Chapter 8

Depression Soils in the Lowland Tropics of Northwestern Belize: Anthropogenic and Natural Origins

Timothy Beach
Nicholas Dunning
Sheryl Luzzadder-Beach
Vernon Scarborough

INTRODUCTION

For decades, Maya scholars have studied and speculated on depressions (or bajos) around ancient sites in the Maya lowlands. These depressions range from large structural basins to smaller karst dolines /1, 2/. Typically, these depressions contain seasonal wetlands with woody vegetation adapted to annual drought conditions. To archaeologists, these bajos have represented an obvious focus for ancient economic activities. After all, most scholars have maintained that these regions are agriculturally limited, yet were surrounded by vast populations that had to feed themselves by some means. Their propinquity to large ancient Maya sites (which, in many cases, spread

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out around bajos) and their surface variability of vegetation, soils, water features, and artifacts make them essential in any attempt to explain ancient subsistence. Moreover, interest in bajos grew even more intense when scholars started to recognize the remains of wetland agriculture in curious swamp polygons (Turner and Harrison 1983; Siemens and Puleston 1983; Pohl 1990). Jacob (1995b:71) summed up a generation of focus on bajos when he wrote: "Understanding the past and present dynamics of wetlands . . . holds a key to understanding the evolution of Maya civilization."

Cowgill and Hutchinson (1963) described many of the previous studies of bajos in their thorough study of an excavation in El Bajo de Santa Fé, Petén, Guatemala. They relate the "first intelligent account" by Fray Andrés de Avendaño of Loyola (Means 1917), who, in the wet season of 1695, crossed bajos with incessant difficulty. Despite these difficulties, scholars have been drawn to these seasonal wetlands. Cooke (1931) hypothesized that these depressions held shallow lakes in the Classic period, which subsequently became filled with eroded sediment (i.e., aggraded). Cooke argued that this loss of soil fertility and water resources led to the collapse of the Classic Maya civilization (see Bennett 1926); this hypothesis was adopted by Ricketson and Ricketson in 1937 and revived by Harrison in 1977. Other scholars argued that the bajo soils they had studied, however, formed from autochthonous parent material (see Cowgill and Hutchinson 1963 for El Bajo de Santa Fé; see Dahlin, Foss, and Chambers 1980 and Scudder, Foss, and Collins 1996 for bajos near El Mirador).

Jacob (1995b: 72) described preliminary research on the clayey, shrink-swell, bajo soils called Vertisols near the site of Nakbe, which is about 10 kilometers (km) from El Mirador (see Figure 8.1)[3]. He describes Vertisol topsoils (largely different from the current surface topsoil) that are buried by 50 to 150 centimeters (cm) of soil. These soils are similar to the soil studied by Cowgill and Hutchinson (1963), although they interpreted the horizon displacement as due to rotting roots. These highly distorted buried soils are darker, have distinct redoximorphic features (unlike the surface soils), and are possibly pre-Maya (based on one sherd in the overburden)[4]. Based on this evidence, and the evidence that the buried soils have a $^{12/13}C$ isotopic signature indicative (equivocally) of wetlands, Jacob (1995b) suggested that these bajos were more extensive wetlands in Maya times, but had filled from soil eroded from surrounding slopes (cf. Dunning et al., in press).

This article focuses on the aggradation, character, and formation of buried Vertisol paleosols in the bajos of northwestern Belize, within a region known as the Programme for Belize, in order to understand the environmental changes that buried and formed them /5/. After establishing the existence of two widespread paleosols in the depressions of this region, four questions were raised based on geoarchaeological work in this environment:

1. What is the nature of these sediments and soils?
2. What can these paleosols tell us about human-environmental relationships?
3. What caused the burial or aggradation of soils in this landscape?
4. What caused the once horizontal profiles of these soils to become deformed?

In the historical natural sciences, we must always begin with natural explanations because they have been so widespread over geologic time, however, human-caused change has grown to become a dominant force (Hooke 1994). The aggradation of the paleosols is clearly related to ancient soil erosion, but that deformation of the soil horizons was caused by a combination of anthropogenic and natural processes. Ancient agriculture did not rearrange the soil horizons by direct modification of the soils; rather, it was the heavy load of sediment from substantial upland erosion that allowed the soil deformation and buried Vertisol formation.

ENVIRONMENTS

The Three Rivers Region of the Maya lowlands lies in northwestern Belize, bordering Mexico and Guatemala, and is situated within the Cretaceous period carbonate rock plateau of the southern Yucatán Peninsula (King et al. 1992: 35; Dunning et al. 1998) (Figure 8.1). This region ranges in elevation from less than 20 meters (m) at Booth's River to above 200 m mean sea level (msl) along the La Lucha Escarpment.

Several normal faults slice through the region, aligned as a sequence of SSW-NNE trending horst ridges that rise about 100 m above the surrounding graben valleys[6, 7]. With their east-facing escarpments, these faults give the region a stair-stepped appearance rising from Belize's Northern Coastal Plain, centered around the New River, into the Bravo Hills, around the Rio Bravo, and then toward the Petén to the west. The grabens, occupied by underfit streams, are low-gradient depressions (henceforth bajos) that contain a range of wetland ecosystems. We focus on soils in these alluvial lowlands and in karst sinks on the upland horsts.

As with much of the Maya lowlands, the Three Rivers Region consists predominantly of carbonate rocks (limestones and dolomites), with marl or saprolite layers and scattered concentrations of chert nodules. The uplands are covered with karst-solution features such as dolines and poljes (called rejollades where well drained, and aguadas where waterlogged) and rounded karst hills (mogotes). The region's natural vegetation is subtropical moist forest—a medium-high broadleaf, evergreen forest with a few dry-season deciduous trees. These diverse communities have an evergreen broadleaf, tall forest with an interior canopy of palm species such as corozo (Orbignya

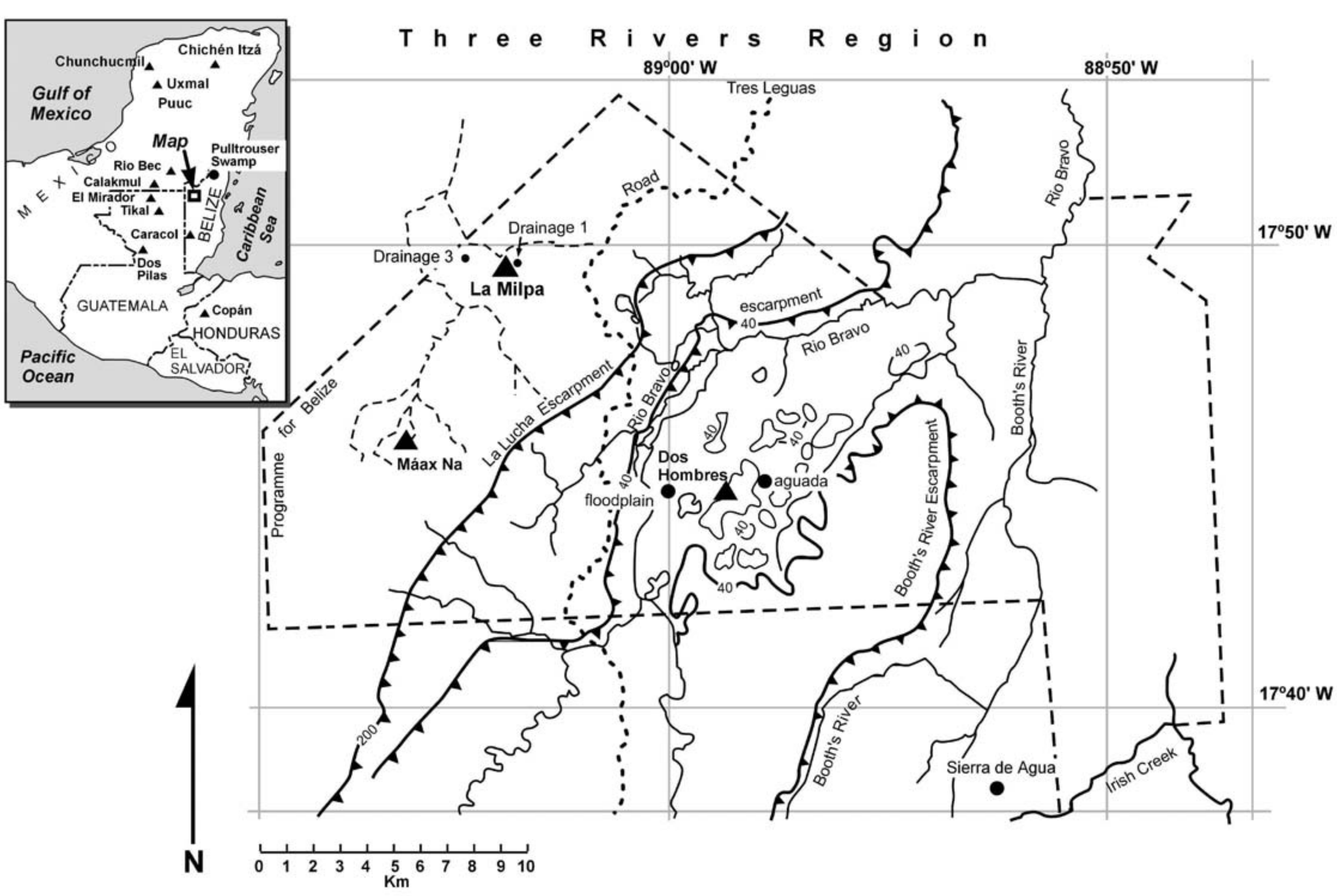

FIGURE 8.1. Map of the Three Rivers Region of northwestern Belize, with an inset showing the Maya lowlands. Black circles around La Milpa indicate the study sites.

cohume), and a patchy canopy of such tropical hardwoods as mahogany (Swietenia macrophylla) and cedar (Cedrella odorata) (Brokaw and Mallory 1993).

The climate is perennially hot and humid, with about 1,500 millimeters (mm) of rainfall annually; the Holdrige system places it in the Subtropical Moist Life Zone. Temperatures vary from a mean monthly maximum of 26.5 to 31.5°C. In United States Department of Agriculture (USDA) soil description terms, the soil temperature regime is hyperthermic (the warmest category), and the soil moisture regime is tropudic (or aquic in many bajos), but the border of the tropustic regime is nearby (which means the soils in their control section are dry for nearly 90 consecutive days in most years; see Van Wambeke 1987). The wet season runs from June through December with bimodal peaks in June and September; the dry season occurs from January to May and has periodically severe moisture deficits exacerbated by the low available water capacity of the region's fine, clay soils. The end of the dry season in April and May shows dramatic signs of water deficits, with large soil cracks and widespread leaf wilting.

HOLOCENE HUMAN-ENVIRONMENT RELATIONS

In northern Belize, most human-environment relations occurred during the Late Holocene (i.e., during the last 5,000 years). Agriculture and deforestation began about 4500 14C yr. B.P., and widespread agricultural intensification occurred from 4000 to 3000 14C yr. B.P. (Pohl et al. 1996). The earliest artifacts found thus far in the Three Rivers Region are nonstructural materials dating to the Middle Preclassic (900–400 B.C.). This period probably had a small rural population that modified the environment by slash-and-burn practices. Indeed, Holley et al. (2000) found evidence for sedimentation in the Preclassic linked to upland erosion.

Large-scale urbanization in this regions started in the Late Preclassic (350 B.C. to A.D. 250) with the advent of monumental architecture at the large site centers. With this growing nucleus at the site center, however, population remained largely rural and diffuse throughout this period (Dunning et al. 1999). Growth was spotty in the Early Classic (A.D. 250–600) at the large sites of La Milpa and Dos Hombres in our study area, but the sites of Blue Creek and Rió Azul—approximately 25 km north and northwest of the study region—expanded significantly at this time (Adams 1995; Guderjan 1998). As with many agriculturally-based societies, the Classic Maya began to link their rulership symbols to ideas of agriculture and environment (Schele 1995). At this time, the major hydraulic manipulation of La Milpa and the lowlands also started (Scarborough 1993).

Any discussion of anthropogenic impacts on soils in this area must start with the last period of major disturbance—the Maya Late/Terminal Classic (A.D. 600–900). All evidence indicates that this period had the greatest environmental alteration, population, and construction, but it also had the greatest amount of soil conservation (Beach and Dunning 1995; Beach et al. n.d.). The bulk of settlement and architecture at La Milpa and many other regional sites date to after A.D. 700 (Hammond and Tourtellot 1999), and the sites seem to be abandoned with immediacy by A.D. 850 (Hammond et al. 1998). After the Maya Collapse, there seems to have been a shifting population, but populations must have been small because there are virtually no Postclassic artifacts. Whatever the case, we have found little environmental impact has been found in the Postclassic.

The growing evidence for a significant drought during the Maya Late Classic is also a potential impact on soil formation (Hodell, Curtis, and Brenner 1995; Hodell, Brenner, and Curtis 2000; Pope et al. 2000; Webster, Reeder, and Reynolds 2000). Major desiccation (especially if exacerbated by human-induced environmental alteration) could lead to any number of possible environmental changes—for example, increased fire, and thus increased soil erosion and sedimentation, or increased soil shrink-swell. Increased aridity may have other complex responses, however, if accompanied by other meteorological changes such as more intense, but less frequent, precipitation.

SOILS

The region's soils have been investigated in a variety of geomorphic positions over various catenas (toposequences) and landscapes since 1992, although there have been few soil studies in this region upon which to build (see also Coultas, Hsieh, and Post 1998; Reeder, Brady, and Webster 1998; Fedick 1995). Soils range from depression Histosols and Vertisols through upland Mollisols, Inceptisols, and Alfisols. Most of the unsaturated soils on uplands and some fans are Rendolls, in the Lithic and Vertic subgroups respectively.

According to government soil surveys (King et al. 1992, 221), the Yaxa soil suite covers most of this region[8]. These are well-drained to poorly drained clays that formed on Cretaceous to Early Tertiary period limestone. Yaxa and other regional soils, largely phyllosilicate clays, have formed mostly in place from impurities in the limestones, including chert nodules. Yaxa is composed of five subsuites, three of which occur in this region: Yalbac, Jolja, and Irish Creek[9]. Yalbac are generally fertile upland soils, although they are not well endowed with phosphorus (P) and potassium (K), and their major limitations are thinness and erodibility, especially to gully formation

(King et al.1992, 224). One other limitation in these smectitic or vermiculitic soils is profile inversion and cracking, which is uncommon under forests but common in intensively-farmed areas (King et al.1992, 223).

King et al. (1992, 223–225) describe a topographic- and drainage-based four-part subdivision of the Yalbac Suite: (1) the shallow soils (generally thinner than 60 cm) are probably Lithic Rendolls or Eutropepts in the USDA taxonomy (Rendzic Leptosols in the FAO/UNESCO taxonomy);[10] (2) the modal soils (50–90 cm deep) are Vertic Rendolls and Eutropepts (or Vertic Cambisols), (3) the deep unmottled soils are Vertisols and Vertic Rendolls, and (4) the deep-mottled soils are probably Vertisols. The deeper soils that form in karst depressions also tend to have saprolite (sascab) parent materials (Darch 1981) as well as gypsum crystals in the lower horizons, although we found this only in bajos west of La Milpa. Beach (1998b) described a catena of soils similar to these in the Pasion Region of Guatemala's Petén with the same sequences occurring across the crest, shoulder, back, footslope, and depression.

The Irish Creek subsuite is a Tropopept (USDA taxonomy) of the wetland margins. The dominant feature of these deep soils is their redoximorphic gray and reddish mottles. These clay soils have some sand lenses, gypsum crystals, and iron (Fe) and manganese (Mn) concentrations, and were formed from the slopewash of upland calcareous clays in conditions of impeded drainage (King et al.1992, 229). Ford and Fedick (1988) considered these soils along Irish Creek to be the site of ancient Maya wetland fields, but currently the poor drainage and modest fertility make them undesirable (King et al. 1992, 230).

The Vertisols and other soils analyzed here are located in karst depresssions on escarpment horsts and floodplain grabens. Vertisols are said to be the easiest to identify soils because of their obvious diagnostic features: gilgai, or hogwallow topography; surface cracks; slickensides (i.e., active planes of shear), or smooth, shiny, often grooved, black surfaces; and wedged-shaped soil structures called sphenoids. These Vertic properties in soils are formed by shrink-swell processes related to high clay content (usually greater than 30 percent), large amounts of the fine clay fraction, and high fractions of 2:1 or 2:2 clays (especially smectites), although some are high in kaolinite (a 1:1 clay) (Coulombe, Wilding, and Dixon 1996; Eswaran et al. 1999). These factors lead to swelling with hydration and shrinking with dehydration; maximum Vertic properties occur with intense dry and wet seasonality. They occur in solutional karst sinks, throughout rejolladas and floodplains (drained most of the year), and on the margins of aguadas (saturated most of the year). The latter depressions commonly have Histosols in the most saturated areas, but Vertisols on the margins where sediment deposition and weathering have been sufficient to form soils 1 to 2 m in thickness.

METHODS

From 1992 to 1998, we studied depression and upland soils, in relation to geoarchaeology and paleoecology, in more than 30 trenches and pits around the Three Rivers Region (Dunning and Beach 2000; Dunning et al. 2000). All the sites occur around the major archaeological sites of La Milpa, and all have been largely undisturbed since the ancient Maya period. Soil pits of 1 m x 2 m up to 20 m were excavated by pick and shovel, or backhoe, usually down to bedrock. These were all level, very slowly draining sites that showed no evidence of erosion. In each pit and trench, we analyzed all exposed sides for soil morphology and formation processes and collected evidence about their chronology of formation. We carefully screened all the excavated material for artifacts that could provide chronological information about soil development, and we analyzed soil following standard methods for description and sampling (Soil Survey Staff 1996; 1998).

Morphology, color, texture, structure, HCl reaction, and other features were observed and described based on the Soil Survey Manual (Soil Survey Staff 1998). The University of Wisconsin-Milwaukee Physical Geography and Soils Lab analyzed pH; exchangeable cation concentration in calcium (Ca2+), magnesium (Mg2+), sodium (Na+), and potassium (K+) cations by atomic absorption; particle size by the pipette method; base saturation; estimated cation exchange capacity (CEC) from exchangeable cations by the CEC method; organic carbon (O.C.) (Walkley-Black); and DTPA–extractable zinc (Zn) (Soil Survey Staff 1996) (Tables 8.1 and 8.2). They also analyzed phosphorus (P) through fractionation into three subsets (Table 8.3), and clay mineralogy through X-ray diffraction.

The Beta Analytic Laboratory also dated samples by standard and accelerated mass spectroscopy radiocarbon analyses and measured carbon isotopes (Table 8.4). Little charcoal was found throughout this region, and radiocarbon samples were mainly bulk soil carbon samples collected from the top of buried A horizons. Because such samples can give mainly the mean residency time of the carbon in the paleosols, these samples can only represent minimal dates (Birkland 1998, 138; Wang, Amundson, and Trumbore 1996; Smith and McFaul 1997). We attempted to sample to minimize the humate dates (14C from soil organic matter; see Matthews 1985, 282) samples from the top 5 cm of buried A horizons. All soils were formed in the Holocene; moreover, most have some artifacts that provide another date (albeit broad) for comparison.

TABLE 8.1. Soil Textures: Pipette particle size analyses in percent (%). Numbers to the particles class (in µm [micrometers]).All samples fall within the clay texture class.

Site No. of Horizons	Sand > 50:	Co. Silt 50–20:	Med. Silt 20–5:	Fine Silt 5–2:	Co. Clay 2–1:	Fine Clay < 1 :
D05 A	10.1	13.8	10.9	7.8	3.1	54.4
D05 Ab2	11.2	11.1	2.3	0.8	0.8	73.8
D05 C1	4.9	11.2	0.8	0.8	1.6	80.8
D06 Ab1	7.9	14.4	6.2	4.7	0.8	66
BH9-2 AC	6.4	5.7	13.6	8.6	6.5	59.2
BH9-4 C	6.8	1.7	7.5	6.8	3.3	74.1
BH9-5a Ab	6.9	3.9	8.5	7.3	5.7	67.6
BH9-6Cb	6.8	3.4	9.4	8.2	6.7	65.4
RB2-10a-A	0.5	3.0	2.2	0.5	3.6	90.2
RB2-10a-Ab	6.4	10.4	8.4	3.9	6.9	64.0
RB59-2-1-A	4.8	5.5	5.1	4.7	4.0	75.9
RB59-2-1-AC	13.2	6.1	6.1	2.6	0.4	71.6
RB59-2-1-Ab	6.6	8.1	5.8	0	1.4	78.1
RB25V-A	4.8	2.6	6.5	5.2	1.0	79.9
RB25V- C	6.3	4.0	5.7	4.1	0	79.9
RB25V-Ab	8.9	3.4	5.7	3.3	1.1	77.6
RB2-9DAC	2.9	3.4	5.3	4.3	1.8	82.3
RB2-9DAb	6.0	4.6	7.6	4.6	3.8	73.4
RB25D9AC	12.1	5.7	9.4	5.6	0.6	66.6
RB25D9C	8.3	5.3	7.5	3.5	1.1	74.3
RB25D9Ab	3.9	0.5	12	10.5	9.8	63.3
RB25D9Cb	8.0	10.2	3.5	0.8	1.4	76.1

TABLE 8.2. Soil chemical characteristics

Sample Horizon	O.C. % WB	pH	SO4 $^{2-}$ mg/kg	Mg $^{2+}$ mg/kg	Ca $^{2+}$ mg/kg	Na $^{+}$ mg/kg	ex. K $^{+}$ mg/kg	Zn $^{2+}$ (DTPA) mg/kg	CEC meq/ 100g	BS %	N
TBVA2	1.82	6.8	–	2412	8198	72	86	–	113	–	–
TBVAB	0.64	6.7	–	2861	7216	86	62	–	117	–	–
La Milpa Drainage 1: RB25											
D05A	2.74	7.5	–	4410	8369	75	43	–	140	–	–
D05Ab2	0.78	7.6	–	6039	8900	93	62	–	184	–	–
D052C1	0.37	7.7	–	5819	7534	87	59	–	170	–	–
D06Ab1	0.78	7.7	–	3331	7338	161	86	–	125	–	–
La Milpa Drainage 1: D09											
D16 u 4 AC	1.25	8.0	–	2398	11361	99	79	0.000	146	97.7	0.09
D17 u 5 C	0.27	8.4	–	3125	9017	107	72	0.000	141	97.6	0.04
D18 u 6 Ab	0.96	8.3	91	5208	5829	394	79	0.000	140	99.1	0.06
D19 u 7 Cb	0.18	8.3	–	4942	3996	288	102	0.000	122	98.7	0.04
La Milpa Aguada: RB25V											
D7 11 A	1.97	6.1	178	1618	8118	87	67	0.001	100	97.3	0.17
D8 60 C	0.85	7.8	–	1464	10649	85	65	0.000	127	97.3	0.03
D9 100 Ab	0.86	7.9	90	1375	11470	89	75	0.000	133	97.4	0.08
La Milpa Far West Bajo: Drainage 3											
BH9 A2	6.6	5.8	–	940	6416	83	114	2	68	97.1	0.33

Sample Horizon	O.C. % WB	pH	$SO4^{2-}$ mg/kg	Mg^{2+} mg/kg	Ca^{2+} mg/kg	Na^{+} mg/kg	ex. K^{+} mg/kg	Zn^{2+} (DTPA) mg/kg	CEC meq/ 100g	BS %	N
BH9 C	1.79	4.5	–	1155	5952	314	27	0.2	75	98.8	0.02
BH9 Ab1	1.94	5.0	–	1450	6874	857	23	0.1	89	99.5	0.01
BH9 Ab2	8.3	7.6	–	–	–	–	–	–	–	–	–
BH9 Cb	0.96	7.11	–	1290	6342	988	49	0	83	99.5	0.01
Dos Hombres Settlement Survey Floodplain: RB2op10a											
D125-30 AC	1.25	6.9	190	2894	11094	175	49	0.000	151	98.4	0.09
D2 91-97 Ab	1.22	8.0	582	3798	9200	534	25	0.000	147	99.3	0.05
Sierra de Agua: RB59op2-1											
D3 10-13 A	3.29	6.2	–	2064	9204	117	70	0.001	110	97.9	0.33
D4 20-24 A2		–	495								
D545-48 C	0.87	7.9	–	1599	10043	79	86	0.000	123	97.2	0.05
D6 79-82 Ab	1.10	6.1	253	1889	11828	86	125	0.000	143	97.5	0.04
Dos Hombres Settlement Survey Aguada: RB59op2-1:											
D11 U 2 AC	0.35	5.6	134	1421	7535	221	40	0.001	98	98.4	0.01
D12 116 C	–	–	258								
D13 129 Ab	0.08	5.5	261	1594	7062	634	48	0.001	97	99.3	0.00
Barba Terrace: Rb52op3a:											
D22 50 Ab	4.55	7.7	–	3018	11358	90	74	0.000	135	98.0	0.44

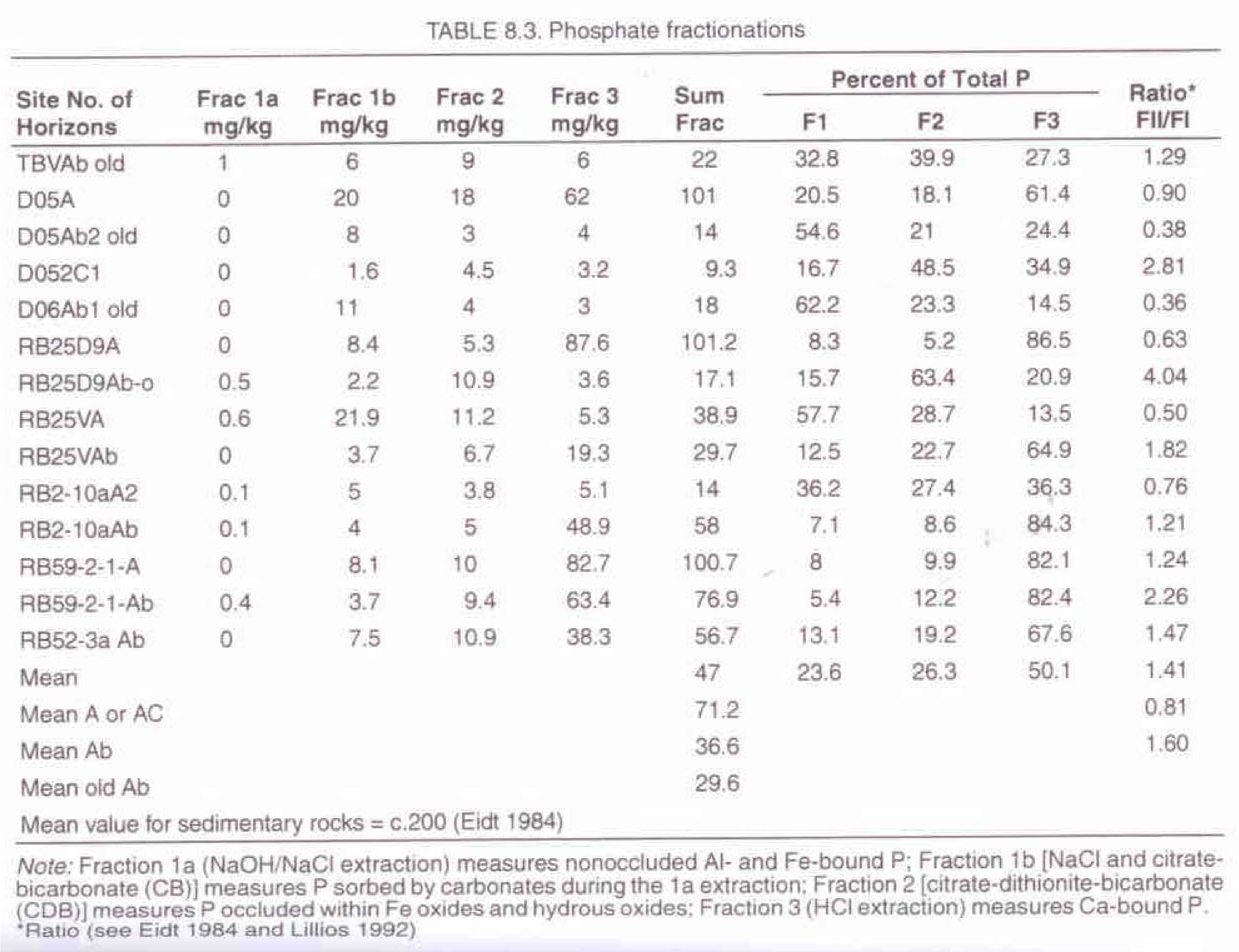

TABLE 8.3. Phosphate fractionations

Site No. of Horizons	Frac 1a mg/kg	Frac 1b mg/kg	Frac 2 mg/kg	Frac 3 mg/kg	Sum Frac	Percent of Total P F1	Percent of Total P F2	Percent of Total P F3	Ratio* FII/FI
TBVAb old	1	6	9	6	22	32.8	39.9	27.3	1.29
D05A	0	20	18	62	101	20.5	18.1	61.4	0.90
D05Ab2 old	0	8	3	4	14	54.6	21	24.4	0.38
D052C1	0	1.6	4.5	3.2	9.3	16.7	48.5	34.9	2.81
D06Ab1 old	0	11	4	3	18	62.2	23.3	14.5	0.36
RB25D9A	0	8.4	5.3	87.6	101.2	8.3	5.2	86.5	0.63
RB25D9Ab-o	0.5	2.2	10.9	3.6	17.1	15.7	63.4	20.9	4.04
RB25VA	0.6	21.9	11.2	5.3	38.9	57.7	28.7	13.5	0.50
RB25VAb	0	3.7	6.7	19.3	29.7	12.5	22.7	64.9	1.82
RB2-10aA2	0.1	5	3.8	5.1	14	36.2	27.4	36.3	0.76
RB2-10aAb	0.1	4	5	48.9	58	7.1	8.6	84.3	1.21
RB59-2-1-A	0	8.1	10	82.7	100.7	8	9.9	82.1	1.24
RB59-2-1-Ab	0.4	3.7	9.4	63.4	76.9	5.4	12.2	82.4	2.26
RB52-3a Ab	0	7.5	10.9	38.3	56.7	13.1	19.2	67.6	1.47
Mean					47	23.6	26.3	50.1	1.41
Mean A or AC					71.2				0.81
Mean Ab					36.6				1.60
Mean old Ab					29.6				

Mean value for sedimentary rocks = c.200 (Eidt 1984)

Note: Fraction 1a (NaOH/NaCl extraction) measures nonoccluded Al- and Fe-bound P; Fraction 1b [NaCl and citrate-bicarbonate (CB)] measures P sorbed by carbonates during the 1a extraction; Fraction 2 [citrate-dithionite-bicarbonate (CDB)] measures P occluded within Fe oxides and hydrous oxides; Fraction 3 (HCl extraction) measures Ca-bound P.

*Ratio (see Eidt 1984 and Lillios 1992)

TABLE 8.4. Radiocarbon dates in Text (AMS technique except where * appears)

Sample	**Lab #**	**Site**	**Depth cm**	**Soil**	**^{14}C bk Conv B.P.**	**^{13}C/^{12}C Ratio[a]**	**$^{\text{Cal }14}$C 2 ð, 95% P**
Beta-135557	D17	La Milpa D2	62	Ab terrace	1540+/-80 B.P.	-23.5 ‰	365–655 A.D.
Beta-94465	D05	La Milpa D2	130	Ab Vert	3360 +/- 60 B.P.	-22.7 ‰	1745–1450 B.C.
Beta-94770	DO6	La Milpa D2	130	Ab Vert	2990 +/- 70 B.P.	-20.2 ‰	1365–1070 B.C.
Beta-112475	D09-3	La Milpa D2	25–70	Ab Vert	1810 +/- 40 B.P.	-28.5 ‰	120–340 A.D.
Beta-112476	D09-6	La Milpa D2	95–170	Ab Vert	3440 +/- 50 B.P.	-29.2 ‰	1885–1620 B.C.
*Beta-112471	B25pv1 5	La Milpa Aguada	100	Ab Vert	3080 +/- 100 B.P.	-25.0 ‰[b]	3080 +/- 100 B.P.
Beta-135558	V45b-3	La Milpa Res A	105	Ab	2400 +/- 40 B.P.	-19.1‰	755–390 B.C.
Beta-135559	V41a-5	La Milpa Res B	125	Ab	3910 +/- 40 B.P.	-24.7 ‰	2465–2330 B.C.
Beta-118305	Rb25bh 6-3	La Milpa D3	60–80	Ab Fluvial	1640 +/- 70 B.P.	-23.2 ‰	235–555 A.D.
Beta-118306	Rb25bh 6-5	La Milpa D3	120–145	Ab Fluvial	2300 +/- 80 B.P.	-22.8 ‰	760–190 B.C.
Beta-112474	RB25v3 3a-6	La Milpa D3	60–80	Ab Fluvial	2880 +/- 50 B.P.	-31.0 ‰	1200–910 B.C.
Beta-135563	BH1-4	La Milpa D3	80	Ab Fluvial	2270+/-80 B.P.	-22.4 ‰	500–155 B.C.
Beta-135562	BH1-6	La Milpa D3	175	Ab bajo	7470+/-40 B.P.	-24.1 ‰	6420–6235 B.C.
Beta-121443	BH9-5b	La Milpa D3	50–90	Ab Vert	1840+/-40 B.P.	-18.3 ‰	A.D. 15–110
Beta-135564	BH12-9	La Milpa D3	180	Ab Vert	2140+/-40 B.P.	-20.8 ‰	355–55 B.C.
Beta-135556	RB2-8a36.8	Dos Hmbrs Plaza	400	Ab	2130 +/- 40 B.P.	-21.4 ‰	350–50B.C.

TABLE 8.4 (*continued*)

Sample	Lab #	Site	Depth cm	Soil	^{14}C bk Conv B.P.	^{13}C/^{12}C Ratio[a]	Cal ^{14}C 2 ð, 95% P
*Beta-112469	RB2-10A	Dos Hmbrs Fluvial	100	Ab	2000 +/- 100 B.P.	-25.0 ‰[b]	B.C.205–A.D.240
Beta-135555	RB2-21a	Dos Hmbrs Aguada	91–97	AB Vert	1890 +/-140 B.P.	-19.8 ‰	195B.C.–430A.D.
*Beta-112470	RB59O p2-1	Sierra de Agua	80	AB fluvial	3020 +/- 100 B.P.	-25.0 ‰[b]	1490–940 B.C.

[a] Difference in quantity of ^{13}C and ^{12}C is reported in units of ^{13}C relative to the usual standard.

*[b] Ratios estimated

SOIL FINDINGS: PHYSICAL AND CHEMICAL CHARACTERISTICS

Bajo soils on the upland ridges occur in several types of sinkholes or human-made depressions. The natural sinkholes are either seasonally inundated with water or freely draining, but both landscape positions are depositional and contain the deepest soils in this region. Bajo Vertisols occur within rejolladas or freely-drained dolines. In these locations, soils develop both by weathering of the parent material and deposition of eroded soil, producing a mean depth of around 150 cm. Soils studied in the lowest parts of aguadas, which are seasonally saturated dolines, are clayey Histosols with around 2 m of soil depth.

The typical soils of this region are chiefly clay in texture, ranging from 57.5 to 93.8 percent clay (see Table 8.1). Much of the region's limestone is high in calcite, and little residual mineral grains remains after dissolution, but the trace minerals from the limestone and aerial deposition with high carbonate concentrations form the dominantly silicate clay soils (Beach 1998a). Soil organic carbon ranges from high levels in the thin regional O horizons that cover undisturbed environments, to moderate levels (1.25 to 6.6 percent) in A horizons, and low levels in deeper horizons—except for buried, former surface soils (Ab horizons) that range widely (< 1 to 8.3 percent) (see Table 8.2).

Soil pH is generally neutral to moderately alkaline in upland soils (7.2–8.4) because of basic parent material, but can be basic or acidic in depression soils (4.5–8.3) depending upon the source of vegetation that goes into forming organic matter. Two seasonally inundated sites, BH9 and RB2-9D, had acidic conditions throughout their upper soil profiles.

Sulfate ($SO4^2$-) is often high (up to 582 mg kg^{-1}) with common gypsum ($CaSO_4$•2H2O) crystals in the region's depression soils, as are magnesium (Mg^2+) (ranging from 940–6,039 mg kg^{-1}) and calcium (Ca^2+) (ranging from 3,996–11,828 mg kg-1) in most regional soils due to the carbonate parent materials. Zinc (Zn^2+) is always low (very nearly 0 mg kg^{-1} in all but one case) in these parent materials and the regional soils, and sodium (Na+) can be high (up to 988 mg kg^{-1}) depending on local impurities in the parent material. Most upland soils are generally fertile, however, with high cation exchange capacity (68–184 meq/100 g), base saturation (nearly 100 percent), and the previously mentioned cations. In topsoils, nitrogen (N) is high (0.33–0.44 percent) and C:N ratios (9.3–11.9) conducive to plant uptake where organic matter is high. Farmers would have three major limitations here, though: (1) maintaining enough phosphorus and nitrogen to sustain crop yields after organic matter decomposes, (2) maintaining enough soil depth on these skeletal and erodible slopes for plant rooting and soil water storage through the dry season, and (3) managing high shrink-swell activity and poor drainage on the deforested, depression Vertisols (King et al. 1992, 223–224; cf Beach 1998a).

The 14 phosphate fractionation analyses show that phosphorus (P) is low throughout these soils (mean = 47 mg kg^{-1}), ranging from only 9.3 to 101 mg•kg^{-1} in the summary of all fractions. To begin with, the limestone parent material is low in P, as shown in the one sample from a near bedrock C horizon with the lowest summary of P fractions of 9.3 mg kg^{-1} (see Table 8.3). The mean is far lower than means of 538.9 and 233.5 mg kg^{-1} found in the northern Yucatán Peninsula (Beach 1998b). As in many calcium-rich soils, Fraction 3, which measures Ca-bound P, was the highest fraction—averaging about 50 percent of all measured P. The next large difference lies between A horizons and the Ab horizons or paleosols in this environment. The Ab horizons have been buried and removed from recycling of P and are thus depleted in P, having only half the quantity of the A horizons. The buried soils are especially depleted in the available Fraction 1, and thus have higher ratios of Fraction 2 to Fraction 1 (mean = 1.6:1) compared with the A horizons (mean = 0.8:1) (see Table 8.3). Fraction 2 measures P occluded within iron (Fe) and hydrous oxides, and several scholars have used it to suggest ancient P enrichment from fertilizers (Eidt 1984; Lillios 1992; Beach 1998b). The elevated Fraction 2 to Fraction 1 ratios may provide evidence for this because these show that, in Ab vs. A horizons, Fraction 2 remains at a higher ratio to fraction 1 in all but one of the paired results. Because no historical evidence exists for fertilization that would have increased P Fraction 2, it is possible these heightened levels are linked to ancient intensive fertilization. We think most of these sites in the bajos were agricultural, and the P fractionations do not contradict this hypothesis.

X-ray diffraction of 10 soil samples by University of Wisconsin-Milwaukee Physical Geography and Soils Lab has provided evidence on clay mineralogy. The general findings from these analyses indicated four major peaks: (1) the air dry peak occurred in the low 2-theta region of 14.7 to 15.6 Å (angstroms), which expands somewhat with glycolation; (2) a broad but small peak in the 16–20 2-theta region; (3) a peak in the 12–13 2-theta region of 7.1–7.3 Å; and (4) a peak in the 24–25 2-theta region of 3.5–3.6 Å. These patterns to indicate randomly interstratified chlorite/smectite, with smaller amounts of smectite and vermiculite. A significant peak of calcite, and lesser ones of gypsum and quartz, occured in some samples. The clay fraction is largely composed of 2:1 clays, but types that have much less expansion and contraction than does smectite. Nevertheless, the study area soils are fine clays with high specific surface area, which can still have substantial shrink-swell potential (Coulombe, Wilding, and Dixon 1996).

SOIL EXCAVATIONS AROUND LA MILPA

This study focuses on five main sites in northwestern Belize. These sites include a soil catena running from the backslope into the depression at La Milpa Drainage 1 and 2, a group of depression soils in La Milpa Drainage 3, alluvial soils in the Rio Bravo floodplain and in the Irish Creek floodplain near Sierra de Agua, and depression soils in an aguada near Dos Hombres.

We based the soil catena at La Milpa Drainage 2 on 15 soil pits to bedrock running from the backslopes, through footslopes and toeslopes, toward the center of the bajo (Figura 8.2). Crests and backslopes have thin Rendoll soils similar to those described in the Petén (cf Beach 1998a). Backslopes generally have 15 to 50 cm of O-A-AC horizons on shallow slopes of 5 to10 degrees. The only deeper backslope soils we observed lie behind ancient Maya terrace walls. Backslope soils merge into footslope and alluvial fan soils on the edge of seasonally inundated depressions. Footslopes and fans have much deeper soils, gravel layers, and rudimentary slickensides.

Some of these soils have overthickened, cumulic A horizons (O-A1-A2-A3-C), but in La Milpa Drainage 2 the two fan soils have distinct buried paleosols (Figure 8.2: Op D5 and Op D8). The upper fan soil had the following sequence: O horizon from the surface to about 2 cm; A1 and A2 horizons that are black to very dark gray and reach down to 25 cm; AB horizon that is very dark gray, with 40–60 percent limestone gravel that reaches down to 45 cm; C1 and C2 horizons that are yellowish brown and

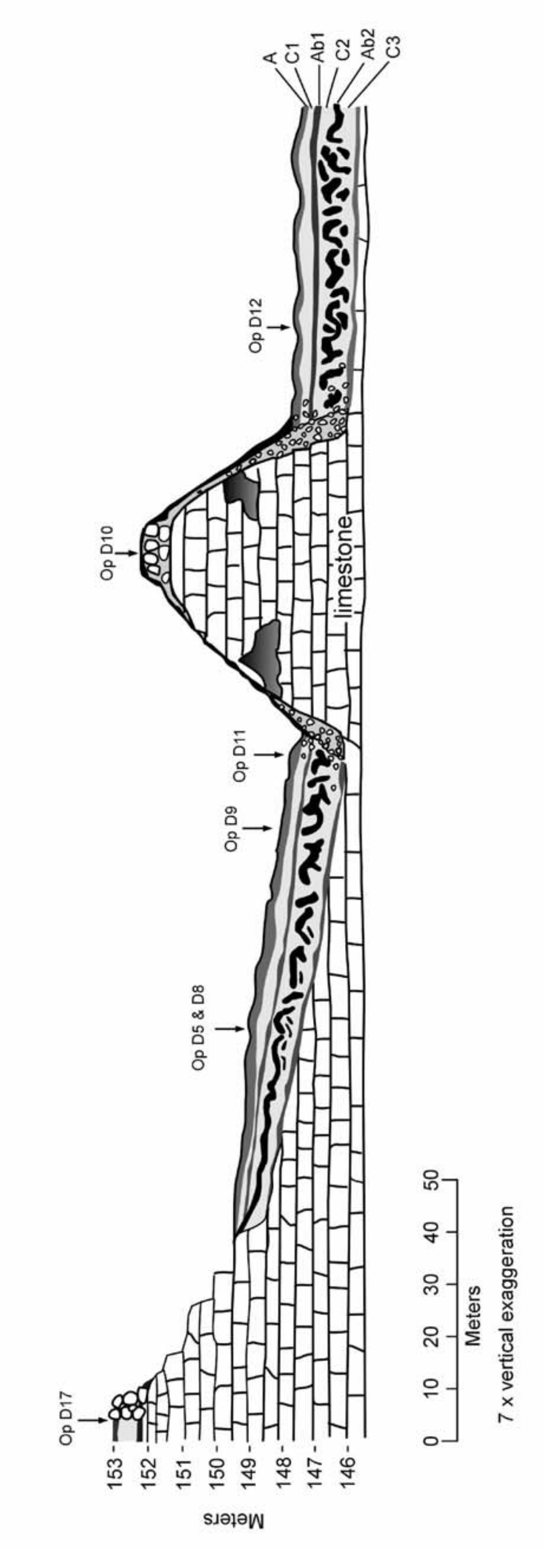

FIGURE.8. 2. Idealized cross section of La Milpa bajos. The arrows refer to site operations at La Milpa Drainage 1; the letters (A, C1, Ab1, C2, Ab2, C3) represent the sequence of soil horizons. (Note: Not all excavation units are shown.)

reach down to 77 cm; Ab horizons (Abss1 and Abss2) from 70 to 140 cm that are black and overlie additional C horizons (2C1 and 2C2) and weathered limestone down to about 150 cm (Figure 8.3).[11] This sequence has a low, almost flat gradient in the upper O through C1 horizons, but all the horizons below C2 are moderately deformed into a wavy pattern with incipient slickensides. Soil textures do not vary by different horizons except for the prominent gravel layers in the AC horizons.

The excavations that go farther into the bajo (D6, D8, D9, D11, D12) show a similar pattern of horizontal soil layers in the top 0–45 cm, but the underlying paleosols (Ab horizons) that also range down to 150 cm are deformed to the point of being broken apart. Each of the excavations reveal a similar arrangement of soil horizons. These paleosols, informally called "tiger Vertisols," are deformed so much that segments have black A horizons and yellowish brown C horizons that run vertically and diagonally (see

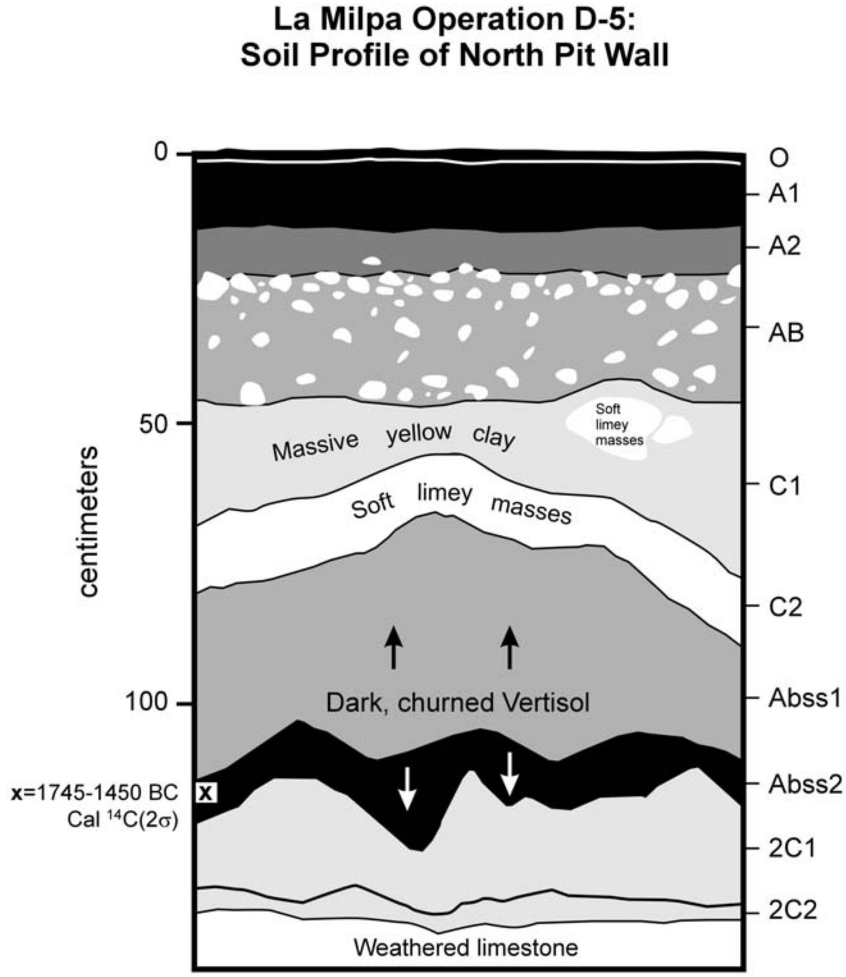

FIGURE 8.3. Soil profile of Operation D5 (Op D5) in the alluvial fan of the bajo of La Milpa Drainage 1. The soil profile is of the north pit wall.

Figure 8.4 for Op D6 [Corozal Bajo] and Figure 8.5 for Op D9 [La Milpa]). Despite the deformed lower soil horizons, the upper soil horizons remain horizontal over the 130-m distance in the five excavations (except the hillock separating D11 by 60 m from D12). Because the buried soils exhibit well-defined horizons (albeit massively deformed), they must have formed horizontally as A, B, and C horizons at some time and been deformed thereafter.

One of the excavations (D11) was placed at the edge of a bedrock outcrop, over what surficially appeared to be a channel, in order to investigate this transition from limestone outcrop to bajo. The excavation showed a 35 cm sequence of the same top three soil horizons (O-A-AC) overlying a 1 m deep gravel- and cobble-filled channel covered by boulder and larger cobble. Next to the channel, toward the bajo, the excavation showed a transition toward the same bajo sequence described above, with up to 1 m of horizontal fill over a distorted paleosol. The excavation suggests the following relative dating sequence: (1) a natural channel transitioning into a flat, upland soil; (2) mass wasting from the hillslope onto the channel and bajo; and (3) low-energy deposition over the channel and bajo.

Dating this sequence precisely is more difficult. We have only the relative dating suggested above, broadly datable artifactual material, and five radiocarbon dates from bulk carbon sources are available. Curiously, no charcoal for dating these excavations was found, and so relied on soil organic carbon was used. As the five radiocarbon samples can provide only mean residency time (MRT) dates on these two shallow paleosols and three deep paleosols, we consider these dates to be minimal ages.

The first paleosol (i.e., the excavation associated with Op D17) lies in the arroyo, approximately one hundred meters upstream from the bajo, and is buried 62 cm deep behind an ancient Maya cross-channel terrace (Scarborough et al. 1995). The paleosol yields a calibrated AMS date of A.D. 365 to 655 (95 percent probability), while ceramic evidence dates the soil surface to before the Late Classic (A.D. 600–900) (Beach et al n.d.). Operation D9 also yields an AMS date from 60 cm in an upper-buried soil that dates to A.D. 120–340 (95 percent probability), with ceramics dominantly Late Classic in age (Figure 8.5). These two radiocarbon dates give about the same age-buried soils from before the Late Preclassic and Classic (A.D. 250–900), with the top 60 a 62 cm of sediments depositing during or after the Classic. The archaeological evidence shows an abrupt collapse of the Maya at La Milpa by A.D. 850 and little human-induced environmental change thereafter (Hammond et al 1998).

The deeper-buried soils are all Vertisol paleosols buried from about 100 to 150 cm deep at D5, D6, and D9 and date to 1745 to 1450 B.C., 1365 to 1070 B.C., and 1885–1620 B.C. (calibrated AMS, 95 percent probability), respectively; therefore, these paleosols are from the Early Preclassic (1500–

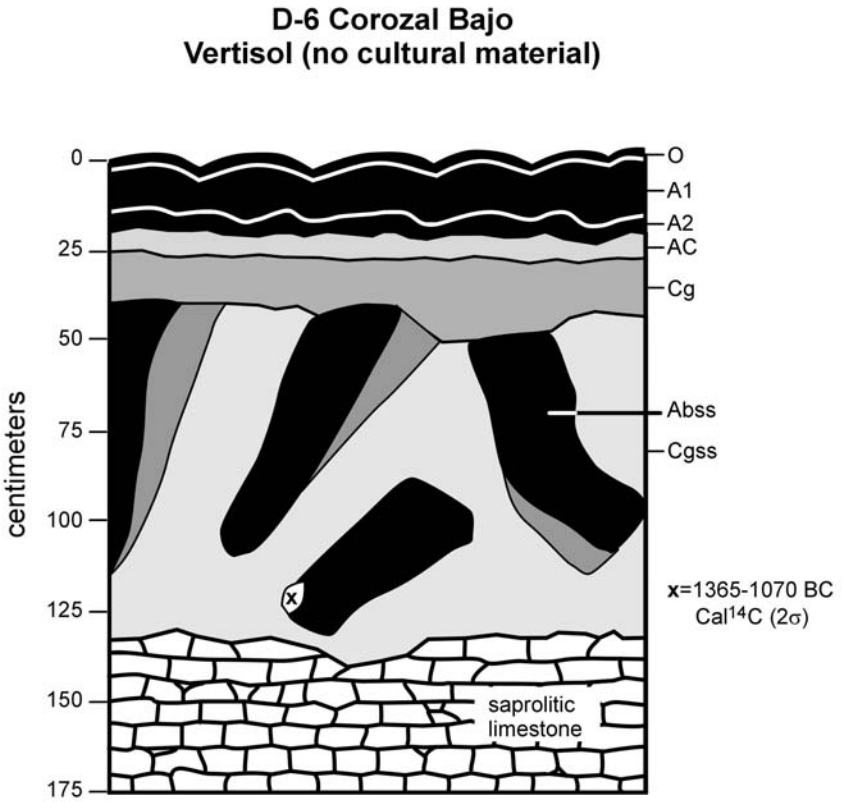

FIGURE 8.4. Soil profile of Operation D6 (Op D6) in Corozal Bajo near the mouth of La Milpa Drainage 2. The deeper-buried soils are all vertisol paleosols with no cultural artifacts found.

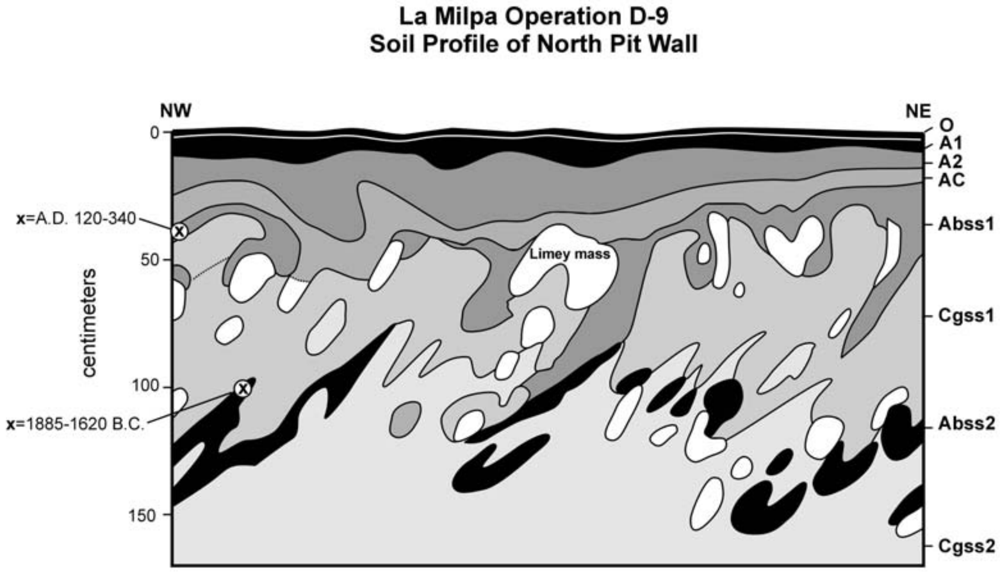

FIGURE 8.5. Soil profile of operation D9 (Op D9) in La Milpa Drainage 1. The soil profile is of the north pit wall.

900 B.C.), or earlier. We found no ceramic material in these deep layers; ceramics only reach down to about one meter. These paleosols appear to represent the pre-Maya mid- to late-Holocene soil surface because these MRT radiocarbon dates are consistently early, and the region's first archaeological evidence dates to the Middle Preclassic (900–400 B.C.) (Dunning et al. 1999).

A series of trenches from La Milpa Drainage 3 into the Far West Bajo were also excavated. These excavations sampled a sequence of geomorphic surfaces ranging from the floodplain of Drainage 3 to the fan delta of BH1 and BH6, as well as the open bajo at BH9 and BH12. The 6 m long excavation at V33a ran across the channel and floodplain of Drainage 3, revealing a complex fluvial sequence (Dunning et al., in press). The floodplain showed a Rendoll soil formed in the top 60–70 cm with A1, A2, AC, and C horizons overlying a Rendoll paleosol, and Ab, Bw, and C horizons over limestone. One calibrated AMS date of 1200–910 B.C. (95 percent probability) from the paleosol corresponds with the Early Preclassic dates of the deeper paleosols in Drainage 1. Channel and floodplain deposits above the paleosol show aggradation with evidence for at least one high-energy event and subsequent low-energy overbank deposition. The sediments above the paleosol had mostly unidentifiable or Late Classic ceramics.

Downstream, the channel disappears onto the bajo, and here 12 trenches were made through these sediments. This sequence of trenches shows a similar pattern to Figure 8.2 without the bedrock outlier of La Milpa Drainage 1. BH1 was particularly important not only because it ranged from the edge to 9 m into the bajo, but also because it yielded two paleosols. The A1, A2, and AC horizons formed in the top 60 cm of aggraded clay on top of an anthropogenically-disturbed paleosol that was created in 100 to 120 cm of aggraded clay, which, in turn, settled above a paleosol that is 130 to150 cm deep. The topsoils are horizontal in the top 40 to 60 cm across the whole trench, but the upper paleosol ranges from horizontal at the bajo margin to a highly-deformed Vertisol with strongly developed slickensides from 4 to 9 m into the bajo. This upper paleosol has Abss, ACbss horizons, and zones of boulders, cobbles, and ceramics that may indicate human attempts to manipulate this soil, or occasional large magnitude floods. The lower paleosol, formed in the bottom 30 to 40 cm of the trench, has simple horizontal A1ss, BW, and C horizons. Radiocarbon analyses from these two layers yielded dates of 500 to 150 B.C. in the upper paleosol and 6420 to 6235 B.C. in the lower paleosol (calibrated AMS, 95 percent probability). Again, because these dates represent MRT, the dates are minimal; hence, the first date come from the Late Preclassic or earlier, and the second represents the Early Holocene or before.

The trenches at BH6, BH9, and BH12 also yielded upper and lower paleosols. BH6 runs through a fan delta with evidence of higher-energy sedimentation overlying the lower paleosol. The 5 m long trench at BH6 showed a largely horizontal topsoil sequence of A1, A2, A3, BW, and C horizons overlying a paleosol at 125 cm, with a similar sequence of Ab, ACb, and Cbss horizons. The upper A3 horizon was also a faint paleosol buried around 60 cm. Radiocarbon analyses from the two buried A horizons yielded minimal dates of A.D. 235–555 in the upper paleosol and 760 to 190 B.C. in the lower paleosol (calibrated AMS, 95 percent probability).

The 5 to 14 m long trenches at BH9 through BH12 show both horizontal and highly-deformed segments of the bajo, and all have both horizontal upper 30 to 40 cm layers and paleosols buried at approximately 1 m in depth. Radiocarbon analyses from two paleosols yielded dates of A.D. 15 to 110 in BH6 and 355 to 55 B.C. in BH12 (calibrated AMS, 95 percent probability). The BH9 paleosol is a thin Saprist (muck) layer that also contained a pollen assemblage indicative of a perennial wetland, whereas the BH12 paleosol is well-drained upland Rendoll (Dunning et al. 2000). The BH9 sample had visible leaf matter deposited over a short time period; thus, its radiocarbon date is more accurate.

Two lines of evidence from these trenches seem to point to rapid aggradation in parts of the environment—that, the BH9 trench has a buried organic soil at a depth of 120 cm, and BH10 has discernable laminations in the C horizon. Under the conditions of the current topsoil, organic carbon is high at this site (6.6%), but not as high as the buried muck (c. 20 percent); organic matter should decompose quickly if not rapidly buried and rendered anaerobic. Laminations also are very rare in this environment because bioturbation near the surface should expunge them if not buried quickly.

ALLUVIAL LOWLANDS: DOS HOMBRES AND SIERRA DE AGUA SURVEYS

A number of excavations were made to below 2 m deep, as well as to bedrock or saprolite (sascab) across the lowlands of Dos Hombres and Sierra de Agua (see Figure 8.1). Our survey ranged across the escarpment to the wet, active floodplain; to broken karst ridges; to upland bajos; to transitional uplands; and to an aguada. As with La Milpa Drainage 2 on the La Lucha escarpment, the cross-channel terraces on the Rio Bravo escarpment, were excavated, which also dated to the Late Classic (Beach et al. 2000). The soils ranged from thin, well-drained Rendolls to deep, waterlogged Inceptisols; to deep fluvial Mollisols; and to Vertisols.

Across all of these ecozones, soil pits were excavated—including four pits in the Rio Bravo floodplain at an elevation of approximately 20 meters. Two of the pits showed continuous clay alluvium from overbank flooding in the top 2 m, but two other pits had paleosols buried at 91 and 190 cm. Only the shallower buried soil was tested. This site (RB10a—1,350 m west of Dos Hombres) in the Rio Bravo floodplain had a fluvial Inceptisol at the surface with a strongly-developed paleosol buried at about 90 cm deep (Figure 8.6). This is a typical soil sequence of O, A1, A2, AC, and Css horizons to a depth of 85 to 90 cm, which lie on top of the thick paleosol. The paleosol consists of a black (Munsell color: 2.5Y3/0), 25 to 30 cm thick Abss horizon, with rudimentary slickensides that gradually transitions below to a highly mottled, redoximorphic, Cg horizon, which extends down to over 2 m in depth. A radiocarbon date (205 B.C.–A.D.240) from the top of the paleosol yields a Late Preclassic date, and we found unidentifiable ceramics throughout the topsoil to the very top of the paleosol were found.

Excavation and coring at the bajo site of Sierra de Agua provide yet another buried soil. Here, excavation to bedrock revealed a well-developed topsoil over the top 74 cm with O, A1, A2, AC, and Css horizons lying on top of a thin paleosol from 74 to 96 cm with Ab, ACb, and Cb horizons formed on

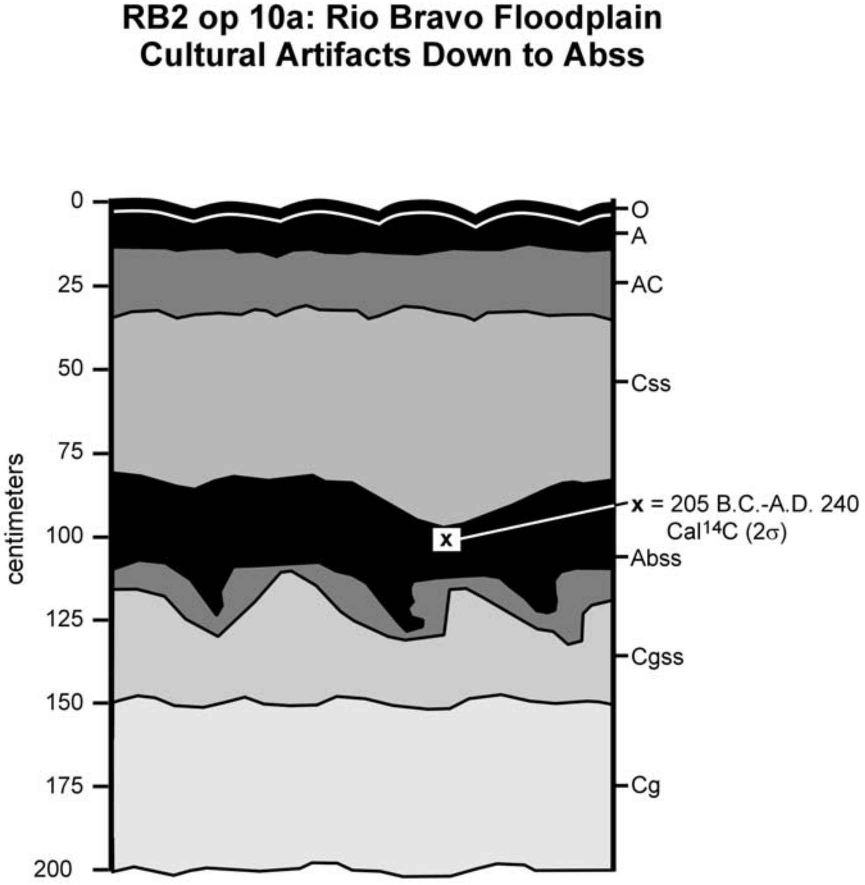

FIGURE 8.6. Soil profile from a Rio Bravo floodplain excavation (RB10a). This is essentially the same profile as a floodplain at Sierra de Agua. Cultural artifacts were found down to the Abss horizon.

channel gravels and bedrock. Ceramics, mostly unidentifiable but with some Late Classic examples, occurred decreasingly downward throughout the topsoil, but the paleosol was free of artifacts. This soil profile was essentially the same as Figure 8.6, although the paleosol is much older here with a radiocarbon date of 1490–940 B.C. (calibrated AMS, 95 percent probability) (see Table 8.4). This paleosol again dates to the Early Preclassic like the lower paleosols at La Milpa, but this one had scant artifactual evidence.

Excavations across the large Rio Bravo graben-lowland showed typical Vertisol soils as in the upland bajos and footslopes with well-developed gilgai topography. The upland ridges and transitions had typical Rendoll soils, and the only paleosol studied throughout this zone was buried under architecture at Dos Hombres. This black Rendoll soil dates to 350–50 B.C. (calibrated AMS, 95 percent probability) and lies beneath Late Preclassic (350 B.C. to A.D. 250) artifacts. This soil again represents the surface the Maya first encountered at this later site and generally correlates with the Rio Bravo floodplain-buried soil.

Two excavations were also made in the far eastern escoba palm aguada on transect B of the Dos Hombres Settlement survey, about 1,500 m east of Dos Hombres. This area lies a short distance east of a densely populated, Late Classic Maya site on a shallow ridge with dry-slope terraces and a possible box terrace (Beach et al. 2000). In the aguada, two excavations showed highly-contorted Vertisol horizons beneath a horizontal topsoil of c. 35 cm (Figure 8.7). Again, the contorted horizons lie unconformably below the topsoil sequence of an O, A, and AC horizon. The buried and folded sequence includes an Abss, ACb, Cgss, and in situ decomposed limestone. One radiocarbon sample from organic sediment in the Ab horizon at c. 95 cm dated to 195 B.C. to A.D. 430 (95 percent probability, 2σ [sigma] level), which is the Late Preclassic to Early Classic. This date is comparable to the two other dates on buried paleosols across these lowlands and to the younger paleosols around La Milpa.

Another line of evidence on this site is the micromorphology of a soil monolith. The analysis found slickensides throughout, as was found in the field. It also described a sterile or acultural base (or Cg horizon) of iron-stained clayey marl, and an increase in organic matter, charcoal, numerous phytoliths, chert, and possibly freshwater sponge spicules in the Ab and ACb horizons. These organic parts of the core may or may not be associated with human activity, The book, therefore, is far from closed on agriculture in this site; because it always has been far above the perennial water table, wetland farming in this site could only have been seasonal. The lack of artifacts in these pits so close to dense habitation, however, does not suggest intensive agriculture. Although this is intriguing culturally, the most parsimonious explanation for soil morphology in this aguada is natural Vertisol and

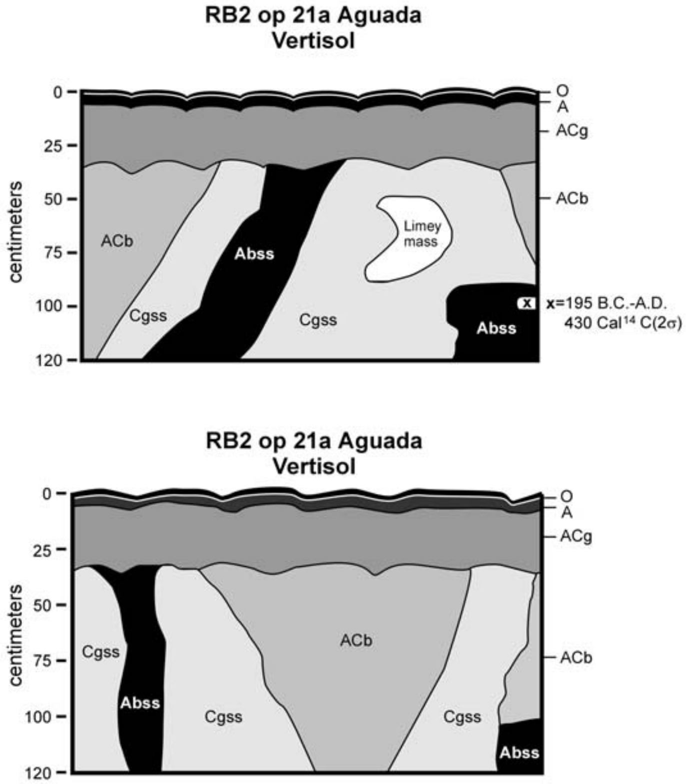

FIGURE 8.7. Two soil profiles (RB21 a) from an aguada located 1,500 m east of Dos Hombres.

geomorphic formation with human-induced aggradation in the Late Classic.

INTERPRETATION: RADIOCARBON DATES

Distinct paleosols (buried A horizon) exist in many different lowland bajo sites and situations around La Milpa. All of the ^{14}C samples from the top 10 cm of the paleosols and organic sediments were obtained. The radiocarbon dates on buried A horizons run into two distinct groups: (1) approximately 50 to 75 cm deep paleosols that have calibrated AMS dates ranging from A.D. 15 to 655, and (2) approximately 95 to 150 cm deep paleosols that generally have calibrated AMS dates from earlier than 1000 B.C. These patterns do not fit such geomorphic situations as floodplains, where paleosols with younger dates are buried deeper, or the 150 cm deep paleosol at BH1 that dates to 6420 to 6235 B.C. All the other paleosols at this depth date to 1000 to 2000 B.C.; thus, this soil may represent localized early sediment burial, or much higher contamination from old carbon.

Most of the buried soils date to the Preclassic or Classic, but these dates represent the mean residence times for carbon in the soils; thus, they represent minimal dates for these soils. The paleosols are not related to the current A horizons because morphology and chemistry are different. Ceramics of either unidentified or Late Classic dates occurred above and through each of the upper buried soils, but no ceramics occur as deep as the lower Ab horizons or in underlying Cg horizons.

Paleosols buried under architecture at the sites of La Milpa and Dos Hombres were also dated for comparison with bajo paleosols. In La Milpa's Plaza B, a Vertisol Abss horizon dates to 805–540 B.C.; in Dos Hombres plaza, an Ab horizon dates to 350 to 50 B.C. (both AMS calibrated, 95 percent probability). Both of these paleosols are buried beneath sites that started in the Middle to Late Preclassic (900 B.C. to A.D. 250) and lie beneath Early Classic (A.D. 250–600) structures. Paleosols under well-dated Late/ Terminal Classic period (A.D. 600–900) terraces date to A.D. 145 to 655. In each of these cases, the AMS radiocarbon dates of the paleosols range from 0 to 1,000 years earlier than the overlying structures. Another independent means of dating paleosols is datable artifacts. Many sherds were found in and through the later paleosols, but none as far down as the early paleosols.

The widespread nature of buried soils in regional lowland sites suggests a period of equilibrium pedogenesis associated with the development of mature topsoils that occurred through, or into the Preclassic. Sometime in the Preclassic or later, this site underwent a period of aggradation, with soils buried by about 60 to 130 cm. Two dates from one soil pit (see Table 8.4: D09) in La Milpa Drainage 1 provide additional information: (1) D09-6 is an Ab horizon buried up to 170 cm and dated at B.C. 1735 (intercept date), and (2) D09-3 is an A3 horizon buried up to 70 cm and dated at A.D. 235 (intercept date). Sometime in the intervening 2000 years, this site aggraded up to one meter; after about A.D. 235, in the Early Classic, the site aggraded again by up to 70 cm (with 40–60 percent pebble to cobble size chert and weathered limestone at this site just downstream from an alluvial fan). Several other sites also show aggradation of 50 to 100 cm sometime during or after the Early Classic.

ENVIRONMENTAL CHANGE AND BAJO AGGRADATION

What changes may have caused the large landscape alteration that inundated bajo soils across this landscape? Geomorphically speaking, either increased erosion from uplands and deposition onto lowlands, or increased deposition or aggradation could have buried soils across this landscape. Increased erosion certainly did occur because of devegetation caused by humans, and was probably accompanied by massive, widespread fire. On the other hand, increased deposition could be engendered by sea-level and thus base-level rise in the region, which could cause stream profiles to rise or aggrade as an adjustment. This occurred north of the study region near sea level (Pope et al. 2000), but this is a highly unlikely scenario as this region is far removed and insulated by greater elevation from likely base-level influences.

The widespread nature of the older paleosols in regional lowland sites suggests a period of steady pedogenesis, with formation of well-developed topsoils through the Holocene to the Preclassic or later; sometime in the Preclassic (or later), some large systemic change caused sedimentation of soils by about 60 to 130 cm. The younger paleosol is not widespread and often occurs with the cumulic A horizon in many depression soils. It is associated with Classic period ceramics, and all evidence dates it to the Classic period—perhaps even to the less human-influenced Early or Middle Classic.

The soils, stratigraphy, and artifacts point to ancient Maya-induced soil erosion as the source of bajo aggradation based on three lines of evidence. First, aggradation in fluvial and karst systems induced by sea-level rise should have been a steadier process that would not have caused one disequilibrium of widespread aggradation in the Late Holocene when sea-level rise was slowing; otherwise, there should be several other older buried soils, rather than the one, very spatially-limited Early Holocene paleosol. Second, the coincidence of a buried soil with the Preclassic when pioneer cultivators first expanded onto hillslopes, and one with the Late Classic when land use was the most intense, is compelling. Third, the dominance of Late Classic or Terminal Classic artifacts in the top aggraded sediments, and those and earlier artifacts down to the old paleosol, shows humans were involved in these soils since the old paleosol.

Moreover, there are many examples in depressions in the southern Maya lowlands of paleosols buried by "Maya Clays" (Dunning, Beach, and Rue 1997). For example, in coastal northern Belize and the Belize River Valley, there are buried surfaces from the Early Preclassic, with Late Classic "Maya Clay" fill of about the same depth as this study region (cf. Jacob 1995b; Pohl et al. 1996; Holley et al. 2000). Evidence in northwestern Belize about these "Maya Clays" has only provided a broad date for the early buried soil surface and a *terminus post quem* date for the period of aggradation. Yet, the less common upper paleosol and pattern of artifacts suggest two episodes of aggradation in the Preclassic through Early Classic and the Late Classic, or later, sandwiching the latter paleosol, which perhaps developed in the Early Classic through Middle Classic. Especially telling here are agricultural terraces choked full of Late Classic ceramics that extend down into the younger paleosols buried under the terraces and on alluvial fans. This indicates a five-part sequence: (1) soil formation into the Preclassic, (2) soil erosion sometime before the Early Classic that buries soils up to 100 cm,

(3) less disturbed soil formation during the Middle Classic, (4) accelerated soil erosion again in the Late Classic, and (5) minimal change during the Postclassic. Even with widespread soil conservation in the Late Classic, soil erosion probably remained high because Late Classic ceramics choke regional deposits and terraces cannot stop all erosion (Beach and Dunning 1995).

HYPOTHESES ABOUT SOIL PROFILE DEFORMATION

Deforming normally horizontal soil layers into diagonally folded patterns by Vertisol processes requires a confining pressure created by a certain depth of overlying soil and the vertical upward force of the swelling pressure, which creates a shearing force (Eswaran et al. 1999). Shearing only occurs below about 60 cm, where the overburden of soil can counterbalance the upward swelling, and only at a critical soil moisture when the soils are plastic. The downward extent that slickensides can form each year is only to the depth of rain infiltration, because these soils must moisten and become plastic. Thus, leaching transports carbonate and gypsum below active slickensides, and calcic and gypsic horizons can form here. These Vertisol properties will vary across a landscape due to environmental gradients. For example, areas of undulating bedrock will place more potential for shearing in the basins because these will limit expansion. Moreover, seasonal wetlands will have less Vertisol-induced deformation near their low points, or other areas where they dry up the least, because such areas have the least contraction (Coulombe, Wilding, and Dixon 1996; Eswaran et al. 1999).

Another related process that can deform horizontal layers is the response of sediment to differential loading, and the formation of diapirs or piercement structures. In this process, clays can squeeze out from areas of greater to lesser overburden and ultimately spread out over the surface, while the overburden sags down into a lower horizon. This may form a sequence of diapirs, or domes of upward extruded clay, across a region. These formations are best known as salt domes that form in deltas of rapid deposition, but few studies have applied these ideas to soil studies (Paton 1974; Paton, Humphreys, and Mitchell 1995:98). The soil morphology uncovered in our trenches do not suggest this pattern of piercement from below—only aggradation from above, and shearing from below. Moreover, all paired radiocarbon dates from lower soils are older than upper soils, suggesting normal superposition.

The influence of tree roots, large earthquakes, and organism digging (bioturbation) can also greatly deform typical soil horizons (Schaetzl et al. 1990; Lutz and Griswold 1939; Saucier 1991). The mass of soil moved by root throws can be very high, and this can significantly alter the surface topography and subsoil in this region (Beach 1998a). Similarly, earthquake-induced sandblows rupture and deform soil horizons; yet, no reports exist for any such events in this region. Moreover, ancient Maya (and animals) digging across this bajo to create wetland or other agricultural fields also could have greatly transformed soil stratigraphy, but a small minority of our excavations show a morphology associated with human and animal bioturbation. The most likely of these deformation agents is root throw, but this process is inadequate to explain the widespread and consistent occurrence of these buried paleosols. Also, the paired radiocarbon dates, as suggested above, do not indicate that younger soils lie below older soils in these examples, although the patterns in the Dos Hombres aguada (see Figure 8.7) and one excavation at La Milpa Drainage 2 (see Figure 8.5) probably suggest some tree root or bioturbation caused soil deformation.

The bajo Vertisols in this study all have a typical horizon sequence in the top three horizons (A-AC-Ab) to 70-cm deep, but have highly distorted melanges of horizons in the lower three or four horizons, which range downward to more than 180 cm. One explanation for this unusual arrangement of horizons suggests disturbance to the lower horizon before the upper unit was deposited. Any explanation, however, must explain several factors: first, the development of normal soil horizons; second, the disturbance of the lower soil horizons; and third, the deposition of the upper unit. Ceramic evidence and radiocarbon dates indicate the following sequence: (1) erosion from upland soils deposited the top 35 to 70 cm of three or four cumulic and occasional buried A horizons, and (2) earlier erosion deposited 40 to 110 cm on the lower widespread paleosol.

The following hypothesis is suggested to explain this soil formation. Up until the Early Preclassic, the bajo soils were 35 to 60 cm thick and formed in limestone saprolite with lesser amounts of allochthonous material. When Maya farmers first became a factor of soil formation in the Early Preclassic, they began to farm these bajos and the slopes around them, which accelerated erosion and the deposition of “Maya Clay.” We think the lower sediment of 40 to 110 cm started the deformation process in the Preclassic or Early Classic by the shearing described above—that is, sediment loading on clays that provided counterbalance mass, which then led to shearing against upward swelling. Deformation may also have been exacerbated by greater extremes in soil moisture with the first anthropogenic burning and deforestation and concomitant root decomposition and krotovina formation. The last 35 to 70 cm of horizontal deposition occurred during and after the Classic Period, which forming weakly-developed topsoils above the lower, deformed sequence. This later episode of erosion and deposition corresponds to urbanization at La Milpa, and may be tied with the building of masses of check dams and diversion channels throughout La Milpa Drainage 2 (see Figure 8.2). The expansion and contraction had little affect on the upper, aggradational unit because rapid reforestation following this site's collapse would have maintained more stable and moister soil conditions.

A changing hydrology in antiquity may have complicated soil formation here. The three best known environmental changes were deforestation, altered water recharge regimes, and the "Maya Drought." It is well known that deforestation would lead to increased runoff and higher water tables in most regions, including the tropics (see Lal 1990:433). Jacob (1995b), for example, writing about Cobweb Swamp, Belize, north of this study area, reasons that because forests transpire huge amounts of moisture, deforestation associated with the first Maya by 3900 14C yr. B.P. may have influenced the rising of water levels in the swamp after 3400 14C yr. B.P. Also, Tindall and Kunkel (1999, 234) state that roots deplete "water at a rate far in excess of that by soil evaporation alone."

Deforestation started here in the Preclassic and continued until the Terminal Classic with periods of forest regrowth, such as occurred during the Middle Classic. The first response to deforestation should, therefore, have been moister soil conditions and less of the clay contraction needed to drive Vertisol formation. But this is a much more complex challenge because we are unsure about how two important variables may have affected soil moisture—that is, ancient Maya deforestation and drainage (see Beach et al. n.d.; Scarborough et al. 1995). Additionally, the rapid accumulation of clay sediments in many depressions may have sealed them from perched aquifers. Such aggradation by clays could have interfered with recharge and discharge, thus altering the soil moisture and wetland ecology of these bajos (Dunning et al. 2002).

Further complicating the enigma is the "Maya Drought" (Hodell, Brenner, and Curtis 2000; Gill 2000). We have no evidence in the study area proper for the Classic Period Maya drought discussed previously, but Pope et al. (2000), working north of the study area in northern Belize, and Webster, Reeder, and Reynolds (2000), working south of the study area in the Vaca Plain in central Belize, both suggest separate lines of evidence for this drought. A period of aridity would clearly induce greater clay contraction, and possibly greater Vertisol development. The drought alone, however, could not explain all of the deformation, because deformation required a greater depth that was supplied by ancient soil erosion and deposition.

Whatever the complicated and poorly-known factors, the soil horizon sequences, ceramics, and radiocarbon dates in these lowland soils indicate the following sequence: (1) equilibrium soil development before and possibly into the Preclassic, (2) disequilibrium conditions in the form of 45 to 110 cm aggradation from the Preclassic to the Early Classic, (3) the start of buried soil deformation with differential sediment loading, (4) a brief episode of equilibrium soil formation in the Early to Middle Classic, (5) a period of erosion and aggradation from the Early Classic through Late Classic, and (6) a Postclassic period of little change.

CONCLUSION

Depression soils in northwestern Belize are diverse, and many are deformed by ancient aggradation. They include a few thin Rendolls formed in the upper 30 cm of bedrock and saprolite, deep fluvial Inceptisols and Rendolls in active floodplains and fans, and deep Vertisols in karst sinks. These soils are dominantly clay in texture, and the clay minerals are randomly interstratified chlorite/smectite, with smaller amounts of smectite and still smaller amounts of vermiculite. Even though the soils exist in seasonally inundated depressions, they generally have low amounts of organic carbon, and are high in CEC, base saturation, and Ca^2+ and Mg^2+ cations. Soil pH ranges from very strongly to moderately acid in moist soils, to slightly to moderately alkaline in most other soils.

The edges of these bajos are surrounded by ancient Maya footslope terraces and diversion networks, and the bajos themselves have a significant number of mounds as well as artifacts scattered through all but the lower paleosol. Thus, the ancient Maya clearly used these bajos in antiquity, even though our phosphate fractionation tests show equivocal evidence for ancient fertilization.

Most of the study's trenches show one or two buried paleosols, especially along the peripheries of depressions, and in floodplains and alluvial fans. One of the paleosols appears to be an anomalous holdover from the Early Holocene, perhaps buried by some rare natural event. The most widespread paleosol lies buried from beneath 70 to 180 cm of sediment, and probably represent the pre-Maya soil surface of the Preclassic or earlier. Above this lies up to 180 cm of aggraded sediment, which we trace to two episodes of erosion. The first episode is an artifact-poor period that we associate with the Preclassic and Early Classic, and ends in an infrequent paleosol or simply artifact-rich strata buried at 50 to 65 cm. We think the first episode of erosion coincides with the Preclassic Maya pioneer farmers moving from the bajos onto the hillslopes, and then using fire to clear forests.

The second paleosol may have formed in the Early to Late Classic, and it is infused with Late Classic to Terminal Classic ceramics from this layer up to the surface. Thus, the second episode of erosion is almost certainly associated with the highest populations and agricultural intensification of the Late Classic, especially after A.D. 700. Both of these paleosols together parallel the "Maya Clays" of many lake cores in the Petén and depressions in Belize that originate about 3,000 years ago and last through the Late Classic through Terminal Classic to the Tenth Century A.D.

The karst depression soils are much more deformed and contorted than the floodplain and fan soils. All such paleo-Vertisols occur below 35 to 70 cm of relatively horizontal top A and C horizons that show incrementally less distortion to the surface, as if they were filled in over a hummocky gilgai surface. The ancient paleosol has diagonal and contrasting Ab, Bwb, and Cb horizons that must have formed originally as horizontal layers. They probably began to deform diagonally in the Preclassic with the first episode of deforestation, erosion, and sedimentation. The actual processes for deformation are complicated, but the explanation that explains most of their morphological clues is differential sediment loading that induced shearing by expansive clays against the sediment overburden.

The hydrologic changes induced by deforestation and the possible Maya Drought may have influenced this soil deformation. Reforestation occurred in the Postclassic, and hydrologic regimes became steadier possibly with the return of moister conditions after the Late Classic dry period. Thus, erosion and sedimentation returned to background levels, and Vertisol expansion and contraction certainly continued thereafter, but compelled considerably less under the dense forest of the last millennium.

NOTES

1. Karst refers to weathered limestone landscapes that often have sinkholes and caves.
2. Dolines are dissolved or collapsed sinkholes that are often formed in limestone bedrock.
3. Vertisols are one soil order in the USDA Soil Taxonomy. Vertisols are generally clayey and go through seasonal sink and swell cycles.
4. Redoximorphic features are soil colors and features different from the soil matrix; they are caused by reduction and oxidation of iron (Fe) and often manganese (Mn).
5. Paleosols are soils formed in a different environment of the past, and sometimes they may be buried by sediments and surface soils.
6. Horsts are up-faulted blocks on normal faults.
7. Grabens are down-faulted blocks on normal faults.
8. Suite refers to a group of related soils.
9. Subsuites are the soils within a suite.
10. The USDA taxonomy is an American soil classification system, while the FAO is an international taxonomy adopted by the United Nations (U.N.).
11. AB refers to an intergrade between A and B soil horizons; Ab is a buried A horizon; and Abss refers to a buried A horizon with slickensides.

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