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A 2000-year history of forest disturbance in southern Pacific Costa Rica: pollen, spore, and charcoal evidence from Laguna Santa Elena

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To the Graduate Council:

I am submitting herewith a thesis written by Kevin John Anchukaitis entitled "A 2000-year history of forest disturbance in southern Pacific Costa Rica: pollen, spore, and charcoal evidence from Laguna Santa Elena." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Sally P. Horn, Major Professor

We have read this thesis and recommend its acceptance:

Kenneth H. Orvis, Carol P. Harden

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Accepted for the Council:

Vice Provost and Dean of Graduate Studies

A 2000-YEAR HISTORY OF FOREST DISTURBANCE IN SOUTHERN PACIFIC COSTA RICA: POLLEN, SPORE, AND CHARCOAL EVIDENCE FROM LAGUNA SANTA ELENA

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Kevin John Anchukaitis
August 2002

DEDICATION

This thesis is dedicated to my parents, Stephen and Melanie, and my brother Jeff, for their strength and love, and to my wife, Ryn, *por todo y para siempre*.

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The research and writing of this thesis would not have been possible without the help and support of numerous people. First and foremost, I wish to thank my advisor, Dr. Sally Horn, for letting me find a niche within ongoing research in Costa Rica and in the vicinity of the Las Cruces Biological Station, and for encouraging me to explore not only the paleoecology but also the archaeology of the region. I am immensely grateful for all of Dr. Horn's support, guidance, and insight throughout every stage of this thesis. I count myself very fortunate to have been involved with the research of her lab. I also want to thank Dr. Ken Orvis for spending countless hours helping me understand and puzzle through issues of geomorphology and sedimentation, among others, both on campus and in the field. I benefited immeasurably from Dr. Orvis' patient mentoring and insightful ideas. I am also grateful to Dr. Carol Harden for her support and helpful suggestions during all stages of this project.

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The sediment core from Laguna Santa Elena was recovered with the help of Lisa Kennedy, Martin Arford, and Sally Horn. The lake was initially spotted by Sally Horn and Robert Sanford, Jr. during reconnaissance of potential coring sites. For permission to sample the lake I thank Alvaro Hidalgo, who farms the surrounding area, and the Ministerio de Ambiente y Energía, who granted our research permit. Sergio Chávez of the Sección de Arqueología kindly assisted with the permit application.

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ABSTRACT

Paleoecological records reveal information about past changes in vegetation composition and disturbance in tropical ecosystems. These environmental histories have direct bearing on modern ecological studies and the management of protected areas, and provide information about the interaction between prehistoric peoples and their environment. In this study, I reconstruct prehistoric and historic forest disturbance and vegetation change from southern Pacific Costa Rica, in the vicinity of the Las Cruces Biological Station and the La Amistad International Park and Biosphere Reserve.

Pollen and charcoal in sediments from Laguna Santa Elena reveal a nearly continuous record of human alteration of these tropical forests over the past two millennia. The basal portion of the core shows nearly intact premontane forests approximately 1800 cal. yr. BP, although there is evidence of human presence on the landscape in the form of maize pollen and charcoal. Clearing for agriculture resulted in the dominance of disturbance taxa in the watershed beginning at least 1400 cal. yr. BP. The pollen record reveals only one possible, brief hiatus from human occupation of the watershed, although secondary succession began to occur in the Laguna Santa Elena watershed prior to that time, starting about 700 cal. yr. BP. Three eruptions of nearby Volcán Barú at approximately 580, 1080, and 1440 cal. yr. BP apparently had little effect on the prehistoric populations in the immediate vicinity of the lake. Historic and modern land clearance has perpetuated a vegetation assemblage of disturbance and successional taxa.

The pollen and charcoal records from Laguna Santa Elena demonstrate that this region of Costa Rica has a long history of forest clearance, which has implications for science and conservation in nearby ecological reserves and research stations, as well as for ongoing archaeological investigations in the region.

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INTRODUCTION

The last decade has seen a paradigm shift in our understanding of Holocene environments in the Neotropics. Whereas popular and even scholarly perceptions of American tropical environments in the past tended toward a vision of Central American forests as "virgin" vegetation only recently disturbed in historic times by European settlers and modern economic activity, contemporary research and scholarship has demonstrated that this is not the case. The work of geographers and archaeologists in Mexico and Central America has revealed a long history of human alteration of tropical landscapes. Our current understanding of paleobiogeography in the Neotropics is the result of a fundamental reexamination of ecology in general and New World archaeology in particular. Three primary lines of evidence coalesce around the idea of Neotropical forests as dynamic ecosystems whose structure, composition, and functions change at a diversity of temporal and spatial scales in response to human activity and climate forcing.

First, and at a very fundamental level, the "New Ecology" approach to ecosystems underpins recent scholarship on the prehistoric human impact on Central American ecosystems (Botkin 1990, Zimmerer 1994, Denevan 2000, Lentz 2000c). Where ecological theory once viewed ecosystems as proceeding in a unidirectional march towards maturity, "New Ecology" integrates disturbance and change as elements of meta-stable biological systems.

Secondly, the relationship between prehistoric environments and human civilizations in the Americas has been revised to dispel the "pristine myth" that "ecologically noble" indigenous groups lived in harmony and balance with nature (Denevan 1992). Evidence developed not only from paleoecology, but also from archaeology, geoarchaeology, and limnology points toward sometimes massive alteration of the physical environment by pre-Columbian people. Prehistoric peoples manipulated and managed both plant and animal communities for subsistence and economic reasons.

Thirdly, this human alteration of Neotropical ecosystems is understood to be spatially and temporally complex. Investigations of prehistoric population size, settlement and land use patterns, and resource limitations have revealed that cultures throughout the Americas used or engineered their environments differently, with varying levels of success, longevity, and stability (Turner and Harrison 1983, Sánchez 1995, Dunning 1996, Fedick 1996a, Fedick 1996b, Dunning and Beach 2000, Lentz 2000a, Lentz 2000c).

Understanding the patterns of environmental change, both as a consequence of and constraint on human civilization, is a task that has been taken up by geographers, often in collaboration with other earth and social scientists. Prehistoric Mesoamerican civilizations wrought well-documented changes on the ancient environment of Mesoamerica (Tsukada and Deevey 1967, Deevey *et al.* 1979, Turner and Harrison 1983, Binford *et al.* 1987, Leyden 1987, Metcalfe *et al.* 1989, Byrne and Horn 1989, Metcalfe *et al.* 1991, Whitmore *et al.* 1996, Beach 1998, Goman and Byrne 1998, Lentz 2000a and references therein). Even in less-populated regions outside of the Mesoamerican and Andean empires, pre-Columbian groups in Costa Rica and western Panama also significantly altered their environments (Northrop and Horn 1996, Behling 2000, Clement and Horn 2001). This includes areas once thought "pristine" or "virgin" (Kennedy and Horn 1997, Horn and Kennedy 2001).

Prehistoric cultures throughout the Americas occupied a diverse collection of environments, and as such would have been subject to a heterogeneous mix of environmental constraints. In turn, pre-Columbian groups responded to these constraints in different ways. The process of anthropogenic landscape change, therefore, would have followed a different pattern according to the particular environmental constraints of a region and the extent to which humans altered or engineered that environment. Central American paleoecology is faced with the task of understanding this spatially and temporally diverse pattern of landscape change.

The environmental and human history of southern Pacific Costa Rica is just beginning to be understood and interpreted. Clement and Horn (2001) published the first paleoecological study from the region. Behling (2000) conducted another study at Laguna Volcán in western Panama. However, archaeological data indicate that there may be distinct differences within and among prehistoric groups in southern Pacific Costa Rica (Hoopes 1996, Corrales 2000), and therefore it should be expected that the timing and magnitude of human impacts on vegetation are likewise heterogeneous and asynchronous.

In this study I present the results of my paleoecological investigation of Laguna Santa Elena, a small lake in the mid-elevations of the Canton of Coto Brus, at the foot of the Cordillera de Talamanca in southern Pacific Costa Rica. The Laguna Santa Elena watershed is located within 20 kilometers of the Organizations for Tropical Studies' Las Cruces Biological Station, the La Amistad International Park (a UNESCO Biosphere

Reserve), and the Las Tablas Protected Zone. It therefore presents an opportunity to explore the cultural biogeography and environmental history of an ecologically important region. The present study adds an important data point to a growing body of paleoenvironmental and archaeological data being developed by Sally Horn and her students and collaborators, and by Costa Rican archaeologists (Horn and Sanford 1998, Sánchez and Rojas 2001).

The primary goal of my research, and the larger project of which it is a part, is to better understand the environmental history of tropical forests that are in or near ecologically important areas, including biological research stations like Las Cruces (Horn and Sanford 1998). A related goal is to provide temporal information and cultural ecological background to archaeological research currently being carried out at Las Cruces and in the Coto Brus region.

Using paleoecological indicators in the sediments of Laguna Santa Elena, I address the following questions: When was the Laguna Santa Elena watershed first occupied by human groups and for how long did settlement continue? When (if ever) was the watershed abandoned? How did human activity influence the forest around Laguna Santa Elena? What can we learn about subsistence patterns and strategies prior to the arrival of the Spanish from lake sediments? And how did the arrival of Europeans change the relationship between humans and the environment at Laguna Santa Elena?

The necessary context for these questions is explained in Chapter 2, where I describe both the physical environmental setting and the cultural history of the area. Chapter 3 explains the field and laboratory methods used in the study. I present the results of my investigation in Chapter 4, and discuss them in Chapter 5. I conclude and summarize my findings in Chapter 6.

CHAPTER 2

ENVIRONMENTAL AND CULTURAL SETTING

Physical Environmental Setting

Laguna Santa Elena (8° 56'N; 83° 56'W) is located in the Canton of Coto Brus in southern Pacific Costa Rica, in the foothills of the Cordillera de Talamanca, at an elevation of 1100 meters (Figure 2.1). It is a small lake, with an approximate current area of only 0.25 hectares. Shoreline morphology and information from local residents indicate that the lake was significantly larger (perhaps as large as one hectare) as recently as the mid-20th century. Maximum depth in January 2000 was approximately 4 meters. The lake itself occupies a truncated stream channel between two east-west trending ridgelines, with a watershed area of only 0.5 km^2. In January 2000 water entered the lake through a low-energy marsh environment fed by a small stream, and exited through an artificially widened channel at the opposite (west) end of the lake.

Situated on the Pacific flank of the Cordillera de Talamanca and bordering on the Terraba-Coto Brus River Valley, the Laguna Santa Elena watershed and the surrounding region is characterized by undulating to steep terrain and is dissected by tributaries and their associated stream terraces. The Terraba trough, a forearc basin that forms the intermontane valley of the Terraba-Coto Brus River, is bounded on the west and south by the Fila Costeña (or Cordillera Costeña). This steep coastal mountain range, reaching altitudes of 1000 meters or more, is a fold/thrust belt composed of Eocene to Early Miocene or Early Pliocene calcareous sedimentary rock with intrusive volcanic dikes and sills (de Boer *et al.* 1995, Alvarado *et al.* 2000). Major northwest-trending fault zones

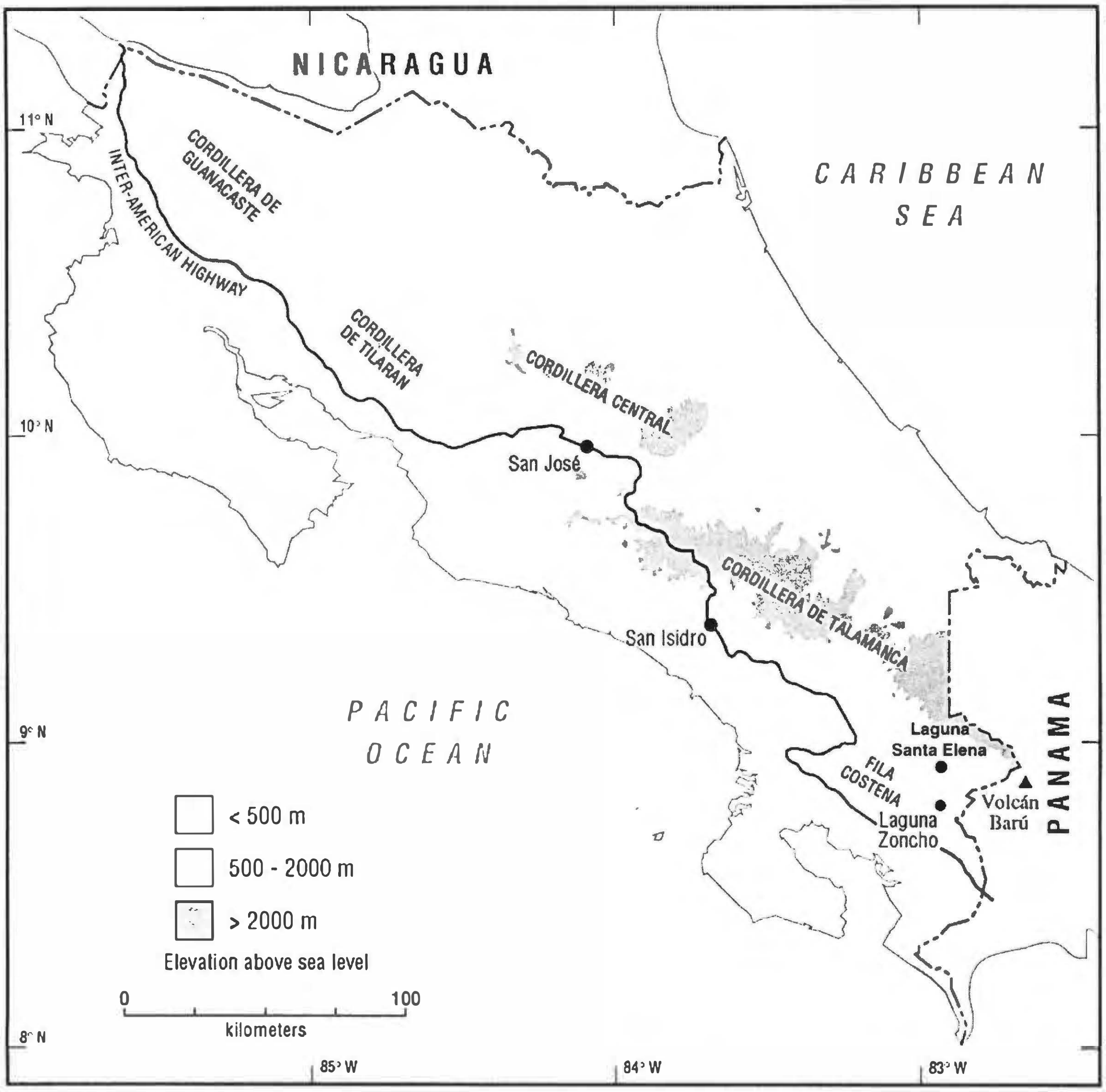

Figure 2.1 Map of Costa Rica showing the location of Laguna Santa Elena and other locations mentioned in the text. Laguna Volcán is 15 km west of the summit of Volcán Barú.

separate the Fila Costeña from the Osa Peninsula/Golfito units to the west and the Terraba trough to the east and north. Northwest trending normal and reverse faults separate the Terraba trough from the Cordillera de Talamanca (de Boer *et al.* 1995). The Rio Térraba-Coto Brus, within the forearc basin, is underlain by Eocene to Quaternary-age sediments and rocks of mostly volcanic origin (de Boer *et al.*1995, Alvarado *et al.* 2000, Montero 2000). Recent alluvial sedimentary deposits are found along the major river floodplains in the Coto Brus and Térraba River drainage (ITCR 2000).

To the north and east of the Coto Brus region, Tertiary-age intrusive igneous rocks, of largely granitic composition, dominate the lithology of the Cordillera de Talamanca. The Talamancas are a relatively young mountain chain, uplifted when the oceanic Cocos Ridge began to be subducted under the Costa Rican island arc (Kolarsky *et al.* 1995). De Boer *et al.* (1995) suggested a date of 5 million years ago for the beginning of this event, with the most rapid uplift occurring in Plio-Pleistocene times. The shallow subduction of the Cocos Ridge within the Middle American Trench caused a volcanic "gap" in the Cordillera (Weyl 1980, Kolarsky *et al.* 1995). From the Irazu-Turrialba complex in central Costa Rica to Volcán Barú in western Panama there are no stratovolcanoes of the type known from Mexico southward through Guatemala, El Salvador, Honduras, Nicaragua, and northwestern-central Costa Rica (de Boer *et al.* 1995). Volcán Barú (also sometimes referred to as Volcán Chiriquí), some 30 km east of Laguna Santa Elena, marks the resumption of stratovolcanoes in the Central American Cordillera Volcánica. Geological (Stewart 1978), archaeological (Linares and Ranere 1980), and paleoecological (Behling 2000, Clement and Horn 2001) evidence all indicate that Volcán Barú was active in recent prehistoric times. Dating of tephra layers in cores from Laguna Volcán and Laguna Zoncho has pointed to the most recent eruption approximately 600 yr. BP (Behling 2000, Clement and Horn 2001). Two main soil types dominate in the Coto Brus region. Andept Inceptisols derived from volcanic parent material are found on moderate to severe slopes (15 – 60%), while deeply weathered, orange-red Humult-Tropohumults (Ultisols) predominate on some steep slopes and escarpments (greater than 60%) (Vásquez 1983, ITCR 2000).

Meteorological data from San Vito (Figure 2.2) show an average annual rainfall for this region of 3500 to 4000 mm, with a pronounced but short dry season (*verano*) from January to March (Herrera 1985, ITCR 2000). Average annual temperature is 21 – 23°C. (Herrera 1985).

Laguna Santa Elena is located in the "premontane wet forest transition to rain forest" in the Holdridge bioclimatic classification system (Holdridge 1967, Hartshorn 1983, ITCR 2000). Potential vegetation in the Premontane Wet Forest is semi-evergreen trees with a multi-level canopy (Hartshorn 1983). Where it still stands, the upper strata in this type of forest are composed of canopy trees, and there is a well-developed fern and shrub layer. The Premontane Rain Forest is composed of evergreen trees with palms, tree ferns, *Selaginella,* and aroids making up the middle and lower strata (Hartshorn 1983). Lower Montane forests upslope from Laguna Santa Elena are dominated by *Quercus*.

Around Santa Elena, modern vegetation and land-use patterns are coffee cultivation and small-hold farms. The vegetation on the steep slopes surrounding the lake itself is a mix of pasture, banana plants, coffee bushes, and secondary growth. The Laguna Santa Elena watershed is situated within 20 kilometers of the Organization for

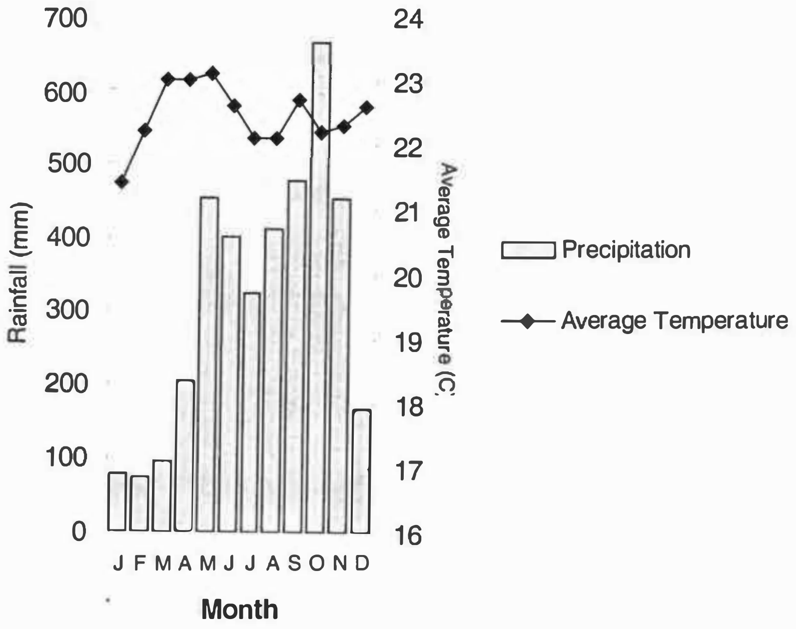

Figure 2.2 Average Monthly Climate Variables for San Vito de Java (890 meters). Based on 1954 – 1979 data from Herrera (1985)

Tropical Studies' Las Cruces Biological Station, the La Amistad International Park (a UNESCO Biosphere Reserve), and the Las Tablas Protected Zone (Figure 2.3).

Cultural History

Costa Rica is part of an archaeological region commonly known as the Intermediate Area, which includes both Lower Central America and northwestern South America, and encompasses parts of Honduras and El Salvador, and all of Nicaragua, Costa Rica, Panama, northern Ecuador, Colombia, and western Venezuela (Willey 1971, Willey 1984, Lange 1986, Lange 1992a). The *Canton* (a political division roughly equivalent to a county in the United State) of Coto Brus falls within the boundary of a large archaeological region known as Greater Chiriquí, which includes significant areas of southern Pacific Costa Rica, western Panama, and the Bocas del Toro region. Greater Chiriquí itself is divided into subregions (Figure 2.4, Figure 2.5). Sites in the Terraba-Coto Brus valley are in the Diquís subregion, which encompasses the Costa Rican half of the Pacific portion of Greater Chiriquí. The Western Panama portion of Greater Chiriquí is also known as the Chiriquí subregion. Recent work by Chávez *et al.* (1996) has indicated that sites in the southeast of Costa Rica, on the Caribbean coast near the border with Panama, should also be included within the boundaries of the Greater Chiriquí region, based on similarities in ceramic assemblages.

From its inception, the conceptual construction of an "Intermediate Area" situated geographically between the civilizations of Mesoamerica and the Andes has been tinged by what Sheets (1992) has called a "pervasive pejorative." Characterizations of the prehistory of the area, even by investigators of the region, have tended towards negative

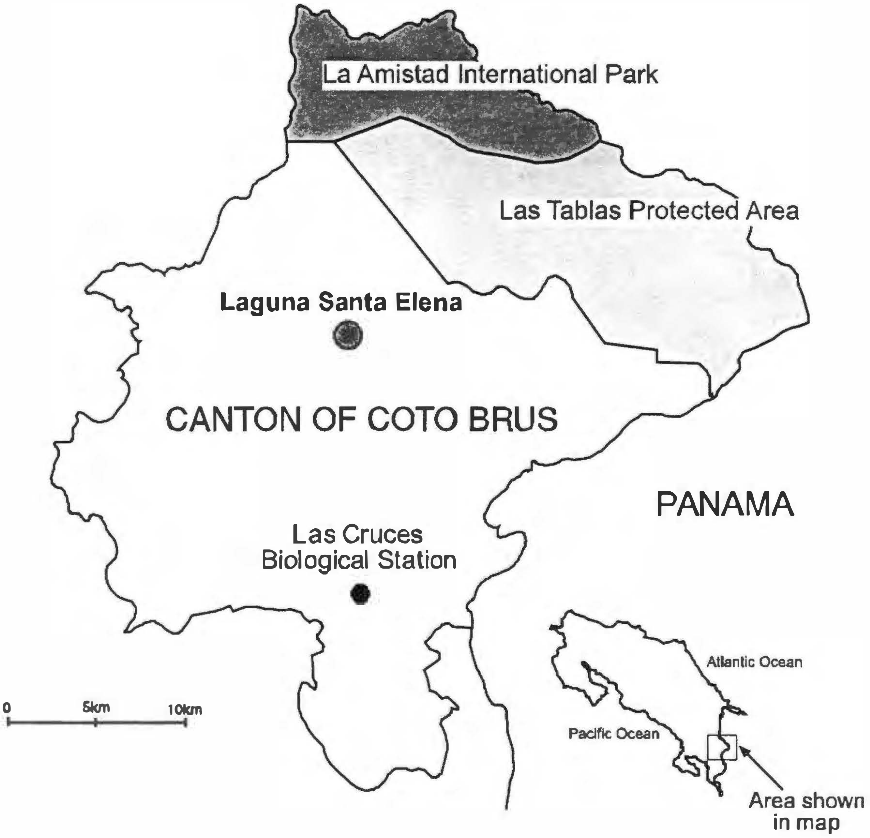

Figure 2.3 Map of the Canton of Coto Brus. La Amistad International Park and the Las Tablas Protected Area both extend beyond the borders of the canton (after Manger 1992).

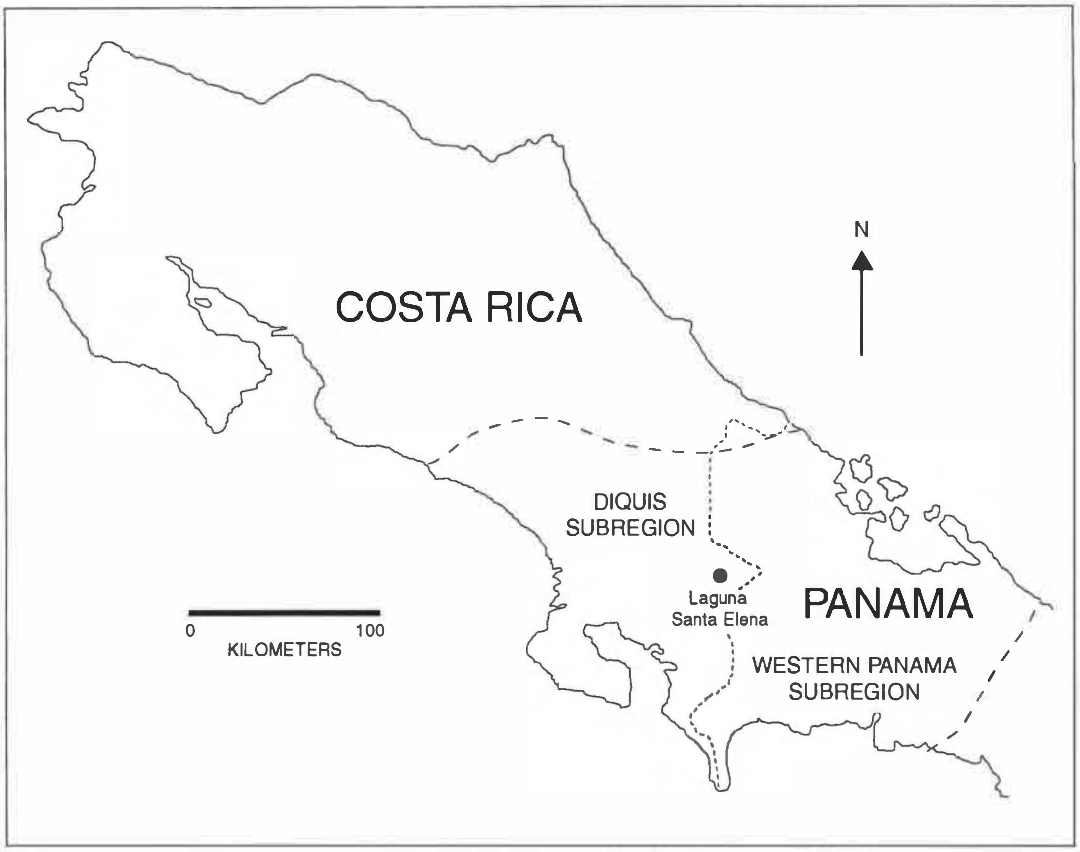

Figure 2.4 Map showing the approximate boundaries of the Greater Chiriquí archaeological region and the Diquís and Western Panama subregions within it (after Corrales 2000).

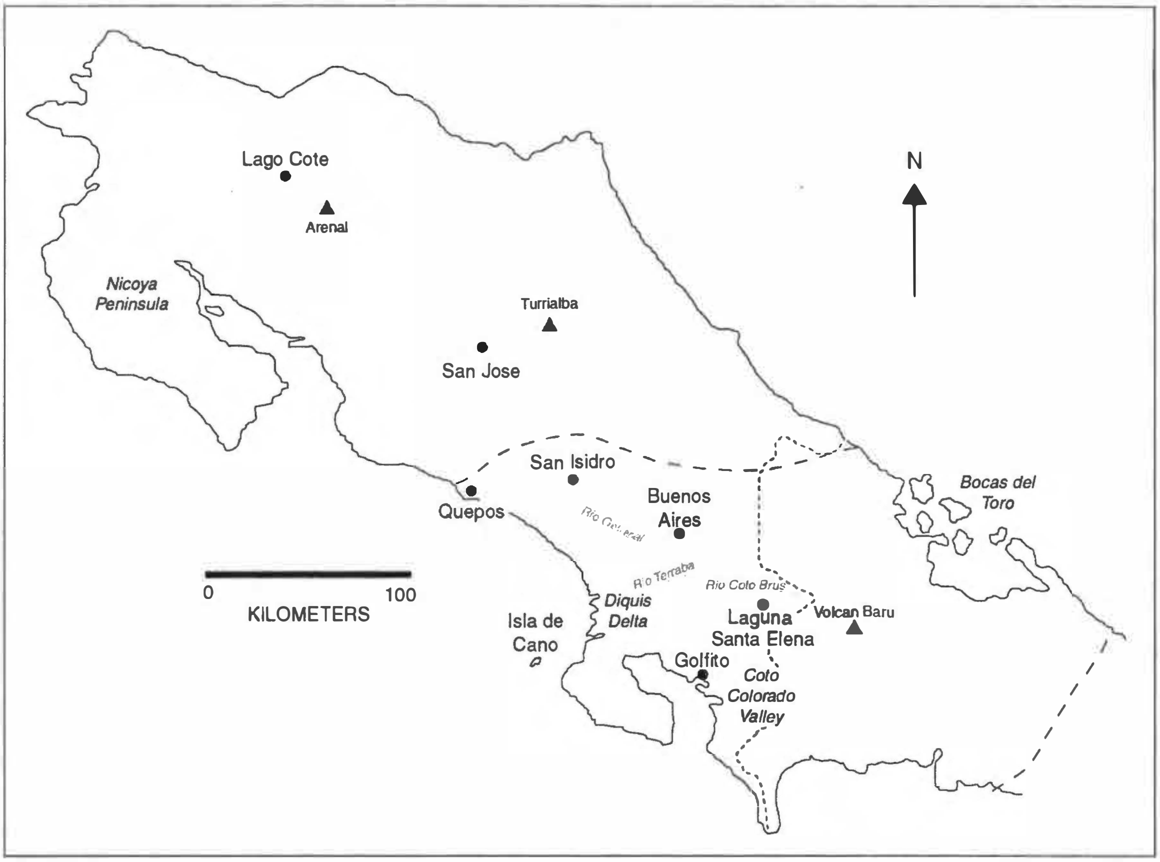

Figure 2.5 Map of Costa Rica and western Panama showing approximate locations for places mentioned in the text.

comparisons to more complex civilizations. Archaeologists, based largely on recent scholarship in archaeology, genetics, and linguistics, have proposed the denomination of the Chibchan-Chocoan Cultural Area (Cooke and Ranere 1992, Fonseca 1993) in place of the extra-referential Intermediate Area. Studies by Barrantes *et al.* (1990) and Barrantes (1993) on human genetics and microevolution, and by Constenla (1991, 1994) on linguistics, have demonstrated a persistent cultural occupation that is also reflected in the archaeological record (Lange 1993, Corrales 2000). The Guaymi Indians who currently live in southern Costa Rica are the modern representation of thousands of years of continuous human settlement and cultural traditions.

Sheets (1992) characterized Intermediate Area/Chibchan-Chocoan cultures as more egalitarian than Mesoamerican or Andean civilizations, with relatively simple ranked societies and a propensity towards an "avoidance of the state" (either intentional or fortuitous) which, along with socioeconomic and religious ties, resulted in long-term stability of cultures within the region. On the whole, he found that Intermediate Area cultures persisted considerably longer than ones in the Mesoamerican core or periphery, and that their stability extended to "adaptations, economies and societies" (Sheets 1992).

Attempts to create a cultural chronology for Greater Chiriquí have been ongoing since the middle of the 20th century[1]. However, radiocarbon dating of cultural sequences

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[1] The academic literature dealing with the excavation of archaeological sites frequently uses BC/AD instead of yr. BP. This reflects not only the relevance of placing archaeological findings in the context of human history-prehistory, but also the fact that not all dates cited in archaeological literature are based on radiocarbon determinations. Stylistic comparison of artifacts is often used to place sites within a regional chronology of human occupation and activity. In this thesis, I will provide radiocarbon dates associated with archaeological phase/periods when available. The reader is reminded that the dates given for the span of cultural phases or site occupations by archaeologists reflects a combination of relative and absolute dating techniques, and that even radiocarbon assays are fraught with problems of context and contamination.

has been fraught with problems of contamination, context, and stratigraphic control (Linares and Sheets 1980, Lange and Stone 1984a, Hoopes 1996). There are few radiocarbon assays from the Costa Rican side of Greater Chiriquí, and only two dated series for the critical Aguas Buenas Phase (Zoncho and the Diquís Delta, see below). The cultural chronology is therefore largely built upon radiocarbon dates from archaeological contexts in western Panama and stylistic comparisons between Greater Chiriquí ceramics and dated sequences from outside the region (Table 2.1). Summaries of the progress and problems in research on the prehistory of southern Pacific Costa Rica are found in Corrales *et al.* (1988), Drolet (1992), Hoopes (1996), and Corrales (2000).

There are no known Paleoindian sites in the Diquís subregion or in all of Greater Chiriquí[2]. On the Atlantic slope of Costa Rica, Snarkis (1984) identified a Paleoindian quarry and workshop near Turrialba. Sheets (1994) identified Clovis-type chipped stone tools in the Cordillera de Tilaran and along the shores of Lago Arenal as part of the Proyecto Prehistórico Arenal. Cooke and Ranere (1992) have described a Paleoindian site with fluted points at La Mula-West in Central Panama.

Bradley (1994) and Sheets (1994) also identified Fortuna Phase Archaic-period occupation in the Arenal region. No Archaic period sites have been identified in the

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[2] Here, the archaeological terms "Paleoindian", "Archaic", "Formative" and "Classic" refer to broad, generalized periods of cultural development. I use the definitions suggested by Fiedel (1992) and the time range for Greater Chiriquí from Corrales (2000). *Paleoindian*, 10000 (?) – ~7000 BC: big game hunting, band organization. *Archaic*, ~7000 – ~2000 BC: foraging-intensive collection; band-tribe organization, incipient agriculture, earliest ceramics. *Formative*, ~2000 BC – 800 AD: agriculture, ceramics, villages, tribes, and chiefdoms. *Classic*, 800 – 1500 AD: intensive agriculture, cities, and states. The actual dates and cultural elements of each period will differ from region to region.

Table 2.1 Cultural Chronology for Greater Chiriquí (based on Corrales 2000)

	DIQUÍS SUBREGION PHASES	General Valley	Middle Terraba Basin	Diquís Delta	Coto Brus Valley	WESTERN PANAMA SUBREGION PHASES
1500 AD 800 AD	CHIRIQUÍ *Classic*	Chiriquí	Chiriquí	Palmar Sierpe	Chiriquí	Chiriquí San Lorenzo *(Coastal)*
0 300 BC	AGUAS BUENAS *Formative*	Aguas Buenas Quebradas	Aguas Buenas	Camibar	Aguas Buenas	Bugaba Buríca Barriles Concepción
1500 BC	SINANCRÁ ? *Formative*		Curré?	Curré?		

Date ranges are based on radiometric methods, stratigraphy and superposition, and qualitative comparisons.

Diquís subregion of Costa Rica, although Corrales *et al.* (1988) and Drolet and Siles (1988) have found several possible locations in the General and Terraba Valleys. None of these sites, however, have so far yielded definite evidence of early occupation. However, in the western Panama subregion of Greater Chiriquí, Ranere's (1980) excavations of four rockshelters led him to postulate two pre-ceramic phases: the Talamanca Phase (4600 – 2300 BC) and the Boquete Phase (2300 – 300 BC). Lithic artifacts found in the rock shelters suggested root crop (manioc) processing, but not maize (*Zea mays*) grinding. Macrobotanical remains included palm fruits (*Acrocomia sp*., *Sheelia zonensis*, and a third unidentified species), nance (*Byrsonima sp.*) and *Hymenaea courbaril*, but no maize. Based on the lithic and macrobotanical assemblage, Ranere (1980) suggested that preceramic cultures in the highlands of Chiriquí relied on a subsistence strategy of root crops, and wild floral and faunal resources.

The earliest evidence of prehistoric sedentary habitation in the Diquís subregion is from the sites of Curré in the Diquís delta (Corrales 1985) and Ni Kira in the Coto Colorado valley (Corrales 2000). Based on excavations at these two sites, Corrales (2000) postulated the Sinancrá Phase, which he dated by stylistic comparison to other ceramic complexes to the period 1500 – 300 BC. However, radiocarbon assays intended to date the Curré assemblage returned dates of 400 – 900 AD (Hoopes 1996: footnote #6 and #10) and the absolute chronology of the phase remains poorly established. Corrales (2000) has suggested that other "unidentified" ceramics from sites in lowland western Panama, the Trapiche-Schoolyard-Horacio Gonzalez sites in highland western Panama, and Isla de Caño near Drake Bay in southwestern Costa Rica could correspond to the Sinancrá Phase. Excavations and surface collections at several sites in the Coto Brus region may also have yielded a few pre-Aguas Buenas ceramics that could correspond to the time period theorized for this phase (M. Sánchez, personal communication). Corrales (1985) also excavated small microlithic fragments at Curré that he identified as pieces of a scraper for processing manioc. From this, and the lack of *manos* or *metates*, he theorized that Sinancrá Phase populations at Curré were not maize agriculturalists, but rather relied on root crops. However, too few sites with firmly established Sinancrá Phase occupation have been identified at this point to draw any conclusions about settlement patterns or regional distribution, and data from Curré remain inconclusive with regards to both subsistence strategies and absolute chronology. However, if ceramic collections from the San Vito-Coto Brus region and Isla de Caño do prove to have evidence of an earlier Formative occupation contemporary with that which Corrales (2000) has hypothesized for Curré and Ni Kira, this would suggest the possibility of widespread but low-density populations in the Diquís subregion prior to the better-documented Aguas Buenas Phase.

The Aguas Buenas cultural phase was first defined by Haberland (1955, 1957) based on his excavations of the prehistoric site of the same name, situated near San Vito and adjacent to the modern border with Panama. It is generally defined in archaeological contexts by specific ceramic types and wares (Moravia Red, for instance, being one of the commonly encountered types). The "Aguas Buenas" Phase is a much-abused term, since a wide variety of dates and ceramic sequences have been applied to it in the past, and artificial geographic and cultural distinctions have been made between Costa Rican and Panamanian elements of the phase (Hoopes 1996). Moreover, Haberland (1984a) and Hoopes (1996) have argued that the Aguas Buenas Phase represents a cultural tradition and not a simple, single cultural unit. Hoopes (1996) emphasized that the relatively small and generally dispersed populations within Greater Chiriquí were probably less integrated and more heterogeneous than their grouping within the Aguas Buenas Phase suggests.

Aguas Buenas was a spatially and temporally extensive cultural phase. Ceramics associated with it have been found from the westernmost parts of the General Valley north of San Isidro south to both Atlantic and Pacific western Panama. Dates typically given for this period of cultural occupation of the Greater Chiriquí region are 300 BC – 800 AD. The date for the beginning of the phase, however is still a matter of debate and might be anywhere between 500 BC and 200 AD (Drolet 1984, Haberland 1984a, Haberland 1984b, Hoopes 1996, Corrales 2000). Considerable uncertainty exists concerning early (prior to 200 AD) Aguas Buenas dates, and the exact beginning of the phase is not well constrained by trusted radiocarbon determinations. Drolet (1984) gave an early date (500 BC) for the beginning of Aguas Buenas culture based in part on Linares' (1980) diffusion hypothesis (Hoopes 1996). In Linares' (1980) model, ceramic-crafting, maize agriculturalists migrating from southern Costa Rica to western Panama founded prehistoric sites associated with Bugaba (200 – 600 AD) and Barriles ceramics in western Panama. Stylistic comparison to the Zoned Bichrome ceramic type of Gran Nicoya Zoned pottery (itself dated to 300 BC) is also used to suggest pre-200 AD dates, a conclusion which Hoopes (1996) has strongly questioned. Hoopes (1996) considers *all* radiocarbon dates for an early beginning of Aguas Buenas problematic.

Bugaba Phase ceramics from western Panama, confidently dated to 200 – 600 AD by 14 radiocarbon assays (Linares 1980), are accepted by investigators as part of the Aguas Buenas Phase, and overlap with Aguas Buenas in terms of styles, techniques, and types (Hoopes 1996, M. Sánchez, personal communication). Despite the confusion induced by multiple seriations and typologies of Aguas Buenas Phase ceramics, the Aguas Buenas Phase includes all ceramics identified as Barriles, Bugaga, Aguacate, and Buríca Phases elsewhere in the Greater Chiriquí region (Einhaus 1984, Hoopes 1996).

Few radiocarbon dates are associated with Aguas Buenas Phase material in the Diquís subregion, however. Baudez *et al.* (1996) established local ceramic sequences based on excavations in the Diquís Delta. Their Camibar Phase (which consists of Aguas Buenas-type ceramic wares) was associated with a radiocarbon date of 656 – 784 AD (1294 – 1166 cal. yr. BP), which overlaps with the dates believed to correspond to the late Aguas Buenas Phase. It is not clear whether the Camibar Phase represents a distinct ceramic tradition or should be simply considered a local assemblage within the larger Aguas Buenas Phase. Excavations at Zoncho (Soto and Gómez, in preparation) near San Vito have radiocarbon dates associated with Aguas Buenas material (1560 – 1400 cal. yr. BP, 1540 – 1360 cal. yr. BP, 1700 – 1520 cal. yr. BP) and all are more recent than 200 AD (S. Horn and M. Sánchez, personal communication).

The Quebradas ceramic type from the General Valley north of San Isidro may date as far back as 500 BC, but appears to overlap somewhat with the Aguas Buenas tradition in the Terraba-Coto Brus-Diquís Valley (Haberland 1984a, Drolet 1988, Drolet 1992, Hoopes 1996), and is somewhat similar in style to Concepción ceramics from western Panama (Hoopes 1996). Sites in the Upper General Valley with Quebradas ceramics have radiocarbon dates that place them as early as 300 BC. Drolet (1988) has suggested that the Quebradas ceramics represent a distinct occupation within the General Valley, separate from the Aguas Buenas tradition. Corrales' (2000) examination of selected Diquís subregion ceramics, however, led him to categorize Quebradas ceramics as a specific type within the larger Aguas Buenas tradition. The termination date of the Aguas Buenas sequence is also problematic because it may be spatially distinct within Greater Chiriquí. The San Lorenzo phase, not Aguas Buenas, is found immediately below Chiriquí ceramics at coastal sites along the Gulf of Chiriquí and inland sites near San Vincente in Panama (Corrales 2000), and seems to have been contemporary with Chiriquí-type ceramics elsewhere in Greater Chiriquí.

Drolet (1992: 211) stated that during the Aguas Buenas Phase in Greater Chiriquí, "elevated, flat terraces close to secondary rivers, smaller streams, and lagoons were the preferred zones for village placement." The location of Laguna Santa Elena fits this description. In Panama, Linares and Sheets (1980) found that stream terraces were the preferred settlement sites, and that prehistoric villages were located "near but not at the edge of streams." Their site survey revealed settlements of "discontinuous villages" and individual dwellings separated by 40 to 50 meters. They established a settlement hierarchy, with small hamlets, farming villages, villages dedicated to specific craft specialization, and a few regional centers. These findings correspond well to Drolet's (1988) review of settlement patterns in the Diquís subregion, where he found widely spaced settlements with no more than five dwellings per village. As with Linares and Sheets' (1980) study from the region around Volcán Barú, Drolet found that smaller hamlet-sized sites were associated with larger, regional centers. These earlier studies are being confirmed and expanded by the work of Maureen Sánchez of the Universidad de Costa Rica and her collaborators and students (Sánchez and Rojas 2001, Sánchez and Rojas in press, M. Sánchez, personal communication), who have found numerous small village sites with a small number of individual dwellings, as well as spatially extensive centers that probably served as the foci of economic and religious life.

While there is general agreement by various archaeologists on settlement patterns in Greater Chiriquí, the interpretation of the patterns with regards to subsistence strategies remains divergent. Linares and Sheets' (1980) site hierarchy model led them to conclude that the Formative period inhabitants of the Chiriquí highlands were "intensive farmers" whose agricultural strategy focused largely on beans and maize; however, Drolet (1988) concluded that wild, gathered resources were important in Aguas Buenas phase culture in the Diquís subregion, and that the settlement pattern he described was not indicative of intensive farming of a few staples.

In western Panama, macrobotanical remains of maize are all younger than 300 BC (Ranere 1980, Smith 1980). Galinat (1980) identified maize remains dated to 200 AD from a highland Chiriquí rock shelter. Although both Galinat (1980) and Smith (1980) suggested that maize was introduced to highland western Panama prior to 200 AD, there is no dated macrobotanical evidence for this early arrival. Although evidence exists in the form of both macrobotanical remains and stone grinding implements (Haberland 1984b) in the Chiriquí subregion for a shift to maize and beans as staple crops following the preceramic Archaic occupations of highland Panama, Drolet (1992) has claimed that findings from the Diquís subregion settlements do not demonstrate the same record (Drolet 1992, Hoopes 1996). Blanco and Mora (1994) have, however, reported carbonized maize and bean (*Phaseolus*) remains from Sitio Monge and Sitio Las Brisas in the Upper General Valley near San Isidro. Hoopes (1991, 1996) has been a strong proponent of the idea that maize was not an important *grain* crop during the Aguas

Buenas Phase in the Diquís subregion. He suggested that maize may have been cultivated not as a staple, but rather as a special crop, perhaps specifically for ceremonial or political (ritual feasting) use.

Paleoecological studies in Greater Chiriquí have shed some light on the debate concerning the timing and use of maize in the region. Clement and Horn (2001) found maize pollen in nearly all levels of a 3000-year record from Laguna Zoncho near San Vito. Behling (2000) found maize pollen in a core from the western Panama highlands beginning approximately 1800 yr. BP. These paleoecological studies establish the presence of maize in southern Costa Rica and western Panama *prior* to the Aguas Buenas Phase (as it is currently temporally defined), and confirm its presence in both the Diquís and Chiriquí subregions during both the Aguas Buenas and Chiriquí cultural phases.

The Chiriquí Phase (Precontact period) follows the Aguas Buenas Phase in southern Costa Rica and western Panama, and dates from approximately 800 to 1500 AD, although different investigators have used a range of beginning dates from 600 – 1000 AD for the cultural period (Linares 1980, Drolet and Siles 1988, Corrales *et al.* 1988, Drolet 1992, Corrales 2000, Sánchez and Rojas 2001). In essence, the Chiriquí phase lasted from the termination of the Aguas Buenas phase until the arrival of the Spanish in the early 16th century, although in coastal Chiriquí the San Lorenzo phase apparently preceded the Chiriquí phase, and might therefore have overlapped with the Aguas Buenas Phase in the Diquís subregion (Corrales 2000). At the Rivas site in the Upper General Valley, Quilter and Blanco (1995) have 14 radiocarbon dates for Chiriquí-age deposits, 12 of which cluster within the range 890 – 1440 AD (1060 – 510 cal. yr. BP). Two outliers from Rivas give dates of 3820 – 3470 cal. yr. BP and 1280 – 980 cal. yr. BP.

Baudez *et al*. (1996) reported a radiocarbon date from stratigraphic levels associated with Chiriquí Phase (which they call the Palmar Phase) remains at 869 – 1145 AD (1081 – 805 cal. yr. BP). Corrales (2000) has a single date on Chiriquí levels at Curré of 890 – 1170 AD (1060 – 780 cal. yr. BP). Linares' (1977) dates for Chiriquí from western Panama range from 650 – 1230 AD, but the dates have error ranges as large as ± 170 and ± 150.

Precontact, Chiriquí Phase culture in Greater Chiriquí apparently represents a dramatic shift in material culture and organization within the region. The change from Late Formative Period Aguas Buenas cultures to those of Classic Period Chiriquí is seen within the archaeological record not only in the ceramics (which are distinctly different, more elaborate and well-made) but also in the beginnings of metallurgy (gold, copper, and combinations of metals) (Drolet 1992, Sánchez and Rojas, in press). Settlements and settlement patterns also changed, moving toward increased internal complexity and larger sites, with artificial mounds, retaining walls, platforms constructed from river cobbles, and very large circular houses and *palenques* (Corrales *et al*. 1988, Drolet 1992). Based on his investigations in the Rio Térraba-Coto Brus Valley, Drolet (1983a, 1983b, 1984, 1988, 1992) postulated that settlement patterns also shifted altitudinally, away from the highland and river terrace or "piedmont pattern" (Linares *et al*. 1975, Sheets 1980) and toward more consolidated regional centers in the lowland alluvial areas. Drolet (1984) went so far as to suggest that there were no small residential/habitational sites during the Chiriquí Phase, and that populations were concentrated exclusively in large regional centers. Recent investigations, however, reveal that this may not be entirely true, and that mid-elevation centers may have existed contemporaneously with lowland alluvial sites (Corrales 2000, Sánchez and Rojas 2001, M. Sánchez, personal communication).

However, these mid-elevation sites are also larger and more internally complex than their Aguas Buenas predecessors.

Most archaeologists see evidence in the material culture and settlement systems of the Chiriquí Phase for hierarchical organization and ranked societies (Corrales *et al.* 1988, Drolet 1992, Sánchez and Rojas in press). Corrales *et al.* (1988) have suggested that the increasing importance of grain production would have led to the dissolution of societal linkages based on clan, tribe, and ancestor, and their replacement by political and economically oriented connections. Hoopes (1996) has pointed out, however, that distinguishing between cause and effect with regards to a near-simultaneous increase in social differentiation and the development of intensive, grain-based agriculture is difficult, and that likely they proceed in tandem throughout the Formative, rather then with simple linear causality.

The Chiriquí Phase lasted until the arrival of the Spaniards in the early 16th century. Christopher Columbus explored the Caribbean coast of Costa Rica during his fourth voyage in 1502, and the expedition of Juan de Castañeda and Hernan Ponce de Leon entered the Golfo Dulce on the southern Pacific coast near Golfito in 1519 (Fernández Guardia 1913, Corrales *et al.* 1988). The first direct European contact with indigenous groups in the Diquís subregion probably occurred in 1522 with the expedition led by Gil Gonzalez Davila, which passed through the Diquís subregion and the Valley of the Rio Terraba:

> The Captain-General [Gil Gonzalez] undertook the journey with one hundred men, at times penetrating into the interior for more than ten leagues from the coast. On his way he baptized many Indians and gathered an abundant harvest of gold ... He stopped at Buríca and at the

> Gulf of Dulce and has passed through the territories of the caciques Boto, Coto, Guaicara, and Durucaca ... his suffering forced him to take refuge in a house of a leading cacique, who lived on an island of the Río Grande de Térraba." (Fernández Guardia 1913: 77-78)

The next major interaction between the Spanish *conquistadores* and the indigenous population of southern Pacific Costa Rica came forty years later with the expedition of Juan Vásquez de Coronado in 1562 – 63. Vasquez de Coronado's account, in Ricardo Fernández Guardia's *Cartas de Juan Vásquez de Coronado*, provides one of the best records of both the cultural and physical landscape of the Diquís subregion of Costa Rica at the time of the Conquest. In alliance with the *cacique* of Quepo (near modern day Quepos on the central Pacific coast), Vásquez de Coronado set out to conquer the *cacicazgo* of Coctú, with who the *cacicazgo* Quepo was in conflict prior to the arrival of the Spaniards. After a two-day walk along the Pacific coast, the group of Spanish soldiers and Quepo Indians turned inland at the mouth of the Río Grande de Térraba. Entering the mountains and proceeding northeast, they encountered extensive areas of *sábana* (savanna or grasslands). Five days of walking eventually took its toll on the Spanish soldiers, and an immediate attack on Coctú was delayed. An advance group of soldiers, led by Francisco de Marmolejo, were attacked and forced to retreat by the Indians defending Coctú. Vásquez de Coronado, arriving with the rest of the troops, describes Coctú in a now-famous passage:

> The village of Coctú lies on a spur of the sierra and has the shape of an egg, narrow at first and somewhat broader in the middle. It possesses eighty-four houses, arranged in good order. At each extremity stands a house, a little farther on two more, forming a triangle, and then follow three, and finally four, grouped in a square. Each house is located at a distance of four feet more or less from its neighbor and the result is most

> orderly in appearance. In the midst of each group of four houses there in a small plaza, approached through narrow, artificial lanes, for the houses are raise to a height of half a yard about the ground ... The fort is surrounded by two palisades with a ditch in between ... In these lands there has not been seen anything as strong or well devised. (Fernández Guardia 1913: 232 – 234).

Coronado described gardens of "beautiful aspect" in the deep ravines on either side of Coctú, as well as large plantations of maize, beans and fruit trees. The Coctú wore cotton clothing, and apparently hunted "tapir, deer, and wild hog" (*puerco*) and fished the rivers for "trout and shad" (Fernández de Guardia 1919: 235). Coronado also described fine, well-made pottery. His descriptions of the fortifications and fierce defense of Coctú, as well as the conflict between the territorial *cacizagos* in which he became embroiled, suggests a region where warfare over territory and property was not uncommon. Drolet (1983b, 1984, 1992) suggested that Coctú was one of five or six major regional centers that dominated Precontact culture in the Diquís. Smaller village sites had apparently been abandoned because of warfare between the larger polities in the region.

Spanish settlement of the Diquís subregion commenced with the founding of Nueva Cartago (near present day Buenos Aires) in 1563 and Nombre de Jesús near the confluence of the major tributaries of the Térraba-Coto Brus rivers in 1571 (Corrales *et al.* 1988). Indigenous settlement persisted during the Spanish colonization of the region, as evidenced by the intermingling of Chiriquí-type ceramics and European manufactured artifacts (including glass). At sites near Paso Real (Quintanilla 1986) and Portrero Grande (Corrales 1986), European ceramics and glass in indigenous cemeteries is evidence of some degree of co-existence of Spanish colonization and post-Contact Diquís subregion groups (Corrales *et al*. 1988). Southern Pacific Costa Rica remained only lightly settled well into the 20th century (Hall 1985).

Modern Setting

Modern settlement of the Coto Brus valley began in earnest with the founding of the Italian agricultural colony at San Vito in 1952, although prior to that time, Panamanian squatters had been crossing the border and settling in the Coto Brus region (Masing 1964, Dixon 1993). Vito Sansonetti (1995) told in his account of the colony at San Vito of journeying far beyond the Italian land grant, and encountering a farmer who had entered the region in 1949, three years before the first Italian settlers. Prior to the mid-20th century, settlement in the region had been sparse. In the late 19th and early 20th century, Colombians fleeing their country (which until that time had included present day Panama) had also crossed the border into southern Pacific Costa Rica (Hunter 1992). Political unrest may also have driven groups of Guaymi Indians into Costa Rica during the first half of the 20th century (Manger 1992). The population of the Coto Brus region in the late 1800s and early 1900s was a mix of Costa Ricans, Panamanians and Guaymi Indians, carrying out a largely subsistence-based agriculture of maize, beans, and sugar cane (Manger 1992). The modern towns of Buenos Aires, Portrero Grande, Villa Neily, and Golfito were founded between 1900 and 1950 (Sandner 1962, Manger 1992). In the 1940s, prior to the arrival of the Italian settlers at San Vito, the US Army built a road from Villa Neily on the western site of Fila Costeña to Sabalito near present day San Vito. With building of the military road, Costa Rican settlers began to arrive in the region, and settled on small *fincas*, mostly near Sabalito (Manger 1992).

The establishment of San Vito and the Canton of Coto Brus by the Italian immigrants stimulated the current settlement of the region and the flourishing of modern commercial coffee agriculture.

Archaeological Investigations at Laguna Santa Elena

Maureen Sánchez Pereira and Patricia Rojas Hernández of the *Sección de Arqueologia* at the Universidad de Costa Rica conducted reconnaissance, surface collection, and limited test excavations at mid-elevation archaeological sites they had identified in the Coto Brus region in 2000 (Sánchez and Rojas 2001). On hilltops surrounding Laguna Santa Elena (Site P-651 SE), they recorded four dispersed (~50 m apart) dwelling sites. They identified lithic artifacts and Aguas Buenas Phase ceramics from surface collections and test pits, but found no Chiriquí Phase remains. Approximately two kilometers east of the Laguna Santa Elena site, they identified a new, extensive site named Fila Tigre (P-652 FT). Based on surface collection and exploration of the site, they reported that the site covers an area of at least one square kilometer. Ceramic artifacts from this site were predominately Aguas Buenas Phase, although there were three sherds that corresponded to the Chiriquí Phase. They also reported evidence of possible house sites and burials. Based on the size of the site and the artifact assemblage, they suggested that Fila Tigre was probably a significant regional center that had served as the focus for political and economic activity.

Several kilometers to the north of Laguna Santa Elena and the Fila Tigre site are a cluster of sites within the Las Tablas Protected Zone (Leon 1986), which extends roughly from the Río Coton northward to the border with Panama. Although Leon's (1986) study of ceramic functional types included only seven sites (all of which corresponded to the Aguas Buenas Phase), nearly 70 sites have been recorded for this region. In addition to Aguas Buenas ceramics, Chiriquí material was found in surface collections from looted sites in the Las Tablas area (Corrales 2000). To the south of Laguna Santa Elena and Fila Tigre, numerous archaeological sites have been registered between Colonial Gutierrez Braun and San Vito, the two closest being Piedra Pintada (P-287 PP) and Rio Negro (Sánchez and Rojas 2001). Both sites correspond to the Aguas Buenas Phase.

CHAPTER 3

METHODOLOGY

Field Methods

In January of 2000, Sally Horn, Martin Arford, Lisa Kennedy, and I recovered a 7.13-meter sediment core from Laguna Santa Elena. We used a Colinvaux-Vohnout locking piston corer operated from a platform anchored near the center of the lake to collect contiguous 1-meter sections (Colinvaux *et al.* 1999). The softer material at the sediment-water interface was sampled using a plastic tube fitted with a rubber piston (PTC). Core sections were returned to the University of Tennessee still encased in the aluminum tubes. The sediments in the PTC were extruded in the field, sliced in one-centimeter sections, and stored in labeled plastic bags.

Laboratory Methods

At the University of Tennessee, we opened the cores by slicing the tubes lengthwise with a modified table router, and all core sections were immediately photographed. I described the stratigraphy of each section, including Munsell colors and general sediment type. I also noted the presence of intact wood, plant material, and charcoal. I removed six organic samples from the core for radiocarbon dating. The material was rinsed with distilled water and oven-dried, and sent to Beta Analytic Laboratory for the determination of radiocarbon age. Calculated radiocarbon dates were corrected for $^{13}C/^{12}C$ ratios. I used the CALIB v4.3 program (Stuiver and Reimer 1993) and the INTCAL98 dataset to calibrate dates (Stuiver *et al.* 1998). I estimated dates for each pollen sample by interpolating between calibrated radiocarbon dates and assuming a constant sedimentation rate. In the case where a ^{14}C date calibrated to more than one calendar year, I used the median of the intercepts with the calibration curve.

I took 29 samples from the core at intervals of 16 – 32 cm for pollen and sediment analysis. Sample volumes were 4.8 cc or 1.2 cc from the PTC, and 0.5 cc from the more consolidated material in the piston core sections.

I determined the relative content of organic material, inorganic material, and carbonates in each sample using loss on ignition (LOI; Dean 1974). LOI samples were first oven-dried at 100°C for 16 – 24 hours to remove water from the sediments. I then combusted the samples at 550°C to remove organic matter and recorded the change in weight. The samples were then combusted at 1000°C to remove carbonates, and weighed again.

I concentrated pollen and spores in the samples by chemically processing the sediments following standard palynological procedures (HCl, KOH, HF, acetolysis; Berglund 1986, Appendix A). One tablet containing a known number of exotic *Lycopodium* spores was added to each pollen sample as a control (Stockmarr 1971).

I scanned slides from each level at low power (100x) to determine the presence or absence of maize pollen or other large cultigen pollen such as *Cucurbita* or *Manihot*. An initial two slides from each level were scanned. If maize was not found on either of these slides, an additional three slides (for a total of five slides) were scanned. Maize was identified based on maximum grain dimension (see below).

I counted a minimum of 300 grains per level, exclusive of spores and indeterminates, at a magnification of 400x. Early counts revealed a high percentage of grains from the family Cyperaceae, which potentially masked significant changes in other pollen types. For this reason, I counted these and all subsequent levels to 300 grains excluding spores, Cyperaceae, and indeterminate grains.

I identified pollen grains based on an extensive reference collection of Neotropical pollen types created from vouchered herbaria specimens, as well as published keys, drawings, and photographs (Heusser 1971, Markgraf and D'Antoni 1978, Hooghiemstra 1984, Horn 1986, Roubik and Moreno 1991, Colinvaux *et al*. 1999, Kapp *et al*. 2000). Taxonomy follows that currently used by the Costa Rican *Instituto Nacional de Biodiversidad* (http://www.inbio.ac.cr/bims/PLANTAE.html). Identification was to the lowest possible taxonomic level, although for the purpose of analysis and display, I grouped some rare taxa by family (i.e. *Cestrum*-type and *Physalis*-type Solanaceae). Most pollen grains were identified to the family or genus level. Genera in the families Melastomataceae and Combretaceae are almost all heterocolpate and overlap considerably in size. I tallied them together as the composite group Melastomataceae-Combretaceae. Likewise, the Sapotaceae and Meliaceae have similar morphological characteristics, and so were tabulated as a combined group (Sapotaceae-Meliaceae). Undifferentiated monocotyledons were placed into groups based on sculpturing and aperture: monosulcate psilate, monosulcate scabrate, and other monosulcate.

The order Urticales contains four families (Ulmaceae, Utricaceae, Cecropiaceae, and Moraceae) whose pollen shows considerable overlap in size and structure. Pollen in this order tends to be small, psilate-scabrate, and have small, circular pores. I classified by pore number: diporate, triporate, 4-porate, and polyporate. Individual grains in this order whose pore number could not be determined (often because of damage to the grain) were recorded as "Undifferentiated Urticales." Within the Urticales, certain specific genera can be distinguished; I differentiated *Ulmus, Cecropia, Trema*-type *and Celtis*-type. I also separated *Ficus*, basing my identification on the distinct elongated "lozenge-shape" (Horn and Ramirez 1990). Some *Ficus* in Costa Rica do not have this distinct morphology, so counts of this taxon should be considered conservative. Some *Ficus* pollen may be included in the Diporate Urticales group.

I identified maize (*Zea mays* subsp. *mays*) grains by the length of the maximum diameter. Whitehead and Langham (1965) have reported the range of diameters for *Zea mays* as 58 – 99 μm. Ludlow-Wierchers *et al.* (1983) found certain Mexican races of maize with maximum dimensions up to 120 μm. Sluyter (1997) found that mounting pollen residue in silicone oil does not significantly expand or contract Poaceae grains. Maize overlaps in size with other wild *Zea*, including teosinte *(Zea perennis, Zea mays* subsp. *parviglumis, Zea mexicana).* However, there currently exists no evidence that teosinte was present in prehistoric Costa Rica. The use of other characteristics to differentiate between *Zea mays* and other large Poaceae has proven unreliable (Fearn and Liu 1995).

For each grain that could not be identified but whose morphology could be determined, I drew and described it, recorded its position, and assigned a number. I classified as "indeterminate" those grains that could not be identified due to mechanical damage or corrosion, or that were obscured by adhering organic or inorganic residue.

Spores were classified by morphology (monolete or trilete) and surface sculpturing (psilate, scabrate, verrucate, reticulate, striate, echinate). I identified certain distinct genera, including *Osmunda*-type and *Pityogramma*. I also identified and counted two types of Anthocerotophyta (*Anthoceros*, hornworts).

I counted charcoal particles during pollen counts and grouped them into two size classes: 25 – 49 μm and >50 μm. I only counted as charcoal those fragments that were black, opaque, and angular. The abundance of charred particles in the Laguna Santa Elena core precluded counting pieces smaller that 25 μm. I graphically displayed the changing percentages of fossil pollen taxa, spore types, and charcoal concentrations with depth using a modified version of the CALPALYN program (Bauer *et al.* 1991).

CHAPTER 4

RESULTS

Sediments and Stratigraphy

The Laguna Santa Elena core is 7.13 meters long (Table 4.1). Upper portions of the core range from dark brown-yellow to black (Munsell 2.5Y 3/2 – 10YR 2/1) clay and silt material with an organic content that ranges from 20% – 43%. The basal portion of the core (597 – 713 cm) is a soil profile, with an upper layer of relatively large, partially decomposed black organic materials (10YR 2/0) and a lower light colored (10YR 4/2 – 3/2) strongly-weathered stratum with abundant root traces and easily detectable ped structure. There are two well-defined volcanic tephra-ash layers at 312 – 314 cm and 415 – 417cm. Another likely tephra layer is found at 538 cm.

Radiocarbon Dating

Radiocarbon assays on six samples yielded a normal stratigraphic sequence extending back to 1950 – 1856 cal. yr. BP (0 – 94 AD; 1950 +/- 30 ^{14}C yr. B.P.) (Table 4.2). The uppermost radiocarbon date (156 – 157 cm, 291 – 0 cal. yr. BP) is problematic because it calibrates to such a wide range of dates. Sedimentation rates estimated using the intercept of the radiocarbon dates with the calibration curve are highly variable over the length of the core (Figure 4.1).

Table 4.1 Sediment Stratigraphy of Laguna Santa Elena Core

Depth (cm)	Sediment Description	Munsell Color Description
0 – 42	organic, poorly consolidated 2.5Y 3/2 w/ horizontal stripes of 2.5Y 5/4 and 2.5Y 4/4	Very dark grayish brown, light olive brown
42 – 61	organic, 10YR 2/2	Very dark brown
61 – 71	organic, better consolidated but very soft 10 YR 2/1 with some lighter layers	Black
71 – 73	horizontal band 10YR 3/2	Very dark grayish brown
73 – 213	Organic, 10YR 2/1 with some lighter layers	
213 – 219	three lighter layers w/ clasts stripes light colored with 2.5Y 4/2, 2.5Y 3/2	Dark grayish brown, dark olive brown
219 – 304	dark organics, 10YR2/1	Black
304 – 306	two thin mineral layers 2.5Y 4/2	Dark grayish brown
306 – 312	10YR 2/1	Black
313 – 315	Tephra layer, 2.5Y 7/1-6/1	Light gray-gray
315 – 325	10YR 2/1, gritty w/ sand-sized particles	Black
325 – 334	several horizontal layers of larger, sand-sized particles, 10YR 3/2 –10YR 2/1; several thin, black layers	Very dark grayish brown – black
334 – 375	10YR 2/1, very fine, very black	Black
375	thin layer 10YR 5/3	Brown
376 – 378	10YR 2/1	Black
378	thin layer 10YR 5/3	Brown
379 – 390	2.5 YR 3/2-2.5Y 3/3	Very dark grayish brown-dark olive brown
390 – 395	sharp boundary; 10 YR 3/2	Very dark grayish brown
395 – 415	10YR 2/0, some slight fluctuations toward 10 YR 3/2 and 5YR3/2	Black, dark grayish brown, dark reddish brown
415 – 417	Tephra. Significantly larger, angular clasts, 5Y 4/1	Dark gray
417 – 443	10YR 2/1 fine organics	Black
443 – 460	10 YR 4/1 very fine	Dark gray
460 – 461	2.5Y 4/2	Dark grayish brown
461 – 472	10YR 2/1 very fine, black organics	Black
472 – 479	varies smoothly between 10YR 2/1 and 2.5Y 3/2	Black, very dark grayish brown
479 – 538	10YR 2/1 fine, black organics	Black
538 – 539	Tephra? Light olive, gritty 5YR 5/1-6/1 Angular quartz and tourmaline grains	Gray
539 – 581	10YR 2/1 silt to sand texture—fine	Black
581 – 583	10 YR 3/1 with large, chunky organics	Very dark gray
583 – 597	2.5Y 5/2 fine clay with little silt	Grayish brown
597 – 634	10YR 2/1 lots of coarse organics,	Black
634 – 643	10YR 2/1 with 10YR 3/2 mottling	Black, very dark grayish brown
643 – 675	10 YR 4/2-3/2 with darker mottles (10YR2/1)	Dark grayish brown, very dark grayish brown
675 – 686	10 YR 3/1	Very dark gray
686 – 713	10YR 4/2-1; soil ped structure, root traces and materials	Dark grayish brown, dark gray

Table 4.2 Radiocarbon Determinations on Material from the Laguna Santa Elena Sediment Core

Lab Number	Depth (cm)	Material Dated	Uncalibrated ^{14}C Age (^{14}C yr. BP)	Calibrated Ages (cal. yr. BP)	Calibrated Age Range (cal. yr. BP) ±2σ	Calibrated Age Range (BC/AD)
ß-158436	156	Wood	150 ± 40	268, 216, 144, 19, 3	291 – 0	1659 – 1952 AD
ß-150706	312	Plant Material	640 ± 60	648, 581, 568	675 – 532	1275 – 1418 AD
ß-145347	434	Wood	1240 ± 40	1174	1274 – 1059	676 – 891 AD
ß-145348	530	Charcoal	1510 ± 40	1406, 1401, 1392	1519 – 1308	431 – 642 AD
ß-141242	580	Wood	1880 ± 30	1822	1884 – 1717	66 – 233 AD
ß-121243	683	Wood	1950 ± 30	1916, 1914, 1889	1985 – 1823	BC 36 – 127 AD

All analyses were AMS performed by Beta Analytic Laboratory, Miami, FL. Radiocarbon ages were calibrated using the CALIB v4.3 program (Stuiver and Reimer 1993) and the INTCAL98 dataset (Stuiver *et al.* 1998).

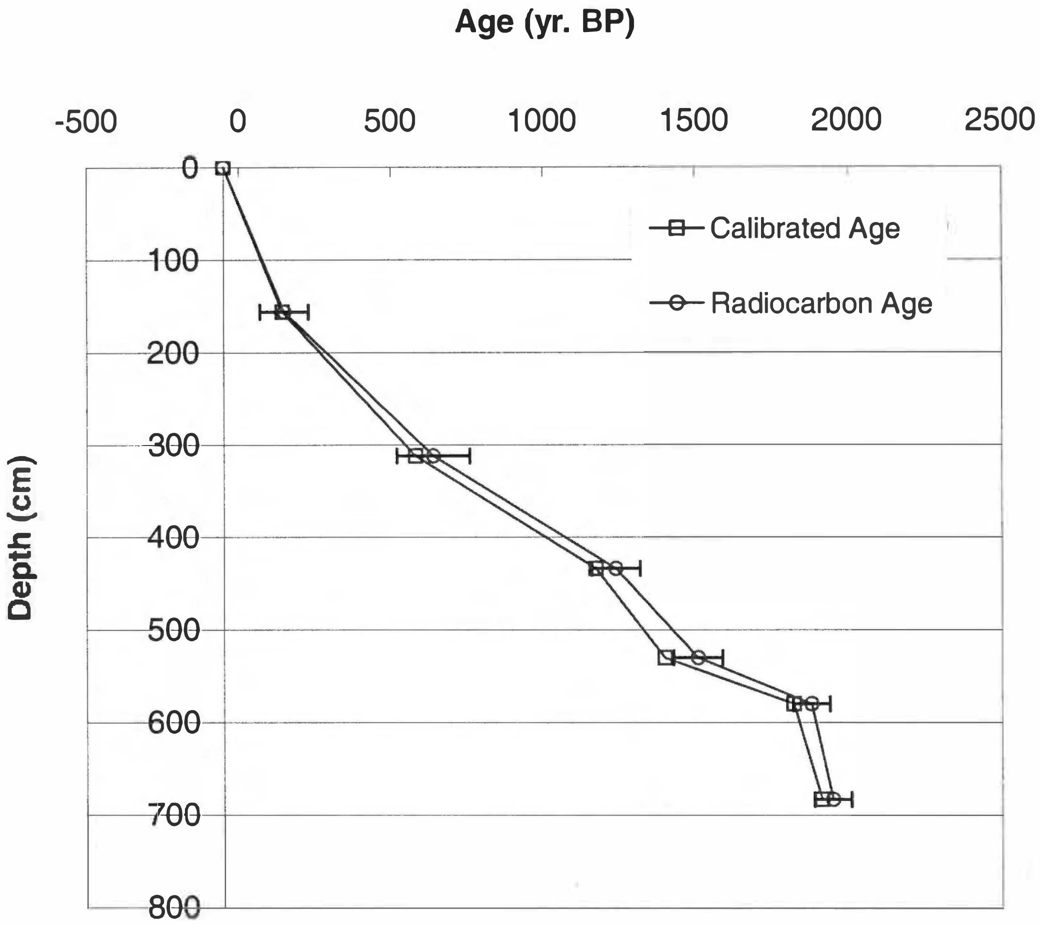

Figure 4.1 Age vs. Depth based on radiocarbon dating of organic material from Laguna Santa Elena. Error bars on ^{14}C dates are 2 standard deviations.

Pollen and Spores

Of the 29 levels processed and examined for pollen, 25 showed good palynomorph preservation and concentrations adequate for counting. The lowest four levels contained little pollen or spores. Visual examination of the processed residue from these levels revealed abundant *Lycopodium* controls and a few undamaged pollen grains. These observations indicate that it was not chemical and mechanical processing of the sediment samples, but rather the original or subsequent taphonomic processes that resulted in low pollen concentration.

For the upper 25 levels that showed good preservation, I counted a total of 9670 pollen grains. Of this total, 838 (8.7%) were damaged or permanently obscured by adhering material, and I could not determine their morphology and therefore could not identify them. These were classified as indeterminate pollen grains, and I did not include these grains in calculations of pollen percentages. The number of indeterminate grains per level ranged from a maximum of 58 to a low of 7.

I classified a total of 150 individual pollen grains as "unknowns" (<2.0% of total pollen). These grains had features that could be readily identified, but I was unable to classify them into a specific taxa grouping. Many of these were tricolporate, small-to-medium size, and reticulate-to-scabrate. Other investigators have indicated the difficultly in identifying grains with this general morphology (Roubrik and Moreno 1991, Rodgers and Horn 1996). The number of "unknown" pollen grains per level varied from a high of 21 grains (~7%) to a low of 1 (<1%). In general, sampled levels that had a high diversity of identifiable pollen taxa also had a higher number of "unknown" pollen grains. I included grains classified as "unknown" in calculations of pollen percentages.

The 15 most common pollen taxa in the Laguna Santa Elena record (Poaceae, Cyperaceae, Melastomataceae-Combretaceae, Asteraceae, *Hedyosmum* (Chloranthaceae), *Alchornea* (Euphorbiaceae), *Piper* (Piperaceae), diporate Urticales, *Weinmannia* (Cunoniaceae), *Trema* (Urticales), *Quercus* (Fagaceae), *Cecropia* (Cecropiaceae), triporate Urticales, Fabaceae, and unknowns) account for almost 85% of all pollen tabulated. Poaceae was by far the most common taxon encountered, at 27.7% of all counted grains.

Pollen and spore concentrations (Figure 4.2) are highly variable over the length of the Santa Elena core. The lowest pollen sample counted (576 cm) has a concentration approaching 200,000 grains per cm^3 of wet sediment, and spore concentrations of approximately 30,000 per cm^3 wet sediment. Pollen and spore concentrations are considerably lower through most of the lower half of the core, however. Pollen concentrations stay below 100,000 grains per cm^3 for the length of the upper portion of the core, dropping even lower in the most recent sediments. Spore concentrations increase to over 40,000 per cm^3 in the middle of the core. Charcoal concentrations are highest in the lower half of the core, with the exception of the basal sample.

There were a total of 8832 pollen grains that I could classify (7745 excluding Cyperaceae). I identified 93 pollen types (Appendix B). Figure 4.3 is a summary diagram, showing changes with depth in the percent of total pollen of selected taxa. In this and subsequent diagrams, pollen percentages are calculated with reference to a total pollen number that excludes spores, indeterminate grains, and Cyperaceae (only

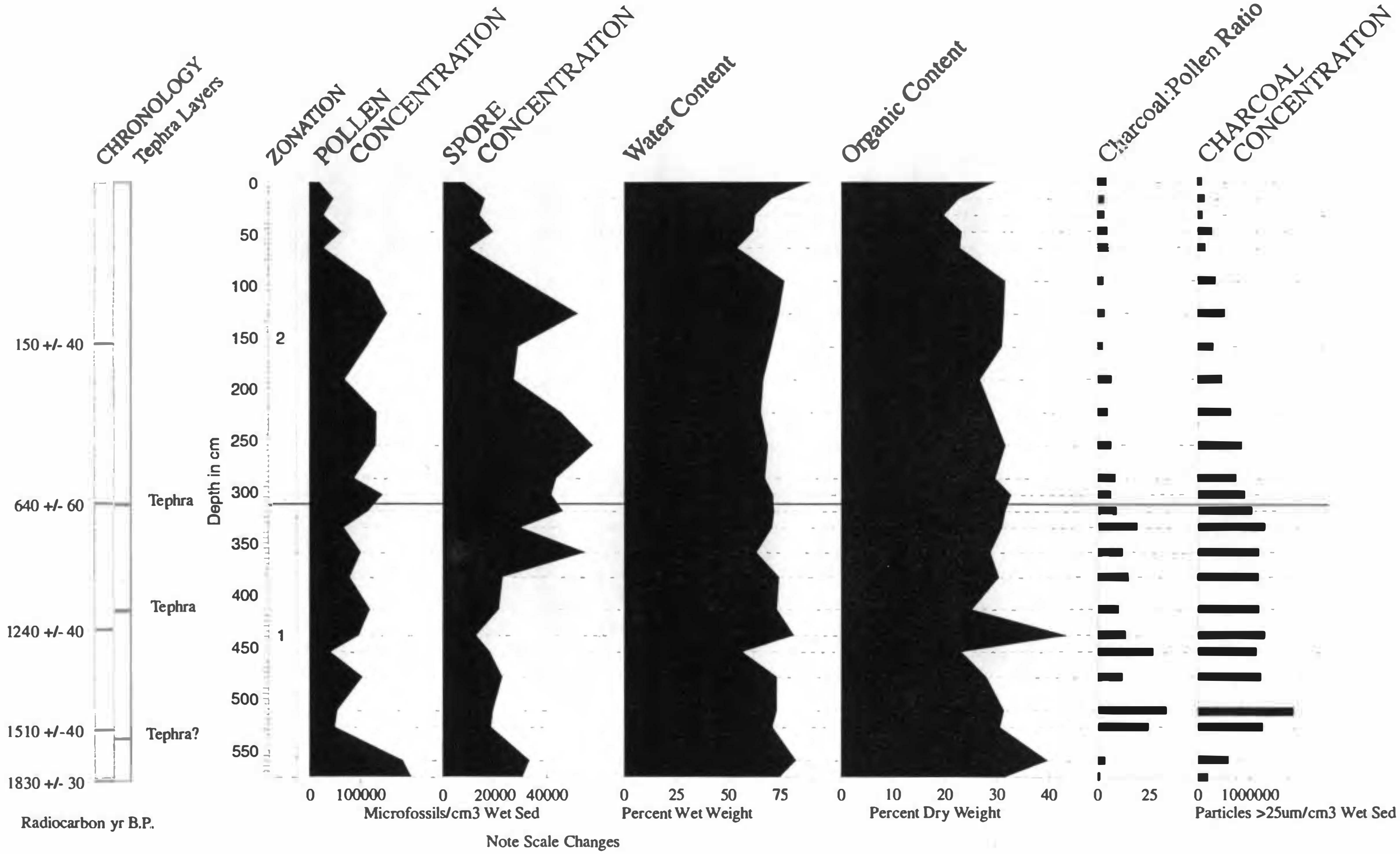

Figure 4.2 Laguna Santa Elena Sediment and Palynomorph Concentration Diagram

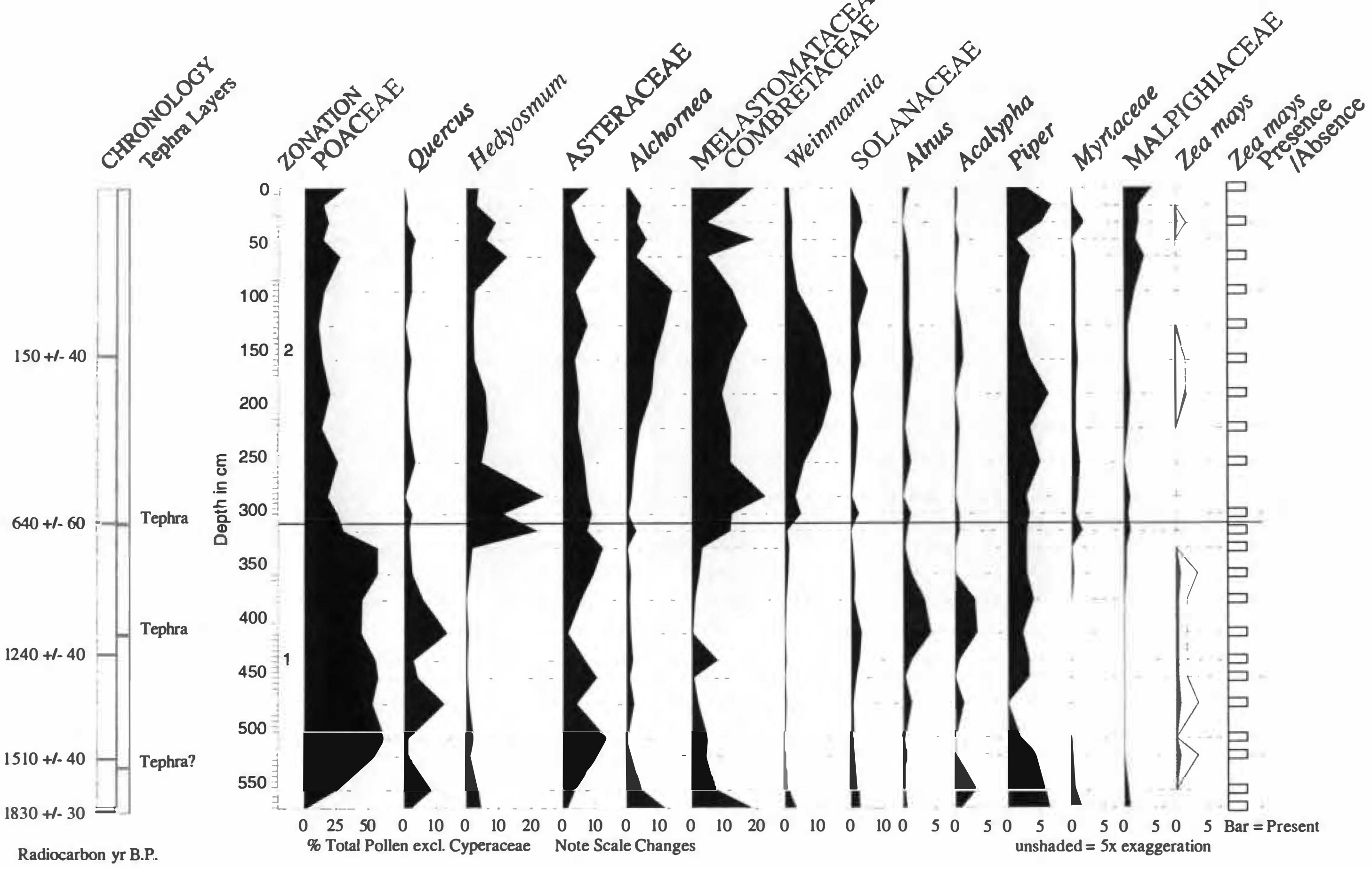

Figure 4.3 Laguna Santa Elena Summary Diagram

calculations for Cyperaceae grains use a pollen total that includes Cyperaceae). For the purposes of discussion, I delineated two pollen zones (Zone 1 and Zone 2) based on major trends in pollen percentages and the position of tephra from the most recent eruption of Volcán Barú (312 cm).

The representation in the core of premontane and montane taxa is shown in Figure 4.4. Inclusion of taxa in this group is based on studies of tropical ecology, modern pollen distribution, and other paleoecological studies from Central America (Byrne and Horn 1989, Rogers and Horn 1996, Kennedy 1998, Bush 2001). The two lowest levels show considerable pollen from this group, especially *Quercus*, *Alnus*, *Hedyosmum*, *Myrsine*, and *Ulmus*. High percentage spikes in *Quercus* occur at three depths (415 cm, 480 cm, and 560 cm), all in Zone 1. *Hedyosmum* shows significant peaks at the boundary of Zone 1 – Zone 2, and in more recent sediments toward the top of Zone 2. *Myrsine* and *Ulmus* are found in low but relatively consistent percentages within Zone 1, and are still present (but less consistently) in Zone 1. *Alnus* pollen is likewise persistent throughout the Santa Elena record, with its highest percentages at 384 cm and 415 cm in Zone 2. *Ilex*, *Podocarpus*, Araliaceae and *Alfaroa*-type appear rarely within the core. *Weinmannia* percentages are highest in Zone 2.

Disturbance taxa are shown in Figure 4.5. Extremely high grass percentages are present through much of the core, especially within Zone 1 where Poaceae pollen exceeds 60% of total pollen in some levels. Cyperaceae levels are also high, with peaks above 20 percent in Zone 1 (440 cm and 512 cm). Cyperaceae levels do approach zero in the lowest sample (576 cm) and in several modern levels (16 cm, 48 cm and 64 cm). Asteraceae (composites) are present throughout the core, ranging from near 1% to as high

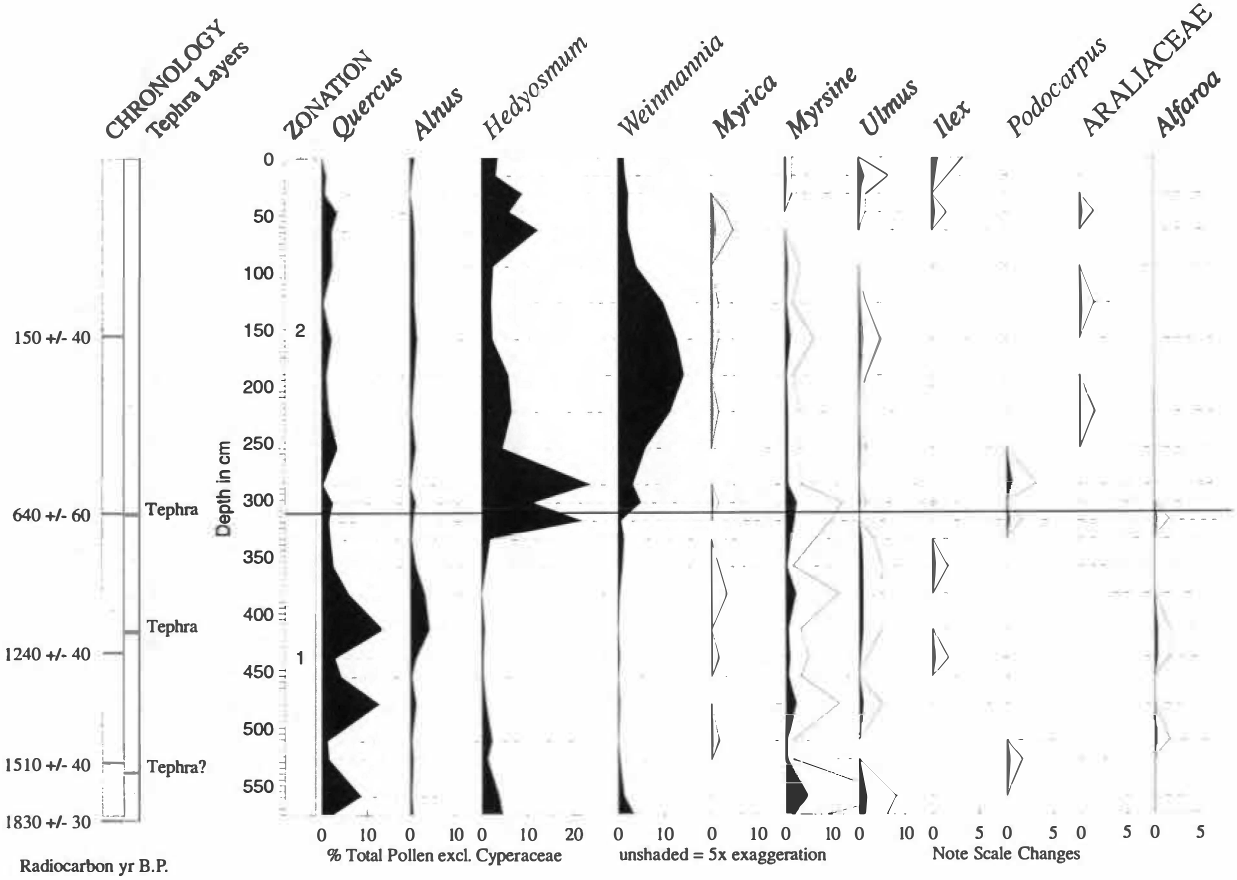

Figure 4.4 Laguna Santa Elena Montane/Premontane Taxa Diagram

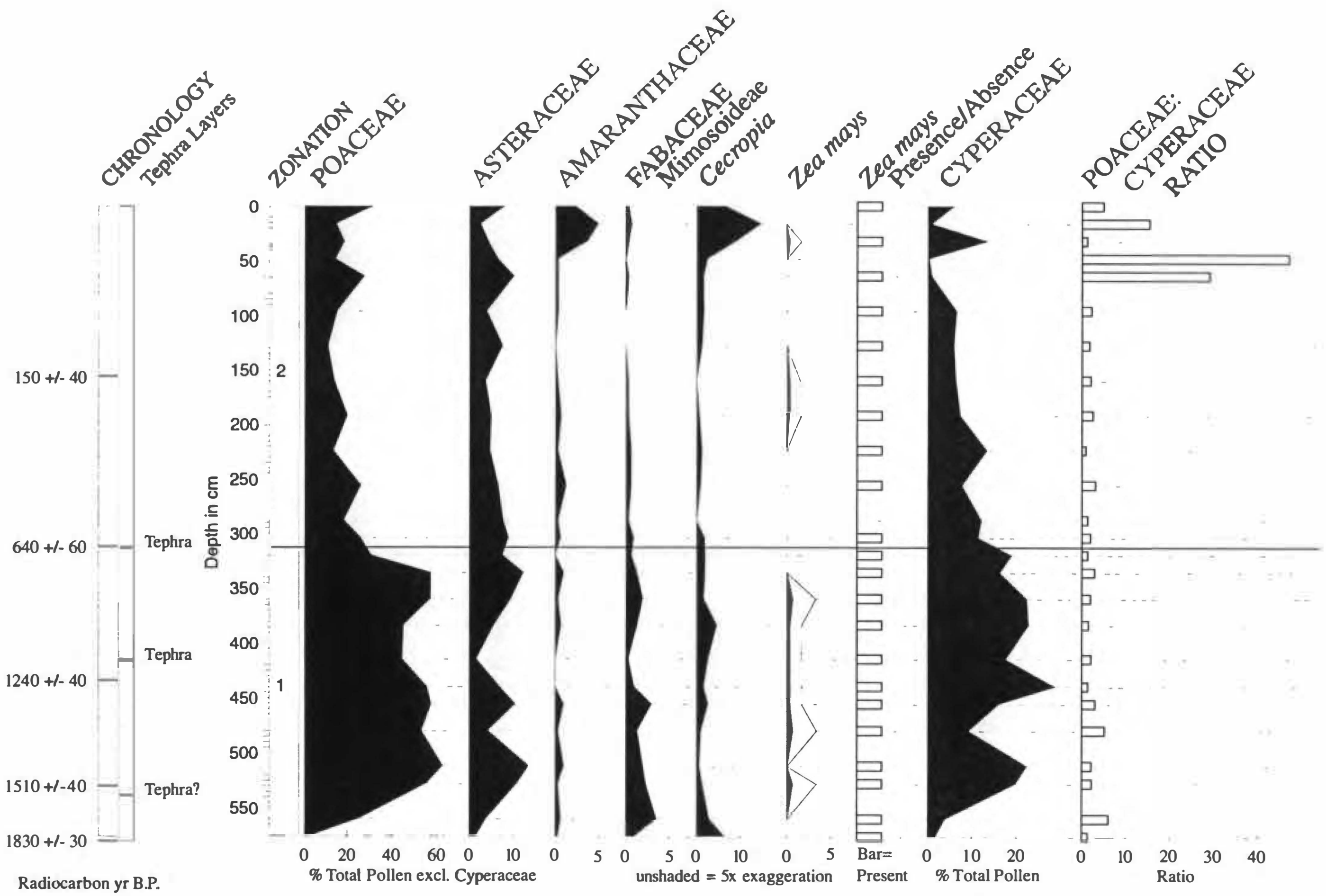

Figure 4.5 Laguna Santa Elena Disturbance Taxa Diagram

as 10%. Significant peaks in Asteraceae percentage occur in Zone 1 at 512 cm, 456 cm, and 336 cm. Amaranthaceae occurs in low percentages through most of the Santa Elena core, except in the most recent levels where they account for as much as 5% of total pollen. Mimosoideae type Fabaceae, nearly all of which are the weedy *Mimosa pigra*-type, are also present throughout the core, with higher levels in Zone 1. Surprisingly, *Cecropia* pollen is only a small percentage of total pollen, overall and in most individual levels. The highest percentages of *Cecropia* pollen are found in the lowest counted level and in more recent sediments near the top of the core. I found *Zea mays* in standard pollen counts in both Zone 1 and Zone 2, although more often in the former. Additional scans for maize pollen revealed it to be present in almost every level (see below).

Pollen percentages within the order Urticales (including *Cecropia*) are shown in Figure 4.6. Diporate and Triporate Urticales are present throughout the core, generally in higher percentages in levels within Zone 2. Within Zone 1, peaks in diporate and triporate Urticales grains occur between 384 cm and 415 cm. A significant peak in 4-porate Urticales is seen at 415 cm in the middle of Zone 1. *Trema*-type pollen is present throughout the core, although nearly absent at 528 cm, at 192 cm, and in surface sediments. *Celtis*-type pollen shows spikes at 560 cm, 128 cm, and 64 cm. Small peaks in *Ficus* pollen occur at 96 cm, 224 cm and 528 cm.

Maize Pollen

Maize pollen was present in all but three of the 25 levels with sufficient pollen concentrations (Figure 4.5, Table 4.3). As many as 13 grains were found on a single level (480 cm, ~1280 cal. yr. BP). No maize grains were found in complete scans of 5

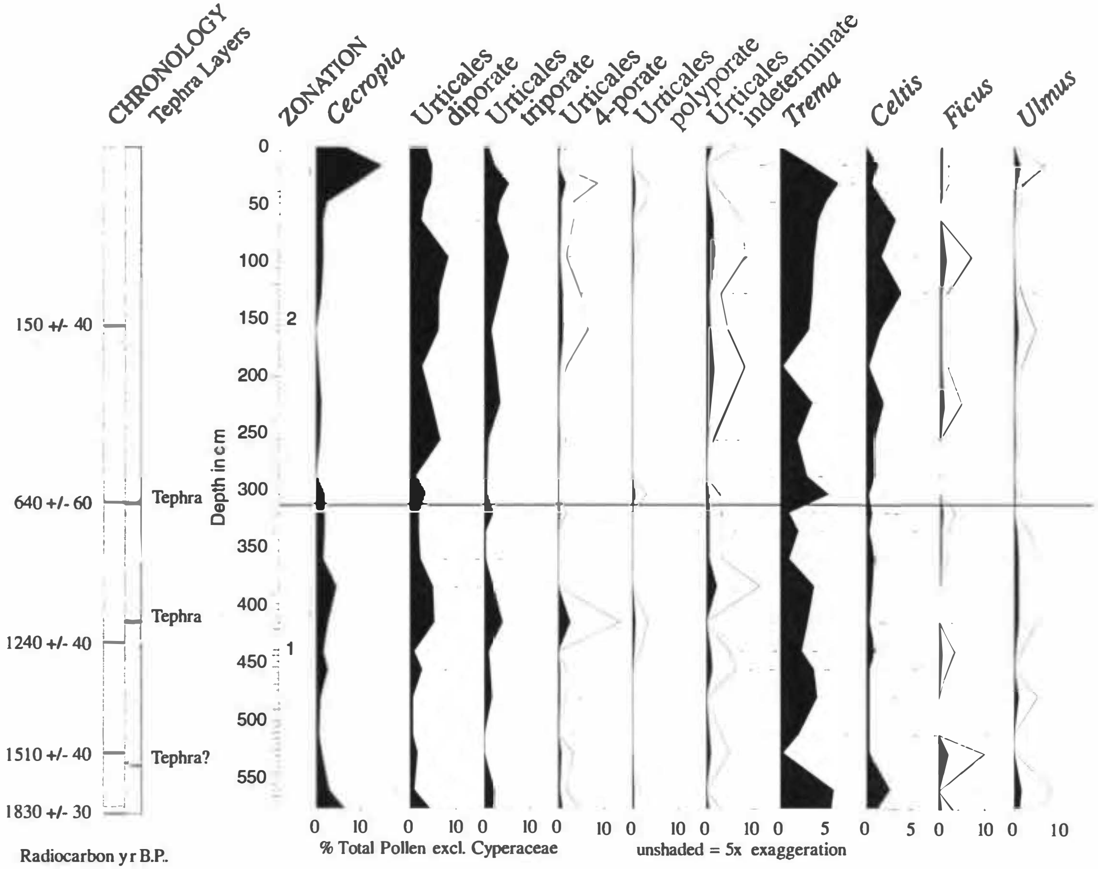

Figure 4.6 Laguna Santa Elena Urticales Taxa Diagram

Table 4.3 Results of Additional Maize Scans.

Depth	# slides	# grains	Grain (annulus) diameter
0	2	3	75 (13) 73 (12) 76 (15)
16	5	0	-
32	2	3	85 (12) 72 (18) 85 (16)
48	5	0	-
64	2	2	63 (12) 86 (17)
96	2	2	65 (12) 75 (14)
128	5	1	77 (14)
160	2	4	72 (13) 70 (13) 72 (14) 79 (13)
192	2	1	62 (11)
224	2	2	70 (13) 76 (15)
256	2	4	82 (?) 75 (?) 70 (13) 75 (15)
288	5	0	-
304	5	2	70 (13) 67 (15)
320	2	1	78 (14)
336	2	5	72.5 (15) 67.5 (12) 70 (13) 73 (12) 68 (13)
360	2	5	60 (10) 70 (16) 62 (12) 72 (12) 67 (12)
384	2	4	66 (14) 69 (12) 70 (17) 64 (11)
415	2	2	61 (13) 60 (9)
440	2	6	65 (12) 72 (15) 75 (13) 65 (13) 73 (14) 78 (15)
456	2	1	68 (14)
480	2	13	65 (15) 60 (12) 65 (12) 65 (10) 65 (13) 67 (?) 63 (14) 66 (14) 69 (12) 70 (17) 68 (13) 64 (13) 72 (17) 67 (11) 74 (14) 63 (13)
512	2	5	70 (13) 73 (12) 68 (15) 72 (12) 70 (14)
528	2	4	60 (13) 62 (14) 68 (13) 67 (12)
560	5	4	60 (12) 71 (13) 60 (11) 60 (10)
576	5	1	65 (13)
592	5	0	-
608	5	0	-
632	5	0	-
672	4	0	-

A (?) for annulus diameter indicates that it was too damaged to obtain an accurate measurement.

slides for the levels corresponding to near-modern sediments (16 cm and 48 cm), and ~510 cal. yr. BP (~1440 AD; 288 cm).

Fern Spores

I tallied a total of 2528 spores, including those that I classified as one of the two *Anthoceros*-types (Anthocerotophyta). Monolete psilate and trilete psilate were the most common morphotypes (23.3% and 24.1% of total spores, respectively) (Figure 4.7). A Trilete echinate-type was also abundant (8.7% of total spores), especially in Zone 1. The two *Anthoceros*-types also had their highest percent representation in Zone 1. Trilete spores tend to be more common in Zone 1, relative to monolete types, while monolete spores show increased representation in Zone 2, especially the most recent levels. Trilete *psilate* spores actually decreased in percent of total spores within Zone 1 relative to the basal sample of Zone 1 and all of Zone 2.

Charcoal

There was charcoal present in all 29 sampled levels (including the lower 4 levels, not shown, which had extremely low pollen content) (Figure 4.8). I counted over 70,000 individual charcoal particles with a maximum dimension greater than 25 μm. In the Santa Elena core, 10 out of 25 levels have total charcoal (>25 μm) concentrations greater than 1.0×10^6 particles/cm^3 of wet sediment. Zone 1 generally had higher charcoal concentrations, although the lowest pollen sample, 576 cm, had one of the lowest charcoal concentrations and pollen/charcoal ratios of the entire Santa Elena core.

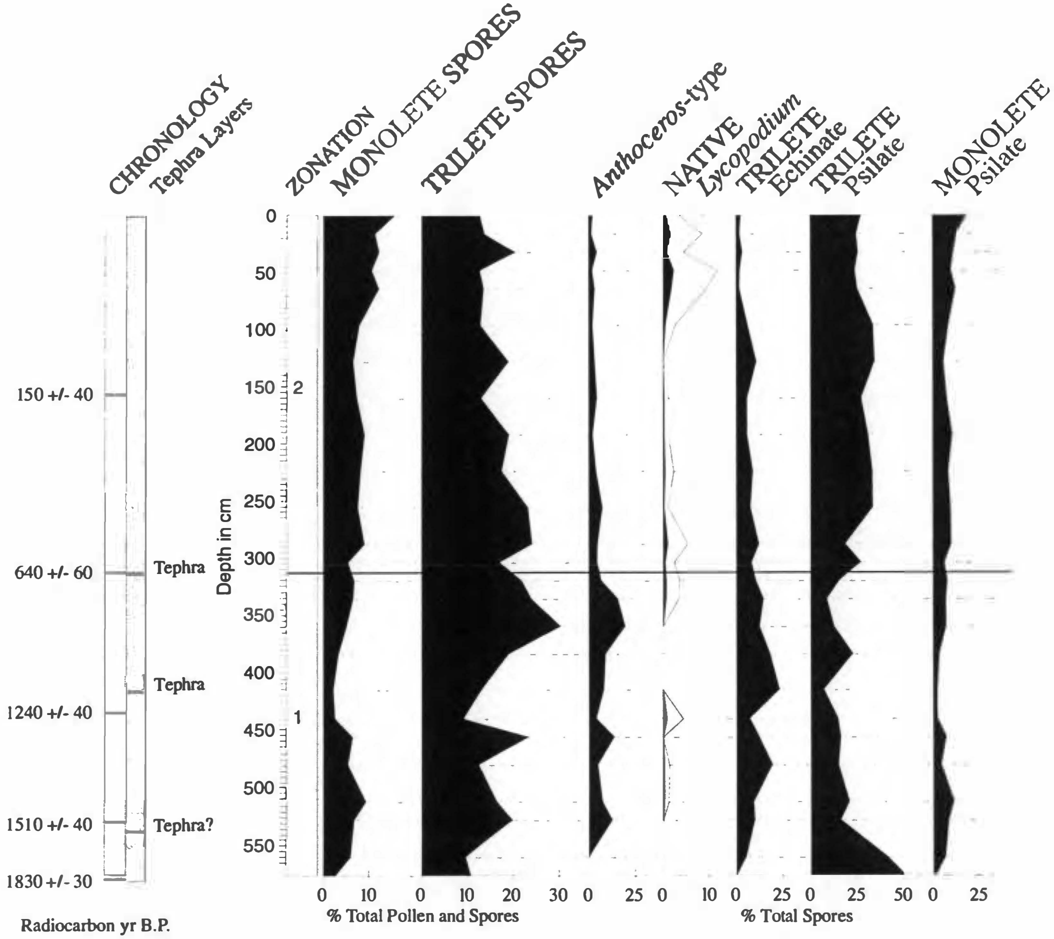

Figure 4.7 Laguna Santa Elena Spore Diagram

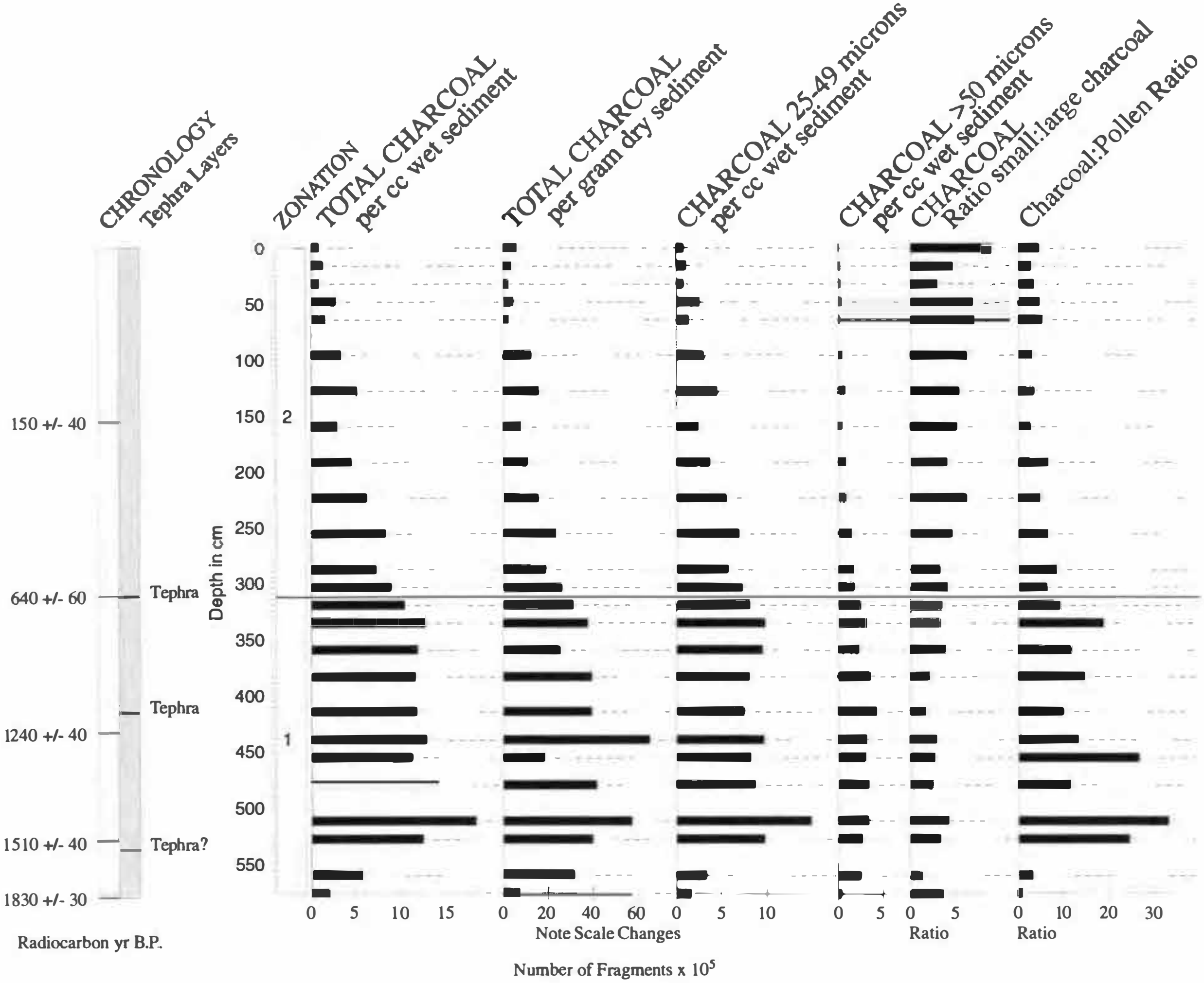

Figure 4.8 Laguna Santa Elena Charcoal Diagram

CHAPTER 5

DISCUSSION

The sediment record from Laguna Santa Elena provides multiple lines of evidence that contribute to an understanding of environmental and human history in southern Pacific Costa Rica. It provides information on the timing of recent eruptions of nearby Volcán Barú, on the presence of fire in tropical forests, on the cultivation of maize by prehistoric cultures in the region, and on forest dynamics related to human influence on vegetation. In this chapter, I discuss my interpretations of these various lines of evidence that form the paleoecological record of Laguna Santa Elena. I begin with a consideration of the geomorphic and stratigraphic evidence for the formation of the lake. I continue with my interpretation of the eruptive history of Volcán Barú and its archaeological importance. I then discuss changes within the pollen, charcoal, and sediment record. I synthesize these multiple lines of evidence into an interpretation of a nearly continuous but variable human influence on the vegetation of the Laguna Santa Elena watershed. Finally, I place the paleoecological record from Laguna Santa Elena in its regional context.

Lake Formation

The basal portion of the core that was recovered from Laguna Santa Elena contains evidence of the genesis of the lake. This part of the core (581 – 713 cm) is not lake sediment but rather soil that developed in place prior to the formation of the lake or was translocated as an intact unit in an earlier mass movement. Inspection of this material, along with geomorphic reconnaissance conducted in January 2002 and examination of air photos, indicate that the lake most likely formed as a consequence of the damming of a stream by a large slump-rotation event, probably originating from the ridgeline to the north of the lake with the slipface extending below the level of stream, and a series of associated landslides (Ken Orvis, personal communication).

Two radiocarbon dates at depths of 683 cm (1985 – 1823 cal. yr. BP) and 580 cm (1884 – 1717 cal. yr. BP) indicate that the lower portion of the core accumulated or was deposited rapidly. The upper part of the pre-lake unit (597 – 643 cm), a stratum of dark black (2.5 YR 2/0) coarse organic sediment with visible and partially decomposed plant material, is pollen-poor, which lends further credence to the theory that these materials were deposited quickly.

Above this soil stratum is a 16 cm layer of fine, light brown (2.5Y 5/2), mineral material (583 – 597 cm). Black rip-up clasts (10 YR 2/0) in the bottom of this layer (~594 – 597 cm) indicate that this mineral layer was deposited rapidly and with considerable horizontal momentum on top of the black organic layer, and probably represents a single, discrete event.

The stratigraphy of the core, in combination with the geomorphic evidence, indicates that at least one (possibly two or more) mass movement events into the stream channel caused the formation of the lake. The organic-rich layer (597 – 643 cm) may represent alluvial soils and vegetation near the former stream course that were covered by upstream spilling of debris from the landslide that blocked the stream and caused water (and subsequently lake sediments) to build up behind the natural dam. Alternatively, this layer may be a buried Histosol that had developed rapidly in a saturated environment that later became the lake. With its steep slopes and numerous tributaries, mass movements and fluvial processes are likely the most important modern components of landscape evolution in the Coto Brus region. Koshear (1995) reported observing a recent landslide that had created a lake by damming Quebrada Pita in the Guaymi Indian Reserve near San Vito. Slightly elevated percentages of Fabaceae pollen in the pollen level upcore from the landslide debris in the Santa Elena core may represent vegetation colonization of the slide by leguminous species, as Koshear (1995) observed at Quebrada Pita.

Barú Eruptions Recorded at Laguna Santa Elena

The Laguna Santa Elena core contains at least two, probably three, tephra layers (312 – 314 cm, 415 – 417 cm, and 538 – 539 cm). Volcán Barú in western Panama is the most likely source of this tephra since it is the closest stratovolcano to Laguna Santa Elena, and the only nearby volcano known to have been active in recent prehistoric times. Tephra identification was based on visual examination. The uppermost tephra deposit is well-dated by a radiocarbon date immediately upcore from it. The ^{14}C date for that eruption (640 ± 60 ^{14}C yr. BP.) intercepts the calibration curve at three points, 648, 581, and 568 cal. yr. BP, and the 2σ range is 675 – 532 cal. yr. BP (1275 – 1418 AD). This firmly places the most recent eruption of Volcán Barú prior to the arrival of the Spanish in the early 16th century. There is general agreement between the date obtained for the latest Barú tephra from the Laguna Santa Elena core, and from Laguna Volcán and Laguna Zoncho. Behling (2000) gives a 2σ range of 635 – 465 cal. yr. BP for the most recent tephra layer in his core from Laguna Volcán on the slope of Barú. In Laguna Zoncho (Clement and Horn 2001), the tephra layer is found approximately 20 cm above a radiocarbon date of 540 ± 60 ^{14}C yr BP (650 – 510 cal. yr BP).

A weighted average of the Laguna Volcán and Laguna Santa Elena uncalibrated radiocarbon dates (Long and Rippeteau 1974) gives a date of 570 ± 42 ^{14}C yr. BP (649 – 521 cal. yr. BP, 1301 – 1429 AD). Using the Stuvier *et al.* (1998) Method "B" (relative area under probability distribution), there is a ~60% probability that the actual date falls within the time period of 649 – 579 cal. yr. BP (1301 – 1371 AD), vs. ~40% probability for the more recent half of the calculated 2 sigma range.

The date delimited by the radiocarbon dates from cores from Santa Elena, Zoncho, and Volcán (ca. 1300 – 1430 AD) is in stark disagreement with the ca. 600 AD date given for Volcán Barú's most recent eruption in various publications concerning the prehistoric archaeology of western Panama (Linares *et al.* 1975, Linares 1980, Linares and Ranere 1980, Linares and Sheets 1980, Sheets 1980) and oft repeated in the archaeological literature (Hoopes 1996, Corrales 2000, Sheets 2001).[3] The Volcán and Santa Elena records clearly refute the assumption of a date of 600 AD for the latest eruption of Barú. Although Behling (2000) recognized that his Volcán core provided evidence of an eruption ~700 years later than previously reported, he seems not to have appreciated that his new date was problematic for the cultural chronology of Greater Chiriquí.

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[3] Haberland (1984b) seems to be the only investigator to have expressed skepticism about the purported 600 AD (1350 yr. BP) date given by many archaeologists for the most recent eruption of Barú:

> "Linares and associates ... think that a larger than usual eruption of the Volcán Barú was the beginning of the end of [Aguas Buenas] since a massive layer of pumice capped the Aguas Buenas occupation at Sitio Piti and at Barriles. This might be possible, but the eruption is obviously not dated directly and might have occurred later, since Barú has been active into historical times."

The source of the 600 AD date may be Stewart (1978). Although in his report he gives a radiocarbon age of 740 ± 150 yr. BP (1210 AD ± 150) for the most recent Barú eruption, there are additional dates reported from Sitio Piti in Panama in the range of 600 AD. However, the strata these dates were taken from do not seem to date the ash and pumice deposits, but rather several of the excavated levels containing cultural material. The only radiocarbon determination that seems to accurately date a tephra layer is from Barriles (BU-24, Cut #2; I-7263), which is the origin of the 1210 ± 150 AD date.

Behling (2000) reports two additional dates for eruptions of Volcán Barú at 1055 – 780 cal. yr. BP (1020 ± 60 ^{14}C yr. BP) and 1830 – 1560 cal. yr. BP (1790 ± 50 ^{14}C yr. BP). The first of these corresponds well to the interpolated date of ~1080 cal. yr. BP (~870 AD) for the same eruption in Laguna Santa Elena (415 – 417 cm. However, the oldest eruption recorded in Laguna Volcán does not match well with the interpolated date of ~1440 cal. yr. BP (510 AD) from Santa Elena. There are several possible explanations for this discrepancy. First, it is possible that the tephra layer in the Santa Elena core is volcanic material from an earlier eruption that was reworked from the shore and redeposited in the lake. I consider this unlikely, however, since the well-defined, sharp boundaries of the tephra layer with respect to the lake sediments above and below it suggest that this is not secondary deposition. It is also possible that the material is not tephra. However, under microscopic inspection, the layer appears to be composed of unsorted, angular (unweathered) quartz and tourmaline (M. Arford, personal communication), and not the rounded weathered grains that would be expected from fluvial deposition. If the material is indeed tephra that was deposited by airfall, then at least one of the dates determined for the antepenultimate eruption of Barú from the Volcán and Santa Elena cores is incorrect.

Behling (2000) relied on bulk sediment for his radiocarbon assays from Laguna Volcán. The date for the oldest of the three eruptions of Barú comes from dating of sediments immediately below the 1.5 cm-thick tephra layer. Volcán is a small lake (one hectare), although slightly larger than Santa Elena. However, while Santa Elena has 7.13 meters of sediment in a nearly 2000-year record, Volcán has only 1.28 meters with a basal date of 2860 ± 50 ^{14}C yr. BP. The two oldest Barú eruptions, as recorded in Laguna Volcán, are physically only 5 cm apart, and yet are dated ~800 yr. apart. For a small lake where pollen evidence suggests land clearance and agriculture, this extremely slow sedimentation seems unusual.

I suggest that the determination of the oldest eruption of Barú recorded in Laguna Volcán is problematic. One or more radiocarbon dates from Laguna Volcán may be misleading, perhaps due to the introduction of radioisotopically "dead" carbon related to volcanic activity. Alternatively, the seemingly unusual sediment accumulation rate may point to a discontinuity in the stratigraphy of the Laguna Volcán. Volcán is small in area, but 12 meters deep, suggesting a steep-sided bathymetry that may be prone to underwater sliding.

Based on the Santa Elena core, it appears that the last three eruptions of Barú occurred approximately 580, 1080, and 1440 cal. yr. BP (1370, 870, and 510 AD). These ages, derived from analysis of the Laguna Santa Elena sediments, may provide useful time markers for ongoing archaeological work in the region. Furthermore, the date of the ultimate eruption of Barú as determined from the Santa Elena record calls for a reexamination of the interpretation of archaeological excavations in western Panama that assumed a ca. 600 AD eruption of Barú.

Forest Disturbance and Succession at Laguna Santa Elena

With a modern surface area of only ~0.25 hectare, and a prehistoric area no more than 1 hectare, the pollen record from Laguna Santa Elena predominantly represents local vegetation composition. Following the pollen-source area models of Jacobson and Bradshaw (1981), Sugita (1994), and Prentice (1985), Santa Elena should be expected to receive a higher percentage of local pollen, as opposed to pollen from a larger, regional area. However, Jackson and Lyford's (1999) model shows that unstable atmospheric conditions and topography can increase the effective dispersal range of taxa. *Quercus* or *Alnus* trees, therefore, occupying ridgeline positions, might disperse their pollen beyond their expected range. Given Santa Elena's position at the foot of the Talamanca range with its montane *Quercus* forest, it is not possible to rule out long-distance transport and deposition of montane forest pollen types in the lake basin. This could be reflected in the percentages of *Quercus*, *Alnus*, and *Weinmannia* in some levels. Overall, however, I expect that the pollen record from Santa Elena reflects mostly local pollen rain, and that the highest percentage of total pollen is from within a few hundred meters of the lake. Bush (2000) demonstrated that downslope transport of pollen should not be a significant contribution to the pollen record in Central American lake sediments.

Peterson and Haines (2000) investigated succession in abandoned pastures in premontane Costa Rica, and found considerable variation in species composition of early colonizers. Dominant species at their study sites included *Miconia* (Melastomataceae), *Croton* (Euphorbiaceae), and Asteraceae. Kappelle's (1993) study of successional stages in tropical montane *Quercus*-dominated forest in the Cordillera de Talamanca (>2000 meters elevation) found common early pioneer species to include Asteraceae, *Bocconia* (Papaveraceae), and Polygalaceae. Early secondary species included Melastomataceae (including *Miconia*), *Hedyosmum* (Chloranthaceae), *Ilex* (Aquifoliaceae), and *Oreopanax* (Araliaceae). There was considerable overlap between late secondary and primary forest taxa in the Kappelle (1993) study. Late secondary taxa included Myrsinaceae, *Zanthoxylum* (Rutaceae), and Myrtaceae, while primary forest taxa included Melastomataceae, Araliaceae (*Oreopanax* and *Schefflera*), Rosaceae, Clusiaceae, Myrsinaceae, Rhamnaceae, *Zanthoxylum* (Rutaceae), and Fagaceae (*Quercus*). Holl's (1999) study of forest and pasture at Las Alturas, northeast of Laguna Santa Elena and five hundred meters higher in elevation, found forest taxa to include *Ocotea* (Lauraceae), *Prunus* (Rosaceae), *Piper* (Piperaceae), and *Ficus* (Moraceae). Pasture colonizers included *Psychotria* (Rubiaceae), *Solanum* (Solanaceae), and *Miconia* (Melastomataceae). *Solanum* was found close to the forest edge. Kappelle and Zamora (1995) found the greatest diversity in lower montane forests within the families Rubiaceae, Lauraceae, Melastomataceae, and Myrsinaceae. Genera that were particularly diverse included *Piper*, *Miconia*, and *Solanum*. At 2000 meters elevation, Kappelle and Zamora found that the forest included species of *Alchornea*, Araliaceae, *Hedyosmum*, *Miconia* and other Melastomataceae, *Sapium*, *Tovomitopsis*, Asteraceae, Rubiaceae, Solanaceae, and Myrsinaceae.

Disturbance taxa in the Laguna Santa Elena record include Poaceae, Asteraceae, *Zea mays*, Amaranthaceae, and *Mimosa pigra*-type Fabaceae. Taxa that may be indicative of forest regrowth are Melastomataceae-Combretaceae, *Alchornea*, *Piper*, and *Hedyosmum.* Taxa that could be considered successional include Rubiaceae, Solanaceae, Melastomataceae, *Bocconia*, Polygalaceae, and Asteraceae. There are also taxa which may be indicative of either successional/secondary or primary forest, including *Alchornea*, Araliaceae, Melastomataceae-Combretaceae, *Hedyosmum, Weinmannia, Zanthoxylum,* and *Piper*. The fact that certain taxa are found in several or all stages of secondary growth means that individual taxa identified in the Santa Elena core are not necessarily diagnostic of a specific successional stage. Taxa or groups of species comprising pollen taxa may occupy a number of positions along altitudinal, climatic, and seral gradients. Therefore, interpretation of forest composition and land-use is based on a composite assessment of taxa and other evidence (charcoal, sedimentation rates, maize).

Pollen taxa identified in the Laguna Santa Elena core that represent premontane and montane forest taxa are *Quercus* (Fagaceae), *Alnus* (Betulaceae), *Ulmus* (Urticales-Ulmaceae), *Myrica* (Myricaceae), Myrsinaceae, *Podocarpus* (Podocarpaceae), *Ilex* (Aquifoliaceae), *Hedyosmum* (Chloranthaceae), *Weinmannia (Cunoniaceae*), Araliaceae, and *Alfaroa* (Juglandaceae) (Rodgers and Horn 1996, Bush 2000). However, as mentioned previously, some of these taxa would be expected to appear in early successional stages after the abandonment of agricultural areas. Some forest taxa pollen might represent relicts left standing in fields while other forest trees and shrubs were cleared.

The basal pollen sample at 576 cm (~1780 cal. yr. BP) contains the highest percentage of total premontane-montane taxa, indicating a mostly intact, mature premontane forest surrounding Laguna Santa Elena following lake formation. Low amounts of Poaceae, Asteraceae, and Cyperaceae, and significant percentages of *Quercus*, *Hedyosmum*, *Alchornea*, Melastomataceae-Combretaceae, *Piper*, Myrsinaceae, *Ulmus*, *Trema*, *Celtis*, and diporate Urticales, indicate significant areas of primary forest dominated by trees and shrubs. The pollen and charcoal spectra from the remainder of Zone 1 indicate clearing of forests around the lakeshore, burning of biomass, and maize cultivation. Three levels within Zone 1, however, do show spikes in the percentage of *Quercus* pollen in the core (415 cm, 480 cm, and 560 cm). While these could represent long-distance and/or downslope transport of pollen, the lack of similar spikes in other wind-pollinated, montane forest taxa suggests that the *Quercus* pollen in the lower two levels (480 and 560 cm) is from the vicinity of the lake. Moreover, in his study of modern pollen in Costa Rica and Panama, Bush (2000) found that there was not significant downslope transport of the pollen of montane forest elements into lower elevations. The upper spike (415 cm) of *Quercus* pollen occurs at the same time as other forest tree taxa such as *Alnus* and diporate Urticales also increase and disturbance indicators decrease, which I interpret to indicate that forests within the Santa Elena watershed began to regenerate at this time. The lower *Quercus* spike (560 cm) coincides with higher percentages of other forest taxa including *Hedyosmum*, which probably reflects incomplete clearing of the watershed or long fallow periods that allowed substantial recolonization of agricultural fields or *milpas* by forest trees.

Very high percentages of both Poaceae and Cyperaceae in some levels probably indicate hydrarch succession within the lake. For example, somewhat higher sedimentation rates after ~1680 cal. yr. BP probably led to infilling of the lake edge, on which a fringing marsh environment of grass and sedges established. Some percentage of

Poaceae pollen therefore may correspond to this near-lake marsh, and not to agricultural fields (Bush 2002). However, hydrarch succession at Laguna Santa Elena could also be considered as further evidence of intensive human land use around the lake, since accelerated soil delivery to the lake basin as a consequence of land clearance for agriculture would lead to more rapid hydrarch succession (Bush 2002). Abrupt changes in the ratio of Poaceae/Cyperaceae in the lower part of the core (560 cm) likely correspond to the rapid, initial clearing of the forest around the lake for agriculture. Extremely low (<1%) Cyperaceae levels at 64 and 48 cm (near-modern sediments) may be related to the partial draining of the lake in the mid-20th century, which would have reduced or eliminated the fringing marsh for a period of time. Higher percentages of trilete echinate and *Anthoceros*-type spores may also be related to forest clearance for agriculture, hydrarch succession, or both, since they coincide with high percentages of Poaceae and Cyperaceae in Zone 1. Spores of *Anthoceros* species have been found in context with prehistoric disturbance and cereal pollen in the Netherlands, and their presence there was interpreted to correlate with agriculture (Koelbloed and Kroeze 1965).

Poaceae pollen shows a short period of lower percent representation in the levels corresponding to ~1080 – 930 cal. yr. BP (~870 – 1020 AD; 415 and 384 cm). Simultaneously, there are increases in *Alnus*, *Quercus*, *Cecropia*, diporate and triporate Urticales, 4-porate and polyporate Urticales, and other successional taxa, as well as a slight decrease in charcoal concentrations. This suggests a possible reduction in the intensity or extent of agriculture around Santa Elena, although maize pollen remains in the pollen record. These levels are also immediately upcore from the eruption of Barú dated to ~ 1080 yr. BP.

A decline in Poaceae pollen percentages and an increase of forest taxa actually occurs before both the ~580 cal. yr. BP eruption of Barú and the apparent temporary abandonment of Santa Elena at ~510 cal. yr. BP (288 cm). Poaceae pollen declines rapidly between ~700 cal. yr. BP and 510 cal. yr. BP, while *Hedyosmum*, Melastomataceae-Combretaceae, *Weinmannia*, and *Trema* increase. This agrees broadly with the paleoecological records from Zoncho and Volcán, which also show a decline in disturbance taxa and a rise in forest and successional taxa percentages. The concurrence between the records suggests a region-wide phenomenon potentially connected to political and/or economic changes in prehistoric cultures.

One interesting aspect of the Santa Elena record is the lack of significant percentages of *Cecropia*, especially in levels in which disturbance taxa are abundant. *Cecropia* (~2.3% of total pollen in the Laguna Santa Elena core), is commonly identified in Neotropical lowland records as evidence of disturbance (Piperno *et al.* 1990, Bush and Colinvaux 1994, Northrop and Horn 1996, Colinvaux *et al.* 1999, Bush 2000, Bush *et al.* 2000), although Bush's (1991) modern pollen study found 20% of sampled Amazon sites contained no *Cecropia* pollen. *Cecropia* percentages reach as high as 30% at Laguna Zoncho, while the highest percentage at Santa Elena is only ~10%. However, the Santa Elena record does agree somewhat with the qualitative representation of *Cecropia* in both Zoncho and Laguna Volcán. During periods in which evidence for intensive or extensive agriculture exists (disturbance taxa, *Zea mays*, charcoal), *Cecropia* levels tend be low at all three lakes. In fact, *Cecropia* percentages are consistently less than 5% of total pollen at Laguna Volcán until after the lake was apparently abandoned ~580 cal yr. BP. Only at that point does *Cecropia* pollen reach or exceed 20%. At Laguna Zoncho, the highest

Cecropia percentages are found when other disturbance indicators *decline*. *Cecropia*, while predominantly at levels of 10% or greater throughout the Zoncho record, is at its lowest percent representation when other indicators of disturbance are highest. This pattern holds true for Santa Elena. Higher *Cecropia* rates are found in the lowest pollen level (576 cm), where the pollen spectra indicate mostly intact premontane/montane forest (with a recent landslide scarp), and also to the most modern levels. The mid-elevation records from small lakes in southern Pacific Costa Rica and western Panama demonstrate that *Cecropia* may actually be a better indicator of long-fallow, less intensive use of the land or even normal ecosystem disturbance and successional dynamics in the absence of extensive human interference. Clement and Horn (2001) concluded that relatively low percentages of *Cecropia* reflected suppression of successional pathways during intensive human use of the area around Laguna Zoncho. My interpretation of the Laguna Santa Elena record agrees with this conclusion.

In Zone 2, despite the continued presence of human farmers on the landscape (as evidenced by the presence of maize pollen in the core, see below), forests in the region around Santa Elena begin to regrow. Secondary succession is represented by significant increases in *Alchornea*, Melastomataceae-Combretaceae, and *Weinmannia*, and by somewhat higher percentages of forest taxa including *Hedyosmum*, *Celtis*, and several types of Urticales.

Maize Agriculture

Maize is present in all but three of the 25 pollen-rich levels sampled from Santa Elena. Maize pollen is large, and under normal conditions will not disperse far from the plant. Raynor *et al.* (1972) found that most maize pollen falls within 60 meters of the plant (only 5% of pollen remained airborne 60 meters from the plant). Maize pollen dispersal is similarly limited under Jackson and Lyford's (1999) calculation of pollen dispersal incorporating atmospheric conditions, distance, and the sedimentation velocity of pollen grains. Maize has extremely high sedimentation (or settling) velocities at 18 – 30 cm/s (DiGiovanni *et al.* 1995, Jackson and Lyford 1999), and therefore the percent of pollen remaining airborne at increasing distance from the plant rapidly approaches zero. Jackson and Lyford (1999) demonstrate, however, that atmospheric instability (turbulence and gustiness) can substantially increase the percentage of pollen that remains airborne at any given distance. Maize pollen grains in the sediments of Laguna Santa Elena most likely indicate cultivation in the immediate vicinity of the lake, although under particularly turbulent conditions maize pollen could still be dispersed in significant amounts beyond a 60 meter radius (Jackson and Lyford's (1999) model predicts several orders of magnitude difference in dispersal percentages depending on atmospheric conditions). The presence of maize pollen is good evidence of agricultural occupation of a watershed, but the absence of maize pollen in any level is not necessarily evidence that it was *not* being cultivated nearby. Thus, although maize is indicative of human cultivation, caution is still warranted in its interpretation and it must be considered in light of other lines of evidence.

The earliest known pollen record of maize, dated to ~7000 cal. yr. BP, is from the San Andres site on the Gulf Coast of Mexico (Pope *et al.* 2001). Earlier microfossil records of maize depend largely on phytoliths (Piperno and Clary 1984, Piperno *et al.* 1985), some with questionable chronological control (Fritz 1994). The oldest known macroscopic remains (carbonized cobs) are from highland Oaxaca and are directly dated by AMS to ~5400 cal. yr. BP (Piperno and Flannery 2001). The earliest macrobotanical maize in Costa Rica comes from the northwestern part of the country near Volcán Arenal (dated to 4450 ± 70 ^{14}C yr. BP, 3360 – 2920 cal. yr. BP), and appears to actually predate that region's Formative, Early Ceramic Tronadora Phase (4000 – 2500 yr. BP) (Bradley 1994, Mahaney *et al.* 1994). Arford (2001) found a single maize pollen grain in Lago Cote in northwestern Costa Rica at a depth corresponding to ~3900 cal. yr. BP. Horn and Kennedy (2001) found maize pollen in a core from La Selva Biological Station beginning about ~2700 cal yr. BP.

The Santa Elena pollen record is too short to further our understanding of the timing of the arrival of maize in Greater Chiriquí. Maize is present in the lowest sampled level with adequate pollen concentrations (576 cm, ~1790 cal. yr. BP). Maize pollen was present in nearly all levels of the ~3000 year record from Laguna Zoncho (Clement and Horn 2001), and Behling (2000) reports maize after ~1780 cal. yr. BP at Laguna Volcán. Longer paleoecological records are needed from southern Pacific Costa Rica and western Panama in order to definitively establish the arrival of maize in the region. The absence of maize in the level dated to approximately ~510 cal. yr. BP (288 cm) may represent a temporary abandonment of the site, near the time of the arrival of the Spanish and after the most recent eruption of Volcán Barú. The two samples in the upper section of the core (16 and 48 cm) that lack maize pollen may represent a lack of human occupation of the Laguna Santa Elena watershed at that time. Alternatively, the absence of maize could be the result of the establishment of commercial coffee agriculture in the region, which would have made landowners less likely to grow their own subsistence crops.

Sedimentation in Laguna Santa Elena

Sedimentation rates derived from radiocarbon dating of the core reveal several distinct periods of deposition (see Figure 4.1 and Table 4.2). As discussed above, portions of the bottom of the Santa Elena core accumulated rapidly, through a possible combination of alluvial deposition and mass movement. With the formation of a permanently inundated lake basin, lake sediments began to accumulate at a relatively slow average rate of 0.12 cm/year. The pollen spectra that coincide with the earliest lake sediments show high pollen concentrations and indicate the presence of largely intact premontane forests.

However, not long after the formation of the lake, sedimentation became much more rapid. Between approximately 1400 and 1100 cal. yr. BP (530 – 434 cm), high amounts of charcoal and Poaceae in the core, and low pollen concentrations, correspond to a period with an average sedimentation rate of 0.42 cm/year. More rapid sedimentation during this period almost certainly was in part the result of replacement of lakeshore forests with cleared land for agriculture. Sedimentation rates slow somewhat between ~1100 – 600 cal. yr. BP, to a calculated average of 0.21 cm/yr. This period partially corresponds to a temporary reduction in disturbance pollen in the core.

Increases in forest taxa around the lake at this time likely slowed erosion rates and deposition in the lake basin.

Beginning at a depth of 312 cm (~580 cal. yr. BP), sedimentation rates increase upcore through to modern times. Using an average of the calibrated dates from the uppermost radiocarbon-dated sample, rates of sediment accumulation appear to average 0.36 cm/yr between 312 and 156 cm (~580 – 140 cal. yr. BP) and 0.81 cm/yr between 156 and 0 cm (~150 cal. yr. BP – present). However, this uppermost radiocarbon date is relatively recent, and its calibration gives a wide range of possible true ages (290 – 0 cal. yr. BP). It is therefore difficult to determine exactly how quickly sediment accumulated in Laguna Santa Elena during various periods since 580 cal. yr. BP. Overall, however, sedimentation in the upper part of the core was rapid, even accounting for compaction, with over 3 meters of deposition in approximately 600 years (an overall average of 0.50 cm/yr).

Sedimentation rates determined for Lake Salpeten in the Peten District of northern Guatemala (Leyden 1987) are instructive in assessing the relative rate of lake sediment deposition at Laguna Santa Elena. Salpeten, located in the heartland of prehistoric Maya civilization, contains a Holocene record of vegetation change and human landscape disturbance. Pre-Maya and early Pre-Classic Maya sediments in the lake accumulated at an average rate of 0.027 cm/yr. Sedimentation rates during the height of Maya civilization range from 0.263 – 0.62 cm/yr., with the highest rate occurring during the Late Classic Period. Post-Maya sediments accumulated at a high rate as well (0.42 cm/yr) which Leyden (1987) interprets as indication of the long-lasting effects of human disturbance of the ecosystems of the Peten, even after the depopulation of the area and the "collapse" of Maya civilization.

Sedimentation in Laguna Santa Elena demonstrates a similar trajectory to Lake Salpeten. The early stages of colonization of the lakeshore have low rates of sediment deposition, with forest dominating the pollen spectra even though evidence (in the form of a single grain of maize) attests to human presence on the landscape. With the clearing of the forest around Laguna Santa Elena, soil erosion increased and so did deposition in the basin. Nutrient flux to the lake would also have been altered by the conversion of the watershed to an agricultural landscape. Even when extensive clearance and maintenance of agricultural fields subsided (although Laguna Santa Elena was only temporarily abandoned if it was abandoned at all) sedimentation rates remained high as the effects of human alteration of the landscape persisted. High sedimentation rates during Post-Conquest times may represent a combination of the long-term consequences of anthropogenic forest disturbance and a continued, although less intensive occupation of the lake shore. The juxtaposition of apparently lower rates of erosion during the height of Chiriquí Phase settlement in the vicinity of Santa Elena and higher rates after European contact suggests the intriguing possibility that erosion-prevention techniques were practiced during Precontact phases that were subsequently lost or forgotten in the chaos of the Conquest period. No such modification of agricultural landscapes, such as terracing or check dams, have been identified in the Greater Chiriquí region, although archaeologists do report retaining walls and other engineered features in Chiriquí Phase sites (Corrales *et al.* 1988, Drolet 1992).

Fires at Laguna Santa Elena

The Laguna Santa Elena core contains evidence of the occurrence of fires in the form of charcoal particles within the lake sediments. In 10 of 25 levels, total charcoal (larger than 25 μm) concentration reaches >1.0x10^6 particles/cm^3 of wet sediment. In the Laguna Zoncho core, which had abundant charcoal in some prehistoric levels, maximum charcoal concentration was ~2.0x10^6, but charcoal tallies included pieces <25um (Clement and Horn 2001), and only 8 levels equal or exceed 1.0x10^6 fragments per cc wet sediment.

Sanford *et al.* (1985) found charcoal in soil profiles from the upper Rio Negro region of the Venezuelan Amazon, and subsequent radiocarbon dates revealed that the region had experienced forest fires for at least the preceding 6000 years. This, and subsequent studies, forced a general reassessment of the previous paradigm of tropical rainforests as ecosystems undisturbed by fire except in modern times.

Numerous records of Holocene fires in the Neotropics now exist. At Lake La Yeguada in Central Panama, approximately ~11,000 yr. BP, charcoal concentrations increase rapidly by an order of magnitude from previously negligible levels (Bush *et al.*, 1992). The authors attribute this to human activity. Bush and Colinvaux (1994) show a ~3800 year record of human disturbance and charcoal evidence for biomass burning in eastern Panama. Lake Geral in eastern Amazonia contains a sediment record of 7500 years of fire, with nearly negligible levels from 7500 to 5800 yr. BP, followed by a rapid and dramatic increase after 5800 yr. BP (Bush *et al.* 2000). Nearby Lake Comprida, however, shows only periodic spikes in charcoal concentrations interspersed with significant periods without fire. Two substantially different charcoal records occurring in lakes in close proximity lead the authors to conclude that the different fire regimes in the watersheds of the lakes are due to differing levels of human impact – that the area around Lake Geral was relatively densely settled, while Lake Comprida experienced only periodic human influences.

In Costa Rica, evidence of climate-modified fire regimes comes from Horn and Sanford (1992). Charcoal from high altitude páramo lakes and rainforest soils at La Selva Biological Station both cluster around two periods: 2430 yr. BP and 1110 – 1180 yr B.P. This suggests that, as the authors point out, overall drier climate conditions led to more extensive burning during certain times in the Holocene. Many tropical paleorecords show dramatic increases in charcoal simultaneous with other evidence for a human presence on the landscape (Bush *et al.* 1992, Bush and Colinvaux 1994, Kershaw *et al.* 1997, Dunning *et al.* 1998, Behling and Lima da Costa 2000, Bush *et al.* 2000, Haberle and Ledru 2001).

Kauffman *et al.* (1988) and Uhl *et al.* (1988) show that, under normal climate conditions of significant humidity and extremely moist microclimates, intact tropical forests are non-flammable. Drought, either century- or millennial-scale aridity forced by large-scale phenomena, or relatively short but potential severe drought brought about by periodic interannual events such as El Niño, is frequently cited as a cause of increased biomass burning in the past. Indeed, the occurrence and severity of tropical fires in modern times has increased dramatically during ENSO related droughts in Southeast Asia and the Amazon (Sanford *et al.* 1985, Hammond and ter Steege 1998, Kinnaird and O'Brien 1998, Nepstad *et al.* 1998, Uhl 1998, Laurance and Fearnside 1999, Laurance 2000). However, *intact* rainforests can remain fire-free even during severe ENSO-driven droughts (Uhl and Kaufmann 1990, Hammond and ter Steege 1998, Nepstad *et al.* 1998). Studies of tree mortality during drought from Panama and Amazonia reveal that, despite some statistically significant increases in mortality, individual trees and forests as a whole have a considerable ability to tolerate and survive even severe dry periods (Condit *et al.* 1995, Williamson *et al.* 2000). Moreover, the study by Williamson *et al.* (2000) shows that mortality rates returned to normal immediately following severe drought years.

Uhl *et al.* (1988) were able to experimentally induce flammable conditions in fuel biomass in open canopy and younger, short canopy forest stands after excluding rainfall for 4 to 6 days. However, even after 41 days of artificially excluding rainfall, they were unable to ignite fuel loads in tall, closed canopy forests. Stand microclimates in these intact forests prevent fuel drying by maintaining high relative humidity even in the absence of precipitation.

The presence of humans within Neotropical forests could create the necessary conditions for rainforest fires. First, in the past as in the present, human activity in the rainforest could have increased opportunities for fuel biomass to dry, increased ignitions sources, and altered forest stand structure to be more susceptible to carrying fires. Even if humans were not engaged in actively burning the landscape, subsistence activities that created or maintained gaps in the canopy or changed the structure of the forest could have contributed to increasing fire susceptibility.

Once fire has occurred in a tropical rainforest, it is more likely to occur again. Succession following fire is likely to involve early colonizing species – grasses, lianas and vines (Pinard *et al.* 1999) – that are more flammable that mature forest. Furthermore, forest edges bordering previously burned or cleared areas may act as a medium for carrying fire deeper into intact forests (Gascon *et al.* 2000). Incursion of fire into forest edges creates a progressively wider and denser band of secondary succession, which itself has an increased likelihood of fire, resulting in rapid encroachment of fire into intact forest (Didham and Lawton 1999). Fire intrusion into closed canopy rainforest can initiate positive feedback conditions as well. Even minor ground fires, perhaps enabled by fuel drying and combustion along forest edges, can kill a significant portion (~95%) of even mature rainforest trees (Uhl and Kauffman 1990, Cochrane *et al.* 1999). Standing dead trees subsequently provide increased fuel load as woody debris falls to the forest floor. This renewed fuel load, allowed to dry due to the newly opened canopy, increases dramatically the probability that this forest will burn again, and burn more catastrophically. In previously burned forest, Cochrane and Schulze (1999) calculated that as little as nine rain-free days could result in flammable conditions, awaiting only a natural or human ignition source.

Even with evidence of the existence of Neotropical forest fires in the Holocene present in the paleorecord, the exact interpretation of charcoal fragments from sediment cores for determining the temporal and spatial element of fire events remains a contentious issue. While conventional wisdom holds that microscopic charcoal in lake sediments is from more distal fires, and macroscopic charcoal from local fires, Pitkanen *et al.* (1999) found that local fires in Finland deposited abundant microscopic fragments as well. They concluded that charcoal ranging from 50 μm to 600 μm could represent very local fires or fires kilometers away. Even the smallest particles (<50 μm) could be from local fires, although small particles have a potentially large, regional-scale source area (Pitkanen *et al.* 1999). Chemical and mechanical processing of sediments for palynology can break up charcoal fragments, minimizing the usefulness of size classification for the determination of the proximity of fires to a lake core site (Clark 1984).

In temperate Europe, Blackford (2000) and Ohlson and Tryterud (2000) found that macroscopic charcoal was good evidence of local fires, while Ohlson and Tryterud (2000) determined that the *lack* of macroscopic charcoal was not good evidence for the lack of local fires, since in several cases, even within the perimeter of a forest fire, soil samples revealed no macroscopic charcoal. Even macroscopic charcoal may be problematic in identifying the occurrence of local fires from lake sediments, since Gardner and Whitlock (2001) found macrocharcoal that didn't correspond to any known fire in the watershed of their study site in Oregon, USA. Macroscopic charcoal can be transported considerable distances (Earle *et al.* 1996, Whitlock and Millspaugh 1996), possibly by atmospheric conditions and winds created by the fires themselves (Clark 1988). Additionally, charcoal may be reworked from soil or sediments and redeposited in the lake basins as much as 30 years or more after a fire event (Whitlock and Millspaugh 1996, Gardner and Whitlock 2001).

All this complicates considerably the task of the paleoecologist in interpreting charcoal fragments in lake sediments. This is doubly true for tropical paleoecologists working in regions for which few, if any, taphonomic studies on charcoal deposition exist. For this reason, I am cautious in my interpretation of the charcoal record in the Laguna Santa Elena core. High concentrations of charcoal in parts of the record point toward considerable burning during phases of human occupation of the Santa Elena watershed and the surrounding Coto Brus region. However, only qualitative assessments can be made as to the timing and spatial extent of biomass burning in the past.

In Zone 1, there is evidence that, immediately following the genesis of the lake, there was little charcoal deposition and little forest burning in the immediate vicinity of Santa Elena. Even with slow sedimentation rates in the lower portion of the core, the lowest levels of the core show the some of the lowest charcoal concentrations in the entire record. Charcoal:pollen ratios are also extremely low in the basal levels. I interpret this to mean that the immediate vicinity of Laguna Santa Elena saw minimal burning in the early part of the sediment record. However, by 528 cm (~1400 cal. yr. BP) charcoal concentrations and charcoal:pollen ratios had increased dramatically. High charcoal concentrations persist throughout Zone 1, with charcoal:pollen ratios as high as 25:1, indicating considerable biomass burning. The contemporaneous nature of high charcoal concentrations, maize pollen, and high percentages of disturbance indicators strongly suggests humans as the cause of fires during this period.

There is nothing in the pollen or charcoal evidence at Santa Elena that suggests a climatic influence on wildfire, although we cannot rule one out. Total charcoal concentrations, as well as concentrations for both size charcoal size classes, become progressively lower in Zone 2, reaching their lowest levels in modern sediments. This is likely indicative of lower populations around the lake and decreased burning for agriculture. The charcoal decline in the most recent sediments is probably partially attributable to rapid sedimentation rates, and partly to the advent of commercial coffee agriculture and cattle raising, which do not require landowners to use fire for the maintenance of agricultural fields.

Synthesis of Human and Environmental History at Laguna Santa Elena.

The Laguna Santa Elena record contains evidence of the human occupation of the lakeshore, from shortly after the genesis of the lake through to modern times with only brief hiatuses. The oldest pollen levels in the core indicate that initial land use around the lake by prehistoric peoples probably took advantage of natural clearing around the lake, the stream, or in the forest. Forest alteration at Santa Elena was relatively minor until ~1400 cal. yr BP, when grass pollen and charcoal percentages increase dramatically. Spikes in *Quercus* pollen during periods of abundant grass and charcoal may reflect a combination of relict trees left standing in cleared areas and long-distance transport. Agriculture around the lake continued unabated until ~510 cal. yr BP (~1440 AD) when the apparent absence of maize pollen in the core signals a possible temporary hiatus in human occupation. Forest regrowth, however, began even before this time. The area around Laguna Santa Elena continued to be occupied even after the eruption of Barú ~580 cal. yr. BP (~1360 AD), as evidenced by the continued presence of maize in the pollen record. During the period of prehistoric settlement, there was a short period (~1080 – 930 cal. yr. BP; 870 – 1020 AD) when disturbance taxa and charcoal decreased while forest and successional taxa increased, indicating a change in agricultural intensity or extent near the lake. Starting ~700 cal. yr. BP (~1250 AD), forest began to regrow around Laguna Santa Elena. Modern occupation of the area around the lake, although less extensive than the prehistoric era, is confirmed by the persistence of disturbance taxa, charcoal, and maize in the recent paleoecological record.

Human domination of landscape processes during the middle and late Holocene in Central America obscures palynological evidence of climate change and climatic influences on vegetation (Leyden 1987). This holds true for Laguna Santa Elena, as it does for Laguna Zoncho and Laguna Volcán. Still, the timing of the decrease in disturbance taxa and charcoal between 1080 and 930 cal. yr. BP (870 – 1020 AD) is intriguing because it coincides generally with both the transition from Aguas Buenas to Chiriquí Cultural Phases, and a potential pan-Central American drought evidenced by soil and sedimentary charcoal in Costa Rica and paleolimnological investigations in the Yucatan (Horn and Sanford 1992, Hodell *et al.* 2001). Although the decrease in disturbance taxa is insufficient to warrant any grand conclusions regarding prehistoric culture at the time of the Aguas Buenas-Chiriquí transition, it suggests an interesting line of future research, perhaps using other paleoecological or paleolimnological methods that would be less influenced by human impacts.

Prehistoric groups in Greater Chiriquí would have had available a wide array of wild or cultivated resources, many of which we would not expect to appear in the pollen record (Colinvaux *et al.* 1999). Ethnographic, archaeobotanical, and paleoethnobotanical research indicates that pre-Columbian groups in Costa Rica could have collected or cultivated *Zea mays* (Poaceae), *Manihot esculenta* (Euphorbiaceae) *Cucurbita pepo* (Cucurbitaceae), *Persea americana* (Lauraceae), *Byrsonima crassifolia* (Malpighiaceae) *Phaseolus spp.* (Fabaceae), *Theobroma cacao* (Sterculiaceae), *Spondias mombin* (Anacardiacae), *Hymeneae courbaril* (Fabaceae), *Psidium guajava* (Myrtaceae), Arecaceae including *Acrocomia spp.* and *Bactis spp.*, *Sechium edule* (Cucurbitaceae), *Capsicum spp.* (Solanaceae), *Smilax spp.*(Smilacaceae), *Carludovica spp.*

(Cyclanthaceae), *Aechmea spp.* (Bromeliaceae), *Mammea americana* (Clusiaceae), *Manilkara achras* (Sapotaceae), *Xanthosoma sagittifolium* (Araceae), *Brosimum alicastrum* (Moraceae), *Gossypium spp.* (Malvaceae), *Dioscorea spp.* (Dioscoreaceae), and Marantaceae including *Calathea* and *Maranta* (Sánchez 1995, Lentz 2000b). Most of these would be unlikely to be present in pollen records because they are insect-pollinated. Others (especially *Manihot*) might be removed on the 125 μm sieve during pollen processing. Still others would be difficult or impossible to distinguish to the species level or separate into cultivated and wild taxa. The paleoecological record, therefore, gives an incomplete record of ethnobotanical and subsistence activities. However, in conjunction with archaeological and paleoethnobotanical research, paleoecology can help determine both the timing and magnitude of human agricultural activities and resource utilization.

Laguna Santa Elena in a Regional Context

My investigation of Laguna Santa Elena represents the third paleoecological study of anthropogenic landscape change in the Greater Chiriquí region. It is shorter than the records from Laguna Zoncho (~3000 years; Clement and Horn 2001) and Laguna Volcán (~2800 years; Behling 2000), but presents the possibility of a high-resolution reconstruction of human-induced vegetation change. Twenty-five samples from a core covering approximately 1800 years give an average time interval between pollen levels of 72 years. As such, the Laguna Santa Elena may provide the temporal resolution to not only describe the Late Holocene environmental history of premontane forests in the southern Pacific Costa Rica, but also better understand the prehistoric groups that inhabited the region.

There are important similarities and striking differences among the three lake core records. All three lakes show considerable human modification and disturbance of premontane/lower montane forests in Greater Chiriquí during both the Aguas Buenas and Chiriquí cultural phases. In all three records, forest regrowth appears prior to both the most recent eruption of Volcán Barú and the abandonment of the areas around the lakes. At Volcán, abandonment was apparently the result of the eruption of Barú ~600 yr. BP (Behling 2000). The area was not reoccupied until modern times. At Zoncho, abandonment of the lake was temporary, but forests experienced considerable regrowth. At Santa Elena, the apparent abandonment was short and likewise temporary, but forest regrowth was slow and vegetation composition (as represented by pollen taxa percentages) is markedly different in modern times compared to pre-disturbance forests.

The reason for the possible hiatus in agriculture around Laguna Santa Elena and Laguna Zoncho is not altogether obvious from the paleorecord. The eruption of Barú, which seems to have depopulated the highlands of western Panama, did not have the same effect at Santa Elena, since the pollen sample immediately upcore from the latest Barú tephra still contains maize. Therefore, perhaps the most striking comparison to be made between the paleoecological records from Santa Elena, Zoncho, and Volcán is the heterogeneous and asynchronous nature of Post-Contact land use. It is possible that the internecine warfare and apparent abandonment of village sites in the Río Grande de Térraba Valley described by Vásquez de Coronado (Fransisco Guardia 1913, Drolet 1992) was a late Chiriquí Phase phenomenon, the result of regional instability caused by the displacement of highland Chiriquí populations by the eruption of Barú. Abandonment at Santa Elena and Zoncho may also have resulted from societal upheaval or disease associated with the arrival of the Spanish.

The existing ceramic information from Laguna Santa Elena may be problematic in the face of evidence of land clearance for agriculture lasting from at least ~1400 cal. yr. BP to ~510 cal. yr. BP. Surface collection and test pits from around Laguna Santa Elena revealed only Aguas Buenas Phase ceramic sherds. Yet, the paleoecological record clearly documents forest clearance and agriculture during the time that corresponds to the later Chiriquí Phase. It may be, once full excavations have been performed at Santa Elena, that evidence of Chiriquí habitation will be found. Alternatively, there may have been no habitation of Santa Elena during the Chiriquí Phase, and evidence of agriculture in the pollen record may reflect large populations living at the Fila Tigre site (only 2 kilometers distant), and farming extensive areas of land around the large, regional center, including the Santa Elena watershed. Finally, it may be that the chronology for Aguas Buenas-Chiriquí needs to be reexamined in light of recent paleoecological studies. At Laguna Zoncho, a 3000 year record of maize cultivation and forest clearance (Clement and Horn 2001) contrasts with an archaeological record which thus has found the earliest occupation of the site to be ~1750 cal. yr. BP (Soto and Gómez, in preparation, M. Sánchez and S. Horn, personal communication). Paleoecological studies at Zoncho and Santa Elena therefore point to potential chronological problems with the cultural sequence for the area, as it is currently understood. Interestingly, the record of *Zea mays* cultivation for the last 1800 years at Laguna Santa Elena suggests that maize was indeed grown as a staple and not as a ritual food (as suggested by Hoopes 1996). A small site (perhaps four extended family groups) would have been unlikely to grow maize if the use of the crop was connected strictly to the maintenance of rank-hierarchy connections. However, it remains possible that, as a satellite community of the larger Fila Tigre regional center, the prehistoric Santa Elena community may have grown maize as part of its tribute or economic connections.

It is intriguing to speculate about the cause of the transition from the Aguas Buenas to Chiriquí Phase in Greater Chiriquí. The decrease in disturbance taxa at Santa Elena that coincides with this transition, and evidence from Costa Rica and Yucatan for a significant drought during that period, present interesting lines of evidence for archaeologists and paleoecologists to pursue. A volcanic eruption at ~1080 cal. yr. BP (870 AD) also precedes the decrease in disturbance taxa.

The high resolution of the Santa Elena study also reveals that the site remained populated even after the ultimate eruption of Barú. Whereas Laguna Volcán was apparently depopulated by the event (Behling 2000), Santa Elena was not. This may imply that the area around Laguna Zoncho (Clement and Horn 2001) was not depopulated by the eruption either, but by some other cause, perhaps related to indigenous warfare or the arrival of the Spanish.

There exists an ongoing debate concerning evolutionist vs. diffusionist models of Chibchan-Chocoan Cultural Area prehistory in general and that of Greater Chiriquí in particular (Stone 1977, Snarkis 1984, Linares 1980, Linares and Ranere 1980, Hoopes 1996, Lange 1993, Corrales 2000). Diffusionist theorists see major discontinuities between cultural phases as the result of the immigration or invasion from outside of the Intermediate Area/Greater Chiriquí, which in turn brought new material culture, economic patterns, and political structure to the region (Stone 1972, Snarkis 1984, Linares and Ranere 1980). The Evolutionist theorists, a relatively recent group less inclined to look for Mesoamerican or Andean influences in the Chibchan-Chocoan Cultural Area, believe that changes in Greater Chiriquí culture are endogenous, and result not from invasion but from dynamic, internal change or interaction within "spheres of influence" with other Central American, Mesoamerican, and Andean cultures.

Lange (1993), following Sheets (1992), articulated a new paradigm for the understanding of prehistory in lower Central America. Under this paradigm, Chibchan-Chocoan cultures are seen as "local polity organizations in nonhierarchical contacts with one another." Central American societies maintained this non-hierarchical independence with one another, as Lange identified it, because of widespread availability of a diversity of natural resources and a focus on "local resources" (as opposed to exotic trade goods). Those that favor an evolutionary approach to Chibchan-Chocoan archaeology (Lange 1993, Corrales 2000) point to the long temporal periods and persistence of genetic, linguistic, and cultural traits for the last 4000 or 5000 years. All this is beyond the scope of the study of a single, temporally limited paleoecological record. However, Laguna Santa Elena and other paleorecords add another piece of evidence that speaks to the persistence of Greater Chiriquí cultures, and will continue to be critical to future understanding of the cultural history and paleobiogeography of the Greater Chiriquí subregion .

The Laguna Santa Elena record, in concert with those of Zoncho and Volcán, also informs our understanding of local ecology. The paleoecological evidence from these lakes indicates that humans have been influencing the vegetation of southern Pacific

Costa Rica and Panama for thousands of years, through subsistence activities and the clearing of the forest with fire. Moreover, the three lakes demonstrate significantly different post-Conquest land use histories, and distinct temporal and spatial patterns in forest succession. Modern ecological studies need to take these environmental histories into account, since these differences could have influenced current landscape patterns and function (Horn and Sanford 1998).

CHAPTER 6

CONCLUSIONS

The paleoecological record from Laguna Santa Elena shows a nearly 2000-year record of forest disturbance in the premontane forests of southern Pacific Costa Rica. It provides clear and compelling evidence that human cultures, even those outside of the Mesoamerican and Andean empires, were continuously involved in changing the composition and structure of vegetation in tropical forests for thousands of years. As such, it supplies fundamental background information to both modern ecological studies and archaeological investigations.

A record of long-term human alteration of forest within the Laguna Santa Elena watershed, situated within 20 kilometers of the La Amistad International Park and the Las Cruces Biological Station, suggests that prehistoric human cultures could have had a significant influence on modern vegetation. The Las Tablas Protected Zone alone has at least 70 prehistoric archaeological sites (Leon 1986). Likewise, within the La Amistad International Park, there is evidence of human occupation (Corrales 2000). Modern forests in southern Pacific Costa Rica represent, in part, the result of thousands of years of human influence. The forests around Laguna Santa Elena returned, following the height of prehistoric settlement, but they were different than what had been there before.

The paleoecological study of Laguna Santa Elena highlights the need to undertake archaeological and paleoecological studies in tandem when attempting to understand the Holocene environmental history of tropical forests. For several thousands of years, humans have been one of the most powerful agents of landscape change in these

Neotropical forests. Carrying out archaeological investigations is critical to interpreting late Holocene paleoecological studies. Paleoecology, for its part, provides insights into cultural chronology, settlement patterns, and agriculture and subsistence strategies.

Laguna Santa Elena has been home to prehistoric, historic, and modern peoples for the last two millennia. Populations occupied the watershed during the Aguas Buenas and Chiriquí phase, and continued though the Post-Conquest era until the modern day. By demonstrating this environmental history of nearly continuous human-environment relations during the Late Holocene, paleoecological studies such as this one, and those from Laguna Zoncho and Laguna Volcán, may be added to existing evidence from human genetics, linguistics, and archaeology that point toward a long-term persistence of indigenous occupation of southern Pacific Costa Rica.

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APPENDICES

APPENDIX A

POLLEN PROCESSING SCHEDULE FOR LAGUNA SANTA ELENA SEDIMENTS

Processing of sediments from Laguna Santa Elena followed PROC JR2, developed by John Rodgers III and Sally Horn. This processing procedure is particularly effective for sediments prone to clumping. 6 samples are processed at a time in 15 ml polypropylene test tubes. All procedures should be done under the fume hood. We used an IEC tabletop centrifuge at ~2500 rpm.

PROCEDURE:

1. Start water boiling on hot plate in fume hood. At this time, label six clean, vacuumed vials and corks.

2. Add 1 *Lycopodium* tablet (batch #307863 and #710961 were used for Laguna Santa Elena) to each polypropylene tube containing the sediments.

3. Add a few ml 10% HCl, and let reaction proceed; slowly fill tubes until there is about 10 ml in each tube. Stir well, place in hot water bath for 3 minutes. Remove from bath, centrifuge for 2 minutes, and decant.

4. Add hot distilled water, stir, centrifuge for 2 minutes, and decant (hereafter abbreviated SCD). Repeat for a total of two washes.

5. Add about 10 ml 5% KOH, stir, remove stick, and place in boiling bath for 10 minutes, stirring after 5 minutes. Remove from bath, SCD.

6. Wash 4 times with HOT distilled water. SCD.

7. Fill tubes about ½ way with distilled water, stir, and pour through 125 um mesh screen, collecting liquid in a labeled beaker underneath. Wash out material remaining in test tube with more distilled water.

8. Centrifuge down material in beaker by repeatedly pouring beaker contents into correct tube, centrifuging for 2 minutes, and decanting.

9. Add 8 ml of 49 – 52% HF and stir. WEAR GLOVES, GOGGLES, MASK, AND BE CAREFUL! Place tubes in boiling bath for 20 minutes, stirring after 10 minutes. Keep sashes closed on fume hood when not stirring tubes. Centrifuge 2 minutes, decant into waste receptacle.

10. Add 10 ml HOT Alconox solution. Stir well and let sit for 5 minutes. Centrifuge and decant (Alconox solution is made by mixing 2.4 cm^3 of Alconox with 1000 ml distilled water).

11. Add more than 10 ml HOT distilled water to each tube, so top of water come close to top of tube. SCD. Samples with a lot of silica may require repeated HF treatments.

12. Continue with hot distilled washes for a total of 3. SCD.

13. Add 10 ml glacial acetic acid, SCD.

14. Acetolysis. Add 8 ml acetolysis mixture (9 parts acetic anhydride to 1 part sulfuric acid) to each tube and stir. Place in boiling bath for 5 minutes, stirring after 2.5 minutes. Centrifuge and decant.

15. Add 10 ml glacial acetic acid, SCD.

16. Wash with hot distilled water, SCD.

17. Add 10 ml 5% KOH, stir, and heat in vigorously boiling water bath for 5 minutes, stirring after 2.5 minutes. Centrifuge 2 minutes and decant.

18. 3 hot distilled washes, SCD.

19. After decanting last water wash, use VORTEX Genie for 20 seconds to mix sediments in tube.

20. Add 1-2 drops of safrinin stain to each tube, use VORTEX Genie for 10 seconds. Fill to 10 ml with distilled water, SCD.

21. Add a few drops TBA, use VORTEX Genie for 20 seconds. Fill to 10 ml with TBA, SCD.

22. Add 10 ml TBA, SCD.

23. Mix well with VORTEX Genie and transfer to clean, glass vials. Centrifuge down vials. Decant TBA.

24. Add several drops (3-6) silicone oil to each vial, stir with clean toothpick.

25. Place uncorked vials in clean, dust-free location overnight to let TBA evaporate. Do not let the sample dry out.

26. Check samples the following day; stir and cork when TBA has fully evaporated.

APPENDIX B

POLLEN TAXA IDENTIFIED IN THE LAGUNA SANTA ELENA CORE

FAMILY OR HIGHER TAXONOMIC LEVEL	**Lower Taxonomic Level or Morphological Type**
ALISTAMATACEAE	
AMARANTHACEAE	
AMARANTHACEAE	Fenestrate type
ANACARDIACEAE	
ANACARDIACEAE	*Tapirira*-type
ANACARDIACEAE	*Spondias*-type
APIACEAE	
APOCYNACEAE	
AQUIFOLIACAE	*Ilex*
ARACEAE	*Philodendron*-type
ARACEAE	*Anthurium*-type
ARECACEAE	
ARALIACEAE	
ASTERACEAE	high-spine
ASTERACEAE	low-spine
ASTERACEAE	fenestrate-type
BEGONIACEAE	
BETULACEAE	*Alnus*
BORAGINACEAE	*Cordia*
BORAGINACEAE	*Tournefortia*
BURSURACEAE	*Bursera*
CARYOPHYLACEAE	
CARYOPHYLACEAE	*Drymaria*
CECROPIACEAE	*Cecropia*

FAMILY OR HIGHER TAXONOMIC LEVEL	**Lower Taxonomic Level or Morphological Type**
CHLORANTHACEAE	*Hedyosmum*
CLETHRACEAE	*Clethra*
CUNONIACEAE	*Weinmannia*
CYPERACEAE	
ELEOCARPACEAE	
ERICACEAE	
EUPHORBIACEAE	*Acalypha*
EUPHORBIACEAE	*Alchornea*
EUPHORBIACEAE	*Croton*
EUPHORBIACEAE	*Sapium*
EUPHORBIACEAE	*Chamaesyce*
FABACEAE	*Mimosa pigra*-type
FABACEAE	Other Mimosoideae
FABACEAE	Papilionoideae or Caesalpinioideae
FAGACEAE	*Quercus*
JUGLANDACEAE	*Alfaroa*
LAMIACEAE	
LORANTHACEAE	
LYTHRACEAE	*Cuphea*
MALPIGHIACEAE	
MALPIGHIACEAE	*Byrsonima*
MALVACEAE	
MELASTOMATACEAE-COMBRETACEAE	
MENISPERMACEAE	
MONIMACEAE	
MONOCOTYLEDON UNDIFFERENTIATED	Monosulcate psilate

FAMILY OR HIGHER TAXONOMIC LEVEL	**Lower Taxonomic Level or Morphological Type**
MONOCOTYLEDON UNDIFFERENTIATED	Monosulcate scabrate
MONOCOTYLEDON UNDIFFERENTIATED	Monosulcate other
MORACEAE	*Ficus*
MYRICACEAE	*Myrica*
MYRSINACEAE	*Myrsine*
MYRSINACEAE	*Ardisia*-type
MYRTACEAE	
ONAGRACEAE	
PAPAVERACEAE	*Bocconia*
PIPERACEAE	*Piper*
PIPERACEAE	*Peperomia*
POACEAE	
POACEAE	*Zea mays*
PODOCARPACEAE	*Podocarpus*
POLEMONIACEAE	
POLYGALACEAE	
RHAMNACEAE	
RUBIACEAE	*Borreria*
RUBIACEAE	*Galium*-type
RUBIACEAE	*Psychotria*
RUTACEAE	*Zanthoxylum*
SAPINDACEAE	
SAPOTACEAE-MELIACEAE	
SAPOTACEAE-MELIACEAE	*Carapa*-type
SCROPHULARIACEAE	
SOLANACEAE	
SOLANACEAE	*Solanum*

FAMILY OR HIGHER TAXONOMIC LEVEL	**Lower Taxonomic Level or Morphological Type**
SOLANACEAE	*Cestrum*-type
SOLANACEAE	*Physalis*-type
TILIACEAE	*Apeiba*-type
TILIACEAE	*Luehea*-type
TILIACEAE	*Mortoniodendron*
ULMACEAE	*Ulmus*
URTICALES	diporate
URTICALES	triporate
URTICALES	4-porate
URTICALES	polyporate
URTICALES	undifferentiated
URTICALES	*Trema*
URTICALES	*Celtis*
VERBENACEAE	
VITACEAE	
VOCHYSIACEAE	
PTERIDOPHYTES	
MONOLETE	psilate
MONOLETE	scabrate
MONOLETE	coarse verrucate
MONOLETE	low verrucate
MONOLETE	echinate
MONOLETE	rugulate
MONOLETE	other
TRILETE	psilate
TRILETE	scabrate

FAMILY OR HIGHER TAXONOMIC LEVEL	Lower Taxonomic Level or Morphological Type
TRILETE	coarse verrucate
TRILETE	low verrucate
TRILETE	echinate
TRILETE	rugulate
TRILETE	other
TRILETE	Native *Lycopodium*
TRILETE	*Selaginella*-type
TRILETE	*Osmunda*-type
TRILETE	*Pityrogramma*
TRILETE	*Dicranoglossum*
ANTHOCEROTOPHYTA	
Anthoceros	Spiny-type
Anthoceros	Smooth-type

VITA

Kevin John Anchukaitis was born in Niskayuna, New York on June 22nd, 1976. He graduated from Niskayuna High School in 1994. He received his Bachelor of Science degree from Georgetown University in Washington DC in 1998, graduating *cum laude* and with Departmental Honors in Science, Technology, and International Affairs. He spent his junior year at the University of Kansas/University of Costa Rica Program for Tropical Studies in Golfito, Costa Rica. He became interested in paleoecology, biogeography, and archaeology while working in 1998 and 1999 with the Chunchucmil Regional Economy Project in Yucatan, Mexico. Kevin entered the graduate program in geography at the University of Tennessee in 1999 to study paleoecology in Costa Rica.

While at Tennessee, Kevin participated in field research in Costa Rica funded by The A.W. Mellon Foundation. He served as a Teaching Assistant for classes in introductory physical geography and world regional geography, and was a Research Assistant on a project funded by a grant to his advisor, Sally P. Horn, from The A.W. Mellon Foundation. He also conducted research in North Carolina on climate teleconnections and dendroclimatology sponsored by a grant from the Stewart McCroskey Memorial Fund of the Department of Geography. In 1999, he received a two-year fellowship from the United States Environmental Protection Agency's National Center for Environmental Research STAR Program. After graduating from Tennessee, Kevin will be attending the University of Arizona to earn his Ph.D. in Geosciences.