Effect of Ancient Maya Agriculture on Terraced Soils of Caracol, Belize

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ABSTRACT

During their Classic period (A.D. 550-900), the Maya of Caracol, Belize constructed extensive stone-walled terraces, presumably to conserve soil and water and intensify agriculture. These terraces reduced slopes from about 6 to 2%. Four soils were examined in the upper and lower portions of two contiguous terraces. The soils were high in clay, dominantly smectite, and shallow over limestone bedrock. There was no evidence of clay translocation. Extensive fine subsoil cracking was evident at the end of the 1991 dry season and slickensides were common in three soils. Surface soils were dark brown becoming slightly lighter in color with depth. Organic C content was high at the surface, and decreased gradually with depth. Total P contents were moderately high, with the highest concentration usually at or near the surface. Extractable Ca and Mg were determined to be in adequate supply for most crops (extractable Ca was over 6,000 mg/kg in all surface horizons). Extractable K amounts were high at the surface, but medium to low at lower depths. N and extractable P amounts were the most limiting elements measured. Micronutrients were in adequate supply.

Uniformity of morphological properties could be interpreted as the lack of major human distrubance in the soils. However, this uniformity was probably the result of haploidization. The origin of the soils' parent material is still uncertain. Physical, chemical, and mineralogical data indicated that the soils did not form from the almost pure calcitic limestone. Also it was assumed that the soil was not transported and deposited by humans. Wind and water are two other possible agents for transport of the parent materials.

Terraces were used for agricultural production, but that the collapse of the Maya civilization was partially due to the deterioration of soil productivity cannot be stated with certainty. Even though several studies have been reported on the agricultural production capabilities of the Maya, additional soil investigations need to be conducted.

INTRODUCTION

Caracol was one of the largest ancient Maya cities in the southern lowlands of Central America (Figure 1) with a population matching in an 88 sq km area that of the modern country of Belize, in which the site is located (Chase and Chase, 1987, 1991). During their Classic Period (A.D. 550-900), the Maya were a highly sophisticated native society and constructed elaborate buildings, water storage structures, roadways, and agricultural terraces (Healy *et al.*, 1983) and because of their high civilization, many Maya ruins are being studied in Central America to learn why the Mayas disappeared (Demarest, 1993). Some academics believe that the Mayan civilization depleted their soil resources, but Demarest (1993) feels that they may have been involved in intensive warfare.

Caracol has been studied intensively and since the work by Wilken (1971), much of the research interest in Mayan areas has been the "raised fields" and terracing (Healy *et al.*, 1983). Even though there has been some attention given to the terraces, Healy *et al.* (1983) reported that the terraces constructed by precolumbian people have not received the same intensive examinations as the raised fields. As a result of the conclusions discussed by Healy *et al.* (1983) concerning the soil composition of Maya terraces, additional information about the soils located on the terraces at Caracol was collected. During May, 1991 an area of approximately 150 ha at Caracol was examined. Subsequently, four areas on the lower and upper portions of 2 stone-walled, contiguous terraces were excavated for more detailed examination (Figure 2).

The objectives of this study were (i) to characterize representative terrace soils at Caracol, (ii) to understand their nature; and (iii) to determine the possible effect ancient agriculture had on their properties. This investigation is a segment of a large, on-going, long-term attempt to better understand ancient Maya agriculture.

MATERIALS AND METHODS

Soils on the lower terrace - lower part (LL), upper part (LU); upper terrace - lower part (UL), upper part (UU) (Figure 2) were examined, described, and sampled following procedures

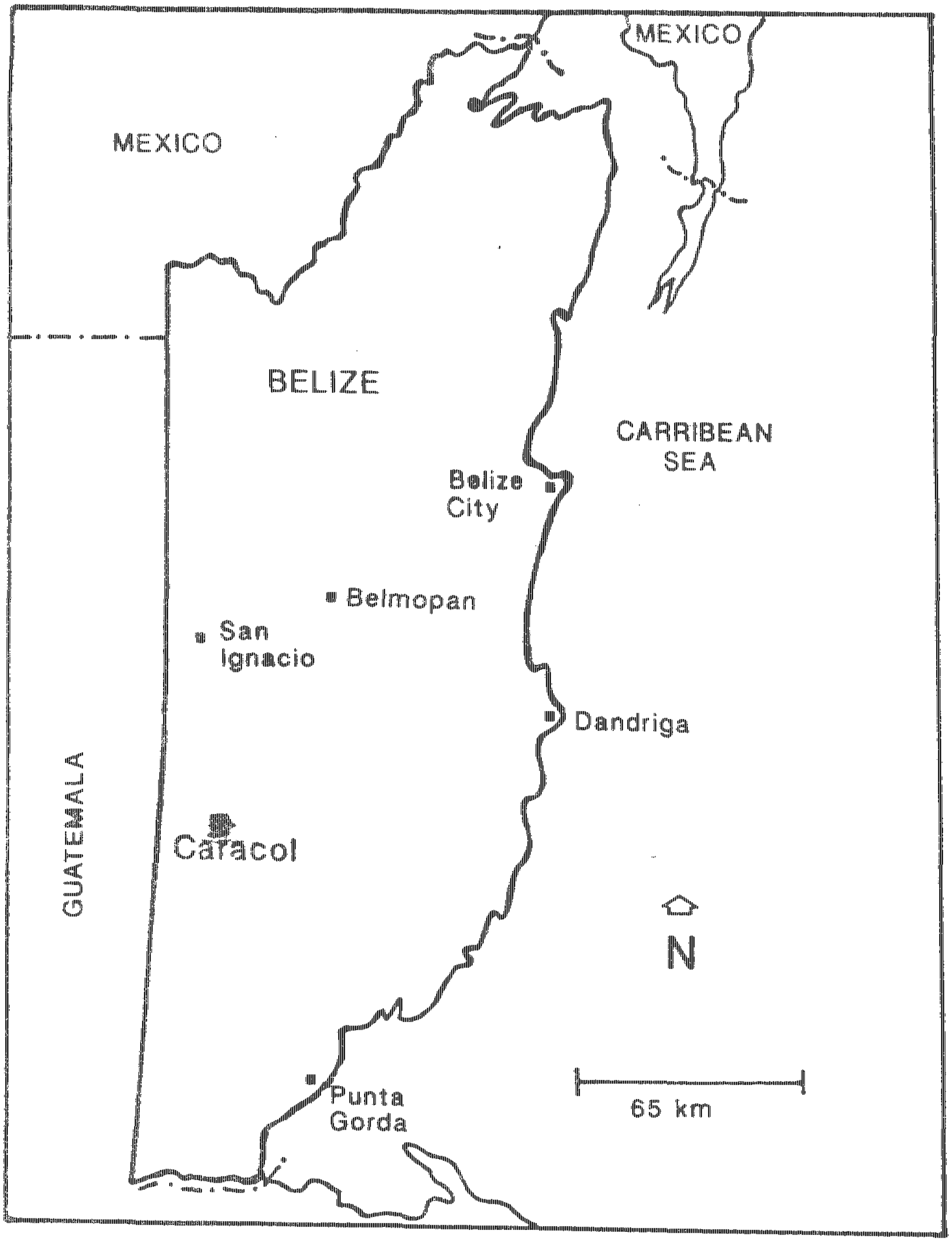

Figure 1. Location of Caracol, Belize.

given in the Soil Survey Manual (1981). The following laboratory determinations were performed: pH in 1:1 water and 1:2.5 KCl (Jackson, 1958), total nitrogen (N) (Bremner, 1965), organic carbon (C) (Jackson, 1958), extractable macro- and micro-nutrients using the Mehlich-3 method on acidic horizons (Mehlich, 1984) and the ammonium bicarbonate -- DTPA procedure (Soltanpour and Schwab, 1977) on calcareous horizons. Electrical conductivity measurements (EC) were made on surface samples (Soil Survey Staff, 1984). Total P content was determined after digestion with perchloric acid (Olsen and Sommers, 1982). Metallic elements were determined using an ICP mass spectrometer (Jarrel Ash model 750).

Particle-size was determined using the pipette method after destruction of organic matter with H_2O_2 (Day, 1965). Mineralogy of the < 2-micron clay fraction was determined by X-ray diffraction (Cu-K alpha radiation) according to the procedures of Whittig and Allardice (1986).

Some analyses were completed in the Wetland Ecology Laboratory at Florida A & M University. Particle-size analysis and clay-size mineralogy were determined in the Environmental Pedology and Land Use Laboratory at the University of Florida. Micro and macro-nutrients were extracted and determined at a commercial laboratory (Micro-macro International, Athens, GA).

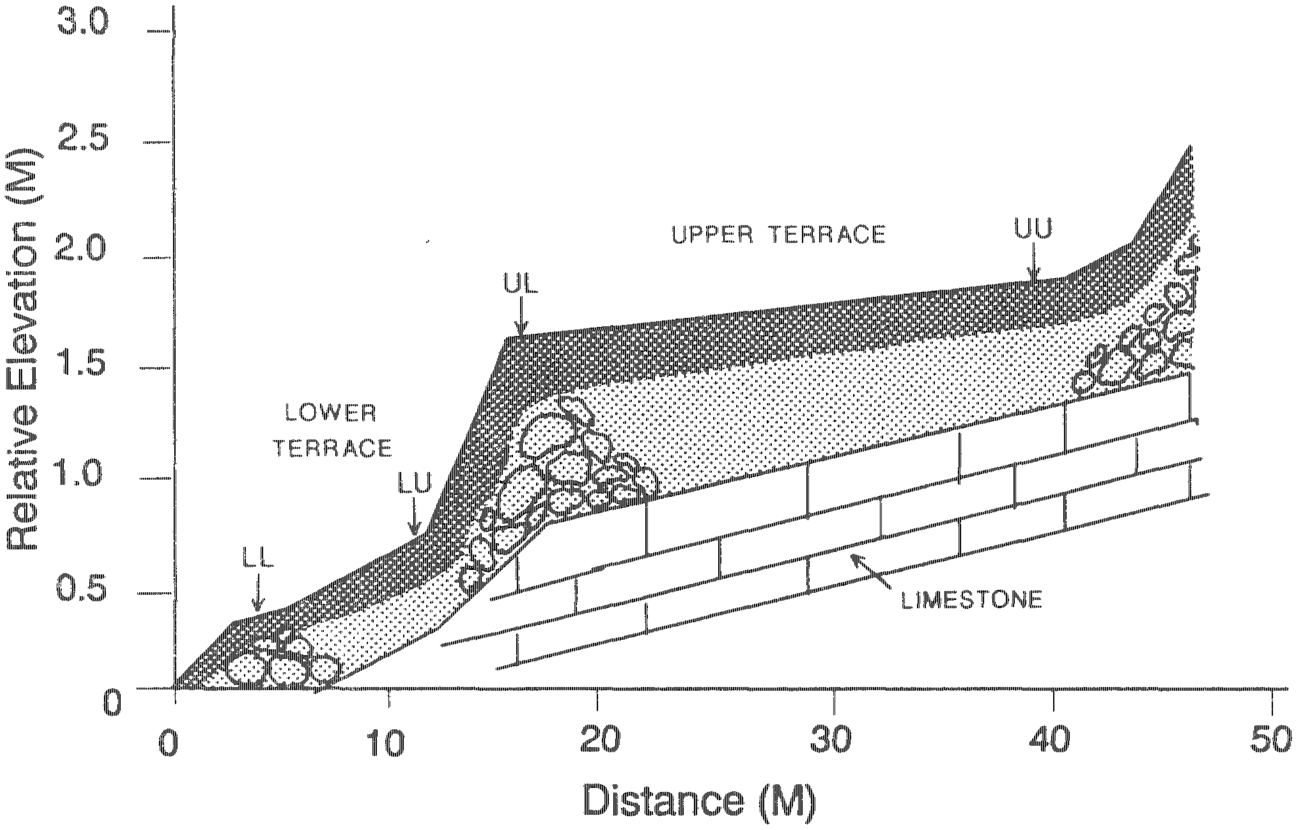

Figure 2. **Schematic cross-section of two terraces and location of soils sampled at the study site. LL = Lower part, lower terrace; LU = upper part, lower terrace; UL = Lower part, upper terrace; UU = Upper part, upper terrace.**

Although good climatological records are not available for the Caracol area, measurements done in the late 1950's for areas close to the towns of Millionario and Augustine show an average of 1480 and 1560 mm of rainfall per year with 154 and 163 days of rain per year and an intense dry season from February through May (Johnson and Chaffey, 1973 p.9). Elevation is between 500 and 600 m. The area is heavily vegetated with tall broad-leafed tropical forests with little understory vegetation. Modern vegetative coverage on the terraces at Caracol was reported by Healy *et al.* (1983).

RESULTS

Morphologically, the terraced soils studied were dark brown (dry color) in the A horizon changing to brown (dry color) in the B horizons. All horizons had clay textures (Table 1). Limestone was at a depth of 80 cm or less. There was a thin layer of organic material (partially rotted leaves) at the soil surface. Roots were common, but most abundant near the soils surface. The soils had uniformally well developed fine to medium angular blocky structure that was firm or very firm when dry. Slickensides occurred in the Bss horizons of the LL, UL, and UU soils; but not in the LU. This soil did not have a Bss horizon.

Most soil horizons were slightly acid (6.3) to mildly alkaline (7.8) in reaction as measured in water (Table 2), but became more acidic upon measuring with KCl. This decrease in pH suggests the presence of extractable Al. Horizons immediately above the limestone had the highest pH values. Organic C content was high in the surface horizons ranging from 5.68 to 6.38%. Organic C contents decreased with depth, but significant amounts occurred at the soil-limestone interface. Total N was low relative to organic C with C/N ratios ranging from 27 to 64, with most horizons in the 35 to 42 range. Total P contents were highest at or near the surface and ranged from 468 to 826 mg/kg. Extractable P was low (2.9 to 10.9 mg/kg) and generally decreased with depth. Electrical conductivity measurements were low indicating low amounts of soluble salts.

Calcium was the most abundant extractable element, ranging from 6,170 to 9,770 mg/kg extractant (Figure 3). Extractable Mg was the next most abundant element, but at much lower amounts than Ca (0.6 to 508 mg/kg). Ca/Mg ratios were lowest at the surface (14-18) and ranged from 14 to 174 in the soils (Table 3). Potassium content was highest at the surface in all soils, but at very low amounts (82 to 90

Table 1. **Description of four soils on the lower and upper terraces at Caracol, Belize.**

Horizon	Depth (cm)	Color (dry)	Texture	Structure	Consistence	Additional Notes
Lower terrace - Lower part (LL)						
A	0-20	7.5YR 3/2	c*	f, m blky	v. firm	abund f to m roots; occ. shards
Bss	20-38	7.5YR 4/2	c	f, m blky	v. firm	f to l roots with slickensides
Bw	38-55	7.5YR 4/2	c	f, m blky	v. firm	f to m roots
2R	55	white limestone, wavy surface				
Lower terrace - Upper part (LU)						
A	0-20	7.5YR 3/2	c	f, m blky	v. firm	abund f to l roots
Bw1	20-34	7.5YR 4/2	c	f, m blky	v. firm	freq f to m roots
Bw2	34-38	7.5YR 4/4	c	f, m blky	v. firm	freq gr occ f roots
2R	38	white limestone, wavy surface				
Upper terrace - Lower part (UL)						
A	0-22	7.5YR 3/2	c	f, m blky	v. firm	abund f to m roots
Bw	22-32	7.5YR 4/2	c	f, m blky	v. firm	freq f to m roots

(Continued next page)

Table 1. **Description of four soils on the *lower* and *upper* terraces at Caracol, Belize (*continued*).**

Bss1	32-53	7.5YR 4/2	c	f, m blky	v. firm	occ m to f roots; slickensides vertical cracks
Bss2	53-72	7.5YR 4/2	c	f, m blky	v. firm	rare f roots; slickensides
Bw'	72-80	7.5YR 4/3	c	f, m blky	v. firm	rare f roots
2R	80	white limestone, wavy surface				
Upper terrace - Upper part (UU)						
A	0-20	7.5YR 3/2	c	f, m blky	firm	abund m to f roots occ l roots
Bw	20-32	7.5YR 4/2	c	f, m blky	firm	occ m to f roots; vert. cracks
Bss	32-52	7.5YR 4/2	c	f, m blky	firm	occ f to l roots; slickensides
Bw'	52-55	7.5YR 4/2	c	f, m blky	firm	rare m to f roots; cal gr
2R	55	White limestone, wavy surface				

* Abbreviations: c = clay, f = fine, m = medium, blky = blocky, v = very, occ = occasional, l = large, abun = abundant, freq = frequent, cal = calcareous, gr = gravel.

Table 2. **Physical and chemical properties of soils studied on the lower and upper terraces at Ceracol.**

Depth cm	pH H_2O	pH KCl	Organic C %	Total N %	C/N	Total P mg/kg	Extract P mg/kg	Electric. Conduct. $S\ m^{-1}$
Lower terrace - Lower part (LL)								
0-20	6.4	5.6	5.68	0.138	41	623	10.0	0.050
20-38	6.3	5.4	2.88	0.083	35	604	8.8	
38-55	7.6	6.8	2.11	0.055	38	598	4.6	
Lower terrace - Upper part (LU)								
0-20	7.0	6.4	6.38	0.152	42	807	10.9	0.075
20-34	6.8	6.1	2.32	0.062	37	690	8.0	
34-38	7.3	6.5	2.32	0.037	63	643	5.0	
Upper terrace - Lower part (UL)								
0-22	6.9	6.0	5.84	0.120	49	485	9.5	0.050
22-32	6.3	5.5	2.50	0.061	41	654	8.4	
32-53	5.8	4.9	1.66	0.026	64	526	7.8	
53-72	7.3	6.4	1.41	0.046	31	604	9.3	
72-80	7.8	6.9	1.20	0.031	39	612	2.9	
Upper terrace - Upper part (UU)								
0-20	6.8	5.9	5.84	0.100	58	826	10.4	0.048
20-32	6.1	5.1	2.39	0.088	27	748	7.9	
32-52	6.1	5.2	1.66	0.039	43	468	7.4	
52-55	7.6	6.8	1.58	0.039	41	602	5.5	

Phosphorus was extracted from the upper horizons of all soils using Mehlich-3 procedure. In the horizon just above the limestone, because it was alkaline, the ammonium bicarbonate--DTPA extraction was used.

Table 3. **Extractable micro-nutrient contents in soils studied on the lower and upper terraces at Caracol.**

Depth (cm)	Mo	Zn	B	Cu	Fe	Mn	Ca/Mg
	mg/kg						
Lower terrace - Lower part (LL)							
0-20*	0.6	1.5	4.6	2.0	75	93	14
20-38*	0.6	0.8	0.7	1.1	58	46	30
38-55**	1.0	0.5	0.0	1.1	19	3.8	25
Lower terrace - Upper part (LU)							
0-20*	0.6	2.3	2.6	3.1	57	152	16
20-34*	0.6	0.8	0.4	0.9	56	28	27
34-38**	1.0	0.4	0.0	0.9	17	3.5	14
Upper terrace - Lower part (UL)							
0-22*	0.6	1.6	1.6	2.0	63	107	15
22-32*	0.6	0.9	0.7	0.9	51	36	36
32-53*	0.6	0.6	0.2	0.9	50	24	43
53-72*	0.6	0.5	0.3	1.2	30	49	174
72-80**	0.6	0.4	0.0	1.3	6.1	1.4	44
Upper terrace - Upper part (UU)							
0-20*	0.6	1.5	1.2	2.1	81	77	18
20-32*	0.6	0.8	0.2	0.8	59	30	52
32-52*	0.6	0.8	0.2	0.9	62	40	85
52-55**	1.1	0.5	0.0	1.4	15	3.9	161

* Mehlich 3 extractant

** Ammonium bicarbonate - DTPA extractant

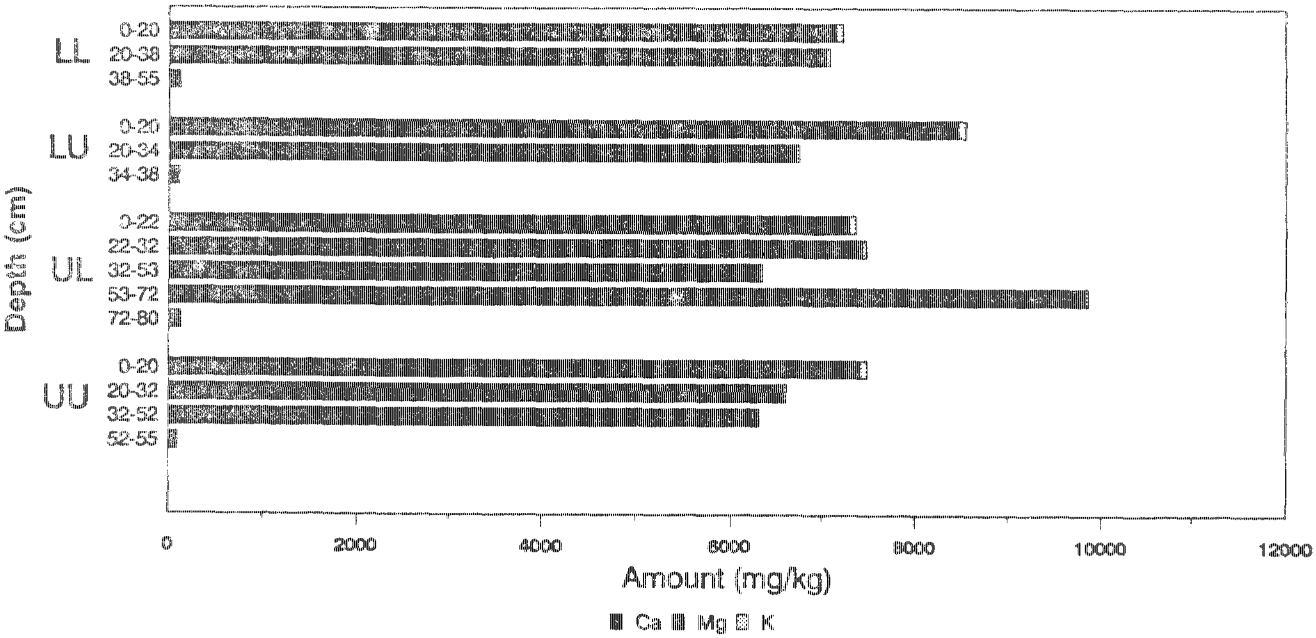

Figure 3. Extractable macro-nutrient contents from the soils studied at Caracol.

mg/kg) relative to Ca and Mg.

Micro-nutrients generally were highest at the surface and decreased appreciably in the lower horizons (Table 3). Extractable Mo tended to be fairly uniform or increased slightly in the horizon overlying the limestone. Extractable Mn was considerably higher in the A horizons, decreasing rapidly in the subsurface horizons, and in the horizons immediately above the limestone.

Particle-size depth distributions are presented in Figure 4. All soil horizons were high in clay ranging from 64.8 to 75.2% with no indication of clay translocation. These soils contained little sand (4.0 to 12.0%) with slightly higher amounts in the horizon adjacent to the limestone. The mineralogy of the clay was dominantly smectite with small amounts of kaolinite and quartz. There appears to be no particular pattern to the distribution of the clay-size mineral suites except that there was a continual increase in kaolinite and a decrease in smectite with depth in the soil at the lower site on the upper terrace. The limestone was composed of calcite with few impurities.

DISCUSSION

The effect of the terraces on slope and soil thickness are indicated in Figure 2. The terraces have been effective in slowing soil erosion or, at least, the soil was thicker just above the terrace than it is at the upper side of the terrace floor. Slope has been reduced from about 6% to less than 2%. There has been some obvious anthropogenic disturbance: the culling of stone from the inter-terrace soil, the construction of the terrace, and the presence of pottery sherds, sometimes directly on bedrock.

Although the soil was examined at the end of an extended dry period, the soils did not have vertically oriented, wide cracks from the surface tapering into the subsoil. In similar soils exposed to the sun in the dry season in Northern Belize, wide surface cracking tapering into the subsoil was common. If the soils were cleared of their current vegetation for planting, the soils would become warmer and drier at the end of the dry season and wide surface cracking would occur.

The presence of slickensides, slip surfaces developed in the subsoil, raises questions concerning soil disturbance and the time required for the development of this feature. Slickensides indicate the presence of high amounts of 2:1 readily expandable clays (*e.g.*, smectites) that undergo changes in moisture conditions (Soil Survey Staff, 1992). Some believe that this feature can develop in a few hundred years (L. Wilding, Texas A&M, personal communication). If wide cracks developed in the surface during Maya occupation and massive movement (inversion) of the subsoil material occurred, it is easy to imagine how artifacts dropped on the soil surface could have become mixed into the subsoil by natural processes. Therefore, it is difficult in soils with high amounts of expandable clays to make inferences about artifact location in the soil (Wood and Johnson, 1978).

Though these soils were high in clay, difficult to work with modern equipment, and relatively shallow, they were high in many nutrients needed for crop production. The soils were well supplied with organic C which, along with clay, enhances the soils capacity to hold nutrients and water. Nitrogen and extractable P were the elements most limiting to crop production, now and also probably during the Classic Maya era. Extractable Ca and Mg were in good supply and the Ca/Mg ratios were favorable in the surface layers. Potassium was

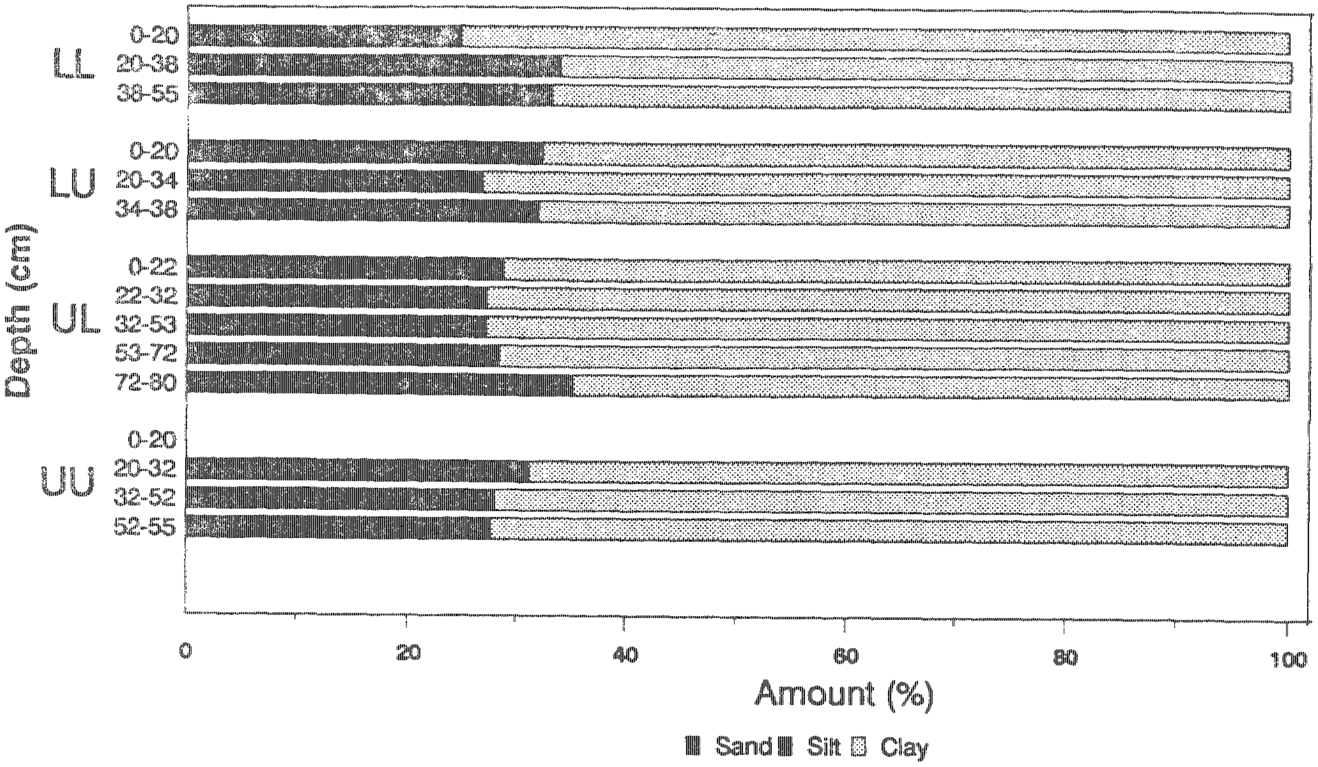

Figure 4. Particle-size depth distributions in the soils studied at Caracol.

adequate in the surface soil, but became limiting for most crops with depth. Micro-nutrients, specifically those needed for crop production, were high in the soil surface which may be the result of biocycling, but decreased with depth. Soluble salts would not limit crop production as indicated by the low EC measurements.

Several investigations have taken place at Caracol to study the soils on the terraces. An intensive study of the terrace soils was done by Healy *et al.* (1983), but it is difficult to compare Healy *et al.* soils' analyses with those reported in this paper because they did not report the laboratory methods used. Some general comparisons, though, can be made. Both studies reported the soils as being high in clay. Healy *et al.* reported that the high clay contents were the result of weathering of the natural soils under intensive, continuous cultivation. By this assumption, clay contents in the surface should be higher than clay contents in lower horizons. This was not true in Healy *et al.* soils'. Only the LL soil had a higher amount of clay in the surface.

The soils studied by Healy *et al.* (1983) were lower in pH, but higher in organic matter. The amount of macro- and micronutrients were considerable lower in Healy *et al.* terraced soils than the soils reported in this study. They commented on the relatively high contents of exchangeable Al and Mn, feeling that the high levels of Al may have led to Al toxicity. Exchangeable Al was not measured in the terrace soils, but based on pH values, Al levels would be low.

The soils are relatively young pedogenically speaking and unweathered as indicated by the high content of smectitic clay, the high content of bases, and the lack of significant morphological development. There has been no clay translocation in the soil. Therefore, the question arises: What has been the effect of ancient agriculture on modern soils?

As others have observed, the terraces have been effective in slowing erosion and, presumably conserving moisture. Rocks have been culled from the inter-terrace soil for the construction of the terrace walls and most likely for inclusion as fill in other Maya constructions. The surface horizons were higher in plant nutrients than the subsoil and the horizons immediately above the limestone were generally lowest in nutrients. Whether these high amounts are due to amendments applied by the ancient Maya or natural bio-accumulation is unknown. Elevated P levels are sometimes used by archaeologists as an indicator of ancient intensive agriculture, or at least habitation (Dunning, 1993), but we can conclude little from these data. Fractionating P compounds following Chang and Jackson's (1957) procedures may yield some clues concerning very ancient agricultural practices. Sandor *et al.* (1986), though, reported that total P and most P fraction amounts were reduced by cropping between 1,000 and 1,150 AD on terraced soils in southwestern New Mexico. Additional studies must be done to answer these concerns.

The morphology of these soils raises some interesting queries as to their origin. Healy *et al.* (1983) stated that the lack of a "C" horizon (layer of disintegrating limestone in this case) indicated major disturbance and concluded that the soil was transported and deposited by humans. Maya moving soil to build terraces, raised fields, or to fill-in swamps have been mentioned by several investigators. Pohl *et al.* (1990) calculated the amount of uphill soil that must be moved to fill-in a 600 ha swampland. They estimated that 7.8 million tons had to be transported. Their question was: "If the Maya did fill-in the swamp, where are the borrow pits?" We ask a similar question. If these terraces were built by transporting soil, where did the soil come from? One of the largest terraces studied by Healy *et al.* was approximately 30 m wide and 100 m long. If one assumes a depth of 1 m and an average bulk density of the mineral soils of 1.3 gm/cm3, for this terrace 4,290 tons of soil would have to be moved. Would the Maya move this amount of high clay soil? Where are the borrow pits?

An abrupt boundary between the soil and the underlying limestone was noted implying distinct changes, but there was also a thin transitional layer (some limestone gravel and lighter colors) just above the limestone bedrock. This layer may have formed since the terraces were constructed more than 1,000 yrs ago. The sequence and uniformity of horizons, both vertically and horizontally, could be interpreted as a lack of major human disturbance. However, this uniformity is probably due to the pedogenic process of haploidization by argillipedoturbation (Buol *et al.*, 1989). Argillipedoturbation "rejuvenates" the soil by continually "circulating" the soil material from the subsoil to the surface. Thus, this process "homogenizes" the soil.

What is the origin of the soils' parent material? Assuming that the limestone is nearly pure calcite, the physical, chemical, and mineralogical data strongly suggest that the soils did not form as a result of limestone dissolution, even though Healy *et al.* (1983) reported that the local soils were "a product of the general limestone formation of the area." As a result of this conclusion, the characteristics of the Caracol soils are puzzling. If one follows general pedologic philosophy and contends that soil development did not occur in situ and was not transported and deposited by humans, then what could be, for the sake of argument, the mechanism(s) for these soils' genesis?

Wind and water are two other agents for transport of parent material. It is possible that a fraction of the soil minerals have been weathered from wind-blown deposits such as volcanic ash or loess. Volcanic activity is common to the southwest below the Peten in the Guatemalan highlands. Minerals common in volcanic deposits were not investigated in the soils. One can only speculate if they were present. Also, there are no stream systems in the area which could account for the source of possible loess. Another possible parent material would be marine sediments. In northern Belize, High (1975) noted a Holocene marine transgression that flooded a considerable area of the coast and fluvial systems. Even though marine sediments were deposited, because of the relatively high elevation of the terraces, we do not believe that these soils developed from marine sediments.

Three of the soils studied (LL, UL, and UU) have some of the properties associated with Vertisols, *i.e.*, high amounts of smectitic clay and slickensides. They do not, however, form wide deep cracks to the surface under present vegetation. All of the soils do resemble Mollisols having dark colored, high base status surface horizons, but the peds are very firm when dry. Therefore, LL, UL, and UU soils would probably classify as Vertic Ustropepts; the soil without slickensides (LU) would be a Typic Ustropept.

Assuming that the four terrace soils studied represent many of the Maya terrace soils, it can be concluded that the soils were reasonably productive for the ancient Maya. The Maya may have enhanced the soils productivity with composts of plant, animal, and human wastes, but there is limited evidence for this. The Maya did protect the soil from destructive erosion and conserved water with the construction of stone terraces. Finally, the soil data presented in this paper disagree with some of Healy *et al.* (1983) conclusions. It is true that the terraces were used for agricultural production, but that the annihilation of the Maya civilization at Caracol was partially due to the deterioration of soil productivity cannot be stated with certainty. Therefore, soil investigations are continuing at Caracol. Other inquiries are providing clues as to the collapse of the Maya civilization (Demarest, 1993).

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Special Publication 93-03

Proceedings of the First International Conference on Pedo-Archaeology

February 16-20, 1992

Sponsored by:

The University of Florida
Institute of Food and Agricultural Sciences
The University of Tennessee
Florida Museum of Natural History
Soil Science Society of America
National Park Service
Southeast Archaeological Center
and
Canaveral National Seashore Park

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Published by The University of Tennessee
Agricultural Experiment Station
Knoxville, TN