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PRECOLUMBIAN AGRICULTURE, FIRES, AND VEGETATION DYNAMICS IN A LOWLAND RAINFOREST: PALEOECOLOGICAL EVIDENCE FROM LAGUNA BONILLA AND LAGUNA BONILLITA, COSTA RICA

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Lisa Anne Northrop

May 1994

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DEDICATION

This thesis is dedicated to my grandmother

Ruth Bickford Northrop

for countless encouraging letters and words of wisdom

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ABSTRACT

Issues of where, when, how, and to what extent preColumbian humans affected the natural landscapes of Central America have been debated for years. While many studies have been conducted in Guatemala and other areas of Olmec, Aztec, and Mayan influence, little attention has been paid to peripheral areas. It has been suggested that indigenous populations were small in countries such as Costa Rica, Nicaragua, and northern Panama (Origgi 1981), but little is known about how these sparse populations affected their environment. As part of a broader study aimed at exploring prehistoric human-environment relationships throughout the Central Atlantic watershed of Costa Rica, several lake sediment and soil cores were obtained from two lowland tropical lakes -- Laguna Bonilla and Laguna Bonillita. The lakes are located in a region of Costa Rica that has been used for millennia as a trade route by both northern and southern cultures. Many archaeological sites are located within the region and much work has been carried out to establish archaeological sequences for the area. While the archaeology of the area is fairly well established, very little is known about prehistoric vegetation patterns, disturbance factors, and human-induced environmental change.

This thesis provides some of the first direct evidence of preColumbian human impacts on vegetation in the tropical wet lowland rainforests of Costa Rica. Paleoecological profiles constructed from the analysis of pollen grains, charcoal fragments, and sediment characteristics provide a continuous record of human occupation in the two lake basins since preColombian times. The paleoecological sequence of Laguna Bonillita firmly establishes human settlement within the lake basin before 2560 yr B.P. But problems with the presence of old carbon within the lake system at Laguna Bonilla has made the radiocarbon dating of these sediments difficult. *Zea* is the only food crop that was identified in the pollen assembalges in the lake sediments, and the relatively high abundance (up to 5 percent of total pollen) of this heavy pollen type indicates that the crop was being

grown on or near the lake margin. The lake sediment analyses document widescale forest disturbance in the basins during the past several thousand years. Macroscopic charcoal present in soil cores from the Laguna Bonillita basin record fire as an important disturbance factor in the late Holocene.

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CHAPTER 1

INTRODUCTION

The extent to which indigenous populations altered the natural environment of the Latin American tropics has long been a matter of debate (Tsukada and Deevey 1967; Harrison and Turner 1978; Vaughan *et al.* 1985). On one hand, there is the idea of the pristine forest, populated by noble savages living in harmony with nature (Bennett 1968, 1975). On the other hand is the view that rainforests of Latin America were so heavily altered by prehistoric people that they should be considered as artificial human constructs. Denevan (1992a) and other researchers (Redford 1990; Jordan 1992; Turner and Butzer 1992; Butzer 1993) have argued persuasively against the "Pristine Myth," but knowledge of where, how, and to what extent Latin American landscapes were impacted by prehistoric people remains incomplete.

Just how potent prehistoric human populations were as agents of ecological change must have varied from place to place across the Latin American tropics. In Guatemala and southern Mexico their impact was clearly major. Extensive forest clearance associated with Mayan agricultural activity is documented by fossil pollen and charcoal records from lakes throughout the region (Tsukada and Deevey 1967; Binford *et al.* 1987). In other areas, the evidence of human modification of neotropical landscapes is more subtle, and is only just beginning to be recognized. For example, the distribution of *Iriartea* palms in the "virgin" lowland rainforest at the La Selva Biological Station in Costa Rica recently has been linked to past human food harvesting (Clark *et al.* 1993; Yoon 1993). Since ancient times, *Iriartea* palms have been the preferred source of "heart of palm," a local delicacy that requires felling of the tree. A survey of the distribution patterns of seven palm species in

the oldest known tracts of forest at La Selva revealed that all species except *Iriartea* had distributions that could be explained by ecological factors. The current distribution of *Iriartea* palms seems not to reflect the ecological requirements of the plant, but rather the impact of human activity. The palm is found today mainly in remote, difficult to access sites; a distribution that Clark *et al.* (1993; and quoted in Yoon, 1993) attribute to the selective harvesting of the plant from more accessible areas in past centuries.

Untangling the often inconclusive and fragmentary bits of evidence that help to describe the history of human modification of neotropical landscapes is a challenge. In most areas there is very little direct botanical evidence that attests to the magnitude and extent of preColumbian human disturbance. Indirect evidence from the archaeological record is of some use in reconstructing past human activities, but in most of tropical Latin America, the archaeological record is fragmentary. Even well-documented sites generally preserve little evidence of preColumbian human-environment interactions. Additionally, little can be gleaned from the archaeological record concerning indigenous agricultural practices and the extent to which these agricultural activities brought about changes in vegetation.

Direct evidence of human-environment interaction is provided by paleoecological records, which are based on the study of pollen grains, charcoal fragments, and other plant microfossils and macrofossils that are preserved in lake sediments and soil profiles. Such records can track long-term changes in forest cover, fire events, agricultural crop production, erosion, and other environmental disturbances that are associated with human activity (Deevey 1979; Byrne and Horn 1989; Piperno *et al.* 1990). The use of paleoecological records in conjunction with information from the archaeological record provides a considerably more complete picture of past human impacts and their role in shaping present day landscapes.

This thesis presents some of the first direct evidence of prehistoric human disturbance and vegetation history in lowland Costa Rica. The evidence derives from pollen grains and charcoal fragments preserved in lake sediment and soil cores collected within and near two lakes, Laguna Bonilla and Laguna Bonillita, in the Río Reventazón Valley of Costa Rica. This river valley, on the central Atlantic slope of Costa Rica, has for millennia served as a communication route and cultural conduit between the central highland basin (Meseta Central) and the Atlantic coast. The area is rich in archaeological sites, two of which are situated on the shores of Laguna Bonilla and Laguna Bonillita.

As part of a broader study of vegetation history throughout the central Atlantic drainage, Dr. Sally Horn of the University of Tennessee (UT) visited Laguna Bonilla and Laguna Bonillita in March 1991. With the assistance of Lic. Maureen Sánchez of the Archaeology Laboratory of the University of Costa Rica (UCR) and several UT and UCR students, she recovered one sediment core from each lake. In July 1991, she returned with Dr. Kurt Haberyan of Troy State University, Alabama, to collect limnological samples and data (Horn and Haberyan 1993). In June 1992, I joined Dr. Horn on a third trip to the lakes, during which time we recovered three additional cores from Laguna Bonilla. Finally, in February 1994, Dr. Horn and I revisited the lakes to remonitor limnological conditions and to recover soil cores to complement the lake sediment analyses at Laguna Bonillita.

In this thesis, I present the results of paleoecological analyses of the lake sediment and soil cores. By tying the paleoecological record to the archaeological record, I seek to reconstruct how humans impacted their natural environment in prehistoric times. In particular, I attempt to resolve a number of issues related to human-forest interaction at Laguna Bonilla and Laguna Bonillita. The specific questions that guided my research included: 1. When was the area around these Central Atlantic watershed lakes permanently

settled and farmed? 2. How does the paleoecological evidence for the timing of human activity compare with the regional archaeological record? 3. Are crop plants such as maize and others represented in the pollen record? 4. To what extent were tropical forests impacted by agricultural clearing or other human activities? 5. What type of fire history is documented by the charcoal record? and 6. Are there indications of regional climatic shifts during the time period represented by the cores?

This thesis is divided into seven chapters. Chapter 2 follows with a review of past paleoecological work in Costa Rica and adjacent areas. The environmental setting and current vegetation of the study site are presented in Chapter 3. In Chapter 4, I review the cultural history of the Atlantic slope of Costa Rica as reconstructed from archaeological evidence. I describe the lake and soil core sites, and field and laboratory methods in Chapter 5. The results of my analyses are described and discussed in three chapters. Chapter 6 describes the sediment stratigraphy and presents and interprets the results of the radiocarbon and ^{210}Pb dating of the lake sediments. In Chapter 7, I present the results of the pollen and charcoal analyses. In Chapter 8, I discuss the paleoecological record from Laguna Bonilla and Laguna Bonillita and draw conclusions about the role that preColumbian human activity played in influencing vegetational patterns in the lake basins. I then attempt to place the human-dominated vegetational histories of these two lake basins into the broader context of human alteration of environments through space and time within the Latin American tropics.

CHAPTER 2

PREVIOUS PALEOECOLOGICAL STUDIES IN COSTA RICA AND ADJACENT AREAS

In Costa Rica, as in other areas of the neotropics, it is becoming increasingly apparent that knowledge of historical patterns of anthropogenic disturbance is critical to an understanding of contemporary ecological patterns and processes (Hamburg and Sanford 1986; Binford *et al.* 1987; Pierce 1992; Clark *et al.* 1993; Sanford *et al.* 1993). But few studies in Costa Rica have yet attempted to link past human activities with changes in vegetation through use of paleoecological or archaeological records. Paleoecological studies are only just beginning in most areas of Costa Rica (Horn 1992), and most studies that have been undertaken have not had as a central goal the reconstruction of long-term human-environment interactions.

A paleoecological investigation of shifts in montane vegetation as influenced by Pleistocene climatic cooling was initiated by P. Martin in 1959, at the Parque Vicente Lachner bog in the Cordillera de Talamanca (Martin 1964). In two sections of the 13 m core that Martin recovered, montane forest pollen types were largely replaced by herbaceous pollen types and fern spores. This lead Martin to suggest that two periods of climatic cooling in the past depressed treeline and facilitated the spread of treeless páramo. Though intended as the first step in a major paleoecological study, Martin changed research focus after analyzing this one core, and no further paleoecological research was conducted in Costa Rica for over 20 years. In 1974, R. Kesel presented preliminary pollen data from surface exposures of ancient alluvial and lacustrine deposits in the Río General Valley, located in the southern Pacific lowlands of Costa Rica. Based on radiocarbon-dated soil

samples that were rich in grass pollen, he suggested that a tropical grass savanna containing scattered woody species occupied the valley by 17,050 yr B.P. (radiocarbon years before present). A slightly greater abundance of pollen from woody taxa in a sample that dated to 12,830 yr B.P. was interpreted as indicating an increase in precipitation. Kesel concluded that by 8800 yr B.P., vegetational assemblages and climate conditions had reached their present day configuration. Kesel additionally attempted to determine the presence or absence of preColumbian occupation sites in the area and was initially encouraged by a radiocarbon date of 37,000 yr B.P. on what appeared to be partially burned bone. A follow-up investigation of the site where the sample was recovered yielded large amounts of organic debris but nothing that could be identified as human or animal bone. While many pot sherds were found in the area, Kesel concluded that they were of relatively recent origin and suggested that the Río General Valley area was not occupied during prehistoric times (Kesel 1974).

In the early 1980s, S.P. Horn analyzed the pollen content of samples from the upper 24 meters of a core from Deep Sea Drilling Project Site 565, off the Nicoya Peninsula in northwestern Costa Rica. Her results confirmed Martin's findings of vegetational shifts during the last glacial cycle, but were complicated by probable drilling disturbance in the Holocene section, which precluded the possibility of a detailed reconstruction of possible human-induced changes in Costa Rican vegetation (Horn 1985a). Preliminary analyses of two 1 m long sediment cores from Golfo Dulce, Costa Rica, did indicate possible human disturbance of vegetation, but these sediments were not dated (Horn 1985b).

In 1985, Horn recovered two short cores from Lago Chirripó, a glacial lake located in the Chirripó highlands of the Cordillera de Talamanca. Charcoal analysis of the sediments revealed that fires have affected the Chirripó páramo for at least 4,000 years (Horn 1989). In 1989, she recovered cores from nearby Lago Morrenas that confirmed and extended the

Chirripó charcoal record. The pollen diagram from Lago Morrenas showed that the Chirripó massif has been covered with páramo-like vegetation since deglaciation about 10,000 years ago (Horn 1990, 1993a). Horn concluded that natural or human-set fires have occurred throughout the Holocene but that they were probably not responsible for a vegetational shift from forest to páramo, as has been suggested for the Buenavista páramo (Janzen 1973, 1983; Hartshorn 1983).

Hooghiemstra *et al.* (1992) described the pollen stratigraphy of cores and soil profiles from the La Chonta bog and vicinity near the bog investigated by Martin (1964). Their analyses document altitudinal shifts in montane forest and páramo communities attributed to climatic oscillations during the Late Pleistocene and Holocene. Because the presence of microscopic charcoal never was mentioned in the study, it is possible that this area may have had a very different fire history from that of Horn's (1989, 1993) Chirripó site.

K.H. Clary (1990) studied pollen preserved in soils at nine archaeological sites in the Cordillera de Tilarán, located within the Greater Nicoya archaeological subarea of southwestern Nicaragua and northwestern Costa Rica. She identified *Zea* (maize) and possible *Phaseolus* sp. (beans) and *Persea schiediana* (avocado) pollen grains. While the presence of these pollen types provides some indication of human subsistence, their context within regional vegetation patterns is lost because of poor pollen preservation and low pollen counts. When pollen grains from all stratigraphic levels and sites were summed, a total of only 562 pollen grains were tallied -- not nearly enough to reconstruct past vegetation composition on any scale (Delcourt *et al.* 1986). These preliminary pollen data, however, may be helpful in determining which agricultural crops were in use by indigenous cultures during the prehistoric period.

In another study, Clary (1986) examined a sediment core from a mangrove swamp downstream from the Nacascolo archaeological site in northwestern Costa Rica. The

purpose of her study was to see if the pollen record provided evidence of vegetational change brought about by human disturbance. Again, she was thwarted by poor pollen preservation, with only the lowest levels in her 2 m core having sufficient pollen for a standard count (200 grains). Two poorly preserved grains of maize were found in one of the deeper sections of the core, supporting the contention that maize was cultivated in prehistoric times in this area. She suggested that fluctuations in microscopic charcoal concentrations in the core may provide further evidence of human activity in the area.

I. Quintanilla (1990) described the recovery of artifacts and charcoal fragments from trial archaeological pits dug at the La Selva Biological Station in the Atlantic lowlands of Costa Rica. Charcoal fragments were abundant at soil depths between 10 cm and 80 cm and were associated with small ceramic fragments. Quintanilla suggested that the large quantities of charcoal found in the soils might indicate the locations of prehistoric cooking sites or periodic prehistoric burning of agricultural fields perhaps dating to the El Bosque Phase (2300 - 1500 yr B.P.). Two soil charcoal samples from the archaeological sites yielded radiocarbon dates of 1110 ± 70 and 2430 ± 80 yr B.P. The older date fits nicely with radiocarbon determinations on two samples of charcoal recovered from soils under mature forests in other areas of La Selva, which yielded dates of 2410 ± 220 yr B.P. and 2430 ± 80 yr B.P. (Horn and Sanford 1992).

Uncertainty exists over the origin of the charcoal found in the soil cores that were collected in areas of La Selva that are not known to have been used as prehistoric settlement or campsites (Horn and Sanford 1992; Sanford, unpublished data). The charcoal in the soils could reflect local burning of prehistoric agricultural plots, as suggested by Quintanilla (1990). However, Horn and Sanford (1992) have speculated that some of the charcoal might reflect the burning of intact forests during exceptionally dry periods. Such fires could have been initiated by humans through inadvertent escape of cooking or agricultural

fires. Alternatively, fire may have resulted from natural ignition sources (e.g. lightning or volcanism). Intriguingly, radiocarbon dates co-eval with those on La Selva charcoal have been reported for charcoal-rich sediment recovered from Lago Chirripó, 120 km southeast of La Selva. Horn's (1989, 1993) Lago Chirripó Core 2 contains two charcoal layers that may have been deposited during a period of drier climate when lake stands were lower. Samples of the charcoal-rich sediment yielded radiocarbon dates of 1180 ± 70 yr B.P. and 2430 ± 100 yr B.P. The correspondence between radiocarbon determinations at this site and at La Selva may offer support for the hypothesis that some burning at La Selva was linked with regional droughts. Horn and Sanford (1992) have suggested that Holocene droughts could be related to either short-term atmospheric variability (possibly linked to El Niño events) or to longer-term shifts in climate.

While specific paleoecological information concerning the long-term effects of human activity on lowland rainforests in Costa Rica is lacking, a large body of literature exists regarding prehistoric human influence on forest history in other neotropical areas. Pollen records have been published from twelve countries within the Latin American tropics. In the following paragraphs, I review selected records that provide evidence of forest clearance or regeneration resulting from prehistoric agricultural activities or other anthropogenic disturbances.

Two lake core studies conducted by Byrne and Horn (1989) and Goman (1992) provide evidence of prehistoric agricultural disturbance and post-disturbance forest recovery in the "Olmec Heartland" of southern Veracruz, Mexico. Goman presents a pollen record from Laguna Pompal, a small lake that may have been formed by a lava flow. Two periods of forest regeneration after maize agriculture are evident in the fossil pollen record. During the first period of agricultural activity, pollen from weedy taxa and charcoal concentrations increased, while arboreal pollen decreased. *Zea* pollen was present during

this phase, indicating that maize agriculture was initiated about 4250 yr B.P. Directly after this short agricultural phase, forest regeneration was represented by a large peak in Urticales pollen and increases in *Cecropia, Liquidambar,* and *Quercus* pollen. Concentrations of microscopic charcoal declined during this period. The second period of agricultural activity was again marked by a decline in all arboreal taxa, except *Pinus*; long-distance transport of this wind-dispersed pollen type may have been aided by reduced forest cover (Goman 1992). *Cecropia* pollen percentages declined to their lowest values in this period. Maize pollen and pollen of weedy composites indicative of agricultural disturbance comprised the bulk of the pollen being deposited in the lake during this period. After this period of agricultural activity, land was abandoned and the forest again regenerated, as indicated by increases in *Liquidambar,* and then *Ulmus* pollen. Percentages of *Cecropia* and other Urticales pollen also increased during this period. Goman concluded that it only took about 200 years for the tropical forest to regain its former importance. Pollen spectra in sediments deposited after agricultural abandonment showed initially high percentages of pollen of early successional shrubs and trees characteristic of forest-edge environs, such as *Cecropia*, *Piper*, and *Alchornea.*

Byrne and Horn's (1989) study of Lago Catemaco provided a nearly continuous record of maize agriculture that is estimated to span the last 3,000 years. The middle section of the pollen diagram was especially high in *Zea* pollen and pollen of other herbaceous taxa such as *Ambrosia.* This assemblage of cultigen and ruderal species was interpreted as indicating a period of intensified agricultural activity. Upon abandonment of agricultural lands, the Urticales group experienced a peak -- perhaps reflecting the initial regrowth of successional species as in Goman's study. Regeneration of forests was also marked by initially high percentages of *Liquidambar* pollen, with this type was later replaced by *Ulmus* and *Quercus* pollen. The reestablishment of forests near Lago Catemaco was marked by a relatively sharp increase in arboreal pollen percentages (with

the exception of *Pinus*, which never regained its former importance). The regeneration of forests in this area at this time may have been attributable to population decline following European contact.

Pollen records from lakes in Guatemala (primarily in the Petén region) and El Salvador have documented widespread vegetational change resulting from Mayan occupation. In interpreting a pollen record from Laguna Petenxil, a small lake in northern Guatemala, Tsukada (1966) was the first to suggest in print that the modern rainforests of the Petén region were the product of long-term human disturbance. Tsukada and Deevey's (1967) subsequent study of sediment cores from three highland lakes and one lowland tropical lake in Guatemala and El Salvador further reinforced Tsukada's concept of human-controlled landscapes in this region of the Latin American tropics. Their palynological analysis and comparison of sediments from the four lakes established a conceptual framework for determining how forests respond to cyclical fluctuations in disturbance severity. Through statistical analysis and systematically staggered correlations between carbonized fragments and pollen indicators of agriculture, they concluded that the pollen records for these lakes provided weak evidence of the burning-planting-fallowing (swidden) cycle.

However, the possibility of detecting swidden cycles from pollen records seems improbable. Traditionally, adjacent swidden plots are of different ages and are at a different stage in the swidden cycle. Unless a lake is very small and located completely within a single swidden plot, indicators of multiple stages in the burning-planting-fallowing cycle would be integrated and "smoothened" at each level in the sediment core. Bioturbation of sediments within lakes would further blur evidence of the swidden cycle in the pollen record. Furthermore, the expectation of finding evidence of slash and burn cycles in the pollen record may be unjustified, as the extent to which slash and burn agriculture was used in prehistoric times as a land management tool has been questioned.

Turner and Harrison (1978) have pointed out that paleoecological evidence from the Maya lowlands seems to point to an extremely short-fallow system of cultivation that very rarely infringed on wooded lands. Denevan (1992b), in a comparative study of prehistoric and post-Conquest agricultural practices in the Amazon, suggested that clearing land using a stone axe would require 19 times the labor inputs required to clear land using a metal axe. From this evidence he concluded that shifting cultivation is largely a post-Conquest agricultural development that was uncommon in prehistoric times. Lands that were cleared in prehistoric time were most likely kept clear for long periods of time using a short-cropping cycle, thereby avoiding the need to invest large amounts of time and labor to prepare new agricultural plots.

In their 1967 paper on pollen cores from four Mayan lakes, Tsukada and Deevey considered why some species were more abundant in post-disturbance forests than others. They postulated that differing life strategies of selected taxa, such as *Alchornea*, may have influenced their ability to survive in human-dominated landscapes. Tsukada and Deevey suggested that *Alchornea* may have been favored by selective clearing by humans because of its ecological preference for forest-edge conditions. Forests that did regenerate after the height of Mayan occupation were complex and differed regionally. However, these postMayan forests were generally more open in nature than preMayan forests as evidenced by larger proportions of herbaceous taxa in later sections of the pollen records.

In a review paper focusing on tropical paleoecology, Binford *et al.* (1987) discussed the impact of long-term human settlement on forest ecosystems in tropical lowland areas of Guatemala, Haiti, and Florida. Using both new and previously published pollen records from six lakes in the Petén region of Guatemala [Lakes Yaxha, Sacnab, Quexil, Macanche, Salpeten, and Petenxil (earlier analyzed by Tsukada)], the authors noted that changing land uses associated with the rise and fall of the Maya civilization were directly evident in the

pollen deposition and sediment influx rates of the lakes. Absolute dating of the sediments from these lakes has been notoriously difficult and the authors have inferred their chronologies from "a couple of reliable dates" on wood fragments from Lake Quexil. Accordingly, their discussion of tentative dates and influx rates should be treated with caution. Their analysis has suggested that amelioration of glacial climates at about 10,750 yr B.P. caused forest composition to change from species associated with temperate forest to those of mesic tropical forests. These mesic forests persisted until about 3000 yr B.P. when early Mayan inhabitants began deforesting the area. During Mayan times (3000 - 400 yr B.P.), vegetation changed from forest to a mosaic of forest and grasslands. Sediment accumulation rates reported in their study also indicated increased erosion rates and impoverishment of soils during Mayan occupation, presumably as a result of swidden agricultural practices. Only within the last 400 years did arboreal vegetation once again became dominant, permitting the regrowth of understory vegetation and restabilization of soils in the area.

In a separate paper, Leyden (1987) provided a more detailed account of the Lake Salpeten pollen record and the evidence it contains of widespread forest clearance associated with Mayan occupation. The 18 m core recovered from the lake provided a complete record of human occupation, but the presence of old carbon in the sediments precluded radiocarbon dating. Therefore, using what she term "pollen time lines," Leyden attempted to palynologically match changes in this core with dated sequences from Lake Quexil. She concluded that the pollen-poor gypsum sediments at the base of the core were Pleistocene in age. By about 11,000 yr B.P., gyttja with abundant pollen was being deposited in the basin. The lowest pollen zones recognized did not have signs of anthropogenic disturbance and were characterized by high percentages of *Brosimum* pollen, *Chlorophora*-type pollen, and a "broad spectrum of semievergreen forest pollen present at low percentages" (*Trema* and other Urticales, *Acalypha*, *Pinus*, and *Quercus*).

Cecropia pollen was nearly absent. In the next three successively younger pollen zones, the paleoecological assemblages recorded forest destruction associated with human occupation. Total arboreal pollen declined markedly, while pollen of *Zea*, weedy herbaceous taxa (Gramineae, Cyperaceae, and Compositae) and successional trees (*Cecropia* and *Trema*) increased. The most severe period of human disturbance was marked by the presence of *Ambrosia* and what Leyden regarded as savanna taxa (*Byrsonima, Bursera,* and *Quercus*). The uppermost and youngest pollen zone reflected forest recovery after the devastation caused by prehistoric human occupation. The *Brosimum* pollen curve increased sharply tracking the establishment of a mature, closed canopy forest. However, Leyden (1987) asserted that "after 400 years, post-Maya forests are not yet identical to preMaya forests." Similar to Tsukada and Deevey, she concluded that the forests that regenerated were much more open, being characterized by a higher frequency of successional shrubs and trees, such as *Cecropia, Trema*, and Piperaceae.

Vaughan *et al.* (1985) described a similar sequence of forest decimation and recovery recorded in the sediments of Lake Quexil and Sacnab located in the Central Petén area of Guatemala. Vaughan *et al.* have suggested that preMayan forests were relatively closed. Pollen assemblages were dominated by arboreal species, of which the Moraceae family (especially *Cecropia*) represented 80 percent of total pollen. Also important were Melastomataceae and Urticaceae. The remainder of the arboreal taxa was composed of *Quercus*, *Pinus*, and *Byrsonima* pollen. Weedy herbaceous taxa were relatively unimportant during this period and were represented by Gramineae and Cyperaceae pollen. The period of human influence in the pollen records from these two lakes was split into two zones: an open forest zone and an agricultural zone. The open forest zone was marked by an increase in pollen percentages of *Cecropia* and *Byrsonima*, a decrease in total arboreal taxa, an increase in microscopic charcoal, and an increase in weedy herbaceous taxa. This early period represented an interval of forest clearance and was immediately followed in the

pollen records by the appearance of agricultural indicators. The later agricultural zone was characterized by the loss of many forest taxa from the pollen records, an increased representation of savanna species, and the beginning of maize agriculture. Pollen percentages peaked for agricultural weeds, such as *Ambrosia* and other Compositae, and Gramineae. Curiously, charcoal concentrations declined during this period, perhaps indicating the presence of permanent agricultural plots that did not require continued burning. Alternatively, high charcoal concentrations may reflect prehistoric building practices. B. Turner (personal communication, April 1993) has suggested that significant amounts of charcoal were generated by the firing of materials for temple building during the height of the Maya Empire. Lower charcoal influx during the agricultural zone in Vaughan *et al.*'s (1985) paleoecological study may reflect a post-building phase. This period culminates in the disappearance of *Ambrosia* pollen, which has been interpreted as signifying the end of all widespread agriculture, possibly associated with the "Classical Maya collapse."

Vaughan *et al.* (1985) suggested that it must be disappointing to anthropologists that the collapse of the Maya Empire was "so feebly echoed in the pollen rain" of these lakes. They suggested, however, that this very phenomena points out an important ecological lesson -- a system's damped responses to external forcing (i.e. "resilience" of ecosystems under different degrees of stress) can vary measurably, though not predictably, in degree of homeostatic damping. In other words, once an area has been converted to nonarboreal vegetation, it is much more difficult to differentiate varying human activities from the pollen record. Nonarboreal pollen grains are ubiquitous and usually poorly classified according to ecological niches. Thus detecting changes in landuse from nonarboreal pollen types is much more difficult than from arboreal pollen types. At any rate, initial forest recovery at the sites was documented by an increase in pollen percentages of *Cecropia* and other Urticales. As forest regeneration continued, pollen percentages of savanna taxa and weedy

herbaceous taxa gradually declined, a pattern that has been interpreted as signaling a "closing" of the forest.

An additional study of forest regeneration after human activity in Guatemala was presented by Wiseman (1972). His study sought to reconstruct the nature of vegetation response to the collapse of Maya culture in the lowland rainforests. Wiseman recorded the invasion of successional species into modern abandoned agricultural plots fields over time by sampling modern pollen rain. He then outlined a general post-agriculture forest recovery sequence and compared it with prehistoric paleoecological sequences. He suggested the following recovery sequence: agriculture is followed by an invasion of herbaceous weeds (Chenopodiaceae / Amaranthaceae, high- and low-spine Compositae, and Gramineae), which persist for several years. This is followed by an invasion by weedy shrubs, such as *Trema* and *Acacia*. After a decade or more, secondary forest plants such as *Bursera*, *Manilkara* , and *Zanthoxylum* become dominant. The author supported his observations by comparing prehistoric paleoecological data from Lake Eckixil with modern pollen rain data from the abandoned agricultural plots.

Two studies from Belize presented evidence of forest regeneration after human disturbance. Hansen (1990) used the pollen stratigraphy of a lagoon (Laguna de Cocos) on Albion Island to investigate Mayan subsistence strategies in Northern Belize. The oldest sediments of the 5 m core were dated to about 5000 yr B.P. Pollen assemblages in the basal sediments were indicative of a "dense forest" (high percentages of *Brosimum*, other Moraceae, and Combretaceae / Melastomataceae, and a very low component of weedy herbaceous taxa). *Zea* pollen was present in the next pollen zone and was accompanied by a rise in Chenopodiaceae / Amaranthaceae, followed by a rise in Combretaceae / Melastomataceae, and a decline in Moraceae. This zone continued to have a high component of arboreal taxa, yet some small-scale agricultural clearing was evidenced. The next zone was marked by a decline in *Zea* pollen percentages, an increase in pollen

percentages from savanna species (e.g. *Pinus, Quercus*, and *Byrsonima*), and a continuing high percentage of Combretaceae / Melastomataceae. Hansen suggested that this zone represented a short period of abandonment and hypothesized that the Combretaceae / Melastomataceae pollen represented a vine (*Combretum fruticosum*) that commonly invades fallow maize fields. The pollen of savanna species may have been deposited through long-distance dispersal through a more open forest. The following zone represented a period of intensified agriculture characterized by high percentages of *Ambrosia*, other Compositae, Chenopodiaceae / Amaranthaceae, Cyperaceae, and Gramineae, in addition to greater representation of *Zea* pollen. Percentages of total arboreal pollen were at an all time low, but pollen of savanna species blowing in from outside areas was still represented. Major forest clearance occurred during this period, as witnessed by the high percentages of *Ambrosia.* Hansen made use of Vaughan *et al.*'s (1985) interpretation of disturbance pollen types by stating "while other Composites, Chenopodiaceae / Amaranthaceae, Cyperaceae, and Gramineae may reflect succession as determined by soil aeration, seed availability, or climatic change, *Ambrosia* is definitely an indicator of active human disturbance." The last zone that Hansen recognized represented the recovery of the landscape after severe land clearance, perhaps coincident with the hypothesized Maya collapse. *Ambrosia* pollen decreased while arboreal pollen types, such as Moraceae (including *Brosimum*), Combretaceae / Melastomataceae, Bombacaceae, and Palmae increased in abundance. The presence of savanna species along with high percentages of Chenopodiaceae / Amaranthaceae pollen lead Hansen to consider that the recovering forest was much more open than the original forest. Interestingly, *Zea* pollen continued to be represented in equal or slightly higher percentages during this period of apparent forest recovery. Percentages for *Ambrosia,* however, dropped off steeply. Hansen speculated that this pattern might indicate more intensive agriculture was being practiced on smaller tracts of land. Byrne and Horn (1989), in their study of Lago Catemaco sediments, have

regarded declining *Ambrosia* percentages associated with continued presence of *Zea* pollen as reflecting a change in agricultural practices and not a reduction of area under cultivation. However, the effect of agricultural practices on tropical pollen spectra have not been studied. In Britain, Hall (1988) offered data that showed that changes in harvesting techniques of Cerealia (in this case, *Hordeum*) caused no changes in the distances over which pollen was dispersed or on the concentration of the dispersed pollen. The effect of changing harvesting techniques on weed pollen was not investigated, however.

Healy *et al.* (1983) investigated the hypothesis that Mayans used agricultural terraces as a method to increase food production for a burgeoning population. Six hectares of terraced hillslopes found near a major Maya ceremonial center at Caracol, Belize, attest to intensive agricultural practices. While no pollen was recovered directly from the terraces, Healy *et al.* cored a reservoir that was constructed by the Mayans circa 1600 yr B.P. At the base of the core, they found high percentages of *Zea* and *Ambrosia* pollen. *Zea* pollen was present until about 1200 yr B.P., when "marked vegetational changes [occurred] suggesting site reclamation by the forest, a state it continues in today." Unfortunately, no pollen diagram was published, forfeiting the possibility of interpreting post-Maya forest regeneration sequences at this site.

A study of early agriculture and early Postclassic Mayan occupation in western Honduras was conducted by Rue in 1987. In his study, Rue tracked human-caused forest change as it was revealed by pollen contained in sediments recovered from Lake Yojoa and Petapilla Swamp. The sediments from Lake Yojoa showed a complete cycle of forest destruction and regeneration. "Pre-human" forests were composed of high percentages of arboreal taxa, such as *Pinus*, *Quercus*, and members of the Urticales. It is unfortunate that Rue lumped members of the Urticales order into 2 groups -- "successional" (*Cecropia* and *Trema*) and "climax" (*Ficus* and *Brosimum*). While there is no question that identification

of Urticales pollen to the genus or family is problematic, palynomorphs of *Cecropia* and *Ficus,* when well preserved, can be taxonomically distinguished by morphological characteristics (Bartlett and Barghoorn 1973; Horn 1986). While *Cecropia* can act as a pioneer species invading disturbed sites, it also persists in mature forests and is characteristic of riverine systems (Burger 1977; Sauer 1988). Rue's grouping lumps species that may behave differently and in this way may mask the forest regeneration process.

At about 4500 yr B.P. at Lake Yojoa, arboreal pollen types (especially *Pinus* and Urticales) declined and weedy herbaceous pollen taxa increased and were accompanied by *Zea* pollen (Rue 1987). This zone probably represented early slash-and-burn agriculture practiced by the "preceramic late Archaic peoples" as a part of an expanding system of food procurement. Land clearance associated with agriculture continued until about 3000 yr B.P., when disturbance indicators leveled off. From 3000 yr B.P. to modern times, Rue was unable to identify many trends in the pollen record. This led him to conclude that there was a "high level of ecological stability" at this site through the Classic Maya period, with no evidence of the ~ 1100 yr B.P. Late Classic collapse. But this lack of trends may not indicate high levels of ecological stability. Rather it may be attributable to the use of very generalized taxa groups, or as Vaughan *et al.* (1985) suggest, to the presence of a system that had been so simplified by human activity that further degradation did not register as vegetational changes in the pollen record.

The basal sediments in a 1 m core from Petapilla Swamp (a peat bog at 700 m elevation) were dated to about 1000 yr B.P. (Rue 1987). Three periods have been recognized. From about 1000 - 750 yr B.P., pollen percentages were high for Gramineae and *Zea* and very low for arboreal taxa . Rue has suggested that this period corresponds to the terminal Classic-early Postclassic period, when lowland (and possibly highland) forests

in the area were largely cleared. From about 750 - 200 yr B.P., arboreal pollen types (*Pinus* and Meliaceae) increased, while Gramineae, Compositae, and *Zea* all decreased. From 200 yr B.P. until the present, pollen spectra associated with modern human disturbance dominated. Rue offered no explanation of the last two trends, except to suggest that reforestation occurred and then modern disturbance regimes began -- circa 200 years ago.

Several paleoecological studies in Panama document vegetation change associated with prehistoric human activity. A study by Bartlett and Barghoorn (1973) established a phytogeographic sequence for the Gatun Basin (Panama Canal Zone). While the pollen diagrams included in this study reflect changes within a large pollen source area, they do provide a good synopsis of long-term vegetation change in the basin. Agriculture based on *Manihot esculenta* (yucca) and *Zea* (maize) began quite early (*Zea* and *Manihot* pollen having been present in the sediments by 7000 and 1800 yr B.P., respectively). From the pollen record, it appears that upon abandonment of agriculture, *Alchornea*, *Acalypha*, *Erythrina glauca*, and Malpighiaceae increased in abundance.

Piperno and Clary (1984) used pollen and phytolith analysis to investigate prehistoric plant use on the central Pacific coast of Panama. Soil samples from an archaeological site, Cueva de los Ladrones, contained *Zea* pollen and phytoliths which dated to preceramic times (~5000 yr B.P.) and documented an early establishment of *Zea* cultivation in this part of Panama. However, in the context of post-agricultural forest regeneration, only limited inferences can be made because samples were taken at noncorresponding depths from different areas of the cave . No vegetational shifts associated with human activity were documented in the study.

Analysis of sediments collected at Lake La Yeguada (a lake of volcanic origin located in Central Panama) is the subject of four papers by Piperno, Bush, and Colinvaux (Piperno

et al. 1990, 1991a, 1991b; Bush *et al.* 1992). According to the authors, the pollen and charcoal stratigraphy of the lake sediments records continual disturbance by humans since the late Pleistocene. An horizon dated to about 11,050 yr B.P. that contained large amounts of charcoal fragments (particulate carbon) and weedy plant fragments has been attributed to burning by prehistoric hunter/gatherers. Direct evidence of hunter/gatherer presence was not recovered, but the authors defended their hypothesis by stating,

> The likelihood of this rise [in particulate carbon] being attributable to natural fires is negligible, as particulate carbon content suddenly increased by more than an order of magnitude. Furthermore, the increased influx of particulate carbon was sustained across a boundary of decreasing seasonality and increasing early Holocene lake level (Bush *et al.* 1992, p. 269).

The authors further propose that human disturbance of the watershed increased after 11,000 yr B.P. and cite as evidence charred phytoliths of taxa associated with disturbed forests (*Heliconia*), and increasing levels of Gramineae pollen. Some forest may have regenerated directly after this date as shown by increases in arboreal pollen (*Cecropia* and Myrtaceae). The authors attributed this regrowth to one of two causes: land management practices may have changed allowing longer regrowth periods, or disturbance may have become more concentrated allowing the vegetated landscapes to become more heterogeneous. The appearance of *Zea* phytoliths (and possibly *Zea* pollen) and the disappearance of *Quercus* from the pollen record at about 4000 yr B.P. have been interpreted as an intensification of agricultural practices. The most recent sediments were characterized by a peak in *Trema* pollen and greater representation of *Byrsonima* and other arboreal pollen types; these trends have been interpreted as indicating a final period of forest regeneration within the last couple of centuries.

In connection with phytolith data from the neotropics, it should be noted that Doolittle and Frederick (1991) have argued that the use of phytolith analysis for paleoecological studies may not be as fruitful as some researchers have claimed (Piperno 1989; Piperno and Pearsall 1993). The presence of large cross-shaped phytoliths in lake sediments or archaeological soils has been interpreted as indicating maize agriculture. However, Doolittle and Frederick have stated that maize is not the only species of grass that produces large cross-shaped phytoliths and that phytoliths from maize plants can vary widely in shape and size depending on climatic conditions. In their study, which was based on field tests of four primitive maize races, they pointed out the tenuousness of phytolith classification and rejected the use of phytoliths as a diagnostic tool for determining prehistoric cultivation of maize.

Limited human occupation of the Amazon and Inter-Andean Plateau areas of Ecuador have been documented by Bush *et al.* (1989), Bush and Colinvaux (1988), Liu and Colinvaux (1988), and Colinvaux *et al.* (1988). The sediments of Lake Ayauch[i], a volcanic explosion crater lake located in the southeastern Amazonian lowlands, were used to explore the effects of climatic change and human activity on rainforest vegetation by both Bush *et al.* (1989) and Bush and Colinvaux (1988). Whereas Bush *et al.* (1989) presented evidence establishing the early practice of maize agriculture in the Amazon basin, Bush and Colinvaux (1988) provided a detailed interpretation of the vegetation changes that occurred over the 7,000 year period spanned by the pollen record.

According to pollen diagrams presented in the papers, prehuman forests were composed of high percentages of arboreal taxa, especially species in the Urticaceae, Moraceae, and Ulmaceae families (*Pilea, Ficus, Pilea/Trema,* and *Celtis* are separated out from the group and are all high; *Cecropia* was presented in a separate diagram and was low at this time). High percentages of what the authors term as "mature forest" pollen-types

(*Alchornea,* Anacardiaceae, *Didymopanax, Pachira aquatica, Psuedobombax*, and *Ochroma*) dominated, with fluctuating levels of Gramineae pollen. The first direct evidence of human disturbance was the appearance of maize in the pollen record at about 6000 yr B.P. The presence of *Zea* pollen was associated with a rise in *Cecropia* and weedy herbs (*Acalypha*, Chenopodiaceae / Amaranthaceae, Caryophyllaceae, Gramineae, *Plantago*, and Composites), and a decline in Bombacaceae.

Maize agriculture continued sporadically until about 800 yr B.P., as noted by the fluctuating levels of *Cecropia* and *Zea* pollen between 240 and 50 cm in the core. The 'spikiness' of the *Cecropia* curve has been attributed to swidden agricultural practices -- as cultivated land was fallowed, *Cecropia* invaded; as it was put back into cultivation, *Cecropia* was cut or burned out. Bush and Colinvaux (1988) have suggested that rising lake levels may have forced abandonment of maize agriculture in the lake basin at about 800 yr B.P., but have speculated that social disruption resulting from environmental change or increased internecine warfare also may have influenced local population dynamics. In any case, after about 800 yr B.P., there was a decline of Gramineae and an increase in *Ficus, Alchornea, Pilea,* and *Cecropia* pollen denoting that "land use had reverted to pre-cereal growth patterns."

A very limited amount of information concerning human habitation can be gleaned from Liu and Colinvaux's (1988) study of climate and vegetation changes at Laguna Kumpak[a], a lake occupying an explosion crater in the western Amazon basin. Seven radiocarbon dates have established the 5200 year chronology of the 18 m core that was recovered from the lake. A single maize pollen grain was identified at 384 cm. Its appearance was associated with a slight rise in Gramineae pollen. Although Liu and Colinvaux (1988) recognized that these two bits of information only provide limited evidence of human activity, they inferred that the clearing of forests for cereal cultivation in

the western Amazon lowland occurred at about 1550 yr B.P. No changes in arboreal pollen levels were detected.

In another study, Colinvaux *et al.* (1988) discussed pollen sequences from two Andean lakes, Yaguarcocha (2201 m) and Yambo (2600 m), the latter of which has a record of maize agriculture and forest disturbance. No maize pollen was found at Lake Yaguarcocha, even though considerable amounts had been found in a nearby lake (Lake Cunro), which had been previously studied by the authors (Colinvaux *et al.* 1988). *Zea* pollen was present continuously ($\geq$ 1 percent) in the upper 6 m of the 7.5 m core that was recovered from Lake Yambo. Basal sediments rich in plant fragments were dated to about 2500 yr B.P., but the authors suggested that this date may not be reliable because of suspected contamination by old carbon present in the groundwater.

Lake Yambo lies in the most arid region of the Inter-Andean Plateau and is currently surrounded by sparse desert vegetation composed of Cactaceae, Euphorbiaceae, and Solanaceae. The pollen record constructed by Colinvaux *et al.* (1988) showed a consistent representation of this desert flora with a minor presence of tropical forest elements, representing regional or long-distance pollen sources. Because, as the authors point out, the desert properties of the Lake Yambo watershed "offer difficulties for cereal cultivation," some debate arises over how such a consistent level of maize pollen could be represented in the pollen record. The authors argued that the intense vertical circulation of the Andean atmospheric systems brought in and deposited trace quantities of maize pollen from adjacent moister and warmer watersheds. Because the local pollen rain was underrepresented, the trace quantities of maize pollen were detectable. Colinvaux *et al.* (1988) support this hypothesis by suggesting that the only way that the palm pollen, which was also present, could be present in the core was by long-distance transport. Alternatively, some discussion of the possibility of local maize cultivation seems

warranted. The authors alluded to, but never explained, the irrigated crops that are presently under cultivation at the southern end of the lake. While the elevation may hamper the success with which maize is cultivated, it should be possible at the site if irrigation agriculture is practiced. Purseglove (1972) reports that maize can be grown from 50°N to 40°S and from sea level to 3,300 m in the Andes and Mexico with a minimum rainfall of 200 mm. While areas downslope were undoubtedly used for maize cultivation, the large size of maize pollen grains argues against consistent long-distance dispersal. Experimental work by Raynor *et al.* (1972) has demonstrated that airborne maize pollen concentrations decline by 99 percent within 60 m from the source area of maize cultivation. Perhaps a local source of maize pollen production could more effectively explain its presence in the pollen record. Ancient irrigation of crops in the area of the lake should be considered. If the marshy area at the south end of the lake is presently dedicated to irrigated agriculture, it seems possible that it could have been used in a similar manner in the past for maize cultivation.

• • •

The forests of Latin American tropics are highly diverse and spatially heterogeneous -- factors that lend difficulty to paleoecological interpretation. Careful examination of the pollen record of human-environment interaction in the neotropics reveals that the identification of pollen taxa and their ecological interpretation are far from standardized (Vaughan *et al.* 1985). Some researchers have attempted to separate out families (i.e. Moraceae) and many genera (*Brosimum, Chlorophora*-type, etc.) in the Urticales order, a common rainforest pollen type. Other researchers have cautioned against this, owing to strong overlaps in pollen morphology. Adding to this difficulty are regional differences in vegetation composition and diversity, which may make family or generic differentiation more tenable in some areas than others. Ecological interpretation of taxa has also varied

significantly between authors. For example, *Alchornea* is regarded as a mature forest taxa by some authors, and as a secondary or edge species by others. Similarly, undifferentiated (lumped) taxa in the Urticales are considered successional by some workers, while others recognize both secondary and mature forest taxa in the group. Some of these differences, no doubt, reflect regional biogeography. That is, *Alchornea* species in the Petén area may indeed be forest-edge species, while those in Ecuador may principally occur in mature forest.

Interpretation of pollen spectra must rely on ecological inferences appropriate to the area under study. However, incomplete knowledge of the ecology of most tropical species usually precludes assigning a generalized ecological "meaning" to each pollen type. The degree of ecological ambiguity associated with the taxonomic level to which pollen can be identified in the neotropics defines what the pollen record can and can't tell us. In this study of pollen stratigraphy at Lagunas Bonilla and Bonillita, I have based my pollen taxonomy on pollen reference materials from Costa Rica, and have relied on taxonomic and ecological literature from Costa Rica in interpreting pollen signals.

CHAPTER 3

PRESENT ENVIRONMENT AND VEGETATION

The Río Reventazón is located in the central Atlantic watershed of Costa Rica (Figure 3.1) and its headwaters lie high in the Cordillera de Talamanca in the Province of Cartago. The river flows eastward 155 kilometers and drains into the Caribbean Sea, approximately 47 kilometers north of the Port of Limón. The watershed of the river occupies about 1685 km^2 (Herrera 1985). It is an ecologically diverse area that is mapped under the Holdridge system as containing 9 life zones: Tropical Moist, Premontane Rain, Premontane Wet, Premontane Moist, Lower Montane Rain, Lower Montane Wet, Lower Montane Moist, Montane Wet, and Montane Moist (Kennedy 1968).

The two lakes that are the focus of this study are located within the middle watershed of the Río Reventazón on the lower Atlantic slope of the historically inactive Volcán Turrialba, in the Province of Limón (Figure 3.2 and 3.3). Laguna Bonilla (9° 59' 36" N, 83° 36' 13" W, 380 m elevation) has a surface area of about 30 hectares and a maximum depth of 27 meters. Laguna Bonillita (9° 59' 36" N, 83° 36' 48" W, 450 m elevation) is located one kilometer west of Laguna Bonilla and has a surface area of about 6 hectares and a maximum depth of 20 meters (Horn and Haberyan 1993).

CLIMATE

The climate of the area surrounding Laguna Bonilla and Laguna Bonillita is classed as Afw' in the Köppen system (tropical rainy with maximum rainfall in autumn) and lacks prolonged periods of dryness (Gómez 1986). The lakes are located on the windward side of the mountainous spine formed by the Quaternary volcanoes of the Cordillera Central and

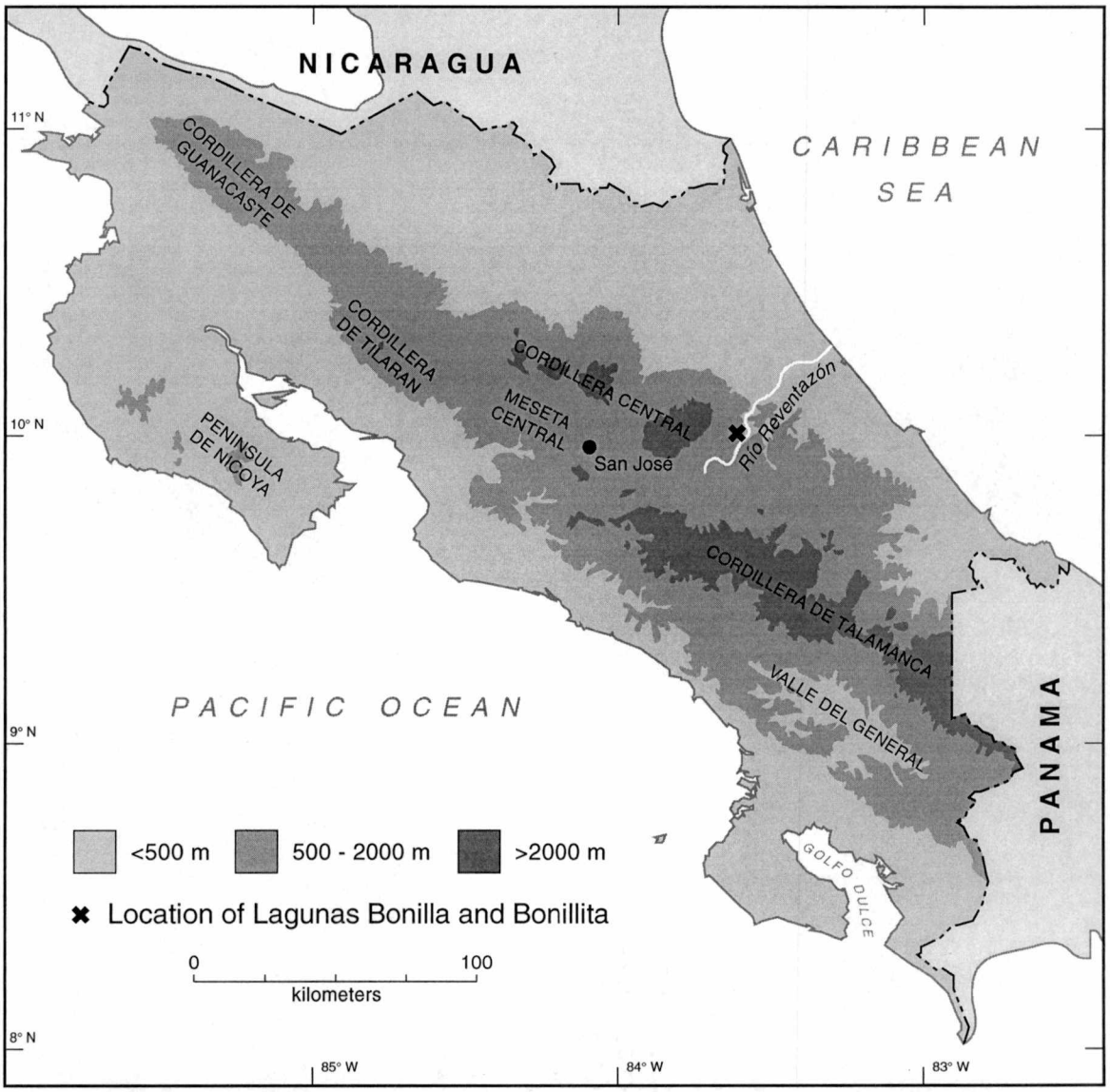


Figure 3.1 Map of Costa Rica showing Elevations and Locations Mentioned in the Text (based on a map published by the Instituto Geográfico Nacional 1966).

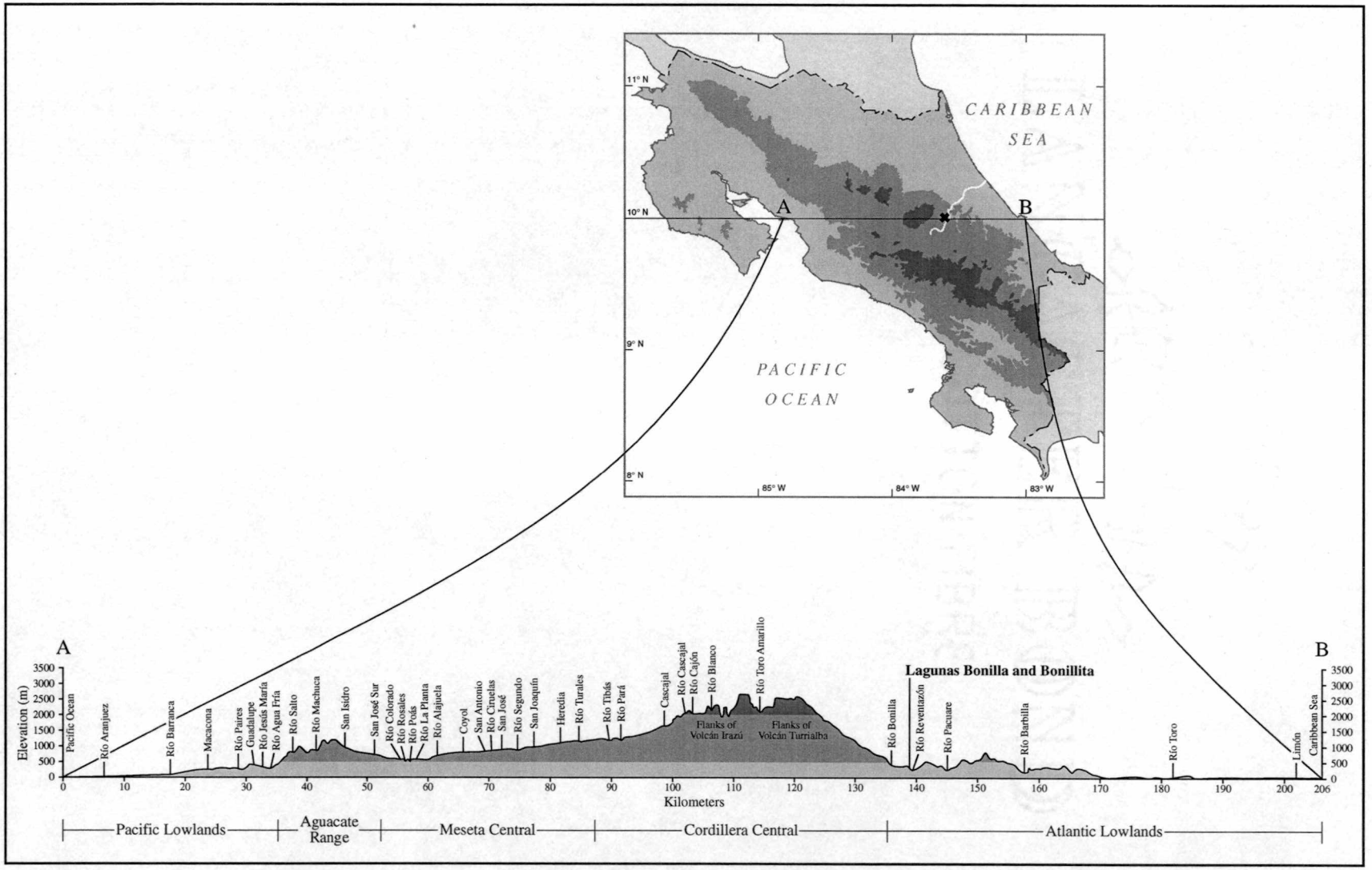


Figure 3.2 Topographic Profile of 10°N Parallel (adapted from Hererra 1986). Shade pattern denotes elevational relief (as on Figure 3.1).

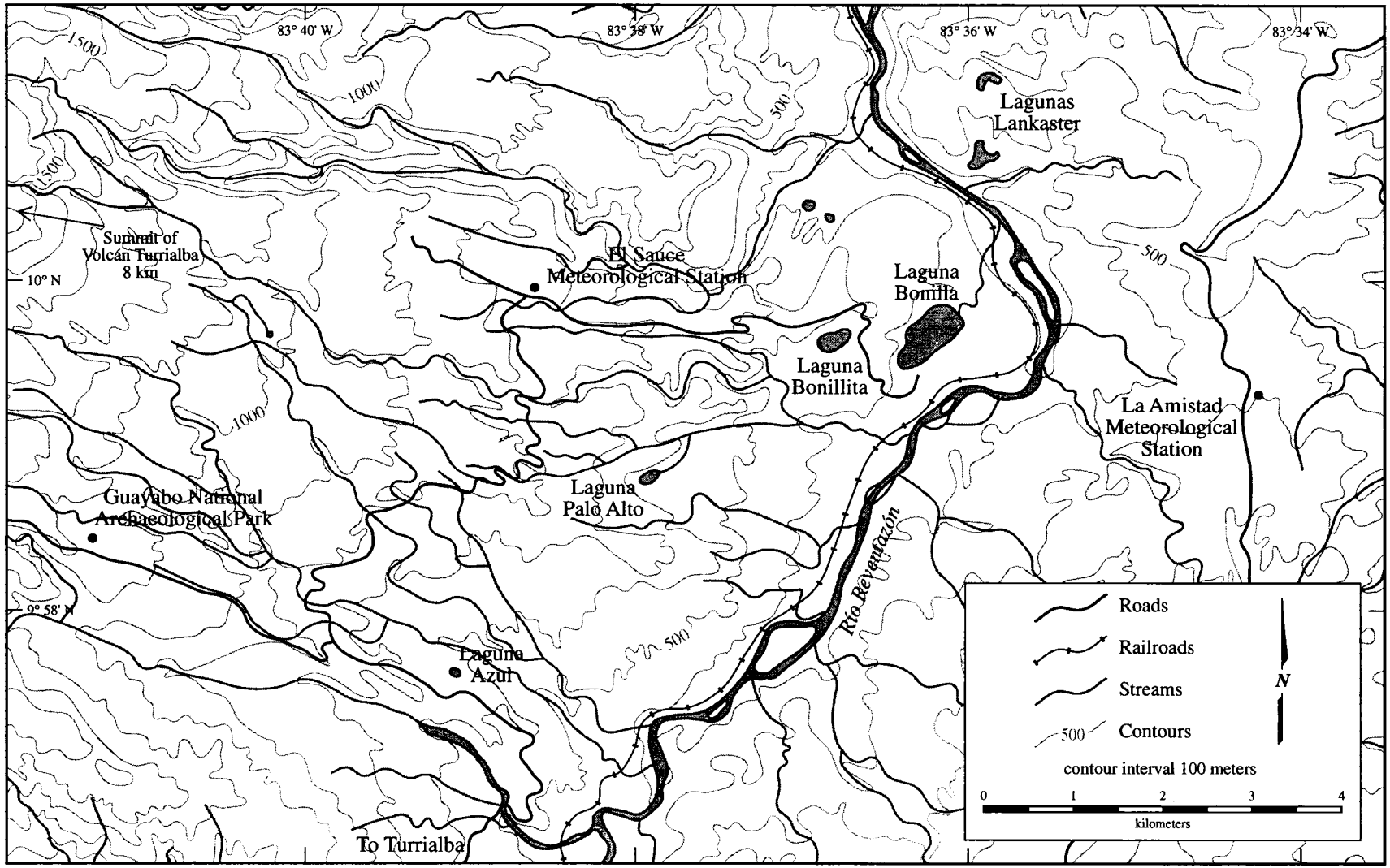


Figure 3.3 Map of the Study Site showing Lakes, Topography, and other Locations Mentioned in the Text (based on 1:50,000 topographic maps (Bonilla and Tucurrique sheets) published by the Instituto Geográfico Nacional 1981).

the older plutonic Cordillera de Talamanca (Figure 3.2). Consequently, most of the rain they receive is generated orographically. Tradewinds push warm, moist, unstable, maritime airmasses inland from the Atlantic (Caribbean) up and over the surrounding mountain ranges. As these unstable, moist airmasses are forced upward, they condense and rain is generated. No meteorological data are available for either lake site, but records from two stations near the lakes provide representative data. The prevailing influence of orographic storms is reflected in the precipitation values recorded at the two stations. The La Amistad station (500 m) is located one kilometer to the east of the lakes and receives slightly less precipitation than the El Sauce station (740 m) situated one kilometer west of the lakes (Figure 3.3). Rainfall occurs year-round but is somewhat seasonal with the driest part of the year occurring from February to April. Average annual precipitation from 1977 to 1989 was 3076 mm at the La Amistad Station. Mean annual precipitation at the El Sauce Station for the same period was 3232 mm. Monthly precipitation averages varied from 144 mm in March to 379 in August at the La Amistad station. The wettest average month recorded at the El Sauce station was June (340 mm) and the driest average month was March (177 mm) (Table 3.1). Mean monthly minimum and maximum temperatures do not vary widely -- minimum temperatures at this latitude and elevation are estimated to range from 18°C in February to 20°C in June and maximum temperatures are estimated to range from 26°C in December to 28.5°C in mid April and late October (Coen 1983).

Table 3.1. Monthly and Yearly Precipitation Averages at the La Amistad and El Sauce Meteorological Stations, 1977-1989.

Site	Average Precipitation (mm)												
	J	F	M	A	M	J	J	A	S	O	N	D	Year
La Amistad	268	205	144	192	233	336	333	379	269	356	279	304	3076
El Sauce	234	208	177	215	270	340	318	337	249	337	269	272	3232

Source: Instituto Costarricense de Electricidad, n.d.

GEOMORPHOLOGY AND LAKE FORMATION

Laguna Bonilla and Laguna Bonillita are situated on ancient fluvial-lacustrine terraces of the Río Reventazón, which presently lies approximately 80 m lower in elevation and 0.5 km to the east of Laguna Bonilla (Figure 3.4). Laguna Bonillita is situated 70 m above Laguna Bonilla on an older, higher river terrace (Figure 3.5; Bergoeing 1987). Radiocarbon dating of sediments conducted for this thesis indicate that the lakes were formed by discrete geomorphic events, but the specific manner by which the lakes formed has yet to be fully resolved. Bergoeing and Malavassi (1982) suggested that the formation of the lakes was related to the former presence of a lava dam across the Río Reventazón. This natural dam, located just downstream of the lakes, was believed to have held back the waters of the Río Reventazón, creating a large lake that covered the present site of Laguna Bonilla and Laguna Bonillita and a large surrounding area. When the lava dam was finally breached, the large lake drained and left two scour pools behind -- Laguna Bonilla and Laguna Bonillita. However, field reconnaissance indicates that local damming of tributary streams of the Río Reventazón by lahars and landslides may also have played a role in forming the lakes. L.G. Brenes of the Department of Geography of the University of Costa Rica has suggested that the lakes have been heavily influenced by faulting and that subsurface faults probably play a role in funneling the flow of groundwater seepage from Laguna Bonillita to Laguna Bonilla (L.G. Brenes, personal communication, February 1994). The complex history of fluvial, volcanic, and seismic processes active in this area and their interaction require further study in order to conclusively determine the mode of origin of these two terrace lakes.

LIMNOLOGY

The lakes appear to be rain-fed as they lack inflowing streams, but they may also receive some water from underground springs. Laguna Bonilla may receive some

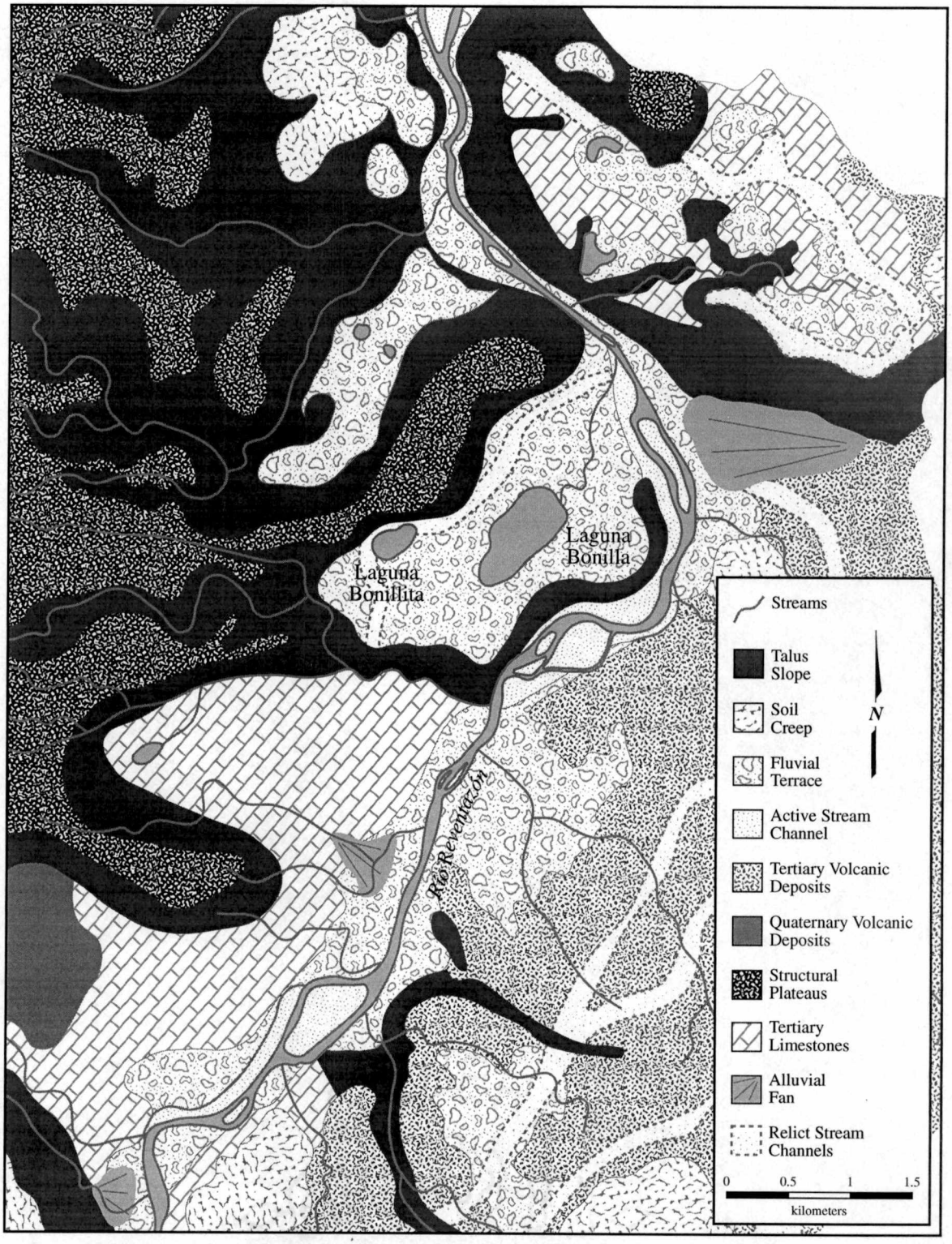


Figure 3.4 Geomorphology of the Study Area (adapted from Bergoeing and Malavassi 1981; Bergoeing 1987).

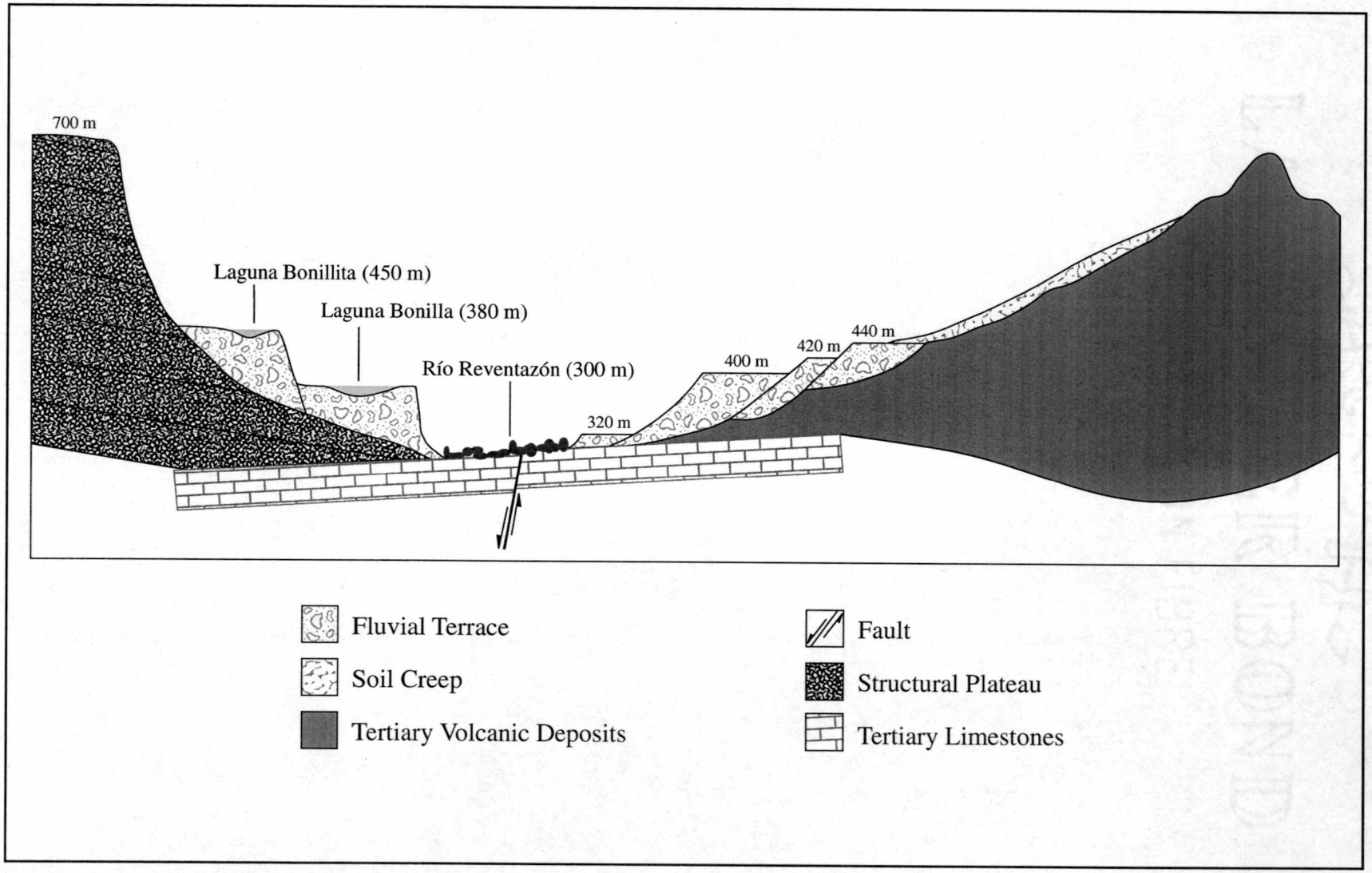


Figure 3.5 Generalized Valley Cross Section showing River Terraces and Lake Sites (adapted from Bergoeing 1987). View is looking North.

subsurface flow from Laguna Bonillita. Landowner Jorge Rossi observed that the water level in Laguna Bonillita dropped ~ 0.5 m following an earthquake in 1991 (Horn and Haberyan 1993). This may support the contention that the lakes are fed in part by subterranean sources. Whereas Laguna Bonillita does not have a surface outlet stream, Laguna Bonilla has a small outlet stream which flows northeast to join the Río Reventazón.

Horn and Haberyan (1993) examined physical and chemical characteristics of the lakes and concluded that both turn over annually. The chemical assays of the lakes indicate that Laguna Bonilla's water is somewhat harder than that of Laguna Bonillita (50.3 mg/L $CaCO_3$ vs. 14.04 mg/L $CaCO_3$). Chlorine and sulfate values for the deep water samples from Laguna Bonillita were higher than those of Laguna Bonilla (3.38 vs. 0.37 ppm SO_4^{-2} and 11.50 vs. 1.89 ppm Cl^-, respectively), reflecting the slightly more chemically-reducing environment of Laguna Bonillita.

VEGETATION AND LAND USE

The vegetation that presently surrounds the lakes has been highly disturbed by human activities. While remnants of a tropical lowland rainforest can be seen, much of the land in the vicinity of the lake is maintained in cattle pasture. The lakes are located within the region Holdridge mapped as the tropical wet forest life zone and are just downslope of the tropical wet forest, premontane belt transition life zone (Holdridge *et al.* 1967; Tosi 1969). The Holdridge classification system is based on climatic parameters but the life zones are equated with vegetation formations. Hartshorn (1983) described the mature forest of the tropical wet forest life zone as tall, multilayered, evergreen forest. A few canopy trees are briefly deciduous during the driest part of the year. Canopy trees are 45 to 55 m tall, with round to umbrella shaped crowns, and reach diameters of 100 to 200 m diameter at breast height. These trees commonly have smooth, thin, light colored bark and high buttresses.

Subcanopy trees are 30 to 40 m tall and have round crowns, slender trunks, and generally lack buttresses. Understory trees are 10 to 25 m tall and have conical crowns and smooth dark bark. Stilt rooted palms are abundant. The shrub layer is usually composed of dwarf palms and giant broad-leaved herbs. Ground vegetation is sparse with ferns occasionally present. Climbing lianas, herbaceous vines, and epiphytes are common.

Mature forests of the adjacent tropical wet forest, premontane belt transition life zone are expected to be transitional in character between the tropical wet forest (described above) and the premontane rainforest of higher elevations (described below). According to Hartshorn (1983) the semievergreen premontane rainforest is similar in appearance to the tropical wet forest and has 2 or 3 strata of medium to tall trees. Canopy trees generally have smaller buttresses and leaves that cluster at the twig tips. The shrub layer is generally dense and is composed of 1.5-2.5 meter tall dwarf palms, treelets, and occasional giant broad-leaved herbs. Ferns are generally the only ground cover.

Still further upslope in the Río Reventazón watershed, climatic conditions fall within Holdridge's tropical lower montane rainforest and the montane rain forest life zones. Hartshorn (1983) describes the vegetation type associated with the lower montane life zone as being evergreen forest of low to intermediate height with two tree strata. Canopy trees are 25-30 m tall and compact, usually without buttresses. Understory trees are generally 10-20 m tall, have slender trunks, and commonly have root suckers at their trunk bases. The shrub layer is very thick and 1.5 to 3 m in height. Ferns, sedges, herbs, and patches of moss typically cover the ground. Shrubby Ericaceous and Melastomataceous epiphytes grow in abundance from moss covered trunks and branches. The mature forests of the montane rainforest life zone are evergreen and are composed of low to intermediate height trees. Canopy trees ate generally 25 - 30 m tall and have short, stout, unbuttressed trunks with rough bark. Understory trees are genrally 5 - 50 m tall and have crooked trunks and

brushlike crowns. The understory forest is open and is characterized by the presence of ferns and dwarf bamboo that grows to a height of 5 m. Moss and epiphytic herbs are common, as are woody vines and canopy epiphytes.

Preliminary data on the arboreal vegetation in the vicinity of Lagunas Bonilla and Bonillita was collected by University of Costa Rica undergraduate students (Acuña *et al.* 1983). Predominant plant families recognized by the students were Moraceae (comprising > 50 percent of all trees surveyed), Leguminosae (28 percent of trees), Lauraceae (12 percent of trees), and Myrtaceae (9 percent of trees).

During February 1994, "laurel" and "annonillo" were being harvested from the pastures surrounding the lakes. Laurel is the common name for *Cordia alliodora*, a fast-growing tree with a wide geographic range that is valued for its fine wood (Opler and Janzen 1973). Annonillo may be *Annona reticulata, A. holosericea,* or *Guatteria oliviformis* (Pittier 1978); the exact species being harvested could not be determined due to inconsistencies in the use of common names for plants in Costa Rica. Other taxa that were noted during the 1994 visit include *Psidium, Persea, Theobroma, Bursera, Gliricidia, Ficus, Cecropia* and other members of the Urticales, Leguminosae, Agavaceae, Cyperaceae, Solanaceae, Convolvulaceae, Passifloraceae, and a large contingency of pasture species such as *Lantana, Asclepias,* various grasses, and members of the Rosaceae, Labiatae, Compositae, and Brassicaceae families. Epiphytic bromeliads, bracken ferns (*Pteridium aquilinum*), other ferns, and a large number of lianas were also noted.

The land in the vicinity of the lakes is presently owned by Lic. Jorge Rossi, a lawyer and former Vice-President of Costa Rica. Rossi uses the land primarily for cattle ranching, but recently has become interested in developing the area near the lakes as a tourist attraction. Pines and eucalyptus have been planted near the lakes for wood and shade. Coffee and cacao are grown as cash crops but no other agricultural crops (e.g. corn, beans,

squash, or rice) were noted during any of the field visits. Historic land use data are sparse, but the area in the vicinity of the lakes is known to have been cleared of trees several times in the past. When Rossi's family bought the land in the 1940s, it was forested but some areas were in secondary growth after an episode of clearing earlier this century. The most recent episode of clearing began shortly after the Rossi family acquired ownership when the land in the vicinity of the lakes was converted to pasture (J. Rossi, personal communication with S. Horn, March 1991).

CHAPTER 4

CULTURAL HISTORY OF THE CENTRAL ATLANTIC WATERSHED

Central America has long been a bridge between the North American and South American continents -- a conduit for plant and animal migration, human migration, and later cultural exchange (Martin 1973; Marshall *et al.* 1982; Lange 1984; Stehli and Webb 1985). Paul Martin (1973) hypothesized that the decimation of native American megafauna may have been caused by the "first Americans" as they swept through the North American continent over the bridge and into South America starting at about 12,000 years ago. Using population growth models, he estimated that the "front of hunters" would have reached Panama at 10,390 yr B.P. The southward sweep of hunters may have resulted in sparse settlements of hunter/gatherers throughout Central America.

The earliest evidence of human presence in Costa Rica is a series of fluted Clovis projectile points that were found in the northwestern province of Guanacaste and in the Turrialba Valley (located on the eastern slopes of the Cordillera Central overlooking the Río Reventazón). The stone projectile points probably date to about 10,000 yr B.P. (Swauger *et al.* 1951; Snarskis 1979). The Turrialba site, where both North and South American-type PaleoIndian points were found, is near a surface exposure of carbonate bedrock that contains occasional nodules of chert- or jasper-like stone. It may have been a workshop site that was used periodically by prehistoric people for several thousands of years. The projectile points probably reflect human dependence on megafaunal hunting in association with the collection of wild nuts, fruits, seeds, and tubers, and possibly fishing (Snarskis 1984).

To date, direct archaeological evidence linking PaleoIndian occupation with permanent early settlement of the area has not been discovered in the Río Reventazón Valley. Although it is recognized that the valley has been a consistent route of travel between the Costa Rican highlands and the lower Atlantic watershed since PaleoIndian times (~ 10, 000 yr B.P.; Lange 1984), permanent human occupation of the area is not documented until about 3000 yr B.P. (Snarskis 1984). This first prehistoric period of human occupancy persisted from 3000 yr B.P. until about 2300 yr B.P. Two archaeological complexes are associated with this period, both of which contain lithic and ceramic artifacts that are distinctively different than artifacts from later dated sequences. The La Montaña complex has been found at several sites in the Turrialba Valley and is characterized by flat, raised rim griddles identical to the *budares* that attest to the processing of bitter manioc at archaeological sites in Brazil, Venezuela, and Colombia (Snarskis 1984). A second co-eval ceramic complex (the Chaparrón complex) was uncovered near the town of Chaparrón in the northern Atlantic watershed of Costa Rica. The composition and style of the artifacts from this site are unlike the artifacts from the La Montaña complex -- there are no *budares* and the ornamentation of the pottery reflects Mesoamerican, rather than South American, influences.

The co-occurrence of these two complexes in the region suggests that early settlement was a time of shifting northern and southern cultural influences (Snarskis 1984). Excavated sites dating to this cultural phase are small and widely spaced, leading some archaeologists to speculate that large amounts of land were needed for subsistence. Quintanilla (1990) has suggested that people living during this phase were incipient agriculturalists subsisting on tubers that they were able to grow in small clearings and on fruits harvested from the surrounding tropical rainforest. Alternatively, Snarskis (1984) hypothesized that these people were the last to depend primarily on root and tree crops and

suggested that the griddles and manos of this phase were associated with food preparation methods that did not persist into later cultural periods.

The next archaeological period lasts from 2300 yr B.P. until about 1500 yr B.P. This period was dominated by the El Bosque lithic complex, which dates from 2100 yr B.P. to about 1500 yr B.P. For years it was thought that this phase represented the oldest evidence of human presence in lower Central America. Older sites have now been excavated, but they are strongly outnumbered by El Bosque phase sites. El Bosque sites are also much larger, as well as much more numerous, than earlier sites. Snarskis (1984) has proposed that this cultural phase represents a period of explosive population growth in the Atlantic watershed of Costa Rica, possibly attributable to the adoption of modified agricultural systems that allowed more land to be placed under cultivation and increased food supplies.

Ceramics of the El Bosque complex are stylistically linked with those of the Chaparrón complex and are most often red on buff. Tools and other lithic artifacts from this period are not made of chipped chert like those of earlier phases. Instead, tools such as celts, axes, daggers, bark beaters, pestles, stirrup-shape mullers, loaf-shaped manos, and several types of mortars and pestles have been roughed out from slate or other hard stones and then ground to their final form. Jade amulets and beads carved in a traditional Olmec style have been found in burials (Snarskis 1984).

Two metate styles have been recovered from sites dating to the El Bosque period. One style is a rectangular or round, thin-plated, rimmed tripod (Figure 4.1). The other style is a roughly oval to square stone tripod with stubby legs and a thick plate, usually troughed in the middle from wear (Figure 4.2). A fair amount of controversy has arisen over the interpretation of these metate styles (Stone 1956, 1977; Kennedy 1968; Snarskis 1984). Some archaeologists have argued that the rimmed metates signify a reliance on root crops. Others have suggested that the rimmed metates were only used for ceremonial purposes, as

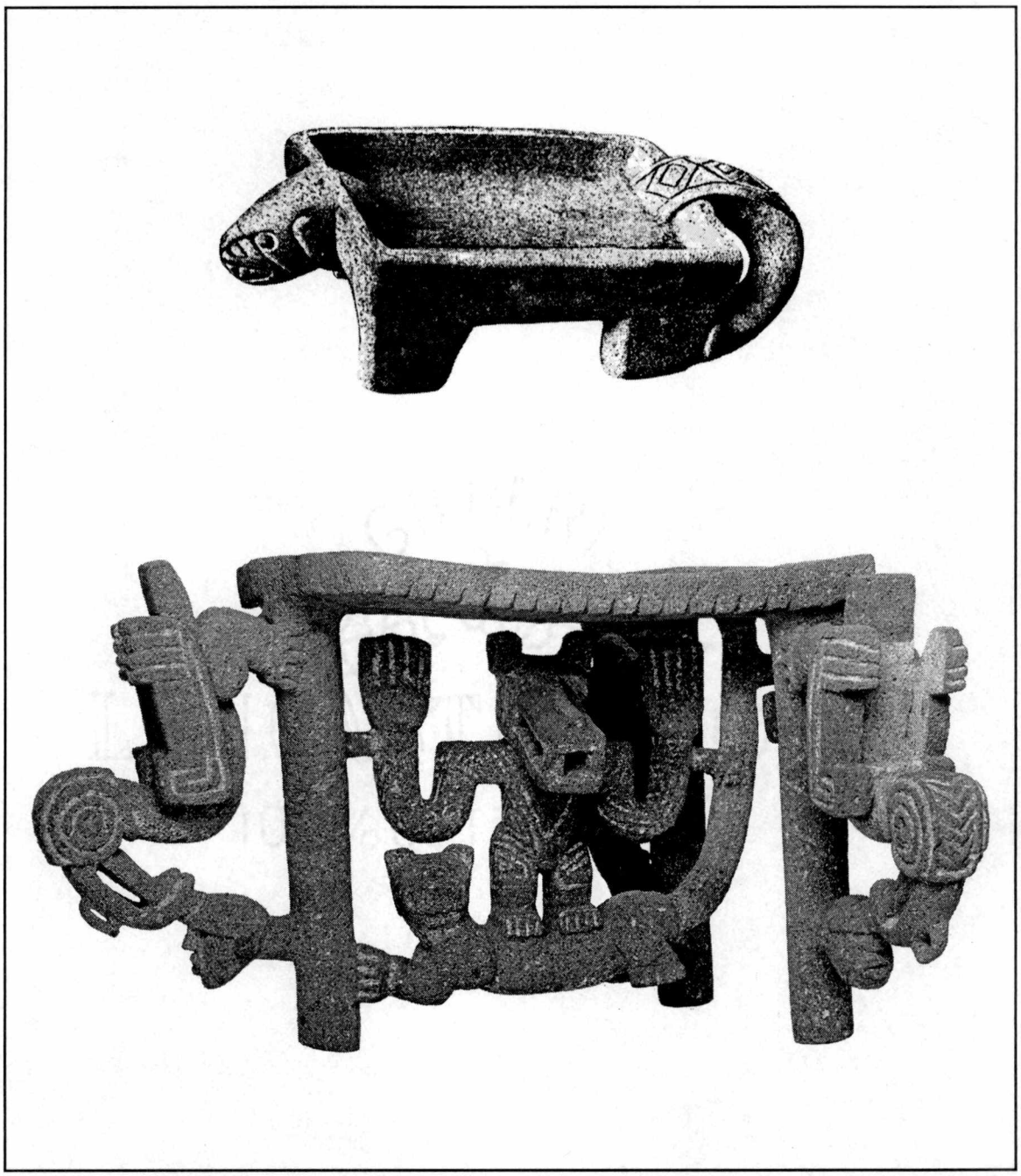


Figure 4.1 Rimmed "Metates" of the El Bosque Period (drawing from Ferrero 1981 and plate from Benson (ed.) 1981).

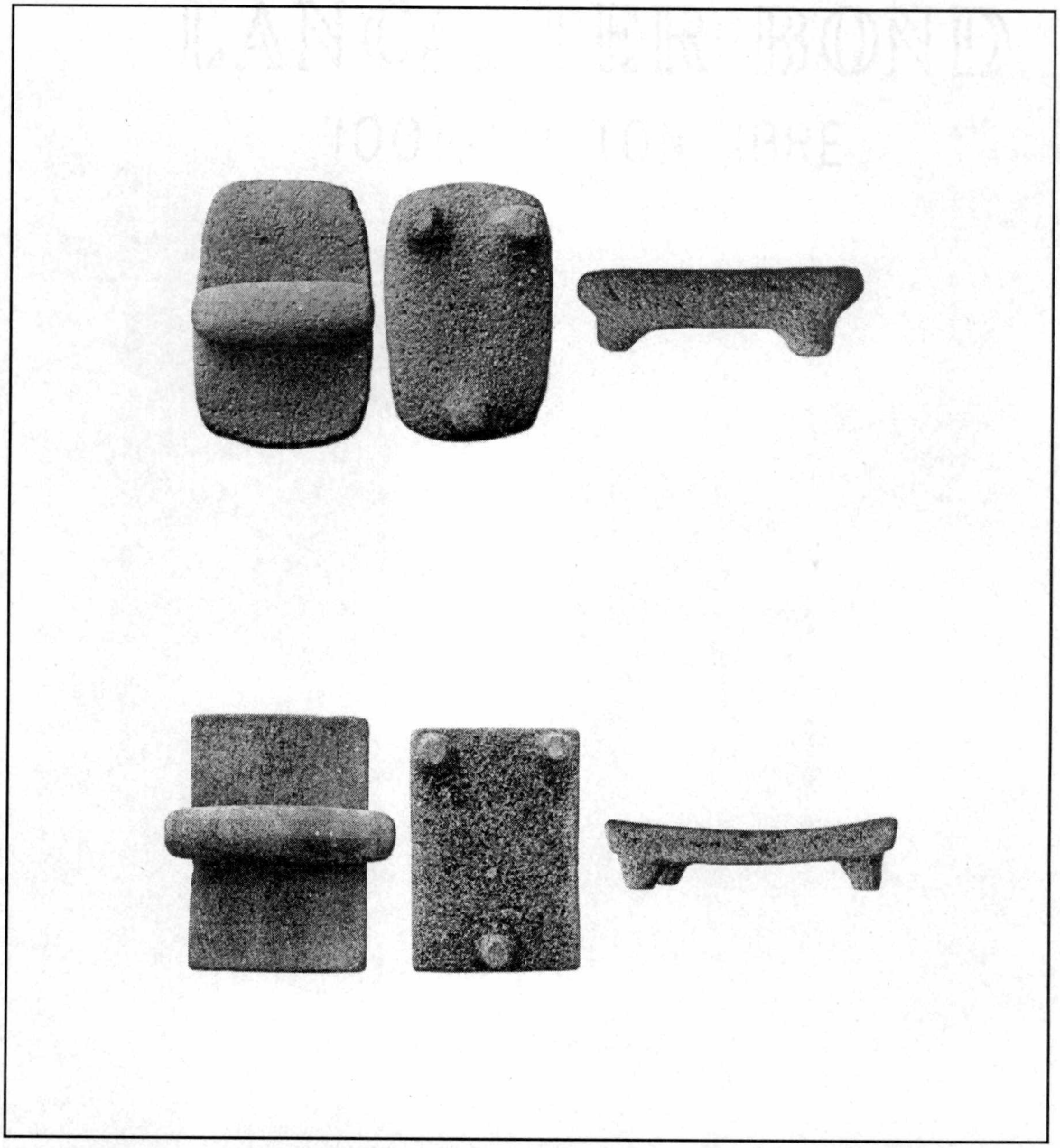


Figure 4.2 Common Unrimmed Metates (plates from Kidder *et al.* 1946).

their thin plates made everyday use impractical. Underlying this controversy is the question of when maize-based agriculture became dominant in the area. Stone (1956) suggested that the rimmed metates reflect the persistence of a subsistence strategy based solely on root and tree crops. According to her interpretation, maize was cultivated by people during this time period for ceremonial purposes and did not play a large role in subsistence strategies. She further contended that the introduction of widespread maize agriculture did not occur until the 15th century when migrants and warrior traders from more northern regions moved into the area.

Snarskis (1984) suggested that due to their highly ornate character and their extreme fragility, the rimmed metates were perhaps used for ceremonial purposes or for seats. Citing the loaf shape of the manos used during this period and the fact that more of the unrimmed metates have been found, he suggested that subsistence centered around maize agriculture supplemented by root and tree crops and game and riverine exploitation. The mano shape indicates that a slight rolling or crushing motion was used to process food; a technique that is compatible with grinding of seeds rather than bulky tubers. While the true purpose of the dual metate styles remains a mystery, it appears that archaeologists are converging on Snarskis' hypothesis as more botanical evidence for early maize agriculture has been found in the region. For example, thousands of maize kernels and five maize cob fragments have been found near the outskirts of the city of San José at a Pavas burial site. This direct agricultural evidence of maize cultivation dates to the same period encompassed by the El Bosque phase for the Atlantic watershed (Stone 1977; Snarskis 1984).

The best known archaeological site from the El Bosque Period is Guayabo, which dates to late in the period. Guayabo is located within the middle watershed of the Río Reventazón (Figure 3.3) and is protected as Costa Rica's only National Monument devoted to archaeology. The park, occupying about 218 hectares, contains the largest excavated

archaeological site in Costa Rica . Here, the remains of a city, 5 main villages, and 8 secondary villages can be found (Aguilar 1972). It appears that initial occupation of Guayabo may date to about 2500 yr B.P. and evidence of continual human occupation lasts until about 600 yr B.P. It has been estimated that up to 2,000 people inhabited Guayabo during its peak (1200 yr B.P. - 1000 yr B.P.; Boza and Mendoza 1981) and that the site was chosen for settlement because of it's protected location and proximity to fresh water supplies (Boza and Mendoza 1981). Ancient causeways, montículos, and petroglyphs are well preserved and the aqueducts are still in use at the site.

Near Lagunas Bonilla and Bonillita, Kennedy (1968) partially investigated two archaeological sites and found a circular grinding stone and other artifacts. He proposed that the oldest of the two sites dates to about 1950 yr B.P and the youngest to about 1550 yr B.P. (Kennedy 1968, 1975, 1976). Kennedy was unable to fully investigate the sites, but he suggested that they seemed ideal for aboriginal habitation or camp sites because they are located on hillsides adjacent to sources of fresh water (Figures 4.3 and 4.4). In addition to the grinding stone, Kennedy found jade beads, a jade pendant, celts, scrapers, red on buff pottery sherds, and a variety of other stone objects. Kennedy also located and described several petroglyphs (Figure 4.5) and what he thought were burial sites. More recent work by Costa Rican archaeologists has confirmed numerous indigenous burial mounds near the lakes (M. Sánchez, personal communication, June 1992). Kennedy (1968), basing his conclusions on the previously described work of Stone (1956), suggested that the sites near Bonilla served as temporary habitation sites. In the context of regional archaeology, Kennedy suggested that people inhabiting the area during this period relied primarily on tuber agriculture, hunting, and fishing for subsistence (Kennedy 1975).

Snarskis' inferred expansion of maize agriculture during the El Bosque phase and the preponderance of El Bosque-age jade artifacts at sites in the Río Reventazón Valley,

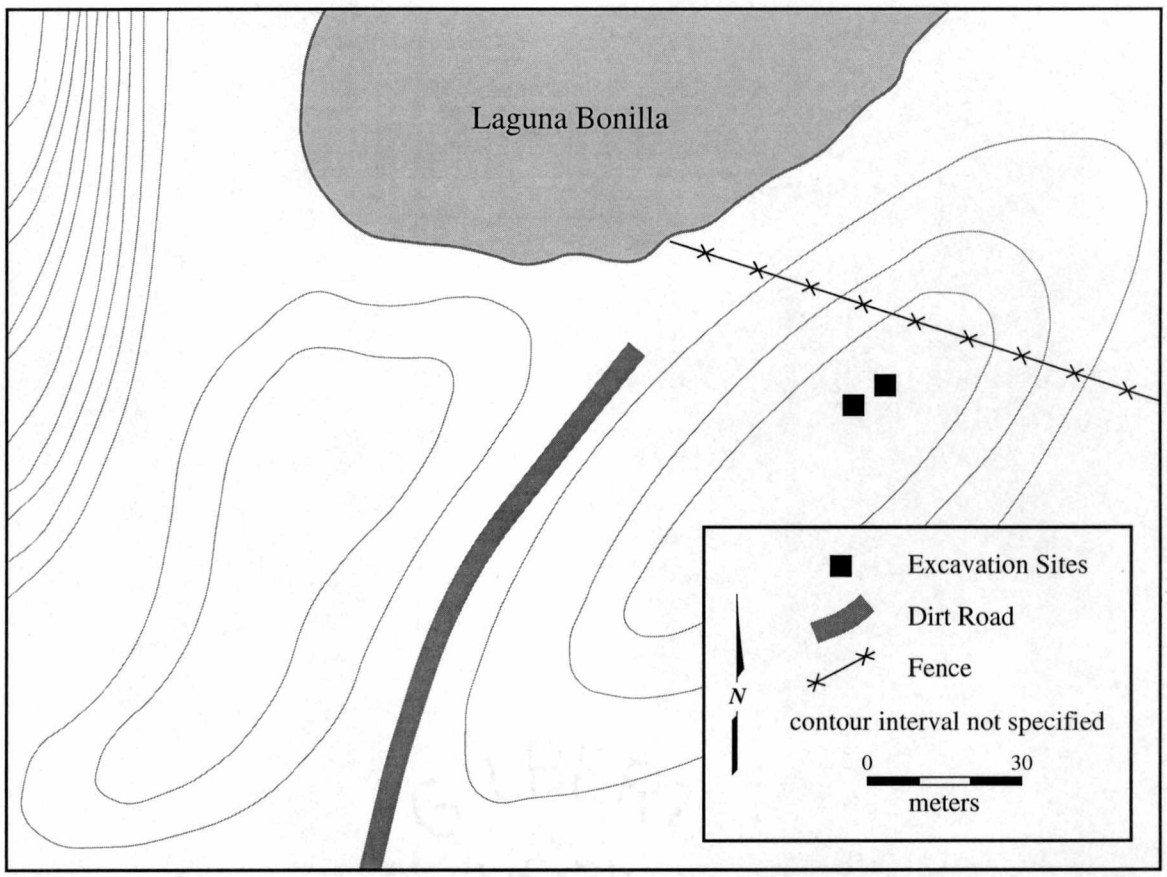


Figure 4.3 Archaeological Site 1 near Laguna Bonilla (adapted from Kennedy 1968).

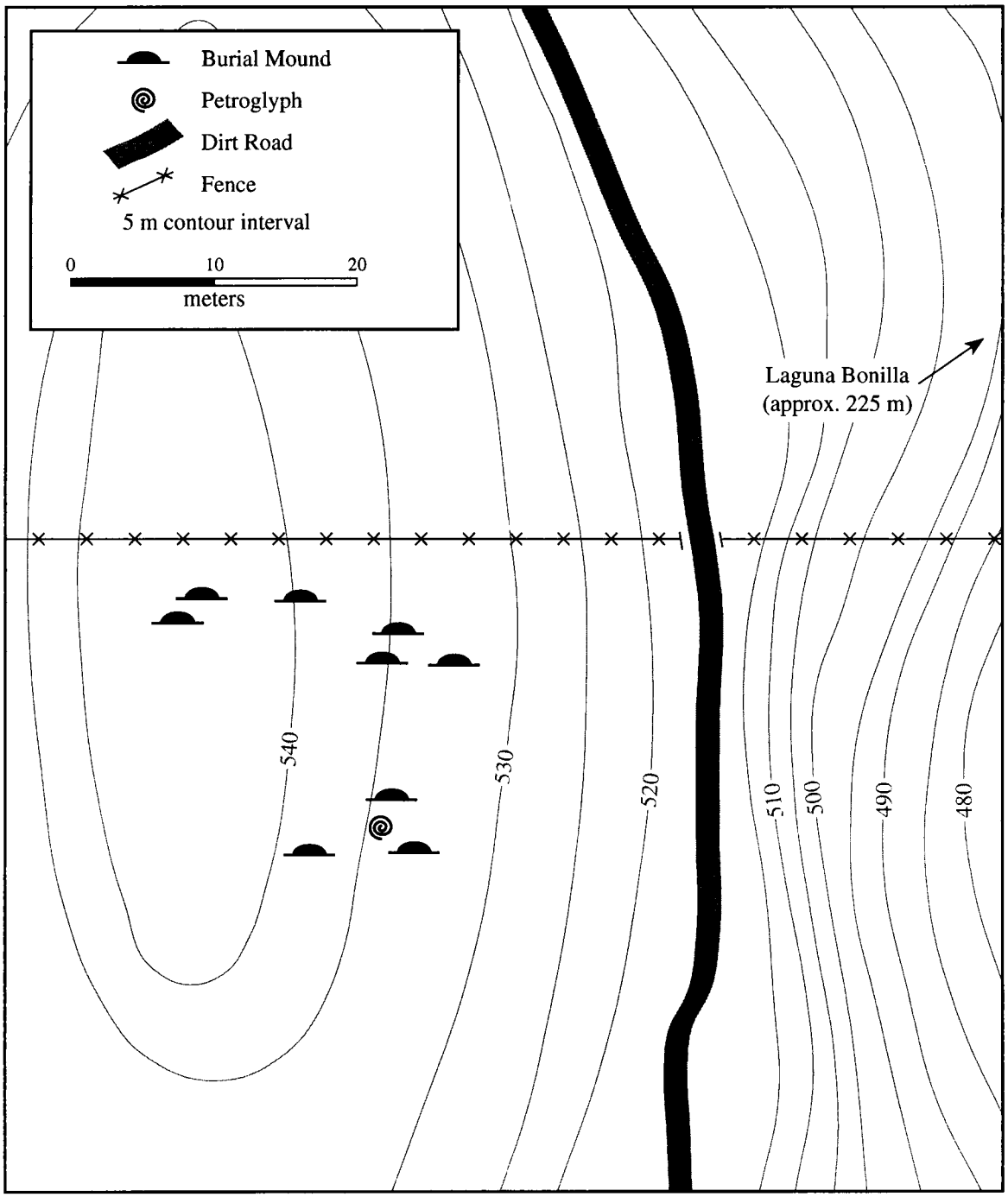


Figure 4.4 Archaeological Site 2 near Laguna Bonillita (adapted from Kennedy 1968).

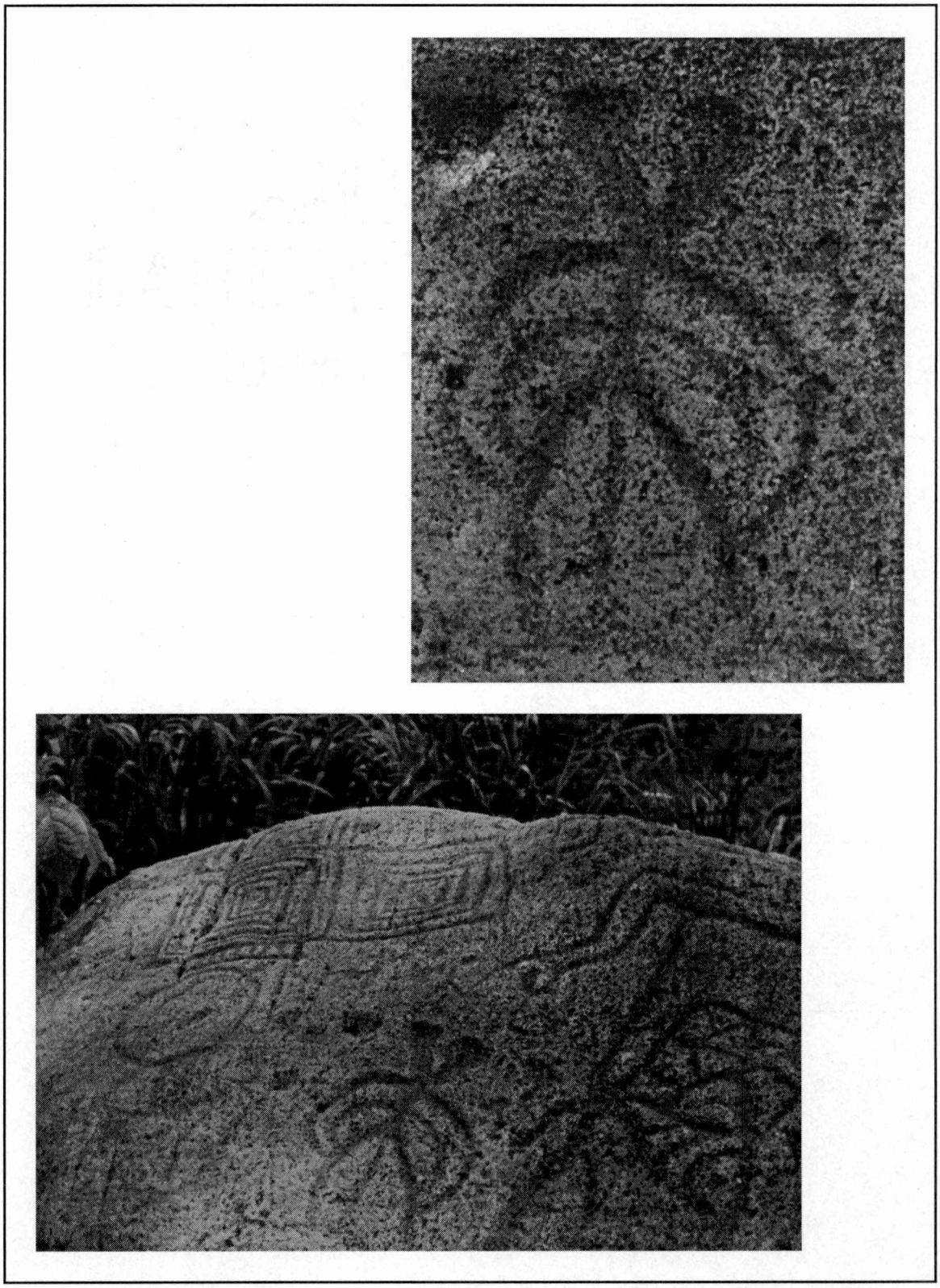


Figure 4.5 **Petroglyphs found near Laguna Bonillita (photographs courtesy of M. Sánchez). The portion of the boulder shown in the lower photograph measures about 1.5 m across.**

suggest that the major cultural tradition in this area was heavily influenced by trade networks with the Olmecs or closely allied cultures to the North. Boza and Mendoza (1981) postulated that Olmec expansion from Mexico started about 3500 yr B.P. Snarskis (1984) further hypothesized that this expansion resulted in an acceptance of Olmec religious iconography and subsistence strategies, and led to the establishment of an elite-driven trade network that sought jade. Most of this trade was probably carried out over land routes through the Rivas corridor (Nicaragua) into northwestern Costa Rica. People inhabiting the lower Atlantic slope of Costa Rica were joined with this trade network through several routes running parallel to and across the mountain chains that bifurcate the country.

It has been suggested by several archaeologists that trade patterns in the whole of Mesoamerica were disrupted about 1700 yr B.P. by a massive explosion of Volcán Ilopango, located in what is now central El Salvador (Willey 1974; Sharer 1974, 1984; Sheets 1981, 1984). There is no archaeological evidence, however, of any hiatus in trade between Mayan cultures and populations in eastern Costa Rica during or even slightly after this time period (Snarskis 1984). Artifacts such as slate-backed pyrite mirrors inscribed with Maya gylphs attest to continued trade with Mesoamerican cultures. But by 1500 yr B.P., Olmec and Maya influence seems to have abated, as revealed by a decline in the quality of jade artifacts recovered from archaeological sites. From the end of the El Bosque phase onward, craftsmen from the lower Atlantic slope of Costa Rica seem to have depended more on local sources of jade, which are inferior to the jades from southern Mexico and adjacent areas of northern Central America. The change in jade sources may reflect an interruption of trade networks perhaps caused by social turmoil in Maya and Olmec civilizations to the north (Snarskis 1984).

The next archaeological period evident for the Central Atlantic watershed of Costa Rica lasted from about 1500 - 1000 yr B.P. and is known as the La Selva phase. The beginning

of the La Selva phase overlaps with the end of the El Bosque phase, but only La Selva phase artifacts persist into later archaeological periods. The La Selva phase is marked by the introduction of gold metallurgy and stylistic changes in ceramics and housing types. While some archaeologists regard these developments as resulting from an expansion of trade networks to the north and south (Bray 1981; Snarskis 1984), others view them as a consequence of increased regional influence or perhaps increased cultural influence from the Caribbean Antilles (Stone 1972, 1977). Quintanilla (1990) stated that the La Selva phase represents a period of heightened social organization characterized by the appearance of complex sedentary communities that were primarily dependent on maize agriculture. Galinat identified the race of maize found in a La Selva-phase cemetery as being a slender popcorn resembling those from Peru or Colombia (Snarskis 1984). This race is highly resistant to the putrification that is common in humid environments such as those of the Central Atlantic watershed.

The last preColumbian archaeological period documented in the archaeological record of the Central Atlantic watershed lasts from about 1000 - 450 yr B.P. Snarskis (1984) and Quintanilla (1990) described this period as being characterized by consolidation of aboriginal settlements into small ceremonial centers. The La Cabaña ceramics of this phase, especially those of the Las Mercedes site (located in the Río Reventazón Valley), are not as complex as those of earlier phases. The stonecrafted common metates from earlier periods almost disappear and are replaced by large, flat, river stones for metates and river cobbles for manos. Ceremonial lithic artifacts such as tetrapod jaguar effigy metates, mortars, trays, and stone sculptures of shaman figures and trophy heads increase in abundance.

Changing trends in settlement patterns in eastern Costa Rica during this last phase have led researchers to speculate that factors other than the availability of agricultural lands

influenced the spatial location of habitation sites (Findlow *et al.* 1979). PaleoIndian workshop sites and habitation and camp sites dating to the La Montaña phase were generally located near hunting and gathering resource bases, whereas sites dating to the El Bosque phase and later show a preference for locating near alluvial lands favorable for agriculture. However, in the last 500 to 600 years before Columbian contact, habitation sites do not seem to be closely associated with the distribution of any physical resource, indicating that food procurement was no longer the primary concern for these later settlements. While this could show a new preoccupation with socio-political boundaries and defense (Snarskis 1984), it could also point to a further expansion of agricultural lands due to degradation of lands already under cultivation, as occurred in other parts of Central America (Binford *et al.* 1987; Vaughan *et al.* 1985). The archaeological record does not provide an adequate test of either hypothesis.

Stone (1977) has stated that war was commonplace in the Atlantic watershed of Costa Rica during the La Selva period. The main motivation for war was to obtain slaves for religious sacrifice, to capture males for trophy heads, and to acquire control of gold bearing rivers. War was carried out among people of regional tribes and with people in extraterritorial regions. Stone suggests that the Spanish conquest of Costa Rica may have been facilitated by the constant military struggle and divisiveness of aboriginal groups.

While the Spanish reached the Atlantic coast of the New World in A.D. 1502 (Ferrero 1988), conquest of inland areas did not occur until much later. Gabb (1875) described the "powerful ally in the forces of nature" that the tribes of eastern Costa Rica had in delaying contact with the Spanish. The lush vegetation, rough terrain, inhospitable climate, and tropical diseases, such as malaria, doomed most early attempts at European colonization. The intense territoriality and warfare of tribes inhabiting the Atlantic slope of Costa Rica also hampered the expansion of European settlement inland from the coast. It appears that

these tribes did not formally submit to the Costa Rican government until about A.D. 1873 (Gabb 1875). There is very little information on the early history of these tribes, but it is likely that their distribution changed rapidly and dramatically as European incursion increased. By early colonial times (A.D. late 1700s - early 1800s), the major tribes of the Atlantic watershed of Costa Rica were probably the Cabecars, Bri-bris, Tiribris, and the Changinas, all subtribes of a larger group collective called the Talamancas or Huetares (Güetares) (Gabb 1875) While some ethnographers disagree with this breakdown (Hogan 1942; Ferrero 1988), all agree that the tribes of the Atlantic slope were intimately associated socially, politically, and religiously.

Decimation of local populations and disintegration of native socioeconomic organization was the final effect of the European invasion of Costa Rica. Epidemics of small pox and a series of other Old World diseases, as well as harsh treatment by Europeans, wiped out entire tribes (Stone 1977; Ferrero 1988). Disruption of local governments through debasement of tribal leaders left communities without leadership and with a depleted sense of cultural identity (Stone 1977). Declining indigenous populations combined with small populations of colonizing Europeans most likely resulted in the abandonment of large tracts of land, which here as throughout the neotropics, eventually became the wilderness of the New World "Eden" (Turner and Butzer 1992; Denevan 1992a; Butzer 1993).

Colonial settlement of Costa Rica was slow because the territory (then a province of the Audiencia of Guatemala) had neither large native populations nor large deposits of precious metals to exploit (Hall 1985). The result of colonial settlement in Costa Rica was an absorption of the native population and intense racial mixing that practically obliterated indigenous populations in all but the most remote of areas of the country. The territory of Costa Rica became independent in A.D. 1821, when Spain relinquished control over most

of Central America. But not until A.D. 1941, 120 years after Independence, were the borders of the country firmly established. Border disputes with Nicaragua to the north and Panama and Columbia to the south over natural resources caused the delay.

Settlement and exploitation of resources on the Atlantic slope of Costa Rica (as well as in the country as a whole) expanded rapidly in the nineteenth and twentieth centuries. Cash crops such as cocoa, coffee, bananas, sugar cane, and recently the African oil palm have played an important role in the development of the country (Hall 1985). In recent years, products from beef and dairy farming have replaced in economic importance almost all other export commodities. Livestock raising primarily for export beef has become so economically important that pasture now occupies over three time as much land as is devoted to crop production (Hall 1985).

CHAPTER 5

CORE SITES AND METHODS

LAKE SEDIMENT CORES

Because of limitations of coring equipment, we were unable to obtain cores from the centers of Lagunas Bonilla and Bonillita, where sediments would have been deepest. We instead recovered cores in flat to gently sloping areas offshore of known archaeological sites with the goal of obtaining sediments with indications of human presence (Burden *et al.* 1986). Lake sediments at Laguna Bonilla and Laguna Bonillita were first sampled in March 1991, when one core was recovered from each lake. The cores were raised from an anchored platform at water depths of 5.64 m at Laguna Bonilla and 6.10 m at Laguna Bonillita. The watery upper sediments of each lake were recovered using a PVC tube fitted with a rubber piston; deeper sediments were sampled using a square-rod piston corer (Wright *et al.* 1984). The core from Laguna Bonilla (Bonilla 1991) was taken about 75 m offshore at the south end of the lake (Figure 5.1); here the total length recovered was 2.15 m. The core from Laguna Bonillita (Bonillita 1991) was raised about 60 m off shore, in the northeastern end of the lake (Figure 5.2); here 9.69 m of sediments were recovered. The piston cores were extruded on the platform, wrapped in plastic and foil, and placed in PVC tubes for transport back to the paleoecology laboratory at the University of Tennessee, where they were stored at 6°C. The cores from the sediment-water interface were sealed in the original PVC sampling tubes and transported back to the lab, where they were frozen (to facilitate extrusion) and sampled at 2 cm intervals. At Laguna Bonillita, a duplicate core segment was recovered for the section from 3.9 to 4.9 m section (from the platform edge rather than the platform center) because the original core segment thickened

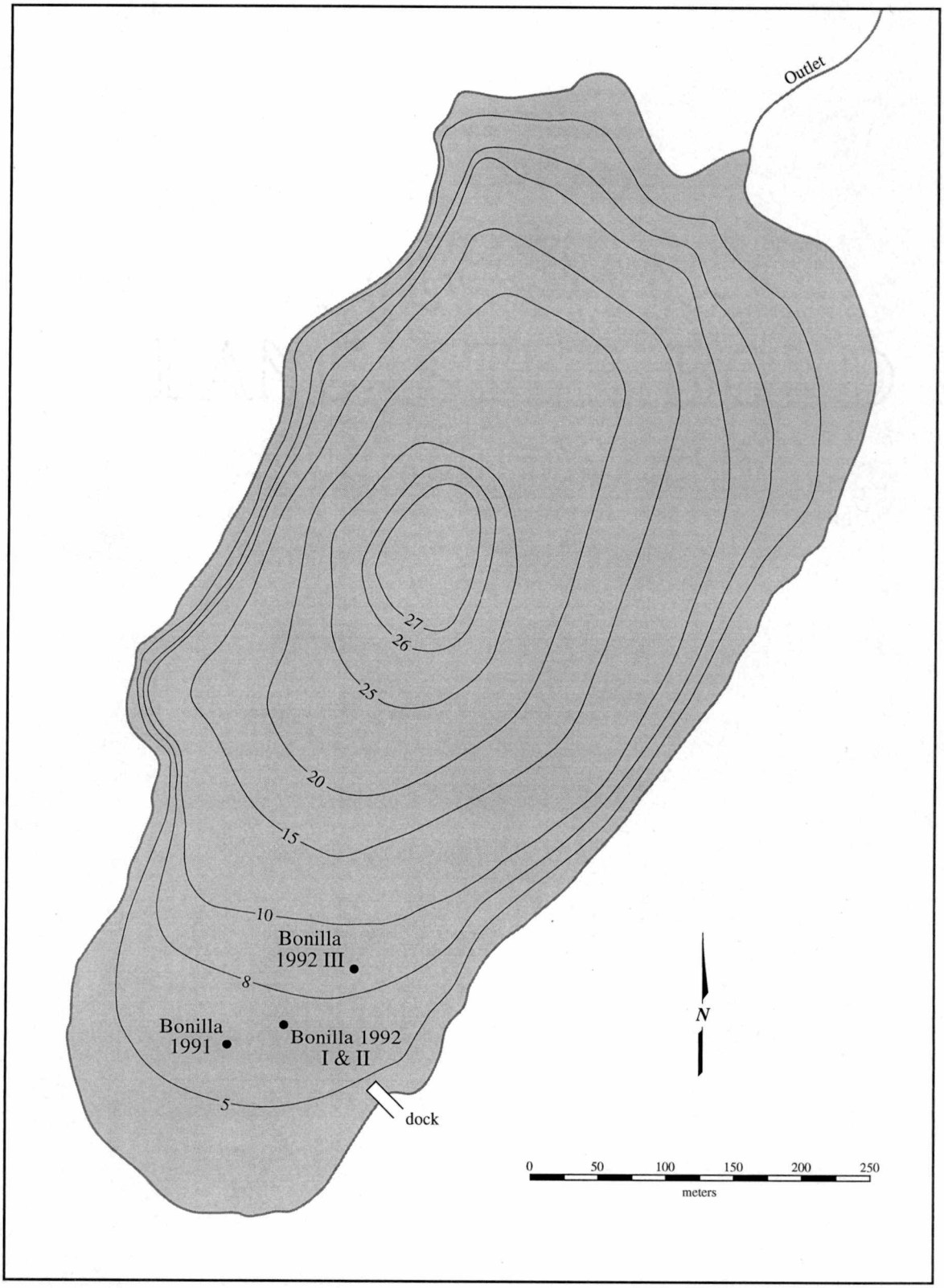


Figure 5.1 Bathymetric Map of Laguna Bonilla showing Coring Locations (bathymetry based on an unpublished report by Mora Jamett 1989).

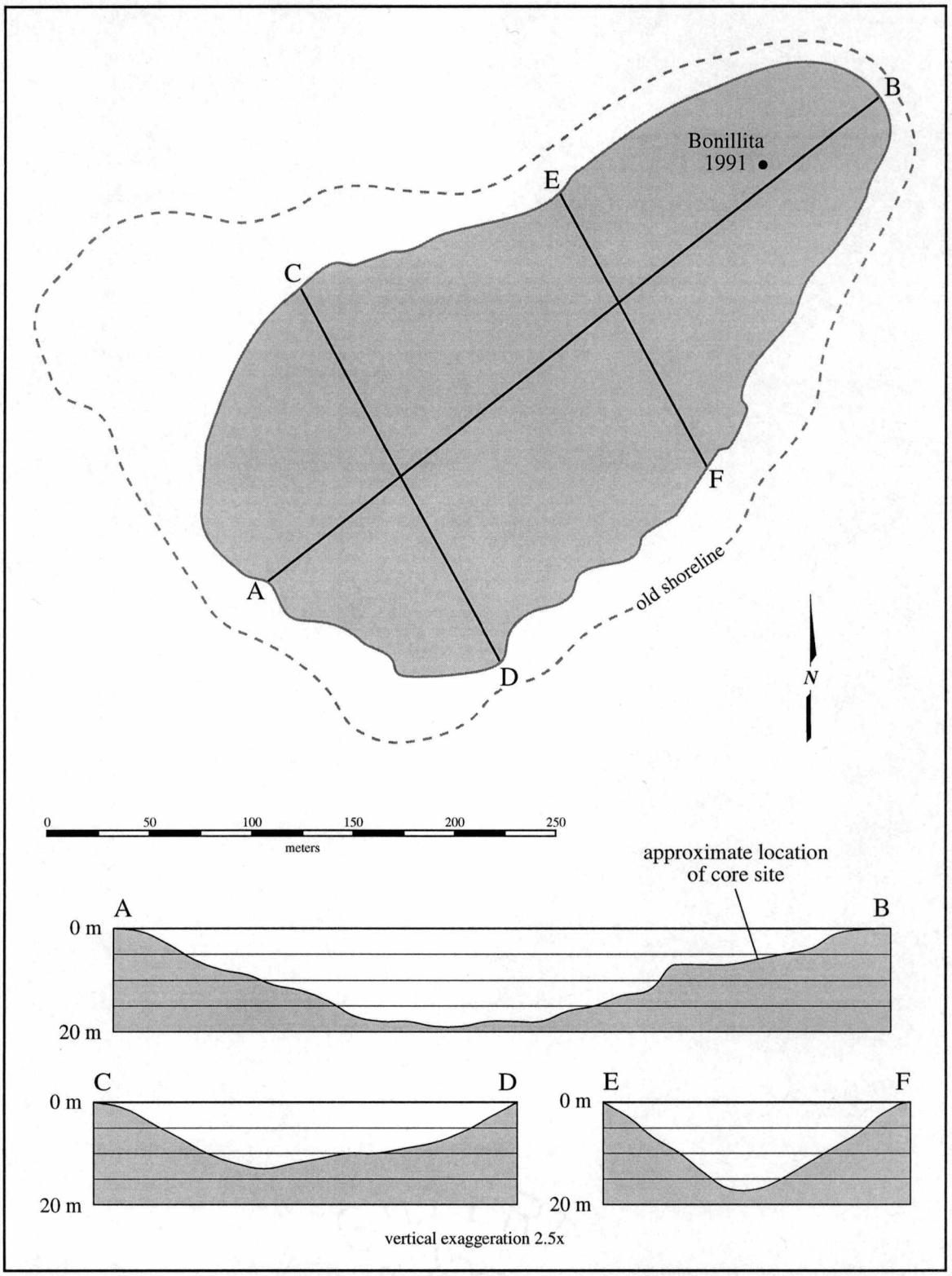


Figure 5.2 Bathymetric Map of Laguna Bonillita showing Coring Location. The position of the old shoreline is inferred from an aerial photograph (Instituto Geográfico Nacional, July 21, 1970, photo number 33).

during extrusion due to a mechanical malfunction. We originally anticipated having problems transporting this "fatter" core, since it would not fit in our core storage tubes, but we were able to modify a tube and transport it without disturbance. This "fatter" section was later used as a check against the duplicate core.

In June 1992 three additional cores were recovered from Laguna Bonilla. Two cores, Bonilla 1992 I and Bonilla 1992 II, were recovered at water depths of 6.20 and 6.34 m, respectively. The third core, Bonilla 1992 III, was recovered a little further off the southern shore of the lake at a water depth of 9.31 m (Figure 5.1). At this core site, a duplicate near-surface (PVC tube) core section was recovered to provide extra material for dating. Table 5.1 shows core site depths and core lengths for all cores collected from Laguna Bonilla and Laguna Bonillita. The 1992 cores were collected in the same manner as before except that the near-surface sediments that were recovered in PVC tubes were field sampled at 2 cm intervals and placed in plastic bags for transport back to the lab.

All cores were examined and remeasured upon return to the laboratory. The stratigraphy of each core was logged by noting changes in sediment texture and color. Sediment colors were determined using Munsell Soil Color Charts (United States Department of Agriculture 1975).

The core recovered from Laguna Bonillita (Bonillita 1991) and the third core taken from Laguna Bonilla in 1992 (Bonilla 1992 III) were selected for pollen analysis, but radiocarbon determinations were carried out for three cores -- Bonillita 1991, Bonilla 1991, and Bonilla 1992 III. A total of thirteen bulk sediment samples were submitted to Beta Analytic Inc. for radiocarbon dating. Four samples from the Bonilla 1991 core, three samples from the Bonilla 1992 III core, and six samples from the Bonillita 1991 core were analyzed for radiocarbon content. In addition, two small pieces of wood recovered in the

Table 5.1. Core Site Depths and Core Lengths, Laguna Bonilla and Laguna Bonillita

core	water depth at core site (m)	core length (m)
Laguna Bonillita		
Bonillita 1991	6.10	9.59
Laguna Bonilla		
Bonilla 1991	5.64	1.51
Bonilla 1992 I	6.20	2.12
Bonilla 1992 II	6.34	2.16
Bonilla 1992 III	9.31	3.47

Bonillita 1991 core and three samples of sieved organic fragments from the Bonilla 1992 III core were submitted for accelerator mass spectrometry (AMS) radiocarbon dating. Radiocarbon dates were calibrated using Calib 3.0, a ^{14}C age calibration program developed by Stuiver and Reimer (1993). We also attempted ^{210}Pb dating of the duplicate near-surface section of the Bonilla 1992 III core at the Palynology Laboratory of the University of California, Berkeley.

Samples for sediment, pollen, and charcoal analysis were taken at 8 cm intervals in the Bonillita 1991 core and at 4 cm intervals in the Bonilla 1992 III core. The water content of the sediments was determined by drying 1 cc samples at 100°C for 24 hours. Loss-on-ignition (Dean 1974) was used to determine the organic content of the samples (organic content is based on loss-on-ignition at 550°C for one hour). Standard palynological techniques were used to process the samples (HCl, HF, KOH, acetolysis; Berglund 1986) and all samples were processed following a similar schedule (Appendix A). A volume of 0.5 cc of sediment was processed for half of the Laguna Bonillita samples, but problems

with clumping of residues made a smaller sample volume necessary. The other half of the samples from Laguna Bonillita and all of the samples from Laguna Bonilla were processed using 0.25 cc of sediment, a volume that resulted in less clumpy residues.

Before processing the samples, I added one tablet of *Lycopodium* spores (Laboratory of Quaternary Biology at the Department of Quaternary Geology, University of Lund, #307862, containing 13,500 spores per tablet) to each of the samples as a control (Stockmarr 1971). The *Lycopodium* tablets make it possible to calculate pollen concentrations and serve as a check against possible palynomorph deterioration that may occur during processing. The residues were stained with safranin and mounted in silicone oil on microscope slides. Counts were made on a Leitz Laborlux microscope at 400 x magnification. A "species area curve" (H.R. and P.A. Delcourt, personal communication, March 1992; after Birks and Birks 1980) was completed and from this curve it was determined that at least 300 grains (exclusive of spores and indeterminate grains) should be counted at each level. Later it became apparent that Cyperaceae was masking variations in other pollen taxa. The pollen sum was therefore increased to 300 pollen grains exclusive of Cyperaceae pollen. Counts for this pollen type were recorded separately from the total pollen counts of 300 grains.

Indeterminate pollen grains were counted and classified according to the factors that contributed to their indeterminate status (e.g. corrosion, degradation, mechanical damage, concealment by authigenic minerals or detritus, or combinations of these deterioration processes; Delcourt and Delcourt 1980). Unknown pollen grains were drawn and measured and their coordinates on the microscope slides were recorded to facilitate later re-examination. Pollen types were identified to the lowest taxonomic level possible using a pollen reference collection and published pollen keys and descriptions (Kapp 1969;

Salgado-Labouriau and Morhy 1969; Bartlett and Barghoorn 1973; Ludlow-Wiechers *et al.* 1983; Horn 1986; Lozano-García and Hernández 1990; Roubik and Moreno 1991).

All slides were completely scanned at low magnification (100 x) to locate pollen grains that were potentially referable to *Zea mays.* The locations of these grains were noted and they were examined and measured at 400 x magnification. In order to be considered as *Zea,* monoporate grass pollen grains had to measure at least 70 μm in diameter and at least 10 μm across the outer ring of the annulus, and had to have a tectate exine. Maize grains that were located on the regular pollen count transects were included in the total pollen sum. The low magnification scans for maize pollen were used to establish presence or absence of the type when no maize grains were found in the regular transects. Fern spores were classified primarily by morphology, owing to incomplete reference material. Charcoal was quantified by counting fragments <25 μm in length that were encountered in the regular pollen count transects. Counts of exotic *Lycopodium* control spores and water content data were used to convert these charcoal counts to a dry weight basis.

Pollen, charcoal, and sediment diagrams were plotted using CalPalyn (Bauer *et al.* 1991) modified to run on a SPARC 10 workstation at the University of Tennessee.

SOIL CORES

In February 1994, soil cores were collected from the southeastern bank of Laguna Bonillita to investigate local fire and agricultural history. Six soil cores (8 cm in diameter) were collected with a root corer from locations that were regarded as possible sites of prehistoric agricultural fields (Figure 5.3). Soil cores 1 through 4 were located in what appeared to be non-depositional environments upslope from an old shoreline of the lake. Soil cores 5 and 6 were also taken in areas that seemed non-depositional but were located in lower-lying areas that could be inundated with water during high lake stands. The cores

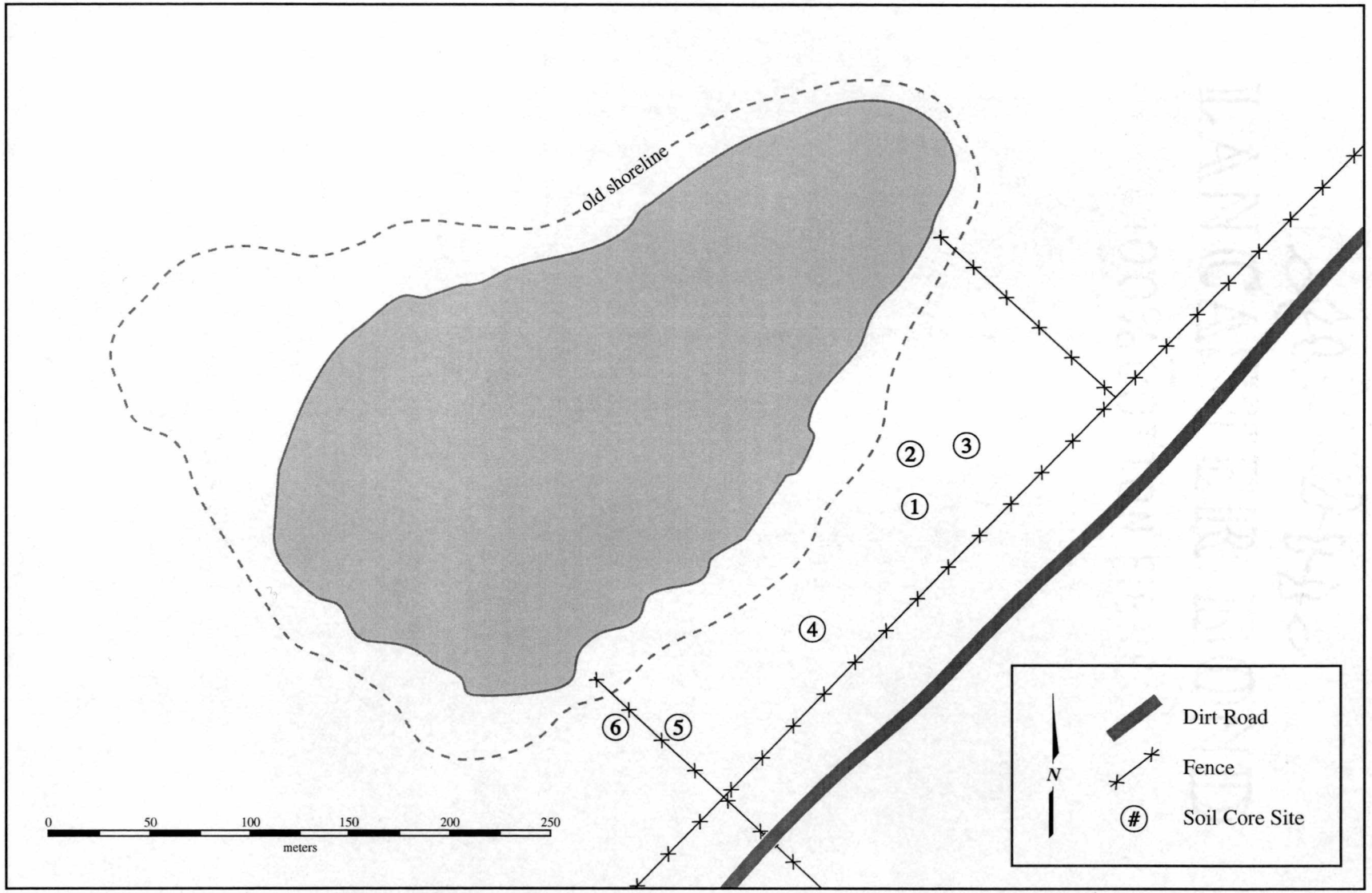


Figure 5.3 Soil Coring Sites at Laguna Bonillita.

were taken in 10 cm increments to the depth at which the soils became too dense for the root corer to penetrate (with four adults exerting force).

Each 10 cm increment was subsampled for pollen by pushing a 15 cm length of standard half-inch copper tubing (sharpened and cleaned) into the unextruded core section while it was still in the corer barrel. Pollen subsamples were taken from the center of the increment and sealed in order to avoid contamination. The remainder of the 10 cm increment was extruded into a plastic bag and sealed for later sieving. Coring equipment was cleaned between increments and sites.

The pollen subsamples from the soil cores were transported back to Tennessee in the copper tubes and refrigerated at 6°C. The larger sections of the soil cores were sieved through 2 mm mesh screens in the laboratory at the La Selva Biological Station. The cores were first soaked in distilled water in the collection bags for 4-12 hours to deflocculate clays. Tap water was used to wash smaller particles through the sieve after soaking. Materials left in the sieves were transferred to aluminum foil and dried at 100°C for 24 hours. These materials were transported back to the laboratory in Tennessee where they were examined for macroscopic charcoal and ceramic pot sherds.

Ten pollen subsamples (1 cc) from the longest soil core, core 2 (94 cm) were processed for microscopic analysis using a slightly modified version of the lake sediment schedule (Appendix B). One *Lycopodium* tablet per sample was again added for control purposes. The residues were stained and mounted in silicone oil on microscope slides. Five slides from each sample were scanned at 100 x for *Zea* pollen grains.

CHAPTER 6

SEDIMENT STRATIGRAPHY AND CHRONOLOGY

SEDIMENT STRATIGRAPHY

The lake sediment cores recovered from Lagunas Bonilla and Bonillita are composed of relatively homogeneous black (Munsell 10 YR 2/1) organic lake sediments. Concentrations of organic macrofossils vary over the lengths of the cores. Some segments of the cores are composed of sticky, silty clay lacking obvious plant fragments, while other segments are so dense with plant fragments that they are grainy to the touch. The sediments from Laguna Bonillita are richer in woody fragments than the sediments from Laguna Bonilla. The sediments in all of the cores become denser with depth, and basal sediments, while lacking obvious traces of bedrock or other confining materials, are hard and clayey.

Surface sediments from both lakes contain an abundance of diatoms, with *Synedra tenera* dominant at Laguna Bonilla and *Cymbella minuta* and *Gomphonema gibba* dominant at Laguna Bonillita (K.A. Haberyan, personal communication, March 1994).

RESULTS OF RADIOCARBON AND ^{210}Pb ANALYSES

Establishing a chronology for the lake sediment cores from Laguna Bonilla and Laguna Bonillita has proven to be especially problematic, not to mention expensive. A total of 18 radiocarbon determinations were made -- 13 standard determinations on bulk sediment samples, and 5 AMS determinations on small organic fragments. The results of

the radiocarbon determinations for Laguna Bonillita are shown in Tables 6.1 and 6.2; those for Laguna Bonilla are shown in Tables 6.3 and 6.4. As is apparent in Tables 6.1 - 6.4, the radiocarbon sequences for the Laguna Bonilla and Laguna Bonillita sediment cores show several dating inversions and other apparent anomalies. For the Laguna Bonilla core, we also attempted ^{210}Pb dating of the near-surface sediments (using the duplicate near-surface section, as the other near-surface section had been used for bulk sediment radiocarbon determinations and pollen and sediment analyses). The results of the analysis, conducted by Dr. R. Byrne of the University of California, Berkeley, are presented in Figure 6.1.

DEVELOPMENT OF CORE CHRONOLOGY

Laguna Bonillita Cores

Initially, the results of radiocarbon determinations on samples from the Bonillita 1991 core seemed straightforward. Three bulk sediment samples were submitted -- one from the surface, one from a mid-section, and one from the base of the core (Beta-47263, Beta-53559, and Beta-47264). Surface sediment dated as modern, the base dated to about 2560 yr B.P., and the midpoint fell in between (Table 6.1). To get a better idea of the *Zea* cultivation chronology, two additional bulk sediment samples were submitted -- one from above and one from below the midpoint of the core. The dates from these samples (Beta-65516 and Beta-65518), when added to the existing radiocarbon date sequence, resulted in a dating inversion near the base of the core (Table 6.1). Up to this point, a replacement segment for the 3.9 - 4.9 m section of the core had been used because the original segment of the core did not extrude properly and became shortened and thickened. As the dating inversion was potentially caused by the core substitution, a sample from the original "fat" core at the same approximate depth was submitted (Beta-66490). The dates from the substitution core and the "fat" core segments were identical. (Later pollen counts proved

Table 6.1. Radiocarbon Determinations on Bulk Sediment Samples from Laguna Bonillita

Lab. Number	Core	Depth Below Sediment-Water Interface (cm)	Radiocarbon Age (yr B.P.)	Calibrated Age[1] (calendar yr B.P.)
Beta-47263	Bonillita 1991	0 - 15	125 % of modern	modern
Beta-65516	Bonillita 1991	230 - 246	810 ± 60	730
Beta-66490	Bonillita 1991 (duplicate core)	454-470[3]	1960 ± 60	1920
Beta-53559	Bonillita 1991	466 - 481.5[2]	1960 ± 60	1920
Beta-65518	Bonillita 1991	710 - 726	1490 ± 60	1370
Beta-47264	Bonillita 1991	949 - 959	2560 ± 60	2720

[1] Stuvier and Becker 1993, [2] Depths differ by 11 cm because of slightly differing water depths at the coring sites.

Table 6.2. AMS Radiocarbon Determinations on Wood Fragments from Laguna Bonillita

Lab. Number	Core	Depth Below Sediment-Water Interface (cm)	Radiocarbon Age (yr B.P.)	$\delta^{13}C$	Calibrated Age[1] (calendar yr B.P.)
Beta-67835	Bonillita 1991	766 - 769	1880 ± 50	-27.6	1770
Beta-67836	Bonillita 1991	950 - 954	1790 ± 50	-26.8	1690

[1] Stuvier and Becker 1993.

Table 6.3. Radiocarbon Determinations on Bulk Sediment Samples from Laguna Bonilla

Lab. Number	Core	Depth Below Sediment-Water Interface (cm)	Radiocarbon Age (yr B.P.)	Calibrated Age[1] (calendar yr B.P.)
Beta-47261	Bonilla 1991	0 - 15	101 % of modern	modern
Beta-53558	Bonilla 1991	108 - 116	11,700 ± 60	13,640[2]
Beta-47262	Bonilla 1991	126 - 136	11,520 ± 80	18,120[2]
Beta-53557	Bonilla 1991	141 - 151	11,830 ± 70	13,790[2]
Beta-54820	Bonilla 1992 III	0 - 10	3010 ± 80	3210[3]
Beta-54821	Bonilla 1992 III	157 - 165	3080 ± 70	3320[3]
Beta-54822	Bonilla 1992 III	333 - 341	3690 ± 70	4060[3]

[1] Stuvier and Becker 1993, [2] Bard *et al.* 1993, [3] Pearson and Stuvier 1993.

Table 6.4. AMS Radiocarbon Determinations on Organic Macrofossils from Laguna Bonilla

Lab. Number	Core	Depth Below Sediment-Water Interface (cm)	Radiocarbon Age (yr B.P.)	$\delta^{13}C$	Calibrated Age[1] (calendar yr B.P.)
Beta-67837	Bonilla 1992 III	84 - 86	4085 ± 55	-33.2	4420
Beta-65517	Bonilla 1992 III	277 - 281	4190 ± 60	-30.1	4780
Beta-67838	Bonilla 1992 III	331 - 333	4845 ± 55	-27.9	5580

[1] Stuvier and Becker 1993.

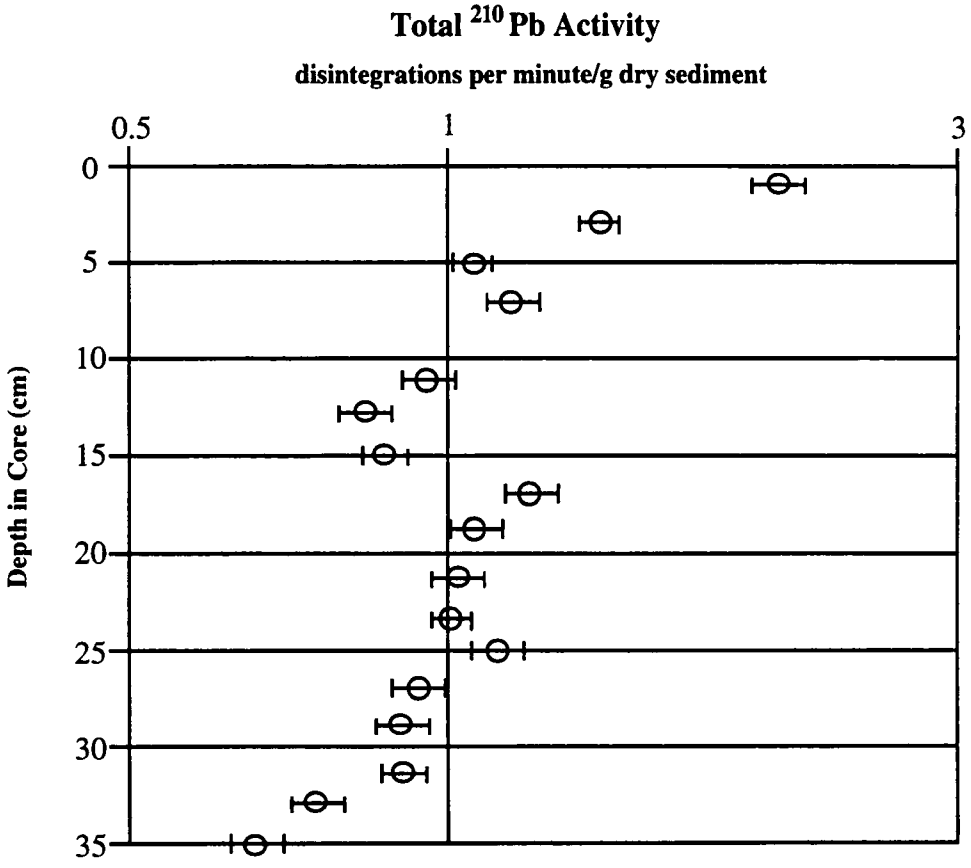


Figure 6.1. Total ^{210}Pb in Near-Surface Sediments of the Bonilla 1992 III Core

that there was good correlation between the two core segments). As a final check on the bulk sediment dates from the 3.9 - 4.9 m sections, two samples of small wood fragments were submitted for AMS dating: one from the base of the core (from a subsample that had been kept in reserve when the basal bulk sediment sample was submitted) and one from a depth of 7.66 - 7.69 m (from a core section located about 0.5 m lower than the bulk sediment sample (Beta-65518) that had been previously submitted. The resulting dates (Beta-67865 and Beta-67837) did not entirely solve the problem, but offered important evidence for interpreting the dating reversal. As discussed in the next section, present evidence favors acceptance of a chronology that rejects the basal AMS date and relies on the

basal bulk sediment date of 2560 yr B.P. to establish the time period represented by the Laguna Bonillita 1991 core.

Laguna Bonilla Cores

In the initial stages of this study, one surface and one sub-bottom bulk sediment sample from the Bonilla 1991 core (Beta-47261 and Beta-47262) were submitted for radiocarbon dating. The results were very exciting -- the surface sample dated as modern, and the sub-bottom sediment date (11,520 ± 80 yr B.P., uncalibrated) indicated that the core might span the entire Holocene (Table 6.1). However, that over 10,000 years of record could be contained in 1.51 m of sediment seemed unlikely, especially given the much younger radiocarbon age (2560 yr B.P.) of the considerably longer (9.59 m) core from Laguna Bonillita. For the basal dates on both the Bonilla 1991 and Bonillita 1991 cores to be correct would require that sediments had accumulated at the rate of only 0.013 cm/yr at Bonilla, but at the rate of 0.375 cm/yr (or nearly 30 times as fast) at Bonillita.

To test the basal Bonilla date, one sample from above (Beta-53558) and one from below (Beta-53557) the previously dated interval were submitted for analysis. These new determinations made the first date seem even less reliable. Both samples dated as a few hundred years older than the 11,520 year date, such that the series showed a reversal. The sequence of the 11,000 year dates on the Bonilla core also showed a lack of age progression, as all samples were very close to the same radiocarbon age (dates were within two standard deviations of each other).

In an effort to develop a reliable chronology, three bulk sediment samples from the Bonilla 1992 III core were submitted (Beta-54820, Beta-54821, and Beta-54822). The resulting radiocarbon dates were younger than the dates for the samples from the Bonilla 1991 core but all depths reported generally similar dates. The surface sample was not dated

as modern, but rather as 3010 yr B.P. and the basal sample dated to 3690 yr B.P. (Table 6.1). Attempting to circumvent this problem, we submitted three samples of macroscopic organic fragments that were sieved from the sediments of the Bonilla 1992 III core (Beta-65517, Beta-67837, and Beta-67838) for AMS radiocarbon determinations. The results were encouraging in that there were no dating reversals, but the dates suggested some rather unlikely variations in past accumulation rates at the core site: 0.021 cm/yr for 0 - 86 cm interval, 0.79 cm/yr for 86 - 281 cm interval, and 0.079 cm/yr for 281 - 333 cm interval. Present evidence, as discussed in succeeding pages, indicates that all of the Bonilla core radiocarbon determinations are spurious. The actual time period represented by the core seems to be only about 1050 years, despite the many older dates obtained.

Discussion and Interpretation of Radiocarbon Determinations

Of the two cores analyzed for pollen, the core from Laguna Bonillita shows less evidence of radiocarbon dating problems and has the firmer chronology. The bulk sediment dates from this core show a generally good age progression. Only the two dates covering the same sediment interval (from the original "fat" and duplicate core segments; samples Beta-53559 and Beta-66490; Table 6.1) are out of order. This inconsistency, in an otherwise acceptable progression of bulk sediment dates for Laguna Bonillita, probably resulted from some sort of localized disturbance in the lake basin. The two dates of 1960 ± 60 yr B.P. (uncalibrated) are from sections of the core that show slight increases in inorganic percentages and much higher amounts of charcoal (next Chapter). The highly inorganic nature of soils on slopes surrounding Laguna Bonillita and the abundance of microscopic and macroscopic charcoal within them leads to the suggestion that the dated overlapping core sections may reflect a period of increased terrestrial input to the lake sediments. This increased sediment influx, possibly related to prehistoric agricultural practices, may have introduced old carbon to the lake and led to the dating anomaly.

The two Laguna Bonillita AMS dates were obtained on wood fragments that are regarded as having a terrestrial origin (Table 6.2). The $\delta^{13}C$ values (-26.8 ‰ and -27.6 ‰) are within the expected range of terrestrial and emergent aquatic plants (Metcalfe *et al.* 1991). The uppermost AMS date on wood fits well with the chronology of all bulk sediment radiocarbon dates other than the two overlapping dates that have already been noted as being out of order. Lacking contradictory evidence, I accept this uppermost AMS date as correct, and consider it further evidence that the two co-eval bulk sediment dates are incorrect. However, the lower AMS date for the Laguna Bonillita 1991 core does not fit with the chronology inferred from the bulk sediment dates or with the upper AMS date. MacDonald *et al.* (1990) have cautioned that bulk sediment dates that conflict with AMS dates on samples from the same interval may cast doubt on the veracity of the bulk sediment date. But in this case, given the lack of strong evidence for contamination of other bulk sediment samples, a more reasonable interpretation is that it is the AMS date that is out of place. The reason that the lower AMS date is younger may be because what was actually dated was a piece of woody root (from a terrestrial or emergent aquatic plant) that penetrated the sediments after they were deposited. I interpret the series of radiocarbon dates, $\delta^{13}C$ values, and sedimentological evidence as indicating that the Laguna Bonillita core spans approximately the last 2,560 years, or roughly two and a half times the time period spanned by the less well dated Laguna Bonilla 1992 III core. As can be seen in Figure 6.2, the calculated sedimentation rate is highest between 2.38 and 7.18 m, in the interval that includes what is believed to be a period of higher sediment influx.

At Laguna Bonilla, dates appear strongly affected by some variant of the old carbon problem that has hampered dating of other lakes throughout the Latin American tropics (Leyden 1987; Olsson 1986; Bush and Colinvaux 1990). The sediment and macrofossil samples from the lake have yielded unreliable dates because their radiocarbon content has been diluted by the input of old carbon. This old carbon may enter lakes in the form of

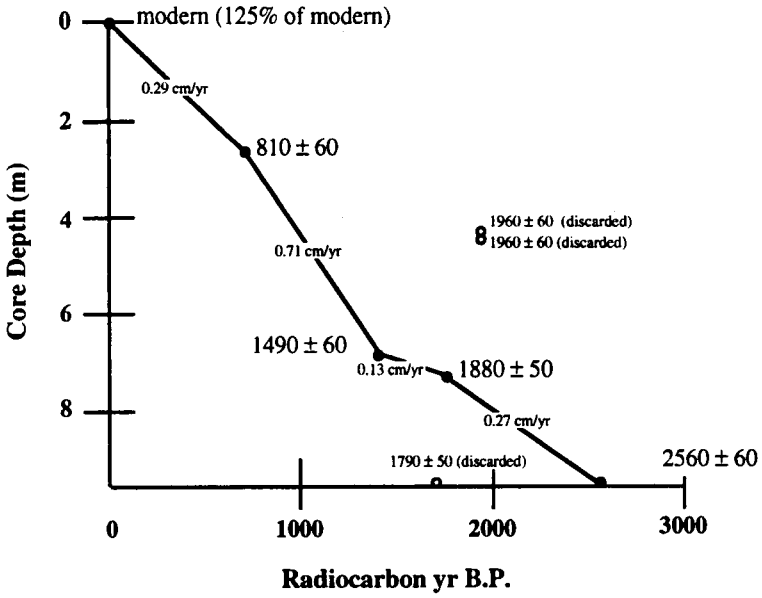


Figure 6.2 Age/Depth Diagram for the Laguna Bonillita 1991 Core

terrestrial carbon (e.g. soil charcoal or inorganic soils) washed in from surrounding slopes (as in the case of Laguna Bonillita), or as volcanically derived CO_2 that is isotopically "dead." Regardless of the source, this old carbon results in estimated ages that are spuriously old (MacDonald *et al.* 1991).

MacDonald *et al.* (1991) have suggested that the best strategy to avoid or detect potential radiocarbon dating problems is to cross reference standard radiocarbon dates with independent chronological measures obtained through AMS dating or other techniques. Because the AMS method requires much smaller amounts of sample and because there is potentially greater selectivity about what is dated (Linick *et al.* 1989), the effect of old carbon should be minimized. However, the use of this method on small organic fragments from the Bonilla cores still resulted in questionable determinations.

The reason for this appears to lie in the nature of the material dated. When I sieved sections of the Bonilla core to recover macrofossils to submit for radiocarbon dating, I

selected fragments that looked more "woody" than the rest, but I did not find any pieces that were unquestionably terrestrial wood (as used for the AMS dates at Bonillita). Based on the dates and on further examination of the plant macrofossils in the Bonilla core, I believe that most of the very small (< 3 mm long) fragments that I dated were fibrous stems and other tissues from aquatic plants that may have included submerged as well as emergent plants. The resulting AMS dates on this organic material seem to have been contaminated with isotopically dead, volcanically produced CO_2 that may have entered the lake through underground springs or groundwater flow.

In assessing the likelihood and extent of this contamination, it is instructive to consider the $\delta^{13}C$ values reported for the AMS samples (Table 6.4). These values indicate the ratio of ^{13}C to ^{12}C contained in the sample and may be linked with past changes in lake productivity. It has been suggested that as a lake matures, its productivity increases, perhaps resulting in spuriously old dates of upper sediments as more ^{13}C enriched aquatic plants are incorporated in the sediments (Aravena *et al.* 1992). The $\delta^{13}C$ values from the basal Bonilla 1992 III AMS sample (-27.9 ‰) is in the expected range of terrestrial and emergent aquatic plants that use atmospheric CO_2 for photosynthesis (Metcalfe *et al.* 1991). But from the base to about 1/5 of the way up the core, the $\delta^{13}C$ values decrease to about -30.1‰, perhaps suggesting that the lake was becoming more productive. By 84 cm below the sediment surface, the $\delta^{13}C$ value has decreased further to -33.2 ‰, a value that suggests even higher productivity levels, and greater possible contamination by old carbon in the lake system.

I presently regard all Bonilla dates as having been contaminated by old carbon from one source or another. Even the "modern" surface date (101% of modern) on the Bonilla 1991 core appears to have been affected by old carbon contamination in that it does not contain as much radiocarbon as expected. The surface radiocarbon determination at Laguna

Bonillita (125% of modern) is much more in line with the expected radiocarbon content of sediments deposited in the 1970s and 1980s. The Bonilla surface date probably contains bomb carbon (as does the Bonillita sample), but its activity is diluted by a large amount of old carbon (J. Southon, personal communication with S. Horn, April 1994). However, while all radiocarbon determinations for samples from the Laguna Bonilla 1992 III core are too old, I believe that the relative rates of change in the radiocarbon content of the samples provide indications of the time period represented by the core.

Following Davis (1969), I have attempted to "correct" for old carbon contamination by subtracting the youngest radiocarbon dates from the oldest dates and have used the resulting sedimentation rates to estimate ages at other depths. Applying this approach to the AMS dates, the calculated time span represented by the 84 - 333 cm interval is 760 years, and the calculated sedimentation rate for this interval (using sample midpoints of 85 and 332 cm), is 0.325 cm/yr. Applying this sedimentation rate to the entire length of the core (347 cm) results in an estimated basal date of 1068 yr B.P. Similar results emerge from subtracting the bulk sediment dates, but indicate a basal age of only about 700 yr B.P. While both the bulk sediment and AMS "corrections" seem plausible, the dating scenario from the AMS dates fits better with the chronology of Laguna Bonillita. The scenario based on the AMS determinations also seems consistent with the pollen data from the two cores. For these reasons, the AMS "corrected" chronology is used to discuss the Bonilla core. As described in the next chapter, we should expect the Bonilla core to cover slightly less than half the time period of the Bonillita core.

The results of ^{210}Pb analysis that were carried out for the Bonilla 1992 III core were inconclusive with respect to refining the chronology of the near-surface sediments, because it is unclear whether background levels of ^{210}Pb were reached in the lowest sample analyzed (Figure 6.1). Because of the short half-life of ^{210}Pb, this dating method is

suitable for samples within the range of 1 to 150 years (Berglund 1986). For this reason, only the upper 35 cm of the core were used for analysis. However, the ^{210}Pb concentrations continue to taper off in the bottom 2 samples analyzed. This means that at a depth of 35 cm, background levels of ^{210}Pb may not have been reached. If this interpretation is correct, it indicates that the upper 35 cm of sediment in the Laguna Bonilla 1992 III core are no older than 150 years. The generally similar ^{210}Pb concentrations for samples taken from 5 to 30 cm imply a period of especially rapid sediment deposition, possibly associated with a slump of lake sediments or with a period of rapid erosion in the watershed. Increased erosion could have resulted from 20th century forest clearance, establishment of pastures, and livestock rearing. The date corresponding with 35 cm according to the "old carbon corrected" chronology would be approximately 108 yr B.P., such that interpretation derived from the ^{210}Pb and radiocarbon analyses are consistent.

Wider Significance of Dating Results

The process of establishing chronologies for Laguna Bonillita and Laguna Bonilla has been challenging and some of the lessons learned may have value in the wider context of Quaternary palynology in the neotropics. Especially when viewed in historical progression, the radiocarbon results presented here make clear the need to critically examine radiocarbon data. Failure to do so can seriously undermine paleoecological interpretations. For example, if the original radiocarbon dates from Laguna Bonilla had been accepted (with no further dating attempted), this thesis would concern late-Pleistocene maize agriculture in Costa Rica -- an exciting find, no doubt, but unfortunately a gross misinterpretation of reality. The common practice of basing neotropical paleoecological chronologies on only one or two dates is not scientifically sound. The old carbon problem needs to be considered in all contexts, as it is not a problem confined only to areas of carbonate rocks or active volcanism. Multiple radiocarbon determinations, both AMS and

standard, should be made, and where possible more than one core should be dated from each site. Serious misinterpretations of the paleoecological record may result where this is not done. Misinterpretation of data is a problem to avoid in all areas, but is perhaps more serious in the neotropics, where paleoecology is less well advanced and where there are fewer pollen records available against which to test interpretations.

CHAPTER 7

RESULTS OF POLLEN AND CHARCOAL ANALYSES

This chapter describes the results of the analysis of the Bonilla and Bonillita lake sediment cores and the Bonillita soil cores.

POLLEN TAXONOMY

The sediments of Laguna Bonilla and Laguna Bonillita contain a diversity of pollen types. Over 75 pollen types were recognized, most occurring in low frequencies. Where possible, taxonomy and ecological characterization follow the Flora Costaricensis Series (1971-1993), edited by W. Burger and published in *Fieldiana Botany*. For groups not covered in the Flora Costaricensis series, taxonomy generally follows Standley (1937-38), Pittier (1978), and Hartshorn and Poveda (1983); ecological information is from these sources and others cited in the text. Numerous unknown pollen types were encountered in the Bonilla and Bonillita samples. None of these, however, ever made up more than one percent of the total count at any stratigraphical level. The most abundant tropical pollen types represented in the cores belong to the Urticales group, which include members of the Moraceae, Urticaceae, and Ulmaceae families (excluding *Ulmus*, a montane genus with a distinctive pollen morphotype). Pollen grains from these families are commonly psilate or scabrate, diporate or triporate (sometimes 4-porate or polyporate) and are generally wind dispersed (they can also be insect dispersed, as in the case of *Ficus*). Trees and shrubs from this group are commonly found in the lowland tropical rainforests of Costa Rica. With a few exceptions, pollen from the Urticales order is difficult to identify to genus or even family (Roubik and Moreno 1991; Byrne and Horn 1989). Distinctive pollen types

from this group include *Cecropia, Ficus, Celtis, Dorstenia,* and *Trema.* In this study, these distinctive pollen types were tallied separately and other Urticales grains were categorized according to the number of pores.

Other pollen types indicative of lowland tropical conditions are rare because they are generally zoophilous. A number of these rare types, however, are represented in the lake sediment cores. In the summary pollen diagrams, trees and shrubs of lowland tropics have been differentiated from that of trees and shrubs of premontane and montane habitats based on the altitudinal ranges of plant taxa on the Atlantic slope. With one exception (described below), taxa designated as premontane and montane are found only above 500 m elevation. Lowland tropical taxa generally occur from sea level to about 500 m but in some cases grow above this limit. Pollen grains of the following families and genera are regarded as derived from lowland tropical trees and shrubs: *Anacardium* (Anacardiaceae), Apocynaceae, *Ilex* (Aquifoliaceae), Bignoniaceae, Bombacaceae, *Cordia* and *Tournefortia* (Boraginaceae), *Bursera* (Burseraceae), Ericaceae, *Acalypha, Alchornea, Croton, Hura, and Sapium* (Euphorbiaceae), Flacourtiaceae, *Hippocratea* (Hippocrateaceae), Mimosoideae and other Leguminosae, *Bunchosia* and *Byrsonima* (Malpighiaceae), Malvaceae, Melastomataceae / Combretaceae, *Virola* (Myristicaceae), *Myrsine* (Myrsinaceae), Myrtaceae, *Iriartea* and other Palmae, *Pinus* (Pinaceae), *Piper* (Piperaceae), Rhamnaceae, Rosaceae, Rubiaceae, *Zanthoxylum* (Rutaceae), Sapindaceae, Sapotaceae/Meliaceae, *Guazuma* (Sterculiaceae), *Mortoniodendron* (Tiliaceae), and Verbenaceae.

Premontane and Montane trees and shrubs represented in the sediments occur at 500 m and above and include *Alnus* (Betulaceae), *Hedyosmum* (Chloranthaceae), *Weinmannia* (Cunoniaceae), *Quercus* (Fagaceae), *Alfaroa* (Juglandaceae), *Malpighia* (Malpighiaceae), *Myrica* (Myricaceae), and *Ulmus* (Ulmaceae). The Podocarpaceae were included with the

Premontane and Montane group because most taxa are highland species. However, one species, P. guatemalensis, has been recorded at lowland sites (deLaubenfels 1990).

Herbs are represented in the Bonilla and Bonillita pollen records by a number of families and genera, including *Alternanthera* and other Amaranthaceae, Caryophyllaceae, Liguliflorae and other high- and low-spine Compositae (the low-spine Compositae is not *Ambrosia*, which reaches its southern limit further north in Central America), Convolvulaceae, Cucurbitaceae, Cyperaceae, *Dalechampia* (Euphorbiaceae), Gentianaceae, *Zea mays* and other Gramineae, Labiatae, Lentibulariaceae, Liliaceae, Onagraceae, Solanaceae, Scrophulariaceae, *Typha* (Typhaceae), Umbelliferae, and *Vitis* (Vitaceae). Cyperaceae pollen, because it dominates the cores to the point that it swamps out other pollen taxa, was counted outside the pollen sum. The Cyperaceae family contains a number of ubiquitous herbaceous plants that generally occur in wet or marshy places but also grow in drier grassland areas (Standley 1937-38, Pittier 1978).

Zea pollen was separated from other Gramineae pollen on the basis of pore and exine characteristics and grain size. Most *Zea* pollen grains measured between 75 and 125 μm in diameter and had pores 12 to 17 μm in diameter. While studies conducted by Ludlow-Wiechers *et al.* (1983) suggest that the minimum size range of some maizes can overlap with the maximum size range of some teosintes, there is no evidence that teosinte has ever grown in Costa Rica. Therefore it seems likely that the large grass pollen grains represented in the cores are maize associated with prehistoric agriculture.

At the beginning of this study, it was hoped that recent plantings of pines and eucalyptus near the lakes would make possible "pollen dating" (Mudie and Byrne 1980) of the upper sections of the cores. However, no Myrtaceae pollen that could be definitively assigned to *Eucalyptus* was found in the core samples, and too few grains of *Pinus* were encountered to make this type of dating useful in establishing sediment ages.

POLLEN PRESERVATION AND CONCENTRATIONS

Pollen preservation was generally very good throughout both cores analyzed. Only one percent of all grains counted were classified as indeterminate (344 grains out of the 27,060 tallied). The greatest incidence of indeterminate grains was between 638 and 770 cm in the Bonillita 1991 core and between 44 and 85 cm in the Bonilla 1992 III core. Table 7.1 summarizes data on deterioration classes associated with indeterminate pollen grain counts. The majority of indeterminate grains counted were in Deterioration Class 5 -- concealed by detritus. The concealed grains in all cases were occluded by organic matter that seemed to be bonded to the grains by a sticky, oily substance that resulted in clumped residues. The clumping problem was only partially resolved by varying the amount of sample processed and by altering the processing schedule to include hot water and hot soap washes. However, while the clumping of residues made pollen counting difficult at some levels, it did not strongly affect the results. Even in the samples from the intervals cited above, less than one percent of the pollen was indeterminable because of clumping.

Pollen concentrations were comparable in the two cores and ranged from 3.1×10^5 to 3.6×10^6 pollen and spores per gram dry sediment or 9.3×10^3 to 1.5×10^5 pollen and

Table 7.1. Percentage of Indeterminate Pollen Grains by Deterioration Class, Bonilla and Bonillita Cores

Class	Type of Deterioration[1]	Description[2]	Percent of Total Indeterminate Pollen
5	Concealment by Detritus	Grain hidden by mineral or organic debris	73
3	Mechanical Damage	Grain broken or crumpled	16
1	Corrosion	Exine locally etched, pitted, or perforated	7
2	Degradation	Exine thinned, fusion of sculptural features, or fusion of structural elements forming the wall layers	3

[1, 2] Delcourt and Delcourt 1980

spores per cc wet sediment (Appendix C). These values are comparable with those reported for lowland lakes in the Amazon (Ecuador), Guatemala, and Mexico (Liu and Colinvaux 1988; Bush and Colinvaux 1988; Leyden 1987; Byrne and Horn 1989), and are higher than found in the Costa Rican páramo and in offshore marine sediments (Horn 1985a, 1993). Pollen influx values were not calculated owing to problems of dating the sediments at Bonilla.

THE BONILLITA AND BONILLA POLLEN AND CHARCOAL RECORDS

Summary pollen diagrams showing selected individual and composite pollen curves and charcoal curves for the Laguna Bonillita 1991 core and the Laguna Bonilla 1992 III core are presented in Figures 7.1 and 7.2, respectively. Composite pollen curves have been constructed for the Premontane and Montane group (excluding *Quercus*), the Lowland Tropical group (excluding *Alchornea, Piper,* and *Myrsine*), and the Urticales group (excluding *Cecropia*). Curves for total spores, organic and inorganic content, pollen and spore concentrations, and taxonomic richness are presented for the Laguna Bonillita 1991 core in Figure 7.3 and for the Laguna Bonilla 1992 III core in Figure 7.4. The taxonomic richness curve shows the total number of different pollen taxa encountered in the standard 300 grains count, plus one to represent Cyperaceae, which was excluded from standard count totals but found in all samples. Individual pollen curves for all Premontane and Montane trees and shrubs can be found in Figure 7.5 for the Laguna Bonillita 1991 core and 7.6 for the Laguna Bonilla 1992 III core. Lowland Tropical trees and shrubs are presented in Figures 7.7 and 7.8 for the Laguna Bonillita 1991 core and Figures 7.9 and 7.10 for the Laguna Bonilla 1992 III core. Urticales taxa are presented for the Laguna Bonillita 1991 core in Figure 7.11 and for the Laguna Bonilla 1992 III core in Figure 7.12. Herbs are presented for the Laguna Bonillita 1991 core in Figure 7.13 and for the Laguna Bonilla 1992 III core in Figure 7.14.

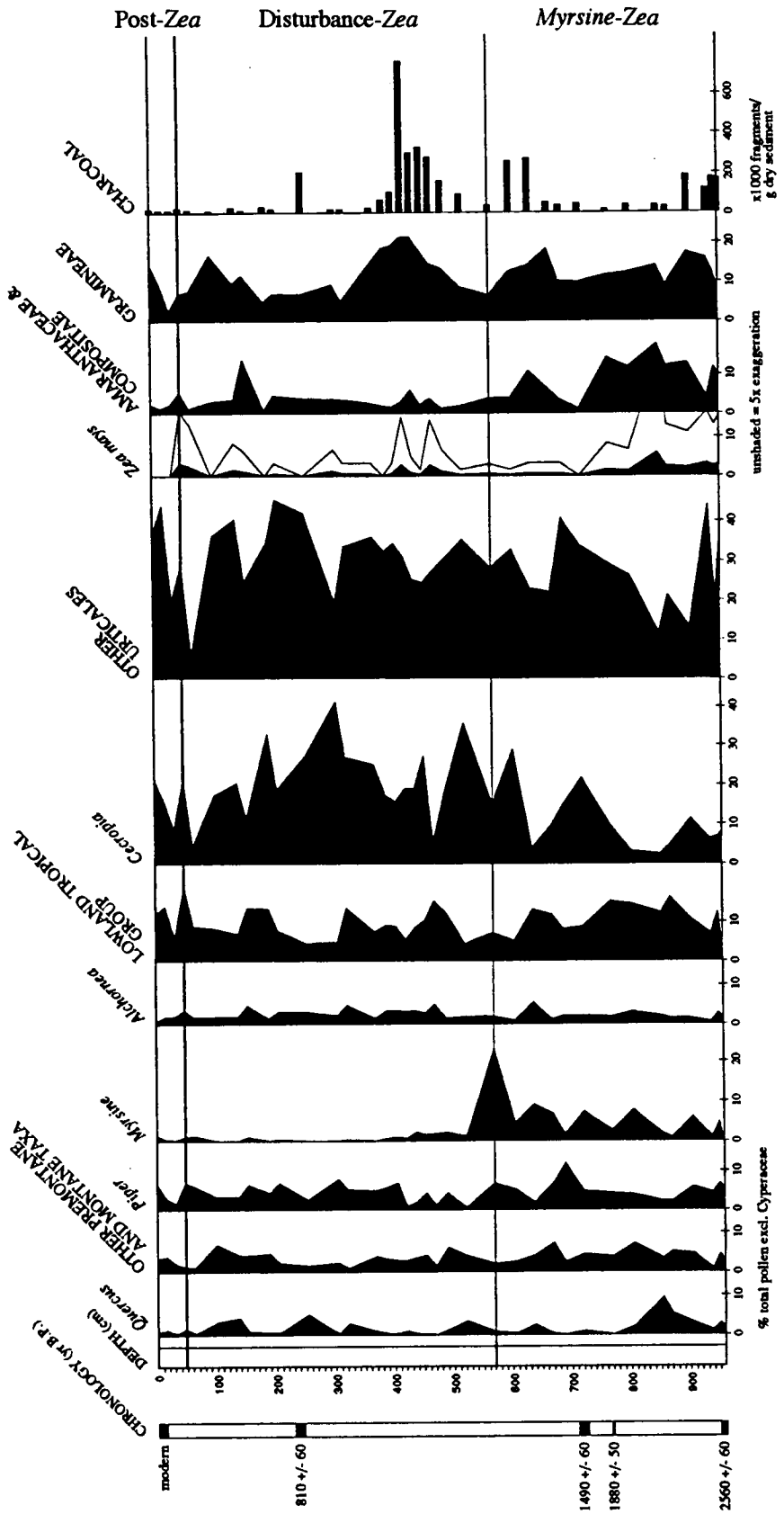


Figure 7.1 Laguna Bonillita 1991 Core: Summary Pollen Diagram

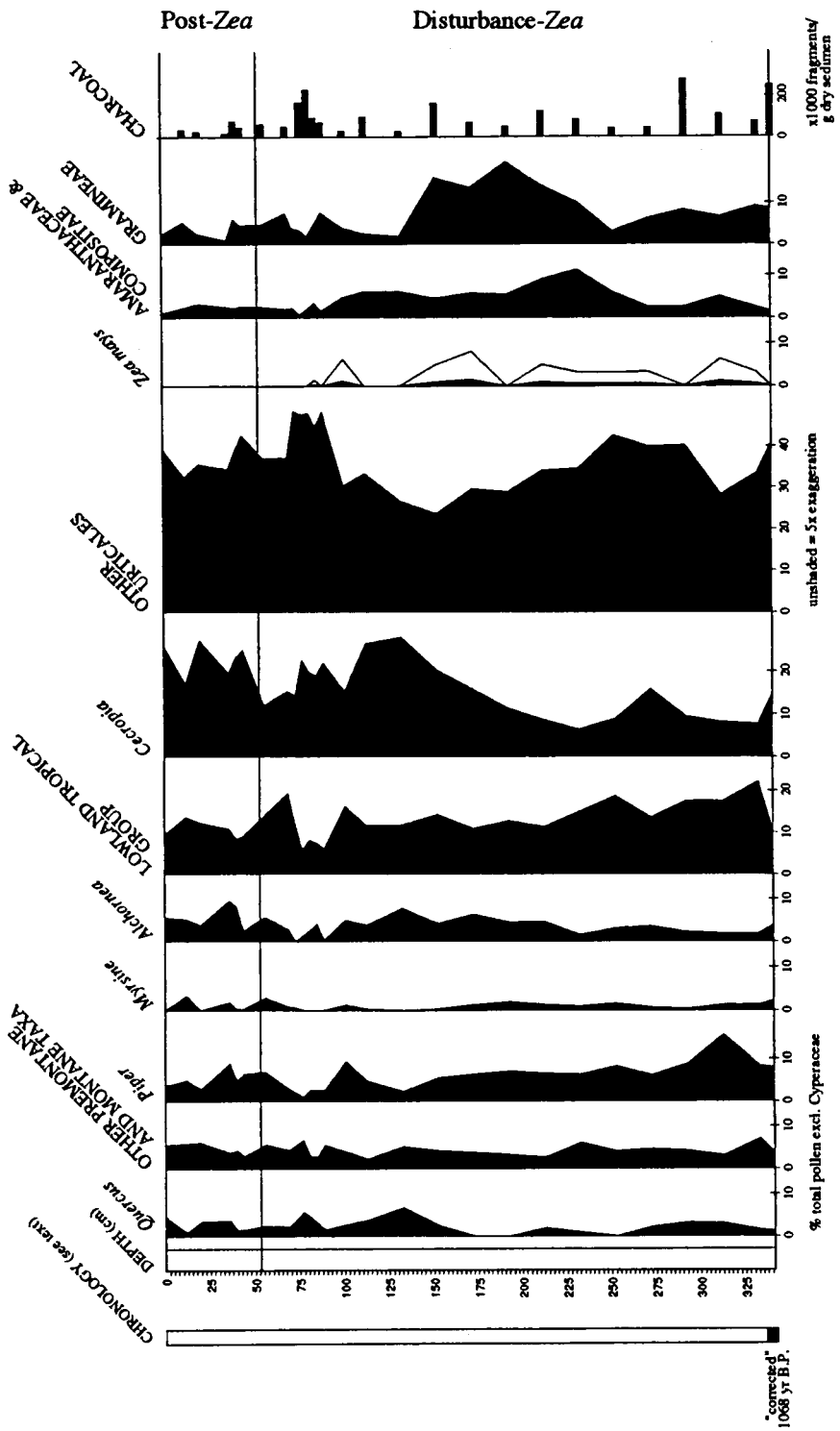


Figure 7.2 Laguna Bonilla 1992 III Core: Summary Pollen Diagram

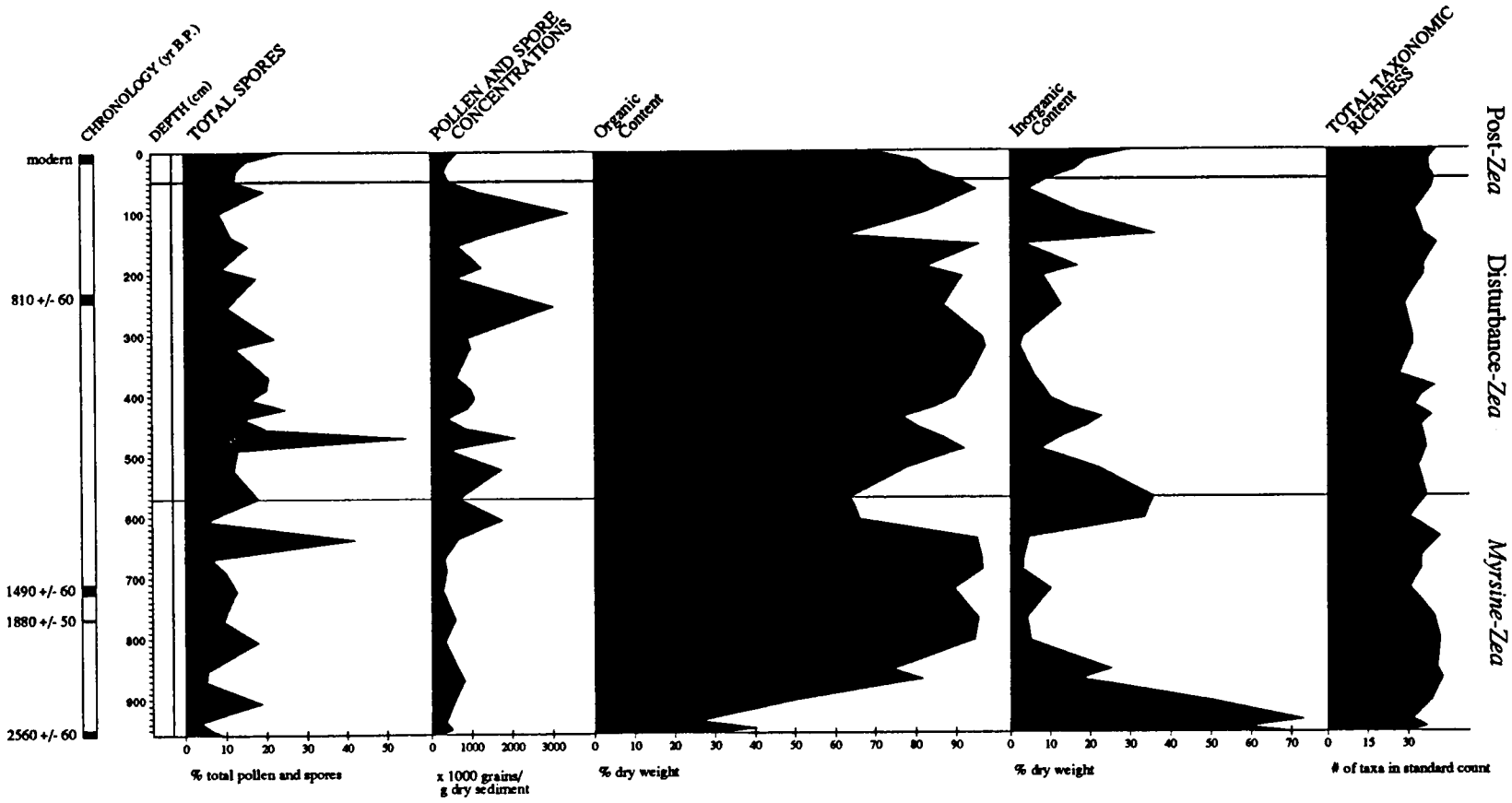


Figure 7.3 Laguna Bonillita 1991 Core: Spores, Palynomorph Concentrations, Sedimentology, and Taxonomic Richness

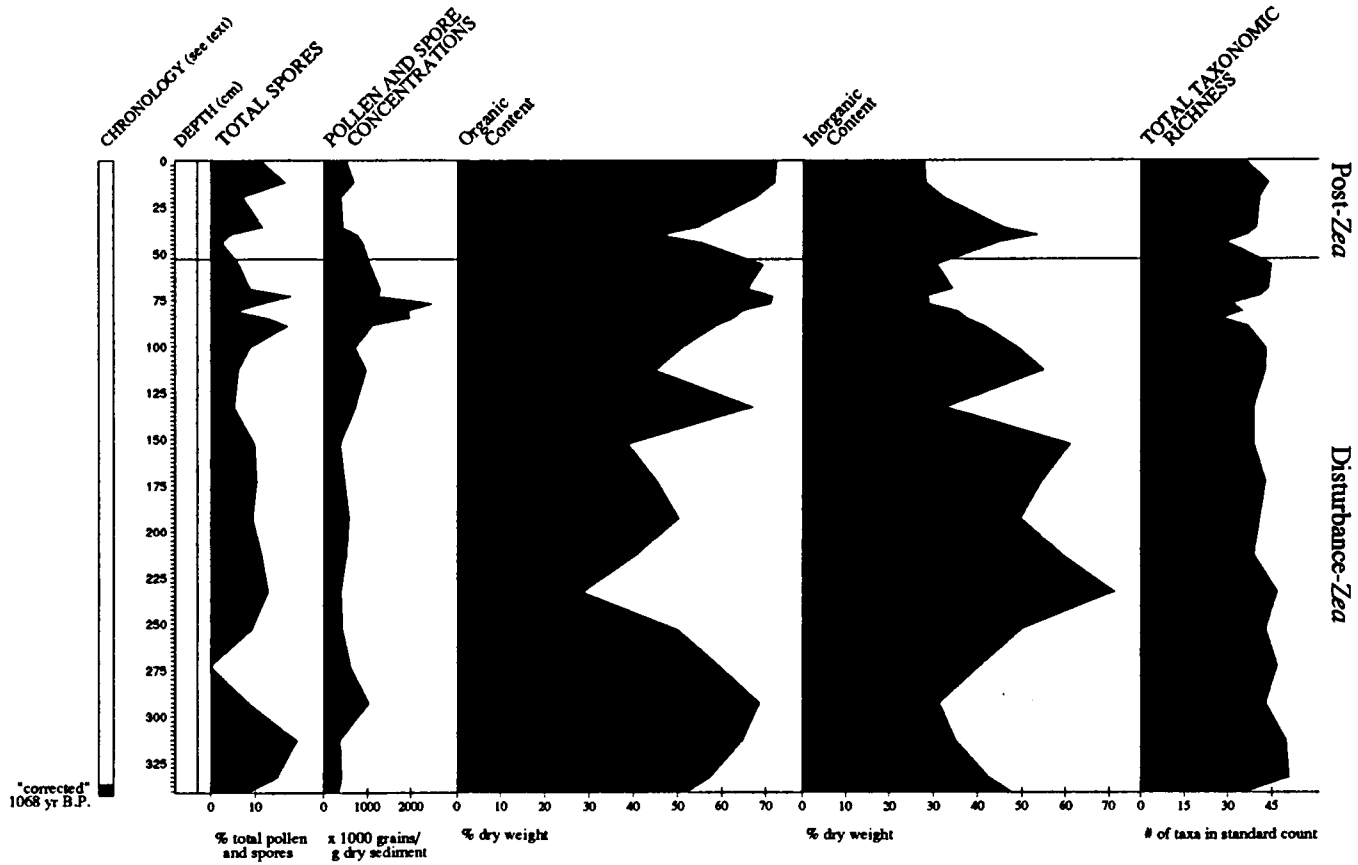


Figure 7.4 Laguna Bonilla 1992 III Core: Spores, Palynomorph Concentrations, Sedimentology, and Taxonomic Richness

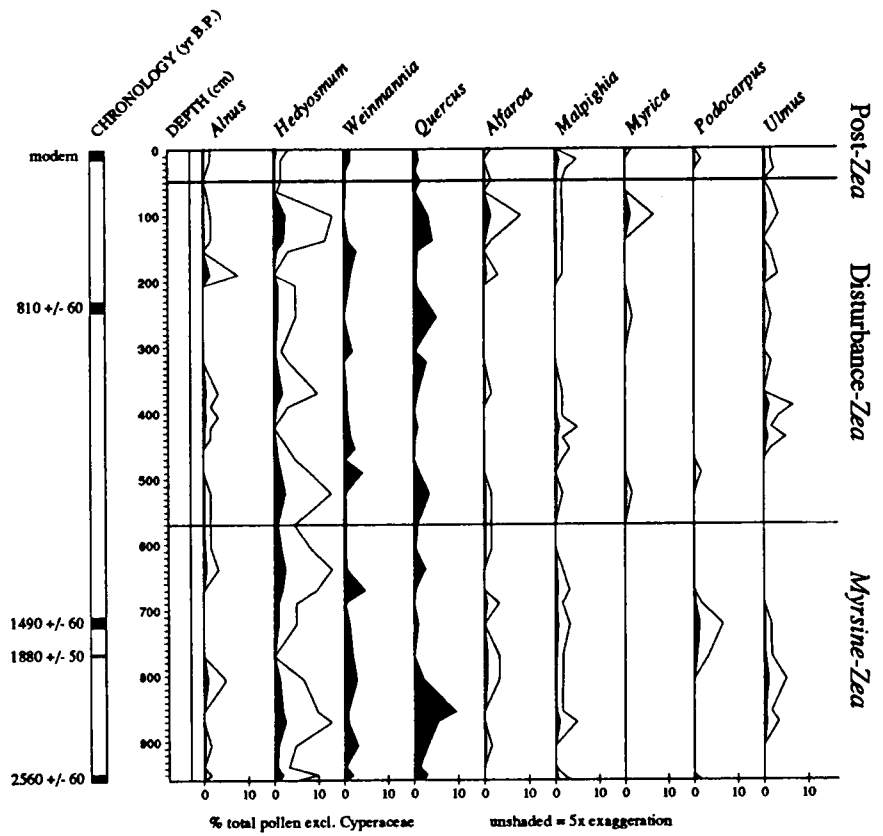


Figure 7.5 Laguna Bonillita 1991 Core: Premontane and Montane Trees and Shrubs

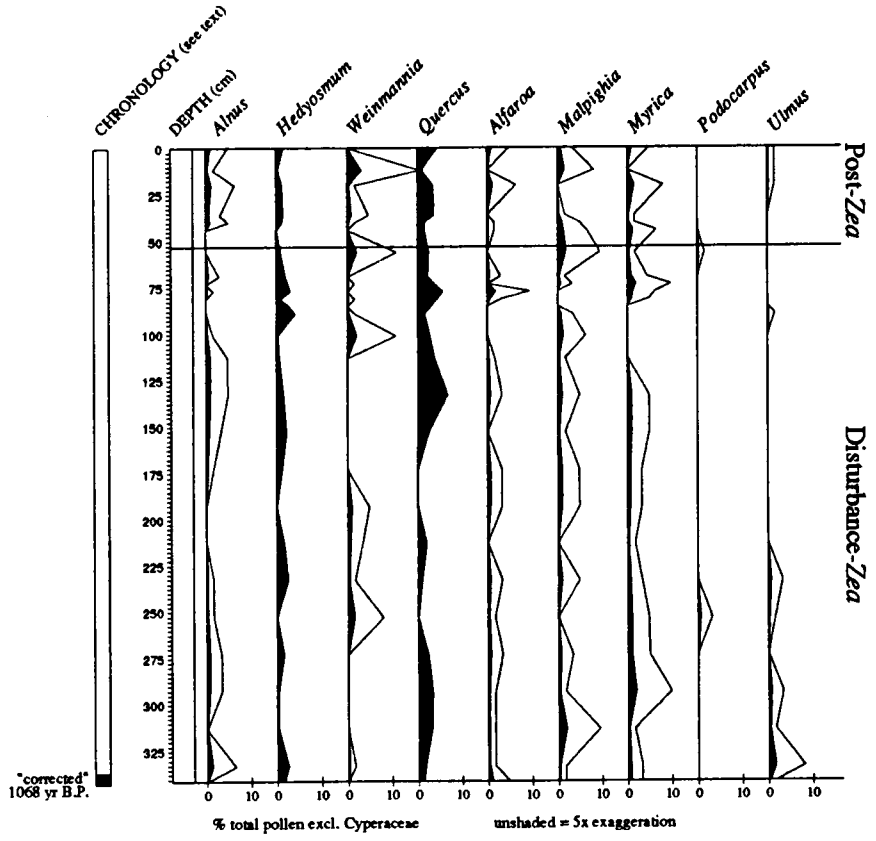


Figure 7.6 Laguna Bonilla 1992 III Core: Premontane and Montane Trees and Shrubs

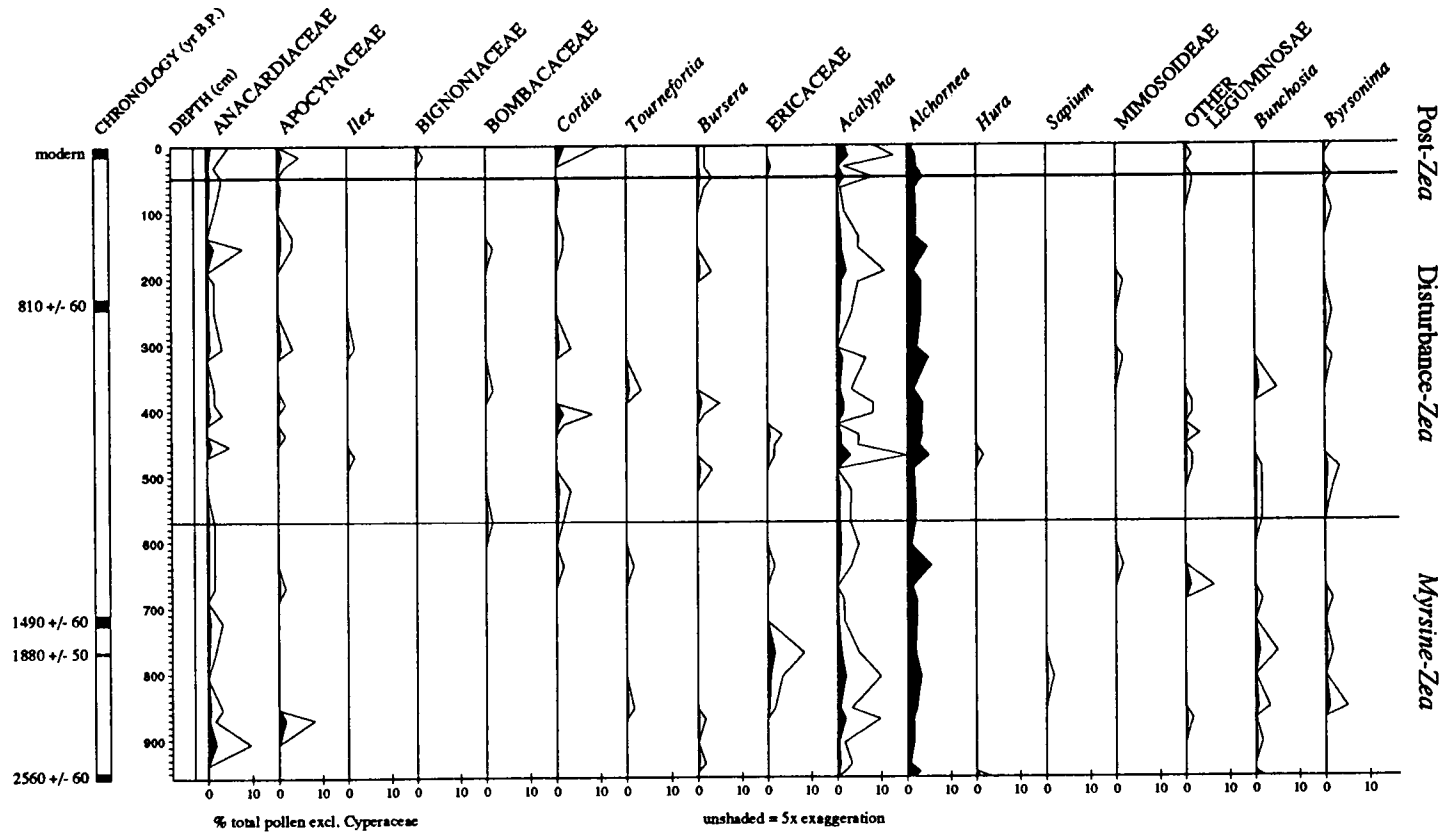


Figure 7.7 Laguna Bonillita 1991 Core: Lowland Tropical Trees and Shrubs (I)

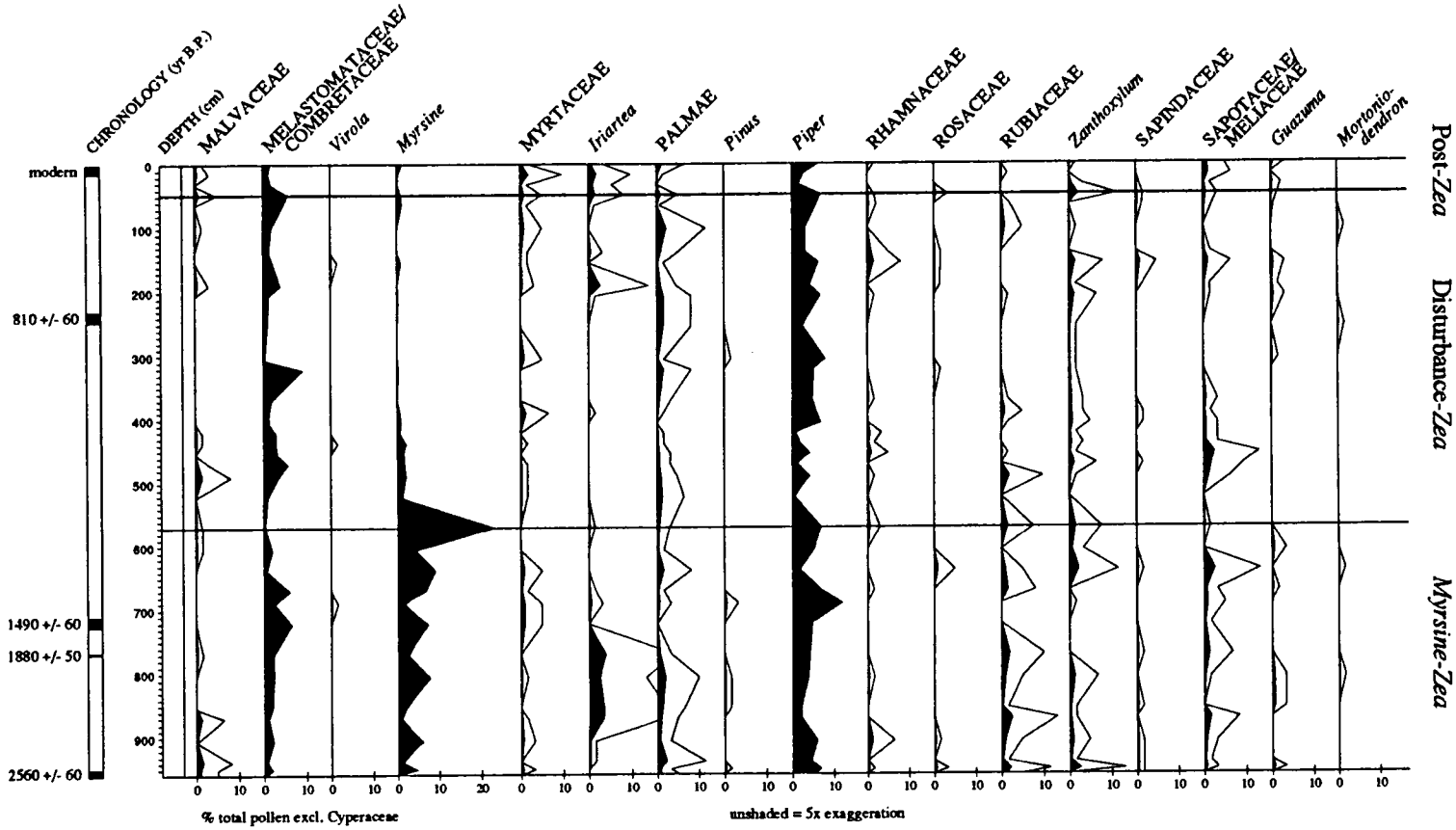


Figure 7.8 Laguna Bonillita 1991 Core: Lowland Tropical Trees and Shrubs (II)

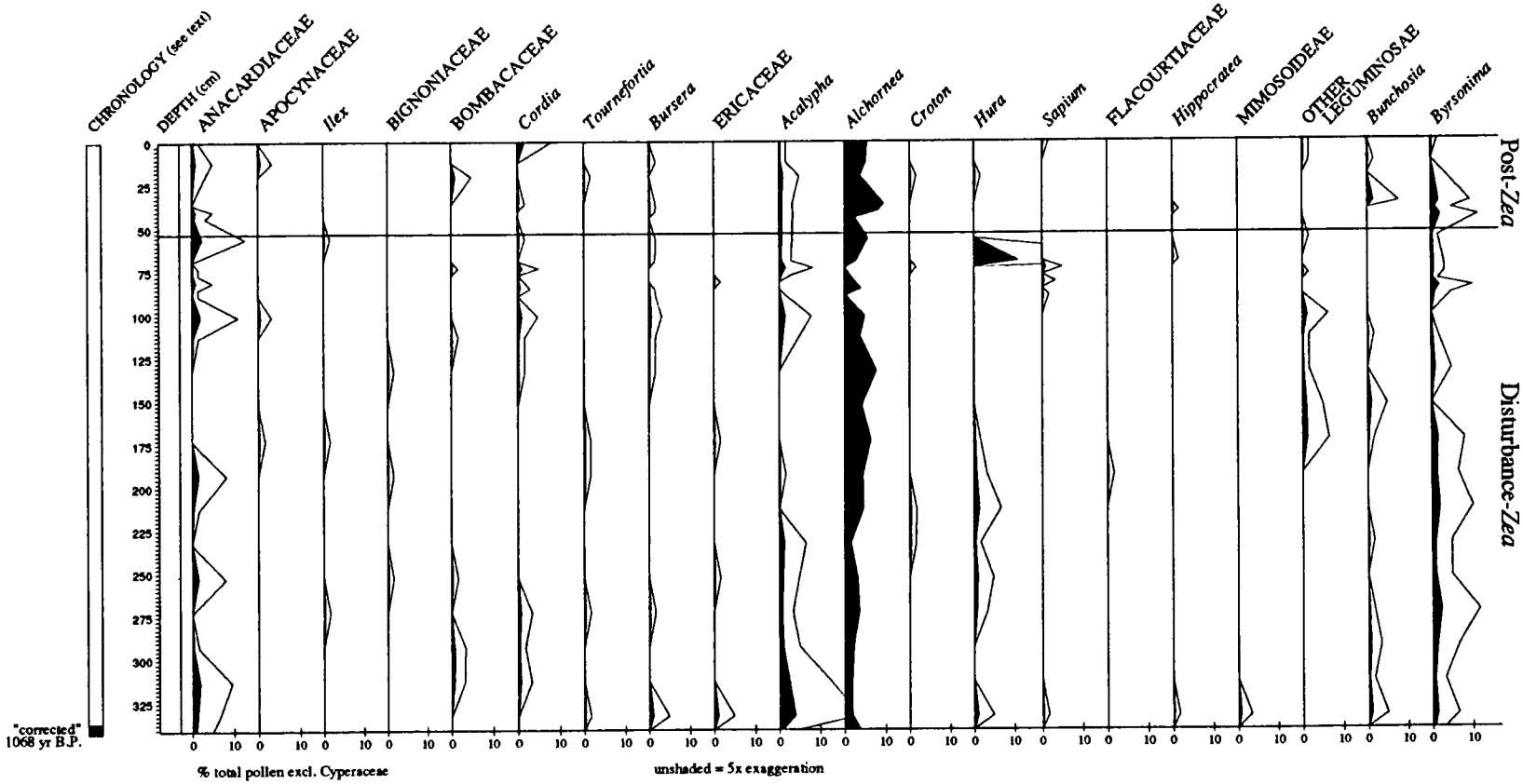


Figure 7.9 Laguna Bonilla 1992 III Core: Lowland Tropical Trees and Shrubs (I)

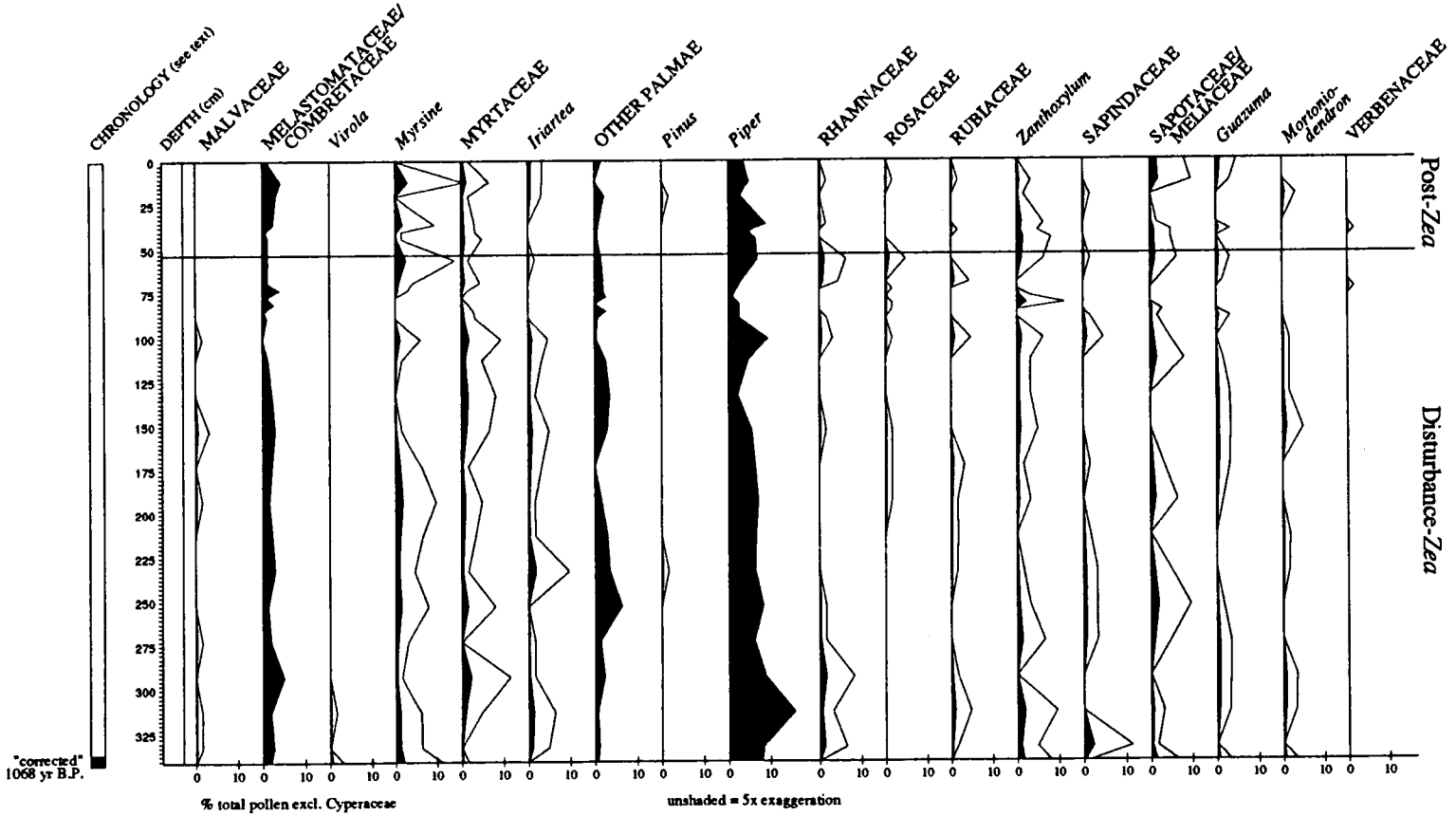


Figure 7.10 Laguna Bonilla 1992 III Core: Lowland Tropical Trees and Shrubs (II)

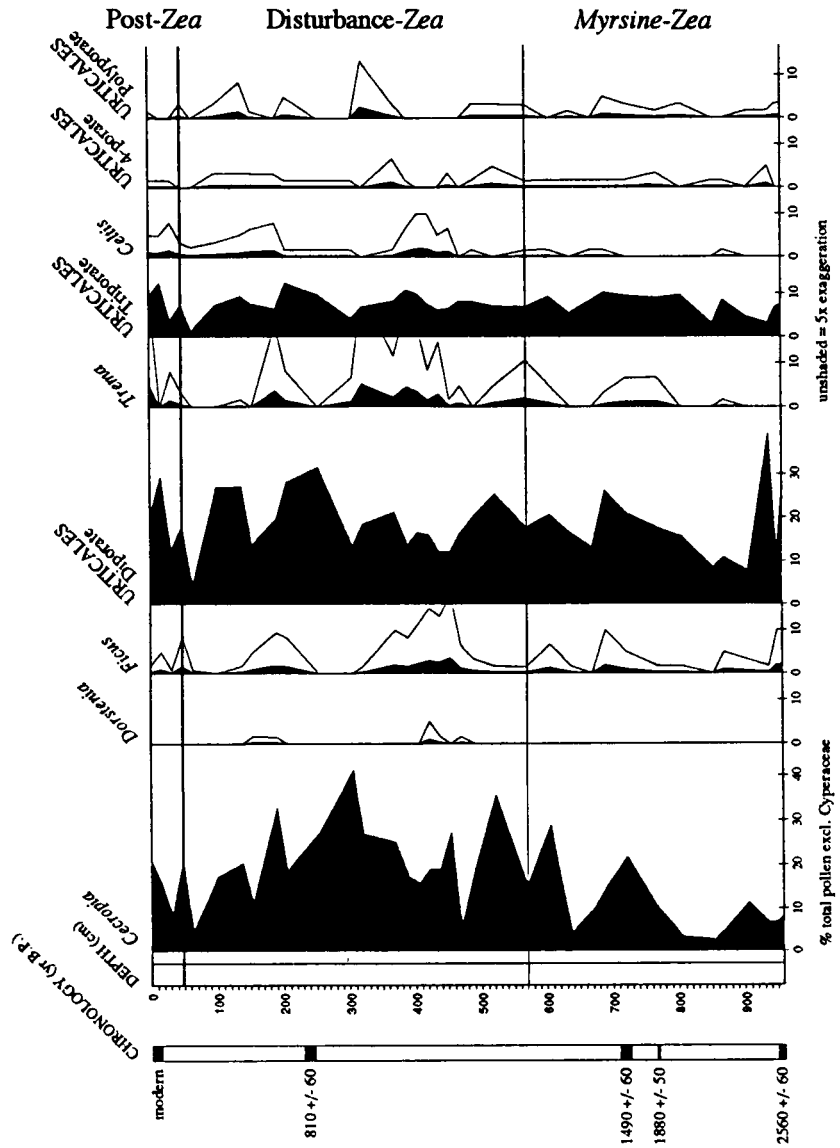


Figure 7.11 Laguna Bonillita 1991 Core: Urticales Group

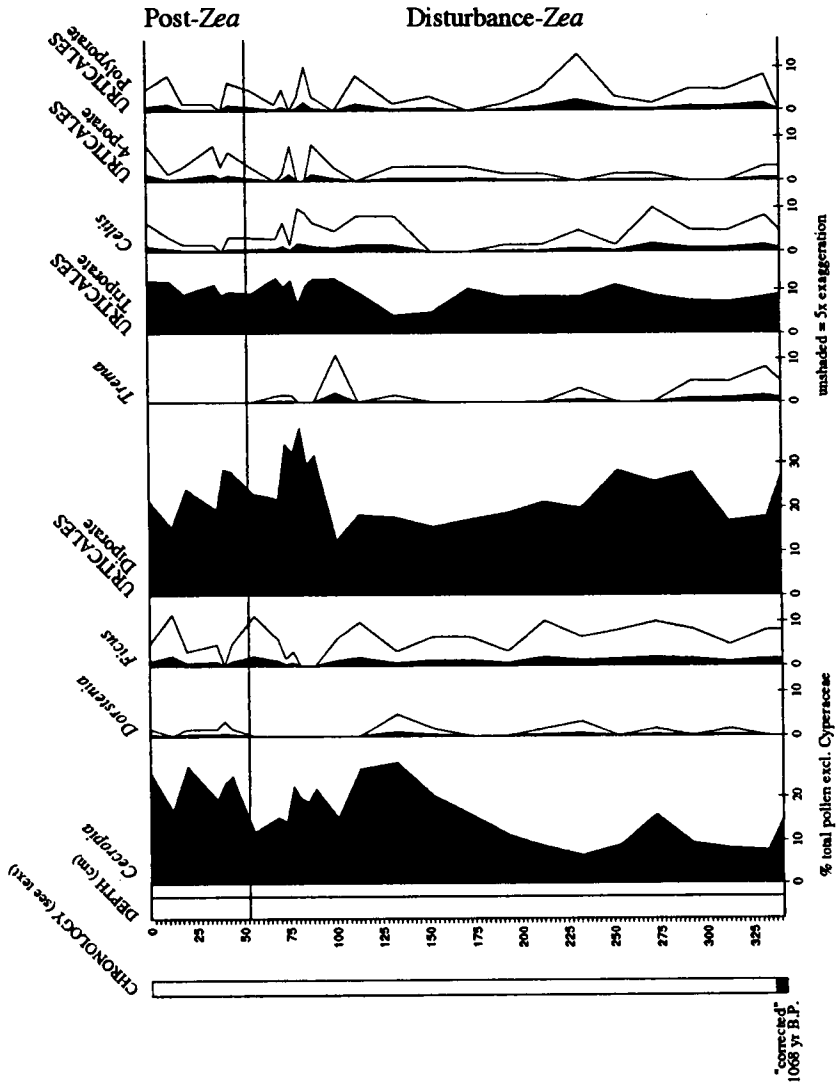


Figure 7.12 Laguna Bonilla 1992 III Core: Urticales Group

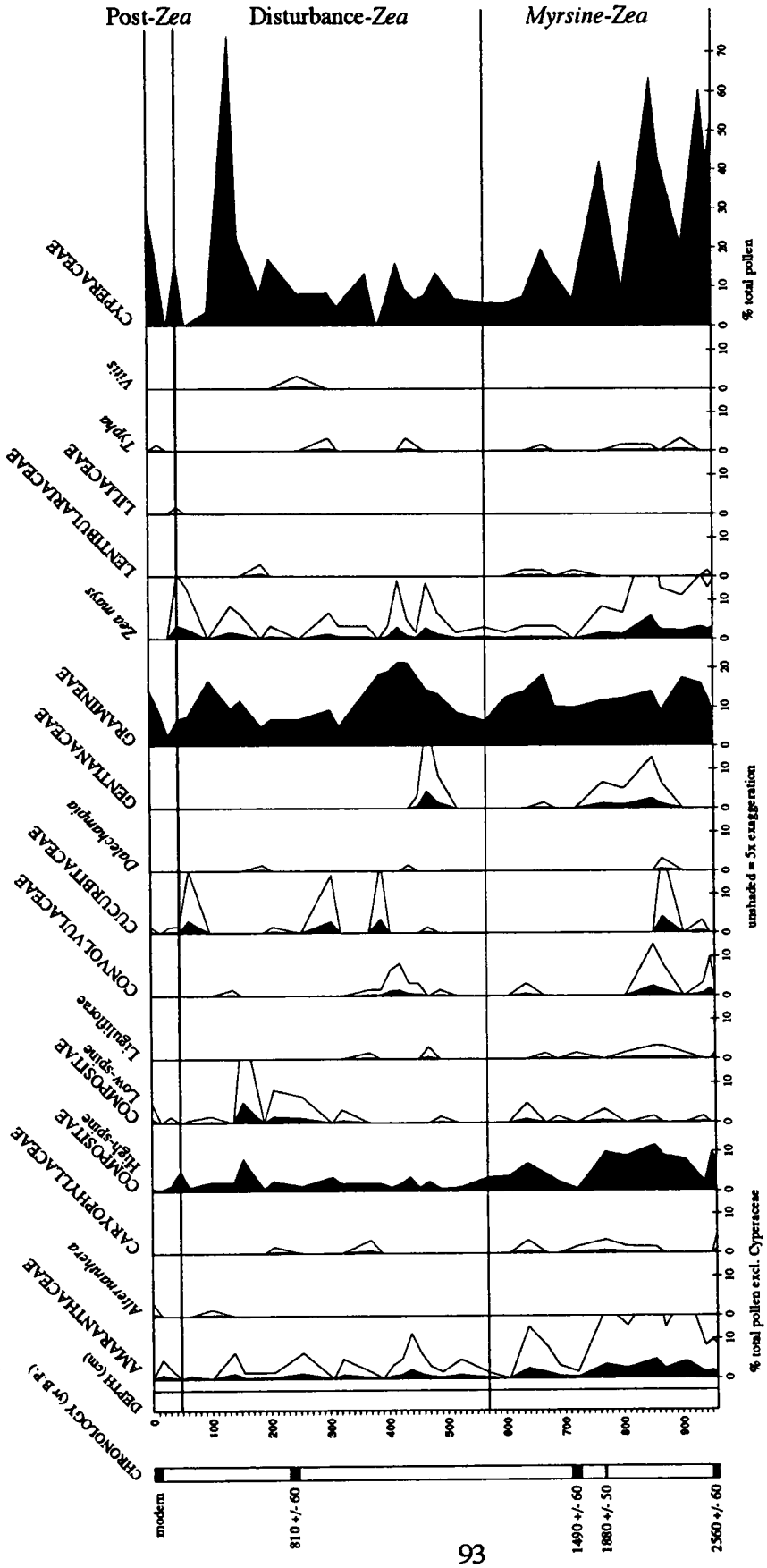


Figure 7.13 Laguna Bonillita 1991 Core: Herbs

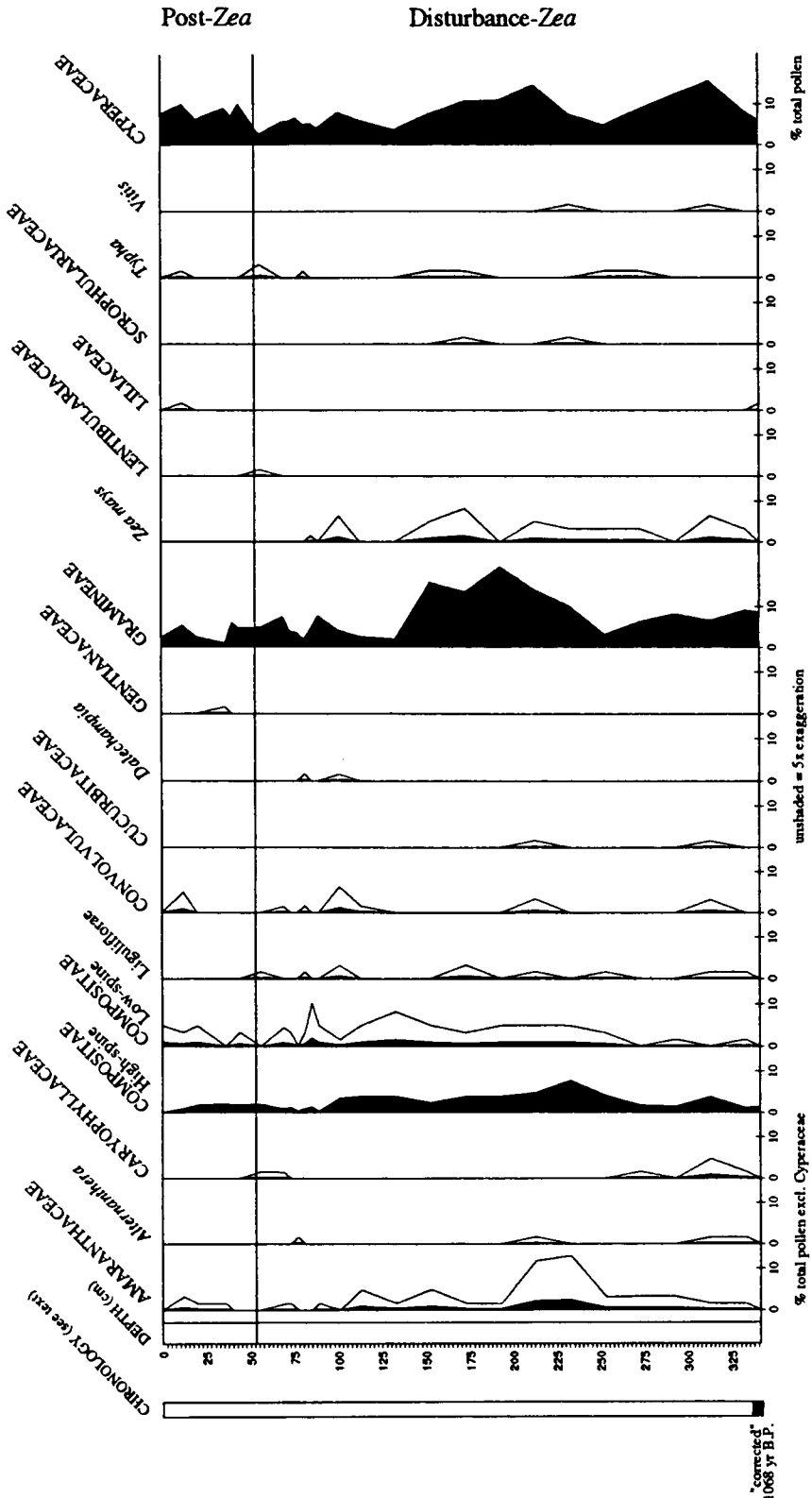


Figure 7.14 Laguna Bonilla 1992 III Core: Herbs

Pollen, spores, and charcoal were tallied for 27 stratigraphic levels in the Bonilla 1992 III core and 36 levels in the Bonillita 1991 core. All pollen curves are based on total pollen counts excluding fern spores, indeterminates, and Cyperaceae. The curves for fern spores have been normalized by dividing by total pollen (including Cyperaceae but excluding indeterminates) and fern spores. The Cyperaceae curves have been normalized by dividing by total pollen counts plus total counts of Cyperaceae pollen, but excluding indeterminates. Charcoal concentrations are expressed as charcoal fragments (> 25 μm) per gram dry sediment.

THE POLLEN ZONES

The pollen diagrams are divided into 3 zones based on the presence or absence of *Zea* pollen and trends in other taxa. A description of changes in the pollen spectra and in the sediment and charcoal curves in these zones for the two cores follows. The correlation of the two cores is based on chronologies inferred from the radiocarbon and ^{210}Pb analyses (Chapter 6) and on the pollen data.

Myrsine-Zea Zone (2560 - 1278 yr B.P.)

This pollen zone is represented by the 959 to 570 cm interval (~ lower third) of the Bonillita 1991 core and is not represented in the shorter and younger (Chapter 6) Laguna Bonilla 1992 II core. The zone is distinctive because it contains notable percentages of *Myrsine* pollen. The curve for this pollen type fluctuates markedly with pollen percentages varying between 2 and 25 percent of total pollen. Pollen from the Urticales group (excluding *Cecropia*) fluctuates through the zone and ranges from 10 to 45 percent of total pollen. *Cecropia* percentages are low in the basal sediments (8 percent), and the curve for this type becomes increasingly spiky towards the top of this zone. The Lowland Tropical group experiences a slight overall decline from 25 percent towards the base of the zone to

about 7 percent at the top of the zone. A peak in total spores at 638 cm is lagged by increases in charcoal fragments. *Zea* is present throughout the zone and makes up approximately 2 to 5 percent of the pollen sum, except for one level (720 cm) where no *Zea* pollen was found. Agricultural weeds (Compositae and Amaranthaceae) mimic the *Zea* curve. Gramineae percentages range between 8 and 18 percent. The basal sediments are highly inorganic and a second period of inorganic deposition is apparent at the top of the zone.

Disturbance-Zea Zone (1278 - 164 yr B.P.)

This zone is represented in the Bonillita 1991 core by the sediment interval from 570 - 48 cm and is partially represented in the Bonilla 1992 III core in the interval from 341 - 53 cm. The pollen spectra in the Bonillita 1991 core shifts dramatically in this zone. *Myrsine* pollen percentages plummet from over 25 percent to 3 percent or less of total pollen. At 470 cm, the Bonillita record is characterized by peaks in spores (55 percent) lagged by peaks in Gramineae pollen (25 percent). A period of high charcoal concentration is evident in the Bonillita 1991 core between 406 - 470 cm. The zone is dominated in both records by the pollen of *Cecropia* and other Urticales, with combined percentages reaching 70 percent of total pollen. Pollen of *Piper*, *Alchornea*, and the Lowland Tropical group are steadily represented in the Bonilla 1992 III record, but vary in the Bonillita 1991 record with percentages ranging from 10 to 25 percent of total pollen. Four of the 20 levels tallied for the Bonillita 1991 core and 9 of 20 tallied for the Bonilla 1992 III core in this zone had no *Zea* pollen. Where present, *Zea* pollen comprised between 1 and 2 percent of the total pollen in the Bonilla 1992 III record and between 1 and 4 percent of total pollen in the Bonillita record. Agricultural weeds (Compositae and Amaranthaceae) are well represented in this zone, though not as well as in the lower zone (2 to 10 percent of total pollen). *Zea* percentages drop to 0 at the top of this zone in the Bonillita record, but slightly below the

top of the zone in the Bonilla record. The last level at which *Zea* was recorded in the Bonilla 1992 III core is at about 89 cm (274 yr B.P., based on the extrapolation explained in Chapter 6). The Bonillita 1991 *Zea* record continues until 48 cm (about 164 yr B.P.).

Post-Zea Zone (164 yr B.P. - present)

The upper sections of both pollen diagrams record post-*Zea* cultivation vegetational sequences as high percentages of Urticales pollen and increasing percentages of Gramineae. Approximately co-eval dips in the Lowland Tropical group at about 108 years in the Bonilla basin and at about 116 years in the Bonillita basin may mark renewed land clearance associated with modern human activity in the lake basins.

SOIL CORES AT LAGUNA BONILLITA

Tables 7.2 and 7.3 show the depths at which macroscopic charcoal and ceramic pot sherds were found in the six soil cores taken near Laguna Bonillita. Results for soil core 2, which was also analyzed for *Zea* pollen, are shown separately in Table 7.3 along with the pollen data. Charcoal is most abundant between 10 - 20 cm and from 30 - 50 cm. Pot sherds were present in 9 of the 31 samples and are abundant between 20 - 40 cm. *Zea* pollen was found in 3 of the 10 samples that were processed.

There was good pollen and spore preservation in the upper 30 cm of soil core 2. Below 30 cm, preservation of spores was good but the apparent taxonomic richness of pollen types declined. *Zea* pollen was only positively identified in 3 of the 10 samples (0 - 10 cm, 10 - 20 cm, and 40 - 50 cm). However, from 50 cm downward a large number of what appeared to be severely degraded maize grains were noted. Unfortunately, these possible pollen grains were so corroded that definite identification could not be made. Other taxa that were noted in the pollen samples from the soil cores include: *Cordia* (Boraginaceae), *Hedyosmum* (Chloranthaceae), *Psidium* (Myrtaceae), *Alternanthera* and

Table 7.2. Macroscopic Charcoal (Ch) and Pot Sherds (PS) in Laguna Bonillita Soil Cores

Depth (cm)	Core 1		Core 3		Core 4		Core 5		Core 6	
	Ch	PS	Ch	PS	Ch	PS	Ch	PS	Ch	PS
0-10	-	-	+	-	-	+	-	-	-	-
10-20	+	-	+	-	+	-	+	-	-	-
20-30	-	-	+	+	-	+			-	+
30-40			+	+	+	-			-	+
40-50			+	-	+	+			-	-
50-60			+	-						

+ present, - absent

Table 7.3. Macroscopic Charcoal, Pot Sherds, and *Zea* Pollen in Laguna Bonillita Soil Core 2

Depth (cm)	Charcoal	Pot Sherds	*Zea* Pollen
0-10	+	-	+
10-20	+	+	+
20-30	+	-	-
30-40	+	-	-
40-50	+	-	+
50-60	+	-	-
60-70	+	+	-
70-80	+	-	-
80-90	-	-	-
90-94	-	-	-

+ present, - absent

other Amaranthaceae, Compositae, Cyperaceae, Ericaceae, Gramineae, Leguminosae, *Malpighia*, Malvaceae, Melastomataceae, Palmae, *Piper*, Rubiaceae, Sapotaceae, Solanaceae, and 2- and 3-pored Urticales. All samples had an abundance of fern spores and microscopic charcoal.

CHAPTER 8

DISCUSSION AND CONCLUSIONS

This chapter presents an interpretation of the paleoecological records from Laguna Bonilla and Laguna Bonillita. Information from the records (such as shifts in pollen spectra, differing amounts of microscopic and macroscopic charcoal, and fluctuating sedimentation rates) joined with available archaeological data serve to elucidate past environments and provides information regarding human settlement and subsistence in the area. My discussion seeks to clarify the debate surrounding the concept of the "Pristine Myth" for this area of Costa Rica. In particular, I attempt to explore when, how, and to what extent the environs of Laguna Bonilla and Laguna Bonillita were impacted by prehistoric people. Future pollen analyses of sediment cores from other sites in the Central Atlantic watershed of Costa Rica may reveal the extent to which findings at Lagunas Bonilla and Bonillita are representative of human-environment interactions at the regional scale.

The pollen and charcoal records from Laguna Bonilla and Laguna Bonillita provide some of the first evidence available on prehistoric human-environment relationships in a Costa Rican rainforest. Some conclusions that can be drawn from the records are highly specific to the study site, while others may have relevance to human and vegetation histories across a broader region. Here I organize my discussion of the paleoecological evidence in terms of the series of questions originally posed in the introductory chapter.

When was the area around these Central Atlantic watershed lakes permanently settled and farmed?

In his doctoral dissertation, Kennedy (1968) suggested that the older of the two archaeological sites excavated near Lagunas Bonilla and Bonillita (Site 1; Figure 4.3) dated to the Early B Period (1950 - 1550 yr B.P.) and the younger (Site 2; Figure 4.4) dated to the Middle A Period (1550 - 1100 yr B.P.). The history of occupancy that he described for these two archaeological sites is characterized as sporadic and transitory. But the pollen record indicates that people have been living in permanent settlements around the lakes since at least 2560 yr B.P. This date extends archaeological evidence of human occupation in this area by 610 years. *Zea* pollen in the basal sediments of both lakes points to early settlement and farming in the area. Because maize is a crop that requires planting, cultivating, and harvesting to survive (Iltis 1983), it follows that humans were settled in the lake basins for the entire period represented by the lake cores. The record of permanent human occupation is strongest from the pollen record of Laguna Bonillita. Here *Zea* pollen comprised over two percent of total pollen in the basal sediments. Turner and Miksicek (1984) have reported that when maize pollen constitutes two percent or more of the total pollen count, cultivation of the species in the immediate area is indicated. Twenty-five of the thirty-six levels counted for this core had *Zea*; indicating a consistent and nearly continuous human presence.

How does the paleoecological evidence for the timing of human activity compare with the regional archaeological record?

The regional archaeological sequence as established by Snarskis (1984) for the Central Atlantic watershed of Costa Rica places early human occupation of the Río Reventazón Valley in the La Montaña Phase (3000 - 2300 yr B.P.) and Kennedy's local archaeological

data places early human presence at the lakes at about 1950 yr B.P. Archaeologists have suggested that these early occupants were incipient farmers who subsisted on tubers that they were able to grow in small clearings and fruits that they harvested from the surrounding tropical rainforest. At Bonilla and Bonillita, the pollen record shows that prehistoric farmers were actively modifying the lake environments for *Zea* cultivation by 2560 yr B.P. The pollen record clearly corroborates regional occupation and provides important insight into the diet of people living in this area. Tubers and tree crops were not the only subsistence crops grown during early occupation. Maize was also part of the diet. The pollen record does not establish whether prehistoric human populations relied principally on a maize, but it does show that this food crop was consistently grown in the area surrounding the lakes.

The cultivation of maize during this early period may indicate that people living in the area of the lakes were culturally tied with more northern cultures. Snarskis' (1984) contrast of the lithic and ceramic assemblage from the El Chaparrón phase and the co-eval La Montaña phase, seems to reinforce the prevalence of northern influence. The El Chaparrón complex is characteristic for its lack of budares, which are commonly tied to southern traditions and root-based subsistence. The presence of Zea pollen in the sediments of Lagunas Bonilla and Bonillita suggests possible ties with non-root crop-based cultural systems, such as those that were operative at the El Chaparrón site.

The population explosion and full scale adoption of maize-based subsistence that Sanrskis (1984) envisioned as associated with the El Bosque phase has been dated elsewhere in the Central Atlantic watershed to about 2250 yr B.P. Evidence of this supposed agricultural and population expansion could be preserved in the paleoecological record at Bonilla and Bonillita as increased sedimentation to the lakes, sharp declines in arboreal taxa as more forests are cleared to make available more farmland, or greater

representation of crop-related pollen (Deevey *et al.* 1979; Binford *et al.* 1987; Murdy 1990; O'Hara *et al.* 1993). The sediments in the Bonilla 1992 III core are not deep enough to test Snarskis' proposal. The Bonillita pollen record, however, does contain sediments dating to this period -- the date of 2250 yr B.P. falls at about 869 cm, in the lower part of the Myrsine-*Zea* pollen zone. The pollen sample from the 870 cm sample shows a high percentage of *Zea* pollen (> 5 percent of total pollen) and in fact represents the peak value of *Zea* in the record. The *Zea* peak might signal population expansion during this period and hence support Snarskis' proposal. But it could also signify a greater use of maize by a static population of people. If the peak in *Zea* pollen in the record had been sustained for a longer period of time, it would provide stronger evidence of an expanding population. But, percentages decline after this level, making it unclear what the peak in *Zea* pollen means.

Are crop plants such as maize and others represented in the pollen record?

Zea mays is the only pollen type identified in the sediments that can be definitively described as a human cultivar. While other taxa were identified that are known to have been used by prehistoric populations for medicinal, subsistence, or building purposes (Table 8.1), it can not be said with any degree of certainty that these plants were "cultivated." Rather, many of these plants may have been harvested from spontaneously occurring populations or conversely, may have been tolerated in the *milpa* for their beneficial qualities (Kellman and Adams 1970; Yoon 1993; Wiseman 1985). Some may have been wild plants that were not used. Turner and Miksicek (1984) have stated that the only pollen types that can, without a doubt, be classified as "cultigens" are maize and squash. They further suggested that care must be taken in the verification of other cultigens because of identification problems (as with cotton) or because they may represent collected, not domesticated, species (as with amaranths). Cultigens are generally underrepresented in

Table 8.1. Economic and Useful Plant Taxa Represented in the Pollen Records

Scientific Name	Common Name	Possible Use	Reference
Alchornea	Canelito	Wood	Carpio Malavassi 1992
Amaranthaceae	Bledo, Amaranth	Food	Sauer 1967
Anacardium	Marañon	Food	Leon 1985
Bursera	Jiñote	Wood	Carpio Malavassi 1992
Byrsonima	Nance	Food/Wood	Leon 1985
Celtis spp.	Hackberry	Food	Leon 1985
Cordia	Laurel	Wood	Carpio Malavassi 1992
Hibiscus	Rosa de Jamaica	Drink	Leon 1985
Hura	Javillo	Wood	Carpio Malavassi 1992
Iriartea	Palmito	Food	Clark *et al.* 1993
Ilex	Mate	Drink	Leon 1985
Myrsine	Ratoncillo, Sierra	Wood	Pittier 1978
Piper	Hinojo Sabalero	Fish Bait	Joly 1985
Psidium	Guava	Food	Leon 1985
Quercus	Roble	Wood	Carpio Malavassi 1992
Sechium[1]	Chayote/Guisquil	Food	Alvarado *et al.* 1992
Zanthoxylum	Lagarto	Wood	Carpio Malavassi 1992
Zea mays	Maíz (Corn)	Food	Ludlow-Wiechers *et al.* 1983

[1] The pollen type found at 390 cm in the Bonilla 1992 III core closely resembled that of the cultivated cucurbit, *Sechium edule*, but insufficient reference material was unavailable to make a firm identification.

pollen diagrams because they are mostly animal (including insect) pollinated rather than wind pollinated, and because environmental conditions in fields where most of the pollen is initially deposited are unfavorable for preservation (Turner and Miksicek 1984).

To what extent were tropical forests impacted by agricultural clearing or other human activities?

The Laguna Bonilla and Laguna Bonillita pollen records reveal a long history of forest disturbance from agricultural activities. According to Jacobsen and Bradshaw (1981),

different size lake basins have different pollen source areas; small lakes are more likely to reflect more local pollen rain whereas larger lakes tend to represent regional or extraregional pollen source areas. Accordingly, the Laguna Bonilla pollen record would be expected to reflect vegetational changes over a larger pollen source area than the record from Laguna Bonillita. For this reason, pollen spectra at Laguna Bonilla may show less of a localized signature of human disturbance because there may be more pollen deposition from areas further away from the lake. The signature of human disturbance in the Laguna Bonillita pollen record is very distinct. In part, this may be due to the shape and size of the Bonillita lake basin, but more likely it records extensive and intensive human use.

Zea agriculture is represented continuously in the pollen record from Laguna Bonillita. The presence of *Zea* pollen in the lowest sample analyzed and throughout the core indicates that agriculture in the Bonillita basin predates the time period represented by the diagram. Arboreal taxa are well represented in the *Myrsine-Zea* pollen zone indicating that maize at this point may have been grown without much land clearance. Perhaps it was grown directly on the lake shore where some areas may have been naturally clear of trees. The Urticales and *Cecropia* percentages rise through the zone and seem to have an inverse relationship with Gramineae and other agricultural weeds, perhaps denoting very localized land clearing that resulted in the creation of more habitat suitable for disturbance taxa.

The most dramatic change in arboreal taxa represented in this record is a sharp drop in *Myrsine* percentages at about 1278 yr B.P. (570 cm). This species appears to be represented at Laguna Bonillita by *Myrsine floridana*; a species that grows at mid-elevation and is described by Pittier (1978) as being used extensively in the construction of indigenous houses. The decline in *Myrsine* is quickly followed by a large influx of microscopic charcoal, two closely spaced peaks in *Zea* pollen, and an increase in

agricultural weed pollen. This sequence is interpreted as a period of land clearance that spread beyond the lake shore onto the gently rolling slopes of the lake basin.

Concurrent with agricultural expansion are sustained high percentages of Urticales and *Cecropia* and fluctuating percentages of the Lowland Tropical group. *Zea* is present in this zone but its representation is much less consistent, perhaps reflecting the use of other subsistence crops. The last palynological evidence of *Zea* cultivation occurs at 164 yr B.P. (48 cm), where *Zea* represents almost 3 percent of total pollen. This last burst of agricultural activity may reflect the final occupation of the lake basin by indigenous people. Higher levels of maize pollen in this late period may reflect the expansion of agricultural lands to grow more food for population expansion associated with the retreat of coastal Indian groups to mountainous areas as European settlement began. Peaks in Gramineae, *Cecropia*, and the Lowland Tropical group in the uppermost zone may signal forest regeneration following aboriginal agriculture and the later establishment of pasture in this century.

The pollen record from Laguna Bonilla does not reflect widespread forest clearance associated with agriculture. *Zea* cultivation is evident, but pollen percentages of this crop plant are typically low ($\leq$ 2 percent) throughout the record, suggesting a limited area of cultivation. Arboreal species are consistently present, suggesting that crops were planted in areas that were naturally clear, such as the lake margin. Clearly, the record of forest disturbance associated with the beginning of *Zea* cultivation in this lake basin predate the base of the core. Lacking a baseline with which to compare, it is difficult to quantify the amount of forest change resulting from agricultural practices in this basin. The last indication of *Zea* cultivation is at 81 cm below the core top. The pollen record above this point seems to weakly reflect forest recovery with a large peak in Gramineae followed by the regeneration of what might be secondary species (*Cecropia* and other Urticales). The

most recent section of the pollen record does not particularly reflect the vegetational disturbance usually associated with grazing (i.e., increased inorganic content of sediments or increases in cattle-dispersed disturbance taxa such as *Psidium*).

It is interesting to speculate as to why prehistoric agriculturalists preferred the Bonillita basin over the Bonilla basin. The Bonillita record shows a more continuous and higher percentage of *Zea* pollen than the Bonilla record and indicates that maize agriculture may have persisted in this basin for about a century longer than in the Bonilla basin. The Bonillita basin may have been more suitable for maize agriculture and therefore was used more intensively than the Bonilla basin both for habitation and agriculture. Reasons why the Bonilla basin was used less may include factors such as the ease with which land could be kept clear, the extent of flat land, drainage, or the effects of Conquest. Crops were probably planted on the lake margins and in areas that relatively easy to keep clear of vegetation. Some of the flatter areas of the Bonilla basin are presently swampy and if these conditions existed in the past they may have led to marginally productive crops due to waterlogging. The Bonillita basin is a shallower basin with gently rolling hills that may generally have better drainage than the Bonilla basin. Alternatively, it is possible that the effects of European settlement may be reflected in the sequential abandonment of the lake basins. Turner and Butzer (1992) have indicated that large tracts of land were abandoned by indigenous populations in other areas of the neotropics as they fled enslavement or as they died off due to rapidly traveling disease vectors that arrived slightly ahead of European settlers. Europeans are not documented to have gained control of the Río Reventazón Valley until 1873 (Gabb 1875), but no doubt their influence was felt decades to centuries before contact was made. Possibly agriculture ended sooner in the Bonilla basin because populations declined and remaining inhabitants consolidated settlement in the Bonillita basin.

What type of fire history is documented by the charcoal record?

The long-term ecological importance of fire in neotropical rainforests has been the subject of considerable debate. Some scientists have argued that fire has played a role in shaping tropical vegetation associations and has contributed to overall diversity (Sanford *et al.* 1985), while other scientists have speculated that tropical rainforests are naturally non-flammable vegetation types that only become more susceptible to fire when they are degraded by human use (Mueller-Dombois 1981). There is no doubt, however, that human use of tropical rainforests has significantly increased their fire susceptibility over time. Fire has been used in tropical forests (wet and dry) to drive game, ease travel through densely vegetated areas, provide new succulent forage for grazing animals, control pests and disease-bearing insects, and clear land for cultivation (Batchelder *et al.* 1967). Considerable amounts of microscopic and macroscopic charcoal fragments have been found in rainforest soils and lake sediments (Chapter 2), findings which, as in temperate regions, serve to provide some information about past fire regimes (Patterson *et al.* 1987).

Deducing fire history from charcoal profiles is complicated because charcoal is produced in pulses while pollen production can be regarded as continuous at the resolution of a typical pollen diagram (J. Clark 1988). Small charcoal fragments can be transported long distances by wind and J. Clark (1988) has argued that particles in microscopic size classes reflect fires over a subcontinental region. However, others have concluded that charcoal size is not especially useful for interpretation because it is vulnerable to modification by physical and chemical processes during transport, sedimentation and preservation, and in subsequent laboratory processing (R. Clark 1983).

Despite disagreements over microscopic charcoal interpretation, it appears that charcoal profiles do provide some insights on human disturbance of neotropical landscapes. Tsukada and Deevey (1967) and Vaughan *et al.* (1985) found that microscopic charcoal

fragments preserved in sediments were positively correlated with *Zea* pollen. Microscopic charcoal horizons and increases in Gramineae pollen percentages were used by Piperno *et al.* (1991b) to speculate about PaleoIndian land uses.

The sediment cores from Laguna Bonilla and Laguna Bonillita contain an abundance of microscopic charcoal, suggesting that fire has influenced vegetation patterns in the area surrounding the lakes. Several periods of increased fire activity can be seen in the records. The sediments of Laguna Bonillita contain two periods of significantly increased microscopic charcoal deposition that attest to changes in fire characteristics (e.g., changes in fire frequency, extent of land burned, and/or fire intensity). While sustained use of fire for agricultural land preparation does not seem to be reflected in the charcoal record at this site, periods of increased *Zea* percentages seem to correspond directly with increased abundance of charcoal fragments. The peaks of charcoal fragments in the basal sediments (2560 yr B.P.) and at about 450 cm (1114 yr B.P.) are interpreted as representing expansion of agricultural lands.

The presence of macroscopic charcoal (>2 mm) in the soil cores at Laguna Bonillita supports the microscopic charcoal record and reflects the occurrence of local fires within the basin. That macroscopic charcoal was found in association with potsherds and *Zea* pollen points to human-set fires, rather than lightning-ignited fires. The consistent representation of macroscopic charcoal along the transect upslope of the old shoreline of Bonillita suggests that maize was cultivated on the margins of the lake, where it may have been easier to keep land cleared. The presence of macroscopic charcoal in all but the deepest sections of soil core 2 indicates a long history of fire at the site, probably in association with agriculture.

At the La Selva Biological Station, soil charcoal has been found to be most abundant between depths of 30 - 50 cm and has been dated to 2430 and 1180 to 1110 yr B.P. (Horn

and Sanford 1992). In the Bonillita soil cores, charcoal seems to be most abundant at depths of 10 - 20 cm and 30 - 50 cm. It is likely that at least the lower charcoal reflects prehistoric burning, although no radiocarbon dating has been carried out. Charcoal found from 10 - 20 cm in the Laguna Bonillita core may reflect later fires or possibly soil disturbance associated with 20th century forest clearance.

Are there indications of regional climatic shifts during the time period represented by the cores?

While the pollen records from Laguna Bonillita and Laguna Bonilla undoubtedly reflect a long history of vegetation disturbance by the prehistoric inhabitants of the basins, they may also reflect fluctuations in climate. It is difficult, however, to tease apart possible climatic signals from the human impacts that may mask them (Leyden 1987; Deevey *et al.* 1979).

Climate driven shifts in pollen assemblages may be reflected especially in the Laguna Bonillita core. Large peaks in Cyperaceae at the base of the core (2560 yr B.P.), at about 138 cm (340 yr B.P.), and again in the surface sediments (present day) may indicate climatic fluctuations that altered water level. Perhaps during these periods, water level was lower due to lower rainfall, leading to the creation of a marshy area along the former shoreline. Sedges and other taxa that are tolerant of marshy conditions may have colonized areas of the exposed lake floor. An apparent old shoreline at the lake evidences the occurrence of higher lake stands in the past (Figure 5.2). This ancient shoreline is located up to 4 m higher than the present day shoreline. Past fluctuations in water level could be tied to climate, but also may have been caused by seismic events. As mentioned, the water level in Laguna Bonillita dropped an estimated 0.5 m after a severe earthquake in 1991.

Two peaks in fern spores co-occuring with rises in Gramineae percentages at about 640 cm (1377 yr B.P.) and at 480 cm (1151 yr B.P.) followed by higher microscopic charcoal fragments also may suggest periods of drier climatic conditions. Mueller-Dombois (1981) suggests that climate may be considered the first determinate of fire occurrence and the first determinate in the character of the vegetation, which in turn influences fire frequency. Horn and Sanford (1992) have speculated that co-evally dated soil charcoal and charcoal-rich sediment from the La Selva Biological Station and the Chirripó páramo may signal the occurrence of regional droughts on the Atlantic slope of Costa Rica at about 2430 and 1180 to 1110 yr B.P. The fern spore-Gramineae-charcoal sequence in the Bonillita core that occurs at 480 cm may reflect a drier period associated with Horn and Sanford's (1992) second postualted interval of regional drought. But the peaks in fern spores and Gramineae pollen at this level are also associated with an increase in agricultural indicators (*Zea,* Amaranthaceae, Compositae, and charcoal). This may indicate that the peaks reflect vegetation changes associated with agricultural activity rather than with climate change. If the higher percentages of *Zea* pollen were due to the availability of an expanded lake margin during a drought period, it could be that the sequence may reflect both human activity and climatic variability.

Diatom analyses of the Laguna Bonilla and Laguna Bonillita cores that are being conducted by Dr. K. Haberyan of Troy State University, Alabama, may provide a clearer basis for interpreting possible climatic shifts in the Laguna Bonilla and Laguna Bonillita basins. Diatoms have been extensively used as indicators of environmental conditions because they are highly sensitive to changes in lake water chemistry, local land use changes, and fire regimes (Dixit *et al.* 1992).

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The preColumbian landscape of the New World tropics has been viewed until recently as an "Eden" where ecologically savvy savages inhabited lush rainforests and lived in harmony with nature. This "Paradise Lost" modern vision of past cultures is increasingly coming under fire as scientists uncover more bits of information regarding environmental conditions of the past in the neotropics. While there is no doubt that the Conquest forever changed the landscapes of the New World, preColumbian cultures also modified landscapes and their impact has been underestimated in some areas. In other areas, preColumbian impacts perhaps have been overestimated, as preColumbian alternation of the environment must have varied over space and time. The scale at which issues of preColumbian forest disturbance are addressed clearly influences our perception of what is a "virgin forest" and what is a "human modified landscape."

The Laguna Bonilla and Laguna Bonillita pollen records provide a "time window" into how landscapes were modified over time in a small area of the Central Atlantic watershed of Costa Rica. Vegetation patterns in the two basins have been influenced by human occupation for the entire period that is spanned by the pollen records. Evidence of *Zea* agriculture attests to the fact that these lake basins have been permanently occupied for at least 2,560 years. Forest clearance associated with human occupation seems to have been sporadic, but destructive. The striking eradication of *Myrsine* from the Bonillita basin was probably linked to human activity; but exactly why this species was singled out remains a mystery. At Lagunas Bonilla and Bonillita, the questions of how, where, and when landscapes were modified by humans has been answered; the question of purpose remains veiled in the lost cultures of this area.

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APPENDICES

APPENDIX A

LAKE SEDIMENT POLLEN PROCESSING SCHEDULE

LAKE SEDIMENT POLLEN PROCESSING SCHEDULE

The following schedule was used to extract pollen from the lake sediment cores. This procedure is most manageable processing six samples at a time and takes about six hours to complete. Treating more than six at once results in samples being left in chemicals too long. The procedure was developed by Dr. Sally Horn based on standard techniques (Berglund, 1986).

PROCEDURE

1. Place 0.25 - 0.5 cc wet sediment in preweighed, 15 ml polypropylene centrifuge tube and reweigh.

2. Add 1 *Lycopodium* tablet to each tube.

3. Add a few ml 10% HCl, and let reaction proceed; slowly add more 10% HCl until there is about 10 ml in each tube. Stir well and place in hot water bath for 3 minutes. Remove from bath, centrifuge for 2 minutes at ~ 2500 rpm (IEC table top centrifuge, model MB), and decant.

4. Add 10 ml distilled water, stir, and place in hot water bath for 3 minutes. Centrifuge for 2 minutes and decant. Repeat for a total of 2 washes.

5. Add 10 ml 10% KOH, stir, and place in boiling water bath for 5 minutes, stirring after half the time has elapsed. Remove from bath to sieve.

6. Stir samples and pour through 125 μm sieves, collecting liquid in a beaker underneath. Wash materials through the sieve by squirting with distilled water.

7. Centrifuge down materials collected in the beakers by repeatedly filling the original tube with the corresponding beaker contents, centrifuging for 2 minutes, and pouring off decant.

8. Add 10 ml distilled water, stir, centrifuge for 2 minutes, and decant for a total of 3 washes.

9. Add 8 ml of 52% HF and stir. Place tubes in boiling bath for 20 minutes, stirring after half the time has elapsed. Centrifuge for 2 minutes and decant. HF is dangerous; wear gloves, goggles, and mask. Close the sash on the hood when not stirring.

10. Add 10 ml 5% KOH, stir, place in boiling water bath for 5 minutes, centrifuge for 2 minutes, and decant.

11. Add 10 ml distilled water, stir, centrifuge for 2 minutes, and decant for a total of 3 washes. Examine the tubes to make sure silica has been removed. If silica is still present, repeat steps 9 through 11.

12. Add 10 ml glacial acetic acid, stir, centrifuge for 2 minutes, and decant into waste receptacle.

13. Perform acetolysis by mixing together 9 parts acetic anhydride and 1 part concentrated sulfuric acid and adding 8 ml of this mixture to each tube. Stir, and place in boiling water bath for 5 minutes, stir after half the time has elapsed. Centrifuge for 2 minutes and decant.

14. Add 10 ml glacial acetic acid, stir, centrifuge for 2 minutes, and decant.

15. Add 10 ml 10% KOH, stir, place in boiling bath for 2 minutes, centrifuge for 2 minutes, and decant.

16. Add 10 ml distilled water, stir, centrifuge for 2 minutes, and decant for a total of 3 washes.

17. Add one drop 1% safranin stain to each tube. Flick each tube to begin mixing. Add 10 ml distilled water, stir, centrifuge for 2 minutes, and decant.

18. Add 10 ml tertiary butyl alcohol (TBA), stir, centrifuge for 2 minutes, and decant.

19. Using a vortex mixer, agitate the samples to mix the microfossils with the TBA that was left in the tubes after decanting. Transfer the samples to clean glass vials. Centrifuge for 2 minutes and decant.

20. Stir 3 drops of silicone oil (2000 centistrokes viscosity) into each sample.

21. Place uncorked vials in a dust-free cabinet to let the residual TBA evaporate.

22. Stir the samples after 24 hours and check for an alcohol smell; if there is no smell, cork the samples.

APPENDIX B

SOIL POLLEN PROCESSING SCHEDULE

SOIL POLLEN PROCESSING SCHEDULE

The following schedule was used to extract pollen from the soil cores taken near Laguna Bonillita in February 1994. This procedure is most manageable processing six samples at a time and takes about six hours to complete. Treating more than six at once results in samples being left in chemicals too long. The procedure was developed by Dr. Sally Horn to process soil pollen samples from the La Selva Biological Station, Costa Rica.

PROCEDURE

1. Place 1 cc soil in preweighed, 15 ml polypropylene centrifuge tube and reweigh.

2. Mix samples with a few ml distilled water using the vortex stirrer. Add more distilled water, stir, and let sit overnight to deflocculate clays. After 24 hours, stir, centrifuge, and decant.

3. Add 1 *Lycopodium* tablet to each tube.

4. Add a few ml 10% HCl, and let reaction proceed; slowly add more 10% HCl until there is about 10 ml in each tube. Stir well and place in hot water bath for 3 minutes. Remove from bath, centrifuge for 2 minutes at ~ 2500 rpm (IEC Centrifuge model MB). If material is floating on top of liquid, add a few drops of ethyl alcohol (ETOH) to reduce density, and recentrifuge for 2 minutes. Decant liquid.

5. Add 10 ml distilled water, stir, and place in hot water bath for 3 minutes. Centrifuge for 2 minutes and decant. Repeat for a total of 2 washes.

6. Add 10 ml 10% KOH, stir, place in boiling water bath for 5 minutes, stirring after half the time has elapsed. Remove from bath to sieve.

7. Stir samples and pour through 125 μm sieves, collecting liquid in a beaker underneath. Wash materials through the sieve by squirting with distilled water.

8. Centrifuge down materials collected in the beakers by repeatedly filling the original tube with the corresponding beaker contents, centrifuging for 2 minutes, and pouring off decant.

9. Add 10 ml distilled water, stir, centrifuge for 2 minutes, and decant for a total of 3 washes.

10. Slowly add 8 ml of 52% HF and stir. Place tubes in boiling bath for 20 minutes, stirring after half the time has elapsed. HF is dangerous and is known to react explosively with some tropical soils; wear gloves, goggles, and mask. Close the sash on the hood when not stirring.

11. Centrifuge for 2 minutes and check for floating materials. If material is floating, stir in a little ETOH and recentrifuge for 2 minutes. Decant.

12. Add 8 ml 10% HCl, stir, and place tubes in hot (not boiling) bath for 3 minutes.

13. Centrifuge for 2 minutes and check for floating materials. If material is floating, stir in a little ETOH and recentrifuge for 2 minutes. Decant.

14. Add 10 ml hot Alconox solution (3 g dry commercial Alconox per 1000 ml distilled water). Stir, let sit for 5 minutes, centrifuge for 2 minutes, and decant.

15. Add 12 ml hot distilled water to each tube, stir, centrifuge for 2 minutes, decant for a total of 3 washes. Examine the tubes to make sure silica has been removed. If silica is still present, repeat steps 10 through 15.

17. Add 10 ml glacial acetic acid, stir, centrifuge for 2 minutes, and decant.

18. Perform acetolysis by mixing together 9 parts acetic anhydride and 1 part concentrated sulfuric acid and adding 8 ml of this mixture to each tube. Stir, and place in boiling water bath for 5 minutes, stir after half the time has elapsed. Centrifuge for 2 minutes and decant.

19. Add 10 ml glacial acetic acid, stir, centrifuge for 2 minutes, and decant.

20. Add 12 ml hot distilled water to each tube, stir, centrifuge for 2 minutes, and decant.

21. Add 10 ml 5% KOH, stir, and place in boiling bath for 5 minutes, stirring after half the time has elapsed. Centrifuge for 2 minutes and decant.

22. Add 12 ml hot distilled water to each tube, stir, centrifuge for 2 minutes, and decant. Repeat for a total of 3 washes.

23. Agitate the samples for 20 seconds using a vortex mixer.

24. Add one drop 1% safranin stain to each tube. Agitate the samples for 10 seconds with the vortex stirrer. Add 10 ml distilled water, stir, centrifuge for 2 minutes, and decant.

25. Add a few ml tertiary butyl alcohol (TBA) and mix with the vortex stirrer for 20 seconds. Add enough TBA to make 10 ml, stir, centrifuge for 2 minutes, and decant.

26. Add 10 ml TBA, stir, centrifuge for 2 minutes, and decant.

27. Use the vortex stirrer to mix the microfossils with the TBA left in the tubes after decanting. Transfer the samples to clean glass vials. Centrifuge for 2 minutes and decant.

28. Stir 3 drops of silicone oil (2000 centistrokes viscosity) into each sample.

29. Place uncorked vials in a dust-free cabinet to let the residual TBA evaporate.

30. Stir the samples after 1 hour, adding more silicone oil if the sample appears to be dry or crusty.

31. Stir the samples after 24 hours and check for an alcohol smell; if there is no smell, cork the samples.

APPENDIX C

POLLEN AND SPORE CONCENTRATIONS

POLLEN AND SPORE CONCENTRATIONS

Laguna Bonillita 1991 Core

Sample Depth (cm)	Pollen and Spores/ g dry sediment	Pollen and Spores/ cc wet sediment
0	6.80×10^5	1.12×10^5
16	4.67×10^5	5.45×10^4
32	3.44×10^5	3.71×10^4
48	4.78×10^5	4.50×10^4
64	1.17×10^6	1.24×10^5
100	3.39×10^6	1.64×10^5
138	1.39×10^6	1.12×10^5
154	7.14×10^5	4.73×10^4
190	1.28×10^6	8.16×10^4
206	7.00×10^5	3.52×10^4
254	3.04×10^6	1.57×10^5
306	9.36×10^5	4.16×10^4
322	1.00×10^6	4.22×10^4
370	6.62×10^5	4.09×10^4
390	1.00×10^6	6.73×10^4
406	1.10×10^6	6.21×10^4
422	9.22×10^5	5.27×10^4
438	4.48×10^5	3.50×10^4
454	8.86×10^5	6.53×10^4
470	2.09×10^6	1.49×10^5
490	5.11×10^5	3.65×10^4
522	1.75×10^6	9.17×10^4
570	7.26×10^5	4.86×10^4
606	1.77×10^6	1.01×10^5
638	6.89×10^5	4.20×10^4
670	3.45×10^5	1.92×10^4
690	3.98×10^5	3.20×10^4
722	3.09×10^5	1.67×10^4
770	6.15×10^5	5.26×10^4
806	3.62×10^5	2.69×10^4

Sample Depth (cm)	Pollen and Spores/ g dry sediment	Pollen and Spores/ cc wet sediment
854	7.15×10^5	7.84×10^4
870	8.36×10^5	7.42×10^4
906	5.84×10^5	9.26×10^3
938	3.76×10^5	1.46×10^5
950	5.32×10^5	1.17×10^5
958	2.63×10^5	1.20×10^5

Laguna Bonilla 1992 III Core

Sample Depth (cm)	Pollen and Spores/ g dry sediment	Pollen and Spores/ cc wet sediment
0	5.17×10^5	1.45×10^5
12	6.97×10^5	1.39×10^5
20	4.01×10^5	2.39×10^5
36	4.47×10^5	9.76×10^4
40	7.73×10^5	1.67×10^5
44	8.88×10^5	1.79×10^5
56	1.06×10^6	7.30×10^4
69	1.30×10^6	3.19×10^5
73	1.27×10^6	2.48×10^5
77	2.51×10^6	4.87×10^5
81	1.95×10^6	3.60×10^5
85	1.96×10^6	4.15×10^5
89	1.12×10^6	2.74×10^5
101	7.37×10^5	1.03×10^5
113	9.77×10^5	1.12×10^5
133	7.44×10^5	1.09×10^5
153	3.90×10^5	1.30×10^5
173	4.95×10^5	1.48×10^5
193	5.92×10^5	1.59×10^5
213	5.38×10^5	1.83×10^5
233	4.12×10^5	2.02×10^5
253	4.49×10^5	1.42×10^5
273	6.23×10^5	1.66×10^5

Sample Depth (cm)	Pollen and Spores/ g dry sediment	Pollen and Spores/ cc wet sediment
293	1.04×10^6	1.52×10^5
313	3.81×10^5	9.24×10^4
333	4.28×10^5	1.20×10^5
341	3.49×10^5	1.03×10^5

VITA

Lisa Anne Northrop was born in San Luis Obispo, California on January 11, 1965. She attended Wilcox Elementary School (Montebello), Eastmont Intermediate School (East Los Angeles), Sierra Vista Elementary School (Placentia), Tuffree Junior High School (Placentia), and graduated from El Dorado High School (Placentia) in June 1983. The following September she entered the University of California, Riverside, and in June 1987 received the degree of Bachelor of Science in Environmental Science. After completing her degree, she served as a United States Peace Corps Volunteer for three years in San Antonio La Paz, El Progreso, Guatemala. There she worked as a Natural Resource Management Extensionist and initiated and coordinated regional reforestation projects and local horticultural programs. Upon her return to the U.S., she worked as an Environmental Scientist with a consulting firm in Aiken, South Carolina, until December 1991. In January 1992, she entered the University of Tennessee, Knoxville, and in May 1994 received a Master of Science degree in Geography.