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TOPOGRAPHIC EFFECTS ON ALUMINOUS LATERITIC SOIL DEVELOPMENT, ELEUTHERA ISLAND, BAHAMAS

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ABSTRACT

Aluminous lateritic soils from Governor's Harbour, Eleuthera Island, Bahamas were investigated to evaluate the relative importance of topography on the mineralogy of soils in carbonate environments. Samples were collected from depressions, crests of hills and on slopes up to 6^{o}. The mineralogy and major element geochemistry was determined. The soils are concentrated in solution pits on a karst surface and range in thickness from 0 to 70 cm. The mineralogy of all the samples was similar consisting of varying amounts of boehmite, hematite, goethite, dioctahedral vermiculite, calcite, aragonite and quartz. The calcite plus aragonite content ranges from 2 to 64% and averages 21%. The SiO_2/R_2O_3 ratio is low (x = 0.58) indicating the soils have undergone extensive leaching and enrichment in Al, Fe, and Ti. No statistically significant relationships were observed between topographic setting and chemical composition or mineralogy. These results suggest that topography does not play a major role in determining the mineralogy of these soils.

INTRODUCTION

Periods of subaerial exposure are recorded in paleosols and they have the potential of being important paleoenvironmental indicators of these time periods. In order to unlock the secrets stored in paleosols it is necessary to understand modern soil forming processes. Factors controlling the development of soils are parent material, topography, climate, biota and time. It is necessary to evaluate the relative importance of these factors before paleosols can be used as paleoenvironmental indicators. This study evaluates the effect of topography on the mineralogy and chemistry of soils in carbonate environments. Aluminous lateritic soils from Governor's Harbour, Eleuthera were investigated. Isolated patches of aluminous lateritic soils occur on Eleuthera, Cat Island, Abaco, Exuma, Little Exuma, Long Island, Mayaguana, and New Providence and are always associated with hard bedrock (Little and others, 1977; Ahmad and Jones, 1969). Little and others (1977) state that these soils are restricted to low spots or "valley" bottoms between dune and beach ridges. Therefore, it was believed that this would be an ideal area to study the effects of topography on soil formation.

The parent material of these soils consists of lithified eolian limestone (Little and others, 1976) plus air borne dust from North Africa (Glaccum and Prospero, 1980; Eaton and Boardman, 1985). The climate of Eleuthera is characterized by warm rainy summers and cooler drier winters with an average temperature of ($25^{o}C$) $77^{o}F$ and an annual precipitation of (114 cm) 45 in.(Little and others,1976). The Köppen classification of the Eleuthera climate would be humid tropical savanna (Gabler and others, 1977). The vegetation in the area is dense mixed broad leaf coppice. An exact age for the bedrock in the study area is unknown due to a lack of radiometric dates, but, it has been mapped as Middle Pleistocene by Little and others (1976).

METHODS

The topography was measured along a transect crossing a prominent ridge south of Governor's Harbour, Eleuthera (Fig. 1). Samples were collected at approximately 50 m intervals and the topographic setting classified as either slope, depression or crest (Fig. 2). The mineralogy of the samples was determined with X-ray diffraction on a Philips APD 3720 instrument with CuKα radiation. Organic matter was removed with Na-hypochlorite buffered to a pH of 9.5 (Jackson, 1969). The untreated sample, insoluble residue and clays after free iron oxide removal were X-rayed. Free iron oxides were removed using the Na-citrate-bicarbonate-dithionite method of Jackson (1969). The clays were also treated with ethylene glycol and heated to 400 and $550^{o}C$ to aid in their identification (Starkey and others, 1984).

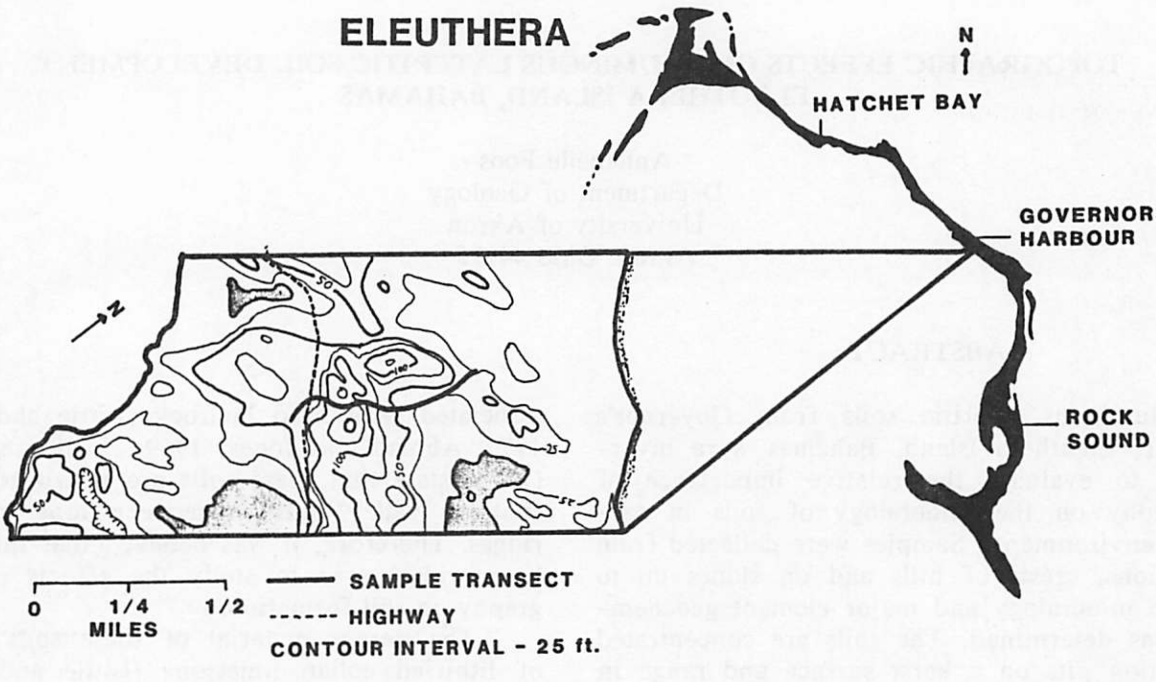

Fig. 1. Location of sample transect.

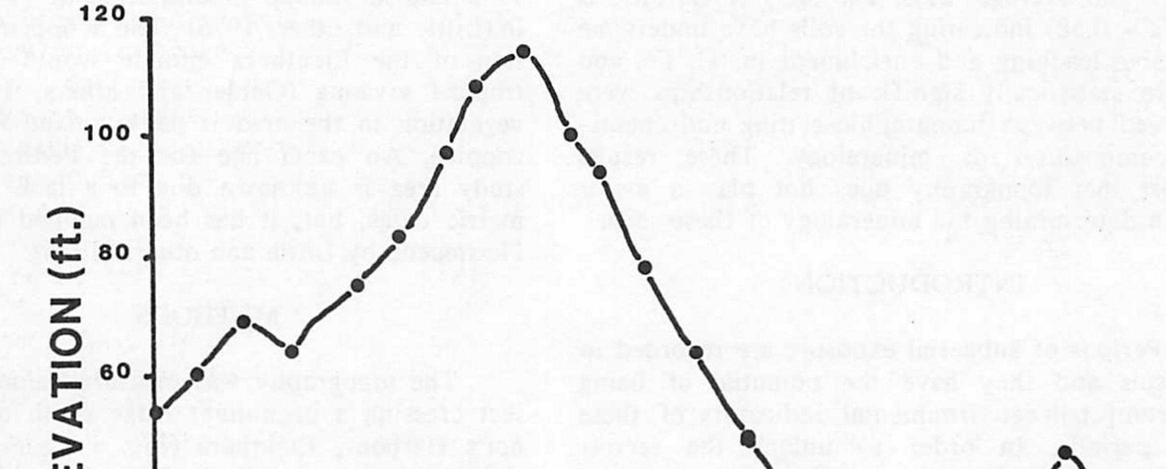

Fig. 2. Vertical profile of sample transect. (see Fig. 5 for key)

The chemical composition of the less than 2 mm fraction was determined by ICP.

RESULTS

The soils are concentrated in solution pits on a karst surface and have a maximum thickness of 70 cm. Bedrock is exposed at all sample localities. The soil profile consist of a layer of leaf litter followed by a uniform B horizon which exhibits a fine to coarse (0.1 to 1.0 cm) crumb texture. Below the B horizon is a C horizon of altered limestone followed by unaltered limestone. Textural analysis prior to removal of organic matter indicates the soils are sandy loams to loamy sands. The soil color ranged from yellow-red (2.5YR 4/8) to red (10R 2/2). Soils in depressions and on the crest of hills tend to be redder than soils occurring on slopes. The soil pH ranges from 7.3 to 8.0.

The mineralogy of all the samples is similar, consisting of varying amounts of calcite, aragonite, boehmite, hematite, goethite, dioctahedral vermiculite and quartz (Fig. 3). Boehmite has XRD peaks at 6.11 and 3.16Å. The dioctahedral vermiculite has a basal reflection at 14.1 and an 060 reflection at 1.50Å. The basal reflection did not shift after solvation with ethylene glycol, collapsed to 13.2Å after heating to 400°C and 12.4Å after heating to 550°C (Fig. 4). Differential XRD indicates that the hematite and goethite are aluminum rich containing up to 16 and 28 mole percent Al respectively.

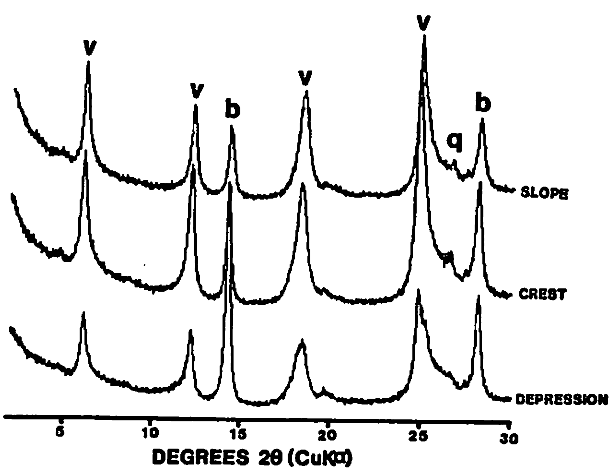

Fig. 3. X-ray diffraction pattern of clay after removal of free iron oxide for representative samples from a slope, crest and depression. (v-vermiculite, b-boehmite, q-quartz.)

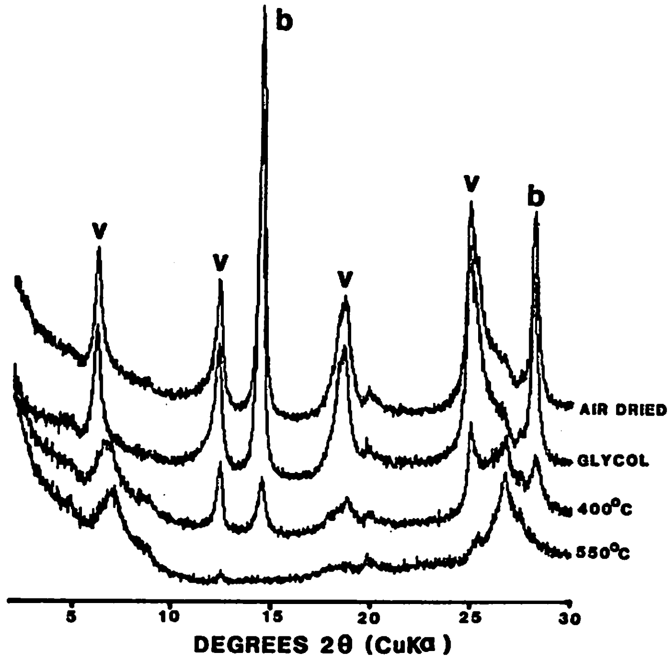

Fig. 4. X-ray diffraction pattern of clay after removal of free iron oxides. (v-vermiculite, b-boehmite)

The average chemical composition is presented 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 composition the oxides were normalized to 100%. The CaO concentration reflects the calcite plus aragonite content which ranges from 2 to 64% with an average of 21%. There is a negative correlation between CaO and all the other oxides reflecting dilution of the insoluble residue with carbonate material (Table 2). The chemical composition of the insoluble residue can be determined by normalizing the data to a carbonate free basis. After normalizing the data a positive correlation was observed between Al_2O_3, Fe_2O_3 and TiO_2. These elements were negatively correlated with SiO_2 and K_2O. These data suggest that there is an inverse relationship between the abundance of boehmite, goethite and hematite with dioctahedral vermiculite and quartz. As the intensity of weathering increases Fe, Al and Ti oxides, hydroxides and oxyhydroxides would accumulate at the expense of vermiculite. The SiO_2/R_2O_3 ratio is low (.58) indicating that the soils have undergone extensive leaching and enrichment in aluminum and iron.

No statistically significant relationships were observed between the topographic setting and chemical or mineralogical composition of the

Table 1. Chemical analysis of soils from Governor's Harbour, Eleuthera. (A. average analysis; B. oxides normalized to 100%)

	A	B
SiO_2	16.57	27.09
Al_2O_3	20.08	33.21
Fe_2O_3	8.56	13.66
MgO	1.14	1.97
CaO	11.87	20.64
K_2O	0.65	1.11
TiO_2	1.04	1.65
P_2O_5	0.26	0.42
MnO	0.14	0.22
LOI	37.75	-----
SiO_2/R_2O_3		0.58

Table 2. Correlation coefficients of chemical analysies of soil samples.

CaO		Normalized*				
			Fe_2O_3	TiO_2	SiO_2	K_2O
Al_2O_3	-.94					
Fe_2O_3	-.96	Al_2O_3	.95	.98	-.98	-.87
SiO_2	-.84	Fe_2O_3		.91	-.96	-.80
MgO	-.42	TiO_2			-.94	-.51
K_2O	-.52	SiO_2				.82
TiO_2	-.94					
P_2O_5	-.77					
MnO	-.87					

* Normalized to a carbonate free basis.

soil (Fig. 5). There is as much variation in the chemistry of a soil within a topographic setting as there is between topographic settings. The only significant topographic trend observed was the increase in redness of soils in depressions and on crests relative to soils on slopes. The degree of redness reflects the relative ratio of hematite and goethite, with redness increasing with increasing hematite content (Taylor, 1982). The distribution of these minerals reflects the moisture regime of soils with dryer conditions favoring the formation of hematite over goethite (Schwertmann, 1985; Trolard and Tardy, 1987).

The crust of altered limestone below the soils (Ck horizon) contains megascopic and petrographic features that have been previously described in paleosols from the Bahamas (Hale and Ettensohn, 1984; Foos, 1987; McCartney and Boardman, 1987) including, laminated micrite, alveolar textures, soil breccia, root cast and iron rich glaebules. Circular voids surrounded by altered limestone are often occupied by plant roots. The mineralogy of the insoluble residue of the crust is similar to the overlying soil (Fig. 6). These data suggest that the soil and crust are contemporaneous and the crust is actually a Ck horizon of the soil profile.

DISCUSSION

The mineralogy of aluminous lateritic soils from Governor's Harbour was not significantly effected by topographic setting and they are not restricted to low spots between ridges. The lateral changes in soils on a hillslope are defined as a catena. They often result from transportation of fine material down slope by the processes of overland and throughflow which may result in an accumulation of clay at the base of the slope (Fig. 7). At Governor's Harbour the irregular karst surface and the relatively impermeable Ck horizon prevent throughflow and limit the amount of overland flow. As a result the net water movement is the same on all parts of the slope and the soils are similar (Fig. 8).

The results of this study indicate that a unique topographic setting is not necessary for the formation of aluminous lateritic soils. The climate, biota and parent material where these soils occur is similar to other areas in the Bahamas where aluminous laterites are not found. Time is most likely the important factor controlling the distribution of aluminous lateritic *soils* in the Bahamas. The mineralogy of Bahamian soils oc-

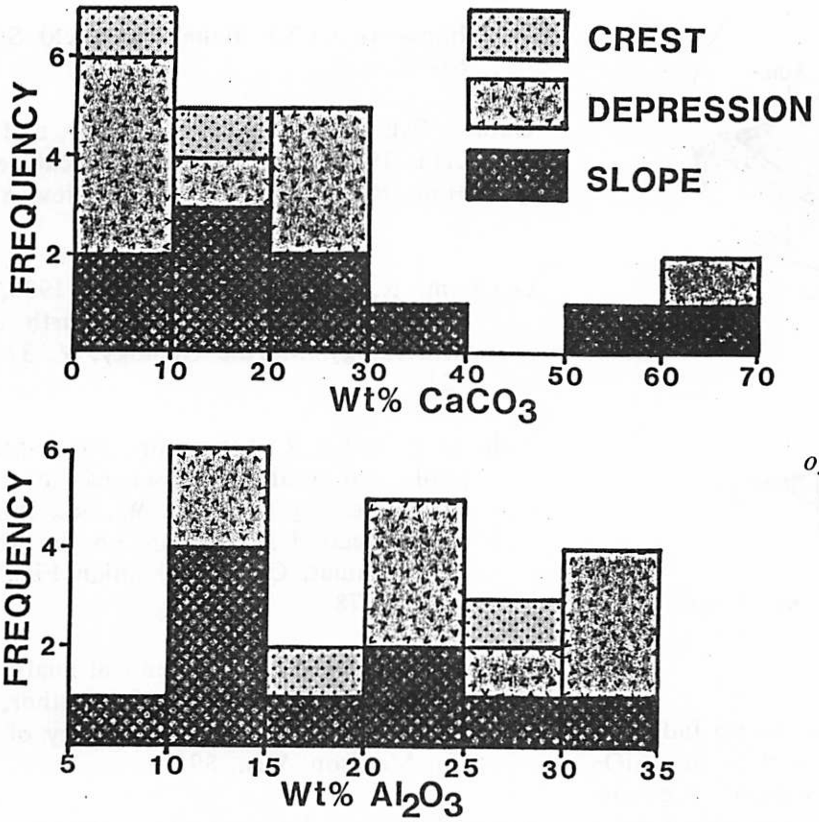

Fig. 5. Frequency distribution of chemical composition.

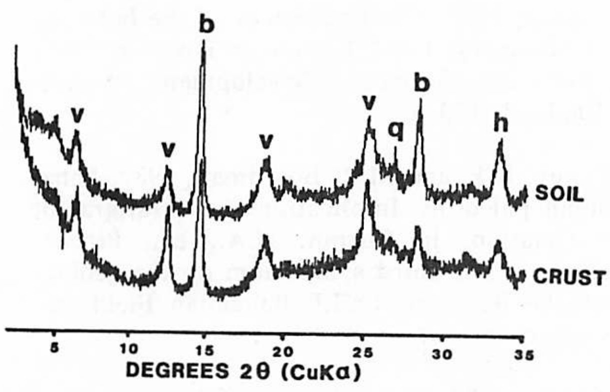

Fig. 6. Representative X-ray diffraction pattern of insoluble residue from a soil and it's underlying crust. (v-vermiculite, b-boehmite, h-hematite, q-quartz)

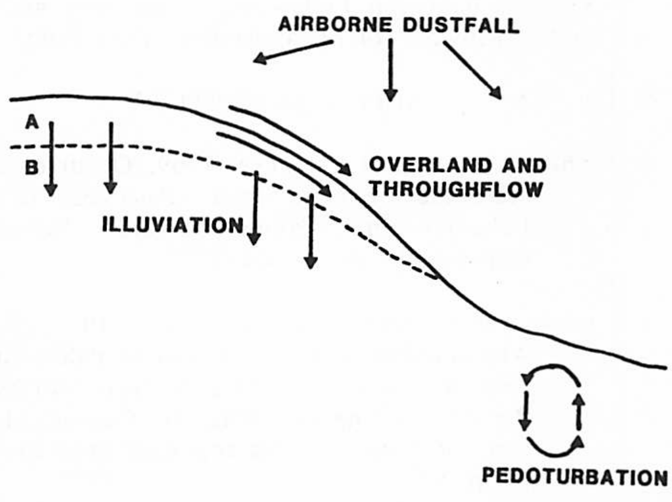

Fig. 7. An idealized example of the effect of topography on soil formation. (After Muhs, 1982)

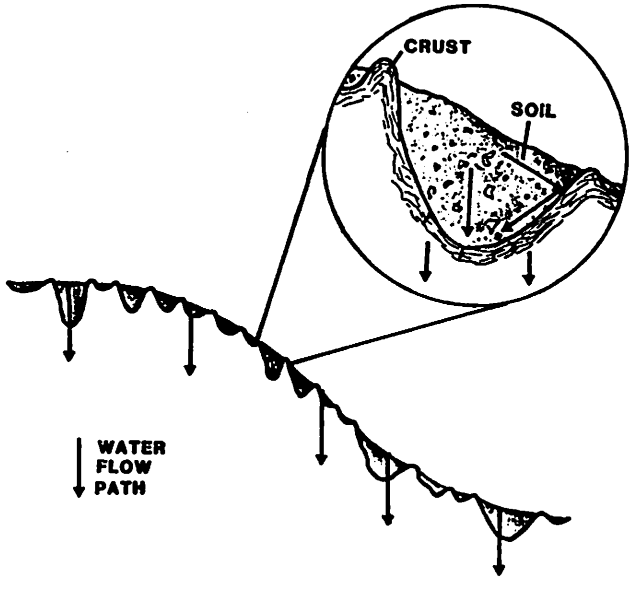

Fig. 8. An idealized view of water movement on a slope overlain by aluminous laterite.

curring on indurated bedrock may be an indicator of the soils maturity. Paleosols with a low SiO_2 $/R_2O_3$ ratio and containing the minerals boehmite and dioctahedral vermiculite would represent more mature soils and long periods of subaerial exposure.

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