Chapter 3

HISTORICAL AND SOCIO-CULTURAL ORIGINS OF AMAZONIAN DARK EARTHS

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1. INTRODUCTION

Amazonian Dark Earths (ADEs), locally known as *terra preta*, are dark soils with highly elevated nutrients and organic matter that are distributed widely throughout Amazônia (Kern et al., 2003). Although once a contentious issue (Myers et al., 2003; Woods, 2003), it is now generally accepted that these soils are "anthropic" or "anthropogenic," the results of human action in the past, though it is not clear whether they were formed unintentionally or intentionally, respectively (Eidt, 1984:23). In any case, ADEs are ubiquitous in the later archaeological record of Amazônia, consistently associated with concentrations of ceramic, lithic, faunal and botanical remains, as well as with archaeological features such as burial mounds and artificial ditches. The socio-cultural practices that generated *terra preta* are still not fully understood, however.

In this chapter, we discuss some hypotheses about ADE formation in light of recent advances in archaeological, geochemical, ethnographic, biogeographical and pedological research. Our major contention is that although the particular socio-cultural or economic practices that generated ADE in the past are not yet understood in detail, the beginnings of ADE formation can be confidently related to late pre-Columbian times in Amazônia. ADE formation is thus seen as the correlate of profound social change that took place across much of Amazônia and other portions of lowland South America from about the onset of the first millennium AD onward. These changes brought about new relationships between human societies and nature, entailing dramatic and lasting forms of landscape transformation in the region, including the appearance of ADEs, among others.

This argument is developed here in the following way: first, we provide a brief summary of human occupation in Amazônia; second, we discuss the practices of

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resource management correlated with this history; and third, we relate the development of ADE formation to the emergence of fully sedentary life in some portions of Amazônia. Although we do not draw any final overarching conclusions about the origin of ADEs, we hope this chapter provides a brief overview of recent advances in ADE research, as seen from an archaeological perspective.

2. HUMAN OCCUPATION AND RESOURCE MANAGEMENT IN AMAZÔNIA

2.1 Pleistocene Climate Change and the Archaeological Record

Amazônia was initially colonized by humans at a time of major global climatic change during the Pleistocene-Holocene transition. Beginning ca. 18,000 years BP at the time of the last glacial maximum, global temperatures underwent a generally similar, though not completely uniform warming process that culminated around 10,000 years BP with the stabilization of climatic conditions similar to those today. This gradual rise in temperature was also followed by an increase in general humidity. The earliest proof of human occupation in Amazônia is dated to the late Pleistocene at around 11,000-10,000 BP (Roosevelt et al., 1996, 2002) (Fig. 1).

Temperature changes during the Pleistocene-Holocene transition resulted in an increase in sea level, as huge glaciers in the high latitudes and others on high mountain chains melted. With the rise in sea level, the Atlantic shore around the mouth of the Amazon slowly receded landward to its current location, up from a point located several dozen kilometers away from and east of the current location of French Guyana and Amapa in Brazil, for example (Maslim et al., 2000). Sea level rise brought changes in the general shape of some of the lower portions of major Amazonian rivers, such as the Tapajós, the Xingú and the Negro (Ab'Saber, 1996). Examination of maps, satellite images and photographs shows that the lower courses of these rivers are, in fact, drowned estuaries and they currently resemble large lakes that are sometimes multiple kilometers wide. With the melting of glacial ice high in the Andes and an increase in precipitation, the water discharge of the main Amazonian rivers increased significantly. This increased water volume and rise in sea level effectively acted as a dam, blocking the flow of water from tributaries into the main river channels. As a result, water flowed straight on to previously exposed river margins and floodplains, creating large lakes. These factors have important implications for early archaeological sites. With the rise in sea level, it is likely that archaeological sites associated with early maritime occupations on the coast are now underwater. The same may well be true for the sites located adjacent to the interior rivers that were naturally dammed.

2.2. Brief History of Human Occupation in Amazônia

One of the remarkable contradictions in the history of the peopling of Amazônia is the fact that in some ways we know more about the beginning and end of pre-Columbian occupation of the region, dating back to more than 10,000 years ago, than what happened in the middle five or six thousand years (see Fig. 1). It remains unclear whether this apparent hiatus results from the poor visibility of early-middle Holocene archaeological remains or an actual gap in human occupation, but we feel that the former circumstance likely accounts for this apparent hiatus.

As recently demonstrated, some of the most ancient evidence of human occupation in South America comes from Amazônia. In Brazil and Colombia, sites dating to ca. 10,000 years BP have been identified in areas adjacent to the alluvial floodplains of some large rivers, such as the main stem of the Amazon and the Caquetá. In the basal layers of Pedra Pintada Cave (near Santarém) in the lower Amazon, Roosevelt (Roosevelt et al., 1996) has dated radiocarbon samples associated with organic remains that date on average to ca. 10,600 BP (Fig. 2). At the sites of San Isidro and Peña Roja in Columbia, located next to the Araracuara rapids on the Caquetá River, the radiocarbon dates are slightly more recent, extending back to ca. 9,000 BP (Gnecco and Mora, 1997; Oliver, 2001). Dates from Gavião Cave in the Carajás Hills of southeastern Amazônia (Magalhães, 1994:62) and the Jamari Basin in southwestern Amazônia (Miller, 1992) cluster even later, around 8,000 years BP.

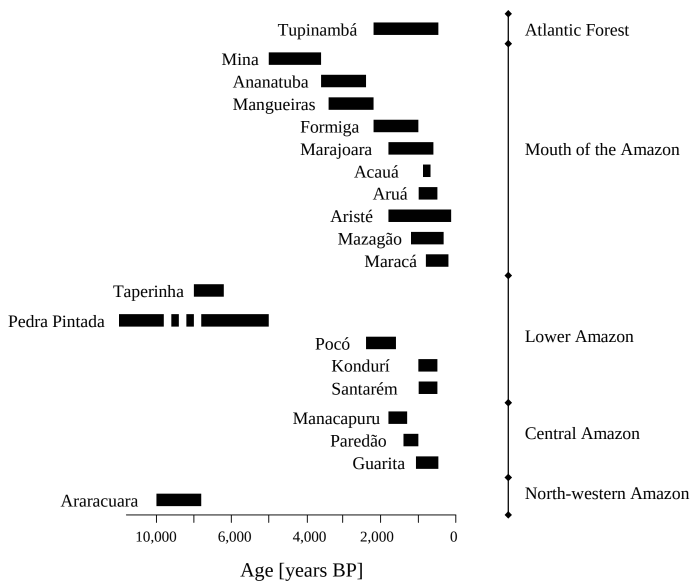

Figure 1: Chronology of archaeological complexes mentioned in the text.

Ceramic production in Amazônia may have begun before 7,000 years BP, based on samples from Pedra Pintada Cave and the freshwater shell mound of Taperinha, both located near Santarém on or near the Amazonian floodplain (Roosevelt, 1995; Roosevelt et al., 1991, 1996) (see Fig. 2). Later but still early ceramics associated with shell mounds on the Atlantic coast date to ca. 5,500 years BP and are grouped into the Mina phase (Simões, 1981). All of these dates place the first ceramics from Amazônia among the oldest in the Americas and, for that matter, in the whole world (Barnett and Hoopes, 1995). The longest sequence of more or less continuous human occupation in the Brazilian Amazon is found at the mouth of the Amazon River. This sequence began ca. 5,500 years BP with the early ceramic-making shell mound occupations of the Mina phase and continued with some interruptions through the final two thousand years of pre-Columbian occupation. The later developments include the sequential ceramic phases centered on and around Marajó Island (i.e. Ananatuba, Mangueiras, Formiga, Marajoara, Aruã and Acauã). This sequence culminated with a cultural "explosion" locally, from the fifth to the thirteenth centuries AD, at the time of the Marajoara phase and the Amazon Polychrome tradition (Roosevelt, 1991, 1992).

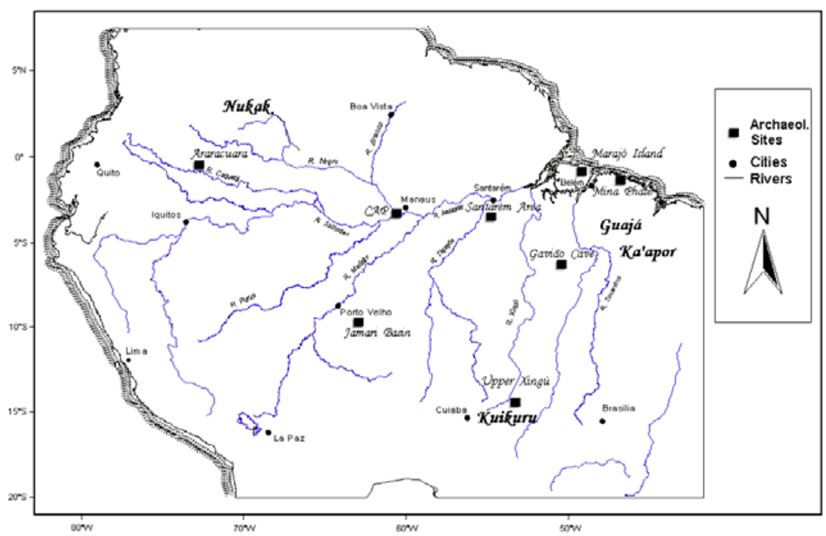

Figure 2: Location of archaeological evidence for the peopling of the Amazon and modern tribes mentioned in the text.

2.3 Resource Use

The first human inhabitants of Amazônia were hunters and gatherers who specialized in the use of diverse tropical forest resources. Though debate continues about early biological conditions, the scanty paleoecological data indicate that by the time of the beginning of human occupation, at the Pleistocene-Holocene transition, large parts of the Amazon Basin were already covered by tropical rainforests similar to those found today (Colinvaux et al., 2000; Van der Hammen, 2001). The early indigenous societies of the Amazon were by necessity already adapted to tropical conditions. Most of the environments they encountered and ultimately modified (over thousands of years) consisted of different types of humid tropical forest. It is against a background of resource abundance and ecological diversity that the history of these societies must be understood. In Pedra Pintada Cave, for example, paleobotanical and faunal data show evidence of a diversified economy based on collecting, fishing and hunting, using a wide range of plants and animals found there at the time of the Pleistocene-Holocene transition (Roosevelt et al., 1996). The occurrence of semi-polished stone axes documents that some form of forest clearing and management took place as early as 8,000 years BP in the broad region (Gnecco and Mora, 1997; Oliver, 2001). Forest clearing in the hinterland also reportedly took place during this time (Magalhães, 1994; Miller, 1992). Once forest clearing began and different economies were developed, Amazonian landscapes and the people that occupied them became thoroughly intertwined. What one considers "nature" and "natural" in Amazônia today has been in fact derived from past human management to some significant degree.

Evidence associated with the most ancient Amazonian ceramics shows that their makers were groups who specialized in the exploitation of aquatic fauna from diverse rivers and floodplains – fish, mammals, reptiles and fowl – as well as from the Atlantic shore. Abundant aquatic fauna provided a continuous intake of protein that allowed for the establishment of semi-sedentary lifeways. Consumption of aquatic fauna was likely complemented by wild plant use and management, including transportation of the seedlings of edible and medicinal plants, as well as plants utilized for spices and drugs, from the forest to incipient house gardens (Lathrap, 1977; Oliver, 2001).

Plant management among Amazonian indigenous groups, both past and present, should be understood in light of the ecological characteristics of Amazônia. As is well known, the tropical rainforest is marked by a high degree of biological diversity, along with typical dispersion of individual plant species. Human plant management in the past modified this pattern, creating concentrations of particular plants of the same species, mostly those with "r-selected" strategies such as palms, including açaí (*Euterpe oleracea* Mart.), bacaba (*Oenocarpus distichus* Mart.), patauá (*Oenocarpus bataua*), pupunha (*Bactris gasipaes* Kunth.) and tucumã (*Astrocaryum vulgare* Mart.) (Lathrap, 1977; Morcote-Ríos and Bernal, 2001; Oliver, 2001; Sauer, 1968). Resource exploitation and plant management may have contributed to reduction of the dispersion of useful species, concentrating them in patches in other words. This can be seen, for instance, in the açaí palm (*Euterpe oleracea* Mart.) and Brazil nut (*Bertholletia excelsa* Humb. & Bonpl.) forests currently found throughout Amazônia.

Modern hunter-gatherer populations in Amazônia show successful adaptations to tropical conditions, probably not unlike those seen in the archaeological evidence from early occupations. These patterns include the direct exploitation of a diversity of resources through hunting, fishing and foraging, but they also practice long-term environmental management that creates patches of useful resources spread over large areas (Politis, 2001). Such patches are mentally mapped and recorded by modern Amerindians, serving as nodal points connecting paths and routes, which in turn extend over extensive areas. Over the years, these processes transformed species distributions within the tropical rain forest. Politis (2001) has shown how the

Nukak Maku, a contemporary hunter-gatherer group in the Columbian Amazon, manage palm species through continuous reoccupation of locations adjacent to ancient camps. With time, this process leads to the formation of patches of food and other resources throughout the forest and these resource concentrations are well known by the Nukak Maku. Another example comes from the Guajá, a modern hunter-gatherer group in eastern Amazônia. The Guajá specialize in the exploitation of resources among the large stands of babaçu palms (*Orgynia phalerata* Mart.). These palm groves represent anthropic forests resulting from the prior management of forest resources by another indigenous group in the area: the sedentary Ka'apor. Ka'apor forest management is done through fire, which is used to burn areas for swidden cultivation. Babaçu seedling emergence is in turn stimulated by fire. The trees are left to grow in the gardens and then become incorporated into the secondary forest (Balée, 1994).

During the sixteenth and seventeenth centuries, early European explorers reported significant agricultural activities along the rivers of Amazônia (Myers et al., 2003). The type and number of resources used to sustain past agricultural societies were clearly different than those that typically support contemporary forest-dwelling people and pre-Columbian Amerindians had a significant impact on natural resources. The paucity of detailed archaeological evidence has prevented us from understanding when agriculture began in Amazônia thus far. The transition to fully agricultural economies in pre-Columbian Amazônia was surely a long-term process, not a short-term rupture with hunting and gathering, and it was likely associated with ancient patterns of resource management. In this sense, ADE formation should be understood within the general framework of the history of natural resource management because there seems to be a strong correlation between ADE formation and some degree of sedentism associated with agricultural food production. This is also reflected by a continuous increase in population density, as documented by the growth in size of some sites located along the Amazonian floodplains (e.g., Roosevelt, 1992; Petersen et al., 2001).

Comparative ethnographic and linguistic data from Amazônia show that agriculture among indigenous groups speaking languages of the Tupi-Guarani family dates rather early, well before 2,500 years BP (Balée and Moore, 1994). Although crop raising in Amazônia may have begun 4000-5000 years ago, or even earlier, it was only by the end of the first millennium AD (ca. AD 500-1000) that a dependence on manioc and other crop cultivation appears to have been widely represented, including different settings such as the mouth of the Amazon River (Meggers and Evans, 1957; Roosevelt, 1991), the central Amazon (Hilbert, 1968; Heckenberger et al., 1999; Petersen et al., 2001), and the Upper Xingú (Heckenberger, 1996; Heckenberger et al., 1999), among others. We are not sure whether a strong reliance on root crop agriculture was already established in Amazônia by ca. 4,000 years BP, as stated by Roosevelt (1995). However, the presence of manioc, surely an Amazonian domesticate, at sites as old as ca. 4,000 BP on the coast of Peru establishes its cultivation well before this date in Amazônia (Pearsall, 1992). It is important to also note that slash-and-burn agriculture among contemporary Amerindians, as we know it, is probably a result of technological changes introduced during European colonization such as the introduction of metal axes (Denevan, 1992).

Colonial and national histories brought about significant demographic and cultural losses for Amerindians in Amazônia, confounding our understanding Of earlier periods. At the same time, extensive resource use may well have decreased, resulting in forests re-growth and restoration of wildlife populations in some areas. This seems to have been the case for the Atlantic rainforest of eastern Brazil. Dean (1995: 33-37) has shown how sixteenth-century chroniclers describe the vegetation of Guanabara Bay – an area heavily settled by Tupinambá Indians for many centuries by this time – as being seemingly composed of different types of secondary forest. The complete decimation of the Tupinambá by the Portuguese and the French led to the later recovery of the Atlantic forest, which was in turn later disturbed and destroyed again in recent centuries by historic gold mining, coffee plantations and urban growth (Dean 1995).

3. FACTORS FOR THE FORMATION OF AMAZONIAN DARK EARTHS

3.1 Anthropic/Anthropogenic Origins – Revisited

It is widely accepted today that ADEs are anthropic (unintentionally formed) or anthropogenic (intentionally formed), but this was not always the case. Different theories have been presented to account for ADE formation such as its creation through aeolian sedimentation originating from Andean volcanoes, or formation as a result of sedimentation in Tertiary lakes or more recent lakes and ponds (see Falesi, 1972, 1974; Smith, 1980; Woods and McCann, 1999 for more complete discussion). In some cases, the hyper abundant artifacts found in some ADEs, including potsherds and bones, etc., were interpreted as the result of Amerindians who sought out such naturally fertile soils for crop cultivation, that is, the fertility occurred first and the people came later. Pottery sherds and stone tools are thus the discards of humans who came to use these soils because they were naturally fertile. Detailed pedological and geochemical investigations ultimately began to show, however, that the basic soil mineralogy and other characteristics of ADEs and adjacent soils are sometimes identical (Costa et al., 1999), and this confirmed earlier perceptions that ADEs represent human transformations of upland, non-floodplain soils that were originally infertile (Gourou, 1949; Smith, 1980). Our discussion here thus concentrates on the question of which human influences led to the formation of ADEs.

One very important distinction has to be made in this respect: The fact that current scholarship confirms the human origin of ADEs by no means necessarily indicates that they were intentionally created, but this is still a possibility. ADE formation may have resulted as an unintentional by-product of human habitation as much as from intentional soil management (see Woods, 2003, for a discussion of the principles of human-altered soil formation). For example, Ka'apor forest management in eastern Amazônia (Balée, 1994: 139) shows that these Amerindians have created long lasting structural transformations in the composition of plant species in local forests. However, the Ka'apor – still managing forests today – are unaware of its long-term effects. The same is probably true for ADE formation in many (or all?) cases, but this is an important open question in ADE research and is touched on below.

3.2 Theories of Amazonian Dark Earth Formation

3.2.1 The Myth of "The Ubiquitous Origin" for ADEs

We should note that there is nothing like "the" origin of ADEs in singular terms. It is not possible to identify any single factor (whether material or practice) that led to the formation of ADEs, either on a small or a large spatial scale, or on some temporal scale. Environmental conditions in Amazônia are as diverse as the area is large. Climatic conditions range widely, from wetter, more humid conditions in western Amazônia to seasonally dry, less humid conditions in eastern Amazônia. The vegetation, soil types and properties change in the same ways (Sombroek, 2000). This indicates that primary human food production, food types, livelihood strategies, and consumption are not identical across the Amazon Basin. Net primary production has been found to be lower in central Amazônia (<1100 g C m^{-2} yr^{-1}) relative to eastern and southern Amazônia (>1300 g C m^{-2} yr^{-1}; NASA data base at http://geo.arc.nasa.gov/sge/casa/amaecospc.html).

In the same way, ethnographic data from northwestern Amazônia reveal a greater range of manioc varieties under cultivation there than in other parts of the basin (Chernela, 1986). Consequently, the quantity and biochemistry of materials that entered the soil must have varied considerably across different areas, as do the properties that we observe today. In the central Amazon, for example, archaeological sites with ADEs vary in size from more than 90 hectares (+), such as Açutuba (Heckenberger et al., 1999), to only 2 hectares or less, such as Lago Grande (Donatti, 2003; Smith 1980). Despite vast differences in size, in both of these particular sites ADE extends to more than 150 cm deep, actually seemingly deeper at the smaller site, Lago Grande, but in the context of mounds (Neves et al., 2003).

Similarly, small-scale heterogeneity of human activities must have affected ADE formation processes. These are linked to household organization, as illustrated by the soil phosphorus (P, Mehlich 1-extractable) levels in relation to homesteads in one Kuikuru village in the Upper Xingú area (Heckenberger, 1996; Heckenberger and Petersen, 1999; also see Sombroek et al., 2003). Thus, we can hypothesize a regular disposal of household refuse in the area behind the houses among the Kuikuru. In front of the houses, the situation is completely different, since the plaza is kept quite clean. These two areas are only meters away from each other and exhibit quite different formation processes.

Besides horizontal or spatial heterogeneity, temporal heterogeneity is also evident among ADEs. Human population densities apparently changed from sparse, low density communities with relatively few inhabitants per village early on to denser and larger populations later in time. Thus, the depth and character of ADE at any one site can be quite variable stratigraphically through the site deposits (Heckenberger et al., 1999; Petersen et al., 2001).

The quantity of organic and inorganic materials produced at settlements with ADEs would have changed accordingly, but ADE formation certainly diminished dramatically after Amerindian societies were disrupted due to European contact. As the result of direct and indirect contact with Europeans, Amerindian populations in Amazônia were greatly reduced because of disease, warfare, enslavement and other factors (Denevan, 1992).

Over time, the shift from hunter-gatherer to agricultural societies in Amazônia produced changes in the quantity and quality of materials brought to human settlements. Terrestrial game may have constituted some significant portion of the diet, along with fish, before the widespread adoption of agriculture, but such a game dependence could not have persisted among farming societies, where growing populations and resultant hunting pressures would have rapidly extirpated local game reserves, at least non-aquatic, terrestrial ones.

Regional differences in food consumption surely pertain when comparing the importance of fish in local diets between settings along major waterways and those without direct access to large rivers (e.g., Steward, 1948: 886; Lathrap, 1977). Comparable differences likely also pertained between interior and coastal regions. ADE formation processes consequently were variable through time and space, as a result of the quantity and quality of materials deposited at habitation sites, and simple, all inclusive hypotheses about these processes may lead to confusion and misinterpretation.

3.2.2 The Age of Amazonian Dark Earths

The demonstrated age of ADEs seems to lead to two important conclusions regarding Amazonian soil ecology: (i) the date of the hypothesized activities that led to ADE formation, and (ii) the stability of the organic matter and nutrient constituents within ADEs. Regional differences in ADE ages seemingly exist across Amazônia and these can be used to explain population dynamics and evolutionary developments in broad terms. Also, small-scale variations in the timing of ADE formation will be helpful in the identification of changing human population densities and landscape usage by Amerindians regionally.

It should be also remembered that many ADE sites have yet to be discovered and some ADE sites may have disappeared due to erosion and sedimentation processes, first triggered by post-glacial effects on marine influenced water levels in Amazônia (see section 2.1). Likewise, more recent settlement sites on bluffs or other elevated floodplain features have been likely affected by river channel migration in certain settings (Denevan, 1996). Some, perhaps many, Amerindian sites may have disappeared over time.

Most known ADE sites in Amazônia are about 500-2,500 years old (Fig. 3). Notable exceptions include the sites of the so-called Massangana phase, identified by Miller (Miller, 1992: 37-38) as preceramic occupations dated ca. 4,800 BP to 2,600 years BP in the Jamari River area within the overall Madeira basin and situated in southeastern Amazônia. These sites are now drowned by the Samuel hydroelectric dam. Miller has interpreted these early occupations as the record of semi-sedentary, incipient agricultural groups. More work is needed to fully assess this claim, however.

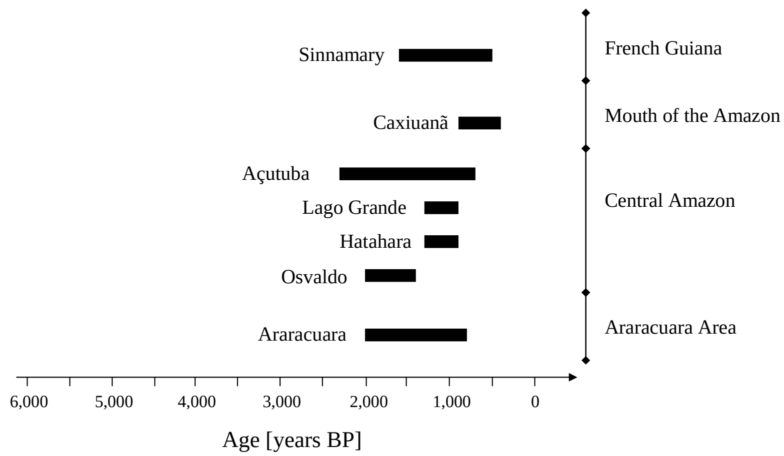

Figure 3: Known periods of ADE formation at selected archaeological sites in Amazônia; Açutuba, Hatahara, Lago Grande, and Osvaldo in central Amazônia (Heckenberger et al., 1999; Neves et al., 2003); Puerto Aturo and Abeja (Mora et al., 1991: 39) in Araracuara Area; Sinnamary in French Guiana (Vacher et al., 1998); Caxiuanã (Kern, 1996).

After contact with European explorers, beginning ca. AD 1500-1600 in the more accessible portions of Amazônia, Amerindian populations rapidly declined and many areas were completely depopulated by ca. AD 1700-1750 (Denevan, 1992a; Myers et al., 2003). ADE formation consequently ceased in most, if not all, parts of Amazônia during the early Contact period on the basis of available evidence.

The initiation of ADE formation has been more difficult to explain so far. It is possible that: (1) earlier sites disappeared due to those landscape processes described above; (2) ADE formation actually began only around 2,500-2,000 years BP; and (3) the soil organic matter in most older ADE sites has been mineralized, leaving only inorganic artifacts behind, without coloration of the substrate by organic matter, and thus, early sites are under-represented.

What evidence exists for the present hypothesis that ADE formation became common place only around 2,500-2,000 years ago, and not earlier? If ADE formation is in fact produced by human habitation but unintentionally, this would indicate that human populations may have drastically increased around this time. Very little archaeological evidence is generally known for the earlier periods of human occupation in Amazônia before ca. 3,000-2,500 BP, although the first people arrived by ca. 11,000-10,000 BP, as noted above. The initiation of ADE formation may well have been correlated with the establishment of fully developed sedentary life styles, as based on agriculture during the third millennium BP and thereafter. Further reflections about the effects of agriculture on soil properties in Amazônia are presented below.

3.2.3 Amazonian Dark Earths and the Development of Agriculture

The establishment of agriculture as a major source of food production in Amazônia set the basic condition for the development of ADEs. The reasons for this may have been two-fold: (1) permanent agriculture requires soil amelioration and ADEs may be in part the result of intentional anthropogenic soil management; and (2) once agriculture was solidly established in Amazônia, residential and economic patterns emerged that were characteristic up to the beginning of European colonization. In other words, sedentary life styles and their economic underpinnings were the basic precondition for the development of ADEs in this scenario (Petersen et al., 2001).

Contemporary hinterland hunter-gatherer societies in Amazônia are certainly characterized by a very high degree of mobility (Politis, 1998) and this mobility was likely characteristic of most non-agriculturalists regionally since humans first arrived. Although it may be problematic to uniformly project this ethnographic pattern into the past, one can easily presume that a dependence on agriculture brought more sedentary lifestyles in areas adjacent to the main floodplains in Amazônia, as well as some interior non-riverine locations (e.g., Woods and McCann, 1999). Sedentism increases the human influence on particular areas of soil that are intensively used.

In shifting cultivation, at least as it is practiced today, farmers cultivate the same field for several cropping seasons until the soil nutrient contents are depleted, significant proportions of organic matter are mineralized, and acidity is increased to the extent that it restricts productive agriculture (Sanchez et al., 1982). Whether or not shifting cultivation was a strategy of land use practiced by Amerindians at all times is discussed further below. In any case, archaeological research in the central Amazon has shown that various ADE sites were continuously occupied for multiple decades and longer, even some or many centuries in the case of the most substantial settlements (Heckenberger et al., 1999; Neves et al., 2003). This suggests that village mobility was much reduced during these times relative to contemporary ethnographic circumstances for Amerindians in the region (Neves, 2000).

3.2.4 Amazonian Dark Earths in the Wider Context of Human Habitation

All societies continuously produce organic waste from food remains, in processed and unprocessed form. Additionally, utensils and energy sources for food preparation contribute to waste materials. When discarded, all of these materials accumulate in the soil and transform its properties. Such changes produce signatures in the archaeological record that enable us to make inferences about the lives of people in the past. It is in this context that we are interested in understanding the sources of ADEs.

As outlined above, we do not expect to find any single type of ADE (see also Kämpf et al., 2003), nor a ubiquitous source for it. Singular categorization will not pertain to any ADE site in its entirety, nor will it necessarily pertain to all areas within it, not even within any given ADE profile in most cases. Variability is to be expected in other words and single samples and single sampling units will not be necessarily representative of any one ADE location. Possible sources of ADE in the context of habitation may be associated with burial activities (human remains, urns, cloth, etc.), food preparation (fire remains such as soot, ash, charcoal; food processing remains such as fish waste or waste from game, blood from hunted animals, inedible parts of fruit, vegetables and nuts, etc.; cooking and storage vessels, etc.), eaten food waste (human excrement, processed food waste such as bones of fish and game), housing (debris of housing materials such as straw or palm leaves, wood, skin), and various other activities (dyes, oils, fiber from palms and bark, etc.). All of these activities probably must have had an influence on ADE formation to one degree or another. One major question remains unanswered, however: what were (and are) the "critical" sources for ADE formation?

Figure 4: Burial urns at Hatahara below the enriched and dark ADE embedded in the A/B horizon, as indicated by the light spots (M. Arroyo-Kalin).

Burial activities certainly played some role in ADE formation. However, it is our experience that human bones are only rarely found in ADEs and the extent to which burial activities are responsible for ADE formation is likely to be restricted to small, localized areas. Near Manaus, burial urns were found at the Hatahara site below the dark soil horizons characteristic of ADE that are rich in carbon (C), P, and calcium (Ca), but the burials themselves were not associated with ADE characteristics since they were often emplaced beneath it (Fig. 4). This circumstance and other comparable examples indicate that burials did not necessarily contribute much to soil enrichment.

Food processing, including cooking, is very likely a major source of ADE formation. The dark black color of ADEs and the contents of so-called “black carbon” (Glaser et al., 2001) indicate the presence of incompletely combusted organic matter. These charcoal-like materials were likely derived from fireplaces used to cook food. To account for large areas of ADE, residential activities must have shifted from place to place over time (Silva, 2003), or there were very large groups represented in some settings, as we believe. The space required for an individual fireplace is typically small, however, and it is likely that the disposal of ash and other resultant cooking (and heating) remains would have taken place in discard areas outside of the houses. This would also explain the high levels of elements such as Ca and P in ADEs that could hardly be derived from charcoal alone (Woods, 2003). Charcoal applications to soil create only moderately high concentrations of available P and typically lack elevated available Ca contents (Lehmann et al., 2003b). Food wastes such as bones of fish and game also would have been found in these discard areas (DeBoer and Lathrap, 1979; Stahl and Zeidler, 1990). Fish bones are especially rich in both Ca and P and may be responsible for the high concentrations of dilute HCl-extractable P characteristic of apatite (Ca-phosphates) found in ADEs (Lehmann et al., 2003a). Fish bones have been identified in ADEs chemically by SEM-EDS (Lima et al., 2002) and visually within archaeological in excavations (Fig. 5). Another possible cause of soil enrichment by C and nutrients is backyard, near-house cleaning and burning. Regular backyard cleaning with piling and burning of vegetation and other organic waste currently contributes to creation of dark soil in the Manaquiri area, for example (E. Neves, pers. obs.).

The typically large number of pottery sherds in ADEs (see Fig. 5) further supports the hypothesis that most ADE sites with artifacts in them represent trash discard areas, at least in part. In addition to the disposal of pottery vessels due to wear and tear through regular usage, Amerindian pottery is sometimes deliberately destroyed when its owner dies (Silva, 2003). Furthermore, in the central Amazon, vast amounts of broken pottery sherds were recycled as raw materials for building funerary mounds (Machado, pers. comm.). Cooking vessels generally occur more often than burial urns or storage vessels in ADEs, since the pottery often shows high concentrations of P (Costa et al., 2003). These high P values are derived from regular preparation of meals that have high P content, specifically indicating foods rich in fish.

Human excrement increases soil organic matter, as well as Ca and P concentrations, very similar to animal manures (Solomon and Lehmann, 2000). However, excrement is unlikely sufficient for ADE formation alone, at least among contemporary indigenous societies in Amazônia, where a constant preoccupation with the cleaning of public spaces and circulation areas has been demonstrated (e.g., DeBoer and Lathrap, 1979). Some evidence suggests that human excrement and urine make important contributions to ADE (Woods, 1984), but these alone would not be sufficient for its formation in our view.

Figure 5: Fish remains found in refuse pits in an excavation at Hatahara, central Amazônia (W. Sousa de Silva).

ADEs could conceivably form around houses as a result of discarded or fallen house debris, or even the collapse of the entire house itself after abandonment. However, house construction and maintenance debris does not contain large amounts of P or Ca. House floors are usually kept rather clean, but specific areas associated with food processing and cooking, craft production activities, and night time urination may contribute to elevated concentrations of these and other elements.

External discard areas outside of houses (Silva, 2003) are larger than areas for food preparation, but they are often restricted somewhat spatially. Where a central plaza or other plaza type exists (Heckenberger, 1996), it will be regularly swept clean and kept free of debris (Silva, 2003). In contrast, discard areas will be typically restricted to areas behind the houses. These potentially show high concentrations of available soil P. In fact, significantly lower P concentrations were demonstrated in the central plaza of the Kuikuru village in the Upper Xingú, for example, relative to those in backyard processing and discard areas (Heckenberger, 1996; Heckenberger and Petersen, 1999). Furthermore, deposition of habitation waste in abandoned subsurface facilities such as storage pits tends to concentrate these materials even more.

The question remains whether large areas of ADE, covering dozens or even hundreds of hectares, resulted from more or less “permanent” villages like the ones one documented by Heckenberger (1996) or were they formed from smaller villages that shifted their location seasonally or otherwise periodically, as repeatedly proposed by Meggers (e.g., Meggers, 1994). Recent evidence from three ADE sites in the central Amazon indicates that ADE formation occurred more rapidly and even episodically, in contrast to the previously suggested ratio of 1 cm of incremental ADE growth for every 10 years (Smith, 1980). Some of the sites found in this area are single occupations, but most are multi-component in nature (Fig. 6). If such chronological and stratigraphic patterns can be confirmed for other locations, one can propose that ADE formation is not so much dependent on the length of time alone, but rather more on the intensity of occupation over time, allowing for the constant input of organic matter and nutrients to the soil. This will help demonstrate that comparatively large and stable villages, sometimes with significant population densities, existed well before the arrival of the Europeans.

ADE formation in the context of discard areas within habitation sites is a likely explanation for many ADE situations that show abundant artifacts. Source materials that seem most critical for ADE formation include charcoal-like materials and food waste such as fish residues, with high Ca and P contents.

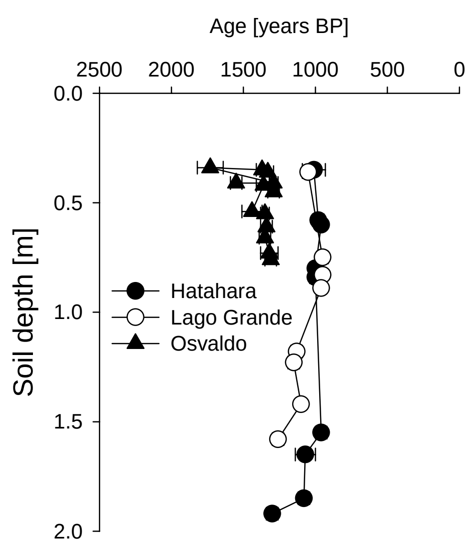

Figure 6: Dates of ADE formation at three sites in the central Amazon; non-calibrated radiocarbon dates, one sigma standard deviation (Neves et al., 2003); different chronological patterns indicate that ADE formation relates more to the intensity rather than to the length of site occupation.

3.2.5 Amazonian Dark Earths in the Context of Agriculture

Sufficient evidence has been presented to consider whether some ADE formation results from agricultural use of soils or even purposeful anthropogenic soil management (e.g., Woods and McCann, 1999; McCann et al., 2001). As outlined above, the existence of large population aggregates in Amazônia would have required productive agriculture. Shifting cultivation techniques, at least as we know them today, would not be able to sustain such population densities. In shifting cultivation, the forest is slashed and burned to clear the land and to amend the soil with nutrients from the resulting ash and charcoal. After a few productive years, soil nutrients are depleted by crop-raising and organic matter in the soil is reduced to such an extent that the farmer has to relocate his fields. Thus, shifting cultivation demands that the farmer slashes and burns a new patch of forest every few years.

Given the fact that only stone axes were available to the Amerindians before European contact, pre-Columbian forest clearance as seen in shifting cultivation would have been a huge task (Denevan, 1992). By necessity, farmers must have explored every possibility to avoid the frequent cutting of large trees in most tropical forest settings. Continuous cropping of the same fields would have had significant advantages in this respect. In the central Amazon, a high incidence of small bifacially flaked axes made from sandstone suggests that only medium to small size trees were felled, since these artifacts would be ineffective for cutting large trees (Costa, pers. comm.). This evidence matches Denevan's (1992: 159) expectation that pre-Columbian agriculture in Amazônia would have been characterized by, among other things, intensive swiddens located on naturally disturbed or old field plots, with young secondary tree growth.

Since upland soils in Amazônia are highly weathered and therefore low in available nutrients (Smyth and Cassel, 1995), significant additions of fertilizer nutrients are typically required to allow sustainable cropping (Sanchez et al., 1982). Obviously, inorganic fertilizers were not available in pre-Columbian times, and organic additions are the only likely source for such nutrients. An organic production system would provide a sensible framework for the occurrence of ADEs in the context of agricultural fields. However, other large areas of ADE that contain abundant artifacts were not likely managed intentionally for agricultural production, but instead they were produced from habitation refuse.

Around the ADEs that contain pottery and other artifacts (called *terra preta*), Sombroek (1966) identified still other ADEs that did not contain many, if any, artifacts, but these were equally or almost as dark as the others (called *terra mulata*). Systematic study of *terra mulata* soils found in many places throughout Amazônia revealed that they contain similar amounts of organic C to *terra preta*, but they have lower available P and Ca contents (Woods and McCann, 1999). This suggests that *terra mulata* soils are not remnants of discard areas or habitation, since these would demonstrate higher Ca and P concentrations (McCann et al., 2001). The locality and chemical characteristics of *terra mulata* make it likely that they were intentionally enhanced for agricultural production. How was that possible? Where did the materials for enhancement come from and what did they consist of?

Glaser et al. (2001) calculated whether the amounts of black C in ADEs could be derived from charcoal gained through incomplete burning of organic matter in the context of slash-and-burn agriculture. Twenty-five cycles would be minimally required to yield amounts of black C in soil similar to those found in ADEs. This scenario is unlikely to be responsible for ADE formation, however, since it would take too long to produce C contents characteristic of ADEs (Glaser et al., 2001). However, single burning of primary and even secondary forests and charcoal production yield substantial amounts of black C (Glaser et al., 2001; Lehmann et al., 2003b) in quantities sufficient to explain their equivalent amounts in ADE. Therefore, the quantities of organic matter in these types of ADE are potentially explainable by on-site C management. Additionally, off-site C inputs may have occurred, including applications of excess charred material from fireplaces. Recurrent in-field burning of crop residues and/or burning of spontaneous vegetation growth may have further contributed to the black C pool in these soils. Hecht (2003) has reported in-field burning among the ethnographic Kayapó that increases the available nutrient content and may increase stable organic C content as well.

However, none of these scenarios fully explains the elevated total nutrient content of ADEs. Despite the fact that P and Ca concentrations are low in these ADEs apparently managed for agricultural production (*terra mulata*, or Agric Archaeo-anthrosol; Kämpf et al., 2003) when compared to artifact-bearing ADEs *(terra preta*, or Cultic Archaeo-anthrosol), agricultural ADEs still have significantly increased total nutrient contents relative to unmodified soils. Increased nutrient availability can be achieved through transformation of nutrients from unavailable contexts into available pools (e.g., by in-field burning, litter fall, crop residues), but total nutrient contents can only be elevated through nutrient inputs. Therefore, nutrient transfer from outside the cropped area is necessary to explain the nutrient levels observed today in many ADEs. These nutrient transfers may have been derived from food wastes such as fish and human excrement, since they contain high amounts of P and Ca, as outlined above. In Araracuara, the presence of algae in ADE from ca. 1,150 years BP and later suggests that silt from flooded river land was incorporated into the fields (Mora et al., 1991: 43), likely to increase soil fertility, and this may have pertained elsewhere too.

4. AMAZONIAN DARK EARTHS AFTER A.D. 1500-1600

Most ADEs currently under study were produced before contact with Europeans, after which Amerindian populations decreased rapidly due to epidemic diseases, enslavement and other forms of disruption (Myers et al., 2003). Therefore, ADE formation generally ceased after A.D. 1500-1600 due to radical transformations among many Amerindians in Amazônia. Pedogenesis and human influence on ADEs were not terminated after the Amerindians stopped producing them, however.

Forest regrowth covered ADE sites after their abandonment and biological processes such as root growth and intense soil fauna continued to alter ADE properties, along with post-depositional disturbance of at least some artifacts through bioturbation. After human inputs of organic matter and nutrients ceased, mineralization of organic C and nutrient leaching most likely produced a net decrease in humus and total nutrient stores. The magnitude of this decrease remains uncertain, since the base level C and nutrient contents at the termination of ADE formation are unknown. Black C, which represents a large part of organic matter in ADEs, is very resistant to mineralization (Glaser et al., 2003) and nutrient losses from ADEs through leaching are very low (Lehmann et al., 2003b).

Additionally, the pottery sherds and other artifacts that are so abundant in many ADEs may have contributed to the chemical and physical stability of these soils. Pottery sherds sometimes constitute a large portion of the total volume of ADE, roughly estimated as 10-25% or more by volume in some cases, often having primarily horizontal orientation within the soil matrix (see Fig. 2 in annex). Preferential flow in soil macropores may be low in ADEs since pore continuity is reduced by the sherds. The sherd surfaces may act as either a source or a sink for nutrients (e.g., they contain large amounts of P probably from cooking; Costa et al., 2003). Overall, the loss of organic matter and nutrients from ADEs may have been less than would be otherwise predicted given the environmental contexts of the humid tropical lowlands.

Human effects on ADEs have been significant since the arrival of Europeans, especially during the past few decades when large-scale farming has affected them. Non-native farmers have settled the Amazon over the past 300-400 years, and many of these newcomers have valued ADEs for their superior soil fertility (German, 2003; Hiraoka et al., 2003). Soil alteration and crop production have led to loss of organic matter and nutrient stripping in many cases. In fact, ADEs have been also physically mined and sold as garden soil in urban centers (Hiraoka, 2003; W. Woods, per. com.). All of these recent natural and human transformations have altered and even destroyed portions of the fine-grained archaeological record as preserved in ADEs. Consequently, we continue to lose our opportunity to understand the full story of past human behavior in Amazônia.

5. FINAL CONCLUSIONS

ADE formation has been attributed to numerous factors in the past, including both cultural and natural forces. As archaeologists, we feel that ADE formation certainly has been the result of diverse factors across time and space, but these were largely, if not solely, cultural. Thus, the present challenge is to identify the key processes and primary origins involved in ADE formation, along with the social and historical contexts that are responsible for these soils. Evidence from archaeological excavations in the central Amazon indicates that ADE formation there sometimes occurred more rapidly than previously thought and it was not necessarily slow and incremental. We suggest that human population density and concentrated activities, rather than time alone, was primarily responsible in ADE formation. In this sense, the development of stratigraphic layers of ADE in sites with multiple occupations is likely an archaeological correlate of population growth. This and other hypotheses need to be tested with further study.

ADE source materials that seemingly have had the largest cumulative effect on soil organic matter and nutrient content are charcoal and food residue. It is not entirely clear through which human activities these materials entered the soil. Localized refuse disposal areas near individual houses certainly played an important role in this respect. Given the existing morphological and chemical evidence, it is also possible that certain types of ADEs (Agric Archaeo-anthrosol, or *terra mulata*) were produced as the result of some sort of agricultural activity. Whether or not agricultural soil management led to the intentional anthropogenic formation of ADEs remains a question that needs to be better resolved through future research. Nonetheless, we feel that the widespread appearance of intensive agriculture in Amazônia around 2,500-2,000 years BP, after many years of previous crop raising, and the concurrent development of sedentary life were important catalysts for the initial formation of many ADEs.

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