 1973, Atlas of quartz sand surface textures: Cambridge Univ. Press, 91 p.

Little, B. G., Buckley, D. K., Cant, R., Henry, P. W. T., Jefferiss, A., Mather, J. D., Stark, J., and Young, R. N., 1977, Land Resources of the Bahamas: A Summary: Land Resources Div. Ministry of Overseas Development, Surrey England, 133 p.

Margolis, S. V. and Krinsley, D. H., 1971, Submicroscopic frosting on eolian and subaqueous quartz sand grains. Geological Society of America Bulletin, v. 82, p. 3395-3406.

Muhs, D. R., Bush, C. A., Stewart, K. C., Rowland, T. R., and Crittenden, R. C., 1990, Geochemical evidence of Saharan dust parent material for soils developed on Quaternary limestones of Caribbean and western Atlantic Islands: Quaternary Research, v. 33, p. 157-177.