The University of Kansas

By

Author Lilian Rebellato

Submitted to the graduate degree program in Department of Geography of the University of Kansas in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

____

Chairperson William I. Woods

____

Stephen Egbert

____

Peter Herlihy

____

Rolfe D. Mandel

____

Ivana Radovanovic

Date Defended: 10/25/2011

Dissertation Committee for Author Lilian Rebellato

certifies that this is the approved version of the following dissertation:

Amazonian Dark Earths: a case study in the Central Amazon

Chairperson William I. Woods

Date approved: 10/25/2011

Abstract

This investigation derives from research conducted over several years and contributes to the understanding of the differential occupational dynamics and use of space in pre-Colonial Amazonia. The goal of this study is to use traditional chemical and physical soil analytical methods to understand the archaeological site formation processes in the study area. Many of the sites in Amazonia have *terra preta* and *terra mulata* anthropogenic soils, that is, soils that are highly fertile and resilient, with elevated concentrations of pottery, charcoal, burials, and lithic and faunal remains. Because these soils have high pH values, the organic materials are well preserved for a tropical forest context. Testing a hypothesis about the use of these soils for food production during the pre-Colonial period was the main goal of this geoarchaeological research; the chronologies of occupation as well the size, shape and permanence of the villages during the pre-Colonial period are also included. The results show that the last occupational group – associated with the Guarita subtradition that occupied the site around 900 AD – discovered the fertile properties of these soils and reorganized them in order to improve their crop production. The evidence for this conclusion comes from chemical and physical analysis of the soils, which revealed a greater concentration of carbon (C) in the surface stratum of the site, while the amount of phosphorus (P) decreases with depth in that stratum. Moreover, a great and rapid spread of *terra preta* in the site surface

corroborates these findings. Therefore, I deduce that a population around 900 AD introduced a different way to use the land; they farmed larger field areas for food production, decreasing the amount of P in the soil, because it was available for plants, but not of C, because carbon is mainly concentrated in black charcoal and is thus not available for plants. Slash-and-burn agriculture was the human action responsible for generating the black charcoal, and was used to increase soil fertility during crop production. The apparent change in land-use by the last group that occupied the site is related to the Amazon Polychromic Tradition (APT) that is associated with the Tupi expansion.

Acknowledgements

First, I would like to acknowledge CNPq (Brazilian Governmental Research Council), for the scholarship without which this work would have been impossible, and the Chairman of my committee, Dr. William I. Woods, who advised me and furnished the conditions for full development of this research. To all members of my committee, Dr. Stephen Egbert, Dr. Peter Herlihy, Dr. Rolfe D. Mandel, and Dr. Ivana Radovanovic, I offer many thanks for their patience and useful comments during this process. Several people connected to research laboratories in Brazil and the USA also provided important conditions for the analyses, including Dr. Wenceslau G. Teixeira from Embrapa (*Empresa Brasileira de Agropecuária*), who also helped me a lot with the statistical analysis, as well as Donald Meyer, President of Rock River Laboratory Inc., and his family, who provided equipment and trained people to assist me. My family, my mother Narzira and sisters Luciana and Livia, played a very important role during this work, giving me emotional support even during the hardest time when fate took my father, Luiz Rebellato, from us. Dr. William Balée, Dr. Robert Carneiro, Dr. Charles Clement, Dr. William Denevan, Dr. Clark Erickson, and Dr. Siu Mui Tsai provided valuable comments and friendship. Dr. David Robinson invited me for an important plenary presentation at the AAG congress in Seattle. The Central Amazon Project leader Dr. Eduardo G. Neves allowed me to carry out investigation in the research area, and my friend Jago J. Birk patiently helped me with data collection and geostatistical analyses. Friends who have been part of my academic development since my Masters—including Suzana Ketelhut, Fernando Dantas, and Andrea Borghi in Manaus, Alexandre Salles in São Paulo; Trisha Jackson and family and Aida Ramos in Kansas; and Monica Barnes and David Fleming in New York—were always present during the

Ph.D. process, and I thank them very much for all of their support. Colleagues in my new job position, including Denise Gomes, Bernadino Figueiredo, Lauro Barata, Anne Daniel, and Claide Moraes, collaborated with this research, and I owe especial thanks to the Directory of the University of Oeste do Pará, the Chancellor Dr. José Seixas Lourenço, and to Drs. Tereza and Marcos Ximenes, who are supporting the finalization of this work. I gratefully acknowledge ongoing support for my research and future work from several people other universities as well: Dr. Denise Schaan, Sanna Saunaluoma, Dr. Alceu Ranzi, and Antonina Barbosa. Without the help of Dr. Manuel Arroyo-Kalin, Leandro Silva, Manoel Taveira, Stevao Souza, and Adriana Meinking I would not have completed all the sample collection or analyses necessary. Thanks to all the technical support staff from University of Kansas, especially Kim Glover, who always helped me with computer support, and Beverly Koerner and Beverly Morey who provided essential information from the department. Finally, thanks very much all those who helped me in a positive way with collaboration and friendship. Last (but not least!) is the Wizard of Oz who gave me a bicycle, which allowed me to finish my credits at the University of Kansas.

Table of Contents

Chapter 1

Introduction

The Amazon has a complex history and encompasses a mosaic of distinct, yet interactive landscapes. Its area extends over nine countries: Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guiana, Peru, Suriname, and Venezuela, of which Brazil holds 50% of the territory, yet no more than 10% of the population (Salati et al. 1990). With annual precipitation levels ranging around 2,300 mm in the central portion (Salati 1990), and temperatures averaging 25°C (Colinvaux 2007), the Amazon represents the largest tropical forest ecosystem in the world and 50% of the rainforest area on the globe, characterized by a warm, humid, tropical climate (Behling et al. 2001). The enormous variability in flora, fauna, and geomorphologic features as well as the presence of numerous rivers represents enormous challenges for all fields, scientific to political, studying past and current societies in these Amazonian countries.

The giant intracratonic Amazon Basin measures ca. 500,000,000 km^2 (3,500 km long and 300 km to 1,000 km wide (Putzer 1984:15)), and is a low, sedimentary valley located between the Guiana and the Brazilian shields. The last consolidation of the Amazon Basin occurred 600 million years ago. The Guiana shield in the north and Brazilian Shield in the south range in age from 0.5 to 2.6 billion years old (Precambrian Kraton), and are a crystalline basement complex formed principally by granites, gneisses, and mica schist (Sombroek 1966, Mertes and Dunne 2007). The Amazon Basin is subdivided into the Acre portion in the west, the Marajó in the east, and the Maranhão Basin in the southeastern region. It narrows at its eastern point where it is compressed by the Guiana and Brazilian shields and gradually becomes wider upstream toward the west (Sombroek 1966:15). A large portion of the sediment in the central part of the basin dates to the Cretaceous and/or Tertiary periods, and is mostly related to the west side of the Amazon valley where the young Andean mountain range is located. Features like relief, coastal delineation, and river systems developed during the Late Cretaceous through Pleistocene time and are related to the Andean uplift (for a detailed discussion, see the section "Landscape" below). The geological event that created the Andean uplift shaped most of the Amazon Basin's physiography, but other natural forces are also responsible for the Amazon Basin's formation process, including earthquakes, sea level fluctuation, and climate change (Mertes and Dunne 2007, Hoorn et al. 1995).

Amazonia is the last frontier for research related to abandoned settlements during the pre-Colonial Period. Current investigations are revealing dramatic perspectives on human settlement systems in the area. From these, two opposing models have emerged concerning the density, size, shape, and duration of Amazonian pre-Colonial settlements (Heckenberger et al. 1998, 1999). One group believes that environmental conditions in the Amazonian region inhibited the social and cultural development of its populations; the principal conditions cited are soil exhaustion (Steward 1946) and low levels of available protein (Gross 1975). Follow-up studies carried out by Meggers and Evans in the mid-20th century posited an association between poor environmental conditions and a lack of cultural complexity. According to Meggers (1954), *"it is evident that differential suitability of the environment for agricultural exploitation provides a potential explanation for differences in cultural development attained around the world"* (op.cit.:802). In addition, Meggers also related the effects of "El Niño" (specifically, the resultant exceptionally low to normal rainfall) to catastrophic events that could have led to unstable climatic conditions responsible for failures in agricultural production (Meggers 2003). The result, according to this line of thinking, was an unsustainability that forced the movement of habitation areas and agricultural fields, creating a constant state of flux for socio-cultural systems (Meggers 1971).

The second group, working in the 1960s and later, presented the Amazonian region not as lacking in cultural complexity but as a cultural innovation center (Lathrap 1970, Brochado 1984) where the oldest pottery in the hemisphere was created, wild plants were domesticated for agricultural systems for the first time in South America, and structures for water control were built to sustain food production (e.g., Denevan 1966a, Clement 1999a, Posey and Balée 1989, Lathrap 1970, Roosevelt 1994, Erickson 1980, Brochado 1989, Petersen, Neves and Heckenberger 2001, Heckenberger, Petersen, and Neves 1999, Balée 1994). Results from archaeological projects throughout Amazonia are producing strong evidence for a complex occupational system very different from that of the formerly proposed models. In the Brazilian Amazon, research is showing integrated villages in the Upper Xingu, earthworks in the western states, enormous mounds on Marajó Island, and huge areas of anthropogenic soils throughout the region (Pärssinen, Schaan, and Ranzi 2009b, Schaan 2000, Teixeira et al. 2009, Woods et al. 2009). Other archaeological finds in the Amazon area include monumental structures in the Llanos de Mojos in Bolivia as well as raised fields in French Guiana, Suriname, Guiana, and Ecuador (Denevan 1966a, Rostain 1991, Erickson 1980, Rostain 1994, Balée and Erickson 2006, Versteeg and Rostain 1997, Zucchi and Denevan 1979). This line of research has continued to be refined over the last decades, with more investigations adding important clues about the use of landscape and cultural diversity in the area. In line with these discoveries, the goal of this research is to understand better the settlement formation processes at Hatahara site in the Central Amazon at the confluence of the Negro and Amazon rivers, and how past human activities connect to both physical and chemical changes in soil characteristics at this site.

During the last 15 years, the Central Amazon Project, led by Eduardo G. Neves, has made significant inroads into these questions. My investigation builds on this valuable work, accumulating and reporting more detailed data on settlement morphology as it relates to the history of occupation by pre-Colonial societies in the central Amazon. Physical and chemical soil properties and pottery analyses carried out at archaeological sites in the region have confirmed the association between a circular concentration of organic material and Amazonian Dark Earths (ADE), named anthropogenic fertile soils. This material is associated with long-term occupations in the area surrounding the plazas at the Hatahara, Oswaldo, and Antonio Galo archaeological sites. These date to the Manacapuru and Paredão periods and, as such, are related to the Arawak and the Amazonian Barrancoid or Incised Rim Tradition (as discussed further in the section entitled “Arawak Diaspora”).

The Central Amazon Project found a posterior settlement distribution presented in a linear shape with the Amazonian Polychromic Ceramic Tradition affiliated with the Guarita phase (Tupiguarani; Rebellato, Woods, and Neves 2009). The village then occupied the riverside border facing the Amazon River and backing onto the areas composed of ADE. Thus, it was possible to confirm pre-Colonial presence in the Central Amazon area through ethnohistorical and archaeological data. Additional confirmation was found in the descriptions made of the first contact between those native societies and European travelers, namely Friar Gaspar de Carvajal, who observed continuous, almost linear, dense village occupations along the Amazon riverside in 1542 (Carvajal 1992).

Porro (1996) attributed the linear pattern for this population to an economy associated with water resources (i.e., fishing, hunting, transportation), a perfectly reasonable conclusion. Results presented in this work also furnish one more reason for the linear shape of the last occupation in the sites: namely, it allowed better use of the ADE area for food production.

Objectives

The study of this pre-Colonial occupation in the Amazon is a way to reconstruct the history of the indigenous population in that region as it relates to their distinct interactions with the landscape. Determining the nature of these interactions allows differences in subsistence modes, settlement patterns, and domestication of the landscape and soil to emerge, as well as an understanding of the ADE formation process, as these soils were generated by culturally distinct landscape management strategies. In order to develop the relevant data for interpretation, archaeologists must first address some basic questions, as presented in Rebellato, Woods, and Neves (2009): What activities did Amazonian peoples engage in to generate those soils? What were the material results (in a chemical-physical depositional sense) of each of these activities? What was the intensity of each activity and what amounts of different materials were deposited over a unit area per unit time? What were the patterns of disposal and how did these relate to the morphology of the contemporary settlement and its diverse activity areas? What was the duration of each activity? What was the duration of each settlement? Why are ADE not found in all archaeological sites over the Amazon? What distinctive activities were responsible for creating these soils? When did people start to use them for agriculture purposes? What kinds of cultivars were they planting?

Thus, the main objective here is to understand the Late Holocene transition from the Paredão phase to the Guarita Subtradition in the Central Amazon. Around 1,000 BP there was a transition from a circularly shaped village (related to the Paredão phase) to a linear village construction (associated with the Guarita Subtradition), as seen in the Hatahara archaeological site. The hypotheses for this change are:

1 – The circular village related to the Paredão phase occupied the Hatahara site for well over 300 years, generating Amazonian Dark Earth soils (*Terra Preta de Índio*, in Portuguese).

2 – Newcomers related to the Amazon Polychrome Ceramic Tradition (Guarita Subtradition) were expanding their territory to look for sources for each of their food production systems.

3 – The expansion of the Guarita subtradition ceramics from the Central to the Upper Amazon is understood as a new system for the use of resources for agricultural purposes.

To test these hypotheses, geoarchaeological research was carried out in the Central Amazon at different archaeological sites. The interventions were made through a systematic collection of archaeological materials and soils in an arbitrary grid. Chapter 2 provides the landscape history, describing soils, floodplains, uplands, vegetation, and climate. Chapter 3 presents a literature review, including an overview of the various stages of occupation, from the earliest occupation through the initial contact with Europeans; implications of this interaction between landscape and humans; and examples of Amazonian Dark Earths and their anthropic effects on the landscape. Chapter 4 describes the Amazonian Dark Earths' research history, distribution, classification, chronology, and current research. Details of the study area and site excavations are provided in Chapter 5. The results of my research are shown in Chapter 6, explaining the formation processes of anthropogenic soils in the Amazon. This dissertation concludes with a discussion of the occupation of the Amazon from an anthropological standpoint and reveals an intricate association between natural and cultural actions that changed the soil characteristics.

The initial formation processes of Amazon Dark Earths are demonstrated by the results of 103 auger holes that extracted soil samples. The results of the soil analyses indicate changes in micro- and macro-nutrients in the soils that are associated with the habitation areas that accreted tons of soil nutrients due to deposition of organic matter. The accumulation and resilience of these nutrients would not be possible without the input of black charcoal at the site surface, which increased the soil cation exchange capacity, allowing the soil to hold nutrients over centuries.

Soil data gleaned from the upper 40 cm of the profile, which captures the last occupation associated with the Guarita subtradition, reveal important information about land use. Specifically, there is a consistent decrease in phosphorus (P) content and increase in carbon (C) content increases with depth in this portion of the site profile. This pattern is attributed to the use of ADE for food production, when the inhabitants spread organic-rich material over the site. The C is concentrated in black charcoal and reflects slash-and-char activities deployed to increase soil productivity, and fire applied to the crop field to clean it after the harvest season. This human action generated enormous amounts of black charcoal, which is the major source of C that tends to remain in the soil profile because it is resistant to leaching. Phosphorus, on the other hand, decreased with depth in the 40 cm of the profile due to leaching and extraction by plants during the agricultural period when the ADE was used for food production.

Chapter 2

History of the Landscape

To grasp the complexity of the Amazon, it is necessary to understand the formation process of this region. To that end, this section presents a brief summary of its paleoenvironmental evolution. An introductory overview of research carried on in the area is followed by a brief general description of the major aspects responsible for the current geomorphological conditions with an emphasis on the Quaternary Period. Climate, soils, and vegetation will be discussed, as well the history of human occupation in the Amazon Basin.

Overview

The variability in the landscape is hidden by a massive evergreen cover with trees towering above 30 m. Mixed in with dense foliage are isolated savanna-like areas. Such green homogeneous territory is cut through by rivers and channels of water, some of them forming lakes. Originally the soils produced here were considered to be of poor quality with little variation across huge areas. Scientists understood this to be a limiting factor in the development of dense human occupation in the Amazon (Steward 1946, Meggers 1971). In the last 100 years, however, various scientists have discovered within the entire Amazon Basin surprisingly fertile soils classified as anthropogenica. Locally these soils are referred to as "*Terras Pretas de Índio*" (Indian Dark Earths, hereinafter, Amazonian Dark Earths or ADE). It is estimated at least that 0.3% of the Amazon has these soils (Woods and Denevan 2009). The variety in the Amazon occurs at all levels, in natural as well cultural environments. Specific patterns disrupt and expand over the territory through time. The present research being carried out in the Central Amazon region investigates archaeological sites dating to the Late Holocene and places them within a geographical context, particularly as it relates to landscape evolution in the region.

Landscape

The formation of the Amazon Basin and its rivers, vegetation, fauna systems, and human occupation has been poorly understood, especially for the Quaternary period. Scholars have disagreed in their interpretations (e.g., Sombroek 1966, Rossetti et al. 2004, Latrubesse and Franzinelli 2002). This is due to the immense area to be investigated, the difficultly of access in the dense vegetation, and the costs of conducting research in such a huge area (Sombroek 1966). However, recent developments in the Brazilian economy as well as the increase in research resources have allowed for unprecedented access into remote areas of the Amazon, bringing to light new information about the diversity formerly hidden in the shadows of the giant tropical forest.

Andean uplift, which occurred in six distinct phases from the Late Cretaceous through the Pleistocene, had its climax during the Pliocene-Pleistocene. It had a strong impact on the physiology of the northern parts of South America as well as the Central Amazon, the latter particularly during the Miocene (Hoorn et al. 1995:238). This uplift triggered a change in to the direction of the drainage flow system from West to East; during the Cretaceous it was discharging into the Pacific Ocean (Forsberg et al. 2000:64). The succession of events caused the Andean range to become barrier-like, which led to the discharge of a large amount of sediment deposited in the Amazon Valley, forming a fluvio-lacustrine environment. Without a connection to the Atlantic Ocean, the Paleo Amazon instead fed the Paleo Orinoco River system, with drainage toward the Caribbean (Hoorn et al. 1995:238-9). This new environment formed during the Early/Middle Miocene—a period marked with strong tectonic events in the northeastern Andes—is considered the precursor of the current Amazon River (Rossetti et al. 2004, Latrubesse and Franzinelli 2002, Rossetti and Toledo 2007). Other factors like tectonic effects, in association with the sedimentation process, marine transgression, and climate change, contributed in vital ways to the evolution of the landscape (Latrubesse and Franzinelli 2002, Rossetti, Peter and Góes 2005, Räsänen, Salo and Kalliolla 1987). Rossetti et al. (2005) pointed out that morphological and sedimentological characteristics of the stratigraphic units in the western Amazon experienced several environmental changes during the Neogene-Quaternary. Moreover, tectonic studies are suggesting that the area between Manaus and Santarém was under compression, creating the conditions that caused an eastward-flowing fluvial system (Rossetti et al. 2005:83-84). According to Latrubesse and Franzinelli (2002:249), the Amazon River in the Central Amazon has a nearly straight main channel, the result of tectonic control on the river dynamics and orientation. Irion (1984a) identifies sea level fluctuation as responsible for the creation of distinct features in the Amazon Basin. The low average slope at the Amazon River valley, about 2cm km^{-1}, reflects the intense influence of sea level on the landscape evolution of its floodplains and terraces (Irion 1984b:201). Moreover, during the Mesozoic and Cenozoic, the variation of tectonic deformations defined the valley gradient of the lowland rivers in the Amazon Basin (Irion 1984b, Costa et al. 2001).

The study area, located at the Amazon-Negro confluence, is seated over the Alter do Chão Formation; that is, a series of depositional fluvial sequences that became sedimentary beds.

The majority of these originated in the Cretaceous strata which form an east–west oriented belt

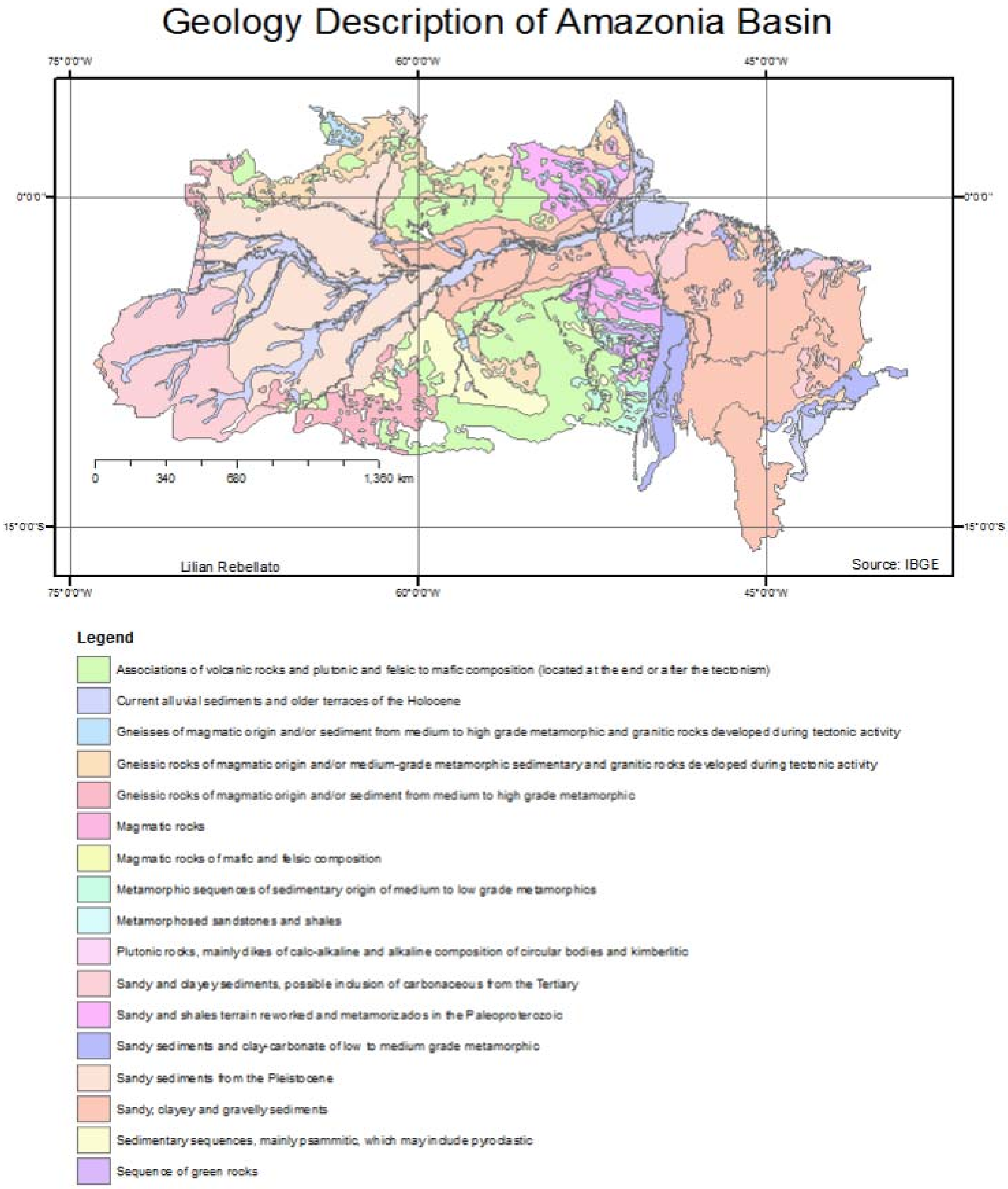


Figure 1 – Geologic formation (source IBGE, Interactive Maps, Public Domain)

overlying Paleozoic bedrocks (Rossetti et al. 2005:80, Costa et al. 2001). The Alter do Chão Formation has a maximum depth of over 1000 m in thickness and presents a medium-to-coarse sandstone grain, reflecting a cool, dry depositional environment (Pereira, Carvalho and Azevedo 2006:338, Costa 2009).

The presence of a lake or many lakes during the Tertiary in lowland Amazonia is widely discussed and described in numerous scientific studies (Rossetti et al. 2005, Sombroek 1966, Sioli 1968, Irion 1984b). The sedimentation associated with marine transgression and tectonic events is too deep in the strata, however, to be able to relate to archaeological sites; therefore, the Tertiary Period is not discussed here.

A few of the oldest archaeological remains date to between 7,000 and 4,000 BP. The preservation (or destruction) of archaeological sites is directly associated with more recent events, especially during the Holocene. To understand the geological and climatic events the sites experienced helps to locate them in the landscape. A succession of events after the Last Glacial Maximum (LGM) in 18,000 BP has been pointed out as being responsible for the mosaic landscape in the region, having had innumerous consequences on the current Amazonian complexity, as presented in the "Biodiversity" section below.

The instability of the Amazon rain forest is being reconstructed from the period of the LGM to the Late Holocene. During 13,000 -10,000 BP a rapid change in the climate accompanied by a rapid increase in the temperature in the Andes created conditions for more precipitation. As a consequence of this condition, the transition of the Pleistocene-Holocene (reflected by the sedimentation phases in some Amazon Basin rivers) suggests a glacial lake-like environment ca. 14,000–10,000 BP (Latrubesse and Franzinelli 2002:2). The glacial lake is attributed to the melting of the Andes glaciers as a consequence of the warmer climate that raised sea levels around the globe. However, some data point to a much colder and drier period during the Younger Dryas (12,600 – 11,500 BP) followed by an increase in temperature and precipitation, but with more influence of precipitation in the Paleo lake formation (Haug et al. 2001).

Thus, there were three different phenomena implicated in the submersion of a vast area of the Amazon Basin in this period, probably after the Younger Dryas, with significant effects on its landscape evolution, namely: (1) glacial melting as a consequence of the increase in the Earth's temperature; (2) the marine transgression creating a "dam-like" feature in the main flow of the Amazon River (Latrubesse and Rancy 2000); and, (3) higher levels of humidity that raised precipitation, was responsible also (via precipitation) for the swamp-like conditions and rapid sedimentation in the river valleys from 13,000 to 10,000 BP, and that continued until the Holocene (van der Hammen and Hooghiemstra 2000).

The Preboreal (11,500 – 10,400 BP) is reported as a warmer and wetter environment with the forest occupying the climax and vegetation adapting to higher precipitation like that in the northwestern, central, and southeastern portions of Amazonia; this area is said to have reached its highest temperature conditions during the Holocene *Thermal Maximum* (10,500 – 5,400 BP) (Haug et al. 2001; van der Hammen and Hooghiemstra 2000). The temperatures are reported as 1° or 2°C higher than today from 8,200 to 4,000 cal yr BP, but with little change in the lowland taxa, as ascertained through core analyses in Consuelo Lake, Peru (Bush, Silman and Urrego 2004).

The Middle Holocene had a drier environment; Sanford (Sanford et al. 1985) reports fire events in the Upper Negro River region of the Amazon during the Mid/Late Holocene (6,260 +/- years BP; 3,080 +/- 1,120 years BP; 1,400 +/- 140 years BP; 640 +/- 50 years BP; 400 +/- 80 years BP), related to drought periods. In addition, human activity changed the landscape by setting fires for a variety of reasons such as an increase of savanna vegetation (Berrio et al. 2000, Sanford et al. 1985). Mayle et al. (2000) reported the increased presence of charcoal as evidence of fire frequency between 7,000 to 3,000 ^{14}C yr. BP that affected the eastern, central, and southern parts of Amazonia (Mayle, Burbridge, and Killeen 2000:2294). Some results pointed out that the driest period was between 2,700 and 2,000 BP, attributing it to a prolonged ENSO event (*El Niño*) (Mayle, Burbridge, and Killeen 2000).

Two Flood Events in the Arid Holocene

The Middle/Late Holocene has been defined as drier than today, interspersed with evidence of flooding events between 6,700 and 2,480 ^{14}C yr. BP as a consequence of the increased humidity in the Intertropical Convergence Zone (ITCZ) (Rossetti et al. 2005:86). Most likely, the flooding that Rossetti et al. (2005) investigated was related to the drastically dry landscape caused by an ENSO in 7,000 BP. When drier conditions persisted, the soil became exposed and the lack of vegetation increased the sedimentation process during pluvial events. Thus, the pluvial water caused the dislocation of more sediments, causing yet more flooding events. Although this presents a plausible explanation, these events did not happen again until 2,480 ^{14}C yr. Therefore, more research needs to be conducted in order to clarify these opposing arguments. The impact of the drier period in the landscape will be discussed at greater length below in the “Vegetation” section.

In order to understand the nature of human occupation and the preservation of archaeological sites, it is important to consider the surrounding landscape, specifically the river systems, as they greatly influenced the positioning of the pre-Colonial occupation sites as well as the preservation or destruction of said sites.

River System

The Amazon drainage obtains water sources from both the Andean Range and the Brazilian and Guiana shields, and as a result of its geological formation the Amazon has the greatest river system on Earth: 7,050,000 km^2, with an uncountable number of large and small rivers, streams, and *igarapés* (creeks) (Sioli 1984:127). Both shields present a low gradient terrain with thin soils, creating rivers with distinct characteristics (Sioli 1968, Irion 1984b). Because it is positioned on the Equator, the Amazonian system includes portions of the Northern and Southern hemispheres; consequently, there is variation in the discharge system throughout the year (Espinoza Villar et al. 2009). Sioli (1956, 1968, 1984) classified the hydrological river characteristics in three types: black-water rivers (e.g., Rio Negro), clear or crystalline-water rivers (e.g., Tapajós), and the white-water rivers from the Andes, examples of which are the Amazon, Purus, Madeira, and Juruá rivers. The white-water rivers generally flow East-North-East (ENE), ending in the Atlantic; they are characterized by annual flooding and high rates of sedimentation (Junk and Piedade 1994, Woods, personal communication, 2011). The tributary rivers from the Brazilian and Guiana shields influence the Amazon River's behavior through a high discharge of water with small amounts of sediments (Mertes and Dunne 2007).

White-water rivers are colored by a yellowish hue related to the amount of sediments present with a pH level around 6.2 – 7.2. These rivers are characterized by high levels of biological activity and fish production (Sioli 1984). During the wet season (*inverno,* Portuguese for "winter"), December through May the lakes, channels, and floodplains are filled. Some researchers estimate that around 20% of the Amazon lowlands are covered by permanently or seasonally flooded wetlands (called *várzea*) (Forsberg et al. 2000). Two-thirds of the Amazon floodplain areas are found along the white-water rivers (Junk and Piedade 1994:155),

Figure 2 – Fluvial system at South America, Source IBGE - Interactive Maps, Public Domain

of which the Amazon River is the most prominent. These *várzea* near the white-water rivers are a complex system of Quaternary sedimentary units of different ages and formation conditions (Latrubesse and Franzinelli 2002:242). The flooding and drought episodes have relevant impact on fauna, flora, and human lives. Fertile areas annually receive a large input of suspended nutrients. These ecosystems are an important local resource, not just for agricultural fields (used during the last dry season), but for the aquatic system in regards to fish, mammals, chelonians, and useful navigation purposes (Lathrap 1970, Denevan 1996, 2001, Porro 1994).

Black-water rivers have an acidic pH level 3.8 – 4.9 and present a brownish, dark-red hue due to the incomplete organic matter (humic and fulvic acids) dissolved from the breakdown of leaf litter in acidic environments and subsequent edaphic processes in the soils (Furch and Junk 1985, Salati et al. 1990, Sioli 1984). Located in sandy soils, podzolic conditions are the main source of the black-water rivers in the Amazon, in large part because in kaolinic soils, the humic acids remain fixed in the clay particles, while in the sandy soils a great portion of the acids are swept into the streams (Furch and Junk 1985:9). The seasonality of the rainy period creates swamps where organic material from flooded forests is accumulated during the dry season and leached out during rainy periods (Furch and Junk 1985). This predictable annual flooding results in the creation of seasonal swamps called *igapó*, described as flood areas colonized by vegetation that grows on sandy soils (Sioli 1956). The black-water rivers are the most common tributaries of the Amazon River, small-to-medium in size, as opposed to the white-water rivers which are the major tributaries, followed by the clear-water (Neves 2008:362).

The clear-water rivers have a greenish color and a pH between 4.5 and 7.8, showing more heterogeneity in their acidity. Representative examples are the Tapajós, Xingu, Trombetas, and

Curuá Una rivers (Sioli 1968, Junk et al. 1985). Both the black and clear-water rivers have very low carbonate content and available nutrients; therefore, their flooding areas contain less productive soils than in the *várzea*. The complex aquatic ecosystems, teeming with more than 2,000 species of fish (Salati et al. 1990), make the white-water rivers the most plentiful of the rivers in terms of fish, while the black- and clear-water rivers flow with less diversity and density of aquatic resources—at least on scale within the Amazon.

The archaeological framework needs also to consider hydrology and its effects; this is fundamental in the prediction of areas of past occupation. The sedimentation process is a key feature in the preservation or destruction of archaeological sites, as highly productive areas tend to be more densely occupied. Thus, knowing the environmental history of the study area and its surroundings is relevant to understanding the variation of the landscape through time as well as the subsistence mode of those societies throughout each period of the Holocene. Sternberg provides an example of how hydrology and sedimentation behavior possibly impacts archaeological remains (Sternberg 1958). Through the analyses of sedimentation processes in the Central Amazon, he reports a chronological depth of 2,000 BP for charcoal at 15 m deep in the Careiro Island, in the Amazon River. This marker gives an idea of the sedimentation effects in the flooding areas. The Amazon and its tributaries have the greatest discharge of sediments in the world (209,000 m^3 /s) (Molinier et al. 1996)

The Amazon River has a complex anastomosed shape in the western region. This volumetrically immense body of water is responsible for many tons of sediment deposited in the floodplains, especially in the Central Amazon (Mertes and Dunne 2007). The sediment flux increases downstream; for instance, 616 Mta^{-1} from São Paulo de Olivença; 1240 Mta^{-1} at Óbidos and all the flow rework causes erosion and 3200 Mta^{-1} of deposition (Mertes, Dunne and Martinelli 1996, Mertes and Dunne 2007). The Amazon Basin traps these sediment influxes and the very low gradient in some regions generates large bars and channel shifting (Räsänen et al. 1987). The dynamic accretion and erosion of these sediments are responsible for the complex geomorphic and sedimentary units, with scroll bars as a representative feature in the Central Amazon (Räsänen et al. 1987).

Floodplains

The classic and static definitions of floodplains do not apply to the dynamic flooding in the Amazon, where permanent and temporary lakes become connected, including those close to Manaus where the Amazon River reaches 29 m in altitude in the floodplain and then joins with the major river channels transporting sediments and water (Junk 1997). Moreover, the large rivers' floodplains, in general, are catchment areas of high-quality organic material for plants and animals, causing migration and dispersion, which distinguish these floodplains from those of the smaller rivers (Junk 1997).

The floodplains in the Amazon are divided into three types: (1) large rivers with predictable pulse and wide amplitude; (2) depressed or insufficiently drained areas, causing a lake-like effect (also predictable with large amplitude); and (3) floodplains of small rivers, characterized by unpredictable flooding (Junk 1997).

Another feature with relevant effects in the Amazonian ecosystem is the seasonality of the rainfall flooding, which covers 300,000 Km^2 during the periodic flooding (*cheia)* and the dry season (*vazante*) (Irion, Junk and Mello 1997). The floodplains *(várzea)* formation process was closely related to the fluctuation of sea levels during the Quaternary sea level fluctuation (Irion, Junk, and Mello 1997). Around 5,000 BP when the sea level reached around the current level, the floodplains were formed as a consequence of well-developed scroll bars and swales, with units with more than 20km (Irion et al. 2009). As defined by Junk, "[In the Amazon], floodplains are areas periodically inundated by the lateral overflow of rivers or lakes and/or by direct precipitation or groundwater; the resulting physiochemical environment causes the biota to respond by morphological, anatomical, physiological, phenological, and/or ethnological adaptation and produces characteristic community structures" (Junk, Bayley, and Sparks 1989:112). Avoiding the oversimplified view of adaptation as a unilateral effect, it is possible to see in both current and past human societies a substantial knowledge how to exploit resources during these seasons of the year, with consequent changes in subsistence and settlement patterns.

The floodplains in the Central Amazon have a close association with the eustatic sea level fluctuation during the glacial periods, when the rivers cut deep and broad valleys into the soft tertiary sediment due to the increase in gradient (Junk 1984:218). The sea level rose and created a dam-like structure that backed the rivers into the Amazon Valley, reducing current velocity. The white-water rivers with high sediment loads filled the valley quickly, forming the large *várzea*, especially after the last glacial period at 18,000 BP (Junk 1984:218). Denevan (1996) proposed a model which predicted a high population density in the floodplains/*várzea,* a much higher figure than that postulated by Meggers (1994) (5 – 15 per km^2 instead 0.3/ km^2). However, the settlements Denevan studied were located in the fringes of the bluffs adjacent to the active river channels. In this Bluff Model, the areas of habitation were thus not subject to flooding (Denevan 1996:655). Bluffs have an almost vertical rise above the river valley, are higher than the water fluctuation of 10 – 20 m, and terraces the area between the alluvium from the *várzea* and the weathered soils of the Tertiary Pleistocene uplands or *terra firme* (Denevan 1996:665). As a result, the bluffs were more densely occupied in the past, but they remained subject to abandonment when major rivers changed course (Denevan 1996). According to Denevan, the sites found today reflect the pattern of occupation in small bluffs close to fresh-water streams, but many of them were destroyed by changes in the river hydrology.

The floodplains (*várzea)* present a large number of clear advantages for past subsistence systems; conversely, uplands have typically been considered poor environment systems with small numbers of villages and dwellers. However, though still few in number, studies related to this issue are bringing to light new discoveries and revealing unexpected patterns in the uplands.

Uplands

The uplands (hereafter called *terra firme),* have an elevation of 50–300 m, extend from the east Atlantic coast to the Andean Range, and are composed of a closed canopy of diverse evergreens mixed with savannas (Haberle and Maslin 1999:28). Great parts of the soils in the Plio-Pleistocene terraces present a variance in texture from loamy sand to heavy clay, with low base saturation, cation exchange capacity (CEC), with most of the available nutrients for plants linked with organic matter in the top soil (5 – 30 cm) (Sombroek 1984:525).

Classified as poor soil lands, these areas were previously understood to have had shifting human occupations due to agricultural cultivation patterns as a result of soil exhaustion; therefore, scarce resources restricted the rise of permanent and densely populated villages (Meggers 1954, 1971). However, Denevan (1998) called attention to the evidence of cultivation and population density in *terra firme* regions in the Amazon, highlighting different strategies of food production in these areas. Considering the inefficiency of stone axes for cutting thick trees in the forest, Carneiro (1961) and Denevan (1998) pointed out a contradiction in Meggers's assumption, which projected small villages in constant movement due to soil exhaustion in the *terra firme* areas. In other words, the shifting cultivation system could never have happened among the traditional farms in the *terra firme* without the introduction of steel axes. The energy and time necessary for cutting trees would have made a constant rotation of fields and crops infeasible (Denevan 1998:54). Denevan also suggested several alternative possible patterns for *terra firme* cultivation and initial clearing in the forest during the past: (1) house gardens; (2) intensive swiddens; (3) patch cultivation; and (4) agroforestry. Additionally, Carneiro (1956, 1961) pointed out that the semipermanent cultivation settlements currently practiced by the Kuikuro, an ethnic group located along the Culuene River, a tributary of the Xingu River, could be attributed to supernatural, warfare, or fissioning village factors rather than soil exhaustion. Thus, "the abandonment of a plot after a brief period of cultivation can be best understood, not as a necessary consequence of rapid soils depletion in the tropics, but rather as the most economical way of carrying on subsistence farming under the prevailing conditions of technology and environment" (Carneiro 1961:140). Finally, Carneiro (1956:231), who tested permanence in villages and food production (crops), demonstrated that slash-and-burn cultivation in that region could be conducted continuously without decreasing the fertility of the soil around a village with a population of approximately 2,000 people.

Denevan (1992a, 1996, 2001) added that in the past, clearings produced by natural tree falls were exploited agriculturally and that these initial clearings were enhanced and expanded over time. Denevan (2001:40) suggested that a mixed cropping system ("polyculture") was the technique used by past societies to combat pests and weeds and to protect the soil from sun and rain. More researchers are pointing to denser areas occupied in the Upper Xingu, as presented by Heckenberger (1998, 2005a). With moats, ditches, and mounds, Heckenberger analyzed the pattern of distribution of defensive structures and field cultivation and concluded a constant increase of village size, instead of abandonment, over time. He observed the distribution over a greater area of moats for protection of villages, which also increased population density.

Now, the discussion will move on to a short description of general characteristics of the forest formation through time and, following that, details about the chronology of occupation in the Amazon.

Soils

The 1970s the Projeto RADAMBRASIL (Radam project) began mapping large areas of the Amazon and examining soils systematically. Even so, there remain wide regions with little or no mapping. Although it is generally believed that the Amazon's soils are invariably ancient, intensively weathered, and lateritic, the tropical soils in the region encompass all taxa (Quesada et al. 2011). Basically, using the Brazilian Soil Classification System the most common soils in the Amazon are *Alissolos, Argissolos, Cambissolos, Espodossolos, Gleissolos, Latossolos, Nitossolos,* and *Plintossolos* (Embrapa 1999). According to Sombroek (1966), the soil classifications used by FAO and U.S Taxonomy, soil distribution in the Amazon is as follows: in the terraces of the Plio-Pleistocene are found Latossolo Vermelho-Amarelo (Brazilian), orthic Ferralsols (FAO), or Harplorthox (U.S. Soil Taxonomy); Acrisols (Paleudults or Thropudults) and Ferralsols (Haplorthox) in the Guiana and Brazilian shields and in the sedimentary portion of the Central Amazon River; Acrisols (Paleudults or Thropudults) in the western portion, near the Andes; Arenosols (Tropaquent/Quartzipsamments), Lixisols, Nitisols (rhodic Paleudalfs), Histosols, and Podzols (Tropaquods) in the vicinity of both shields and the Negro River; Plinthosols also in the Guiana and Brazilian shields as well as in sedimentary regions like the Purus, Madeira, and Juruá rivers; and finally Gleysols (Aquepts, Aquoll) and Fluvisols (Fluvents) in the floodplains (*várzea*) and along the Amazon River (Quesada et al. 2011:1420, Sombroek 1984).

The subject of this research, the ADE, is a category of anthropogenic soils, vaguely classified as *Latossolo Amarelo distrófico antropogênico* in the Brazilian classification system. Widely spread in the Amazon, ADE occurs mostly in the *terra firme*, but recently these soils also have been identified in the floodplains (Macedo 2009). The ADEs remain without a satisfactory classification system, as observed by Woods (1995) and Kampf et al. (2003, 2009) and further presented in the "Current Research" section below.

The soils in Central Amazon result from fluviatle and lacustrine sediments and present high proportions of sandy and kaolinic materials with nutrients and very low pH levels (Furch and Junk 1985). Archaeological sites located in the white-water rivers, predominantly, are over the Latossolos or Ferralsol (FAO) or Oxisols (USDA), located on the Pleistocene terraces. These are described as well drained with low fertility and strongly acidic pH levels, generally with a yellowish hue; the base saturation sits below 40%, and a relatively high exchangeable aluminum is present (Sombroek 1966:125). Latosols/Oxisols are widely spread in the *terra firme* and largely found under forests. Sombroek (1966) subdivided this soil type into Kaolinitic Yellow

Latosol, which generally has a yellow or red hue with more than 15% clay, presenting a clay-like texture to a depth of 30 cm (65 – 75% clay); and very clay-like farther down (reaching 80 – 90% at 2 – 4 m depth) (Chauvel, Lucas, and Boulet 1987). Kaolinitic Latosolic Sand (less than 15%, generally found near rivers), Red Yellow Latosol, and Dark Red Latosol are heavy textured with finer sand fractions (Sombroek 1966:176). Due to the poor drainage in the *várzea* or the Holocene terrains, these soils are predominantly Humic Gley associated with white-water rivers as well as Plintosols. Alluvium soils are found in moderate-to-well drained soils mostly in the floodplains upstream of main rivers (Sombroek 1966:178). In the Central Amazon surrounding the Negro River, a distinct pedologenetic characteristic is found in Ground Water Podzols. These soils, generally located close to both clear- and black-water rivers and regions, are characterized by white sandy podozols. These regions present a distinct water catchment area, with rivers having fewer salts and elements and more acids.

Vegetation

The great diversity in the biomass attracts the attention of a variety of researchers, especially in the *terra firme* with its 60,000 species of plants (Salati et al. 1990). A general classification distinction can be made between lowland forests and *terra firme* forests. Lowland forests are subtyped as *mangue* (mangrove), *mata de igapó* (swamplands), and *mata de várzea* (wetland forests). Prance (1979) observed that different water compositions and waterlogging conditions in white-, clear-, and black-water rivers created distinct vegetation types. Upland forests, in addition to their high diversity of species, also encompass areas of *cipoal* (creep forest), *Tabocal* (bamboo forest), and *Cocal* (palm forest) (Sombroek 1966:56).

In both *terra firme* and floodplains, depending on the climate, soil, or drainage systems, savanna vegetation can be found due to edaphic factors or human activities such as clearing and fire (Salati et al. 1990, Bush et al. 2007). Divisions denoting the various types of savanna are common; for example, lowland savannas, which can be found in rivers, lowlands, and near sea shores where seasonal rainfall accumulates. The upland savannas are called *campo, campina, caatinga,* and *campinarana*. As a general description, the savanna has scleromorphic vegetation on leached white sand soil (Podzol) ranging in structure from open savanna to tree cover that exceeds 10 m in height, characterized as low diversity and high endemism, respectively (Anderson 1981:199, Prance and Schubart 1978). In the research arena these features are associated with archaeological sites located in the Negro River, where the majority of the soils are characterized as podzols. The lowland savannas in the floodplains are called *campo de várzea de rio;* in the white-water rivers, these savannas are "grassy, shrubby with intermittent or permanent waterlogging" (Sombroek 1966:58). The rain savannas (*campo de várzea de chuva*) are grassy vegetation, "half yearly submerged with rain water"; and the last type of savanna region in the floodplains is associated with mangrove forests on the coast (*campo de várzea de mar*) (Sombroek 1966:58).

Climate

The climate is not local; the summer is characterized by convection, which draws moist air from the Atlantic southward, bringing large amounts of rainfall (Maslin and Burns 2000). An important climatic characteristic of the region is a slight average variation of the temperature throughout the year; for instance, during the dry season the average high temperature in Manaus is 27.9° C and, in the rainy season (between February and April), 25.8° C; Belém has an average high temperature in November of 26.9° C and an average low of 24.5° C in March; Iquitos's average high temperatures measure 32° C in November and 30° C in July (Salati and Vose 1984:135). This isothermal condition results from a large quantity of water vapor in the atmosphere (Salati et al. 1990:481). The seasonal cycles of rainfall vary depending on location; the maximum rainfall in the northern regions occurs between June and July, while in the south, those maximums are measured from November to March (Salati et al. 1990:482). Typically, most of the Amazon accumulates annual precipitation of 2 – 3 mm and potential evapotranspiration of around 1,500 mm per year (Chauvel et al. 1987). Salati and Marques (1984) pointed out that in the region, the hydrological cycle contributes to the climate and also to geographic factors. Half of the precipitation is carried by Atlantic winds and the other half derives from the evapotranspiration from the Amazon Basin and its plants, suggesting a strong relationship between vegetation and the amount of precipitation (Junk et al. 1985, Salati and Marques 1984).

The Diversity in the Amazon

In order to understand the diversity of flora and fauna in the Amazon, one must consider the geology, geomorphology, climate history, and human interaction with these elements. One major, though controversial, theory—the *refugia* (refuge)—emerged in early research and was adopted by a number of investigators. This theory contends that around the Last Glacial Maximum (LGM) and post-Pleistocene periods islands of forest surrounded by savanna areas forced a wide speciation of fauna in the lowlands of South America (Haffer 1969; Vanzolini 1970; van der Hammen and Absy 1994; Clement et al. 2010). Meggers (1977) used the refuge theory as an analogy for human societies affected by the environment in the Holocene. The following section will first explore the basic tenets of the refuge theory and consider how it impacted different areas of knowledge related to the South American lowlands; following this will be a discussion of its effects on archaeological perspective. This section will conclude with a presentation of new research on this topic and will explain how these new approaches are affecting reconstructions of past societies' histories, including their impacts on the landscape.

Biodiversity

According to Haffer (1969), the Amazon suffered dramatic climate fluctuation from the end of the Tertiary until the Late Holocene, alternating expansion and contraction of the forest with repeated isolation of the forest animal population. Therefore, during the Quaternary the climate fluctuation caused a contraction and expansion of the forest, which affected animal populations. Haffer (1969) points to a drier and cooler climate during the LGM, with vegetation divided into smaller, more numerous but isolated forests, which he calls refuge areas. Such island-like forests surrounded by savanna vegetation forced speciation among birds (and other faunal resources) due to geographic isolation (Haffer 1969:131). Vanzolini (1970) and Prance (1973) argue that floral and faunal diversities are related to the drier period and subsequent geographic isolation at the end of Pleistocene and post-Pleistocene. Geological evidence like the "stone lines" (lateritic formations) was interpreted as proof of the drier period of forest contraction during the LGM (Ab'Sáber 1977). Thus, the refuge theory was formulated on and supported by distinct field research (Ab'Sáber 1977, Clement et al. 2010, van der Hammen and Absy 1994, Vanzolini 1970). Conversely, Colinvaux (1979, Colinvaux et al. 1996) argued against that hypothesis, pointing to pollen results from Lake Pata. His analysis suggested that during the LGM the decrease in precipitation was not sufficient to fragment the forest as suggested in the refuge hypothesis. The real cause for the diversity of the species was, in Colinvaux's view, a 5° to 6° C decrease in the temperature which pushed communities toward cool-adapted taxa (Colinvaux et al. 1996:87).

While the refuge theory is still being debated, there are now more data available. One of the conclusions emerging from this new information is that the enormous biodiversity in the Amazon has a much deeper timespan than previously thought. The original estimation placed the origin of the Amazon's intense biodiversity in the Neogene era (20 million years ago) and named tectonics and climate change as geographic isolation factors that led toward the speciation of plants, animals, birds, and insects (Hoorn et al. 2010, Rossetti et al. 2005). The biodiversity of plants is now also attributed in part to human influence on the landscape, as early human occupants acted directly on the increase of diversity and the dispersion of plants in the Amazon Basin (Balée 1989, 1994, 2000; Clement 1988, 1999a, 1998; Junqueira, Shepard and Clement 2011; Shepard Jr. and Ramirez 2011). Earlier researchers' more idyllic views of a "pristine" and untouched rain forest are giving way to more complex scenarios that consider the role played by the domestication and semi-domestication of plant species in the current configuration of the forest (Denevan 1992b).

Cultural Diversity

Early research focused on the lowlands of South America held to an environmental determinist view in an attempt to explain the settlement patterns as well the diversity of the archaeological remains in the tropical region. Ecological adaptation was highlighted by Meggers (1971, 1973, 1977) as the principal cause for mobility among indigenous populations in

Amazonia. Meggers asserted that changes in the environment affected human communities, and poor tropical soils forced them to keep in constant movement. She posited an interval of three to five years in any established settlement before the native peoples would have needed to move due to soil exhaustion. Moreover, Meggers (1977, 1979b) used the concept of climatic fluctuation during the Holocene to apply a model that explains the pre-Colonial language dispersion and archaeological pattern of mobility within those societies. In her analysis, from 4,000 to 2,000 BP a cooler and drier period affected the subsistence resource access of those past societies; they were forced to adapt to conditions of lower productivity. The results manifested in migration, mobility, and extinction; all of which are reflected in the linguistic distribution pattern (Meggers 1979:256).

New research has shown, however, that a purely environmental explanation is no longer sufficient to understand the geographic extension and diversity found in the linguistic patterns and archaeological records. Whitten (1979) highlighted that the climatological studies in Amazonia were poorly understood in prior to the 1980s, but the last few decades have brought greater clarification. The isolation of groups of plants, animals, and societies, for example, is now understood to have been another factor in the increase in the diversity of species and languages. Research in different Amazonian countries is showing a distinct variety of human settlement patterns, subsistence modes, and human activities that changed the environment (whether intentionally or unintentionally) in the region. These include: raised agricultural fields in Bolivia, Venezuela, French Guiana; roads and wide villages in the Upper Xingu; large sites with ADE in the Central Amazon and Upper Madeira; and finally, stone alignments in Amapá, the enclosures (geoglyphs) in Acre, and platform-like formations in Marajó (both in Brazil).

Archaeology is finding more old ceramic sites and is helping to reconstruct the puzzle of the pre-Colonial occupation throughout the Amazon rain forest. As a result, a picture of greater diversity of settlement and subsistence practices of previous societies is emerging.

Ethnobotanic research carried out in the Amazon in the past decades presents an interesting example. It points out a rich genetic diversity among crops as “artifacts” in the landscape; that is, huge areas of anthropogenic forest, especially those with palm and fruit trees, are signs of distinct management of the forest by past societies (Balée 1989, 1994). In 1492, there were 138 species cultivated or managed by people. This number is higher than what is cultivated currently, which reflects a genetic “erosion that starts in the Contact Period” (Clement 1999). Through the inventory of plant species at archaeological sites, Junqueira et al. (2010) concluded that sites with *Terra Preta de Índio* have a greater density of domesticated plants per area than surrounding places. Domestication is a co-evolutionary process, where specific selections promote a change in plants’ genotypes, making them more useful and better adapted to the landscape (Clement 1999b; Junqueira et al. 2010:189). Balée (1989) called these anthropogenic forests and projected that 11.8% of the forests in the *terra firme* are archaic and have a cultural origin (Balée 1989:2). Evidence, then, supports the notion that the environment is affected by a great variety of cultures and peoples (Roosevelt 1994) and reflects distinct subsistence modes. The following sections provide greater detail about the culture–nature relationship with a focus on the occupation history in the Amazon.

History of Human Occupation

In the last fifteen years, the Central Amazon project, headed by Dr. Eduardo G. Neves, has witnessed a swell in research from a variety of disciplines focused on the Amazon and its past. Paleoenvironmental, archaeological, and paleobotanical data are allowing a better understanding of the region. As part of this larger project, the goal of this dissertation is to recover part of the late history of occupation through a geoarchaeological perspective. Specifically, this study aims to correlate increases of population and the ADE genesis. A case study was conducted in the area as a way to identify the processes that initiate changes in the landscape and settlement patterns as well as spur interactions among groups. Through soil analysis this study examines whether or not people were exploring ADE areas for food production in the beginning of the second millennium. First, a short review of the human occupation in Amazonia will be provided, followed by a discussion of the major groups studied herein (Arawak and Tupi).

The earliest occupation in the Amazon started at the end of Pleistocene, though research is really only beginning in this area (Roosevelt et al. 1996). As shown in the earlier discussion of Floodplains, the Amazon River and its white-water tributaries are accreting over the time, causing ever-widening floods, burying great portions of these earlier settlements, especially those in the Middle Holocene. Therefore, the Amazon remains unknown in many respects; current research and results are beginning to reveal a complexity in human occupation that evolves in a landscape in constant flux as a result of a changing environment.

Pleistocene-Holocene Transition

Early research understood the rain forest environment to be an ecological barrier for Paleoindians due to scarce resources (Roosevelt et al. 1996); however, sites excavated in different parts of Amazonia set the first dwellers around 11,400 BP (Miller 1992, Roosevelt et al. 1996, Roosevelt 1994, Schmitz 1990, Simões 1976). In the north margin of the confluence of the

Amazon and Tapajós rivers, near Monte Alegre town, the Pedra Pintada sandstone cave reveals an early occupation transition period with a range dated between 11,400 and 10,000 BP (Roosevelt et al. 1996, Roosevelt 1994:4). The region has rock shelters with stylized rock paintings in reds and sometimes yellows, with geometric expressions and anthropomorphic figures (Roosevelt et al. 1996). The strata identified as Paleoindian presented triangular lithics, which are stemmed bifacial points of hyaline quartz or chalcedony shaped as knives, gravers, and scrapers. These were separated from the Holocene deposit by three culturally sterile layers (Roosevelt 1998:167). A large quantity and diversity of fruits in the cave demonstrates the importance of fruit in the diet; moreover, a variety of faunal bones also were abundant and included fish, rodents, mollusks, turtles, amphibians, birds, and large terrestrial mammals, showing a broad-spectrum diet mixing aquatic and terrestrial resources (Roosevelt et al. 1996:379). The rock painting shelters revealed successive Paleoindian cultures. The earlier lithic industry can be divided in two: one in north-central Amazonia with small, finely chopped, tanged spear points; the other in the south, showing large, crudely chipped, heavily worn scrapers (Roosevelt 1994:4). The changes in the shape and size of the tools in the Early Holocene are related to climate change; in the lowlands, this might suggest subsistence adaptation for small mammals and fishing (Roosevelt 1994:5). According to Roosevelt, “The assemblage indicates that Paleoindians visited periodically for more than 1,200 years” (Roosevelt et al. 1996:380). There is a gap in the record after 10,000 BP and then the cave is reoccupied. Data are presented in the “Early Holocene” section.

In the Upper Madeira River the earliest archaeological evidence is attributed to the Periquitos cultural complex dating to 11,940 BP with earlier dates from Pedra Pintada where the buried ecofacts were associated with a paleo-channel (Miller 1992:221). Thus, many sites during the Pleisto-Holocene transition were occupied in isolation from the Pre-Clovis or Clovis cultures despite some chronological overlap. The Paleoindians in the Amazon had different artifacts and art, as well as their own subsistence practices (Roosevelt et al. 1996:381).

Early Holocene

In the Central Amazon at the confluence of the Negro and Solimões/Amazon rivers, the Dona Stella site presented dense and variable lithic technology dating to 9,460 and 4,500 BP (Costa 2009), including bifacial artifacts and a projectile point which were dated to 7,700 BP (Neves 2003). Dona Stella is located in a savanna (*campinaranas*) area; prospecting efforts in the region found a positive correlation between savanna areas and pre-ceramic sites (Neves 2008). Along the Jamari River, a tributary of the Madeira, early archaeological sites reflect various traditions and phases, including the Itapipoca, 9,000 – 5,000 BP, with lithic tools like scrapers, bifacial pre-forms, and pressure flanking from quartzite and criptocrystal; and the Pacatuba, 8,230 – 4,780 BP, represented by flints, pressure flanking, polishers, stone axes, and quartzite and criptocrystal as raw material (Miller 1992:221-22). Evidence shows that the diet throughout these phases was based on fishing, hunting, and gathering.

Along the Middle Caquetá River, Colombia, the Peña Roja site presents a pre-ceramic occupation beneath a ceramics settlement. Evidence dates to 9,250 – 8,090 BP, and includes carbonized seed remains associated with lithic artifacts from a diversity of raw material available in the region like chert, clastic sedimentary rocks, and igneous and metamorphic rocks (Gnecco and Mora 1997:688). The region is located in the Araracuara plateau where researchers have found a consistent reliance on plant resources during this period. Gnecco and Mora also pointed out that low animal biomass and heterogeneous distribution of vegetal species reveals that those groups relied more on gathering than hunting (Gnecco and Mora 1997:689). Human impact on the vegetation, which includes the domestication of plants and gives preferences to palms, is evident beginning as early as 10,000 BP and is related to adaptive strategies in the humid tropics (Gnecco and Mora 1997:689). Clement analyzed the dispersion of *Bactris gasipaes* (Peach Palm) and concluded that, as a seed, its dispersion pattern is limited. Rather, these early people started a domestication process during their expansion of South America (Clement 1988). Clement found that domestication as well territorial dispersion of the *B. gasipaes* had to occur at a very early time, "because the difference between the primitive pejibayes (e.g., G. *microcarpa*, fruit size 4.4 g) and the most advanced landraces (e.g. Putumayo, 100.8 g) is enormous." The fruit size for both species of *Guilielma* increased 2,000% (Clement 1988:831). Clement concluded: "A change of magnitude takes considerable time and requires specific breeding conditions" (Clement 1988:162). Thus, the domestication process and dispersion of plant species created a mosaic in the forest with patches of palm and other trees. These are often associated with early abandoned settlements. The impact of humans can be seen in the ways they changed, dispersed, grouped, and domesticated or semi-domesticated enormous varieties of plant species over thousands of years. These activities generated anthropogenic forests (Balée 1989) as presented in the "Biodiversity" section.

Middle Holocene

Dating to the Early–Middle Holocene transition, two sites at the confluence of the Amazon and Tapajós rivers, Pedra Pintada and Taperinha, present pottery, the oldest in the Western Hemisphere. Pedra Pintada cave is related with the Paituna culture, which is radiocarbon dated to the Paituna phase between 7,580 BP and 6,625 BP (Roosevelt et al. 1991, Roosevelt et al. 1996:380). Markers of the Paituna culture are its red-brown to gray-brown ceramic sherds of sand or shell tempera and a diet specialized in aquatic faunal exploitation. Another site in this region, Taperinha, also presented 12 radiocarbon dates gathered from various materials including shells, charcoal, and reduced charcoal from ceramic fragments that span ca. 8,000 BP – 7,000 BP (Roosevelt et al. 1991:1623). According to Roosevelt, the site, which has been partially destroyed by mining activities, is a riverine shell mound and was a seasonally occupied fishing village, measuring 6 hectares and 6.5 m deep. It was first excavated by Hartt in 1876. Among the archaeological remains are fragments of pottery bowls with a grit-temperate, some of them with incised rim decoration; lithic artifacts like hammer stones, flake tools, and others used for grinding; and mollusk and turtle shells used as scrapers (Roosevelt et al. 1991:1624, Roosevelt 1997).

Pointing to examples on South America’s west coast and the mouth of the Amazon River near Taperinha and Pedra Pintada, Roosevelt (1995) called attention to an association between early pottery and shell mounds (in both fluvial and marine contexts). Following the Paituna phase is the Alaka phase at Guyana, 5,900 – 3,100 BP (Roosevelt 1995:117-18), and the Mina phase on Marajó Island, dated between 3,000 BC and 1,600 BC (5,000 BP to 3,600 BP) (Simões 1981, Roosevelt 1995). The correlation between early ceramic groups, located in the Santarém region, with those phases found on the coast of Guiana and in the Amazon River mouth (Alaka and Mina phases, respectively) is controversial and not fully understood. Some classify the shell mounds at British Guyana as pre-ceramic (Williams 1997), while the Mina phase pottery is associated with shell mounds and is confirmed by various sources (Simões 1981, Roosevelt

1995). Others see problems with the association between ceramics and shell mounds over such a wide timespan and cannot account for differences between the ceramic complexes. For instance, sand temperate vessels from Taperinha and Pedra Pintada are decorated with incision marks; whereas ceramics dating to the Mina phase are undecorated shell temperate (Neves 2008:165-166)

San Jacinto, Colombia, is another early ceramic example in South America. The site, located on a point bar near a floodplain close to the northern coast of the country, is radiocarbon dated between 5,940 BP and 5,150 BP (Oyuela-Caycedo and Bonzani 2005). Caycedo theorizes that these ceramics are not evidence for sedentism, but are related to an intensification of social and economic activities related to group interactions that were restricted or reduced geographically. Better control requiring scheduling, monitoring, and intensive processing would have been necessary to localize available seasonal resources (Oyuela-Caycedo and Bonzani 2005:157). Valdivia, dating to ca. 5,000 BP, on the coast, was discovered by Estrada and excavated by Meggers and Evans. They hypothesized that this was the first equatorial ceramic center and that the new technology was dispersed from here throughout South America (Meggers et al. 1965). This theory, however, is no longer accepted. Nevertheless, chronological overlaps associated with early pottery in different parts of the Lower Amazon are furnishing baselines that support independent invention of pottery throughout different regions of South America (Gomes 2008, Roosevelt et al. 1991); moreover, results are confirming that the oldest pottery of the Americas originated in Amazonia among groups with a predominantly aquatic subsistence. Despite the early radiocarbon dates, the Middle Holocene has distinct chronological occupational gaps that will require more archaeological data. This hiatus in the archaeological record is not just in Amazonia, but covers different regions of both North and South America (Sandweiss, Maasch and Anderson 1999; Araujo et al. 2005, Anderson et al. 2007). Neves (2008) points out a chronological hiatus (from 5,700 BP to 3,800 BP) in the lower Tapajós and Amazon regions, during the Middle and Early Late Holocene just after the Pedra Pintada occupation. The same was observed in the Central Amazon region occupied by Early Holocene hunter-gatherers who, using fire, changed the soil and landscape and created open savanna areas. Neves observed an abrupt interruption in the archaeological record from 7,700 to 2,500 BP, despite over 100 archaeological site excavations within 900 km^2 (Neves 2008:363). At least one hypothesis accounts for this gap. Oliver suggests that in the Araracuara-Caquetá region, the locus of the Peña Roja site, the gap between 8,000 and 4,700 reveals a shift in the subsistence mode from foraging and itinerant farming to agriculture (Oliver 2008). Further archaeological data for surrounding areas may help corroborate this theory (Oliver 2008:206).

These data suggest that people occupied the region during the Middle Holocene despite the scant evidence. Neves (2008) posits that ecological effects had a significant impact on subsistence sources, more so than previously thought (Neves 2008:364) and uses this as an explanation for the gap in the archaeological record. A dry spell created rivers with lower water levels, resulting in the later destruction or burial of most archaeological sites that would now be below hundreds of meters of alluvial sediment in the floodplains (Neves 2008:364). Sternberg (1960) pointed out the high sedimentation system in the floodplains (Careiro Island), with dates around 2,000 BP buried at 15 m. Research carried out in Lake Titikaka demonstrate that maximum aridity occurred between 8,000 and 5,000 BP (Baker et al. 2001:642). Pollen analysis from the same time period from the Carajás region shows an increase of *gramineae* and a sharp decrease of trees during this period (Martin et al. 1993:343). This safely corroborates the theory of a drier period with lower levels of water in the river systems. Therefore, it can be ascertained that current floodplains were former alluvial plains during the Middle Holocene.

With the increase in humidity that occurred after the dry period, archaeological evidence also increases. Some occupational evidence in the Upper Madeira at the Jamari River is associated with deposits at the end of the Middle Holocene during the Girau and Massangana phases, (ca. 4,500 – 2,640 BP). These are associated with the presence of *G. insignia* (chonta) and *G. gasipaes* (pupunha), revealing vegetation management (Miller 1992:221). Clearly, more geoarchaeological research surveys need to be carried out in the area in order to understand more precisely the various cultural and natural events responsible for the gaps in the Amazonian archaeological record.

Late Holocene

Palynological evidence shows dry periods occurring during the Late Holocene. The Central Amazon Basin was affected by some widespread climatic effects associated with long-duration low phases of the Southern Oscillation, particularly during the last 1,500 years, when oscillations were stronger (Piperno and Becker 1996:208). Despite this, this region seems to have experienced a political centralization period in a number of sub-regions once the settlements' occupation periods increased with the advent of more complex agricultural activities. Evidences of systematic cultivations of domesticated crops, like cassava (*Manihot esculenta*) and maize (*Zea mays*), become visible in the archaeological record ca. 3,000 BP (Piperno 1998, Oliver 2008). Therefore, "phytolith analysis from several different regions points strongly to the development of food production in the lowlands of the tropical forest during the Early Holocene, and a subsequent emergence of truly productive slash-and-burn systems 2,000 – 3,000 years later" (Piperno 1998:441). Starch grain from *manihot,* for instance, was detected in the Cauca region and was related to field crops ca. 4,000 BP.

In the Lower Tapajós, finds included utilitarian pottery for cooking as well as storage vessels with remains of manioc and maize for the processing of food and beverages (Gomes 2008). Denevan (1992c) noted the inefficiency of stone axes in slash-and-burn cultivation, which accounted for the absence of these tools. This aided researchers looking for evidence of a distinct subsistence pattern in floodplain and uplands resource exploitation among groups with different strategies. Complementary economies developed a landscape with permanent fields for food production and calendar scheduling associated with agroforestry management practices (Gomes 2008:202) in addition to hunting and fishing activities.

Current research is addressing the chronological hiatus in the Lower Amazon during the Late Holocene at the Santarém region, with a long sequence of occupation by horticultural communities with a sedentary lifestyle (Gomes 2008). According to Gomes, it is possible that pottery was developed in the region in association with an earlier occupation, related to freshwater shell middens (Gomes 2008:177). Sedentism in the region dates to around 3,800 and 3,600 BP and is related to an Incised Rim Ceramic Tradition over a long time period (Gomes 2008). These changes in the settlement pattern related to a sedentary lifestyle are widespread throughout Amazonia. Ceramics, however, represent a mosaic of distinct phases and traditions that developed independently in different places at approximately the same time (Neves 2008:366). Therefore, new evidence suggests a more complex model than previously asserted, showing a wide distinction of landscape management practices associated with a long-term plant domestication process (Denevan 1970, 1992; 1996; Erickson 2003; Heckemberger et al. 1998, 1999; Heckenberger 2008; ; Mora 1991; Neves 2003, 2008; Oliver 2008; Smith 1980; Woods 1995). To provide a context for the current model of complexity, I first present an overview of the interpretative models of the past before delving into the discussion of the new lines of research.

A Retrospective

In *The Upper Amazon,* Lathrap (1970) defined the Central Amazon region as the origin and dispersion center of plant domestication and pottery invention as well as the locus for the most dominant spoken languages of South America, Proto-Arawak and Proto-Tupi. According to Lathrap (1970), the Proto-Arawak language began spreading from the Negro River Basin below its Amazon River confluence to Macro-Arawak groups, and the Macro-Tupi language originated in the Madeira River Basin and its Amazon confluence. According to his model, the languages (Macro-Arawak and Macro-Tupi) started to diverge around 4,000 – 5,000 BP in a rich innovation environment, as agriculture and pottery flourished in South America. Through time, more and more languages began splitting off, taking over other regions as people migrated due to demographic pressures owing to competition for the fertile soils on the *várzea* (floodplain). This evolved into a progressive movement out of the Central Amazon through the rivers' connections. Lathrap (1970) also supposed that these groups were looking for regions similar to their prior settlements, such as fertile alluvial lands found in the white-water rivers' floodplains. Closer to the Andean regions, the Arawak migrated toward the northern coast of South America and the Caribbean through the Negro River and Cassiquiare channel, then taking the Orinoco to its mouth (Lathrap 1970:110-15). The Tupi groups migrated toward the east coast and finally toward the south.

Lathrap's cardiac model differed from Julian Steward's model that classified "environmental-evolutionary" types of cultures and became the standard archaeological perspective of South American pre-Colonial societies until the 1980s (Viveiros de Castro 1996). Julian Steward classified the cultural traits of the Equatorial-Caribbean regions of South America into four groups, which he recorded in the six-volume *Handbook of South American Indians* (1946-1950) as follows: (1) Andean civilization; (2) Circum-Caribbean chiefdoms; (3) Tropical Forest "tribes"; and, (4) Marginal groups. Through these geographic/environmental types, Steward placed societies along a spectrum of "eco-evolutionary" positions, from more complex societies, which he saw in the Andean civilizations down to the bands of hunter-gatherers, primarily located in the Marginal groups (Steward 1946).

The Tropical Forest cultures, applied to the rainforest societies in the Amazon, were set in the "type evolutionary scale" between the Circum-Caribbean chiefdoms and the Marginal hunter-gatherer groups, and then subdivided according to interfluvial and floodplains locations. The Tropical Forest societies were organized into egalitarian and disarticulated villages. The major subsistence systems were extracted from the forest and rivers, as well as through slash-and-burn agriculture, which required a shifting of the fields and often of entire villages. The diet of these societies was based on fish and bitter *manioc*; however, other products were cultivated, including sweet *manioc*, sweet potatoes (*Ipomoea batata*), yams (*Dioscorea*), different varieties of maize, various types of palms, and gourds (*Lagenaria vulgaris*) (Steward 1946:698). Steward also described the settlements oriented near rivers and coasts wherein the people were wellskilled fishermen and users of canoes as watercraft transport. The geographic determinism in Steward's work was based on the conception of a hostile environment in the forest that suppressed the development of complex processes in those societies due to “limiting factors” within the environment. Thus, Steward’s model assessed a degradation of the Circum-Caribbean chiefdoms when the people started migrating toward the Amazon, thus assuming the Tropical Forest “tribe” position in the “scale.”

Steward mixed evolution with environmental determinism and called it Cultural Ecology, a theory strongly defended by Meggers, who used the concept of “limiting factors” as itself evidence for lack of social complexity in the Amazon. This position was easy to defend because of the small amount of data available during the period. On the other hand, Carneiro, in *A Theory of the Origin of the State* (1970), described social or environmental circumscription acting like a “pressure cooker” in the social complexity process. For instance, fertile soils sharply delimited by geographic accidents (e.g., Andean regions) are disputed territories where warfare and competition certainly provided a push toward social complexity. Here, it was not the abundance of ecological resources that provided a catalyst for the development of social complexity, but rather the socio-political, and possibly military, conditions of a denser population in an area where people had to compete for resources. In a war situation, political demands would have been placed on the losing society (those not expelled or exterminated); generally, this meant exacting a price for staying in the area, in addition to taxes and tribute to be paid to the conquerors (Carneiro 1970). The cause/effect of an affluent environment is not based solely on the nutrition and sustenance offered by the physical conditions of the landscape, but on a complex social response to the acquisition of domination over a prosperous region.

Roosevelt (Roosevelt 1980) argued against the notion of social uniformity in the Amazon and considered the complex societies in *várzea* areas to be a result of technological change; that is, adoption of maize crop cultivation that could support a denser population with significant amounts of protein sparked the development of chiefdoms in the Amazon floodplains with good soils able to sustain large-scale agricultural production of this crop (Roosevelt 1980:67).

Two observations here:

1 – All data and conclusions are showing the ecological cardiac model created by Donald Lathrap, which established the Central Amazon as the center of the oldest ceramic and sedentary societies, as more or less correct, when one considers that the radiocarbon dates for the earliest ceramics in the Western Hemisphere were indeed from Amazonia. These were not, however, exactly where Lathrap predicted them to be. Moreover, Lathrap's migration theory does not solve all the problems related to the distribution of early pottery in Amazonia.

2 – Complex societies existed in Amazonia. These were not only associated with the floodplains, as previously thought, but were in many areas. There is a wide diversity of landscape domestication as well as cultures with other subsistence models besides the agricultural (Schaan 2004).

Earthworks

The Marajoara culture is perhaps the best known of all Amazonian cultures. Located at the Amazon River mouth, Marajó is the largest Quaternary tectono-sedimentary fluvial island in the world (Rossetti et al. 2007:2021). The Marajoara phase (400 – 1,350 AD) was the "exception" for a Tropical Culture standard model, according to Meggers' assumption. With earthworks forming terraces 10 – 12 m high and an impressive and distinctive pottery shape and decoration, the Marajoara was interpreted by Meggers (1957) as an intrusive culture from the Circum-Caribbean groups. Once there, "cultural decay" was assumed to have led to the Tropical Culture traits, although the decadence never was proven (Schaan 2008). Roosevelt (1991), analyzing the Marajoara sites, argued that the good soils in the region allowed for crop production, and through microfaunal and macrobotanical remains, she was able to describe their diet based on crop seeds, plant collection, and seasonal fishing, important elements for interpreting the social complexity found in archaeological excavations (Roosevelt 1991:26). On the other hand, Schaan (2004) called attention to the fact that both approaches (from Meggers, as well as Roosevelt) are "agriculturally centered", that is, they focus on regions with good soils for food production that could allow complex societies to flourish. A classic example to contradict the assumption that complex societies are dependent on an environment that supports agriculture lay on the Peruvian coast dating to 5,800 – 3,800 BP. This pre-pottery complex group had more than 13 urban site systems in the Supe Valley (the most studied is the Caral site) with sunken plazas, pyramids, and habitation structures, all centered around a maritime fishing system (Moseley 1975, Shady, Haas and Creamer 2001, Sandweiss et al. 2009). This pattern is also observed in the Amazon Basin. For instance, Schaan (2008) reported that earthworks have a correlation with abundant aquatic resources and suggests they are related to water management catchment. Such conditions would have offered a stable source of maritime-based protein, promoting population growth through an economy centered on an aquacultural system. This could explain the diverse, autonomous communities that arose, rather than supra-regional power-centered societies. The Camutins site “suggest[s] a system of alliances between chiefdoms that is compatible with [a] peer-politic interaction model" as described by Renfrew (1992) (Schaan 2008:354). The pattern here appears to be interaction through exchange, rather than a competitive dispute for areas with abundant resources.

The "cultural uniformity" view of societies in the Amazon has, in fact, begun to give way to interpretations of great diversity; the cultural landscape picture continues to evolve as researchers observe that while the aquatic resource catchments are connected with channels and terraces on the eastern side of the Amazon, in other regions, such as Marajó, some groups related to earthworks seem to have a weak correlation to agricultural systems. Denevan (1970) reported a number of earthworks formed into raised or ridged fields in many areas of South America; for instance, (1) Llanos de Mojos, in the Guaporé-Beni Basin, Bolivia; (2) North coastal region, Suriname; (3) Guyana Rivers, Equador; (5) and, Llanos de Venezuela, in the Orinoco and Apure river systems, Venezuela.

In the lowlands, east of Bolivia, Denevan (1966b, Denevan 1966a) called attention to important features in the landscape that contradicted the “standard model” of the time. Researching pre-Colonial agriculture fields in the Llanos de Mojos, he found evidence of stratified societies with elaborate material culture. Erickson, through landscape archaeology, is currently rebuilding specific exploitation areas, revealing a sophisticated earth management system as well as domesticated landscape over a wide region in Llanos de Mojos. According to Erickson, domesticated landscapes are the result of careful, long-term historical transformations of the resources into a productive landscape for humans and other species (Erickson 2006, 2008). This flooded savanna area in Bolivia changed over centuries, encompassing complex channel systems, causeways, and fish-ponds. Both Denevan and Erickson proposed that a great quantity of the causeways and channels are associated with transportation between habitation areas and fields (Denevan 1966, Erickson 1995). In addition to transportation, Erickson reported that the causeways and channels also served the function of a “flood-control system, artificial levees, and reservoir to control water at optimal levels during the wet season and to conserve moisture for dry season cultivation” (Erickson 1995:73). The aquaculture is also reported as important, especially for raising fish. Through spatial analysis in distinct sites now at the Mamoré basin in Bolivia, Walker (2008) pointed out regional variations in earthworks. Comparing different sites located along the Yacuma and Rapulo rivers, he began to recognize patterns in the earthworks, likely related to distinct groups, including in areas where there were speakers of languages other than Arawak (discussed further below in the section titled, “Arawak Diaspora”). However, Lombardo and Prümers (2010) reported no abrupt changes in the ceramic sequence at the same region in the Mamoré basin (Lombardo and Prümers 2010:1876). One explanation for this is that the Amazon Polychrome Tradition influenced the ceramic complex in northeastern Bolivia around 1,000 AD, when the Tupi speakers began to expand their territories (Saunaluoma 2010:124).

The earthworks, most dating to between 400 AD and 1,400 AD (ca.1,600 – 600 BP), were used and reshaped over the centuries; but there is no agreement about when the first constructions began (Lombardo and Prümers 2010:1876). According to Lombardo and Prümers, each cluster of mounds was constructed by a single community, but all were connected by a regional peer polity, possibly at a supra-regional political level (Lombardo and Prümers 2010).

The diversity of structures, including anthropogenic earthworks, does not stop in Bolivia but continues on the eastern frontier to Brazil, crossing Acre State, and running to the south in

Amazonas State. These “Geoglyphs” (enclosures), dating between 2,500 and 1,000 BP, form geometric and other shapes such as circles, rectangles, walls, ditches, and mounds. Some appear to have had a defensive or ceremonial function (Pärssinen, Schaan, and Ranzi 2009a:1085). Throughout the region, over 200 earthworks were plotted covering hundreds of hectares. This number will likely increase exponentially as the deforestation process happening here continues. Located in the *terra firme* as well as in the *várzea* at the confluence of the Acre and Purus rivers in Amazonas State, Brazil (Ranzi, Feres, and Brown 2007), the Geoglyphs represent a management of the landscape by dense populations. This evidence furthers an increasingly widely accepted theory: complex societies occur not only in the lowlands’ floodplains, but in various distinct areas of Amazonia (Pärssinen, Schaan, and Ranzi 2009). Further, centralized societies respond differently to the environment, changing and improving it through time. Along with the new ways of thinking, old dichotomous classifications, like “floodplains” and “uplands” are breaking down. The result is an increasingly complex approach that considers more material remains, in addition to ceramics and lithics, in the reconstruction of past societies. Through careful analysis Denevan and others are investigating distinct settlement patterns in the uplands (those far from the major rivers) and finding those resources available in the region might reveal more complex interactions, as well as a mutual dependence among the groups. Anthropogenic forests, such as at the Llanos the Mojos (Erickson 2006), and on the Suriname coast (Versteeg 2008), for example, are found to have been associated with raised fields, mounds, and other earth structures. Earthworks in the Central Amazon will be discussed in greater detail in the Site Description below.

A pattern of mounds using pottery as a building material and presented as burials and/or house platforms associated with ADE is being consistently reported in the Central Amazon area (Machado 2005; Moraes 2006; Rebellato 2007). The mound groups present circular or horseshoe-like shapes distributed over the site and are related chronologically with the Paredão phase. The Manacapuru phase is also reported at the archaeological sites with earthworks. While both phases are related to the Incised Rim Tradition, Manacapuru was earlier (see further discussion below in the section titled, “Arawak Diaspora”.

Chapter 3

History of Occupation During the Late Periods

This chapter presents the history of occupation in the Amazon Basin and the connection between different groups through time in the South and North of the region. A general overview of their material and economic characteristics will be discussed.

Roosevelt's general chronology sequence (1994) ordered the occupations as: (1) Paleoindian Tropical foragers; (2) Shell Middens; (3) Tribal and Village horticulturalists; (4) Complex Riverine societies; and (5) Late Pre-Historical times. Heckenberger proposed (1) Archaic (oldest – 3,000 BP); (2) Early Diaspora (3,000 – 2,500 BP); (3) Regional development and diversification (2,000 – 1,500 BP); (4) Late Pre-History "Classic" (1,500 – 1,000 BP); and (5) European (500– 400 BP) (Heckenberger 2008:949).

Based on pottery styles, Meggers and Evans (1961) divided the first chronology summary into four "Horizons." The oldest and mainly known in the island of Marajó (Amazonia) is called "Zoned Hachured", and has its final age around 2,900 BP (Meggers 1977:297). Next, dating from 2,500 BP to 900 AD was the Incised Rim predominantly found in Central Amazonian sites such as in the Hatahara site (Heckenberger and Neves 2008). Following this was the Polychrome, widespread from ca. 1000 AD until the Contact Period, and also the Incised Punctuated Tradition. While this chronological system is no longer accepted because it assigned a ceramics an origin outside of the Amazon and did not encompass the earliest pottery from

Pedra Pintada and Taperinha in the lower Amazon (Neves 2008), it served as a useful jumping-off point for later scholars.

In Lathrap's analysis of ceramics traditions conducted during the 1970s, The Zoned Hachured would be associated with pottery shell mound groups, during the earlier periods, but this view will not be presented here. Later in the 1970s, Lathrap (1970), analyzing the Incised Rim from Amazonia recognized similarities between these pottery styles and those of the Barrancoid Tradition (found in the Lower Orinoco, Guiana, and Suriname). His findings supported his model of migrations from the Central Amazon toward the Orinoco region and northward beyond the borders of South America. Based on the similarities Lathrap saw between pottery from the Central Amazon (related to the Manacapuru phase as defined by Peter Hilbert in 1968), and that from areas north of South America, he proposed a new style which he termed the Amazonian Barrancoid. While the Barrancoid pottery along the Orinoco dates consistently earlier than that of the Incised Rim of Amazonia, the stylistic similarities between them cannot be disregarded. This suggests that influence occurred along the inverse route, namely, from the north toward the Amazon basin (Neves 2008:368).

A history of the occupation of the Arawak and Tupi groups, or Barrancoid and Polychrome Traditions, respectively, is presented in the following section as a way to provide a context for these native populations from approximately 2,500 BP until the Contact Period. This will allow correlations to be drawn between settlement patterns, socio-political organizations, and evidence in the landscape of domestication. This research is centered on the pattern of Arawak and Tupi groups or Barrancoid and Polychrome Traditions, respectively. Thus, the next topics will be dedicated to describing the characteristics of their social organizations, origin centers, and diaspora.

Arawak Diaspora

The origin center of the Arawak dispersion remains uncertain, though the northwestern Amazon, between the Upper Amazon in Brazil and the Middle Orinoco in Venezuela, is the most accepted locale (Heckenberger 2002:103). Initially, the Arawak migrations were described as a sequential colonization of a region by small groups, a sort of *demic diffusion*. However, the picture is now one of *contact* through trade, including regional, and intra-regional or supra-regional exchange (Heckenberger 2002, Heckenberger 2005b, Hornborg 2005). During the Contact Period, the Arawak groups were dispersed from the south upwards through the Caribbean area, and as far north as Florida in the present United States.

Arawak-speaking groups are described as diplomatic traders with intensive agriculture, having hierarchical societies, circular village shape, and regional interactions. The first dispersions seem to have taken place ca. 500 BC – 500 AD (Heckenberger 2008:947). Their characteristics allowed the emergence of a regional exchange system in pre-Colonial Amazonia during the Late Holocene (Heckenberger 2005a, Hornborg 2005). Questions do, though, arise regarding the need to associate the archaeological record with linguistic groups, including a description of their *ethos* and culture.

Heckenberger (2005a) presents the diaspora of the Arawak as one wherein the language and culture changed in concert; the process is not autonomous and sometimes changes minimally (Heckenberger 2005a:43). The Arawak diaspora, therefore, was the trigger for the supra-regional interaction among different regions in eastern, southern, and western Amazonia, connected with the Caribbean region through the Arawak people. Their historical description and geographic distribution is mainly based on 17th and 18th-century European reports. During the beginning of the 20th century, a number of individuals carried out some of the first field studies in this area. Among them was the German historical anthropologist Max Schmidt, who studied the Pareci, Baikari, and Xinguano (Schmidt 1914, 1917, 1942), and Swedish ethnographer and archaeologist Nordenrskiöld (1901, 1914), who made correlations between the material culture and landscape manipulations of groups in Bolivia. Schmidt was the first to posit theories on hierarchical divisions, the importance of agriculture, and the use of space, as well as to describe major migration routes along the river systems south of Amazonia. For the area of the western Amazon (today the Llanos de Mojos in eastern Bolivia), Nordenrskiöld also described man-made channels, causeways, and mounds.

Heckenberger's ethnoarchaeological research carried out in the Upper Xingu among the Arawak Kuikuro revealed new evidence for a continuous history (ca.1,000 – 2,000 AD) preserved in oral traditions, ceramic technology, village layout and location, earthworks, subsistence economics, and interactions with other groups (Heckenberger, Petersen and Neves 2001, Heckenberger et al. 1999). Ditch constructions around pre-Colonial villages were dramatically larger and more structurally elaborate, however, than those in contemporary Xinguano villages, although they share the same circular central plaza configuration (Heckenberger 1996, Heckenberger et al. 1999).

The *longue durée,* or long-term, of oral history connected with archaeological remains and a comparative analysis of the current cultural material validate historical sources of occupation in the southern parts of Amazonia. Heckenberger calls this correlation of sources the larger sociohistorical enchainment (Heckenberger 2005a:43). In contrast to Tupian-speaking groups, endo-warfare was forbidden among the Arawak (Hill and Santos-Granero 2002). Rather, the interactions with other groups were through "siblings," that is, male exogamic marriages, a socio-political endeavor designed to form alliances with neighbors, rather than have confrontation as part of their cultural-social interaction (Hornborg 2005:600). Archaeologically speaking, the connections between the groups are revealed through such characteristics as sedentary farming, earthworks, and similarities in material culture, including shared aesthetic styles of ceramics, circularly shaped villages, and, on a grander scale, evidence of supra-regional contact and trade (Heckenberger 1996, 2005; Hornborg 2005:600).

A word about the circular village shape: While remains are no longer visually evident, the circular layout is detected through physical soil analysis with special attention paid to ADE formation. Some authors have speculated on the significance of the circular shape. Lathrap, for example, sees it as a cognitive model for certain features of the social structure within the community (Lathrap 1970:133). Heckenberger, on the other hand, saw the circular form as offering protection, and therefore tied it to social conflicts and dispute over local resources such as agricultural land and fishing areas (Heckenberger 2005:135).

Tupi Expansion

The first European explorers to the Amazonian region described the costumes and languages of the peoples they encountered. Some of their accounts attest to common characteristics within distinct geographic areas, especially among the Tupi-Guarani speaking groups who occupied the most extensive territory in South America. The most detailed of these early explorer reports are from the Brazilian coast, where the colonization process by Europeans first began in the 16th century.

Geographic mobility is a central characteristic of the Tupi-Guarani language groups, but linguistic research cannot determine if this mobility was due to ecological or cultural factors. Meggers posited ecological adaptation (1971, 1973, 1977, 1979a) as the principal reason for the mobility of the Indians in the lowlands of South America. She understood changes in the environment (such as long-term droughts) as adversely affecting whole communities. These, coupled with poor tropical soils, forced the Indians to be constantly on the move (Meggers 1971, 1973, 1977; 1979a).

Meggers made connections between climatic fluctuation during the Holocene to pre-Colonial language dispersion and as a way to explain archaeological patterns of mobility (Meggers 1977; 1979). However, a purely environmental explanation cannot be enough to understand the extent of the geographical occupation of these groups. The Franciscan friar Father Anchieta, the first to record the languages of peoples on the Brazilian coast, wrote in the 16th century about the grammar of the Tupi-Guarani, the dominant language in this area (Anchieta 1933). He published his findings in 1595 (Anchieta 1933), wherein he described the similarities among the languages in this region. Currently, anthropological and ethnohistorical works are demonstrating that the mobility of the Tupi groups was related not only to ecological adaptations, but to various other circumstances as well, and these interpretations are based on the cultural materials (ceramics, for instance).

Cultural material studies focusing on these areas highlight further connections. In addition to distinct social organizations found in the current societies, there are some geographic inventories of the cultural materials of native groups in Brazil. Alfred Métraux, for example, studying various groups including the Tupi-Guarani, identified such similarities among their material cultures as: manioc, maize, cotton, and tobacco cultivation; the use of bows and arrows; fishing using poison and by creating man-made dams; utilizing wooden mortars for food production; use of hammocks and feathered mantles as well as painted ceramics; and, the collection of trophy heads (Métraux 1928a:301-302).

While the similarities of some material culture items among these groups is intriguing, they do not correspond with the enormous heterogeneity in their social morphology. Rather, there is distinct variability in village morphologies, kinship, ceremonial and shamanistic practices, and warfare (Castro 1992:24). Settlement types range from nomadic hunters' temporary camps (Guajá, Sirionó, Aché) to complex and expanded semi-permanent to permanent Tupinambá agricultural villages. But, as pointed out by Viveiros de Castro, there is more than linguistic homogeneity at play as a unifying factor among them. Linguistic homogeneity allowed access to common religious beliefs and institutional vocabulary that resisted change for centuries (Viveiros de Castro 1992:26). Balée (2000:399) was able to reconstruct pre-Colonial biological knowledge through comparisons based on historical linguistics and modern ethnology among varieties of domesticated and semi-domesticated species of plants and the identification of anthropogenic forests, formed by palms, bamboo, and Brazilian nut species in many parts of Amazonia (Balée 1989).

The variability in the settlement patterns seems to present another example of the divergence of associated pressures during the colonization period that were responsible for large numbers of deaths and the virtual extinction of many groups. The deadly influence of the colonization process on indigenous social organizations is described in numerous sources and has been summarized by Fernandes (1948). However, according to our investigation, another reason for the village morphology variability could be linked to economic issues (not solely ecological or cultural factors); that is, the use of the fertile soil for food production in areas with ADE (Rebellato, Woods, and Neves 2009).

During the pre-Colonial period, the distribution of similar pottery assemblages identifies the large amount of territory occupied by the same chronostylistic tradition, i.e., that generally related to the polychromic painted and corrugated ceramics (Brochado 1984, 1989; Noelli 1998). One must ask why those groups were moving so far, travelling long distances, and settling in different landscapes.

Métraux (1928b) analyzed the first chronicled descriptions of the terror engendered by the anthropophagical rituals conducted by native peoples on each other and on captured Europeans. Some of the latter ultimately escaped and provided accounts of their ordeal (Léry 1927[1578]; Staden and Fouquet Karl of Brazil [from old catalog] 1948; Léry 1927 [1578]; Staden 1948 [1557]; Thevet 1978 [1575]). Cannibalism was characteristic of the Tupi-Guarani family groups and was carried out as a vendetta against their enemies (Métraux 1928a). Viveiros de Castro (1992) made the association between exocannibalism and a revenge-conquest system. Cannibalism was also part of the cosmology, serving to propel the social machine toward the future (Viveiros de Castro 1992:274). Through a complex cosmological triad matrix of nature/culture/supernature, Araweté understood the world in which they lived as immature, while the world of the dead, as the final souls, was fully constructed and, therefore, mature (Viveiros de Castro 1992).

H. Clastres (1975) presented an interpretation of cannibalism that related a prophetic "land-without-evil" with political-religious behavior. Looking for the paradise on Earth, these groups had to be in movement. As such, it was better to be in the belly of the enemy than buried in the grave; by being eaten it was believed that they could reach paradise on Earth. Thus, sacrifice is indispensable for social reproduction and for the relation-to-the-enemy; therefore, the cannibalism was (literally) an incorporation of enmity in order to reach immortality for both the eaters and the eaten. Moreover, the practice of cannibalism unified the Tupinambá (Viveiros de Castro 1992:286). The system was based on consistent warfare periods that also can be pointed out as a mobility-compelling force, pushing incursions toward surrounding territories. This expansion-based mobility of the population was pushing these societies farther and farther from their original territory in a short amount of time.

Movements of native societies in the lowlands of South America can be understood in three distinct periods: (1) pre-Colonial, (2) Contact, and (3) post-Contact. I will focus on the pre-Colonial movements and the reasons these populations spread out over extremely long distances in a relatively short period of time.

Migration or Expansion?

According to Brochado (1984), migration is leaving one place to go to another, but this is not an adequate explanation for the movements of the Tupi people. As archaeological evidence has demonstrated, Tupi speakers spread their territory without abandoning the heartland. Brochado calls this “colonization” and he thought that the causes of these expansions of territory were due to demographic explosion (Brochado 1989). To Noelli (1998), the key to understanding the Tupi expansion was territoriality, which encompassed hunting and fishing areas, agriculture fields, and areas of gathering and forestry management. In addition, expansion of the territories happened through kinship and other types of alignments. Brochado and Noelli also highlighted the importance of agriculture for the Tupi expansion. Planting and field management techniques influenced the rhythm of the expansion because new cultigens were introduced into the new territories that they occupied. So instead of jumps, expansion was characterized by slow flow and continuous territorial attachments. The late expansion along the east coast made many researchers postulate a split from the Amazonian groups around 2,000 to 3,000 years ago or perhaps even more recently (Brochado 1989, Lathrap 1970, Sušnik 1975). Therefore, the coast's recent occupation by these groups raises the question of the location of their starting point.

History, Linguistics, and the Origin Center

The center of origin of Macro Tupi Group (MTG) is a controversial issue. Linguists, anthropologists, and archaeologists agree on at least one thing: namely, that the MTG speakers were spread out all over the lowlands in South America during the Contact Period. Alfred Métraux (1928a, 1928b) pointed to the center of origin as being on the isthmus between the Paraná and Paraguay river basins, with a later occupation toward the east coast of Brazil, based primarily on the Tupi-Guarani languages, also called Tupinambá (old Tupi) or Ňeengatu (or modern Tupi) (Arion 1958). Today, Amazonia is pointed out as the origin of these groups because of colonization on the coast; however, there is more information about coastal populations at the time of contact. The disagreements over discrepancies between linguistic data and archaeological evidence were more heated in the past than they are currently among researchers. Lathrap (1970) and Meggers (1977, 1979) each introduced a hypothetical model for the Amazonian occupation, and both authors felt that it is possible to identify links between languages and archaeological remains.

Urban (1992) proposed that the Tupi groups were the first to move to the Central Amazonian lowlands, but speculated that they did not originate from this area. He established the first phase of dispersion of the Macro-Tupi to be around 4,000 – 6,000 BP. He believed the origin center for the Tupi, Carib, and Ge languages to have been at the head tributaries of the Madeira, Tapajós, and São Francisco rivers (Urban 1992). After some time, those populations started to migrate toward the major rivers in a process Urban called "the periphery hypothesis." Rodrigues (1985, 2005a, 2007) studied the chronological depth of the Proto-Tupi languages through linguistic analysis of words, and pointed out that five of the ten linguistic families are in a region around the Upper Madeira River, currently in the State of Rondônia, Brazil; from the linguistic point of view that locale is, therefore, the origin center.

During the 1980s, Brochado reconsidered linguistic and archaeological discussions as they related to the migration of pre-Colonial populations of the Tupi, and related this to the Amazonian Polychromic Ceramic tradition (APC). Brochado and Lathrap (1980) proposed a direct association between APC and Tupi migration using radiocarbon dating to explain the successive migration routes during the pre-Colonial period, heading south, west, and east across the lowlands, and set the origin point of these Proto-Tupi speakers in the Central Amazon.

Authors report that the Tupi pattern of dispersion is more like explosions and radiations than slow flows. The result is that distant languages reveal similarities. An example of this is the relationship between the Chiriguano in Bolivia and the Potiguara on the Brazilian coast and between groups from the north and south (Urban 1992:92). At this time, however, the archaeological research is not sufficient to allow for an analysis and assessment of the various linguistic models, though increasing multidisciplinary research in the Amazon Basin is allowing more correlations between linguistic and archaeological data. Currently, there is linguistic and archaeological consensus that the Proto-Tupi center of origin is in the southwestern portion of Amazonia around the Madeira, Guaporé, and Mamoré river basins (Rodrigues 2007; Heckenberger 2008). The greatest language family diversity (Rodrigues 2007) occurs in this area. In addition to the high level of linguistic diversity, the minimal geographic dispersion points to it as the origin center of a Proto-Language. Rodrigues (2005b) postulates that the region was occupied by Tupi people for more than 5,000 years. On the other hand, the similarity of the languages spoken in the east led linguists to think that there was a rapid expansion along the coast (Brochado 1989). Such movement Heckenberger calls the Tupi-Guarani diaspora, chronologically occurring ca. 2500 – 1500 BP (Heckenberger 2008:947).

The Amazon Polychrome Tradition

During the last 15 years, the Central Amazon Project has made significant progress in relation to these questions; this investigation continues to accumulate and report more details. First, some results show that the Polychrome Tradition ceramics, associated with Tupi groups in the Central Amazon, did not evolve from the “Incised Rim” or “Barrancoid” traditions associated with Arawak groups, as argued by Lathrap (1970) and Brochado (1984). The relatively late radiocarbon dates refute the hypothesis of a long period of occupation by this tradition (Neves 2008). Although the polychromic ceramics in the region present complex characteristics and suggest sophisticated formation processes, they did not evolve *in situ,* but rather were intrusive (Heckenberger et al. 1998). A profound change in the ceramic tradition around 1,000 BP is interpreted by Neves as the emergence of a wide cultural patterning marked by the replacement of sites with the Incised Rim by Polychromic Tradition sites throughout Amazonia and close to the piedmont of the Colombian, Ecuadorian, and Peruvian Andes (Neves 2008:367).

Diachronic settlement morphology patterns were investigated by the Central Amazon Project in an effort to understand the expansion of Tupi groups associated with the Polychromic Tradition. The physical and chemical soil properties and pottery analyses carried out at the sites within the Central Amazon have since confirmed this association, revealing a circular concentration of organic material and ADE surrounding a plaza at the Hatahara archaeological site. This settlement form is associated with “Incised Rim” ceramics related to the Paredão phase (Arawak) (Moraes 2006; Rebellato, Woods, and Neves 2009). When this type of ceramic abruptly disappears it is replaced by a linearly shaped village with Amazonian Polychromic ceramics affiliated with the Guarita phase (Tupiguarani) (Rebellato, Woods, and Neves 2009). The village then occupied the riverside border, facing the Amazon River with its back to the areas composed of ADE. Thus, it was possible to confirm pre-Colonial relationships in the Central Amazon area through linguistic, ethnohistoric, and archaeological data. Also confirmed are the descriptions made by the first European travelers, who reported continuous, linear villages and dense occupations along the bluffs overlooking the Amazon floodplain [e.g, the 1542 account by Friar Gaspar de Carvajal (1992)].

Porro (1994) associated a linear pattern for this population with an economy associated with water resources. Results presented in this chapter also furnish one more reason for this shape, namely, better use of the ADE area for food production. Because Tupi speakers are generally associated with intensive agriculture (Brochado 1984, Noelli 1998), it is reasonable that a Tupi expansion could be related to the conquest of ADE territories.

Current Context

In the data related to the Hatahara archaeological site, a change in the settlement patterns occurs around the 1,000 BP. Many sites in the confluence region of the Amazon and Negro rivers show an increase of trenches and defensive systems, suggesting a fortification period due to warfare (Neves 2008). This increase in village protection is associated with the subsequent establishment, at some sites, of the Amazon Polychromic Tradition. In addition, the transition from a circular village shape to a linear pattern was observed. I propose that these changes in the village shape and pottery tradition around 1,000 – 900 BP are associated with the Tupi expansion in the area. Heckenberger (2008:950) highlighted that during the beginning of the second millennium, a macro-regional interaction associated with a geopolitical identity and exchange of prestige goods (polychromic ceramics) took place along floodplains of the Amazon and many adjacent tributaries.

Before the establishment of these new settlements, as indicated by the fortifications, there was a period of warfare with former occupants associated with the Incised Rim Tradition ceramics (Arawak groups). My interpretation of those waves of invasions is related to the fertility of the soils of the area. This fertility was associated with both the floodplains of the

Amazon River and the ADE. Bellicosity associated with the Tupi groups was one of the characteristics that suggest the conquest of territory in the Central Amazon; the expansion of these groups was not peaceful, but was aimed at acquiring new territories. The linear settlement morphology strongly suggests that the conquerors of the region were not in fear of attack since linear settlement forms are indefensible. The linear form was excellent for expanding food production since it had the double advantage of ready access to the floodplain and made maximum use of the ADE found within the areas of prior habitation. Indeed, the thick deposits of ADE were so valuable to the Tupi that they spread them out over a wide zone behind their villages in order to enlarge the area covered and thus increase productivity. All indications point to a period of stability for these new occupations and interactions within a well-conformed inter-regional system of exchange between related groups across an extensive area. This stability lasted for five centuries until the European encounters set into motion a new history of movements of the native populations across the entire continent. Ethnohistorical investigations preserved descriptions of the societies that lived along the course of the Amazon River at the time of contact. They reported a dense population on the riverbanks with kilometers of roads and wide extensions of villages overlooking the river channel (Porro 1994). Carvajal recorded that the settlement area "*extended for more than eight leagues for it was all of one tongue, these being all inhabited, for there was not from village to village a crossbow shot, and one which was farthest was not half a league away, and there was one settlement that stretched for five leagues without there intervening any space from house to house… from its resources and its appearance it must be the most populous that has been seen.*" Therefore, this work attempts to integrate distinct sources of information and data in order to prove the existence of a preferential tendency for the last pre-Contact group to settle the study area in re-occupied ADE areas.

Indirect Evidence

Recent technologies in science-related fields are providing larger-scale resolution for data related to climate, vegetation, and human activity over the past two millennia and are supporting evidence of a significant pre-Colonial occupation system throughout the Amazon. Indirect evidence correlates population growth and an intensification of slash-and-burn agriculture and other fire events throughout the Americas. The use of fire in order to manage the landscape is further described in the literature (e.g., Sanford 1985; Mayle, Burbridge, and T. J. Killeen 2000). However, its impact was underestimated until recently, when data of charcoal and pollen isotopes from Meso- and South America, as well Antarctica, began to be published (Dull et al. 2010).

Data show an intensive landscape management system utilizing fire until the Contact Period, when the archaeological record reveals a decrease of human activities in the Neotropics, including the Amazon (Bush et al. 2008; Dull et al. 2010). Evidence for natural fires is so rare in the evergreen tropical forest (except during the arid Middle Holocene 8,000 – 5,000 BP) that most of the charcoal records are associated with human activities (Bush et al. 2008:1796). In addition, ice core analyses from Antarctica reveal a gradual influence of pyrogenic emissions, increasing the methane budget in the atmosphere circa 0 – 1700 AD, as a result of rice cultivation, cattle farming, and biomass burning (Ferretti et al. 2005:1714). They also reveal concentrations of carbon monoxide (CO), a trace gas proxy for pyrogenic emissions, especially woody biomass, which suggests intensive forest burning activities from 0 – 1,500 AD (Ferretti et al. 2005). This presence of carbon monoxide confirms that pyrogenic emissions were substantially affecting the methane budget from the Late Holocene (Anthropocene) to Contact, when an annual decline of methane emission is detected, spanning ca. 1500 – 1700 AD (Ferretti et al. 2005:1715). Moreover, through the isotopic composition, it is possible to distinguish CO from biomass combustion and from hydrocarbon oxidation, thus identifying its major source (Wang et al. 2010:1663). Wang et al. also observed a consistent trend in CO and dO isotope dC isotope, mostly from biomass burning, with similar levels at 1300 AD as during the late 1800s AD (the Industrial Revolution); moreover, it presents a minimum at 1600 AD, after the sweeping changes of Contact (Wang et al. 2010:1664).

Paleoenvironmental research analyzing pollen and charcoal records also validate the hypothesis that from 2,500 BP until 500 BP (1500 AD) intensive human activities took place in the Americas, including in Amazonia (Bush et al. 2008, Dull et al. 2010). Through intensive forest clearing with fire for village and agricultural field expansions, gradually new areas started to be occupied (Dull et al. 2010). Fire activity peaked between 200 and 600 AD (1,800 and 1,400 BP) (Bush et al. 2008). According to Bush, the fire peaks in the records are chronologically related to the adoption of agriculture in Amazonia and the formation of ADE (Bush et al. 2008; Dull et al. 2010). As described by Neves et al. "Profound social changes . . . 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, including the appearance of ADEs, among others" (Neves 2003:29). According to Neves, the results of past human management of the Amazon landscape can be understood as various flows of low and high intensity like pulses over time, reflecting dialectic interactions between people and nature (Neves and Petersen 2006:285). According to the authors, this low-intensity management occurred from the beginning of occupation, ca. 11,000 BP, until ca. 3,000 BP. As a consequence of population growth, the landscape was gradually transformed into large villages and stable settlements based upon agriculture, agroforestry, and fishing systems beginning ca. 3,000 BP until the Contact Period. Therefore, human landscape management intensified these transformations, especially in the beginning of the first millennium AD, as found in the archaeological record and correlated with stable, sedentary, and fully developed agricultural systems (Neves and Petersen 2006:286).

Archaeological, ecological, and paleobotanical research, then, is correlating models of occupation and management of the landscape. As expected, pre-Colonial occupation and landscape management patterns were much different than those today. Instead of a deforested, wide open area, evidence shows us a mosaic of different portions of cleared plots, near each other and managed through slash-and-burn, with different ages and vegetation re-growing in distinct stages, with a mature close-canopy forest nearby (Dull et al. 2010:758). Forests in Europe and China were cleared beginning around 0 AD due to population increase and agriculture expansion, and they never grew back again. In Africa, populations were small (in comparison with the Americas). The major source, then, of biomass burning was the population from the Americas. Moreover, the pyrogenic emissions of methane, during pre-Colonial times, were close to those of today (Ferretti 2005:1715-16).

Dull et al. (2010) supports the thesis that because of large Amazonian populations farming and clearing the Amazon forest and other regions of Neotropics, the levels of CO emissions in the atmosphere were high enough to generate a warm period in Europe. They recalled that after Contact, the population rapidly declined in the Americas, mainly due to European diseases, which together with slavery and warfare killed close to 90% of the native people during the first centuries of conquest (Denevan 1992a). After the population collapses (beginning ca. 1500 AD) a decrease in activities such as burning and planting occurred in the Americas, allowing the forest to reoccupy an abandoned landscape in a natural secondary succession. Once the fire activity was suppressed, tropical biomes rapidly increased woody biomass, making it harder for natural fire events to occur. The lack of human activities and the reforestation in the Neotropics increased CO_2 sequestration from the atmosphere, causing the Little Ice Age between 1500 and 1750 AD (Dull et al. 2010:757).

Therefore, human management of landscapes in the Americas and, ultimately, its decline, had more impact on the environment than has ever been realized. The chronology is consistent across various research sources; that is, an increase in CO and an isotopic signature related to fire events is identified generally from 2,500 BP to 500 BP.

The ADE are the materialization—at least in the Amazon—of those activities confirmed by multidisciplinary research. They represent the signature of both fire and human activities. People set fires for a variety of reasons, from clearing fields to cooking and food preparation. Additionally, fire leakage in the forest and climatic changes brought about by ENSO events brought droughts and an increase of fire events. El Niño alone, however, is not enough to fully explain fire activities in the past (Bush et al. 2008:1797). The high fertility of these anthrosols are well known, and explained in the next section. Their productivity is projected to be able to support at least six million people in the forested area through agricultural fields (Dull et al. 2010:762). The next section discusses fire and the ADE formation processes.

Chapter 4

Landscape and ADE

This chapter presents an introductory overview of anthrosols and of methods developed in the past decades for the analysis of human impact on soils. First is a general description of ADE, followed by a historiography of ADE research and an explanation of its location in the landscape. Finally, the current research results on this topic will be discussed.

Many of the archaeological sites in Amazonia present ADE. Characterized by anthropogenic melanization because of the accumulation of organic materials, especially charcoal, coupled with a host of nutrients, these soils also present a high quantity of archaeological material, mainly ceramics and some lithics, moreover, all sorts of animal and human bones, feces, and house/garden waste (Woods and McCann 1999). Through their habitation activities these past people unintentionally put nutrients into the soil, bringing micro- and macro-nutrients from food, fuel, and building material to the sites of their habitations, where their use and disposal contributed to change the soil's properties (Woods 1975).

The ADE are found in different types of soils, including Latosols, Podsols, Podzolic, and Plinthosols (Smith 1980, Kern, Costa and Frazão 2004c) and generally found in the Pleistocene terraces. They are well known for their high fertility and resilience, with almost neutral pH, high exchange capacity (CEC) and base saturation, and high levels of macro- and micro-nutrients for plants in both available and/or total measurements, including phosphorus (P), calcium (Ca), zinc (Zn), copper (Cu), magnesium (Mg), manganese (Mn), and carbon (C) (Sombroek 1966:174-78). Sombroek (1966) also observed a variation in these anthropogenic soils. He called attention to lightly melanized (brown-hued) soils with few archaeological materials in the matrix, found dispersed concentrically surrounding areas with *terra preta* (TP), and he denominated these lighter soils *terra mulata* (TM). TM is considered the result of intentional agricultural field improvements. The microbiological composition of ADE is responsible for their resilience, for the high activity level of their microorganisms makes them expand and grow (Woods and McCann 1995).

According to Denevan (1996:669-70) *terra preta* and *terra mulata* are indirect evidence of intensive *terra firme* cultivation in permanent or semi-permanent fields, and, undoubtedly, cultivation with fruit orchards, managed fallows, house gardens, and brief bush fallows with semi-permanent settlements, some numbering thousands of people, surrounded by zones of modified forest manipulated by hunting and gathering activities (Denevan 2001:102-132). This viewpoint expresses a very different vision than that of Meggers, who argues for settlement discontinuities due to soil exhaustion and continual reoccupations of the same site through time (e.g., Meggers 1971:12-14). In support of Denevan’s stance, research carried out in the lower Tapajós and Arapiuns drainages has identified very large ADE sites with different densities of archaeological materials whose distribution is suggestive of habitation middens associated with areas formed by long-term agricultural activities (Woods and McCann 1999), and similar results have been found in the Central Amazon.

Although the white-water floodplains are composed of fertile soils, they also contain a important risk factors for food production due to the annual flooding periodicity (Denevan 1996:656). While the uplands are characterized by weathering and poor soils, they do have the advantage of not being flooded annually, and consequently were considered a good place to build villages and house-gardens according to the archaeological records (Denevan 1996; Lathrap 1970; Neves 2003). Through their habitation activities these past people unintentionally put nutrients into the soil, and through these activities they started to generate the Amazonian Dark Earths (Woods and MacCann 1999**;** Petersen at al. 2005; Rebellato, Woods, and Neves. 2009)

The high fertility of ADE is currently used by the local populations for agricultural proposes and presents a model for sustainable soil resource development in the tropics. Therefore, the study of the Amazonian Dark Earths is important to understanding the past, but it also represents key knowledge for the present and future of the biggest tropical forest in the world. The Brazilian government's political agenda calls for development of portions of Amazonia, as well as expansion of its agricultural and development infrastructure ventures, increasing the population density and pressure on resources in this region.

Thus, the ADE are an interesting research object and have been examined by a multidisciplinary group consisting of archaeologists, anthropologists, biologists, chemists, geographers, and soil scientists. Since ADE are a class of anthrosols, a well-studied subject, a short overview of anthrosols is now in order.

Anthrosols

Soils are natural bodies formed by the interaction of climate, relief, parent material, and organisms over time, expressed in the function summarized by the Russian Dokuchaev: $S = f(cl, o, r, p, t)$ (Dudal, Nachtergaele, and Purnell 2002; Jenny 1941). Human societies over the years also have influenced the soil formation process through several daily activities responsible for the changes in their chemical and physical properties through the deposition and decay of organic and inorganic debris (Woods 1975, 2003). These changes induced by human activities and creations can effect changes in the soil's properties, including irrigation, cultivation, waste disposal, terracing, plowing, battlefields, trenches, excavations, mines, cemeteries, fire, manuring, drainage, and all types of changes that can interfere in the soil's properties (Dudal et al. 2002). Moreover, a settlement's floors also expose compaction, accretions, erosions, and all sort of sediments brought by human activities or natural sources to the settlement areas (Stein and Farrand 2001). The elements found directly enriched in abandoned settlements are C, N, P, and Ca, with sources derived from: (1) urine and feces from both humans and animals deposited in the living areas; (2) burials and their offerings; and, (3) manure application to soil for agricultural purposes (Cook and Heizer 1965).

The increase in available methods and techniques for soil analysis, and the development of geoarchaeological research focused on understanding site formation processes, have both proven equally helpful for identifying the fingerprints of human behavior as well population density. Laboratory techniques developed specifically for the analysis of phosphate in anthrosols, for instance, have enabled identification of P concentrations of human origin through the fraction of organic and inorganic P analysis (Eidt and Woods 1974; Woods 1975, 1977). According to Eidt and Woods (1974) settlements change the horizontal and vertical characteristics of the soils, their color as well their chemical composition, creating " important differences from one area of the earth to another" (Eidt and Woods 1974:7).

Phosphorus analysis actually has a long tradition as useful tool in archaeological research, ever since Arrhenius (1934) discovered that the main sources of phosphate in the soils were rocks (as apatite), plants that increase its concentration, and past settlements. An experiment was carried out in Sweden in the 1970s in order to test soils for evidence of prior sugar beet farming based on phosphorus levels (Woods 1975). Dietz (1957) did a survey showing that an easy field test and inexpensive laboratory analysis of available phosphorus could be used to identify abandon settlement with few cultural materials. Through time, the improvement of field and laboratory testing were has furnished impressive tools for understanding past villages and their activity areas.

Other major anthropic indications, in addition to phosphate, are the multi-elemental analyses incorporated in geoarchaeological research identify activity areas (Barba and Ortiz 1992, Parnell, Terry and Nelson 2002, Wells et al. 2000, Middleton and Price 1996). Ash, charcoal, domestic refuse, and field crops leave patterns in activity areas, and sometimes these can be recognized through systematic sample and soil analyses. For instance, carbon (C) and nitrogen (N) are proxies for organic matter content. Potassium (K) and magnesium (Mg) levels are increased by the addition of ashes (Buehrer 1950, Heidenreich and Navratil 1973); magnesium also is correlated with fish and bird bones (Griffith 1980:331).

Zinc (Zn) and copper (Cu) reflect deposition of plant and animal tissues and are excreted in urine (Cu) and feces (Zn) (Browen 1966). Although only trace amounts are excreted, significant deposition of them can result from large settlements or smaller settlements over longer periods of time, with Zn being more stable than Cu (Woods 2003:11).

Among the anthrosols the distinguishing characteristics are color and pH. Color is influenced by the concentration of organic matter deposition; iron (Fe) and manganese (Mn) concentrations; additions of charcoal, ash, plant growth, oxidized earth materials; length of exposure to air; temperature; and calcium and carbonates (Woods 2003). Hearths cause distinctive redness in some soils, those that have sufficient oxygen to supply the Fe compounds; in soils with less oxygen no redness occurs (Limbrey 1975:325).

Humans influence the pH in soil through the addition of wood ash, which is alkaline and includes contents of calcium carbonate and hydroxide, and some calcium sulphate. Ash additions also probably increase the carbonates in soils (Woods 2003).

Amazonian Dark Earths are a consequence of human activities in the past that changed the properties of the natural topsoils in the tropical forest; therefore, they are anthrosols. Derived from natural sediments and soil materials affected by human activities through time, their profiles exhibit a mix of natural and cultural elements that have survived losses by leaching, volatilization, and erosion, and over many years the soil formation is completely within anthropogenically deposited materials (Woods 2003:12).

The intentionality or unintentionality of ADE formation is a challenging question for the current research. Some aspects of human activities must be taken into consideration, including village layout, internal replacement of the activity areas, settlement density and duration, reliability in the agricultural system, and the group's skills of land management. Direct evidence about diet can be accessed through paleobotanic and isotopic analysis, but to determine the intentionality of the soil amelioration is a complex problem. Moreover, post-depositional processes have to be taken into account. For instance, in the micro-scale, factors such as clay and colloidal particles moving downward, nutrients' mobility, biochemical reactions, microorganisms, and cycles of nitrogen and carbon all need to be addressed because they are continuously transforming the sediment/soil and archaeological evidence during the pedogenesis process. At the meso-scale, the challenge is bioturbation from roots and animals (earthworms, armadillos, insects, and all sort of mesofauna), especially in Amazonia, where they represent an enormous impact in the soil profile as well as in the archaeological context. At the macro-scale, besides sedimentation and erosion caused by flooding or drying events, the human impact has to be considered the most complex. Domestic materials, trash pits, earth ovens, pottery manufacture and food processing areas, faunal bones and tissues, burials, ceremonial places, all these human activities caused additions and losses to the soils, and even though they left signatures in the matrix, disclosing this information is a daring proposition. It seems safe enough to say that the ADE formation process began as an accidental by-product of typical human activities, but when exactly people realized that this soil enrichment would be useful for agricultural fields is a difficult question to answer. How to find specific clues related to answering this question is a problem still being addressed.

Results from archaeological research, especially those related to multi-elemental analysis, are improving and becoming less expensive, providing better tools to solve questions about the use of space in sites through time. We can discern important correlations between compounds of elements and human activities carried out in a place, so that social-economic distribution of human activity in an area can be glimpsed through the variability of elemental distributions over it. Still, post-depositional events, subsequent occupations, and natural variation in the soil background need to be taken into account before predictions of prior activity areas are made (Wilson, Davidson and Cresser 2009, Wilson, Davidson and Cresser 2008). The discussion about identification of areas through elemental concentrations will be presented in the Chapter 6. Now, a general introduction, history, and description of Amazonian Dark Earths will be provided, followed by a classification system, chronology, and current research results.

Amazonian Dark Earths

Many of the sites in Amazonia present ADE. Characterized by anthropogenic melanization due to accumulation of organic materials, especially charcoal, coupled with a host of nutrients, these soils also present high quantities of archaeological materials, mainly ceramics and some lithics, plus all sort of animal and human bones, urine and feces, pottery sherds, and house/garden waste (Woods and McCann 1999). Through their daily activities people are always intentionally and unintentionally putting nutrients into the soil, bringing micro- and macro-nutrients from food, fuel, and building material to their sites of habitation, where their use and disposal changes soil properties (Woods 1975). Most of the ADE are located in the Pleistocene terraces, where the annual flooding could not affect these areas; thus, such elevated places where choose for settlement. Moreover, the *várzea* areas could also be used for food production. Although the white water floodplains are composed of fertile soils, they also contain a high-risk for food production due to the annual flooding periodicity (Denevan 1996:656, 2001). If the uplands are constituted by weathered and poor soils, they have an advantage to not be flooded annually, and consequently are considered a good place to build the villages and house-gardens according to the archaeological records (Denevan 1996; Lathrap 1970).

The high fertility of the ADE's make them a valuable resource for current agricultural populations and present a model for sustainable soil resource development in the tropics. Therefore, the study of the Amazonian Dark Earths is important to understanding the past, but it also represents a key knowledge for the present and future of the biggest tropical forest in the world. The Brazilian governmental political agenda calls for development of portions of

Amazonia, as well as expansion of its agricultural as well other development infra-structures ventures, increasing the population density and pressure on resources.

The ADE present a most interesting research object and investigations have been conducted by a multidisciplinary group consisting of archaeologists, anthropologists, biologists, chemists, geographers, and soil scientists. Although, much more is need to fully understand all the socio-economical activities responsible for their existence and persistence, current results are furnishing a great amount of knowledge about their chemical and physical properties, genesis, and distribution.

History of Amazonian Dark Earths Research

In the Brazilian Amazon, the investigations of the anthropogenic ADE have a historical relationship with Natural Science research during the first explorations by naturalists and geologists in the second half of the 19th century, such as James Orton (1875:368) and Charles Hartt (1874a, 1874b, 1885). Hartt died young of yellow fever, and his students (Ladislau Netto, Orville Derby, Herbert Smith, and João B. Lacerda) published his data in the *Archivos do Museu Nacional* volume titled *Valle do Amazonas* (1885). The legacies of Hartt and his students were very important to the development of Natural Science in Brazil (for a detailed account, see Woods and Denevan 2009), and they reported spots with black soils in Taperinha, Diamantina, Panéma, and Itaituba. Orvile Derby, Hartt's student, became his successor and continued the Dark Earth research after Hartt's premature death (Derby 1885-98:374). Herbert Smith described the black earth land near the Santarém region (Pará State), giving details about its extension at intervals of five miles long on the top of the bluffs. One special site was pointed out in his description as: *"(…) from Panéma to Taperinha, and for some distance below, it forms almost a continuous line; indicating, in fact, a single village, or city, thirty miles long, but extending only a little way in from the edge of the plateau. At intervals, there are signs of ancient roads leading down toward the river, as at Diamantina"* (Smith 1879 :169). The next important work related to Amazonian anthrosols was carried out by Friedrich Katzer (1903), who recognized the fertility of these soils and called attention to their cultural origin. He also was the pioneer in applying chemical analysis to soils in abandoned settlements for fertility tests, methods not applied again in Amazonia until Sombroek (Woods and Denevan 2009).

A more detailed survey of the *terras pretas* from the anthropological point of view started during the first decades of the 20th century, with the ethnoarchaeological research conducted by Curt Nimuendajú, who made maps with the dark soils' distribution and conducted excavations in the Tapajós region (1925, 1949, 1952, 1953). Nimuendajú, with the collaboration of Erlan H. Nordenskiöld, who was the director of the Göteborg Museum in Sweden, amplified the collection of ethnoarchaeology artifacts for the museum from South America.

During the 1940's and 1950's, the fertility of the *terras pretas* (TP) was assumed to be due to natural processes, although it attracted people to the specific places where they were found. Initially, TP fertility was hypothesized to be the result of nutrients from the floor of an extinct lake or an effect of volcanic ash deposition (Camargo 1941, Faria 1946, Falesi 1972). The second half of the 20th century Woods and Denevan (2009) have divided into the 'pre-Sombroek' and 'post-Sombroek' periods (1966), calling Sombroek the Godfather of the *Terra Preta*.

A lot of work carried out about TP was associated with the identification and classification of soils for agriculture survey (Falesi 1967; Falesi 1974; Franco 1962; Ranzani, Kinjo, and Freire 1970); in addition, there were important geographic surveys in fluvial floodplains that included descriptions of archaeological sites and Amazonian Dark Earths on the Careiro Island, in the confluence of the Solimões and Negro rivers (Sternberg 1998 [1956]:107-110). Until the 1980's, almost no contributions related to ADE were made by archaeologists, and those that were made were associated with soil scientists and physical geographers.

Sombroek (1966) dismissed idea of a natural formation process of the ADE through a three-pronged analysis that produced three significant findings: (1) the clay fraction is the same of the surrounding soils (predominantly kaolinite); (2) the texture are the same in and out of TP; and, (3) the C horizon always presents the same characteristics as the other soils in the region (Sombroek 1966:176). These findings sparked research about anthrosols in Amazon. He also proposed a model of occupational systems, where the TP (*terra preta*) is interpreted as a result of kitchen-midden deposition and TM (*terra mulata*) as the effect *of long-lasting cultivation from gardens around the past villages* (Sombroek 1966:175). However, through the model of occupation that Meggers supported for Amazonia, the ADE were understood as a consequence of short reoccupations of a site through time, responsible for the genesis of thick and wide deposits of anthrosols due to the partial overlapping of occupations. The major contributions in archaeological research during the following decades were associated with the investigations developed by PRONAPABA (*Programa Nacional de Pesquisas Arqueológicas na Bacia Amazônica*), led by Meggers, which located numerous sites of ADE. However, the group's center of attention was the archaeological remains associated with these sites. The agricultural uses of the soil were considered to be low and their production capacity was calculated at only 4 people/hectare/year or 240 people. However, Miller pointed out that ADE could support agriculture of exigent plants like maize (Miller 1992:220).

Nigel Smith (1980) re-opened the discussion of dark soils and pre-Colonial populations with a well-know paper describing the physical and chemical characteristics of these anthrosols that also propelled the heated debate concerning Amazon occupational systems. According to Smith, the ADE were related to large, dense, and permanent village occupational systems, instead of small groups with a re-occupational settlement strategy. Smith also stimulated a review of standard notions of the carrying capacity of the forest, calling for attention to the resilience, nutrient availability, microorganisms, and vegetation of the TP (*terra preta*) (Smith 1980:562). Finally, he also observed a linear pattern of distribution suggesting linear villages with long periods of occupation correlated with the depth of the deposits of TP (Smith 1980:563).

In Brazil, a group led by Marcondes Lima da Costa (who advised Dirse Kern) and Nestor Kämpf started to work with ADE in the 1980's, producing influential discussions about the associated settlement patterns, geochemistry, site formation processes, classification analysis, and mapping of these anthrosols (Costa and Kern 1999, 2004; Kern and Kämpf 1989; Kern 1988; Kämpf et al. 2004). EMBRAPA (*Empresa Brasileira de Pesquisa Agropecuária*) also invested in research about ADE and its generation for modern agriculture practices, and many other soil researchers joined the discussion. More recently, in the 1990's the University of São Paulo started to contribute to ADE research through Neves' advice and the Central Amazon Project.

In Colombia in the late 1970's and 1980's, Bray, Eden, Herrera, and McEvans identified many sites in the middle Caquetá basin, archaeological sites related to ADE in the Colombian Amazon. Through a comparison of similarities between those anthrosols and the TP in Brazil they recognized a regional pattern of anthrosol formation process in the Amazon as an effect of settlement intensification in the region (Eden et al. 1984). Following this line of investigation, Cavalier, Herrera, Mora, and Rodrigues observed that in an attempt to increase the food production in the region at the Araracuara archaeological site (Caquetá River), around 800 AD the population added alluvial silt in order to increase the soil fertility, thereby generating TP (Mora et al. 1991)

In Germany, the University of Bayreuth became a center of ADE studies thanks to Wolfgang Zech, who led research about the fertility of TP and its holding capacity for nutrients (Zech et al. 1990). Pabst (1991) analyzed the content of OM (organic matter) and found a concentration 6 times higher than in surrounding soils. Glaser investigated the OM and black charcoal from incomplete combustion in the ADE, concluding that their effects were responsible for its fertility (Glaser et al. 2001a). Lehmann added that inputs of charcoal in soils increase the nutrients available for plants while also decreasing the leaching of P, K, Ca, and Zn (Lehmann et al. 2003b). All three are currently continuing to research with many students; their work will be summarized below. The latest publication from Zech's students was Steiner et al. (2007), which demonstrated that modern slash-and-char increases N in ADE, as well as OM additions in the form of charcoal that increase the negative charges and thus the cation exchange capacity of the soils, holding available nutrients longer in tropical conditions (Steiner et al. 2007:287).

In North America, at the University of Wisconsin a group formed that included professors and students led by William Denevan (1998), increasing the amount of knowledge and fieldwork focusing on ADE. Woods and McCann (1999, 2001) boosted the development of new research aimed at studying the formation process of anthropogenic soils, and its relation to pre-Colonial settlements and their agricultural practices. As a consequence of the results reaching the Wisconsin group, a ‘subdivision’ (wrongly so called) from the University of Vermont including James Petersen (Petersen et al. 2001) and Michael Heckenberger (1996) conducted research in Central Amazon and Upper Xingu related to chronology, settlement patterns, and population density in the past, and the implications for human behaviors in the ADE process formation (Heckenberger et al. 1999, Neves et al. 2004).

Therefore, the history of study of ADE can be described as international and multidisciplinary, with long-term traditions and collaboration between the different scholars. Currently, new results are available and will be discussed in the next sections.

Distribution of ADE

The ADE are found in several locations in Amazonia, and with the increase of research in the area certainly more sites will be found in other locations and different contexts. Woods and McCann identified ADE sites along the rivers, in the uplands, and on bluffs; near water sources and not; and associated with both sandy and clayey soil matrices (Woods and McCann 1999:8). Current baselines of research allow us to say that at least 45% of the sites are located between 5 to 25 m above a water source, only 1% are found 2 m above the rivers related to different types of soils, such as Ferralsols, Podzols, Acrisols, Luvisols, Fluvisols, Nitisols, Cambisols, and Arenosols (FAO Classificaiton), and these are usually less than 2 ha in size, but a few of them are more than 100 ha (Kern et al. 2004b). In the lower Tapajós, near Santarém, Woods and McCann (1999) identified very large ADE sites with different densities of archaeological materials whose distribution is suggestive of habitation refuse associated with areas formed by long-term agricultural activities, and similar results have been found in the Central Amazon. Thus, the ADE sites present great variability in terms of extension, age, shape, thickness, and location in the landscape (Kern et al. 2004a).

Classification

Kämpf et al. (2003) called attention to the classification of ADE and the problems in building a taxonomic system due to the extreme variation in the ADE at the micro-scale. The research also pointed out distinct models created over the years in order to provide explanations of the ADE formation processes. The analysis envisioned three models: (1) the midden model (Smith 1980; Woods 1995; Kern 1996); (2) the agricultural model (Woods and McCann 1999); and, (3) the "moundbuilder" model (Erickson 1995). The midden model considered habitation debris as responsible for the origin of *terra preta* (TP), while the agriculture model related to the formation of *terra mulata* (TM). The moundbuilder model reflects the earthworks found in Llanos de Mojos, Bolivia. According to the taxonomic system, ADE are classified as *fimic A horizon* (FAO 1988); or *anthropic epipedon* (Soil Survey Staff 1998); or *anthropic A horizon* (Embrapa 1999); and, finally, *plaggic or hortic horizon (WRB, ISSS-ISRIC-FAO 1998)* (Kämpf et al. 2003:81). Kämpf et al. (2003, 2009) highlighted that the ADE needed better classification, especially because they vary inter- and intra-site, pointing out they are the result of both sedimentary and pedogenic processes, of both cultural and natural activities, and have specific properties (Kämpf et al. 2003). They proposed an *Archaeo-pedological classification* (APC), with the terms defined through horizon characteristics easy to identify in the field, thus saving efforts in the laboratory (Kämpf et al. 2003, Kämpf et al. 2009). This classification system has four taxa. The first level is called an *archeoantropogenic* horizon and encompasses the traditional characteristics of the ADE and depth and quantity of distribution in the profile of archaeological materials, charcoal, and organic carbon. The second level includes *agric, cultic, hortic, protic, scalpic, shellic, terric, thaptic, urbic* horizons. They are directly related with the human activities performed through time. Agric refers to agricultural fields generating *terra mulata;* cultic to a cultural horizon with plentiful artifacts; hortic, a prolonged habitation with the addition of domestic organic refuse and cultural material; protic, those pre-conditioned soils from before the human occupation; scalpic, the total loss of the cultural horizon; shellic, shell accumulations; and terric, the results of additions of mud creating the earth mounds (Kämpf et al. 2003, 2009). Descriptions of the third and fourth levels can be accessed in Kämpf et al. 2003, Kämpf et al. 2009. Recently, Macedo (2009) discovered ADE in floodplains and as a result he proposed a classification for the existence of ADE in *várzea* areas as *Arqueo-antrossolo Tapto-hórtico.*

Chronology

Currently, the ADE chronology does have better time resolution, despite the fact that a pattern of spatial distribution in relation to time is not well defined yet. The current radiocarbon dates for the beginning of ADE have shown a cluster around 2,500 BP (Denevan 2001). Earlier dates, 8,700 and 6,700 BP (Liang et al. 2006), were reported at the Dona Stella site in the Central

Amazon, but the dark coloration was clearly a result of post-deposition pedogenesis, and neither the chemical analysis (Woods, personal communication) nor the micromorphology (Arroyo-Kalin 2009) indicate anthropogenic enrichment. Miller's (1992) dates of 4,800 BP to 2,600 BP have yet to be substantiated by other investigations and, unfortunately, the site that yielded these dates is now inundated. Currently, a beginning date around 2,500 BP and intensification after 2,000 BP are being broadly accepted (Balée 2010); nevertheless, earlier clusters might be identified as research continues. Neves (2008) has also pointed out changes in the political and economic organization of the Central Amazon that overlap with intensification of human management of the resources chronologically correlated with ADE. The sites with ADE in Central Amazon are dated at least to the beginning at the Christian era (Petersen et al. 2001); however, near Manaus in the Paredão archaeological site the ADE is dated to 450 BC (ca. 2,500 BP) (Hilbert 1968:256). On the Rio Ucayali, Peru, in the Hupa-Iya and Yarinacocha area, the ADE are dated ca. 200 BC (ca. 2,200 BP) (Eden et al. 1984:126). On the Rio Caquetá, in the Araracuara region of Colombia, the ADE are dated ca. 384 AD (Eden et al. 1984). Finally, the Upper Xingu River presents the beginning of an ADE process formation at ca. 950 AD (Petersen et al. 2001). There is a correlation between an intensification of sites with deep and wide ADE horizons at different places in Amazon, which is called by some authors the 'Period of Regional Integration' (Petersen et al. 2001:99). This first period of ADE formation is associated with the Arawak people whose spread and domain included a wide territory until 900-1000 AD (Heckenberger 2005).

Current Research

At the turn of the new millennium the enlargement of the ADE research groups and the constant increase of investigation has resulted in three volumes in English (Glaser and Woods 2004, Lehmann et al. 2003, Woods et al. 2009) and one book in Portuguese (Teixeira et al. 2009). Over a hundred articles were produced over the decade as a response to demands for information demands and the intensive work interactions.

Also, given the high importance of soil improvement in tropical regions for sustainable agriculture systems, the huge amount of carbon storage capacity of the ADE was probably a major factor in capturing the international interest of soil scientists (Sombroek, Nachtergaele, and Hebel 1993; Sombroek and Souza Carvalho 2000; Glaser et al. 2001b; Glaser et al. 2004b, Lehmann et al. 2003b; Falcão, Comerford, and Lehmann 2003; Madari, Sombroek, and Woods 2004). Great development also resulted in intensive research about the fertility of the soils. However, in order to learn how to generate ADE it was necessary to understand who, how, why, when, and how long they were generated. Needless to say, that was a job for archaeologists, anthropologists, and geographers.

Kern (1996) was the first pioneer, in Brazil, to analyze ADE sites and their geochemistry in comparison with adjacent soils in order to understand the human activities responsible for their genesis. Sampling of three different sites (Manduquinha, Mina II, and Ponta Alegre) in Pará State presented identified trace elements in the ADE directly associated with human activities. Through geostatistical analyses she was able to map different sources of material by mapping the increase of P, Ca, Mg, K, Mn, Cu, Zn, Ba, and Sr as typical elements related to ADE and to presumed activity areas associated with disposal patterns. Beside this, her work also analyzed the post-depositional effects and pedogenesis that contributed to the formation of ADE (Kern 1996). Afterwards, Costa and Kern (1999) increased the trace element analyses and identified the post-depositional behavior of elements, concluding that (1) hydromorphic conditions changed the physical and mineralogical composition of the ADE; (2) quartz is more abundant in ADE and kaolinite in nonanthropogenic soils; (3) the high concentration of Ca in the A horizon sharply decreases in the B horizon and is associated with the presence of shell fragments; (4) the correlation of Mg and P expresses the contribution of foods of animal origin; (5) Mn, Zn, and Cu come from other type of food and implements, suggesting an association among these elements and the presence of palms, trees, fruits, and other vegetal materials; and, (6) Ca, Sr, Ba, and Cl correlate with accumulation of shellfish and animal foods (Costa and Kern 1999). Lately, archaeological research is showing that ADE formation processes on sites in the Marajó Island are associated with cultural practices, that is, with a high dependence of riverine fauna, and on dump areas responsible for the genesis of ADE (Schaan, Kern, and Frazão 2009).

If Smith's (1980) article sparked new ADE investigations and analysis at sites developed by and analysis in sites developed by Brazilian, German, and North American researchers during the 1980's and 1990's, it is possible to say that in the 1990's the articles by Denevan (1995), Woods (1995), and Woods and McCann (1999) boosted research on ADE in the United States, as well as regenerating the intercontinental discussion nets. In the last ten years the exchange among researchers through meetings (Benicasim 2001; Rio de Janeiro, 2001; Manaus, 2003; Philadelphia, 2006; Manaus 2009) and publications has allowed important conclusions to be reached through interdisciplinary collaboration.

Presenting different questions about the geneses and stability of the ADE, Denevan (1995) and Woods and McCann (1999) provided baselines for different research fields. For instance, the identification of growth and regenerating properties of ADE through soil biota activity related with the melanization process (Woods and McCann 1999:12) resulted in interesting conclusions about these microorganisms, discussed below. Moreover, Woods and McCann called for attention to how the depth-time and color of the ADE corresponded, not only to duration of occupation deposits, but also to nonanthropogenic factors like soil texture and geomorphic context, which could be responsible for the deep profiles of ADE through eluviation or alluvial and aeolian accretion (Woods and McCann 1999:9). Another question is related to the genesis of ADE, and in particular to, on the one hand, the midden model, and on the other to the definition of TM as the result of agricultural fields with a village system composed of "*long standing habitations, sustained by surrounding permanent gardens and fields*" (Woods and McCann 1999:12). Analyzing the differences between TP and TM the authors concluded that the last were generated through mulching and burning of household organic waste that transferred nutrients to the agricultural fields, especially OM and char. The ADE research acquired more and more contributions at the micro-scale, as research about black carbon yielded an understanding of ADE's fertility persistence, as presented below.

Zech studied the resilience and fertility of ADE through soil chemistry analysis, working with students in order to understand the pedological process that could explain such characteristics. Lehman et al. (2003) presented findings on the relation between the amount of available and total elements in ADE, recognizing that although ADE are much more fertile than adjacent soils they do not necessary have availability of all nutrients, like K, Mg, or Fe

(Lehmann et al. 2003a:106). In addition, the release of available elements in the ADE is related to the soil organic matter (SOM) and occurs through biological processes rather than from the weathering of parent materials, for the matrix is strongly weathered (Lehmann et al. 2003). Also, Lehmann et al. (2003) showed that the SOM increases the Cation Exchange Capacity (CEC) of these soils as well the pH and the saturation bases, because only 33% of the CEC is related to the clay contents (Lehmann et al. 2003:109). According to Glaser, ADE present much higher concentrations of black carbon (BC) than surrounding soils. Thus, BC is responsible for the high levels of soil organic matter (SOM) and the stability in these soils; that is, the SOM of ADE consisted of up to 35% black carbon (BC), mostly located in the silt and clay fractions (Glaser et al. 2000:191, Glaser et al. 2001a). Moreover, due to its recalcitrant properties in ADE black carbon increased their fertility and CEC, as well as improved moisture retention and bulk density. In addition, Glaser pointed out that due to the increase of negative charges from SOM these soils slow nutrient leaching when compared with the adjacent soils. The nutrients are released from adsorption and from SOM by mineralization, which according to research results has a low intensity that prevents a fast leaching event (Glaser, Guggenberger and Zech 2004a, Teixeira and Martins 2003, Lehmann et al. 2003a).

Microbiological research both in the Central Amazon and in other areas is being furthered by the contributions of the Center for Nuclear Energy and Agriculture (CENA) at the University of São Paulo, where Professor Siu Mui Tsai and her group are building a clone library of the soil bacterial communities (Tsai et al. 2008). This research has highlighted that indeed the addition of black carbon in the soils modifies the nutrient contents of ADE, but it is still unclear which carbon species and their chemical characteristics impact the microbial populations and what kinds of microbes interact with black carbon (Tsai et al. 2009). Analysis of the Hatahara site samples in particular demonstrated that ADE there have higher bacterial phyla than adjacent soils, even under intensive agriculture practices; therefore, different microbial communities are related with P (*enzyme MspI data*), OM (enzyme *Hha*I data), and black carbon in the ADE versus the surrounding soils. These are responsible for buffering microbial communities in soils of ADE over millennia (Navarrete et al. 2010:799-800). The results of this research found out that microorganism diversity in ADE remains high deep in the profiles in comparison with adjacent soils; this discovery validated Woods and McCann's (1999) projected association between microorganism activity, depth, and growth of the ADE downward.

Recently, Birk observed that the fertility of ADE is not just due to the high density of black carbon in their matrices, but also is associated with the addition human feces contributed to their genesis and resilience. The deposition of feces in the soil transforms the microbial community structure, changing the soil nutrients and carbon dynamics in ways that promote the soil's sustainability. Although feces application to soil is an ancient technique in different parts of the world, the intentionality or not in the ADE case needs further investigation (Birk et al. 2011:1218). Altogether, we can see a multiplicity of elements bringing about the genesis and resilience of the ADE. Micromorphological analysis revealed microscopic anthropogenic inclusions in the ADE such as bone and charcoal, and microscopic fragments of ceramic and baked clay associated with high levels of nutrients (Arroyo-Kalin 2010). The evidence suggests a continuum of *in situ* burning as the profile accretes (Arroyo-Kalin 2010:480).

Analyses carried out by Lima et al. (2002) using scanning electron microscopical analysis observed that most of the total P in ADE presents an amorphous, low-crystalline form associated with bone apatite from fish middens, which through time was adsorbed in the clay (Lima 2001). The calcium pool in these soils also is pointed out as resulting from an increase in apatite bone distribution in the profiles due to earthworms and other faunal pedoturbation (Schaefer et al. 2004). This last work discussed earthworms as one of the major source of bioturbations in the site, and how they redistribute nutrients within the profiles; however, questions about bone apatite from fish spines still need to be clarified (Arroyo 2009, Woods, personal communication, 2011). Thus, at the middle scale the soil fauna definitely contribute to changing the soil signatures left by humans, and because of this, it is important always to consider the context of the nutrients in the profiles in relation to pottery and to radiocarbon dates.

At the macro-level, the anthropological perspective among other things helped to understand the traditional uses of soil and traditional ameliorating techniques that could be responsible for ADE generation. An example is Hecht's (2003) work that revealed the mulching of organic materials among the Kayapó, a native American Indian group located in the uplands within the Xingu River watershed, Brazil. The technique used by the group to ameliorate the soils for agricultural fields consists in preparing a midden with food residues, ashes, old basketry, large animals bones and hides, old roofs and construction material, and palm leaves, and setting a "cool fire", with posterior application of the ashes and black charcoal waste in their fields to enhance fertility by increasing levels of P, C, and K (Hecht 2003, Hecht 2009). In the Assurini do Xingu located in the Middle Xingu River, it was possible to observe the spatial distribution of the activity areas in the village, especially the disposal areas where all nutrients are deposited to form middens (Silva and Rebellato 2004). In the Upper Xingu, Schmidt developed an ethnoarchaeological research project among the Kuikuro and the activity areas in their village. He pointed out that current Amerindians are creating within and around their village soils more fertile and less acid than in surrounding areas. According to the author, besides disposal areas, ritual and domestic activities, plus agriculture practices, have a significant impact on the soils, and their signature can help us to understand past activity areas in sites (Schmidt and Heckenberger 2009).

In the *caboclo* (Brazilian *mestizo*) villages in the Amazon, Winklerprins pointed out the ‘sweep and char’ activity that consists of sweeping the daily debris around the houses of the villages up, placing them in the yard, and charring them, a chore usually carried out every day that generates what she called the *terra queimada* (burned earth). These materials are then placed in house garden areas. According to the author this practice could be responsible for the genesis of ADE over time (Winklerprins 2009). Fraser demonstrated that current populations in the Manicoré, Middle Madeira, and Negro rivers use different types of manioc (*Manihot*) according to the soil’s properties, including changes in compaction of the soils through long-cropping cultivations that increase friability. Moreover, he called for attention to the techniques used to improve the fertility of the soils, suggesting that processes like char applications could generate the *terra mulata* (TM) (Fraser et al. 2009).

Ethnobotanical approaches were carried out with native Indians in Brazil, as well as among traditional communities (*caboclos*) in Amazonia. Junqueira et al. (2010) identified specific species in correlation with ADE, like Murumuru (*Astrocaryum murumuru),* Taperebá (*Spondias monbin*), and Caiaué (*Elaesis oleifera).* In addition, he states that ADE acts as an agrodiversity reservoir. Moreover, Clement et al. (2005) highlighted the large number of domesticated fruit trees and attributed this to the spreading, managing, and increasing the diversity of species by human activities. From the University of Kansas, Thayn integrated the information from satellite images – using Moderate Resolution Imaging Spectroradiometer (MODIS), in order to recognize vegetation signature patterns during distinct seasons, and established correlations between vegetation types and the presence of ADE (Thayn 2009).

Associated with the Central Amazon Project, from University of Cambridge, the project "*Steps Toward and Ecology of Landscape: Geoarchaeological Approach of ADE in the Central Amazon Region*" had as main objectives to understand the time-depth and formation process of ADE (Arroyo-Kalin 2008). Arroyo-Kalin reached three important conclusions: (1) the Paredão anthropogenic soils were formed over already anthropogenic altered soils apparently started by Manacapuru people with less dense settlements; (2) the occupations of the region were constituted by large settlements during the 1st Millennium BC and definitely larger ones in the late 1st Millennium AD; and, (3) the analysis of the mounds profiles in Hatahara and Lago Grande sites associated with Paredão phase suggested that an accretion of house' floor sediments in order to build platforms might be related with ADE formation (Arroyo-Kalin 2008:171). At this same site, Rebellato identified a change in village shape from a circular to a linear pattern with the reoccupation of the site by the Guarita group in the late pre-Contact Period (Rebellato 2007, Rebellato, Woods, and Neves2009).

Also, in association with the Central Amazon Project, a group from the University of Bayreuth, Germany, led by Glaser, developed the research survey "*Reconstruction of Geneses of Terra Preta Using Molecular Biomarkers and their Compound Specific Stable Isotopes*", so that Bayreuth students could accomplish their research in the area. Grosch (2005), for instance, identified the circular-shaped village at the Hatahara site through the analysis of available P.

Also, experiments with the addition of charcoal associated with fertilizer composts in low-productivity soils were shown to be beneficial and important in order to feed enhanced microorganism growth (Birk et al. 2009:322).

At INPA (*Instituto Nacional de Pesquisas da Amazônia*), Manaus, Charles Clement started developing research among the traditional population, studying their agricultural practices and the ADE from a ethnobotanical point of view, and Newton Falcão did the same with an interest in the soils' fertility for modern agriculture (Clement, McCann, and Smith 2004; Falcão et al. 2003; Falcão, Carvalho, and Comerford 2001).

Chapter 5

The Study Area

This chapter will be related to the fieldwork carried out at the Hatahara site and the methodology for analysis of the soils and the archaeological material collected during four seasons of fieldwork (1999, 2002, 2004, and 2007) at the three sites this research is based on. Through this variety of settings and cultural contexts crucial refinements can be made to what has already proven to be a most effective geographic tool, and so aid in developing an expanded, systematic methodology that will greatly facilitate the resolution of basic questions concerning the pre-Colonial occupation of Amazonia and the interaction of those past societies with their environment. Indeed, once fully developed this methodology could be applied to projects throughout the Neotropics.

First, the Hatahara site will be presented, its location and description, and the methodology encompassing fieldwork and laboratory investigations. Results are provided in the Chapter 6.

The study area is located in the Central Amazon, Amazonas State, Brazil. Generally, the soils are some of the oldest and are highly weathered; moreover, the fluvial systems are very well known as the largest in the world. Tertiary Plateaus have better preserved the archaeological records than current T1 and T2 floodplains. The geological formation processes also give some clues about the parental materials of the soils in the Amazon. Besides old and weathered soils, in the floodplains soils are fertile and productive for recessional agriculture (presented above); as are the anthropogenic soils in the uplands. The location of archaeological sites can be associated with abundant water resources. Fluvial systems have different functions, for instance: (a) they are rich in food resources (fish, turtles, aquatic mammals, and reptiles); (b) many of the rivers are navigable, so they served as "roads" in the past (actually, they are being used very intensively as "roads" in the present, too); and, (c) river channel change and flooding through time have erased much of the archaeological record. Therefore, to work in this area, it is necessary to keep in mind that although human societies were most certainly interacting with and using landscape resources, post-deposition, sedimentation, and all manner of natural destruction of the sites were and are responsible for whether or not archaeological settlements are preserved, as discussed above in the topics "River System" and "Uplands."

South America

Figure 3 – South America and the study area (represented with a black spot)

Site Description

The Hatahara site is located at the confluence area between the Amazon/Solimões and Negro rivers (Fig. 3), on the top of a bluff (Alter do Chão Formation - Cretaceous), parallel to the Amazon River. On the top of Alter do Chão Formation, the bluffs are well-drained uplands with low-fertility soils where the pre-Colonial agricultural systems took place as long-fallow shifting cultivation (Denevan 1996:669). The upland and floodplains have a complex relationship with biodiversity, human impact, and settlement locations.

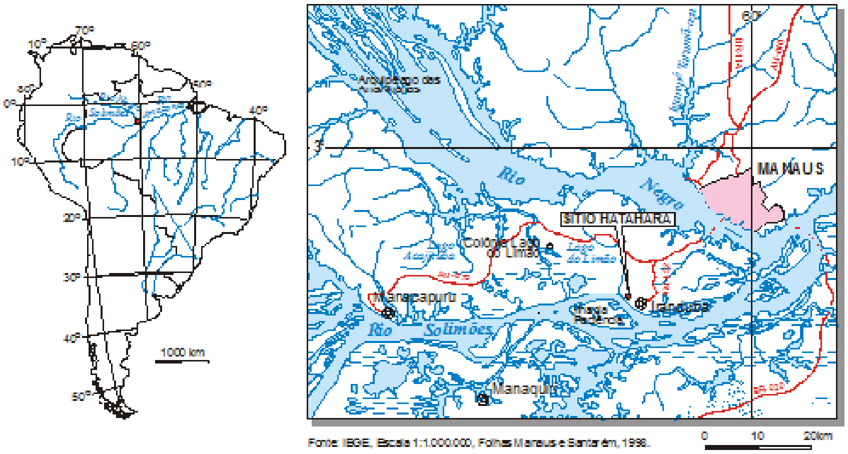
The Hatahara site contains pottery from four different archaeological phases spanning at least 2,000 years of occupation, but I will concentrate only on the final two occupations: the Paredão phase (ca. AD 800-1100) and the Guarita subtradition (ca.1100-1600). They present a complex cultural stratigraphy with deep and extensive black- and brown-colored anthropogenic soil layers, with high and low pottery concentrations, respectively. To understand the archaeological site formation and its association with the human-made soils termed Amazonian Dark Earths, it was necessary to conduct extensive fieldwork across the sites and new fieldwork needed to be done for a better definition of the specific activity areas.

Table 1 - Pottery chronology of the Central Amazon

Pottery Complex	**Reported Radiocarbon Date Ranges**
Açutuba Phase	300 BC – 400 AD
Manacapuru Phase	400 – 900 AD
Paredão Phase	700 – 1200 AD
Guarita Phase	900 – 1600 AD

Sources: (Arroyo 2008; Hilbert 1968, Lima 2008; Neves et al. 2003, Neves et al. 2004)

At Hatahara, the physical and chemical soil analyses have since confirmed the association between a circular concentration of organic material/black earths surrounding a central plaza and the Paredão phase. The circular shapes of villages is associated with warfare during this first millennium in the Amazonia. Around some archaeological sites it is possible to see some trenches or defensive structures that indicate conflict between the habitants within the earlier periods. (i.e., Table 1 for chronological details).



Fonte: IBGE, Escala 1:1.000.000, Folhas Manaus e Santarém, 1998.

Figure 4 – Sites location and study area (map from Rebellato, Woods, and Neves 2009)

The second and more distinctive pattern of settlement morphology is related to the Guarita linear-shaped village (Rebellato et al. 2009). The linear villages indicate a lack of protection against attack; they are indefensible (Woods 2008, personal communication). Results of anterior works also furnish one more reason for this shape, namely, better use of the previously formed dark earth soils for food production. If the Guarita phase with their linear villages were, indeed, Tupian speakers, such use would be associated with their characteristic intensive agriculture, and, as will be shown, the Tupi expansion could also be interpreted as the conquest of territories where these fertile soils were abundant. Moreover, if the linear pattern is confirmed in other sites in the region, it will be possible to relate this group with an extensive territorial domain with linear villages, once it is shown that the territory was occupied by that same group and the warfare in this period was reduced or nonexistent.

Figure 5 – Aerial photography with the site borders represented (from Rebellato, Woods, and Neves 2009)

Methodology

Here is presented the fieldwork statement, followed by a description of laboratory procedures. The fieldwork carried out at the Hatahara archaeological site benefitted from cooperation among different institutions of research from Brazil and other countries. The association with University of Bayreuth (Germany) and University of Kansas (USA) brought together students and researchers in order to understand this complex site's archaeology in Amazonia. Hence, the subsequent field and laboratory work are a fusion of methodologies from archaeological and earth sciences. Here, the emphases will be the pedological perspective in the interpretation of the archaeological evidence; therefore, ceramic and other archaeological artefact analyses will not be the focus, but will be presented in correlation with soil signatures.

Fieldwork

In the field, the investigation included emplacing a topographic network with intersection points of the coordinate axes, already consolidated by a Total Station surveying instrument. A total of 103 cores were taken systematically at a spacing of 25m (carried out at the intersection points of the N/E coordinate axis). With a bucket auger the subsoil material was collected in every test point, at arbitrary depths of 20 cm every collection. The procedure is about sorting out distinct soil layers and ceramic sediment and other archaeological material such as lithics and faunal material (Grosch 2005; Rebellato, Woods, and Neves 2009). All archaeological samples and soils were classified according to location and depth and packed and marked in plastic bags.

Such systematic surveys have been done at many archaeological sites by the Central Amazon Project. Finding out the village layout, activity areas, and use of space at archaeological sites in Amazonia has been a difficult task. The main problem concerns conditions of prior weathering and pedoturbation that change the site context. Therefore, archaeologists need to work with scientists from other disciplines to understand these processes and how they have affected the specific site situation and its included cultural remains.

The Hatahara site presents a complex stratigraphy. It is multicomponential with a thick layer of ADE, some areas with more than 2m. The last four interventions done in this site identified 12 funerary urns and 24 skeletons (well preserved) and large quantities of archaeological remains, including ceramics and lithics.

Sample Collection

Besides the auger pits, test pits and other excavation units were open for better stratigraphic resolution. In this way, the auger pits gave better data about the horizontal distribution of archaeological materials in the sites, while test pits and units gave better details of stratigraphic changes, furnishing accuracy on the specific vertical scale. Each method will be described below.

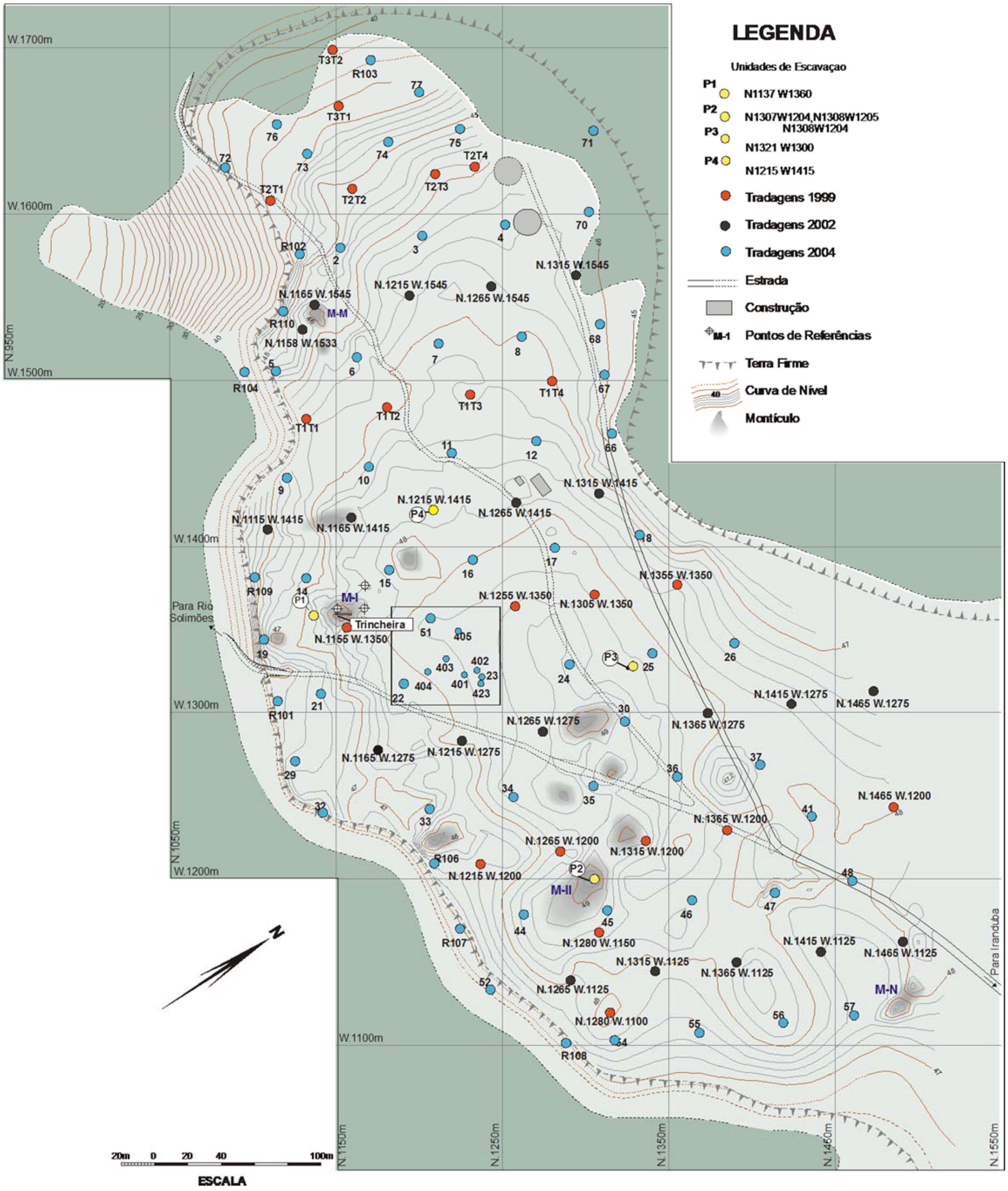


Figure 6 – Map of the site with augers and excavation units (From Rebellato, Woods, and Neves 2009)

Auger and Test Pits

The test points determined in transects produced a total of 600 soil samples. During the fieldwork carried out in 1999 and 2002 seasons soil and archaeological remains, mainly pottery, were collected through arbitrary 20 cm levels until the culturally sterile subsoil was reached. In the 2004 season the auger points reached in to 2 m depth. Soil samples of approximately 300 g were collected from each level, as well as archaeological materials. Each level was described on forms with information about debris pottery quantity, soil texture and color (Munsell), bones, charcoal, and lithic presence in the sample. Soil and archaeological remains samples were placed into plastic bags, each one with a unique provenience number (PN).

Physical soil signatures such as color and texture were described in the field. Color was described using the Munsell Soil Color Chart, while samples were moist. The texture was estimated in the field through hand-texturing and judging the approximate proportions of sand, silt, and clay. Characteristics such as plasticity can reveal whether the sample is a sand, clay, sandy loam, or clay loam (as described in Rebellato, Woods, and Neves 2009).

Figure 7 - Auger pit samples

Currently, new technologies are helping to understand the process of archaeological site formation. Through a comparative investigation in two different archaeological sites in the Central Amazon this research will intend to show distinct ADE formations; namely, the unintentional versus those made intentionally. This is determined through analyses providing physical and chemical soil signatures for these two different contexts.

Figure 8 - Test pit aperture to collect bulk density samples

Units

Units help the understanding of the stratigraphy in both sites once is possible to see the construction process of mounds (Machado 2005) and house floors (Arroyo 2009). In order to understand the occupation and re-occupation process of the site, opportunistic units (1x1 m) were opened in distinct areas, especially those with potential structures (like mounds), areas in the border between TP and TM, central areas, and the periphery of the site. The most understood features in the site are the mound (P1), where a trench was opened to shown direct burial contexts, and the urn sector (P2), with a different work approach (Machado 2005; Lima 2008; Arroyo 2009; Bozarth et al. 2009; Birk 2010; Daniel 2010), see Fig.4**.**

A collection of bulk density samples was carried out at the Hatahara site during two distinct field schools (2006 and 2007). Besides the collection of bulk density samples, Constant Volume Samples (CVS) were collected from each of the 1x1m units 10 cm into the northeast corner. These samples were separated and sent for chemical and phytolith analyses (Bozarth et al. 2009). The results helped to clarify questions about the archaeological process of site soil formation.

Bulk Density

The first data are related with the bulk density of the soils and features at the Hatahara archaeological site. The samples were collected during the 2007 fieldwork season and analyzed by the *Embrapa Solos - Amazonia Ocidental*. Bulk density *is the weight of a known soil volume compared to the weight of the equal volume of water, or weight per unit volume* (Buol et al. 1973). In other words, bulk density is the mass of a unit volume of dry soils (Brasy and Weill 2002). The samples were collected from the profile units excavated with a cylindrical core approximately 5 cm in diameter and 5 cm in height and were extracted without disturbance or compaction with a help of a hammer. With a knife the excess of soil was cut from the edges of the cylindrical core and this action also aided in the preservation of their undisturbed condition.

This technique is routinely applied in earth science surveys to convert data from a weight to a volume basis, to estimate saturated hydraulic conductivity, to identify compacted horizons, and to estimate porosity (USDA 2004; Teixeira and Martins 2003). The soils in some abandoned settlements have distinct physical characteristics, for instance, where distinct social activities were carried out, such as in old plazas, roads, croplands, and trampling areas, the soils show and increase in bulk density and a decrease of porosity.

Laboratory

The samples were prepared in different laboratories. The first soil methodological description took place at Rock River Laboratory Inc., WI, in December 2010. There, we carried out pseudo-total analysis using Inductively Coupled Plasma – Mass Spectroscopy (ICP-MS), pH and some Merlich-3. The term Pseudo-total is applied because the acids do not extract completely the elements in the clay crystals; however, these nutrients are not associated with human activities; they are part of the natural content of the colloidal and crystal soil. The second took place at Embrapa Amazonia Ocidental (Agriculture Agency in Brazil), during the seasons of 2004 and 2007.

Sample Preparation

The samples were air-dried and powdered using agate mortar and pestle and sieved at ≤1 mm. The sieve was cleaned up with compressed air before the procedure was continued with the next sample. To *aqua regia* digestion the samples were weighed to 0.500 g of soil mixed with 10 mL of nitric acid (HNO_3) in glass tubes (cleaned and rinsed with deionized water), and thermal heated (hotplate) for 1 ½ hour at 204^0 C. After that, 10 mL of hydrochloric acid (HCL) were added and thermal heated for ½ hour at 204^0 CA. The *aqua regia* was prepared in the 1:1 HCL:HNO_3 (Pharmo and AAPER) proportion as routinely practiced in the Rock River Laboratory Inc. After cooling off, deionized water was filled to 100 mL in the tube, which was closed, shaken, and filtered with Whatman no. 2 paper rinsed with deionized water added with 5% nitric acid. The solution was filtered in 50 mL duplicate volumetric flasks. The decision to duplicate the samples was because they will be run three times in the ICP, hence the need to ensure the amount of solution for the apparatus. The procedure was carried out in the following order:

- 0.500 g of soil
- 10 mL HNO_3 1 - ½ hour at 200^0 C
- 10 mL HCL - ½ hour at 200^0 C
- Cool down
- Filled until 50mL
- Filtered
- Analyzed - ICP

Aqua regia is strongly recommended for solubilization of trace elements in soils, is commonly used for pseudo-total soil digestion, and has precision and accuracy for the major target elements analyzed (Chen and Ma 2001, Pansu and Gautheyrou 2003). At high temperatures the hydrochloric acid attacks the silicates, oxides, sulfates, and fluoride minerals, while the organic matter is digested by nitric acid (Pansu and Gautheyrou 2003). The digestion in the HNO_3-HCl mix does not extract a total amount of many metals (Falcioni et al. 2000). However, the elements extracted here using ICP-MS (Al, B, Ca, Cu, Fe, K, Mg, Mn, Na, P, S, and Zn) respond well to the technique. The focus of analysis will be concentrated on the elements that are anthropogenically significant, such as Ca, K, Mg, Mn, P, and Zn, since Fe and

Al will not be considered and B, Cu, Na, and S are just presented for specific aspects of the results. Multi-element soil analysis is becoming widely used in archaeology and some standardization needs to be presented, so the procedures applied will now be described.

Inductively Coupled Plasma–Mass Spectroscopy (ICP-MS)

The ICP-MS is useful for tracing elements in soil analysis; it has a multi-elemental capability with high detection power and low sample consumption (Falcioni, Novaro et al. 2000). The apparatus is a Thermo Scientific CAP 600 Series, Model 6300, that injects argon through a standard touch. The solutions are set in racks and correlated with five standard and one 'blank' solution, in a flush time of 5 seconds. It could analyze hundreds of samples in a day's work, but the digestion process is time consuming. In the software samples were correlated with their weight and the correlation between the standard and the solution sample analyzed were accepted ≥0.99.5. The standard solutions were prepared as follow:

Table 2 – Standard solution description

	Acid	**Dilution**
Blank	10 mL - HCL 10 mL - HNO_3	100 mL H_2O
Standard 1	Deionized water	1000 mL H_2O
Standard 2	30 mL - Ca 40 mL - K 10 mL - Mg 10 mL – Na	200 mL H_2O
Standard 3	10 mL - P 10 mL - NHO_3	200 mL H_2O 10 mL HCL
Standard 4	1 mL – Zn 1 mL – Mn 1 mL – Cu 2.5 mL – Fe 272 g – K_2SO_4 1 mL – B 25 mL – Al	1000 mL H_20 10 mL HCL 10 mL - HNO_3
Standard 5	10 mL – P 30 mL - Ca 40 mL - K 10 mL - Mg 10 mL – Na	10 mL HCL 10 mL - HNO_3

A total of 150 samples were analyzed using this method, the same sample was analyzed three times, and the mean of these was used for the statistics. The results will be shown in tables and graphics. The next extraction was to analyze the available elements in the soil, very helpful for working with the human additions to the soil matrix once the context of the samples is well-known.

Mehlich 3

The Mehlich 3 soil test extraction was developed in 1984 (although Mehlich 1 has existed since 1953) (Mehlich 1984). This method was to be a universal soil extractor, although it is not user-instrument friendly. A Mehlich extract is composed of 0.2N acetic acid + 0.25N NH_4NO_3 + 0.013N NHO_3 + 0.015N NH_4F + 0.001M EDTA. The functions of the components are: Acetic acid (CH_3COOH) buffers the extracting solution to pH 2.5 to prevent calcium precipitate in calcium fluoride (Mehlich 1984). The amonium nitrate (NH_4NO_3) facilitates extraction of Ca, Mg, Na, and K. Nitric acid (NHO_3) extracts calcium phosphates and the acid helps to extract basic micronutrients' cations. Ammonium fluoride (NH_4F) extracts Fe and aluminum phosphates. Ethylenediaminetetraacetic acid (EDTA) chelates micronutrients and prevents precipitations of calcium fluoride (Source: NCDA&CS Agronomic Services Division North Dakota).

For those samples analyzed in the Rock River Laboratory Inc. (USA), the procedures are the following: the solution prepared for extracting (20 mL) was added to each sample and they were shaken for five minutes using 200 rpm shaker table. The sample were filtered in Whatman no. 2 filter paper and analyzed in the ICP. Also, three sequences were made in order to have three results of the same samples, and their averages are the results considered. For those analyzed in Embrapa Solos (Brazil), Mehlich 3 was used for extraction, although the results were read in a colorimeter spectrometer.

pH

The pH of some samples was analyzed in 1:1 water 10g.

Bulk Density

At the Embrapa laboratory the samples were first weighed with their field humidity and then dried in the oven at 110 ℃A. The next step was to weigh them again to calculate the dry mass of the soil. The bulk density is the mass of the solids divided by the volume of soils. The major components of the volume of soils are: (1) Pores – that contain air and liquids; (2) Inorganic solids – sand, silt and clay; and, (3) Organic matter. Through this procedure, it was possible to measure the variability of the soil compaction at Hatahara site as is presented in the Table 3.

Figure 9 – Bulk density samples

Chapter 6

Results

This chapter encompasses the results from the Hatahara site. The data will be presented as maps, tables, and figures. The main objective here is to provide data for the discussion about the formation of ADE as well as the elements associated with settlement layout and the formation processes of the sites and features. First, the pseudo-total analysis of the site will be presented, after that, the available results. Each one of the results received distinct statistical treatment; due to this differentiated approach, they will be presented separately and a short explanation of the data analysis will be presented before each result.

The soil sample results were statistically analyzed using different software, such as Past, VESPER, Excell, and R. Past was used to make correlations among different total elements, VESPER helped with the available elements, Excell with the total elements, and R was used to check the normality or not of the data. The bulk density was used to project the amount of elements in the site in order to calculate the quantity of OM inputs in the soils through time.

Bulk Density

The bulk density results are presented below and will be useful for calculating the amount of P, C, and Ca in the site. This information is of great utility in estimating the population at the site. However, these data reflect the *total population*, not the density of each population in the occupational chronology.

Table 3 – Bulk Density result in the mainly profiles in the site

Location	**Cylinder**					**Soil**
Hatarara Archaeological Site	**#**	**Weight**	**Height**	**Diam.**	**Vol.**	**Bulk Density**
Test.Pit-I-Perfil-Sul 47cm	49	114,23	4,07	5,59	99,89	1.48
Test.Pit-I-Perfil-Sul 31cm	50	121,18	4,07	5,58	99,53	1.55
Test.Pit-I-Perfil-Sul 18 cm	51	118,47	4,04	5,58	98,80	1.42
Test.Pit-I-Perfil-Sul 5 cm	52	112,87	4,05	5,60	99,75	1.23
P2 - 186 cm	53	113,59	4,06	5,57	98,83	1.40
P2 - 163 cm	54	113,81	4,06	5,59	99,64	1.28
P2- 124 cm	55	112,58	4,04	5,58	98,80	1.25
P2 - 105 cm	56	113,15	4,06	5,60	100,00	1.21
P2 - 87 cm	57	113,85	4,04	5,58	98,80	1.17
P2 - 42 cm	58	121,14	4,07	5,58	99,53	1.22
P2 - 22 cm	59	114,21	4,08	5,59	100,13	1.24
P2 - 6 cm	60	113,66	4,06	5,61	100,36	1.15

Pseudo-total Elements and Location

The pseudo-total means of each elements' concentration at different locations of the site are here presented. Through the soil analysis it is possible to see activity areas related to elemental concentration. In this section the mean of each profile analyzed will be presented according to its elements; the intention here is to demonstrate the variation of the elements through the two transects analyzed.

Phosphorus and calcium represent the most concentrated elements, and also their means show great similarities around the site. Ca represents the highest concentration of all elements analyzed, and its correlation with P is very high in the mounds and the central part of the site.

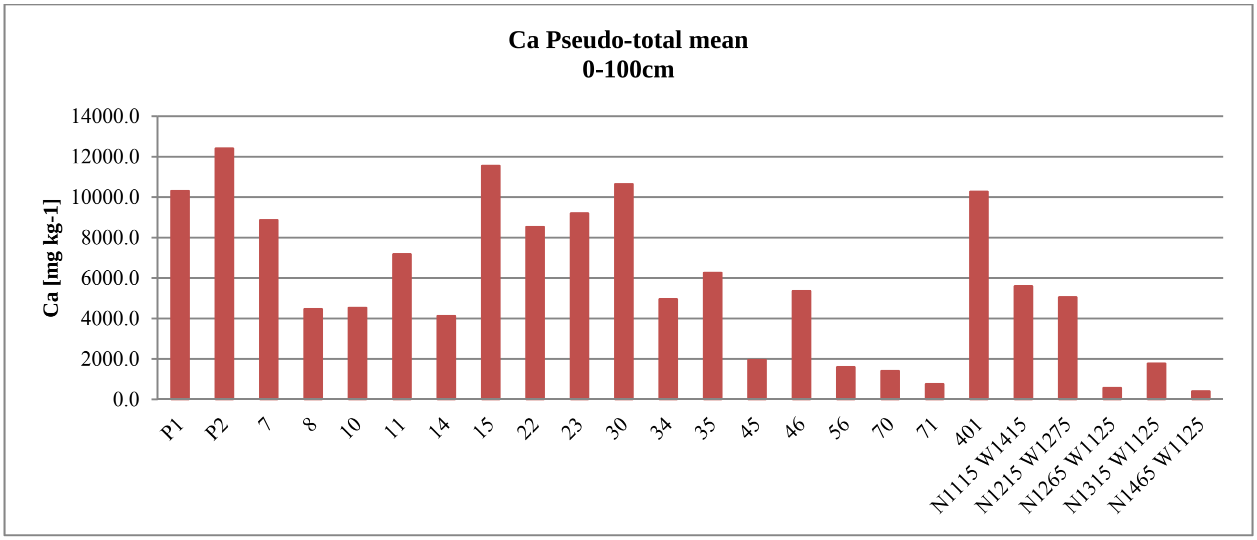


Figure 10 – Pseudo-total calcium concentration in the analyzed points in the site

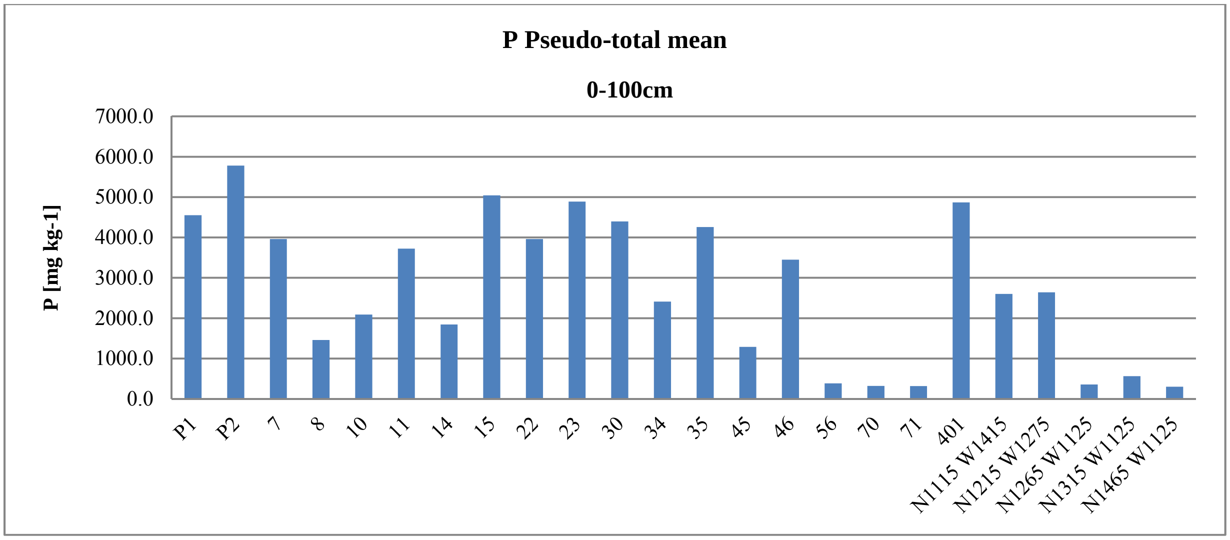


Figure 11 - Pseudo-total phosphorus concentration in the analyzed points in the site

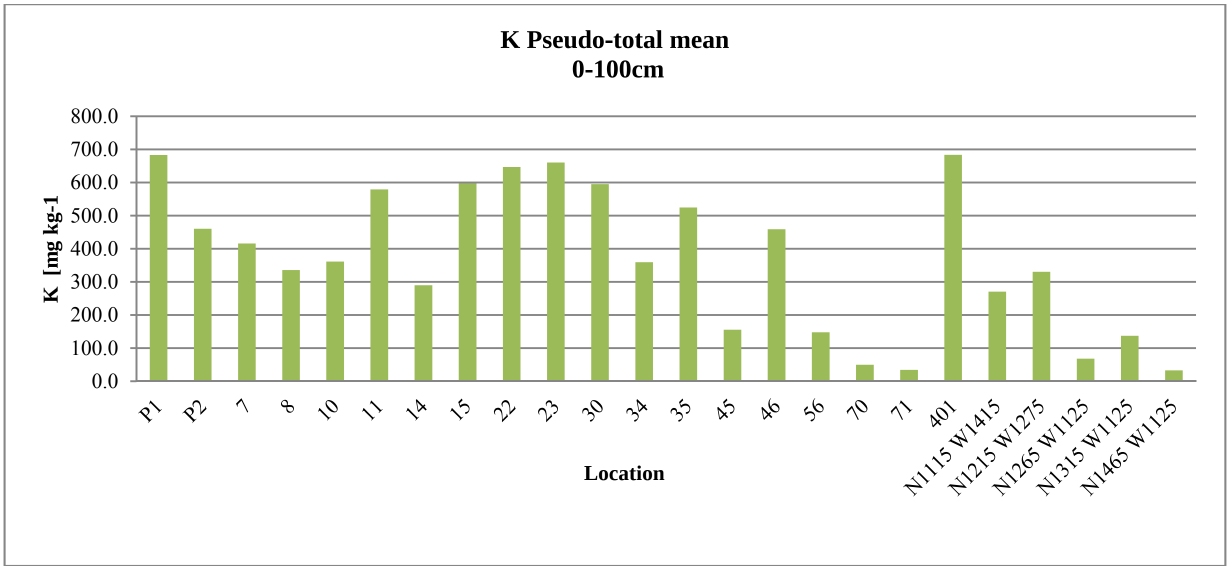


Figure 12 - Pseudo-total potassium concentration in the analyzed points in the site

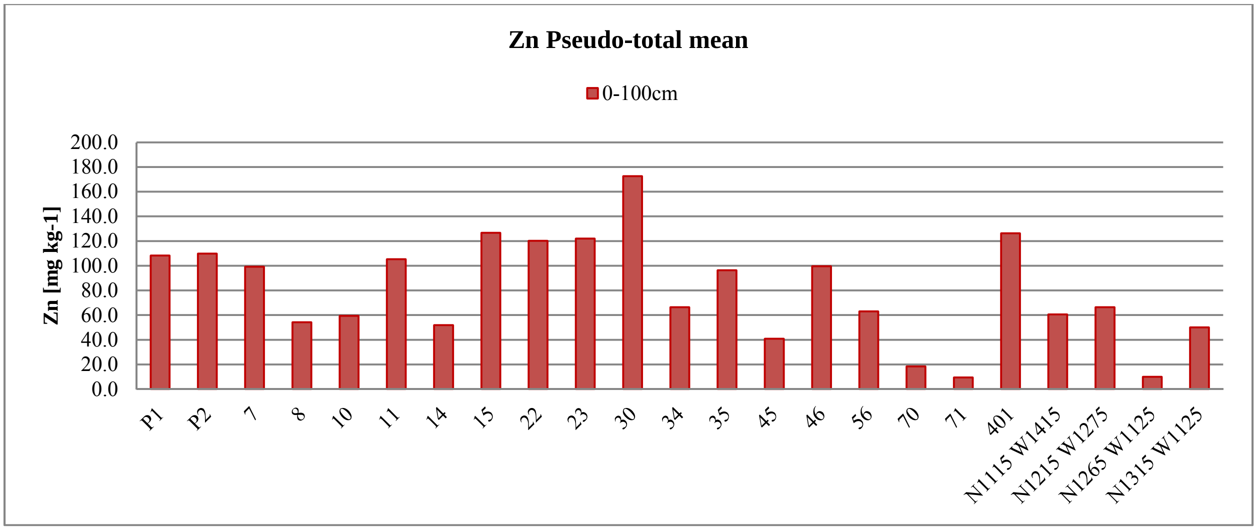


Figure 13 - Pseudo-total zinc concentration in the analyzed points in the site

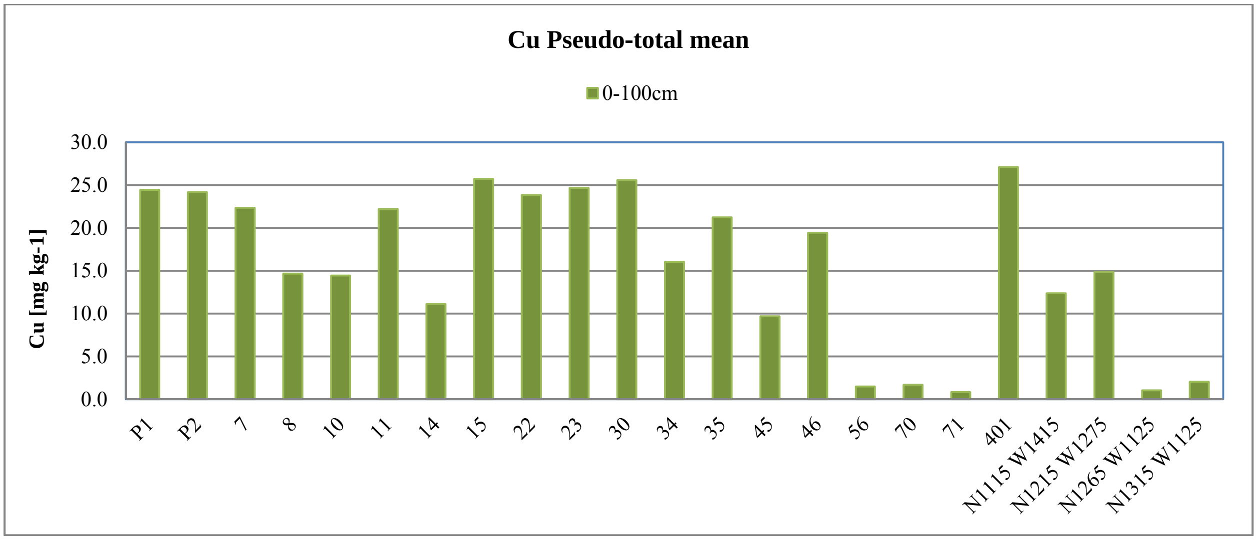


Figure 14 - Pseudo-total copper concentration in the analyzed points in the site

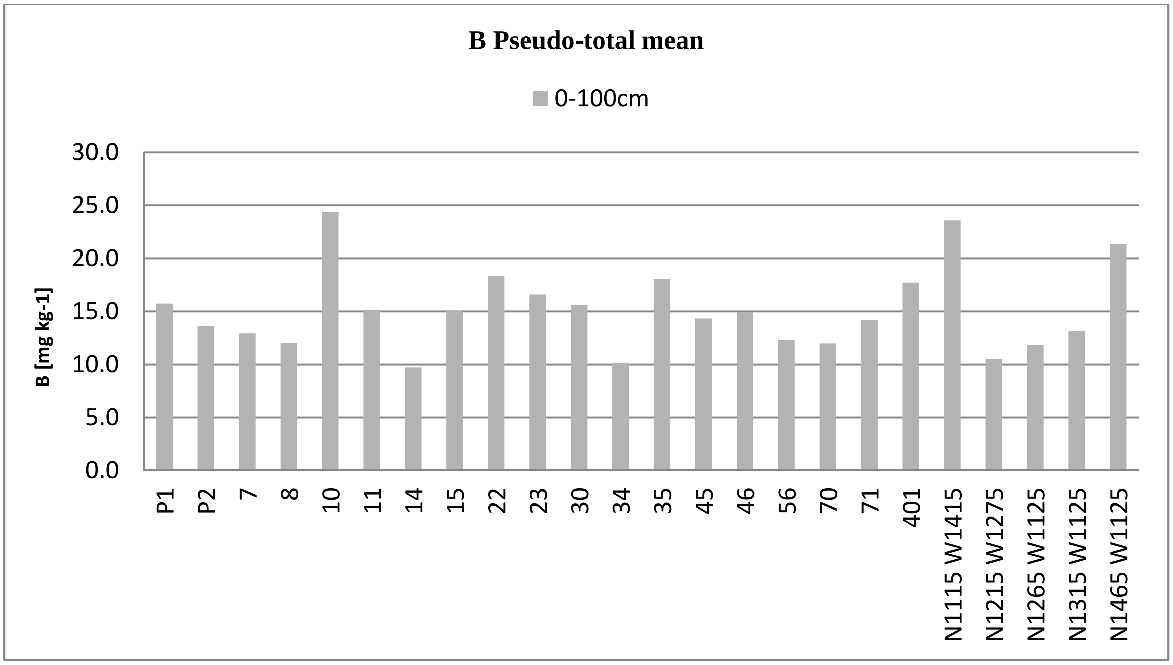


Figure 15 - Pseudo-total boron concentration in the analyzed points in the site

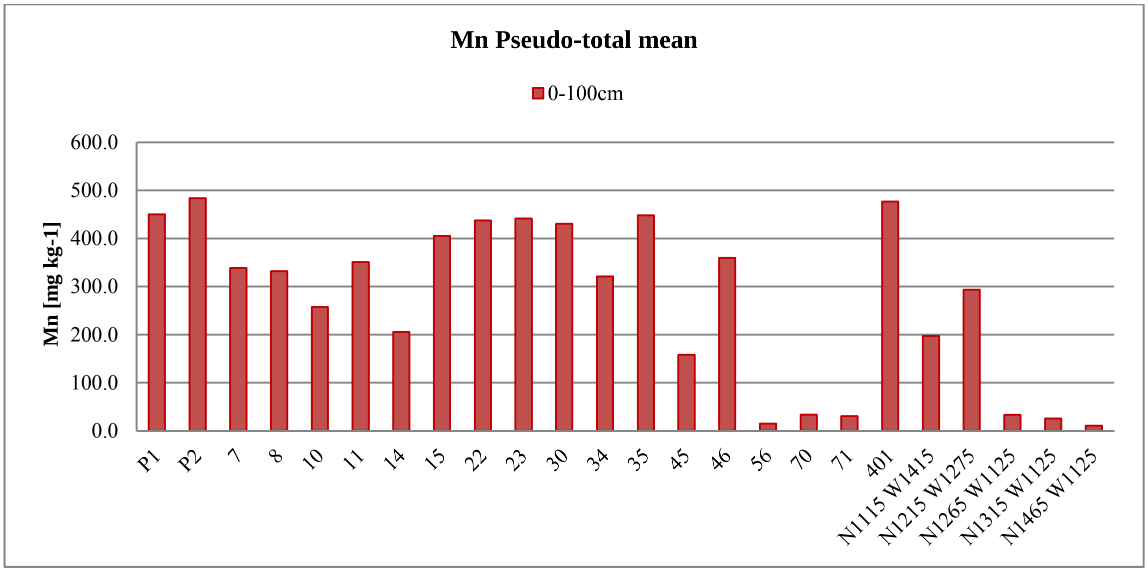


Figure 16 - Pseudo-total manganese concentration in the analyzed points in the site

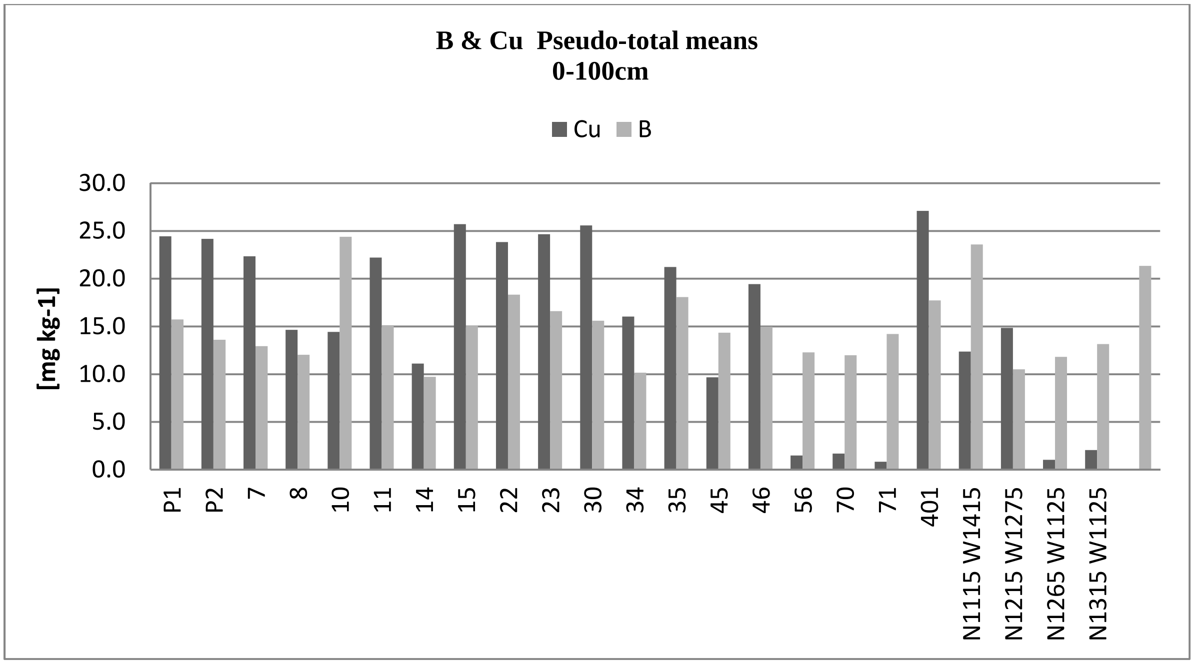


Figure 17 - Pseudo-total boron and zinc concentrations in the analyzed points in the site

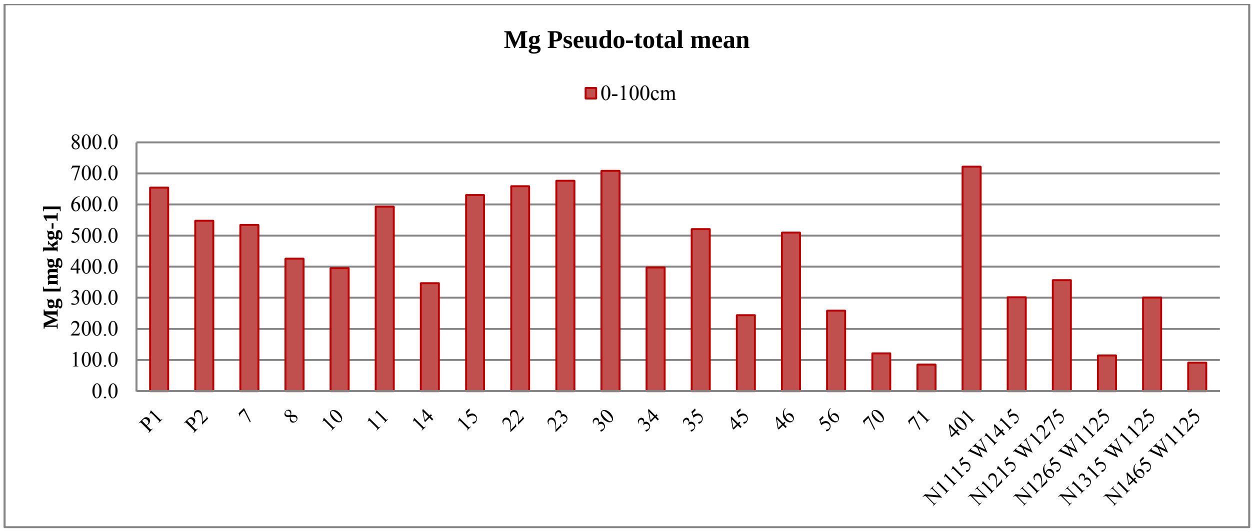


Figure 18 - Pseudo-total magnesium concentration in the analyzed points in the site

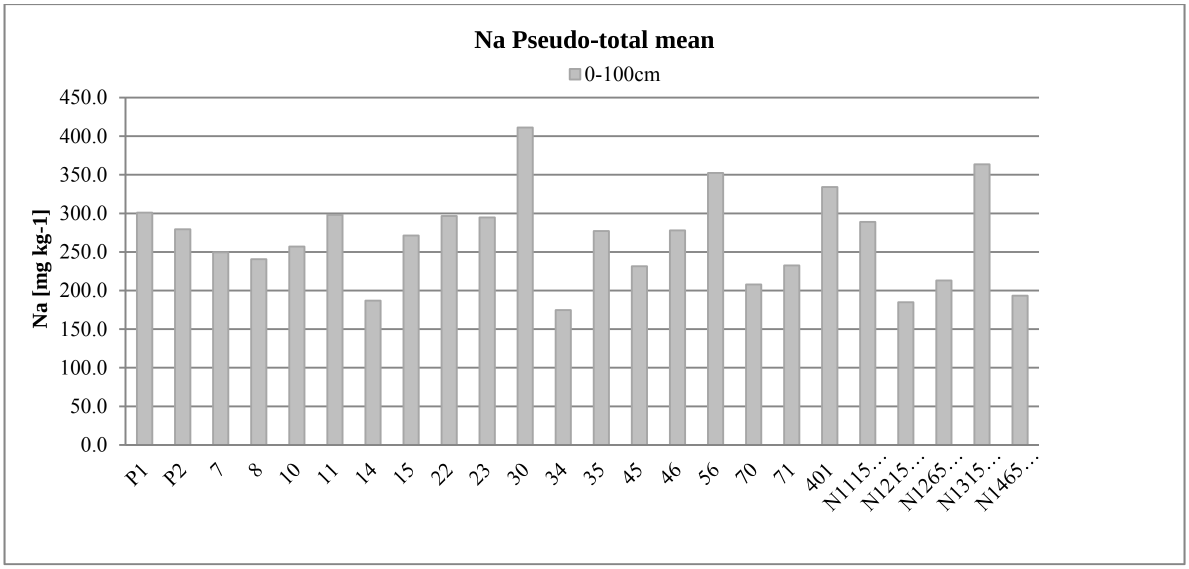


Figure 19 - Pseudo-total sodium concentration in the analyzed points in the site

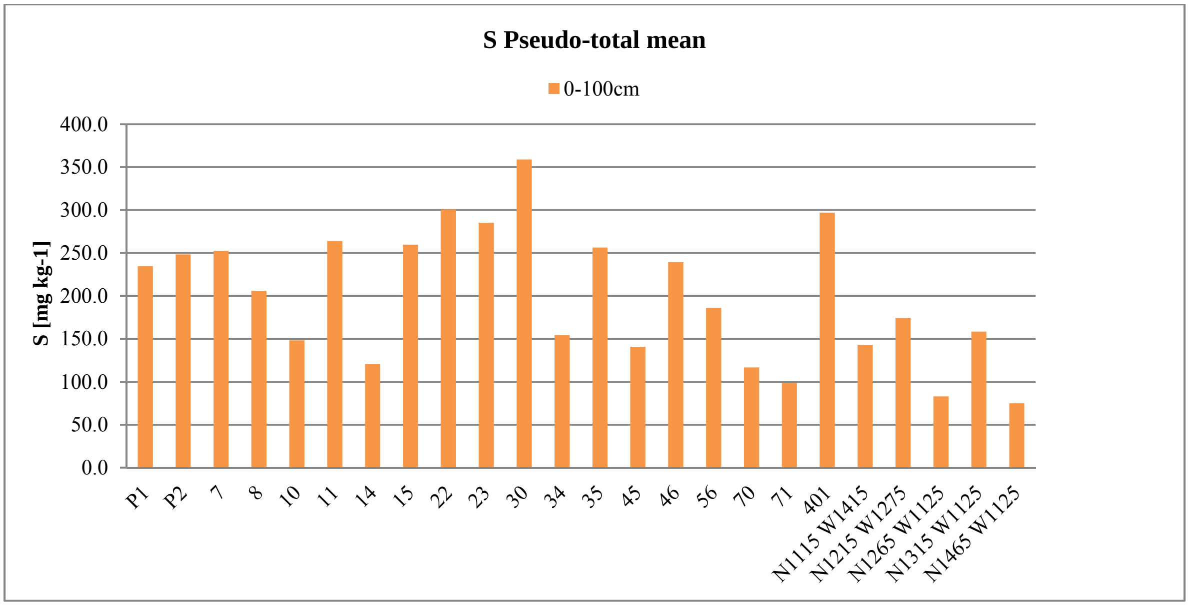


Figure 20 - Pseudo-total sulfur concentration in the analyzed points in the site

The other elements present similar behavior to that observed in P and Ca, with the exception of sulfur (S) and sodium (Na). These are not associated with human activities and so do not present a good characteristic for anthropogenic soil analyses. Although boron (B) presented some similarities with other elements in the site, for instance in the mounds, it cannot be taken into account for purposes of identifying human signatures in anthropogenic soils. Therefore, the major sources of information on human activities in archaeological sites are: C, Ca, K, Mg, Mn, and P. The next graphics present the mean of element concentrations through the site. These charts help to visualize the correspondence of their concentrations in the site locations.

After that, the correlation among the elements and the significance of each correlation will be presented. The positive correlation found among elements does not correlate with the previous analyses from other archaeological sites, and it indicates that different parental materials might be responsible for the distinct behavior of macronutrients in the soils through time (discussed later). Phosphorus certainly is the element most well-known to archaeologists as a human activity indicator (Woods 1975). Studies show that the P is released very slowly in the soils and is conditioned largely by the rate of withdrawal from the soils (Cook and Heizer 1965). The charts below furnish a good resolution of the P behavior, both the available and the total. While P fractionation was not carried out in this research, a few points will be presented as examples and demonstrations of the element's behavior in the profiles.

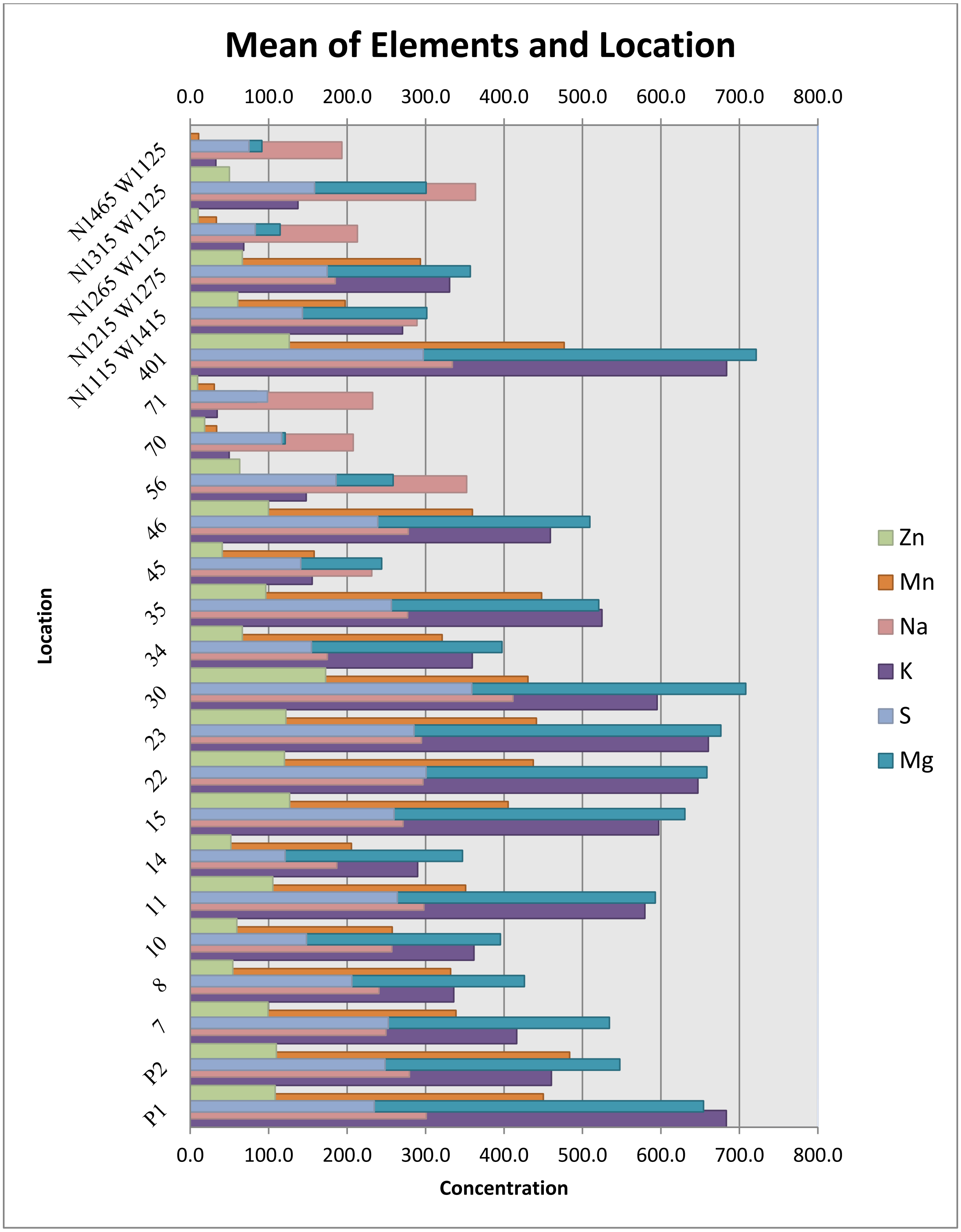


Figure 21 – Mg, Mg, Na, S, and Na elements concentration and location

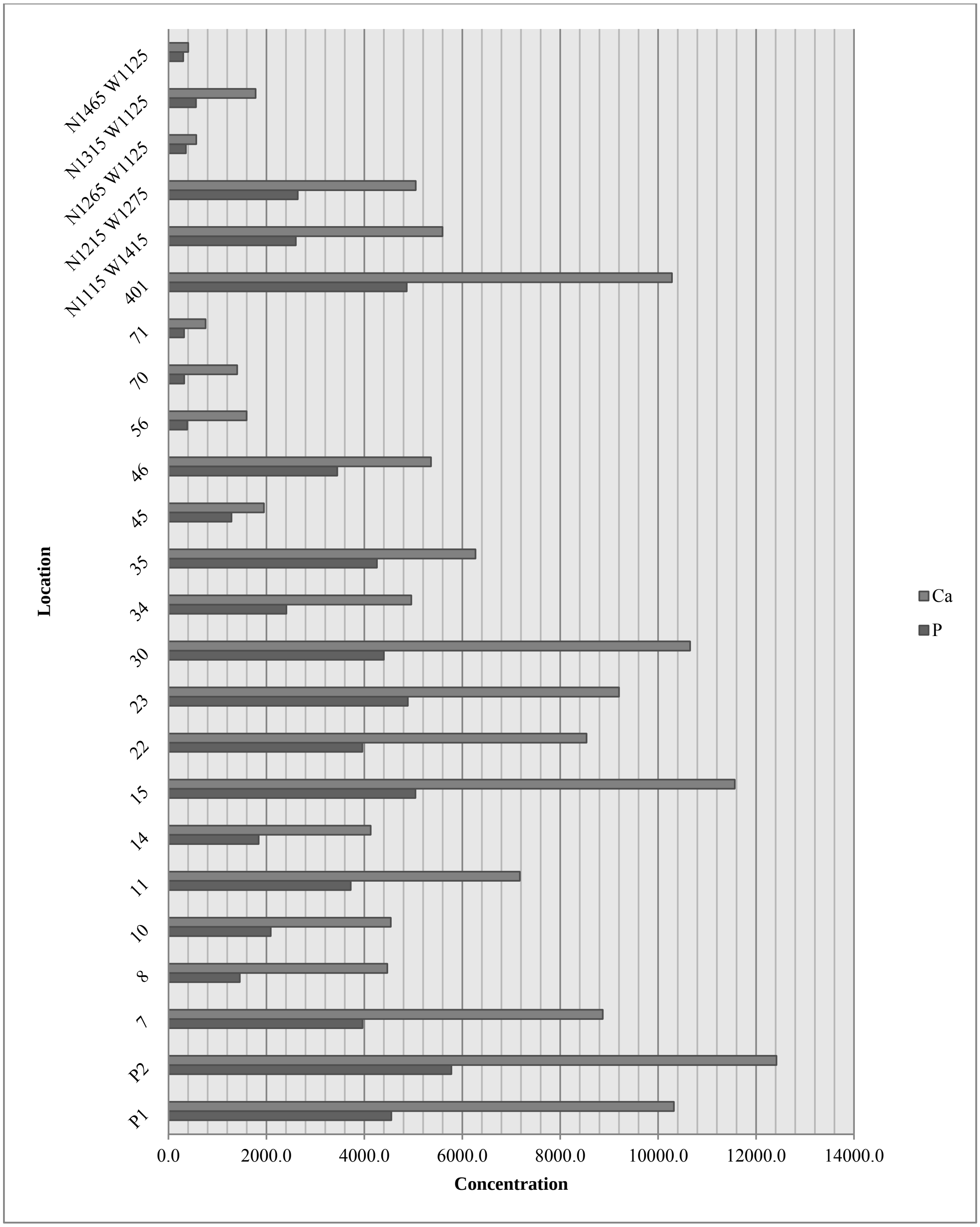


Figure 22 – P and Ca concentrations and location

Elemental Comparison

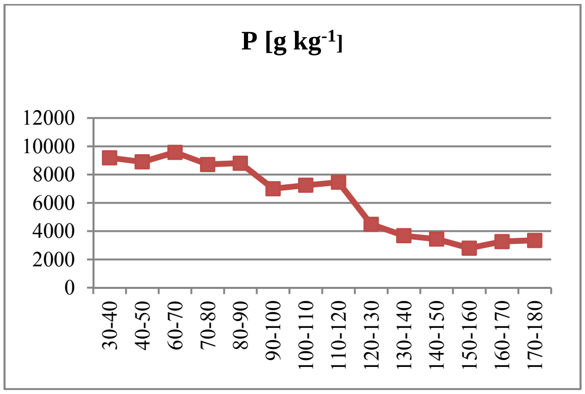


Figure 23 – Pseudo-total phosphorus in P1.1

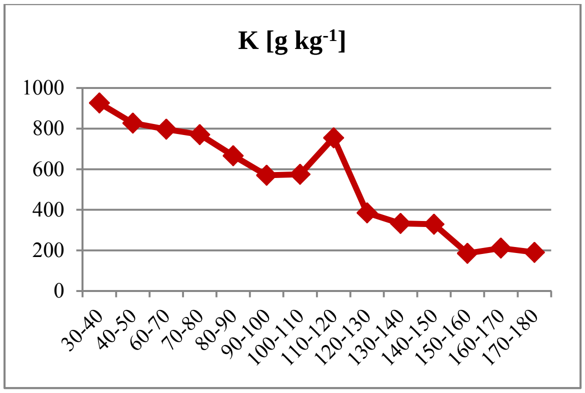


Figure 25- - Pseudo-total potassium in P1.1

P1.1 – Mound with Burials

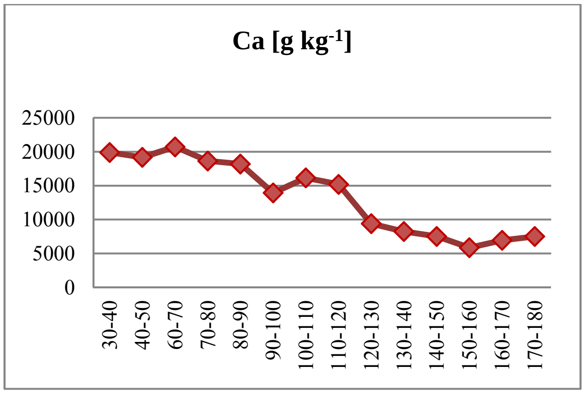


Figure 24 - Pseudo-total calcium in P1.1

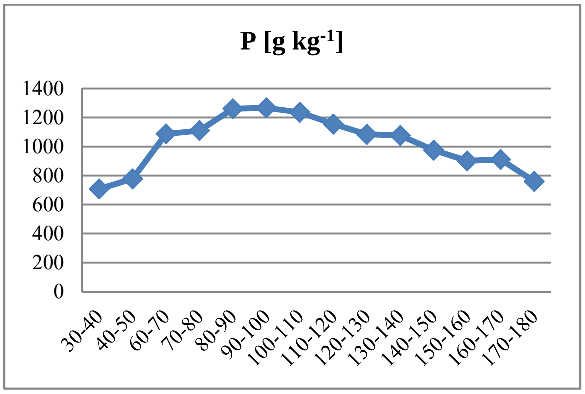


Figure 26 – Available phosphorus in P1.1

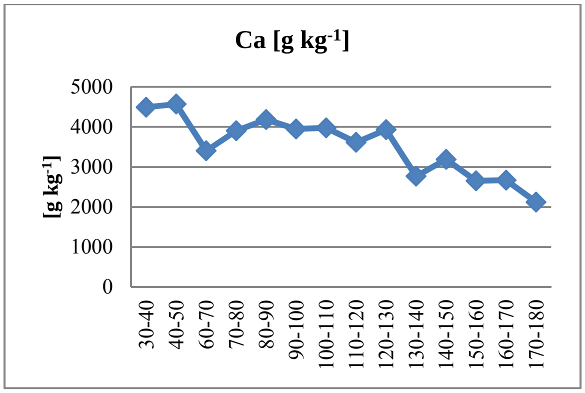


Figure 27 – Available calcium in P1.1

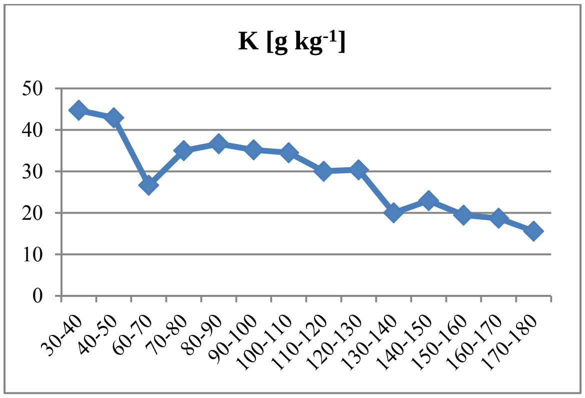


Figure 28 – Available potassium in P1.1

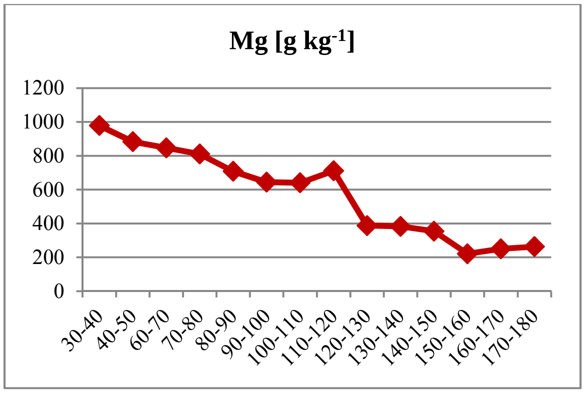


Figure 29 - Pseudo-total magnesium in P1.1

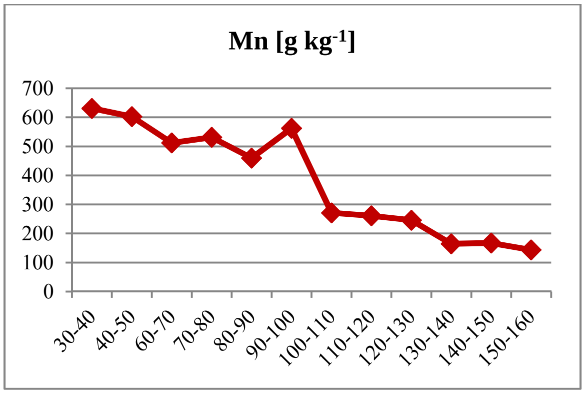


Figure 30 – Pseudo-total manganese in P1.1

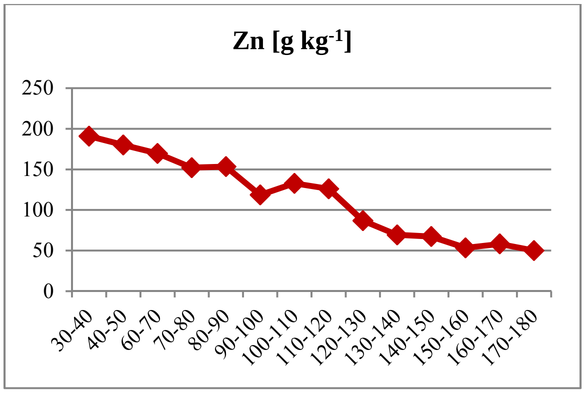


Figure 31 – Pseudo-total zinc in P1.1

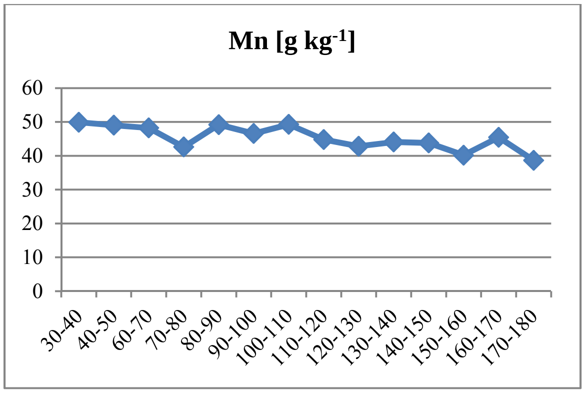


Figure 33 - Available manganese in P1.1

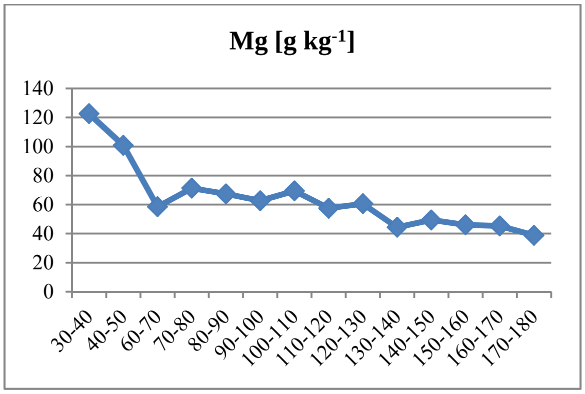


Figure 32 – Available magnesium in P1.1

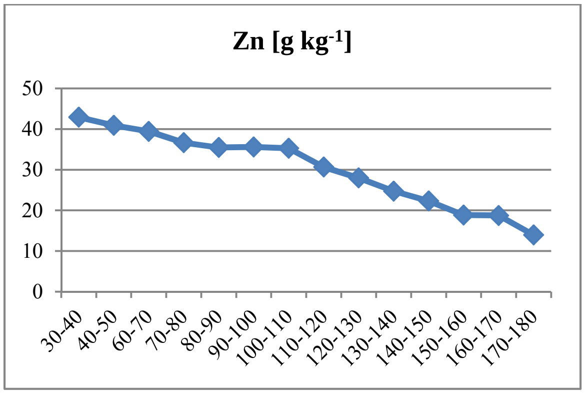


Figure 34 - Available zinc in P1.1

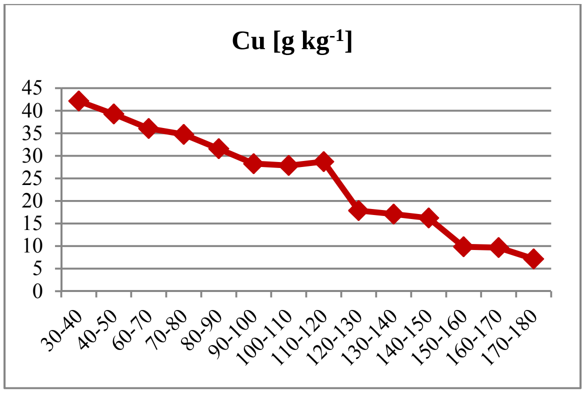


Figure 35- Pseudo-total copper in P1.1

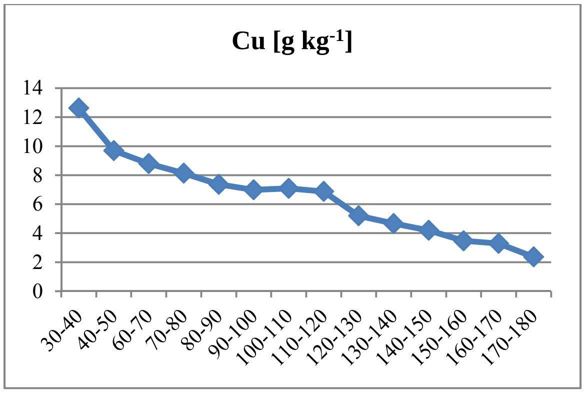


Figure 37 – Available copper in P1.1

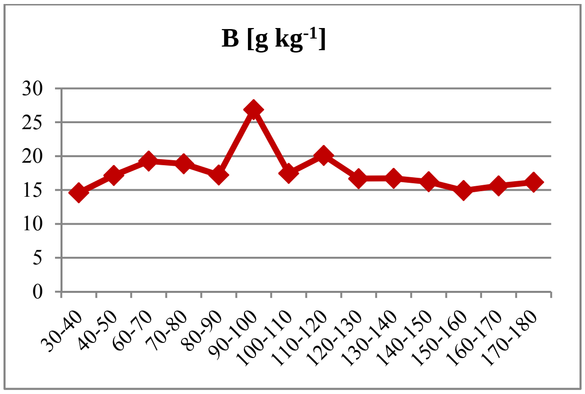


Figure 36 - Pseudo-total boron in P1.1

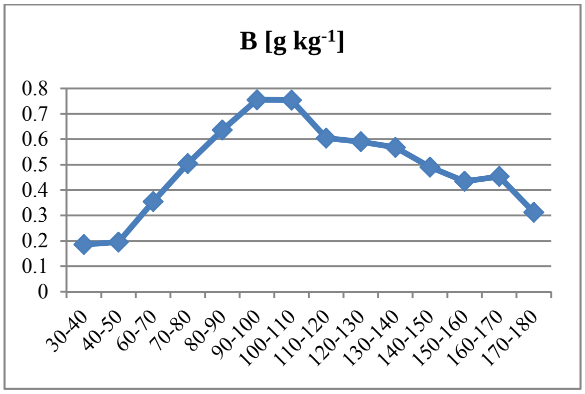


Figure 38 - Available boron in P1.1

Elemental Comparison

P2 – Mound without Burials

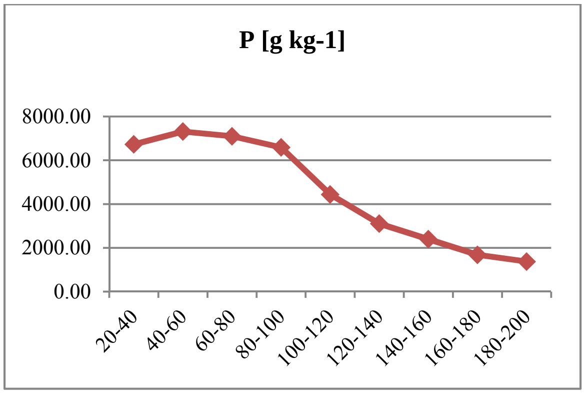


Figure 39 --Pseudo-total phosphorus in P2

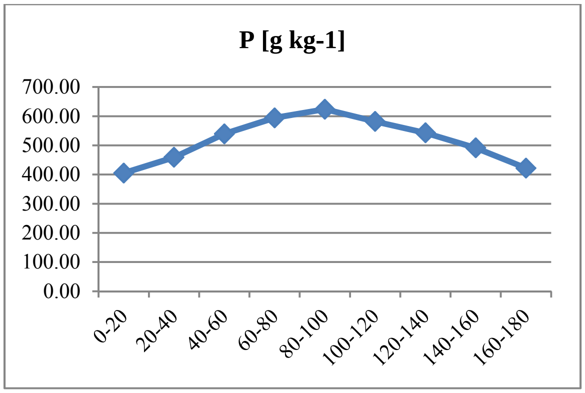


Figure 41-Available phosphorus in P2

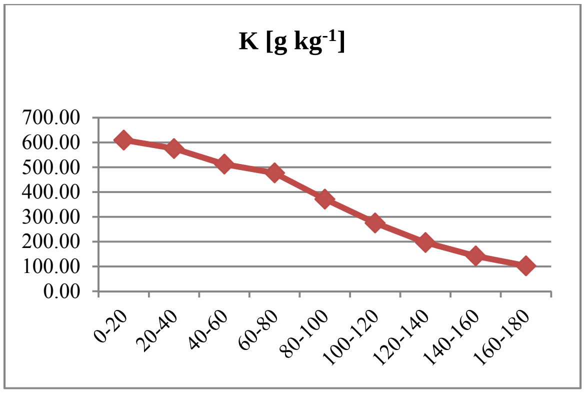


Figure 40-Pseudo-total potassium in P2

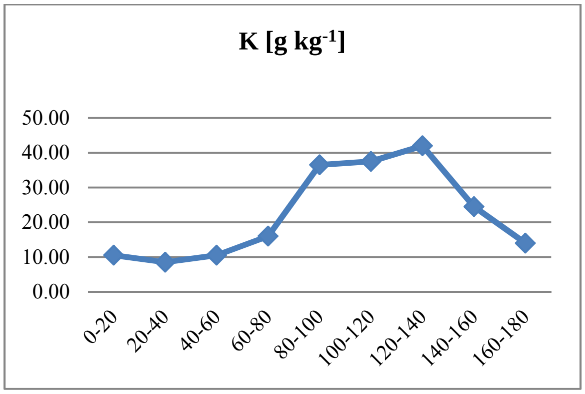


Figure 42- Available potassium in P2

The information presented in the chart above shows that P realease to available for plants shows great variance in the profiles according to pH.

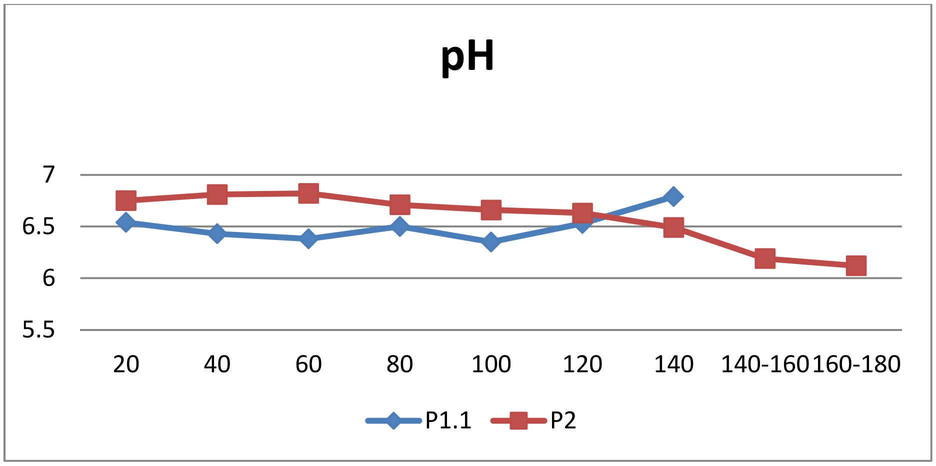


Figure 43 – pH in the mounds

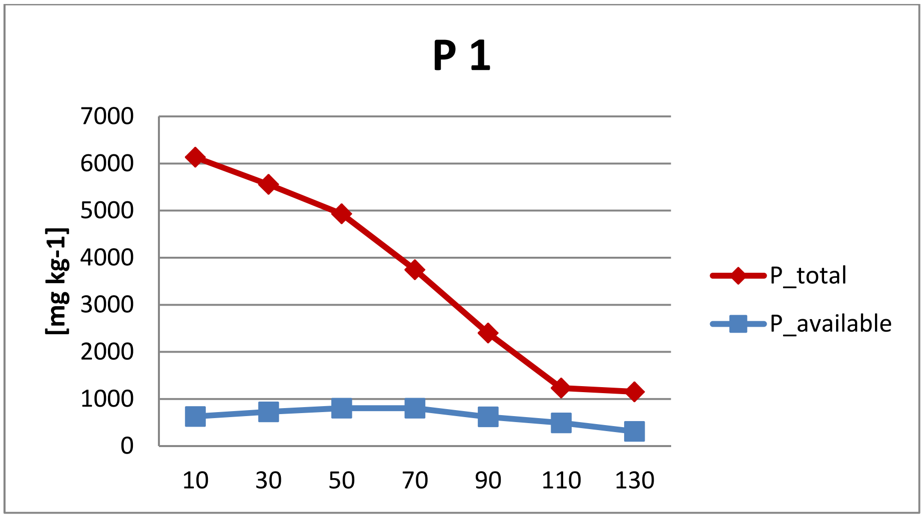


Figure 44 – pH in P1

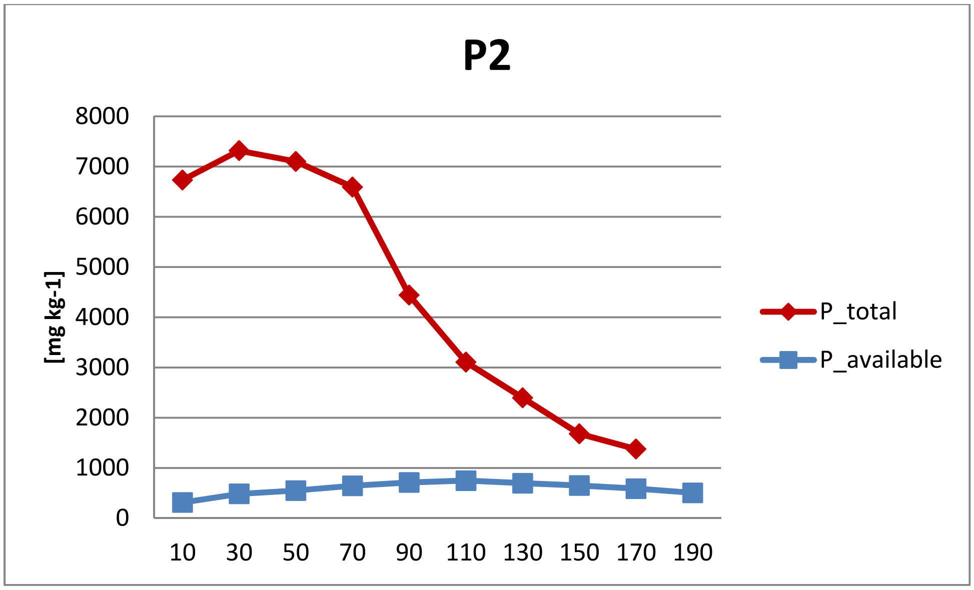


Figure 45 – pH in P2

Cook and Heizer (1965) proposed that because phosphorus can form compounds with calcium and iron in pH between 7.0 and 6.0 and above, and certainly with iron and aluminum below 5.0, the leaching is not rapid though the profile, at least in terms of archaeological time spans (Cook and Heizer 1966:13). Therefore, even in tropical soils, the increase of pH due to the high concentration of organic matter will allow more fixation of phosphorus in these soils, as we can see in the Figures 20, 23, 36, and 39. It is important to mention that manuring with soluble phosphate behaves like inputs of human excreta and refuse (Cook and Heizer 1965). As presented in Birk et al. (2010) ADE include large amounts of human excreta that increase the quantity of P in the soils, improving microorganism growth.

Other elements analyzed also presented important characteristics, for instance, manganese generally presents deficiencies in basic soils, and more soluble forms in acid soils (Hassett and Banwart 1992). While the high concentrations of Mn in the site indicates human activities, it is still difficult to understand the specific causes of those elevations. On the other hand, copper (Cu) and zinc (Zn) are directly associated with hearths at archaeological sites (Wilson, Davison, and Cresser 2009:2331). Therefore, it is possible to identify houses and cultural fires at sites by plotting those elements in a systematic grid. Below, the charts present the variation of Cu, K, and Zn in the soil surface. Each graphic was built according to arbitrary levels of 20 cm.

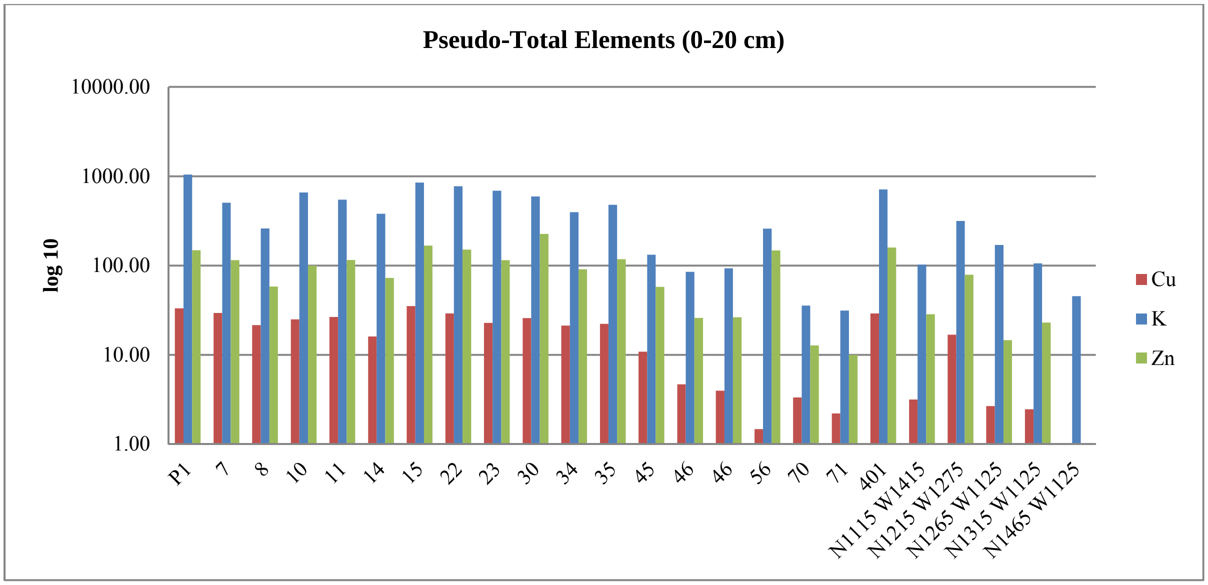


Figure 46 – Concentrations of Cu, K, and Zn at 0-20cm of the site

The concentration presented in the area of the village decreases past the village border

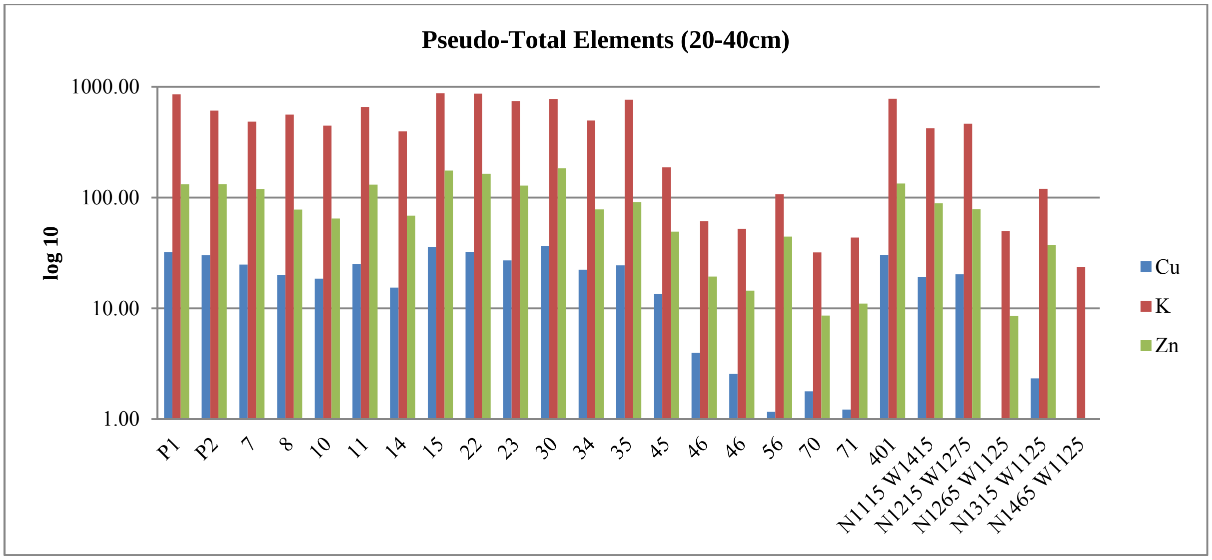


Figure 47 - Concentrations of Cu, K, and Zn at 20-40cm of the site

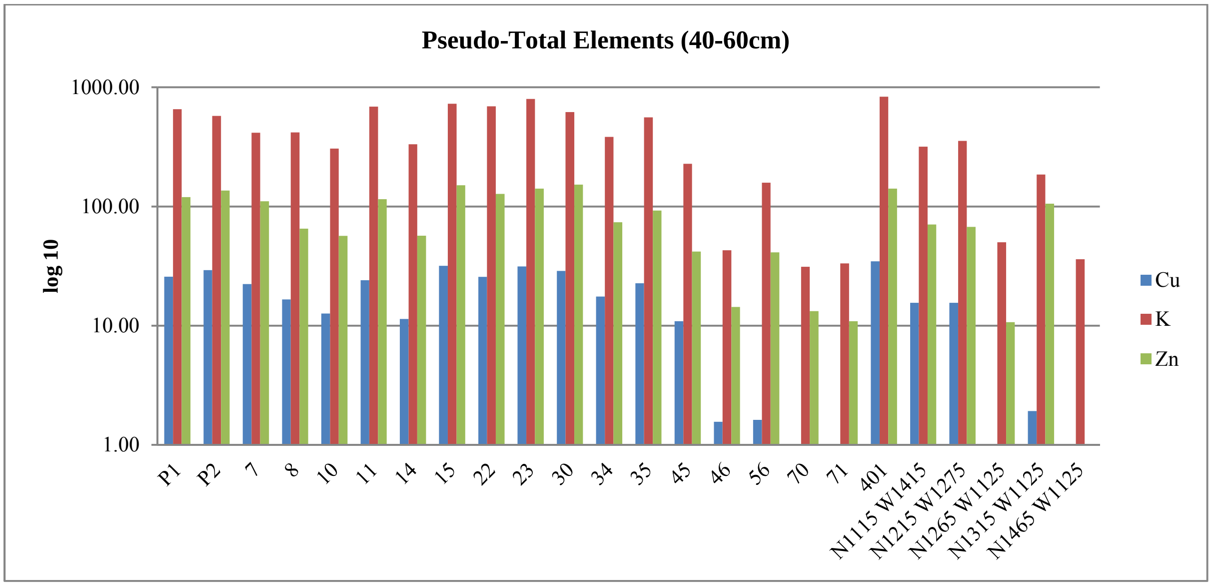


Figure 48 - Concentrations of Cu, K, and Zn at 40-60cm of the site

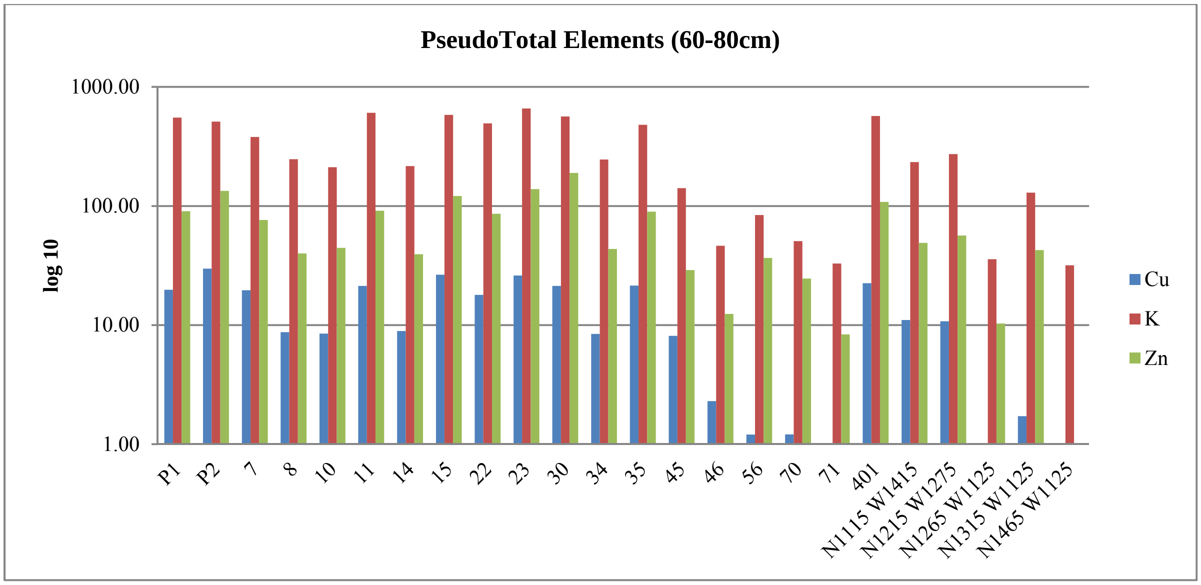


Figure 49 - Concentrations of Cu, K, and Zn at 60-80cm of the site

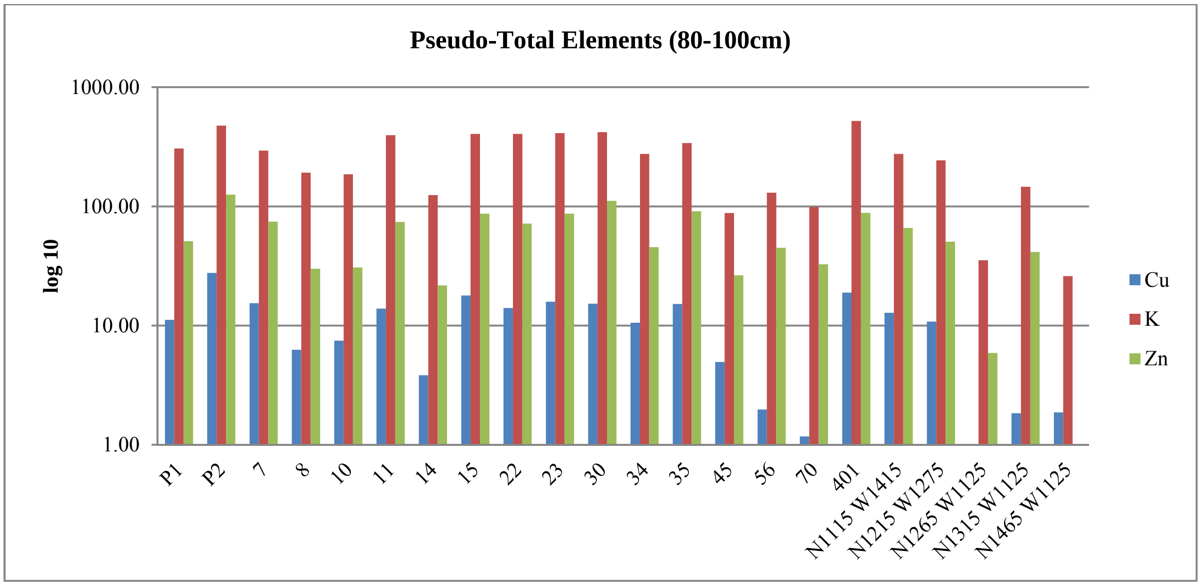


Figure 50 - Concentrations of Cu, K, and Zn at 80-100cm of the site

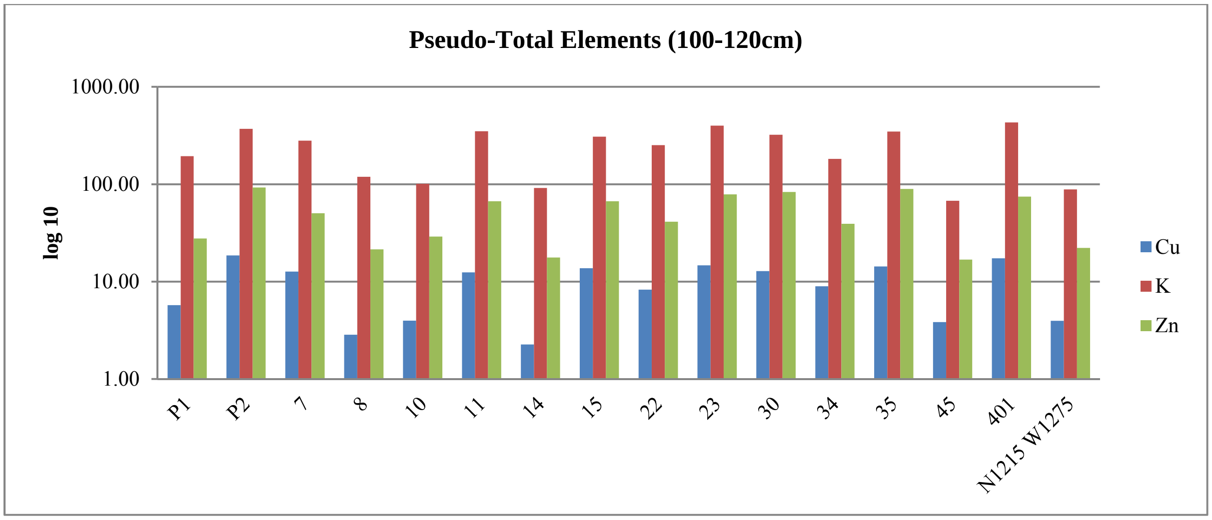


Figure 51 - Concentrations of Cu, K, and Zn at 100-120cm of the site

Although various research points out the variability of Cu, K, and Zn as good indicators of activity areas in archaeological sites, leaching through the profile in tropical soils is still a major obstacle to classifying areas in the site. However, the higher levels of these elements are clearly associated with the village, presenting only a trace concentration in the fields around the settlement and in areas were the human impacts were low; this is especially true of Cu. Thus is better shown in charts from each profile, as presented in Figures 51 and 52 in which the nutrients appear to have the same behavior throughout the profiles. The scale in log 10 is due to the concentrations that represent different units and helps to visualize the leaching and concentration in each depth. Therefore, the most reasonable way to identify variation through the profile and make correlations to activity areas, in this case, is to analyze their correlations to each other.

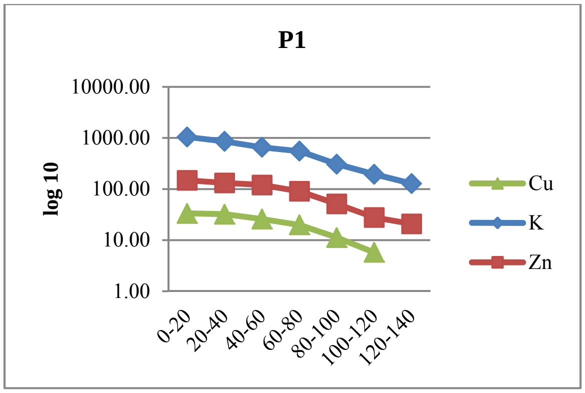


Figure 52 – Cu, K, and Zn in the profile P1

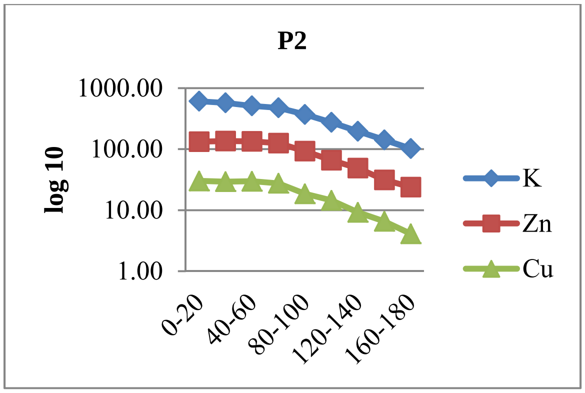


Figure 53 - Cu, K, and Zn in the profile P2

Looking at the the site map below (Fig. 54), these areas are related to later occupations spreading out the previously accumulated ADE to fertilize larger areas of soil in order to increase food production. The linear shape of ADE distribution in archaeological sites is reported by different authors (e.g., Sombroek 1966, Falcão, personal communication, 2011) and associated with the ceramic Guarita subtradition. However, few works revealed the stratigraphy below 40 cm. I present data of a circular shape below the topsoil related with the Paredão phase, as shown in the next figure. In order to confirm intentionality in the use of ADE for food production in the last periods before the contact, it was necessary to correlate data to find clues that corroborate the hypotheses. First, correlations among elements will be presented, and then among the elements that furnish information about field and village areas.

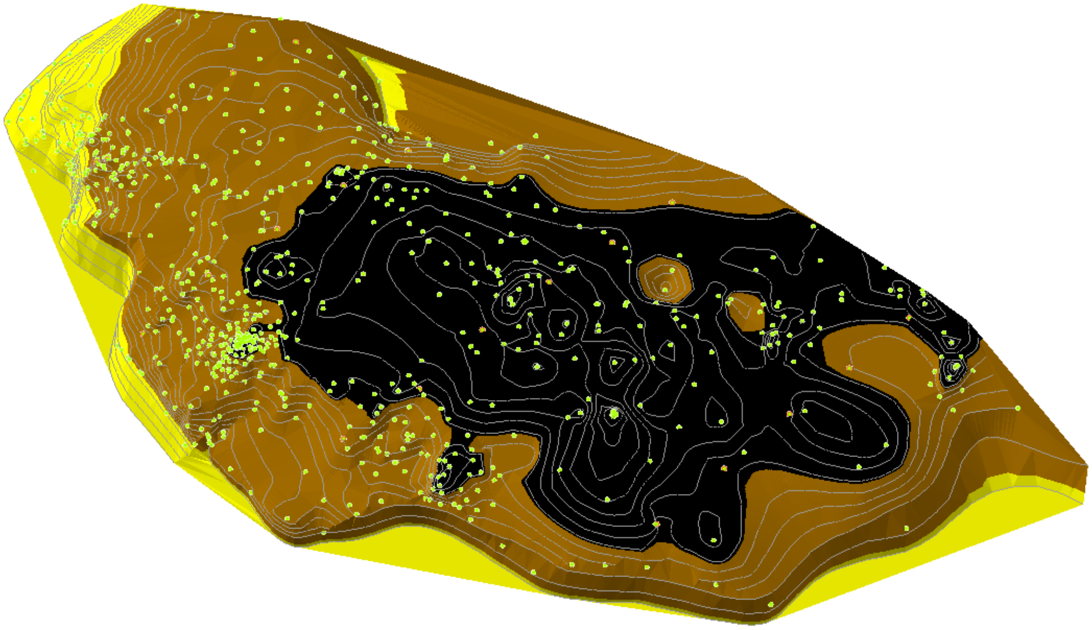


Figure 54 – 3D map (TIN) of site surface (0-20cm) related with the spread of *terra preta*. The map shows use of TP to fertilize soil area for food production (data adapted from Rebellato 2007 and Rebellato, Woods and Neves 2009, Reproduced with authorization).

This map (Fig. 54) shows the concentration of TP and TM in the surface of the site, and the dots represent the topography reading points, made using a Total Station. Different methods of statistical distribution of soil coloration (here made using ArcGIS) show the same results, that is, a rapid increase of TP in the surface of the site in relation to the strata below.

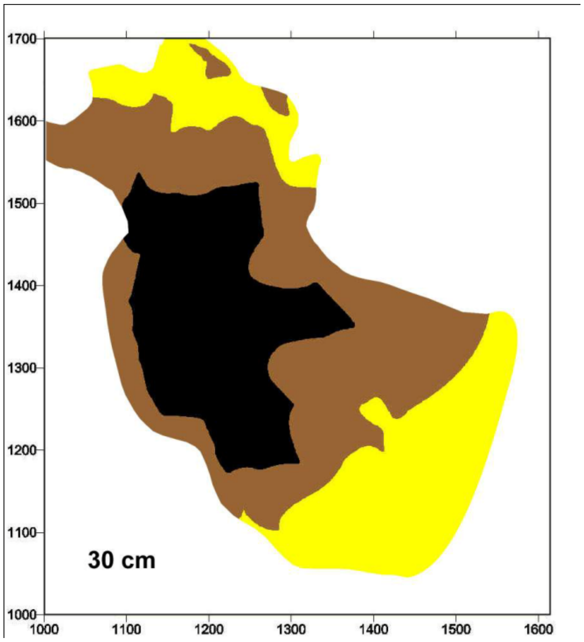


Figure 55 – 2D map with TP and TM in the site at 30 cm

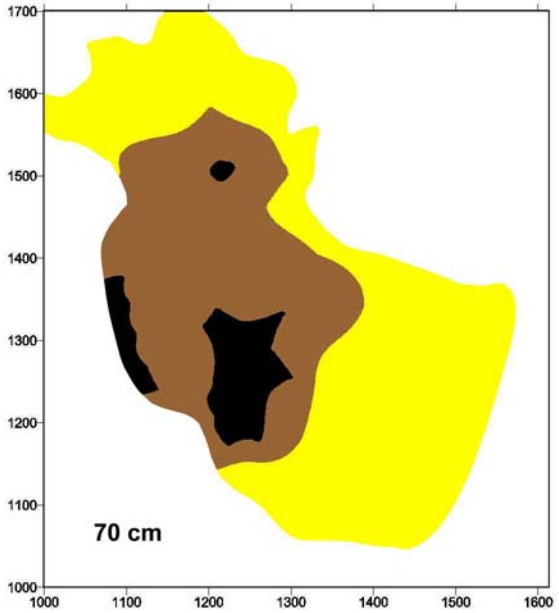


Figure 57 – TP and TM at 70 cm – circular village shape associated with Paredão

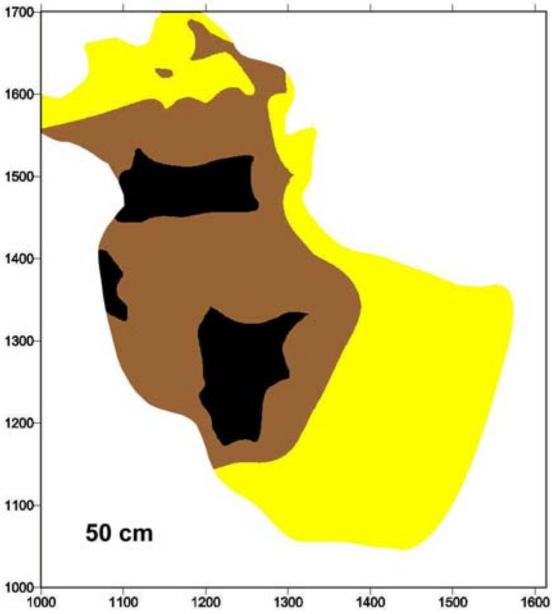


Figure 56 – TP and TM and their distribution at 50 cm

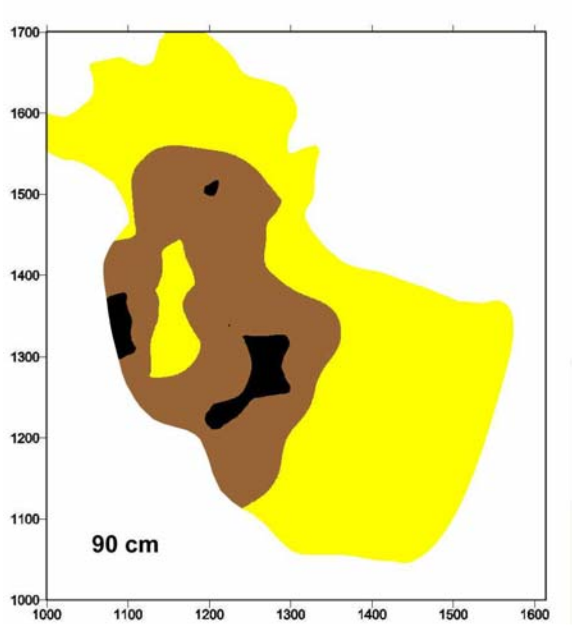


Figure 58 - TP and TM at 90 cm – circular village shape associated with Paredão

The color analyses clearly show the transition from the circular village to the linear village. However, they could not confirm a change in land color or its association with agricultural fields and improvement of food production techniques. The next section discusses the distribution of these elements to verify or falsify these hypotheses

Correlations Between Pseudo-Total Elements

The correlation analyses were carried out using PAST Paleontological Statistics software, version 2.11. It is a free program, first developed for paleontology, but now with a package that encompasses common statistics and modeling (Hammer 2001). The correlation analyses were conducted in order to systematize the results to clarify the behavior between total and available phosphorus, as well as between total and available amounts of other analyzed elements, and finally among all of them. The first data shown are organized among the 10 elements analyzed (B, C, Ca, Cu, Mg, Mn, Na, P, S, and Zn); these were correlated in relation to the total phosphorus taken from all locations. The relation between phosphorus and carbon also will be provided as an important feature in the site. Calcium was correlated separately from the other elements due to its high levels in the soils.

Fig. 57 below shows the elemental concentration of all nutrients analyzed and their proportion found in the site. Calcium has the most significant concentration due to the large quantity of bone remains in the soil. Phosphorus is the second most highly concentrated and resulted from human waste. The Ca/P ratio (total) in the samples analyzed was 2.10 and the Ptotal/Pavailable ratio was 3.87, as illustrated in Fig. 57. According to the literature, the average

Ca/P ratio is related to the bone apatite that has variation in its morphology, since rounded to elongated fish-bones particles (Schaefer et al. 2004:403).

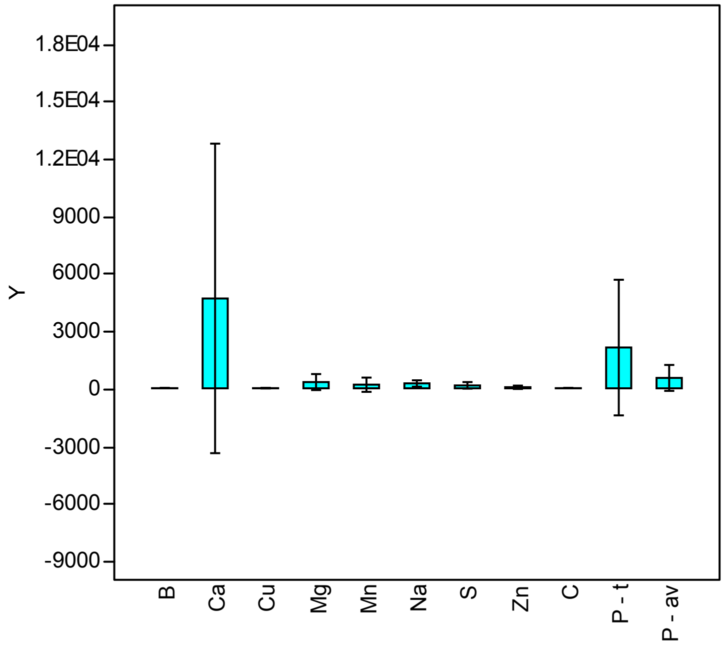


Figure 59 – Amount of the analyzed elements in the site from excavated units and auger pits

The graphics below (Fig. 60 – 78) will present the results from the pseudo-total and available element correlations. As it is possible to see, some correlations are strong, for instance that between phosphorus (P) and calcium (Ca) (Fig. 60), others weak, such as that between phosphorus (P) and carbon (C) (Fig. 61). These results are clues for the next analysis, and are presented in the next set of data results. Two interpretations were achieved here. The first is that the P and Ca are probably coming from the same sources and related to the same activities (burials, food such as fish-bones and mammals). Second, the concentration of C in the soils is directly associated with charcoal, which is not to say that charcoal is always associated with food waste or the other organic discards that increased the P concentration in the site.

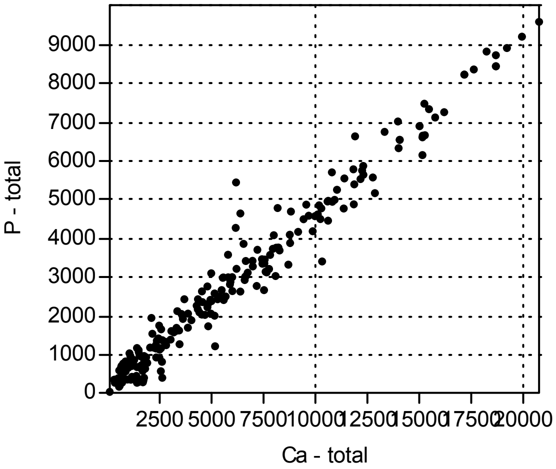


Figure 60 – P and Ca correlations in all selected points

0	Ca - total	P - total
Ca - total	0	6.2384E-138
P - total	0.97319	0

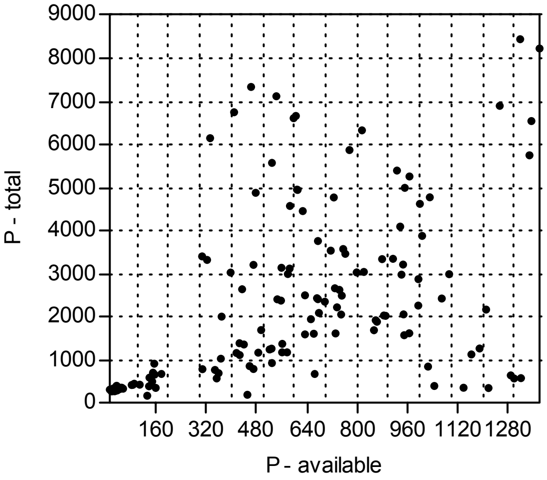


Figure 61 – P total and available correlations

0	P – av.	P - total
P – av.	0	1.1456E-10
P – t.	0.5239	0

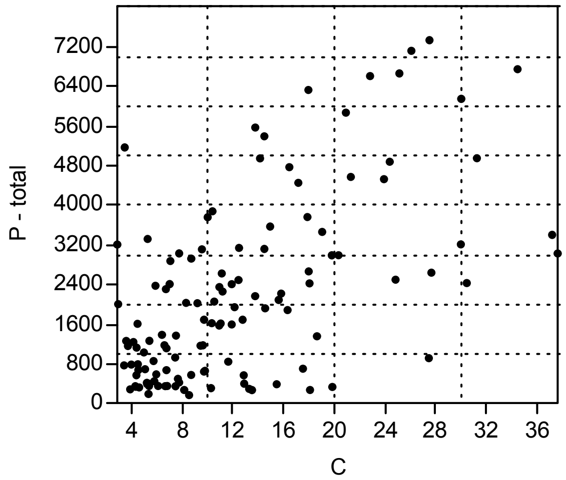


Figure 62 – P and C correlation in all selected points

0	P – total	C
P - t	0	1.5533E-10
C	0.54057	0

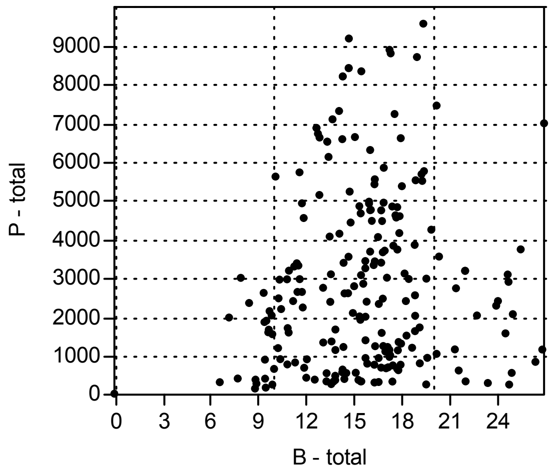


Figure 63 - P and B correlations in all selected points

0	B - total	P - total
B - total	0	0.091854
P – total	0.11525	0

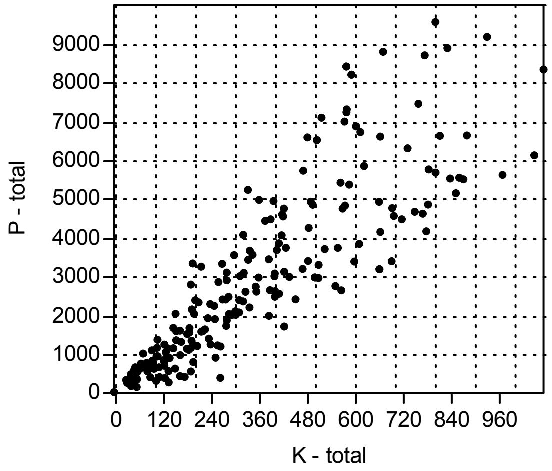


Figure 64 – P and K correlations in all selected points

0	K – total	P - total
K – total	0	1.0549E-90
P – total	0.9237	0

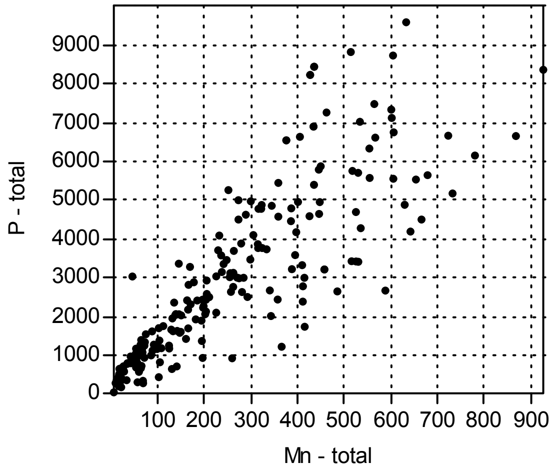


Figure 66 – P and Mn correlations in all selected points

0	Mn - total	P - total
Mn - total	0	3.2611E-83
P – total	0.9112	0

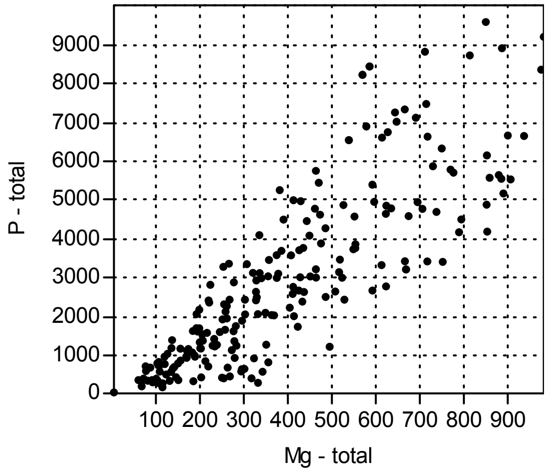


Figure 65 – P and Mg correlations in all selected points

0	Mg – total	P - total
Mg - total	0	1.2041E-71
P - total	0.88231	0

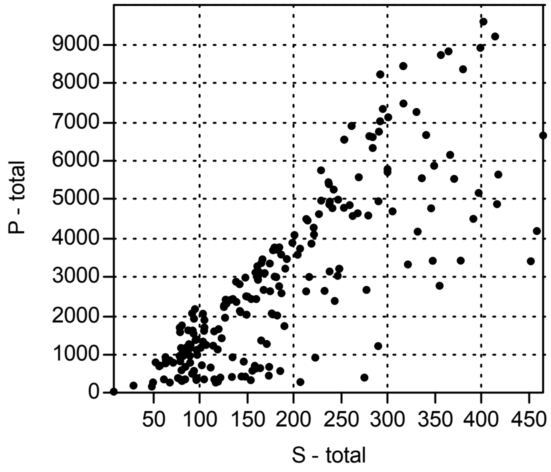


Figure 67 – P and S correlations in all selected points

0	S - total	P - total
S – total	0	9.8897E-55
P - total	0.82514	0

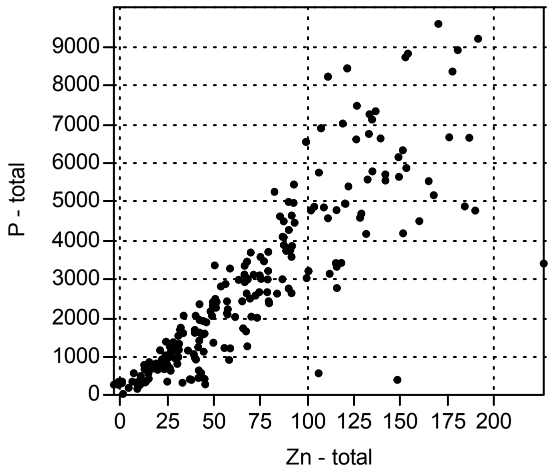


Figure 68 – P and Zn correlations in all selected points

0	Zn - total	P - total
Zn - total	0	1.4771E-80
P – total	0.90402	0

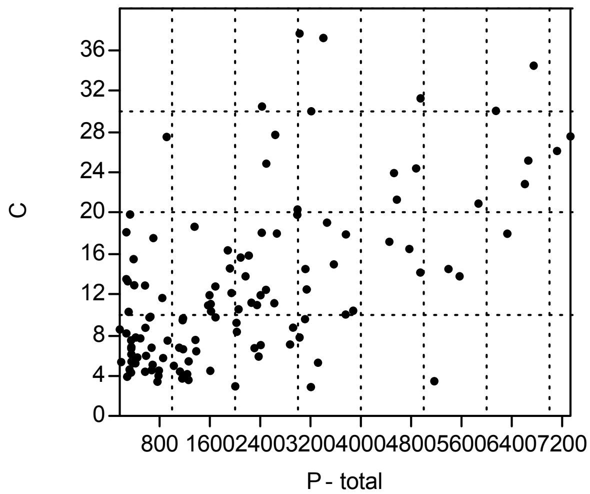


Figure 69 – C and P correlations in all selected points

Burials and elements concentrations

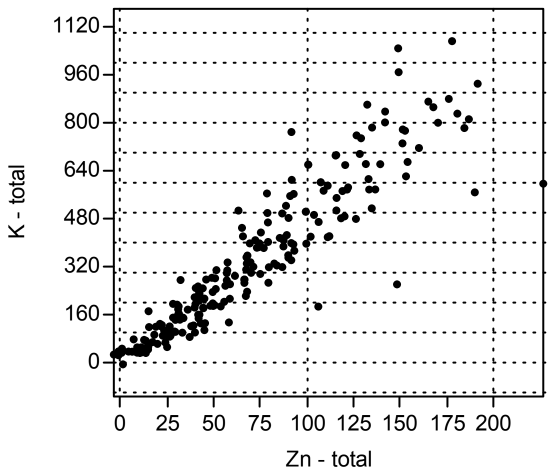


Figure 70 – Zn and K concentration in burials areas

0	Zn - total	K - total
Zn - total	0	6.2265E-111
K – total	0.95141	0

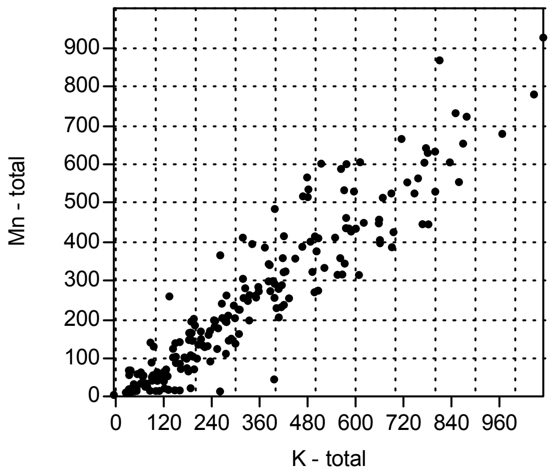


Figure 71 – Mn and K concentration in burials areas

0	K - total	Mn - total
K – total	0	1.4638E-99
Mn - total	0.93871	0

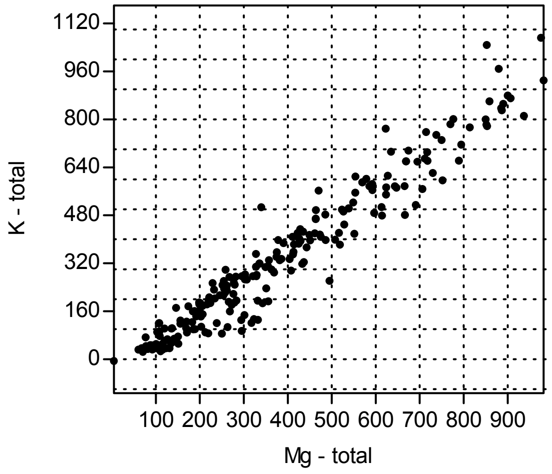


Figure 72 – K and Mg concentration in burials areas

0	Mg - total	K - total
Mg - total	0	4.1149E-127
K - total	0.96601	0

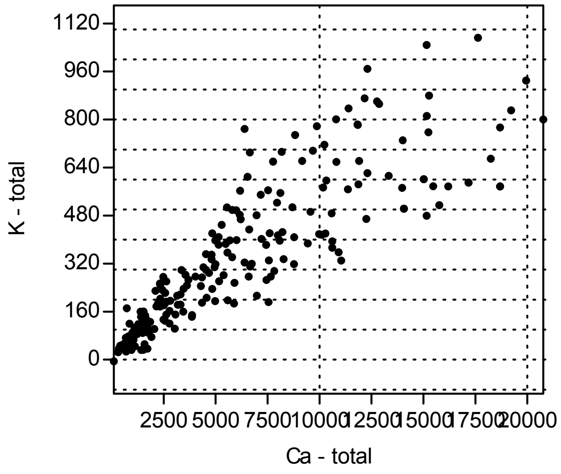


Figure 74 – K and Ca concentration in burials areas

0	Ca - total	K - total
Ca - total	0	1.5551E-91
K - total	0.92511	0

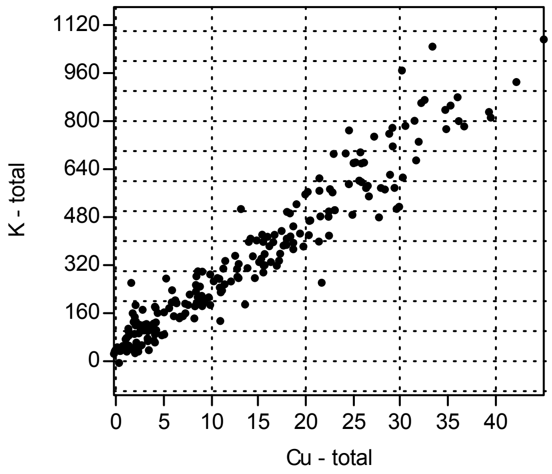


Figure 73 – K and Cu concentration in burials areas

0	Cu - total	K - total
Cu - total	0	1.229E-123
K - total	0.9633	0

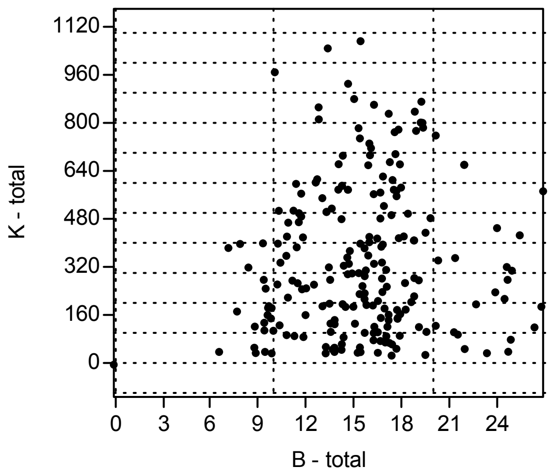


Figure 75 – K and B concentration in burials areas

0	B - total	K - total
B – total	0	0.19383
K – total	0.088956	0

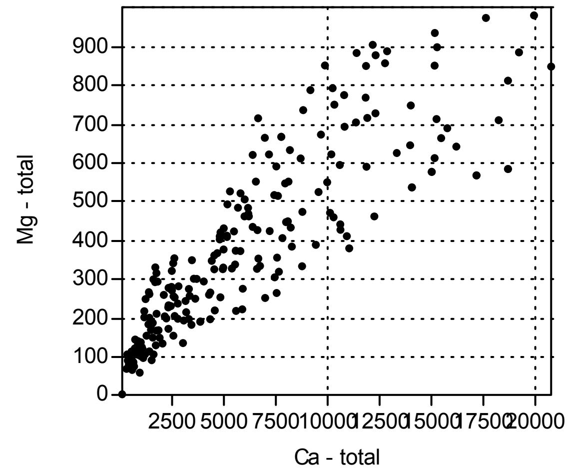


Figure 76 – Mg and Ca concentration in burials areas

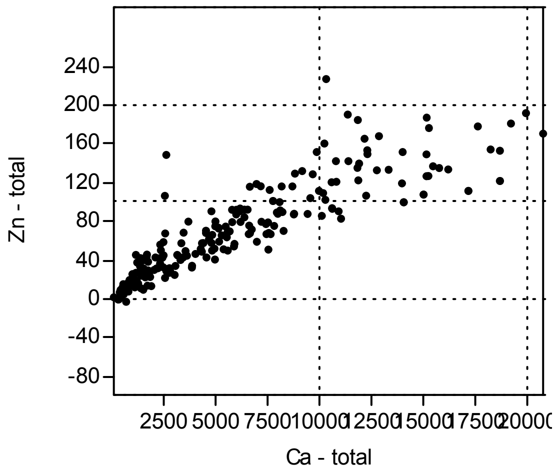


Figure 78 – Zn and Ca concentration in burials areas

0	Ca - total	Mg - total
Ca - total	0	4.6091E-85
Mg - total	0.91334	0

0	Ca - total	Zn - total
Ca - total	0	4.8326E-94
Zn - total	0.92921	0

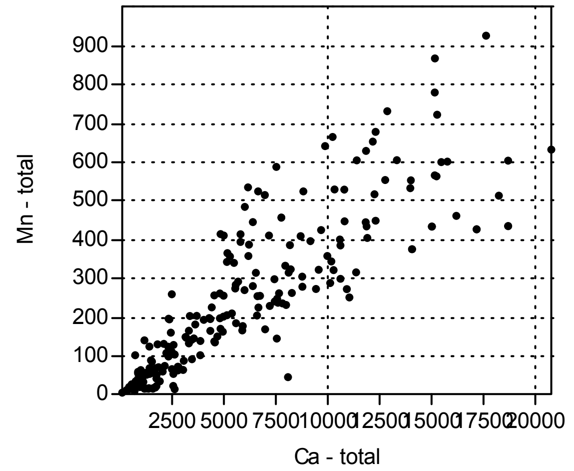


Figure 77 – Mn and Ca concentration in burials areas

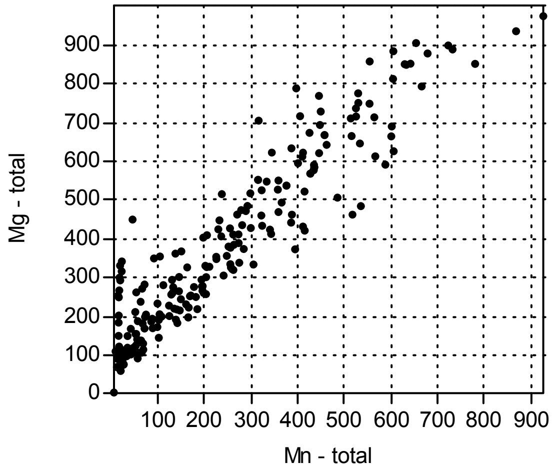


Figure 79 – Mg and Mn concentration in burials areas

0	Ca - total	Mn - total
Ca - total	0	1.8945E-82
Mn - total	0.90964	0

0	Mn - total	Mg - total
Mn - total	0	8.3352E-88

Mg - total	0.92003	0

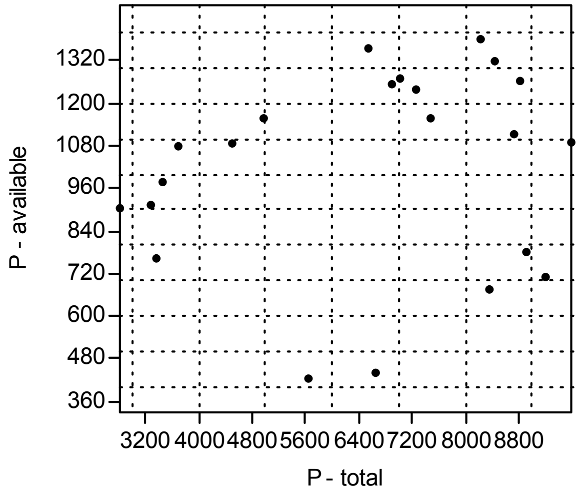


Figure 80 – P available and P total concentration in burials areas

0	P - total	P - available
P – t.	0	0.34534
P – av.	0.21124	0

The information from the correlations pointed to P, Ca, C, and K as most relevant to the hypotheses of this study. The next charts give better information about human activities in distinct areas in the profiles. The variability of the P, C, Ca, and K in the area between each 20 cm layer is apparent (Figs. 79 – 81). An important characteristic identified in these results is the tendency for P to decrease in relation to C in the profiles (7, 8, 11, 15, 45, 46, 70, 71, N1115 W1415, N1215 W1275, and N1465 W1125). Potassium (K) revealed a distinct behavior, sometimes like P and other times like Ca. It is possible to see it at the points 15, 401 (as carbon) and 8, 35 (as P).

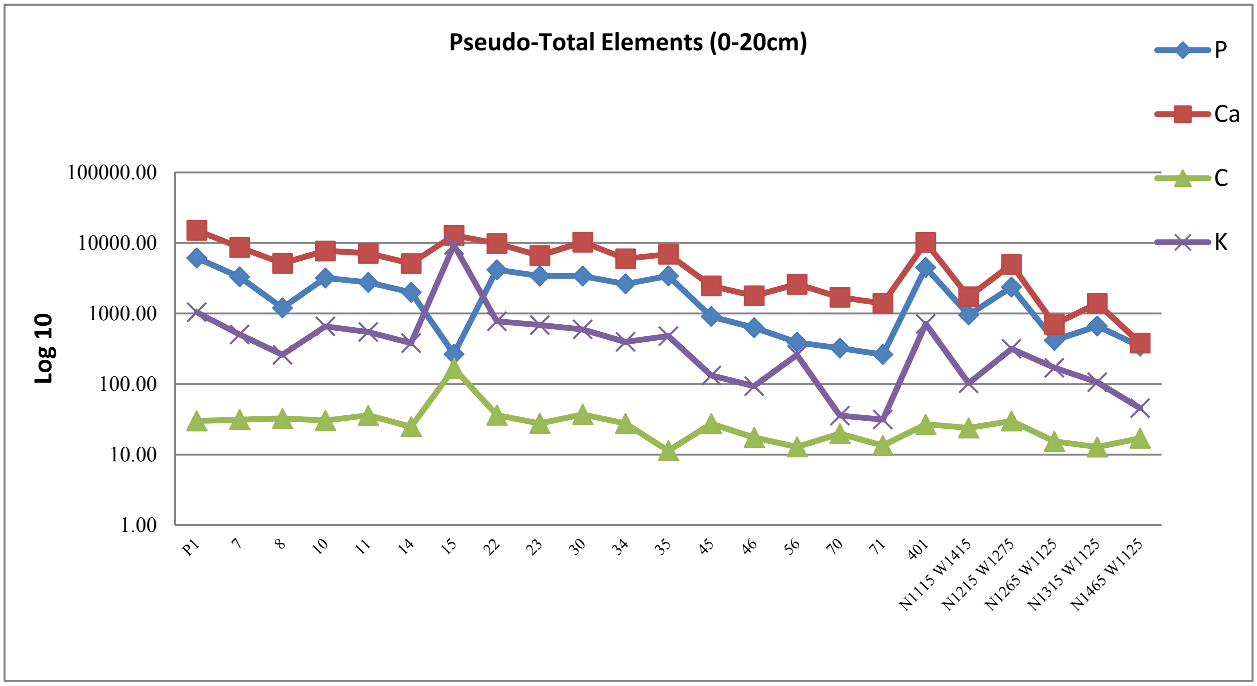


Figure 81 – K, C, Ca, and P in the surface of the site (0-20cm)

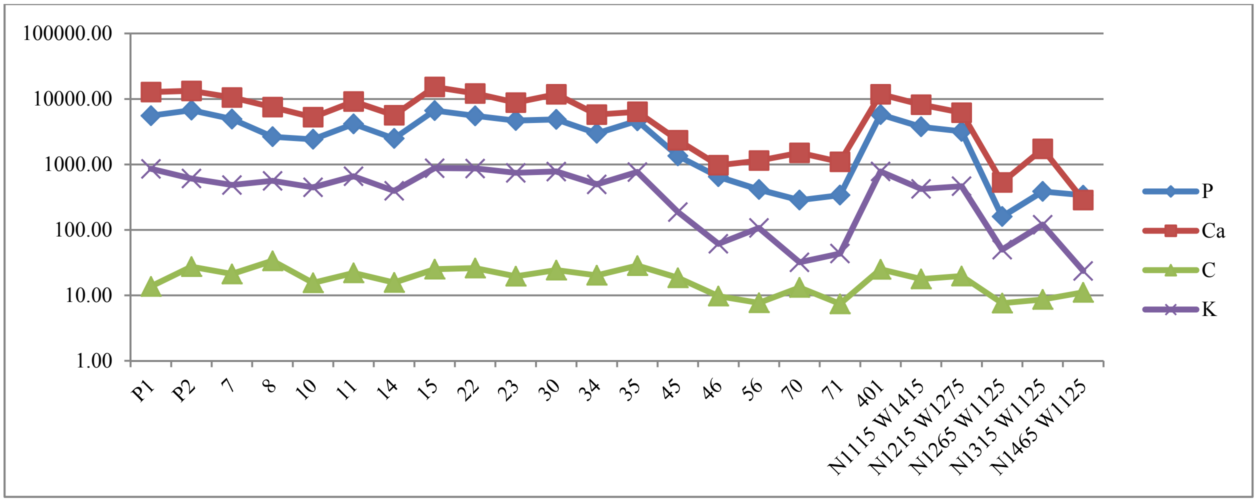


Figure 82 - K, C, Ca, and P in the surface of the site (20-40cm)

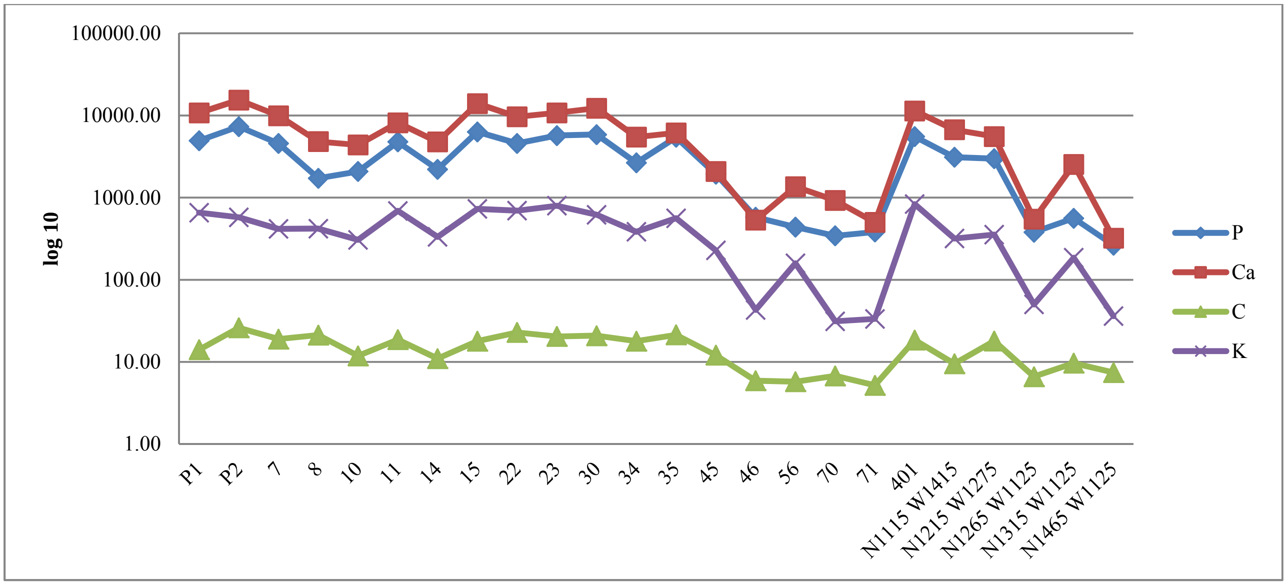


Figure 83 - K, C, Ca, and P in the surface of the site (40-60cm)

After 50cm (in the profile represented by 40 – 60cm) the elements start to present the same behavior in the profile. The correlations among them have shown that they are leaching in the same proportion, which is possible to visualize in the charts presented. The major explanation for this is the inputs of old anthropogenic soils from previous occupations (related to the Paredão phase) in areas that had not been used as agricultural fields. The graphics below show the interaction between phosphorus (available and total) and carbon, facilitating understanding of their variability on-site.

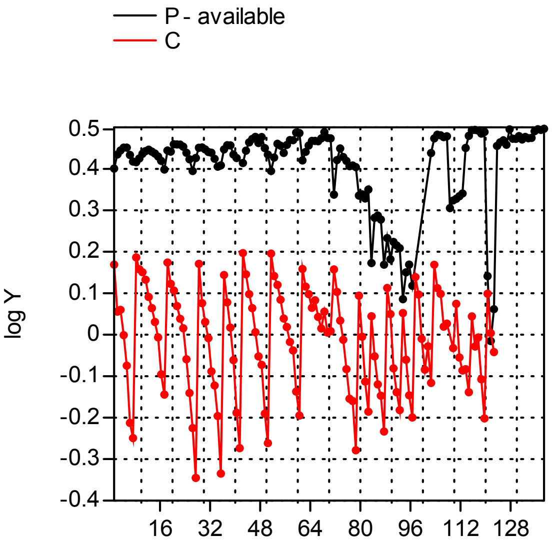


Figure 84 – Distinct picks of C and P available in all points selected. It is possible to see the variation between the higher C concentration and the lower P concentration

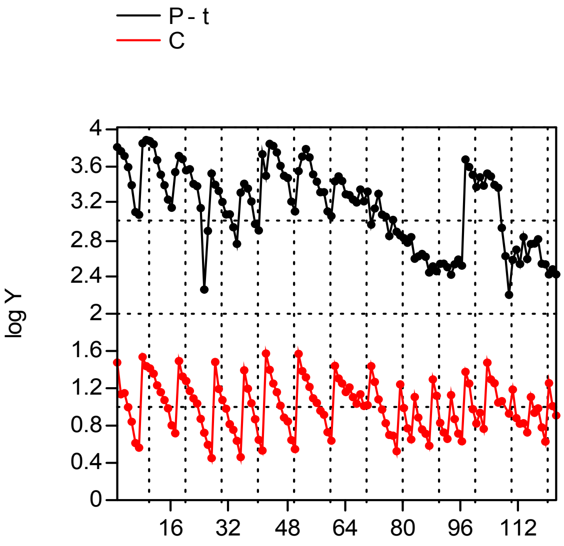


Figure 85 - Distinct picks of C and P total in all points selected. It is possible to see the variation between the higher C concentration and the lower P concentration

The low correlations between C and P (total and available) are demonstrated in Figs. 82 – 83, and these express the different inputs of these elements in the soil profiles. The interpretation of this is that the differences are due to changes in agricultural practices and increased use of fire in the fields during the last occupation. Such practices increased the presence of black carbon in the soil. More details about the carbon in the site are furnished using a statistical program called

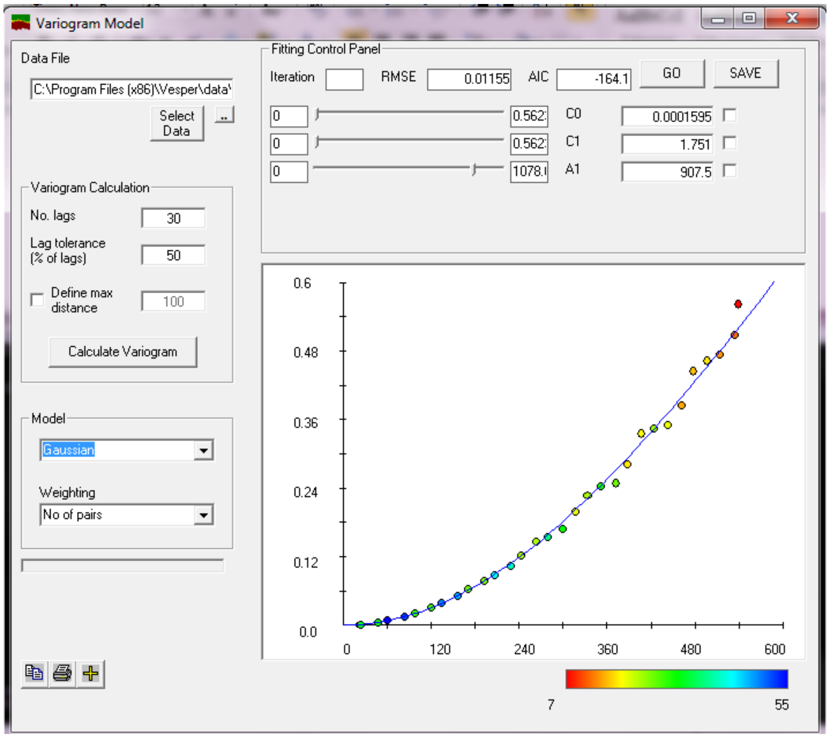
VESPER. The results corroborate previous results published and add more information about the use of space and changes in land-use through time, as shown below.

Interpolation Analysis

VESPER1.5 (Variogram Estimation and Spatial Prediction plus Error) is a free statistic software developed at the University of Sidney specifically for prediction of precision agriculture. It encompasses: variable data density, spatial distribution, and observation uncertainly (Minasny, McBratney, and Whelan 2005). The flexibility offered by use of the sofware's semivariograms and various choices of models made VESPER 1.5 a useful tool to work with archaeological soil data from systematic surveys. Besides this, in VESPER it is possible to build boundary grids or import from another file; in this case, data was generated from an Excell sheet and imported to the program to run a Kriging analyisis. The minimum number of a grid points for analysis is 50 and the maximum over 100ha (Minasny, McBratney and Whelan 2005).

Map models in the program may be built as rasters or using grid points, in this work I chose to use the Grid Model where the values are represented in a set of blocks through Cartesian coordinate locations. The concept of spatial prediction is made using spatial dependence (spatial variability), where the data set blocks are used to estimated a sample's neighbor areas. The software also has two options for predictions, Global and Local. For this study the Local prediction, consisting of only points around the set of blocks, was chosen. This allowed us to produce a continuous surface map for each arbitrarian depth (20 cm). The method also was chosen to test an anterior model in the Hatahara site, where the village layout showed a change in the last 50 cm. Due to the limitation of the minimum of 100 points to build the map, the locations in the site could not be analyzed by the program to a depth of more than 110 cm.

VESPER 1.5 flexibility allowed the data to be fit into different models according to nonlinear squares estimations, such as Linear with sill, Exponential, Gaussian, Double Spherical, Double Exponential, and others. Mainly, the three first models used according with the lower Akaike Information Criteria (AIC), and the sum of square errors (SEE), to make the semivariogram and extract the parameters to Kriging procedures (Akaike 1973, Minasny et al. 2005).


Variogram Model

Data File: C:\Program Files (x86)\Vesper\data\

Fitting Control Panel

Iteration:
RMSE: 0.01155
AIC: -164.1

0 — 0.562 — C0: 0.0001595 ☐
0 — 0.562 — C1: 1.751 ☐
0 — 1078. — A1: 907.5 ☐

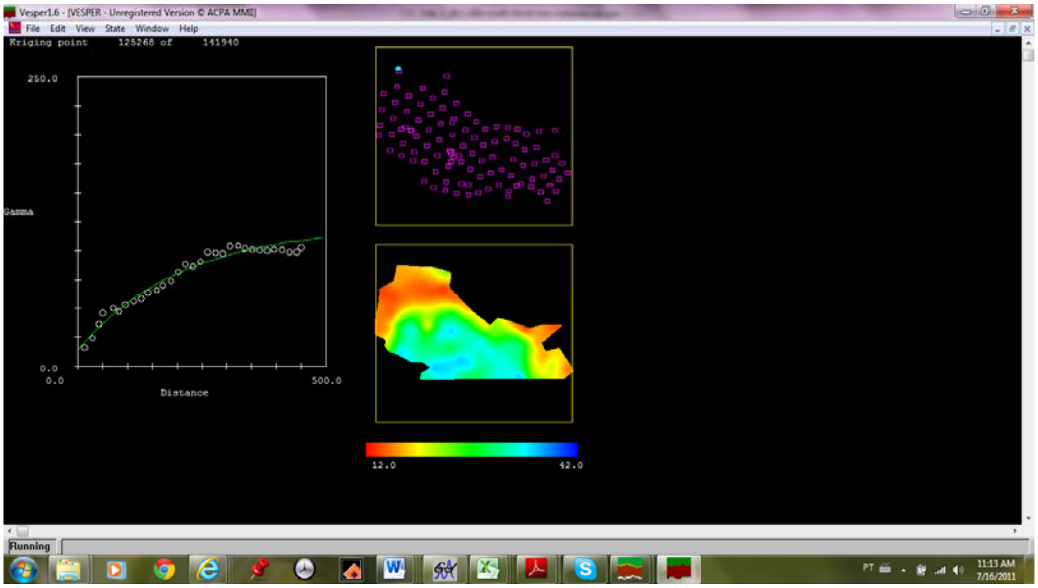
Variogram Calculation

No. lags: 30
Lag tolerance (% of lags): 50
☐ Define max distance: 100

Model: Gaussian

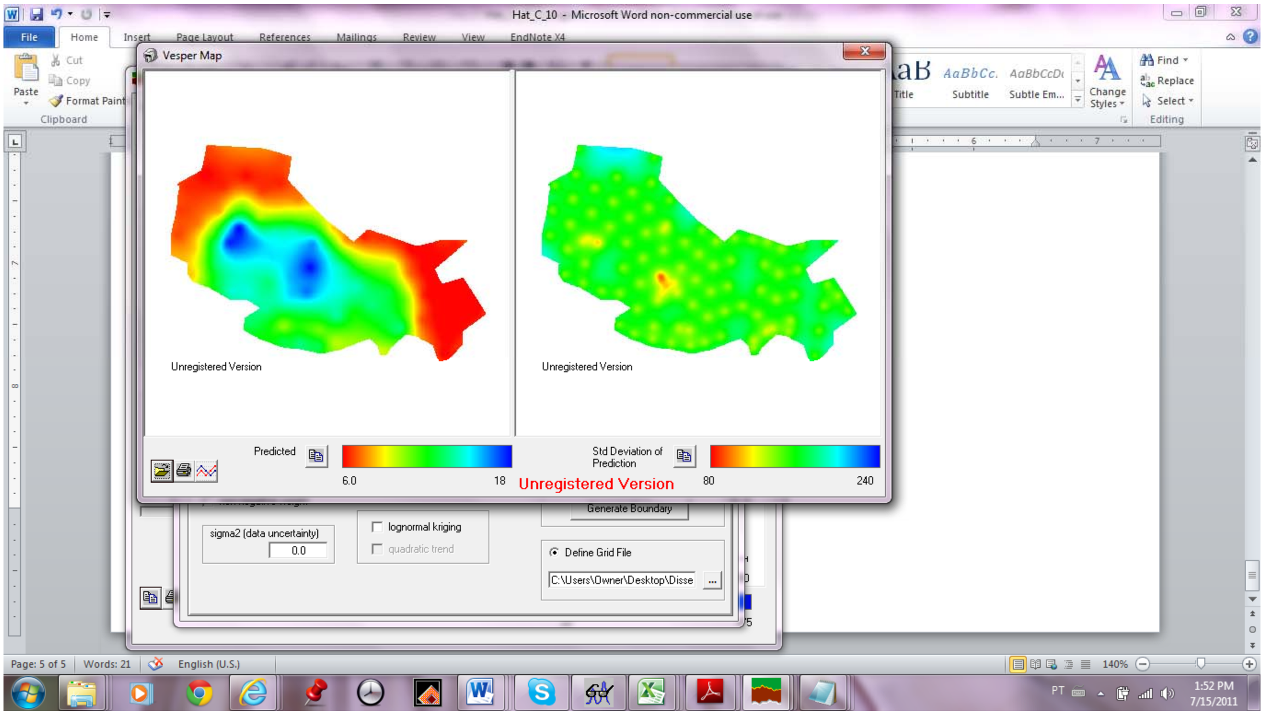
Weighting: No of pairs

Figure 86- Example of modeling data



Kriging point 125268 of 141940

Figure 87 – Interpolation analyses using VESPER



sigma2 (data uncertainty) 0.0

☐ lognormal kriging

☐ quadratic trend

● Define Grid File C:\Users\Owner\Desktop\Disse

Figure 88 – Example of the VESPER treatment of the data and the final maps

The Local variogram makes a surface map with lower and higher variability areas. Local Kriging and Local variogram use is recommended for dense data-sets; therefore, this procedure was used to analyze the results from soil samples from available elements in the soil, namely, Phosphorus, Carbon, and Potassium. Such methods (Local Kriging and variograms) include the changes in the spatial dependence between local neighborhoods (Minasny, McBratney, and Whelan 2005).

C -10 cm

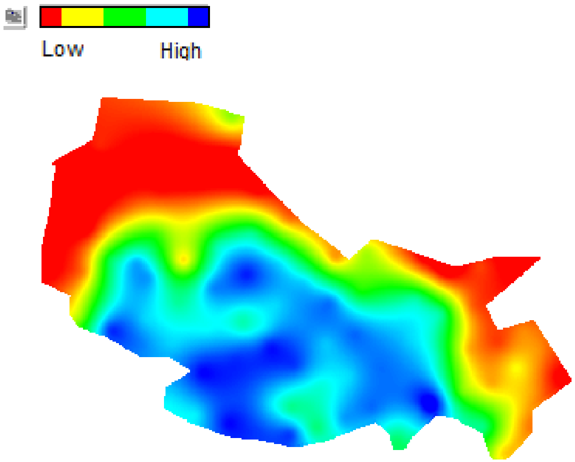


Figure 89 – C predicted concentration in the surface of the site

Variogram model: Linear with sill
Max. distance 450m
Distance between interpolation 1m
Min. data 30
Max. data 300

Std Deviation of Prediction

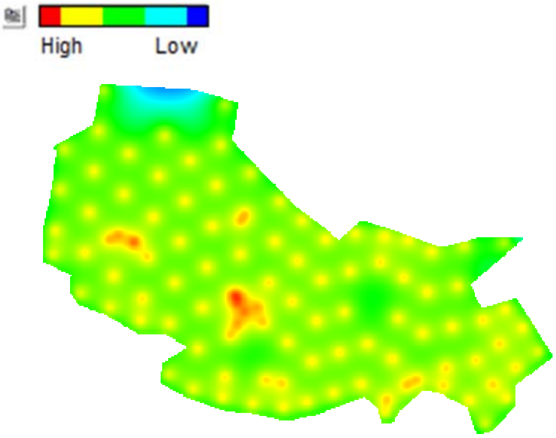


Figure 90 – Standard deviation of prediction map of the soil surface

These figures represent a useful tool in order to allow better visualization of the changes in land-use through the time at the site. The first map represents the predicted data, while the second refers to the standard deviation from prediction. Scales below maps show the confidence of the prediction (high/low).

The map of 10cm of carbon in the site presents an increase of fire over the surface area, probably related to the changes in land-use, with fire intentionally applied to the area for agricultural purposes. The next figures will represent small portions of carbon concentrations related to activities in the previous villages.

30 cm - AIC: 172.4

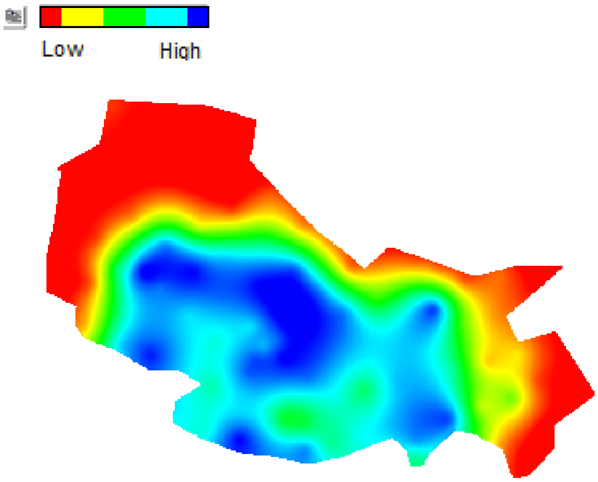


Figure 91 - C predicted concentration at 30 cm

Std Deviation of Prediction

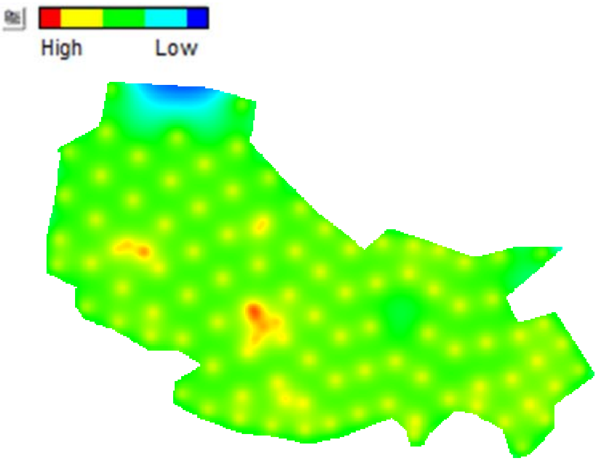


Figure 92 - Standard deviation of prediction map of the soil at 30 cm

Variogram model: Linear with sill
Max. distance 450m
Distance between interpolation 1m
Min. data 30
Max. data 100

50 cm AIC: 179.1

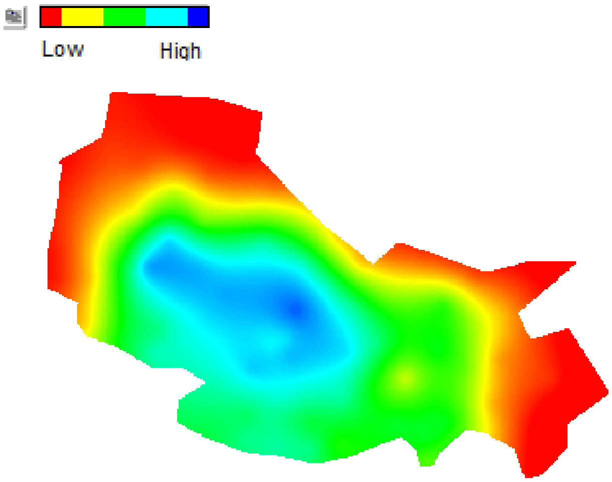


Figure 93- C predicted concentration at 50 cm

Std Deviation of Prediction

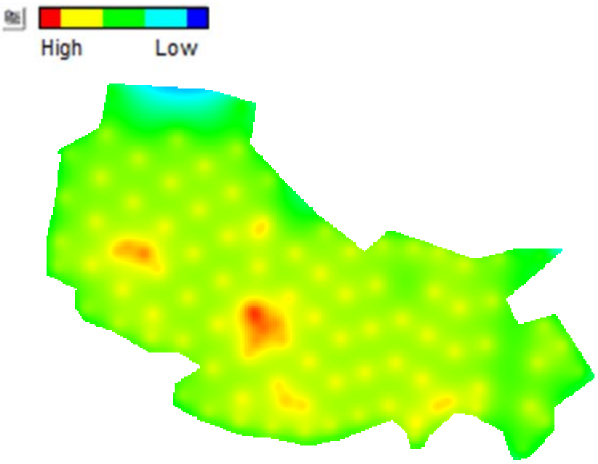


Figure 94 - Standard deviation of prediction map of the soil at 50 cm

Variogram model: exponential
Max. distance 350m
Distance between interpolation 1m
Min. data 30
Max. data 100

C - 70 cm - AIC: 156.7

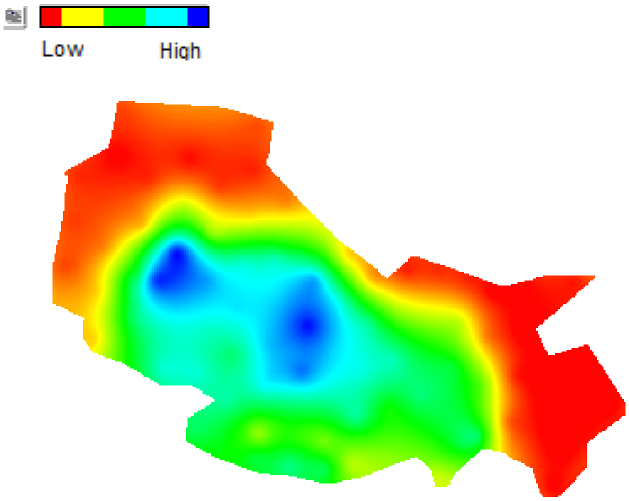


Figure 95 - C predicted concentration at 70 cm

Std Deviation of Prediction

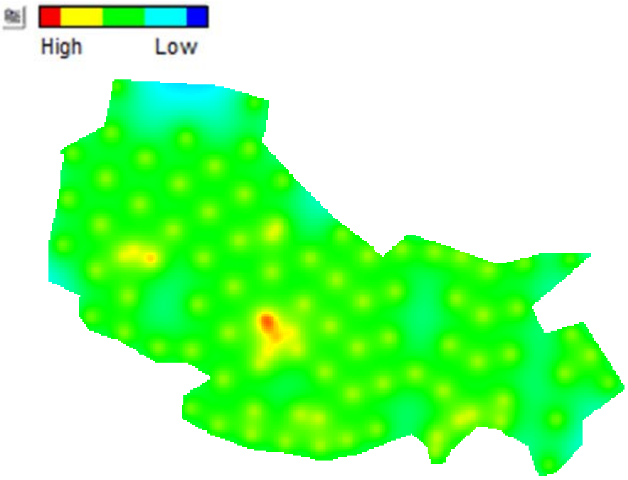


Figure 96 - Standard deviation of prediction map of the soil at 70 cm

Variogram model: Linear with sill
Max. distance 450m
Distance between interpolation 1m
Min. data 30
Max. data 300

90 cm AIC: 157.3

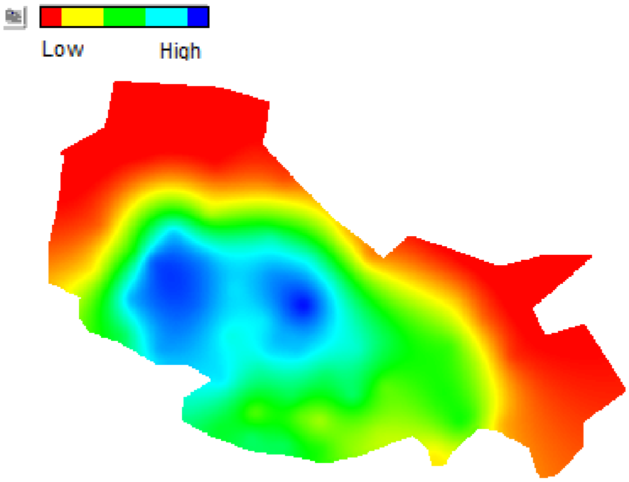


Figure 97 - C predicted concentration at 90 cm

Std Deviation of Prediction

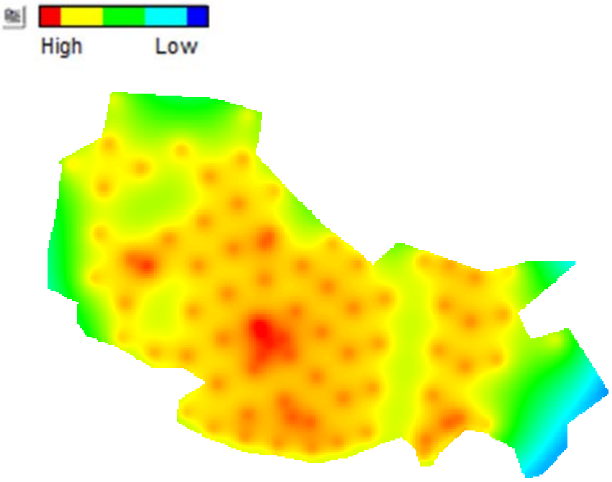


Figure 98 - Standard deviation of prediction map of the soil at 90 cm

Variogram model: Linear with sill
Max. distance 300m
Distance between interpolation 1m
Min. data 30
Max. data 300

C -110 cm AIC: 180.0

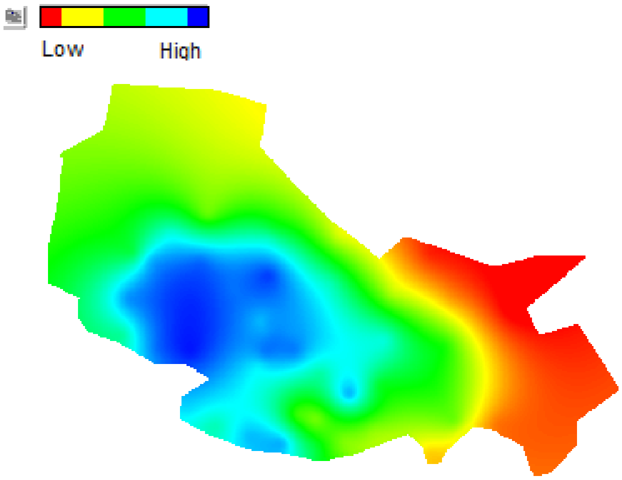


Figure 99 - C predicted concentration at 110 cm

Std Deviation of Prediction

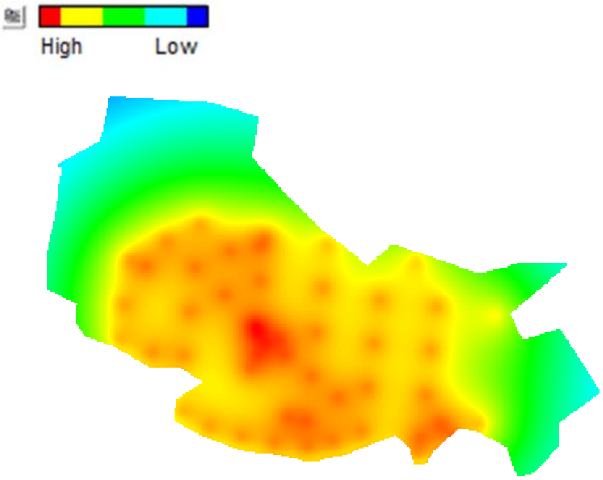


Figure 100 - Standard deviation of prediction map of the soil at 110 cm

Variogram model: Linear with sill
Max. distance 50m
Distance between interpolation 1m
Min. data 30
Max. data 300

The high level of C concentration in the site's soil has an interesting distribution through the profile. The first levels present a high concentration and wide distribution of C, while at 50 cm distribution decreases and C stays concentrated in the center of the site. At 70 cm the C concentration reaches its lowest levels, represented in two spots that maintain the same location of concentration at 70 cm and 90 cm. The C concentrations in both levels are associated with indirect burials and probably are related to ceremonial deposition and fire. Finally, the lowest level presents an increase in C concentration in the center of the site. This depth is associated with the first occupation, called the Açutuba phase. Such evidence may be related either to downward movement of C caused by bioturbation, or to intense use of fire during this occupational period of the site.

The maps show a significant increase of the carbon pool in the soil over time. However, while phosphorus concentration is higher in the layer of soil 20 to 60 cm deep, at the site's surface it tends to decrease. These results are, in this research perspective, derivatives from increased use of fire for agriculture (control and recycling) and soil management. The results also confirm a circular village shape, as well as rapid change in the ADE distribution that indicates changes in the layout of the settlement. The only research question that was unanswered was related to the use of the ADE for food production during the earlier periods of occupation. Chemical results pointed out a consistent pattern resolution of intentional use of these anthrosols for agricultural fields during the last period of occupation of the site.

Conclusion

Settlements concentrate nutrients through the deposition of a variety of materials derived from exploitations of resources and accumulation on the surface of the site through the time (Woods 1995:163). Human food consumption, for instance, brings vegetable remains such as seeds to the settlement areas. “Plants concentrate nutrients in their reproductive parts (seeds, fruits, nuts, and tubers), and it is these that humans are most likely to harvest and bring back to their places of habitation” (Eidt and Woods 1974:04). Within a settlement system, manipulation of these nutrient streams and associated transformations, translocations, additions, and losses in the soil surface, are critical for the long-term success of the nutrient concentrations in the soils (Woods 2003:12). Usually in tropical soils nutrient leaching occurs at a much higher rate than in other regions of the Earth, and under normal conditions the nutrients deposited in archaeological sites in these areas could not persist for so long a time. However, in archaeological sites in Amazonia where ADE are found, nutrients and organic matter (OM) present high concentration levels. The major source of the stabilization of OM, as well as of macro- and micro-nutrients in the soils, is associated incomplete combustion of organic material, called black carbon (charcoal), which creates aromatic structures that “are chemically and microbially stable” (Glaser et al. 2000:37).

Since the 1960s, soil scientists have been studying the stability of OM and soil nutrients in ADE in Amazonia (e.g., Sombroek 1966; Woods and McCann 1999; Glaser et al. 2001; Lehmann et al. 2002; Lima et al. 2002; Schaefer et al. 2004; Steiner et al. 2007; Falcão et al. 2009; Birk et al. 2011). The results of this line of research became a useful and important tool for archaeological investigations of site formation processes in the Amazonia. Geoarchaeological techniques have been applied in the area over the past ten years at sites that present ADE concentrations. Soil nutrient mapping at these archaeological sites, especially of phosphorus, calcium, and carbon, can reveal activity areas, population density, land-use systems, and village layout. Soil analysis thus also allows us to predict activity areas and some human unintentional soil alterations, as seen in the present study and others (Arroyo-Kalin 2008, Arroyo-Kalin et al. 2009; Rebellato, Woods, and Neves 2009; Schmidt 2010). Each one of the new archaeological studies being carried out in Amazonia is producing important revelations about the pre-Colonial societies there, as well helping us to understand the complex interaction of human and landscape and the history of occupation in that region.

For almost 50 years the Amazon was considered an empty area with small villages that had to move from one place to another due to soil exhaustion (Meggers 1954, 1971, 1995). However, new investigations with an interdisciplinary approach are showing a different perspective, and the ADE study is one of the most important elements in furnishing evidence for this historical challenge: to reveal the deep history of land-use by past societies, to know their density, migration, interaction, and settlement distribution in the landscape. Because recent investigations encompass different areas of research and aggregate more information than traditional archaeology research, a new picture of this area is being captured. However, it is still a difficult task to demonstrate site formation processes and the history of occupation in this ecosystem due to the extension of the territory and the natural barriers that make the investigations slow and expensive. As different disciplines strive to complement each other in an endeavor to build our knowledge, it has become apparent that it is crucial to work at various scales in order to understand the cultural and natural elements that are part of site formation processes. Thus, geoarchaeological research projects in Amazonia need to consider the micro-, the meso-, and the macro-scales to succeed in the interpretation of archaeological sites.

All three scales are relevant to understanding how past human activities relate to the ADE formation processes. Soil analyses conducted through an archaeological approach revealed that there is not a singular activity that generated ADE, but rather that a group of human actions interacted with microscopic elements, such as microbiota, to improve the quantity and quality of microorganisms in these soils in ways that increased their resilience and fertility (Tsai et al. 2009; Birk et al. 2011). Beyond a nanometric scale, in the meso-scale the incomplete combustion of organic matters (that generates black carbon) also changed the soil's properties. The insertion of charcoal and the presence of black carbon in the site surface resulted in improvements in the soil's cation exchange capacity as well its bulk density, which increased its porosity, intensifying the soil fauna's biogenic activities of changing and moving elements through profiles (i.e. translocation of nutrients in the biological channels caused by the activity of fauna such as earth worms (Schaefer et al. 2004:405)). The faunal activity in these soils both causes downward movement of Ca-P, Al-P, and black carbon from the A horizon to the B horizon and brings particles from the B horizon upward to the anthropic horizon (Schaefer et al. 2004). Therefore, bioturbation is the major source of enrichment in the non-anthropogenic B horizon, which incorporates a significant amount of P and C, sometimes to depths of 1.5m; however, the lower the depth, the less biological activity (Schaefer et al. 2004:408). This finding, for instance, allows us to make inferences closely related with the carbon distribution in the profile of the Hatahara site. As presented in Fig. 99, at Hatahara there is an increase of C concentration at the level of 110 cm. In other words, at the layer associated with the first occupation (Açutuba and/or Manacapuru phases) there was considerable incomplete combustion of the organic materials, suggesting long-term occupation, because it is not likely that C concentration at this level was due to bioturbation near the surface alone. Why not? Because the intermediate levels consistently do not have high concentrations of black charcoal. This result corroborates Arroyo-Kalin's (2008) finding that earlier occupations in the Hatahara site also changed the soil composition prior the formation of ADE, that is, they also were creating anthrosols, even though the final product was not really ADE like the ones I found in the levels above. This demonstrates how necessary it is to consider the meso-scale as an important element in understanding the soil's changing properties. This finding also reveals a distinct settlement pattern during the Paredao phase, responsible for the initial ADE formation. In the levels 40-90cm, it is possible to identify high levels of phosphorus, but not so much of carbon, suggesting a habitation area with intense organic material deposition in the soil surface. Woods (1975) states that carbon cannot be used as a good source for human settlement signature because it "is drained to lower soil levels and washed away" (Woods 1975:29). This is definitely true for most carbon associated with human refuse and excrement that does not result from a pyrogenic process. However, the ADE located in archaeological sites presents a high organic C concentration associated with black charcoal (Lehmann et al. 2003). What is being proposed is that the C contained in large proportions of black charcoal assumes a stable position in the soils and can remain in the profile for thousands of years (Lehmann et al. 2003; Glaser et al. 2001). This stability in the soil also protects the C's position in the profile, because it is not available for plants and cannot be leached out from the topsoil to the lower levels due to rainfall. However, as described before, it definitely can be moved in the profile (vertically and horizontally) by the biota, especially earthworms, armadillo, and other live fauna in the soil. Nevertheless, Fig. 89 shows a high concentration of carbon in the topsoil, Figs. 90 – 97 present a decrease of its levels, and finally in Fig. 99 we see an increased of carbon levels. Such a pattern of C distribution cannot be explained solely by biota activity or other bioturbations, which certainly affected some of its concentration levels in the profile but does not account for the total distribution. This distribution is much more strongly related to human activities, and needs to be analyzed at the macro-scale.

The macro-scale, where the human daily activities of the past are encompassed, shows that human activities generated depositions of tons of micro- and macro-nutrients in these tropical soils. This scale refers to all human activities carried out through time at the site, including ceremonies, burials, building, food production, refuse disposal, and all sorts of improvements created by past people in order to establish their settlements. Deposition of organic materials increased the phosphorus and calcium pools, and fire-making activities were responsible for the potassium and carbon inputs. People that occupied the site also were responsible for innumerable changes in the soil through building structures, redistributing soils, and increasing agricultural field areas for production. It is interesting to note that the results of C and P analyses are furnishing ideas about the change in the settlement pattern as well as activity areas through time. During the initial periods of occupation (around 2,500 BP) a process of combustion of organic materials took place. These human activities were not directly related to the ADE formation process but they generated changes in the soils that probably helped the posterior human action to create ADE. After that, a change in the element depositions, including much higher inputs of phosphorus, indicates village refuse and fewer pyrogenic activities. This phase definitely changed the soils' characteristics and started around 1,600 BP.

Finally, the last occupation during the 'agricultural period' of use of ADE for food production increased the C inputs in the soil, but lowered levels of P, and is related to Guarita subtradition (beginning around 1,000 BP). It is possible to understand the increase of C as the result of fire applied in the field generating black charcoal. Hecht (2009) presented a case study of the Kayapo group (Brazil), who mulch their fields to increase productivity, calling this action slash-and-char. This practice consists of burning in "cool fire" organic material that generates more charcoal than ashes, and the charcoal is spread on the surface of the field to increase crop production. Such practice reveals agricultural knowledge that may also have been used in the past by the Guarita society. The decreases of P (and other nutrients like N, K, and Ca) are attributed to the extraction of these nutrients by plants during the "agricultural period," when ADE were used for food production by the Guarita.

The sum of all these human actions through time was responsible not just for chemical changes in the soils, but also for their physical and structural alterations, as it is possible to see in the color and bulk density changes. In this way, the ADE resulted from the connection of micro-, meso-, and macro-scales, and they are associated with a period of occupation and population density. Moreover, it is important to say that natural processes also acted with the depth of the ADE in the profiles. The entire process could not have had such impact without a considerable span of time. All these activities can be identified in the archaeological sites through chemical and physical analysis of the soils. The Hatahara site presents soils with higher pH levels (around

6; which is considered very high for tropical soils). In addition, the past intervention at the site enhanced other soil properties beneficial to plants, e.g., cation exchange capacity, percent base saturation, moisture retention, conditions of structure, and soil biotic activity.

Therefore, enhanced levels of soil nutrients are the result of an interaction of natural and cultural sources that, through time, configured better soils in Amazonia. A complete profile of the interaction between humans and their environment also requires discussions of migration, exchanges, and accumulation of knowledge about the environment, topics that have heretofore received more attention. Population increases and the consequent pressures on resources have been studied (Lathrap 1970; Brochado 1984; Denevan 2001). Plant domestication for the area has been well described and verified through empirical experiments, and the improvement of food resources over time has been extensively analyzed and understood (Clement 1999, Clement et al. 2010; Junqueira et al. 2011). On the other hand, soil improvement in Amazonia has for decades been considered to be only an unintentional occurrence and the assumption has been that Amazonian peoples did not reuse soils for food production (Meggers 1954; 1971; 1995). Coincidences of consistently good soil characteristics and high densities of associated archaeological materials were reported, but these were always linked to unconscious processes. The results from this research give us a new perspective on past societies' interactions with soil management. That is, soon after the first settlement unintentionally generated soils that were suitable for food production, their agricultural benefits became known to others in the region. This stimulated migrations into the areas with the rich soils. Demographic pressure provides one of the reasons for the later occupation of areas with ADE and for the reuse of these soils until the Contact Period, when most of population in the Amazon region perished due to diseases, slavery, and wars. This research postulates that ADE are part of a domestication process comparable to the one so well described for plants (Clement et al. 2010; Junqueira et al. 2011), and landscape (Erickson 2008).

Domestication processes encompass changes in the DNA of the object (e.g., plant or animal) modified. It was possible to identify the DNA of distinct bacterial communities in ADE (Tsai et al. 2009). The weathered soils of Amazonia were turned into healthful and fertile soils, and they underwent transformations at every level, from the chemical to the physical, and from the micro- to the macro-scale. Thus, I propose here that ADE are *domesticated soils* in the sense that they received human intervention in order to improve their characteristics. Systematic archaeological studies like this are allowing an understanding that soils can pass through domestication processes like plants and animals do. Whether or not this process was at first unintentional, its continuation formed an ideal location for settlement areas with an almost infinite pool of nutrient resources for food production over centuries.

Nutrient analyses showed that the carbon pool in the topsoil (until 40 cm depth), mostly from charcoal, presented a distinct pattern from the deeper profiles (associated with the beginning of formation of ADE by unintentional activities from previous habitants of the site, and related to Paredão and Manacapuru phases). During the last period of occupation, whcih I am calling 'agricultural period', it is possible to see the increase of C and decrease of P in relation to the levels below. The increase of black carbon in this horizon is associated with increased occurrences of fire, mostly associated with agricultural fields. Why aren't these C levels just as likely to be associated with hearths from villages? Because the phosphorus concentration shows a decrease in this horizon, which does not support a habitation hypothesis;

instead it indicates a crop production area, where the concentration of organic materials was spread over larger areas. At the same time, the P decrease is interpreted here as the result of two factors: (1) the leaching in the profile due to precipitation and bioturbation; and, (2) the extraction of this element by plants during the agricultural period of the Guarita occupation.

The Guarita occupation was responsible for the redistribution of the ADE on the site surface as its people spread out all 2,000 years of accumulated nutrients generated by the daily life of anterior societies. They changed the village layout to a linear shape to guarantee better use of ADE for food production. Beyond the use of ADE for crops, Guarita people also could have engaged in seasonal agriculture using the *várzea* (floodplain) areas during the dry season. The linear settlement also implies that few conflicts with neighbors occurred during this period, for this type of settlement is much more difficult to defend then the circular layout. That furnishes clues that suggest a conquest of the territory by a single group, or else a strategic relationship between distinct societies. Thus, I infer that the Guarita group, related to the Tupi speakers whose origin center lies in the Upper Madeira, expanded their territory from there to the Central Amazon and settled areas where they could find ADE. Why do I infer this? Because there is no Guarita subtraction pottery at an archaeological site that does not also possess ADE in the Central Amazon (Woods, personal communication, 2010). That reflects a selective decision to occupy only areas where ADE were present. Phytolith analyses carried out in the Hatahara site by Bozard et al. (2009) revealed an increase of maize in the first layers of the soil profile. We know, then, that the crop production during the ‘agricultural period’ of the last occupation was based on maize, and this plant demands a lot of nutrients to grow well. This explains the Guarita selection of the areas that have ADE, for in order to growth their main food source, it was necessary to find good soils.

Glossary

Cation Exchange Capacity (CEC) – The capacity of a soil to hold or 'sorb' cations and to exchange species of these ions in reversible chemical reactions. The variations in CEC depend on the **pH** at which determination is made, due to the different reactivity of various exchangers (clay, hydrous oxides, amorphous compounds, and organic matters) (Buol et al. 1973:63). The variation in the CEC with the pH becomes lower in soils highly weathered, composed by kaolinite and hydrous oxides (Buol et al. 1973:64).

pH – The acidity (below 7) or alkalinity (above 7) of soils is associated with the concentrations of H^+ and OH^-. Many chemical reactions are dependent on these ions, which influence the solubility and availability of several essential nutrients (Brady and Weil 2002). Acidity arises with biological activities plus a vigorous leaching of salts and is associated with the rain forest environment, while alkalinity is related with the accumulation of salts and bases with inadequate leaching (Singer and Munns 2006). The analyses for this study have been conducted considering the pH in water and KCl. It is possible make some inferences based on the pH in water, but it is not helpful in understanding the chemistry of the soil, for instance for issues of measuring the exchange acidity, exchangeable aluminium, and exchangeable bases (Buol et al. 1973:67). The pH was determined in water and in 1 mol L^{-1} KCl solution by a potentiometer using a 1:2.5 (v/v) ratio of soil/solution. The comparison between the pH in water and KCl helped to understand the exchangeable Al. Acidic soils usually develop high levels of exchangeable Al and if there is a drop in the values between pH water and pH KCl (one-half) in the range below pH 6 this is due to the amount of Al (Buol et al. 1973:68; Singer and Munns 2006:260).

Base Saturation – This is the percentage of effective cation exchange capacity (CEC) occupied by Na^+ (5%), K^+ (5%), Mg^{++} (20%), and Ca^{++} (50%) (Singer and Munns 2006:259). The exchangeable bases and exchange acidity are generally measured by the Mehlich 1 method. From the results obtained the sum of bases (SB), total (E), and effective (e) cation exchange capacity. The **Percentage of Base Saturation** is expressed by:

PBS = ∑ exchangeable bases x 100/ ∑ exchangeable bases + exchange acidity

The Percentage of Base Saturation is directly related with the pH. So, if the soil presents low pH, the %SB is low and *vice-versa.*

The potential acidity (H + Al) - was determined by extraction with 0.5 mol/L calcium acetate at pH 7.0 and quantified by NaOH titulometry (Embrapa, 1999).

Organic Matter (OM) - The principal components of the OM (organic matter) are carbon (C) and nitrogen (N). The organic carbon was determined by the Walkley-Black method where the soil is digested in an excess of chromic acid, with titration of the unused oxidant (Buol et al. 1973:70). The ratio of C:N is an indicator of the degree of decomposition of organic matter in soils. Soils with a high concentration of organic matter show an increase in the Cation Exchange Capacity once they have a negative charge.

The P, K, and Na elements - were extracted using the Mehlich-1 extractor and determined by flame photometry (K and Na) and colorimetric method (P). This method furnishes just the available elements for plants, not their total values in the soil. Because of this, a new analysis will be processed to reveal the composition of the total elements in the soil to compare with the available.

Bibliography

Ab'Sáber, A. N. 1977. Espaços ocupados pela expansão dos climas secos na América do Sul, por ocasião dos períodos glaciais quaternários. *Paleoclimas,* 3**,** 1-19.

Akaike, H. 1973. Information theory and an extension of maximum likelihood principle. In *Second International Symposium on Information Theory,* ed. I. B. N. P. F. Csáki, 267-281. Budapest: Akadémia Kiadó.

Anchieta, J. d. 1933. *Arte de grammatica da lingua mais usada na costa do Brasil*. Rio de Janeiro,: Imprensa nacional - Biblioteca Nacional.

Anderson, A. B. 1981. White-sand vegetation of Brazilian Amazonia. *Biotropica,* 13**,** 199-210.

Anderson, D. G., K. A. Maasch, D. H. Sandweiss & P. A. Mayewski 2007. Climate and culture change: exploring Holocene transitions. *Climate change and cultural dynamics: a global perspective on mid-Holocene transitions***,** 1.

Araujo, A. G. M., W. A. Neves, L. B. Piló & J. P. V. Atui 2005. Holocene dryness and human occupation in Brazil during the "Archaic Gap". *Quaternary Research,* 64**,** 298-307.

Arion, D. R. 1958. Classification of Tupi-Guarani. *International Journal of American Linguistics,* 24**,** 231-234.

Arrhenius, O. 1929. Die phosphatfrage. *Zeitschrift für Pflanzenernährung, Düngung, Bodenkunde,* 14**,** 121-140.

Arrhenius, O. 1931. Die Bodenanalyse im dienst der Archäologie. *Zeitschrift für Pflanzenernährung, Düngung, Bodenkunde,* 10**,** 427-439.

Arrhenius, O. 1934. Fosfathalten i skånska jordar. Kungl. boktryckeriet, PA Norstedt & Söner.

Arrhenius, O. 1954. Chemical denudation in Sweden. *Tellus,* 6**,** 326-341.

Arrhenius, O. 1963. Investigation of soil from old Indian sites. *Ethnos,* 28**,** 122-136.

Arroyo-Kalin, M. 2008. Steps towards an ecology of landscape: a geoarchaeological approach to the study of anthropogenic dark earths in the Central Amazon region. PhD thesis, Department of Archaeology, University of Cambridge.

Arroyo-Kalin, M. 2010. The Amazonian formative: Crop domestication and anthropogenic soils. *Diversity,* 2**,** 473-504.

Baker, P. A., G. O. Seltzer, S. C. Fritz, R. B. Dunbar, M. J. Grove, P. M. Tapia, S. L. Cross, H. D. Rowe & J. P. Broda 2001. The History of South American Tropical Precipitation for the Past 25,000 Years. *Science,* 291**,** 640-643.

Balée, B. 2010. Amazonian Dark Earths. *Tipití: Journal of Society for the Anthropology of Lowland South America,* 8**,** 1-20.

Balée, W. 1989. The culture of Amazonian forest. In *Resource Management in Amazonia: indigenous and folk strategies. ,* eds. D. A. Posey & W. Balée, 1-21. Advances in Economic Botanic

Balée, W. 1994. *Footprints of the Forest: Ka'apor ethonobotany - the historical ecology of plants utilization by an Amazonian people*. New York: Columbia University Press.

Balée, W. 2000. Antiquity of traditional ethnobiological knowledge in Amazonia: The Tupi-Guarani family and time. *Ethnohistory,* 47**,** 399.

Balée, W. L. & C. L. Erickson. 2006. *Time and complexity in historical ecology : studies in the neotropical lowlands*. New York: Columbia University Press.

Barba, L. & A. Ortiz 1992. Analisis Quimico de Pisos de Ocupacion: Un Caso Etnografico en Tlaxcala, Mexico. *Latin American Antiquity,* 3**,** 63-82.

Behling, H., G. Keim, G. Irion, W. Junk & J. Nunes de Mello 2001. Holocene environmental changes in the Central Amazon Basin inferred from Lago Calado (Brazil). *Palaeogeography,Palaeoclimatology,Palaeoecology,* 173**,** 87-101.

Berrio, J. C., H. Hooghiemstra, H. Behling & K. van der Borg 2000. Late Holocene history of savanna gallery forest from Carimagua area, Colombia. *Review of Palaeobotany and Palynology,* 111**,** 295-308.

Birk, J., C. Steiner, W. Teixeira, W. Zech & B. Glaser. 2009. Microbial Response to Charcoal Amendments and Fertilization of a Highly Weathered Tropical Soil. In *Amazonian Dark Earths: Wim Sombroek's Vision,* eds. W. I. Woods, W. Teixeira, J. Lehmann, C. Steiner, A. Winklerprins & L. rebellato. Springer, Heidelberg.

Birk, J. J., W. G. Teixeira, E. G. Neves & B. Glaser 2011. Faeces deposition on Amazonian Anthrosols as assessed from 5[beta]-stanols. *Journal of Archaeological Science,* 38**,** 1209-1220.

Bozarth, S. R., K. Price, W. I. Woods, E. G. Neves & L. Rebellato. 2009. Phytoliths and Terra Preta: the Hatahara site example. In *Amazonian Dark Earths: Wim Sombroek's vision,* eds. W. I. Woods, W. G. Teixeira, J. Lehmann, C. Steneir, A. M. G. A. WinklerPrins & L. Rebellato, 85-98. Berlin: Springer.

Brochado, J. P. 1984. An Ecological Model of the Spread of Pottery and Agriculture into Eastern South America. In *Department of Anthropology*. Urbana-Champaing: University of Illinois.

Brochado, J. P. 1989. A Expansão dos Tupi e da Cerâmica da Tradição Polícroma Amazônica. *Dédalo, São Paulo,* 27**,** 65-82.

Browen, H. 1966. *Trace elements in biochemistry*. New Yoirk: Academic Press.

Buehrer, T. 1950. Chemical studiy of the material from several horizons of the Ventana Cave profile. In *Stratigraphy and archaeology of Ventana Cave,* ed. E. Haury. Tucson: The University of Arizona Press.

Bush, M. B., D. R. Piperno & P. A. Colinvaux 1989. A 6,000 year history of Amazonia maize cultivation. *Nature,* 340**,** 303-305.

Bush, M. B., M. R. Silman, C. McMichael & S. Saatchi 2008. Fire, climate change and biodiversity in Amazonia: a Late-Holocene perspective. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 363**,** 1795-1802.

Bush, M. B., M. R. Silman, M. B. d. Toledo, C. Listopad, W. D. Gosling, C. Williams, P. E. d. Oliveira & C. Krisel 2007. Holocene Fire and Occupation in Amazonia: Records from Two Lake Districts. *Philosophical Transactions: Biological Sciences,* 362**,** 209-218.

Bush, M. B., M. R. Silman & D. H. Urrego 2004. 48,000 years of climate and forest change in a biodiversity hot spot. *Science,* 303**,** 827-829.

Cabral, A. S. A. C. & A. D. I. Rodrigues. 2007. *Línguas e culturas Tupí*. Campinas, SP, Brasil Brasília, Brazil: Editora Curt Nimuendajú; Laboratório de Línguas Indígenas.

Carneiro, R. L. 1956. Slash and burn agriculture: a closer look at its implications for settlement patterns. In *Men and Cultures. Selected papers of the fifth congress of Antropological and Ethnological Sciences,* ed. A. F. C. Wallace, 229-234. Philadelphia.

Carneiro, R. L. 1961. Slash and burn cultivation among the Kuikuro and its implications for cultural development in the Amazon Basin. In *The evolution of horticultural systems in native South America,* ed. J. Wilbert, 47-67. Caracas: Sociedad de Ciencias Naturales La Salle.

Carneiro, R. L. 1970. A Theory of the Origin of the State. *Science,* 169**,** 733-738.

Carvajal, G. d. 1992. *Descubrimiento del Río de las Amazonas*. Valencia: Estudios Ediciones y Medios.

Castro, E. B. V. d. 1992. *From the enemy's point of view : humanity and divinity in an Amazonian society*. Chicago: University of Chicago Press.

Castro, E. V. d. 1996. Images of Nature and Society in Amazonian Ethnology. *Annual Review of Anthropology,* 25**,** 179-200.

Chauvel, A., Y. Lucas & R. Boulet 1987. On the genesis of the soil mantle of the region of Manaus, Central Amazonia, Brazil. *Cellular and Molecular Life Sciences,* 43**,** 234-241.

Chen, M. & L. Q. Ma 2001. Comparison of three aqua regia digestion methods for twenty florida soils. *Soil Science Society of America journal,* 65**,** 491-499.

Clastres, H. 1975. *La Terre Sans Mal: Le prophétism Tupi-Guarani*. Éditions du Seuil.

Clement, C., J. McCann & N. Smith 2004. Agrobiodiversity in Amazonia and its relationship with dark earths. *Amazonian Dark Earths***,** 159-178.

Clement, C. R. 1988. Domestication of the pejibaye palm (Bactris gasipaes): past and present. *Advances in Economic Botany,* 6**,** 155-174.

Clement, C. R. 1999a. 1492 and the loss of Amazonian crop genetic resources. I. The relation between domestication and human population decline. *Economic Botany,* 53**,** 188-202.

Clement, C. R. 1999b. 1492 and the loss of Amazonian crop genetic resources. II. Crop biogeography at contact. *Economic Botany,* 53**,** 203-216.

Clement, C. R.. .; Klüppel, M. P.; German, L. A.; Almeida, S. S.; Major, J., Aragão, L. E. O.C.; Guix, J. C.; Lleras, E.; WinklerPrins, A. M. G. A.; Hecht, S. B.; McCann, J.M.; Teixeira, W. G.; Kern, D. C.; Madari, B. E.; Lima, H. N.; Woods, W. I. 2010. As Terras Pretas de Índio da Amazônia: Sua caracterização e uso deste conhecimento na criação de novas áreas: Embrapa Amazônia Ocidental, Manaus, 147-161.

Clement, C. R., M. de Cristo-Araújo, G. C. d'Eeckenbrugge, A. Alves Pereira & D. Picanço-Rodrigues 2010. Origin and domestication of native Amazonian crops. *Diversity,* 2**,** 72-106.

Colinvaux, P. A. 1979. The ice-age Amazon. *Nature,* 278**,** 399-400.

Colinvaux, P. A. 2007. *Amazon expeditions : my quest for the ice-age equator*. New Haven: Yale University Press.

Colinvaux, P. A., P. E. D. Oliveira, J. E. Moreno, M. C. Miller & M. B. Bush 1996. A Long Pollen Record from Lowland Amazonia: Forest and Cooling in Glacial Times. *Science,* 274**,** 85-88.

Cook, S. F. & R. F. Heizer. 1965. *Studies and the chemical analysis of archaeological sites.* Los Angeles: Univesity of California Press.

Costa, F. W. S. 2009. Arqueologia das Campinaranas do baixo rio Negro: Em busca dos pré-ceramistas nos areais da Amazônia central. In *Museu de Arqueologia e Etnologia*. São Paulo: Universidade de São Paulo.

Costa, J. B. S., R. Léa Bemerguy, Y. Hasui & M. da Silva Borges 2001. Tectonics and paleogeography along the Amazon river. *Journal of South American Earth Sciences,* 14**,** 335-347.

Costa, M. & D. Kern 1999. Geochemical signatures of tropical soils with archaeological black earth in the Amazon. *Journal of Geochemical Exploration,* 66**,** 369-385.

Costa, M. L., D. C. Kern, A. H. E. Pinto & J. R. T. Souza 2004. The ceramic artifacts in archaeological black earth (terra preta) from Lower Amazon Region, Brazil: chemistry and geochemical evolution. *Acta Amazonica,* 34**,** 375-386.

Denevan, W. M. 1966a. *The aboriginal cultural geography of the Llanos de Mojos of Bolivia*. Berkeley,: University of California Press.

Denevan, W. M. 1966b. *The aboriginal cultural geography of the Llanos de Mojos of Bolivia*. Berkeley: University of California Press.

Denevan, W. M. 1970. Aboriginal drained-field cultivation in the Americas. *Science,* 169**,** 647.

Denevan, W. M. 1992a. *The Native population of the Americas in 1492*. Madison, Wis.: University of Wisconsin Press.

Denevan, W. M. 1992b. The Pristine Myth: The Landscape of the Americas in 1492. *Annals of the Association of American Geographers,* 82**,** 369-385.

Denevan, W. M. 1992c. Stone vs. metal axes: The ambiguity of shifting cultivation in prehistoric Amazonia. *Journal of the Steward Anthropological Society,* 20**,** 153-165.

Denevan, W. M. 1996. A Bluff Model of Riverine Settlement in Prehistoric Amazonia. *Annals of the Association of American Geographers,* 86**,** 654-681.

Denevan, W. M. 1998. Comments on prehistoric agriculture in Amazonia. *Culture & Agriculture,* 20**,** 54-59.

Denevan, W. M. 2001. *Cultivated landscapes of Native Amazonia and the Andes*. Oxford, New York: Oxford University Press.

Dietz, E. F. 1957. Phosphorus Accumulation in Soil of an Indian Habitation Site. *American Antiquity,* 22**,** 405-409.

Dudal, R., F. Nachtergaele & M. Purnell. 2002. The human factor of soil formation. In *17th WCSS*. Thailand.

Eden, M. J., W. Bray, L. Herrera & C. McEwan 1984. Terra Preta Soils and Their Archaeological Context in the Caquet Basin of Southeast Colombia. *American Antiquity,* 49**,** 125-140.

Eidt, R. C. & W. I. Woods. 1974. *Abandoned settlement analysis : theory and practice*. Shorewood, Wisconsin.: Field Test Associates.

Embrapa. 1999. *Sistema Brasileiro de Classificação de Solos*. Brasília: Serviço de Produção de Informação - SPI.

Erickson, C. 1980. Sistemas agrícolas prehispánicos en Los Llanos de Mojos. *America Indígena,* 40**,** 731-755.

Erickson, C. 1995. Archaeological methods for the study of ancient landscape of the Mojos de Llanos in the Bolivia Amazon. In *Archaeology in the lowland America tropics: current analytical methods and recent application*. New York: Cambridge University Press.

Erickson, C. L. 2006. The domesticated landscapes of the Bolivian Amazon. In *Time and complexity in historical ecology: studies in the neotropical lowlands,* eds. B. Balée & C. Erickson, 235-278. New York: Columbian University Press.

Erickson, C. 2008. Amazonia: the historical ecology of a domesticated landscape. *The Handbook of South American Archaeology*, 157-183.

Espinoza Villar, J. C., J. L. Guyot, J. Ronchail, G. Cochonneau, N. Filizola, P. Fraizy, D. Labat, E. de Oliveira, J. J. Ordoñez & P. Vauchel 2009. Contrasting regional discharge evolutions in the Amazon basin (1974-2004). *Journal of Hydrology,* 375, 297-311.

Falcão, N., E. Carvalho & N. Comerford. 2001. Avaliação da fertilidade de solos antropogênicos da Amazônia Central.

Falcão, N., N. Comerford & J. Lehmann 2003. Determining nutrient bioavailability of Amazonian Dark Earth soils–methodological challenges. *Amazonian Dark Earths: Origin, Properties and Management*, 255-270.

Falcioni, R., E. Novaro, M. Marchersini & M. Gucciardi 2000. Multi-element analysis of soil and sediment by ICP-MS after a microwave assisted digestion method. *Journal of Analytical Atomic Spectrometry,* 15, 561-565.

Falesi, I. C. 1967. O Estado Atual dos Conehcimentos Sobre os Solos da Amazônia Brasileira. Rio de Janeiro: Conselho Nacional de Pesquisas.

Falesi, I. C. 1974. Soils of the Brazilian Amazon. *Man in the Amazon. Gainesville*, 201-29.

Fernandes, F. 1948. *Organização social dos Tupinambá*. Instituto Progresso Editorial.

Ferretti, D. F., J. B. Miller, J. W. C. White, D. M. Etheridge, K. R. Lassey, D. C. Lowe, C. M. M. Meure, M. F. Dreier, C. M. Trudinger, T. D. van Ommen & R. L. Langenfelds 2005. Unexpected Changes to the Global Methane Budget over the Past 2000 Years. *Science,* 309, 1714-1717.

Forsberg, B. R., H. Y., A. Rosenqvist & F. P. Miranda 2000. Tectonic Fault Control of Wetland Distributions in the Central Amazon Revealed by JERS-1 Radar imagery. *Quaternary International,* 72, 61-66.

Franco, E. C. 1962. As Terras Pretas do Planalto de Santarém. *Revista da Sociedade dos Agrônomos e Veterinários do Pará,* 8, 17-21.

Fraser, J., T. Cardoso, A. Junqueira, N. P. S. Falcão & C. R. Clement. 2009. Historical ecology and dark earths in whitewater and blackwater landscapes: comparing the Middle Madeira and Lower Negro rivers. In *Amazonian Dark Earths: Wim Sombroek's Vision,* eds. W. I. Woods, W. Teixeira, J. Lehmann, M. Steinitz-Kannan & A. WinklerPrins, 229-264.

Furch, K. & W. J. Junk 1985. Dissolved carbon in a floodplain lake of the Amazon and in the river channel. *Transport of Carbon and Minerals in Major World Rivers, Part,* 3**,** 285-298.

Glaser, B., E. Balashov, L. Haumaier, G. Guggenberger & W. Zech 2000. Black carbon in density fractions of anthropogenic soils of the Brazilian Amazon region. *Organic Geochemistry,* 31**,** 669-678.

Glaser, B., G. Guggenberger, L. Haumaier & W. Zech 2001a. Persistence of soil organic matter in archaeological soils (Terra Preta) of the Brazilian Amazon region. *Sustainable management of soil organic matter. CABI Publishing, Wallingford,* 190-194.

Glaser, B., G. Guggenberger & W. Zech 2004a. Identifying the pre-Columbian anthropogenic input on present soil properties of Amazonian dark earths (Terra Preta). *Amazonian Dark Earths: Explorations in Space and Time, B. Glaser and WI Woods, Editors,* 145-158.

Glaser, B., G. Guggenberger, W. Zech & M. Ruivo 2004b. Soil organic matter stability in Amazonian Dark Earths. *Amazonian Dark Earths,* 141-158.

Glaser, B., L. Haumaier, G. Guggenberger & W. Zech 2001b. The'Terra Preta'phenomenon: a model for sustainable agriculture in the humid tropics. *Naturwissenschaften,* 88**,** 37-41.

Glaser, B. & W. I. Woods. 2004. *Amazonian dark earths : explorations in space and time*. Berlin ; New York: Springer.

Gnecco, C. & S. Mora 1997. Late pleistocene/early holocene tropical forest occupations at San Isidro and Pena Roja, Colombia. *Antiquity,* 71**,** 683-690.

Gomes, D. M. C. 2008. *Cotidiano e Poder na Amazônia Pré-Colonial*. São Paulo: Edusp.

Griffith, M. 1980. A pedological investigation of an archaeological site in Ontario, Canada, I. An examination of the soils in and adjacent to a former village. *Geoderma,* 24**,** 327-336.

Gross, D. R. 1975. Protein Capture and Cultural Development in the Amazon Basin. *American Anthropologist,* 77**,** 24.

Haberle, S. G. & M. A. Maslin 1999. Late Quaternary Vegetation and Climate Change in the Amazon Basin Based on a 50,000 Year Pollen Record from the Amazon Fan, ODP Site 932* 1. *Quaternary Research,* 51**,** 27-38.

Haffer, J. 1969. Speciation in Amazonian Forest Birds. *Science,* 165**,** 131-137.

Hammer, Ø., Harper, D.A.T., and Ryan 2001. Hammer, Ø., Harper, D.A.T., and Ryan. *Palaeontologia Electronica,* 4(1)**,** 9pp.

Hartt, C. F. 1874a. Contribuitions to the geology and physical geography of the lower Amazonas. *Bulletin of the Buffalo Society of Natural Sciences,* 1**,** 201-235.

Hartt, C. F. 1874b. Preliminary Report of the Morgan Exhibitions, 1870-71 - Report of a Reconnaissance of the Lower Tapajós. *Bulletin of the Buffalo Society of Natural Sciences,* 1**,** 1-37.

Hartt, C. F. 1885. Contribuições para a Ethologia do Valle do Amazonas. *Arquivos do Museu Nacional,* 6**,** 1.

Haug, G. H., K. A. Hughen, D. M. Sigman, L. C. Peterson & U. Röhl 2001. Southward Migration of the Intertropical Convergence Zone through the Holocene. *Science,* 293**,** 1304-1308.

Hecht, S. 2003. Indigenous soil management and the creation of Amazonian Dark Earth: implications of kayapó practices. In *Amazonian Dark Earth: Exploration in Space and Time,* eds. B. Glaser & W. I. Woods, 354-372. Berlin: Heildelberg New York: Springer.

Hecht, S. 2009. Kayapó savanna management: fire, soils, and forest islands in a threatened biome. *Amazonian Dark Earths: Wim Sombroek's Vision***,** 143-162.

Heckenberger, J. B. 2002. Rethinking the Arawakan Diaspora: hierachy, Regionality, and the Amazonia Formative. In *Comparative Arawakan Histories: rethinking language family and culture area in Amazonia,* ed. F. S.-G. Jonathan David Hill, 99-123. Urbana: University of Illinois Press.

Heckenberger, M. 2005a. *The ecology of power : culture, place, and personhood in the southern Amazon, A.D. 1000-2000*. New York: Routledge.

Heckenberger, M. & E. G. Neves 2009. Amazonian archaeology. *Annual Review of Anthropology,* 38**,** 251-266.

Heckenberger, M. J. 1996. War and peace in the shadow of empire: sociopolitical change in the upper Xingu of southeastern Amazonia, AD 1400-2000. University of Pittsburgh.

Heckenberger, M. J. 2005b. *The ecology of power : culture, place, and personhood in the southern Amazon, A.D. 1000-2000* New York: Routledge.

Heckenberger, M. J. 2008. Identity, Interaction, and Integration in the Tropical Forest. In *Handbook of South American Archaeology,* eds. H. Silverman & W. H. Isbell. Springer.

Heckenberger, M. J. 2009. Mapping indigenous histories : collaboration, cultural heritage, and conservation in the Amazon. *Collaborative Anthropologies,* 2**,** 9-32.

Heckenberger, M. J. & E. Góes Neves. Amazonian archaeology.

Heckenberger, M. J., E. G. Neves & J. B. Petersen 1998. De onde surgem os modelos? As origens e expansões Tupi na Amazônia Central. *Revista de Antropologia,* 41**,** 69-96.

Heckenberger, M. J., J. B. Petersen & E. G. Neves 1999. Village Size and Permanence in Amazonia: Two Archaeological Examples from Brazil. *Latin American Antiquity,* 10**,** 353-376.

Heckenberger, M. J., J. B. Petersen & E. G. Neves 2001. Of Lost Civilizations and Primitive Tribes, Amazonia: Reply to Meggers. *Latin American Antiquity,* 12**,** 328-333.

Heidenreich, C. & S. Navratil 1973. Soil analysis at the Robitaille site. *Ontario Archaeology Survey Publication,* 20**,** 25-62.

Hilbert, P. 1968. *Untersuchungen am mittlern Amazonas*. Berlin: Marburger Studien zur Völkerkunde.

Hill, J. D. & F. Santos-Granero. 2002. *Comparative Arawakan histories: rethinking language family and culture area in Amazonia*. Urbana: University of Illinois Press.

Hoorn, C., J. Guerrero, G. A. Sarmiento & M. A. Lorente 1995. Andean tectonics as a cause for changing drainage patterns in Miocene northern South America. *Geology,* 23**,** 237-240.

Hoorn, C., F. P. Wesselingh, H. ter Steege, M. A. Bermudez, A. Mora, J. Sevink, I. Sanmartin, A. Sanchez-Meseguer, C. L. Anderson, J. P. Figueiredo, C. Jaramillo, D. Riff, F. R. Negri, H. Hooghiemstra, J. Lundberg, T. Stadler, T. Sarkinen & A. Antonelli 2010. Amazonia through time; Andean uplift, climate change, landscape evolution, and biodiversity. *Science,* 330**,** 927-931.

Hornborg, A. 2005. Ethnogenesis, Regional Integration, and Ecology in Prehistoric Amazonia: Toward a System Perspective. *Current Anthropology,* 46**,** 589-620.

Irion, G. 1984a. Clay minerals of Amazonian soils. *The Amazon: limnology and landscape ecology of a mighty tropical river and its basin. SIOLI, H., ed. Dordrecht, Dr. W. Junk Publishers***,** 537-579.

Irion, G. 1984b. Sedimentation and sediments of Amazonian rivers and evolution of the Amazonian landscape since Pliocene times. In *The Amazon : limnology and landscape* *ecology of a mighty tropical river and its basin,* ed. H. Sioli, xiv, 763 p. Dordrecht Netherlands ; Boston; Kluwer Academic Publishers.

Irion, G., W. J. Junk & J. A. S. N. Mello. 1997. The Large Central Amazonian River Floodplains Near Manaus: Geological, Climatological, Hydrological, and Geomorphological Aspects. In *The Central Amazon Floodplain Ecology of a Pulsing System,* ed. G. Irion, 23-46. Berlin: Springer.

Irion, G., J. Müller, J. O. Morais, G. Keim, J. N. de Mello & W. J. Junk 2009. The impact of Quaternary sea level changes on the evolution of the Amazonian lowland. *Hydrological Processes,* 23**,** 3168-3172.

Israel, Y. & R. M. Barnes 1990. On-line dilution, steady-state concentrations by tandem injection and merging stream. Application to inductively coupled plasma atomic emission spectrometry sequential multi-element soil analysis. *Analyst,* 115**,** 1411-1417.

Jenny, H. 1941. *Factors of soil formation*. New York: McGraw-Hill.

Junk, W. & M. Piedade 1994. Species diversity and distribution of herbaceous plants in the floodplain of the middle Amazon. *Internationale Vereinigung fur Theoretische und Angewandte Limnologie Verhandlungen,* 25**,** 1862-1865.

Junk, W. J. 1984. Ecology of the várzea, floodplain of Amazonian whitewater rivers. *The Amazon limnology and landscape ecology of a mighty tropical river and its basin, Boston: Dr. W. Junk Publishers Dordrecht.*

Junk, W. J. 1997. General Aspects of Floodplain Ecology with Special Reference to Amazonian Floodplains. In *The Central Amazon Floodplain Ecology of a Pulsing System,* ed. W. J. Junk, 3-17. Berlin: Springer.

Junk, W. J., P. B. Bayley & R. E. Sparks 1989. The flood pulse concept in river-floodplain systems. *Canadian special publication of fisheries and aquatic sciences,* 106**,** 110-127.

Junk, W. J., K. Furch, G. Prance & T. Lovejoy 1985. Physical and chemical properties of Amazonian waters and their relationships with the Biota.

Junqueira, A. B., G. H. Shepard & C. R. Clement 2010. Secondary forests on anthropogenic soils in Brazilian Amazonia conserve agrobiodiversity. *Biodiversity and Conservation***,** 1-29.

Junqueira, A. B., 2011. Secondary Forests on Anthropogenic Soils of the Middle Madeira River: Valuation, Local Knowledge, and Landscape Domestication in Brazilian Amazonia. *Economic Botany***,** 1-15.

Kämpf, N., W. I. Woods, W. Sombroek, D. Kern & T. Cunha. 2003. Classification of Amazonian Dark Earths and other ancient anthropic soils. In *Amazonian Dark Earths: origin, properties, and management,* eds. J. Lehman, D. Kern, B. Glaser & W. I. Woods, 77-102. Dordrecht: Kluwer Academic Publisher.

Kämpf, N., 2004. Classification of Amazonian Dark Earths and other ancient anthropic soils. *Amazonian Dark Earths***,** 77-102.

Kämpf, N., W. I. Woods, D. C. Kern & T. J. Cunha. 2009. Classificação das Terras Pretas de Índio e Outros Solos Antrópicos Antigos. In *As Terras Pretas de Índio da Amazônia: sua caracterização e uso deste conhecimento na criação de novas áreas,* eds. W. G. Teixeira, D. C. Kern, B. E. Madari, H. N. Lima & W. I. Woods. Manaus: Embrapa Amazônia Ocidental.

Katzer, F. 1903. *Grundzuge der Geologie des untern Amazonasgebietes (des Staates Pará in Brasilien).* Leipzig: Verlag von Max Weg.

Kern, D., G. D'aquino, T. Rodrigues, F. Frazao, W. Sombroek, T. Myers & E. Neves 2004a. Distribution of Amazonian dark earths in the Brazilian Amazon. *Amazonian Dark Earths***,** 51-75.

Kern, D., G. D'aquino, T. Rodrigues, F. Frazao, W. Sombroek, T. Myers & E. Neves. 2004b. Distribution of Amazonian dark earths in the Brazilian Amazon. In *Amazonian Dark Earths,* eds. W. I. Woods, W. Teixeira, J. Lehmann, C. Steiner, A. Winklerprins & L. Rebellato, 51-75.

Kern, D. C. 1988. Caracterização pedológica de solos com Terra Preta Arqueológica na Região de Oriximiná, Pará. *Caracterização pedológica de solos com Terra Preta Arqueológica na Região de Oriximiná, Pará.*

Kern, D. C. 1996. Geoquímica e pedogeoquímica em sítios arqueológicos com terra preta na Floresta Nacional de Caxiuanã (Portel - PA). In *Departamento de Geociências*. Belém: Universidade Federal do Pará.

Kern, D. C., M. L. Costa & F. J. L. Frazão 2004c. Evolution of the scientific knowledge regarding archaeological black earths of Amazonia. *Amazonian dark earths: explorations in space and time***,** 19-28.

Kern, D. C. & N. Kämpf 1989. Antigos assentamentos indígenas na formação de solos com terra preta arqueológica na região de Oriximiná, Pará. *Bras. Ci. Solo,* 13**,** 219-225.

Lathrap, D. W. 1970. *The upper Amazon*. New York,: Praeger Publishers.

Latrubesse, E. M. & E. Franzinelli 2002. The Holocene alluvial plain of the middle Amazon River, Brazil. *Geomorphology,* 44**,** 241.

Latrubesse, E. M. & A. Rancy 2000. Neotectonic influence on tropical rivers of southwestern Amazon during the late quaternary: the Moa and Ipixuna river basins, Brazil. *Quaternary International,* 72**,** 67-72.

Lehmann, J. & S. Joseph. 2009. *Biochar for environmental management : science and technology*. London ; Sterling, VA: Earthscan.

Lehmann, J., D. Kern, L. German, J. Mccann, G. Martins & A. Moreira. 2003a. Soil fertility and production potential. In *Amazonian Dark Earths: origin, properties, and management,* eds. J. Lehman, D. C. Kern, B. Glaser & W. I. Woods, 105-124. Dordrecht: Kluwer Academic Publishers.

Lehmann, J., D. C. Kern, B. Glaser & W. I. Woods. 2003b. *Amazonian dark earths: origin properties management*. Dordrecht/Boston/London: Kluwer Academic Publishers.

Lehmann, J., J. Pereira da Silva, C. Steiner, T. Nehls, W. Zech & B. Glaser 2003c. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. *Plant and Soil,* 249**,** 343-357.

Léry, J. 1927. *Le voyage au Brésil*. Paris: Payot.

Liang, B. L., J. Solomon, D. Kinyangi, J. Grossman, J. O'Neill, B. Skjemstad, J. Thies, J. Luizão, F. Petersen & J. Neves 2006. Black carbon increases cation exchange capacity in soils. *Soil Science Society of America journal,* 70**,** 1719.

Limbrey, S. 1975. *Soil science and archaeology*. London ; New York: Academic Press.

Lombardo, U. & H. Prümers 2010. Pre-Columbian human occupation patterns in the eastern plains of the Llanos de Moxos, Bolivian Amazonia. *Journal of Archaeological Science,* 37**,** 1875-1885.

Macedo, R. 2009. Atributos físico, químicos e mineralógicos de solos com horizonte antrópico (Terra Preta de Índio) em áreas de várzea do rio solimões, AM. In *Programa de Pós-Graduação em Agronomia Tropical*. Manaus: Universidade Federal do Amazonas.

Machado, J. S. 2005. Montículos artificiais na Amazônia Central: um estudo de caso do Sítio Hatahara.

Madari, B. E., W. G. Sombroek & W. I. Woods 2004. Research on Anthropogenic Dark Earth soils. Could it be a solution for sustainable agricultural development in the Amazon. *Amazonian dark earths: explorations in space and time***,** 170-181.

Martin, L., M. Fournier, P. Mourguiart, A. Sifeddine, B. Turcq, M. L. Absy & J. M. Flexor 1993. Southern Oscillation signal in South American palaeoclimatic data of the last 7000 years. *Quaternary Research,* 39**,** 338-346.

Maslin, M. A. & S. J. Burns 2000. Reconstruction of the Amazon Basin effective moisture availability over the past 14,000 years. *Science,* 290**,** 2285-2287.

Mayle, F. E., R. Burbridge & T. J. Killeen 2000. Millennial-Scale Dynamics of Southern Amazonian Rain Forests. *Science,* 290**,** 2291-2294.

Meggers, B. J. 1954. Environmental Limitation on the Development of Culture. *American Anthropologist,* 56**,** 801-824.

Meggers, B. J. 1961. An experimental formulation of horizon styles in the tropical forest of South America. In *Essays in Pre-Columbian Art and Archaeology,* ed. S. K. Lothrop, 372-388. Harvard: University of Cambridge.

Meggers, B. J. 1971. *Amazonia : man and culture in a counterfeit paradise*. Chicago,: Aldine.

Meggers, B. J. 1977. Vegetational Fluctuation and Prehistoric Cultural Adaptation in Amazonia: Some Tentative Correlations. *World Archaeology,* 8**,** 287-303.

Meggers, B. J. 1979a. Climatic Oscillation as a Factor in the Prehistory of Amazonia. *American Antiquity,* 44**,** 252-266.

Meggers, B. J. 1979b. *Prehistoric America : an ecological perspective*. New York: Aldine Pub. Co.

Meggers, B. J. 1994. Archeological evidence for the impact of mega-Nino events on Amazonia during the past two millennia. *Climatic change,* 28**,** 321-338.

Meggers, B. J. 2003. Natural Versus Anthropogenic Sources of Amazonian Biodiversity: the Continuing Quest for El Dorado. In *How Landscapes Change: human disturbance and ecosystem fragmentation in the Americas* ed. G. A. B. P. A. Marquet, 361. Berlin: Springer-Verlag.

Meggers, B. J., E. S. Ayensu, W. D. Duckworth & Association for Tropical Biology. 1973. *Tropical forest ecosystems in Africa and South America; a comparative review.* Washington,: Smithsonian Institution Press.

Meggers, B. J. & C. Evans. 1957. *Archeological investigations at the mouth of the Amazon*. Washington,: U. S. Govt. Print. Off.

Meggers, B. J. & C. Evans 1977. Early Formative Period Chronology of the Ecuadorian Coast: A Correction. *American Antiquity,* 42**,** 266.

Meggers, B. J., C. Evans, E. Estrada & Jay I. Kislak Reference Collection (Library of Congress). 1965. *Early formative period of coastal Ecuador: the Valdivia and Machalilla phases*. Washington,: Smithsonian Institution; for sale by the Superintendent of Documents.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich-2 extractant. *Communication in Soil Science Plant Analysis,* 15**,** 1409-1416.

Mertes, L. A. K. & T. Dunne. 2007. Effects of Tectonism, Climate Change, and Sea-level Change on the Form and Behaviour of the Modern Amazon River and its Floodplain. In *Large Rivers: geomorphology and Management,* ed. A. Gupta. Chichester, England ; Hoboken, NJ: John Wiley.

Mertes, L. A. K., T. Dunne & L. A. Martinelli 1996. Channel-floodplain Geomorphology along the Solimões-Amazon Reiver, Brazil. *GSA Bulletin, September,* 108**,** 1098-1107.

Métraux, A. 1928a. *La civilisation matérielle des tribus Tupi-Guarani*. Paris,: P. Geuthner.

Métraux, A. 1928b. *La religion des Tupinamba et ses rapports avec celle des autres tribus Tupi-Guarani*. Paris,: E. Leroux.

Middleton, W. D. & T. D. Price 1996. Identification of activity areas by multi-element characterization of sediments from modern and archaeological house floors using inductively coupled plasma-atomic emission spectroscopy. *Journal of Archaeological Science,* 23**,** 673-688.

Miller, E. T. 1992. Adaptacao agricola pre-historica no alto rio Madeira. Taraxacum.

Minasny, B., A. B. McBratney & B. M. Whelan. 2005. VESPER version 1.62. Australian Centre for Precision Agriculture. cMillan Building: The University of Sydney.

Molinier, M., J. Guyot, E. Oliveira & V. Guimarães 1996. In L'hydrologie tropicale. *IAHS Publ,* 238**,** 209-222.

Mora, S., L. Herrera, I. Cavalier & C. Rodrigues. 1991. *Cultivars, anthropic soils and stability: a preliminary report of archaeological research in Araracuara colombian amazonia.* Pittsburgh: Pittsburgh University

Moraes, C. d. P. 2006. Levantamento arqueológico da região do Lago do Limão. In *Museu de Arqueologia e Etnologia*. São Paulo: University of São Paulo.

Moseley, M. E. 1975. *The maritime foundation of the Andean Civilization*. Menlo Park, CA: Cummings.

Navarrete, A. A., F. S. Cannavan, R. G. Taketani & S. M. Tsai 2010. A Molecular Survey of the Diversity of Microbial Communities in Different Amazonian Agricultural Model Systems. *Diversity,* 2**,** 787-809.

Neves, E. G. 2003. Levantamento arqueológico da área de confluência dos rios Negro e Solimões, Estado do Amazonas: continuidade das escavações, análise da composição química e montagem de um sistema de informações geográficas. São Paulo: Fundação de Amparo a Pesquisa do Estado de São Paulo (FAPESP).

Neves, E. G. 2008. Ecology, Ceramic Chronology and Distribuition, Long-term History, and Political Change in the Amazonian Floodplain. In *Handbook of South American Archaeology,* eds. H. Silverman & W. H. Isbell, xxvi, 1191 p. New York, NY: Springer.

Neves, E. G. & J. B. Petersen 2006. Political economy and pre-Columbian landscape transformations in Central Amazonia. *Time and complexity in historical ecology: studies in the Neotropical lowlands. C. Erickson and W. Balée, eds***,** 279-309.

Neves, E. G., J. B. Petersen, R. N. Bartone & M. J. Heckenberger. 2004. The timing of Terra Preta formation in the Central Amazon: Archaeological Data from three sites. In *Amazonian Dark Earths :Exploration in Space and Time,* eds. G. Bruno & W. I. Woods, 125-134. Berlin Heidelberg: Springer Verlag.

Noelli, F. S. 1998. The Tupi: Explaining origin and expansions in terms of archaeology and of historical linguistics. *Antiquity,* 72**,** 648.

Oliver, J. R. 2008. The archaeology of agriculture in ancient Amazonia. In *Handbook of South American Archaeology,* eds. H. Silverman & W. H. Isbell. Springer.

Orton, J. 1875. *The Andes and the Amazon; or, Across the Continent of South America*. New York.

Oyuela-Caycedo, A. & R. M. Bonzani. 2005. *San Jacinto I: A Historical Ecological Approach to an Archaic Site in Colombia*. University Alabama Press.

Pabst, E. 1991. Critérios de distinção entre terra preta e latossolo na região de Belterra e os seus significados para a discussão pedogenética. *Boletin do Museu Paraense Emílio Goeldi, Série Antropologia,* 7**,** 5–19.

Pansu, M. & J. Gautheyrou. 2003. *Handbook of soil Analysis:mineralogical, organic and inorganic methods*. Berlin Heidelberg New York: Springer-Verlag.

Parnell, J. J., R. E. Terry & Z. Nelson 2002. Soil chemical analysis applied as an interpretive tool for ancient human activities in Piedras Negras, Guatemala. *Journal of Archaeological Science,* 29**,** 379-404.

Pärssinen, M., D. Schaan & A. Ranzi 2009a. Pre-Columbian geometric earthworks in the upper Purús: a complex society in western Amazonia. *Antiquity,* 83**,** 1084-1095.

Pärssinen, M., D. P. Schaan & A. Ranzi 2009b. Pre-Columbian geometric earthworks in the upper Purús : a complex society in western Amazonia. *Antiquity Publications,* 83**,** 1084-1095.

Pereira, R., I. d. S. Carvalho & D. d. A. Azevedo 2006. Afinidades Botânicas de âmbares cretácicos das Bacias do Amazonas, Araripe e Recôncavo. *Geociências,* 25**,** 217-224.

Petersen, J. B., E. G. Neves & M. Heckenberger. 2001. Gift from the Past: Terra preta and Prehistoric Amerindian occupation in Amazonia. In *Unknown Amazon, Culture and Nature in Ancient Brazil,* eds. E. McEwan, C. Barreto & E. G. Neves. London: British Museum.

Piperno, D. R. & P. Becker 1996. Vegetational History of a Site in the Central Amazon Basin Derived from Phytolith and Charcoal Records from Natural Soils. *Quaternary Research,* 45**,** 202-209.

Porro, A. 1994. Social organization and political power in the Amazon Floodplains: the ethnohistorical sources. In *Amazonian Indians fro Prehistory to the Present: anthropological perspectives,* ed. A. C. Roosevelt, 79-94. Tucson & London: The University of Arizona Press.

Posey, D. A. & W. L. Balée. 1989. *Resource management in Amazonia : indigenous and folk strategies*. Bronx, N.Y., U.S.A.: New York Botanical Garden.

Prance, G. & H. Schubart 1978. Notes on the vegetation of Amazonia I. A preliminary note on the origin of the open white sand campinas of the lower Rio Negro. *Brittonia,* 30**,** 60-63.

Prance, G. 1979. Notes on the vegetation of Amazonia I. A preliminary note on the origin of the open white sand campinas of the lower Rio Negro. *Brittonia,* 30**,** 60-63.

Putzer, H. 1984. The geological evolution of the Amazon basin and its mineral resources, 15-46. *The Amazon. Limnology and landscape ecology of a mighty tropical river and its basin.*

Quesada, C. A., J. Lloyd, L. O. Anderson, N. Fyllas, M. Schwarz & C. Czimczik 2011. Soils of Amazonia with particular reference to the RAINFOR sites. *Biogeosciences Discussions,* 8**,** 1415-1440.

Ranzani, G., T. Kinjo & O. Freire 1970. Ocorrências de "Plaggen Epippedon" no Brasil. *Notícia Geomorfológica* 10**,** 55-62.

Ranzi, A., R. Feres & F. Brown 2007. Internet software program aids in search for Amazon Geoglyphs. *EOS, Transactions of the American Geophysical Union*.

Räsänen, M. E., J. Salo & R. Kalliolla 1987. Fluvial pertubance in the western Amazon basin: regulation by long-term sub-andean tectonics. *Science***,** 1398-1401.

Rebellato, L. 2007. Interpretando a Variabilidade Cerâmica e as Assinaturas Químicas e Físicas do Solo no Sítio Arqueológico Hatahara, AM. In *Museu de Arqueologia e Etnologia*, 197. São Paulo: Universidade de São Paulo.

Rebellato, L., W. I. Woods & E. Neves. 2009. Pre-Columbian settlement dynamics in the Central Amazon. In *Amazonian Dark Earths: Wim Sombroek's Vision,* eds. W. I. Woods, W. Teixeira, J. Lehman, C. Steiner, A. Winklerprins & L. Rebellato, 15-31. Springer.

Rodrigues, A. D. I. 1985. Relações internas na família linguística Tupi-Guarani. *Revista de Antropologia,* 28**,** 33-53.

Rodrigues, A. D. I. 2005a. As vogais orais do Proto-Tupi. In *Novos estudos sobre linguas indigenas,* eds. A. D. Rodrigues & A. S. C.Cabral, 36-46. Brasilia: Universidade de Brasilia.

Rodrigues, A. D. I. 2005b. Sobre as Linguas Indigenas e sua pesquisa no Brasil. *Ciencia e Cultura,* 57**,** 35-38.

Roosevelt, A. 1998. Paleoindian and Archaic occupations in the lower Amazon, Brazil: a summary and comparison. *Explorations in American archaeology: essays in honor of Wesley R. Hurt***,** 165.

Roosevelt, A. C. 1980. *Parmana : prehistoric maize and manioc subsistence along the Amazon and Orinoco*. New York: Academic Press.

Roosevelt, A. C. 1991. *Moundbuilders of the Amazon: geo-physical archaeology on Marajó Island, Brazil*. San Diego: Academic Press.

Roosevelt, A. C. 1994. Amazonia Anthropology: strategies for a new synthesis. In *Amazonian Indians from Prehistory to the Present: Anthropological perspectives,* ed. A. Roosevelt. Tucson and London: The University of Arizona Press.

Roosevelt, A. C. 1995. Early pottery in the Amazon: twenty years of scholarly obscurity. Smithsonian institution.

Roosevelt, A. C. 1997. The Demise of the Alaka Initial Ceramic Phase Has been Greatly Exaggerated: Response to D. Williams. *American Antiquity,* 62**,** 353-364.

Roosevelt, A. C., M. L. d. Costa, C. L. Machado, M. Michab, N. Mercier, H. Valladas, J. Feathers, W. Barnett, M. I. d. Silveira, A. Henderson, J. Silva, B. Chernoff, D. S. Reese, J. A. Holman, N. Toth & K. Schick 1996. Paleoindian Cave Dwellers in the Amazon: The Peopling of the Americas. *Science,* 272**,** 373-384.

Roosevelt, A. C., R. A. Housley, M. I. d. Silveira, S. Maranca & R. Johnson 1991. Eighth Millennium Pottery from a Prehistoric Shell Midden in the Brazilian Amazon. *Science,* 254**,** 1621-1624.

Rossetti, D. F., A. M. Góes, M. M. Valeriano, M. C. C. Miranda, J. C. N. Epiphanio, L. S. Galvão & L. M. G. Fonseca 2007. Evidence for tectonic reactivations in the Marajó Island (northern Brazil) during the Quaternary: integrating remote sensing and sedimentological data. *Anais***,** 2119-2123.

Rossetti, D. F., T. P. Mann, M. H. Moraes-Santos & A. E. A. Santos 2004. Reconstructing habitats in central Amazonia using megafauna, sedimentology, radiocarbon, and isotope analyses. *Quaternary Research,* 61**,** 289-300.

Rossetti, D. F., M. T. Peter & A. M. Góes 2005. New geological framework for Western Amazonia (Brazil) and implications for biogeography and evolution. *Quaternary Research,* 63**,** 78-89.

Rossetti, D. F. & P. M. Toledo 2007. Environmental changes in Amazonia as evidenced by geological and paleontological data. *Revista Brasileira de Ornitologia,* 15**,** 175-188.

Rostain, S. 1991. *Les champs surélevés Amerindiens de la Guyane*. Cayenne: Centre ORSTOM de Cayenne.

Rostain, S. 1994. L'occupation amérindienne ancienne du littoral de Guyane. 2 v. (721 p.). Paris: Université de Paris I-Panthéon/Sorbonne, U.F.R. d'art et d'archéologie, Centre de recherche en archéologie précolombienne

Salati, E., M. Dourojeanini, F. Novaes, A. Oliveira, R. Perritt, H. Schubart & J. Umana. 1990. Amazonia. In *The Earth as Transformed by Human Action,* eds. B. Turner, W. Clark, R. Kates, J. Richards, J. Malthews & W. Meyer. Cambridge Universty Press.

Salati, E. & J. Marques 1984. Climatology of the Amazon region, 85-126. *The Amazon Limnology and landscape ecology of a mighty tropical river and its basin.*

Salati, E. & P. B. Vose 1984. Amazon basin: a system in equilibrium. *Science,* 225**,** 129.

Sandweiss, D. H., K. A. Maasch & D. G. Anderson 1999. Transitions in the Mid-Holocene. *Science,* 283**,** 499-500.

Sandweiss, D. H., R. S. Solís, M. E. Moseley, D. K. Keefer & C. R. Ortloff 2009. Environmental change and economic development in coastal Peru between 5,800 and 3,600 years ago. *Proceedings of the National Academy of Sciences,* 106**,** 1359.

Sanford, R. L., J. Saldarriaga, K. E. Clark, C. Uhl & R. Herrera 1985. Amazon Rain-Forest Fires. *Science,* 227**,** 53-55.

Saunaluoma, S. 2010. Pre-Columbian Earthworks in the Riberalta Region of the Bolivian Amazon. *Amazônica-Revista de Antropologia,* 2.

Schaan, D., D. Kern & F. Frazão. 2009. An Assessment of the Cultural Practices Behind the Formation (or Not) of Amazonian Dark Earths in Marajo Island Archaeological Sites. In *Amazonian Dark Earths: Wim Sombroek's Vision,* eds. W. I. Woods, W. Teixeira, J. Lehmann, C. Steiner, A. Winklerprins & L. Rebellato, 127-141.

Schaan, D. P. 2000. Recent investigations on Marajoara Culture, Marajó Island, Brazil / Source: Antiquity Vol. 74, no. 285 (2000), p. 469-470 Additional Info: Cambridge.

Schaan, D. P. 2004. The Camutins chiefdom: rise and development of social complexity on Marajó Island, Brazilian Amazon. University of Pittsburgh.

Schaan, D. P. 2008. The Nonagricultural Chiefdoms of Marajó Island. In *Handbook of South American Archaeology,* eds. H. Silverman & W. H. Isbell. Springer.

Schaefer, C. F. G. R, H. N. Lima, R. J. Gilkes, & J. W. V. Mello 2004. Micromorphology and electron microprobe analysis of phosphorus and potassium forms of an Indian Black Earth (IBE) anthrosol from western Amazonia. *Australian Journal of Soil Research,* 42, p. 401-409

Schmidt, M. & M. Heckenberger. 2009. Amerindian Anthrosols: Amazonian Dark Earth Formation in the Upper Xingu. In *Amazonian Dark Earths: Wim Sombroek's Vision,* eds.

W. I. Woods, W. Teixeira, J. Lehmann, C. Steiner, A. Winklerprins & L. Rebellato, 163-191. Berlin: Springer.

Schmidt, M. G. 1914. *Natur und Mensch*. Leipzig, Berlin,: B.G. Teubner.

Schmidt, M. G. 1917. *Geschichte des welthandels*. Leipzig und Berlin,: B. G. Teubner.

Schmitz, I. 1990. Prehistoric hunters and gatherers of Brazil. *Journal of World Prehistory,* 1**,** 53-126.

Shady, R. S., J. Haas & W. Creamer 2001. Dating Caral, a Preceramic site in the Supe Valley on the central coast of Peru. *Science,* 292**,** 723.

Shepard Jr., G. H. & H. Ramirez 2011. "Made in Brazil": human dispersal of the Brazil Nut (*Bertholletia excelsa, Lecythidaceae*) in acient Amazonia. *Economic Botany,* 65**,** 44-65.

Silva, F. & L. Rebellato. 2004. Use of space and terra preta formation: the Asurini do Xingu case study. In *Amazonian Dark Earth: Exploration in Space and Time. Springer, Berlin: Heildelberg New York,* eds. B. Glaser & W. Woods, 159–167.

Simões, M. 1976. Notas sobre duas pontas-de-projétil da bacia do Tapajós (Pará) *Boletim do Museu Paraense Emilio Goeldi,* 6**,** 1-14.

Sioli, H. 1956. O Rio Arapiuns: as águas da região do Alto Rio Negro. *Boletim Técnico do Instituto Agronômico do Norte*.

Sioli, H. 1968. Hydrochemistry and geologyin the Brazilian Amazon region. *Amazonia,* 1**,** 267-277.

Sioli, H. 1984. The Amazon and its main affluents: Hydrography, morphology of the river courses, and river types. *The Amazon: limnology and landscape ecology of a mighty tropical river and its basin,* 56**,** 127-166.

Smith, H. H. 1879 *Brazil: The Amazons and the Coast*. New York: Charles Scribner's Sons.

Smith, N. J. H. 1980. Anthrosols ad human carrying capacity in Amazonia. *Annals of the Association of American Geographers,* 70**,** 553-566.

Sombroek, W. 1984. Soils of the Amazon region. *The Amazon. Limnology and landscape ecology of a mighty tropical river and its basin***,** 521-535.

Sombroek, W. & A. Souza Carvalho. 2000. Macro-and micro ecological-economic zoning in the Amazon region history, first results, lessons learnt and research needs. 3-8.

Sombroek, W. G. 1966. *Amazon Soils: A Reconaissance of the Soils of the Brazilian Amazon Region*. Wageningen: Center for Agricultural Publications and Documentation.

Sombroek, W. G., F. O. Nachtergaele & A. Hebel 1993. Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. *Ambio. Stockholm,* 22**,** 417-426.

Staden, H. & Fouquet Karl of Brazil. [from old catalog]. 1948. *O prisioneiro de Ubatuba*. São Paulo: Edições Melhoramentos.

Stein, J. K. & W. R. Farrand. 2001. *Sediments in archaeological context*. Salt Lake City: University of Utah Press.

Steiner, C., W. G. Teixeira, J. Lehmann, T. Nehls, J. L. V. de Macêdo, W. E. H. Blum & W. Zech 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and Soil,* 291**,** 275-290.

Sternberg, H. O. R. 1960. Radicarbon dating as applied to a problem of Amazonian morphology. *Comptes Rendus du XVIIIe Congrès International de Géographie,* 2**,** 399-424.

Sternberg, H. O. R. 1998 [1956]. *A Água e o homem na várzea do Careiro*. Belém: Museu Paraense Emilio Goeldi

Steward, J. H. 1946. *Handbook of South American Indians*. Washington: U.S. G.P.O.

Steward, J. H. 1963. *Handbook of South American Indians*. New York: Cooper Square Publishers.

Sušnik, B. 1975. *Dispersión Tupí-Guaraní prehistórica : ensayo analítico*. Asunción: Museo Etnográfico "Andrés Barbero".

Teixeira, W. G., D. C. Kern, B. E. Madari, H. N. Lima & W. I. Woods. 2009. *A Terras Pretas de Índio da Amazonia: Sua caracterização e uso deste conhecimento na criação de novas áreas*. Manaus: Embrapa Amazônia Ocidental.

Teixeira, W. G. & G. C. Martins. 2003. Soil physical characterization. Amazonian Dark Earths: origin, properties, managements. In *Amazonia Dark Earth: Origin, Properties, Management,* eds. J. Lehmann, D. C. Kern, B. Glaser & W. I. Woods. Dordrecht/Boston/London: Kluwer.

Thayn, J. 2009. Locating Amazonian Dark Earths (ADE) in the Brazilian Amazon using satellite imagery. In *Departmento of Geography*. Lawrence: University of Kansas, United States -- Kansas.

Tsai, S., B. O'neill, F. Cannavan, D. Saito, N. Falcao, D. Kern, J. Grossman & J. Thies. 2009. The microbial world of Terra Preta. In *Amazonian Dark Earths: Wim Sombroek's Vision,* eds. W. I. Woods, W. Teixeira, J. Lehman, C. Steiner, A. Winklerprins & L. Rebellato, 299-308.

Tsai, S., B. O'Neill, F. Cannavan, D. Campos, R. Medau, S. Fedrizzi, J. Grossmann & J. Thies 2008. Biodiversity in Amazonian Dark Earth: A Contribution for the Sustainability of Tropical Soils from the Microbial Symbioses. *Biological Nitrogen Fixation: Towards Poverty Alleviation through Sustainable Agriculture***,** 35-36.

Urban, G. 1992. A história da cultura brasileira segundo as línguas nativas. In *História dos índios no Brasi,* ed. M. C. Cunha, 87-102. São Paulo Fundação de Amparo à Pesquisa do Estado de São Paulo : Companhia das Letras : Secretaria Municipal de Cultura.

van der Hammen, T. & M. L. Absy 1994. Amazonia during the last glacial. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 109**,** 247-261.

van der Hammen, T. & H. Hooghiemstra 2000. Neogene and Quaternary history of vegetation, climate, and plant diversity in Amazonia. *Quaternary Science Reviews,* 19**,** 725-742.

Vanzolini, P. E. 1970. Zoologia Sistemática, geografia e origen das espécies. In *Geografia*. São Paulo: São Paulo.

Versteeg, A. H. 2008. Barrancoid and Arauquinoid mound builders in coastal Suriname. *The Handbook of South American Archaeology***,** 303-318.

Versteeg, A. H. & S. Rostain. 1997. *The archaeology of Aruba : the Tanki Flip site*. Oranjestad, Aruba, Amsterdam: Archaeological Museum Aruba; Foundation for Scientific Research in the Caribbean.

Viveiros de Castro, E. B. 1992. *From the enemy's point of view : humanity and divinity in an Amazonian society*. Chicago: University of Chicago Press.

Viveiros de Castro, E. B. 1998. Cosmological Deixis and Amerindian Perspectivism. *The Journal of the Royal Anthropological Institute,* 4**,** 469-488.

Walker, J. H. 2008. Pre-Columbian Ring Ditches along the Yacuma and Rapulo Rivers, Beni, Bolivia: A Preliminary Review. *Journal of Field Archaeology,* 33**,** 413-427.

Wang, Z., J. Chappellaz, K. Park & J. Mak 2010. Large variations in Southern Hemisphere biomass burning during the last 650 years. *Science,* 330**,** 1663.

Wells, E. C., R. E. Terry, J. J. Parnell, P. J. Hardin, M. W. Jackson & S. D. Houston 2000. Chemical Analyses of Ancient Anthrosols in Residential Areas at Piedras Negras, Guatemala. *Journal of Archaeological Science,* 27**,** 449-462.

Whitten, R. G. 1979. Comments on the Theory of Holocene Refugia in the Culture History of Amazonia. *American Antiquity,* 44**,** 238-251.

Williams, D. 1997. Early pottery in the Amazon: a correction. *American Antiquity,* 62**,** 342-352.

Wilson, C. A., D. A. Davidson & M. S. Cresser 2008. Multi-element soil analysis: an assessment of its potential as an aid to archaeological interpretation. *Journal of Archaeological Science,* 35**,** 412-424.

Wilson, C. A. 2009. An evaluation of the site specificity of soil elemental signatures for identifying and interpreting former functional areas. *Journal of Archaeological Science,* 36**,** 2327-2334.

Winklerprins, A. 2009. Sweep and char and the creation of Amazonian Dark Earths in homegardens. *Amazonian Dark Earths: Wim Sombroek's Vision***,** 205-211.

Woods, W. 2003. Development of anthrosol research. In *Amazonian Dark Earths: origin, properties, and management*, 3-14. Dordrecht: Kluwer Academic Publishers.

Woods, W. I. 1975. The Analysis of Abandoned Settlements. *The Chesopiean: A Journal of North American Archaeology,* 13**,** 2-44.

Woods, W. I. 1977. The Quantitative Analysis of Soil Phosphate. *American Antiquity,* 42**,** 248-252.

Woods, W. I. 1995. Comments on the Black Earth of Amazônia. *Applied Geography Conference,* 18**,** 159-165.

Woods, W. I. & W. M. Denevan 2009. Amazonian dark earths: the first century of reports. *Amazonian Dark Earths: Wim Sombroek's Vision***,** 1-14.

Woods, W. I. & J. M. McCann. 1999. The Anthropogenic Origin and Persistence of Amazonian Dark Earths. In *Conference of Latin Americanist Geographers,* ed. C. Caviedes, 7-14. Austin: University of Texas Press.

Woods, W. I., W. G. Teixeira, J. Lehmann, C. Steiner, A. WinklerPrins & L. Rebellato. 2009. *Amazonian dark earths : wim sombroek's vision*. New York, NY: Springer Dordrecht.

Zech, W., L. Haumaier, R. Hempfling & P. MacCarthy. 1990. Ecological aspects of soil organic matter in tropical land use. 187-202. American Society of Agronomy, Inc., Soil Science Society of America, Inc.

Zucchi, A. & W. M. Denevan. 1979. *Campos elevados e historia cultural prehispánica en los llanos occidentales de Venezuela*. Caracas: Universidad Católica Andrés Bello, Instituto de Investigaciones Históricas.