Research paper

Multiproxy paleoecological reconstruction of prehistoric land-use history in the western region of the lower Río Verde Valley, Oaxaca, Mexico

The Holocene
20(5) 761–772

DOI: 10.1177/0959683610362811
http://hol.sagepub.com
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Abstract

Paleoecological archives from three paleomeander sites and one archeological feature located in the lower Río Verde Valley, Oaxaca, Mexico, are used to develop a spatial understanding of the patterns of prehistoric agricultural land use over the last ~3000 years. Multiproxy paleoecological data at each site (i.e. magnetic susceptibility, micro- and macroscopic charcoal, pollen and stable carbon isotopes) provide a history of land use. By examining the spatial differences in agricultural indicators at all the sites through time, augmented with our understanding of changes in demography and settlement patterns determined through the archeological record, we are able to reconstruct the complex human/land interactions in the western portion of the valley.

Keywords

charcoal, Oaxaca, prehistoric agriculture, stable carbon isotopes

Introduction

Intensive paleoecological analysis of lake and wetland sediments has provided important evidence of the history of agriculture and the manipulation of the landscape by prehistoric groups for agriculture in Mesoamerica (e.g. Arford and Horn, 2004; Beach *et al*., 2008, 2009; Brown 1985; Byrne and Horn, 1989; Clement and Horn, 2001; Conserva and Byrne, 2002; Curtis *et al*., 1998; Davis, 2003; Deevey, 1978; Deevey *et al*., 1979; Dull, 2004, 2007; Gonzalez-Quintero and Mora-Echeverría, 1978; Luzzadder-Beach and Beach, 2009; Metcalfe *et al*., 1991; Neff *et al*., 2006; Piperno *et al*., 2007; Pohl *et al*., 2007; Pope *et al*., 2001; Rice *et al*., 1985; Rue, 1987, 1989; Sluyter, 1997; Wahl *et al*., 2006; Whitmore and Turner, 2002). This evidence not only complements the archeological data but can temporally extend the record to periods of time for which no material culture remains or has been discovered for a region (e.g. Jones, 1994, Goman and Byrne, 1998; Horn, 2006; Leyden, 2002; Rue, 1989). The paleoecological record has also played an important role in the development and refinement of models of the geography and chronology of maize domestication and diffusion (e.g. Benz, 2006; Blake, 2006; Dull, 2006; Piperno, 2006). While these studies provide a critical basis with which to understand the broad-scale intertwined history of maize dispersal and human cultural development across the landscape of Mesoamerica as a whole, they essentially represent point data for each disparate location in space and time and provide minimal insight into a community's spatial relationship with the land.

In this paper we present the results of the first stage of a long-term, multiproxy project designed to reconstruct the fine-grained spatial context of land use through prehistory within our study region, the lower Río Verde Valley of Oaxaca, Mexico. We specifically use charcoal (micro and macroscopic) data, stable carbon isotope values, presence of maize pollen and magnetic susceptibility data to examine anthropogenic land use at several sites. The paleoecological data complement and enhance our understanding of land-use changes previously deciphered from the archeological record. This research indicates the importance of developing a network of paleoecological sites within a landscape in order to understand the more subtle nuances of anthropogenic land use through time.

Previous archeological and paleoenvironmental research in the lower Río Verde Valley

Since 1988, the lower Río Verde Valley (Figure 1) has been the focus of a long-term regional archeological project, directed by Joyce and his associates (e.g. Barber, 2005; Barber and Joyce,

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Received 11 May 2009; revised manuscript accepted 4 January 2010

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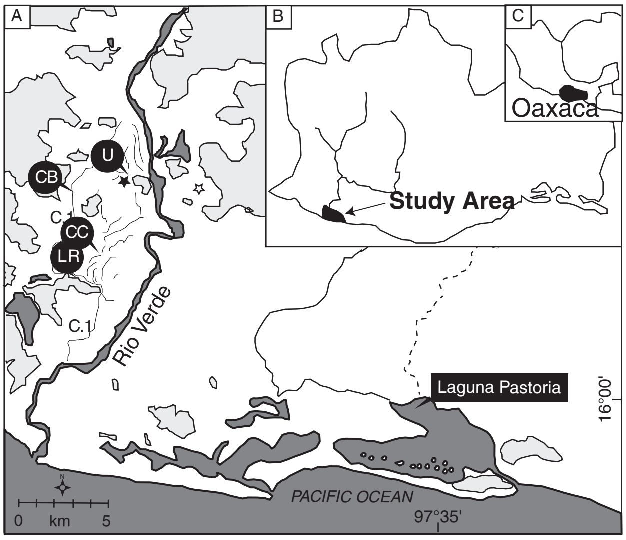

Figure 1. (A) The study region showing paleoecological sites and places mentioned in the text. CB, Charco Barro; CC, Cerro del Chivo; LR, Loma Reyes; U, Mound 2 Feature at Río Viejo. Light gray shading reflects terrain above the 20 m contour interval. The solid star shows the location of Río Viejo archeological site and the open star the site of San Marquitos. (B) The state of Oaxaca and the Upper and Lower Río Verde River. (C) The location of Oaxaca in relation to Mexico

2007; Joyce, 1991a, b, 1999, 2003, 2008, 2010; Joyce *et al*., 1998, 2001, 2004; King, 2003; Levine, 2007; Urcid and Joyce, 2001; Workinger, 2002). Field research has included large-scale excavation at six sites as well as test excavations at 12 others. The entire region has been the focus of a non-systematic surface reconnaissance, while full-coverage surveys have systematically studied an area of 152 km^2. Subsistence practices have been examined through archeofaunal (Fernández, 2004) and archeobotanical (Joyce, 1991b; Woodard, 1991) studies as well as through human bone chemistry and dental microwear (Joyce, 1991b; Taylor *et al.*, 2009). Paleoenvironmental investigations have included a major study of geomorphic change along the drainage basin of the Verde (Joyce and Mueller, 1992, 1997) as well as research on coastal geomorphic and regional paleoecological change (Goman *et al*., 2005, 2010).

The earliest archeological sites in the region date to the Early Formative (4120–2755 cal. BP), although only three small sites have been discovered for this period (Joyce, 2005). The evidence for an initial human presence in the region, however, comes from the paleoecological record. Likely evidence for early maize agriculture is found in the near basal deposits (~4700 cal. BP) of an estuarine sediment core from Laguna Pastoría (Goman *et al*., 2010; Figure 1). This level contained microscopic charcoal, including a fragment with the remains of both a charred dumbbell-shaped silica body, which surprisingly survived the Hydrofluoric acid stage during sample preparation, and the void left by a dumbbell-shaped feature. Dumbbell-shaped phytoliths are characteristic of panicoid grasses such as maize (Wooller, 2002; Middleton, personal communication, 2008). While we cannot categorically say the phytoliths came from maize, their burnt nature as well as the presence of charred grass cuticles and microscopic charcoal in general attests to the presence of human agency for land clearance, most likely for maize-based agriculture.

The regional survey indicates population expansion beginning in the Middle Formative period (2755–2350 cal. BP) and increasing by the Late Formative (2350–2065 cal. BP) (Joyce, 2005, 2010). This demographic expansion is associated with dramatic changes in the form and location of the Río Verde. Geomorphological investigations along the lower Río Verde floodplain indicate that aggradation, alluviation, and a change in stream morphology from a meandering to a braided form occurred by *c*. 2350 cal. BP as a result of anthropogenic erosion in the Verde's upper catchment (Joyce, 1991a, b; Joyce and Mueller, 1992, 1997; Joyce *et al*., 1998). The resulting increase in alluvial deposition expanded the agriculturally productive floodplain of the lower Verde. Sediment carried down the river and discharged into the Pacific Ocean also contributed to the formation of bay barrier features and back-barrier estuaries (Goman *et al*., 2005).

Subsistence and bone chemistry (stable isotope and trace element) data suggest an increasing reliance on maize and estuarine resources following the geomorphic transition (Fernández, 2004; Joyce 1991b; Taylor *et al*., 2009). In addition, increased flooding of the river may have led people to construct massive, multi-use platforms designed to raise communities above the level of severe floods. We suspect that the environmental changes contributed to the demographic expansion at this time (Joyce, 2005; Joyce and Mueller, 1997). By the Terminal Formative (2065–1620 cal. BP) regional population continued to grow and a complex, regional polity emerged with its capital at the urban center of Río Viejo (Joyce, 2010). Only minor environmental changes are thus far evident in the lower Río Verde Valley for the period postdating the major ecological changes at the end of the Formative. During the Classic (1620–1060 cal. BP) and Postclassic periods (1060–505 cal. BP), shifts in settlement and land use appear to be largely triggered by political developments, rather than responses to climatic or landscape change (Joyce, 2003, 2005, 2010; Joyce *et al*., 2001, 2004). The best documented changes in land use involve a series of shifts in settlement between the piedmont and floodplain. Although the lower Verde's floodplain is one of the most agriculturally productive regions in Oaxaca, soils of the piedmont are thin and have low agricultural productivity, with modern cultivation limited to the rainy season (Joyce, 1991a). We assume that during periods of heavy piedmont settlement, people continued to utilize the more fertile floodplain for agriculture (Joyce *et al*., 2001, 2004).

Environmental setting of the lower Río Verde

The Río Verde is one of the largest rivers on the Pacific Coast of Mesoamerica in terms of both drainage area and discharge (Alvarez, 2003; Tamayo, 1964). The upper drainage basin consists largely of several temperate highland valleys, including the valleys of Oaxaca, Ejutla, and Nochixtlán and the western Putla region (Joyce and Mueller, 1997; Figure 1). These valleys lie at elevations ranging from 1500 to 2500 m above sea level with mean annual temperatures of 16–20°C and average annual rainfall varying from 400 to 1000 mm. The river descends from the highland valleys through deep gorges that leave little room for sediment storage.

The lower Río Verde Valley is hot (25–28°C) and humid (annual precipitation 1000–2000 mm); with precipitation occurring almost daily during the wet season (June–September). Much of the natural vegetation of the valley has been disturbed or removed over the millennia through slash-and-burn milpa agriculture and more recently commercial cash crop agriculture, primarily orchards of tropical fruits (lime, papaya, coconuts and mango, but also peanuts and sesame). Natural vegetation persists in the more environmentally harsh localities such as the communities that dominate the coastal sector (i.e. estuarine communities dominated by *Rhizophora mangle, Avicennia nitida, Laguncularia racemosa* and *Conocarpus erectus*) and palm/scrub communities found on the barrier islands (*Sabal mexicana*, *Acrocomia mexicana, Opuntia* sp. and *Ipomoea* sp.; Joyce, 1991a). A preserved tract of forest (~11 500 ha) remains to the south of our study region at the National Park of Lagunas de Chacahua and provides an indication of vegetation composition without the presence of significant disturbance. Here semi-deciduous tropical forest dominates, particularly ramón (*Brosimum alicastrum*), other important tree species include *Bumelia persimilis*, *Godmania aesculifolia*, *Bursera simaruba* and *Calycophyllum candidussimum* (Joyce, 1991a).

Field sites

In the summer of AD 2000 we collected a sediment core and auger samples from three paleomeander sites located along the ancestral course of the Río Verde as well as auger samples from an archeological feature (Figure 1). Charco Barro and Loma Reyes were selected for coring as they are oxbow ponds associated with the oldest known channel of the Río Verde and it was hoped that they would provide a long temporal record (Joyce and Mueller, 1992). The other two sites represent point data for locations situated by known archeological sites and were originally collected for pedological studies. The sample sites are all located along the western edge of the floodplain and fall within a roughly 30 km^2 area.

Charco Barro

Charco Barro (16°02′N, 97°47′W) is an oxbow pond, located on a relict meander channel (C1) of the Río Verde (Figure 1). The pond is approximately 1.5 m deep. A dense mat of floating water hyacinth covers the surface of the lake; this plant was not present on the lake in 1988 (R. Mueller, personal observations). *Typha* sp. and various fruit trees ring the shoreline.

Loma Reyes

The Loma Reyes site (16°03’48”N, 97°45’50”W) is an infilled meander scar also located on channel C1 of the Río Verde (Figure 1). It is currently pasture land. Excavated sediment (70 cm depth) from a nearby irrigation ditch was deposited on the surface of the site sometime between AD 1994 and 2000 (R. Mueller, personal observations, 2000); this overburden is clearly recognizable in the auger profile. A large prehispanic platform is located close to the auger site, which is part of the archeological site of Loma Reyes. Systematic archeological surface survey and test excavations indicate that the platform was utilized during the Late/Terminal Formative (2350–1620 cal. BP), although the site as a whole reached its greatest size during the Early Classic period (1620–1330 cal. BP) and settlement continued into the Late Postclassic (740–505 cal. BP: Joyce, 2005).

Cerro del Chivo

A sample (16°04′19.59′′N, 97°45’42.91′′W) was collected from a sedimentological trench examining buried paleosols approximately 1 km north of Loma Reyes (Figure 1). The paleosols had been truncated by a meander of the Río Verde channel (paleochannel C.22). A sample of organic-rich sediment, indicating oxbow formation, was collected and dated in order to provide an estimate of the timing of the channel shift and soil truncation (Mueller *et al*., 2010). The organic-rich lacustrine sediments were subjected to paleoecological study. The sample lies close to the archeological site of Cerro del Chivo, which covers 29 ha and dates from the Terminal Formative to the Late Classic period (2065–1060 cal. BP).

Río Viejo archeological feature

Auger samples were extracted from an artificial depression associated with a large u-shaped residential platform (Mound 2) at the site of Río Viejo (Figure 1). Río Viejo was occupied from the Middle Formative to the Early Postclassic (2755–740 cal. BP) and was an urban center and political seat of the region during the Terminal Formative and again in the Late Classic (Joyce, 2008, 2010). At least three other similar artificial depressions associated with mounded architecture have been found at Río Viejo and similar features occur at other sites in the region; all are clearly visible in aerial photographs. At Río Viejo, these features range in size from 1 to 2 ha and can be as much as 4 m below the associated platform and at least 1 m below the level of the floodplain. The depression in Mound 2 retains water today well into the dry season. The original purpose of the features is unclear, although it is hypothesized that they may have been water-control features, possibly for specialized agriculture or aquaculture (Joyce, 1999). Another possibility is that they were large, sunken patios although this would have required sophisticated drainage systems given the high rainfall in the wet season. Several auger probes were undertaken to determine local subsurface stratigraphy. Three samples were collected from the Mound 2 feature (16°05′45′′N, 97°44′31′′W) at depths of 150, 185, 210 cm below the modern surface.

Methods

Sediment cores were retrieved using a Livingstone corer at Charco Barro while sediment was retrieved by auger or trowel at the other three sites. The sediment core was x-radiographed and analyzed continuously for magnetic susceptibility using a Bartington Magnetic Susceptibility meter prior to cutting open for stratigraphic description. X-radiographs revealed that no laminations were present in the Charco Barro core. The auger samples from Loma Reyes, Cerro del Chivo and the Mound 2 feature at Río Viejo were also analyzed for magnetic susceptibility. Core and auger samples were described using standard stratigraphic techniques including determination of texture (grain size) by hand, description by Munsell colors and loss on ignition (LOI; Heiri *et al*., 2001). Following lithostratigraphic description, the core and auger samples were examined for a variety of paleoenvironmental proxies. Sediment samples, macroscopic charcoal and seed material were submitted for AMS dating from Charco Barro, Loma Reyes and Cerro del Chivo. Figures are plotted using C2 (Juggins, 2003). Radiocarbon dates were calibrated using INTCAL04 (Reimer *et al*., 2004) and OxCal 4.1 (Bronk Ramsey, 2009). The median two sigma age of the calibrated radiocarbon date is used to develop the age model (Telford *et al*., 2004).

In order to reconstruct the vegetation history of the region pollen analysis was undertaken. An exotic spore (*Lycopodium*) was

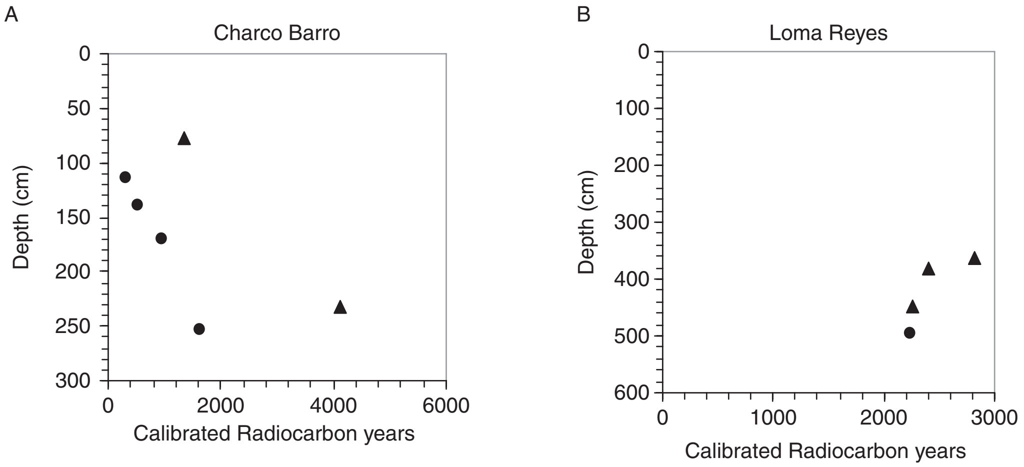

Figure 2. Depth to age for (A) Charco Barro using calibrated radiocarbon dates; (B) Loma Reyes using calibrated radiocarbon dates. Solid circles indicate dates used in age model and solid triangles indicate discarded dates (Table 1)

added to each pollen sample as a control at the beginning of processing, which followed standard techniques (Faegri and Iversen, 1989; Stockmarr, 1971). Pollen was mounted in silicon oil and slides were examined using an Olympus BX51 using 10× and 40× objectives. Pollen was, unfortunately, essentially absent from the samples, when present it was identified using published keys (Bartlett and Barghoorn, 1973; Lozano-García and Hernández, 1990) and a personal reference collection. Grass grains >70 μm in size are identified as *Zea* pollen. This size includes the wild ancestor of maize, *Zea mays* ssp. *parviglumis* (Holst *et al*., 2007).

Regional and local fire history was reconstructed by examining the microscopic and macroscopic charcoal content of the sediments (Whitlock and Larsen, 2001). Microscopic charcoal was quantified using a grid reticule along six traverses per pollen slide from Charco Barro and Loma Reyes. Microscopic charcoal was not quantified for the other two sites. Macroscopic charcoal and plant remains were extracted from the sediment samples by first deflocculating the sample with sodium hexametaphosphate, then sieving through nested sieves of 250, 125 and 63 μm mesh size (Whitlock and Larsen, 2001). Samples were examined every centimeter from the Charco Barro site and in every auger sample from the other sites. Sample volume was approximately 8 cm^3 at Loma Reyes and Charco Barro, while at the Río Viejo feature and Cerro del Chivo approximately ~12 cm^3 of sediment were analyzed per sample. The samples were then examined under a dissecting microscope. Macroscopic charcoal from the >250 μm size range was counted at all the floodplain sites, while the >125 μm size range was examined for all samples from Loma Reyes. Seeds and other potentially identifiable material (such as bones) were picked from each size category.

Samples were also processed for stable carbon isotopes. Lane *et al*. (2004) have shown that stable carbon isotope ratios from lake and swamp settings in the Neotropics can be used as a proxy for prehistoric forest clearance and crop cultivation. Samples (typically 24–30 g) were prepared for stable carbon isotope analysis as follows: sodium hexametaphosphate was added to defloculate the samples, they were then sieved through at 200 μm size mesh to remove large aquatic plant material and large carbonate nodules. The filtrate was treated with 10% HCl to remove any remaining carbonate material. The remaining sediment was dried at ~100°C and finely ground. The samples were analyzed for carbon isotopes at the Berkeley Center for Stable Isotope Biogeochemistry and the Cornell University Stable Isotope Laboratory.

Results

Charco Barro

A 2.55 m core was raised from Charco Barro. The core is composed primarily of lacustrine clays, except at the base of the core which is sandy and the top most 10 cm of the core which comprised a muddy peat. The rest of the core is very inorganic with typically <10% organic matter by LOI (see Figure 3). Magnetic susceptibility exhibits its highest levels in the basal section of the core to ~180 cm, as well as consistently high readings between 140 and 60 cm.

Seven radiocarbon dates were obtained from the site (Table 1, Figure 2). A near basal sediment sample returned a radiocarbon age of over 3700 years, however subsequent dating of macroscopic charcoal extracted from the sediments indicates that this date is too old by almost 2000 years. It is unclear what is causing the large reservoir age as chemical pretreatment removed carbonate material in the sediments prior to AMS radiocarbon analysis. It may be that the basal sediments contained residual old carbon that skewed the date. Four radiocarbon dates are therefore used in the age model for the site. The core encompasses Early Classic (~1600 cal. BP) through to the modern period. Sedimentation rates at the site are relatively constant for much of the core (average of 0.15 cm/yr); however, rates dramatically increase from ~115 cm to the top of the core (0.36 cm/yr; Table 2). The lower section of the core ~180 cm to basal sediments is characterized by high magnetic susceptibility data (>120 SI) although two peaks are present in the data. The record then dips to lows of ~80 SI between 180 and 150 cm. The magnetic susceptibility curve then gradually increases to about ~200 SI around 80 cm and then shows generally declining values to the modern sediments, which exhibit the lowest magnetic susceptibility of all (40 SI).

Pollen preservation was excellent in the peat but was almost entirely *Typha*, preservation in the rest of the core was very poor, with the presence of only occasional pollen grains. A large grass pollen grain (80 μm) was identified at 58 cm depth. Microscopic charcoal abundance was low from the core end until ~120 cm when abundance significantly increases until the surface (Figure 3).

Table 1. Radiocarbon ages for Río Verde sites

Sediment depth (cm)	Material dated	Laboratory number	C^{14} age (BP)	± Error	Median age of calibrated 2σ range (cal. yr BP)[a]	$\delta^{13}C$
Charco Barro[b]						
78[c]	Bulk sediment	AA49362	1424	80	1340	−23.1
114	Charcoal	AA77605	262	62	320	−27.7
140	Bulk sediment	AA55345	507	38	530	−20.19
171	Bulk sediment	AA49363	1050	110	970	−22.3
215[c]	Woody material	Keck 29165	−860	15	–	n/a
233[c]	Bulk sediment	AA42078	3754	55	4120	−22.3
253	charcoal	Keck 29166	1735	20	1650	n/a
Loma Reyes						
360–365[c]	Bulk sediment	AA55347	2730	38	2820	−18.79
377–385	charcoal	AA77606	2351	69	2410	−20.9
440–453	charcoal	Beta 208276	2280	40	2260	n/a
490–500	*Pistia* seeds	Keck 2916	2255	15	2240	n/a
Cerro del Chivo						
140	Bulk sediment	AA41206	2324	39	2340	−11.2

[a]Median age rounded to the nearest decade (Telford *et al.*, 2004) as determined by using IntCal 04 (Reimer *et al.*, 2004) and Oxcal 4.1 (Bronk Ramsey, 2009).
[b]Depths for Charco Barro are decompacted depths because of core shortening.
[c]Refers to dates not used in the age model (Keck 29165 is likely core top contamination).

Table 2. Sedimentation rates

Depth range (cm)	Calibrated age range[a]	cm/yr	yr/cm
Charco Barro			
0–114	0–320	0.36	2.81
114–140	320–530	0.12	8.08
140–171	530–970	0.07	14.38
171–253	970–1650	0.12	8.25
Loma Reyes[b]			
70–495	0–2240	0.19	5.27

[a]Median calibrated age at 2σ (see Table 1).
[b]The sediment overburden created by construction of an irrigation channel is removed from the calculation. 495 cm represents the midpoint of the depth of the auger sample, using Keck 2916.

Macroscopic charcoal shows considerable variability but with distinct phases of more active deposition than others, in particular in sections near the base of the core to ~170 cm and the more recent sediments (20–40 cm). The carbon isotope signal indicates sediments are relatively enriched in C4 plants throughout much of the record but with peak values (mean of $\delta^{13}C$ −17‰) occurring from 55 to 120 cm.

Loma Reyes

The core stratigraphy is very similar to Charco Barro, except that a well-developed soil overlies the lacustrine clays; this is augmented by approximately 70 cm of overburden deposits from the excavation of a nearby irrigation ditch. A thick sand lens was encountered at 2.4–2.6 m and the auger site had to be shifted slightly to the southeast and reaugured. Samples were collected from the entire length of the auger hole; unfortunately label identifiers became erased during shipping for much of the top 3 m,[1] proxy analysis therefore focused on the lowermost and oldest section of the site, which corresponds to the Late Formative (2350–2065 cal. BP) to Late Classic periods (1330–1060 cal. BP) (Figure 4).

Obtaining an unequivocal chronology for Loma Reyes has been problematic (Table 1 and Figure 2). Five samples were submitted for AMS radiocarbon dating, of which four contained enough carbon for dating. The first sample submitted for dating consisted of lacustrine sediment with charcoal particles (AA55347: 2730 ± 38 at 360 cm), subsequent dating of picked charcoal and seeds of the water lettuce (*Pistia* c.f. *stratiotes*) indicate that this age is likely too old by ~ 500 years. The remaining three dates are not consistent stratigraphically with apparently older material overlying younger material. There are several likely causes for this: younger material may have inadvertently become incorporated into the older matrix during the auger drives; there was a long surface residence time for the charcoal before it became incorporated into the lake sediments; or the dated charcoal material reflects the age of the wood when it was originally collected and perhaps utilized for construction and only later burned. Because of these uncertainties we take a conservative approach and use the radiocarbon date obtained from the seeds of *Pistia*; the plant is a floating aquatic that photosynthesizes aerially (Spencer and Bowes, 1990). We also prefer the reliability of the *Pistia* date (Keck 29167 2255 ± 15 BP at 490–500 cm), which comes from basal core sediments as it represents autochthonous-derived material, unlike the charcoal, thus offering the likelihood of a simpler taphonomic history. In order to construct an age model we assume that there has been a constant rate of sedimentation up until the deposition of the irrigation derived overburden (i.e. depth below surface at 70 cm corresponds to present; Table 2).

Magnetic susceptibility data are low throughout the whole record (<20 SI), although the youngest samples between 320 and 305 cm depth indicate a trend to higher magnetic susceptibility values (~24 SI). These values are significantly below those recorded from Charco Barro. Microscopic charcoal values are relatively stable from the basal materials to about 360 cm when they decline markedly and are similar to the basal values at Charco Barro. Macroscopic charcoal concentration at the >250 μm size range is consistently high from the base of the core until about 415 cm, the record then becomes somewhat erratic. These erratic values are in contrast to charcoal concentration in the size 250–125 μm, which shows a sustained peak between 375 and 415 cm. Both macroscopic charcoal records rapidly decline at about 365 cm. Relatively enriched carbon isotope values

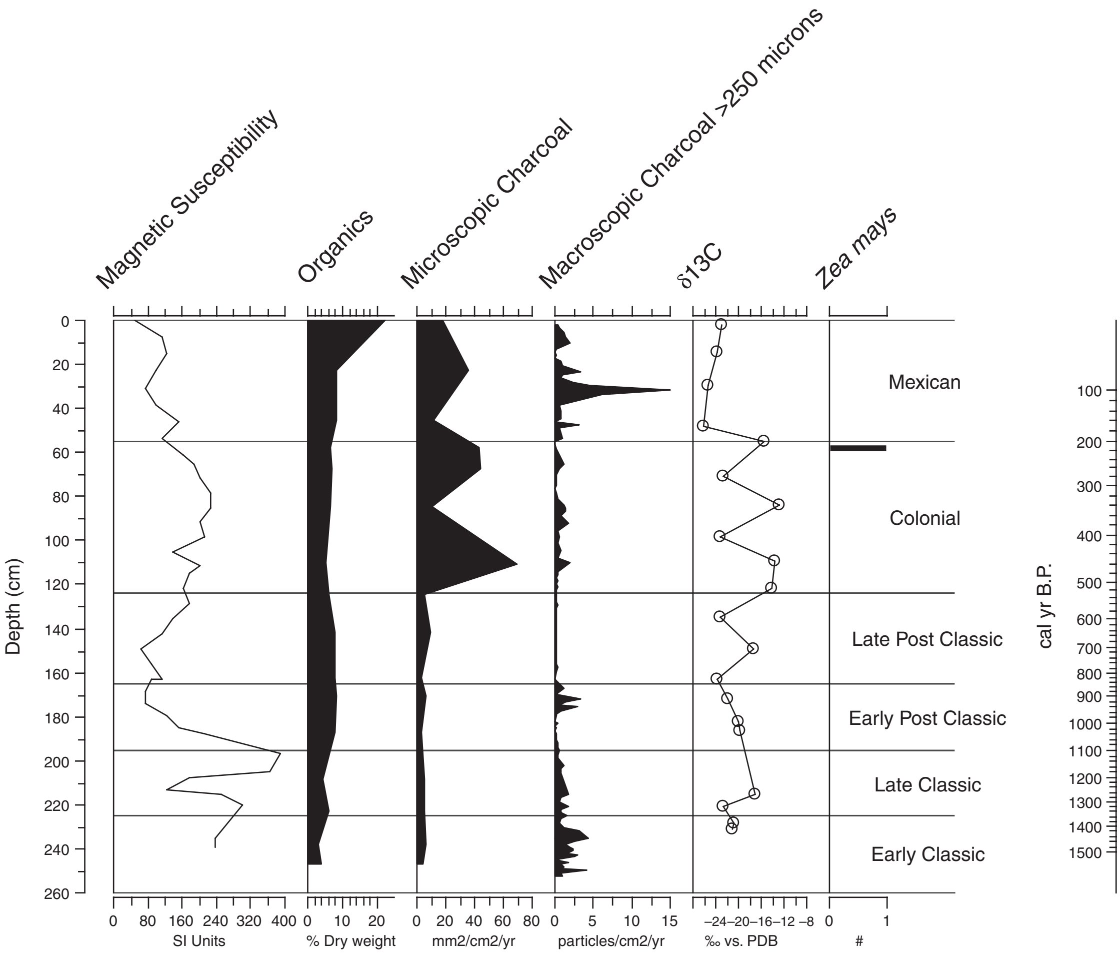

Figure 3. Paleoecological proxy diagram for Charco Barro

(mean $\delta^{13}C$ −20.4‰) also occur during the peak in the 125 µm size charcoal. A decline follows but the last sample at 305 cm indicates a trend towards enrichment again ($\delta^{13}C$ −20.6‰). Three grass pollen grains were identified in the auger sample from 365 to 370 cm, they vary in size from 70 to 83 µm, which is within the size range of Mexican maize pollen (Holst *et al*., 2007).

Cerro del Chivo

The organic, lacustrine deposit recovered from the sample at Cerro del Chivo dates to 2340 cal. BP (Table 1). This represents the oldest material examined for paleoecological proxies from the floodplain region. The proxy-data available suggest that human disturbance at this site was low as the macroscopic charcoal is negligible (only two pieces of charcoal in the >250 µm size range were found in a sample of ~10.6 cm^3 and the magnetic susceptibility data is low (39 SI). The $\delta^{13}C$ value is, however, somewhat equivocal suggesting slight enrichment with C4 plants (−21.4‰). Pollen was not preserved in the sample.

Río Viejo archeological feature

The sample obtained from a depth of 185 cm in the Mound 2 feature at Río Viejo contained numerous sherds, which were unfortunately not diagnostic and so are not useful for dating purposes. However auguring from previous field seasons, within the feature also recovered pottery from comparable levels that date to the Late Classic period (1330–1060 cal. BP), another sample from an auger associated with a buried soil yielded a radiocarbon date of 1120 ± 50 BP (Beta Analytical 80870, R. Mueller and A. Joyce, unpublished data, 1995), which is consistent with the pottery dates as well as the construction date for the nearby archeological features. Of interest is the fact that the carbon isotope data indicate relatively enriched values especially in the two deepest samples indicating the possible presence of maize-based agriculture (Figure 5). Macroscopic charcoal levels were, however, low (range of individual pieces counted 1–23 in average volume of ~13 cm^3, for comparison Loma Reyes average was 108 (N=16) and Charco Barro 52 (N=137) in a average volume of 8 cm^3), indicating a low fire presence, which is curious given the proximity of a residential platform that was occupied at the time. Pollen was not preserved in any of the samples.

Discussion

The records from the Río Verde floodplain add further details to our understanding of human interactions with the landscape from Late Formative times to present and are interpreted as reflecting spatial changes in land use through time.

Previous palynological research from the coastal lagoon site of Laguna Pastoría indicates early occupation of the region to the south-southeast of the study sites (Goman *et al*., 2005, 2010). The charred remains of grass cuticles and panicoid phytoliths indicate that early agriculturalists occupied the area near the then

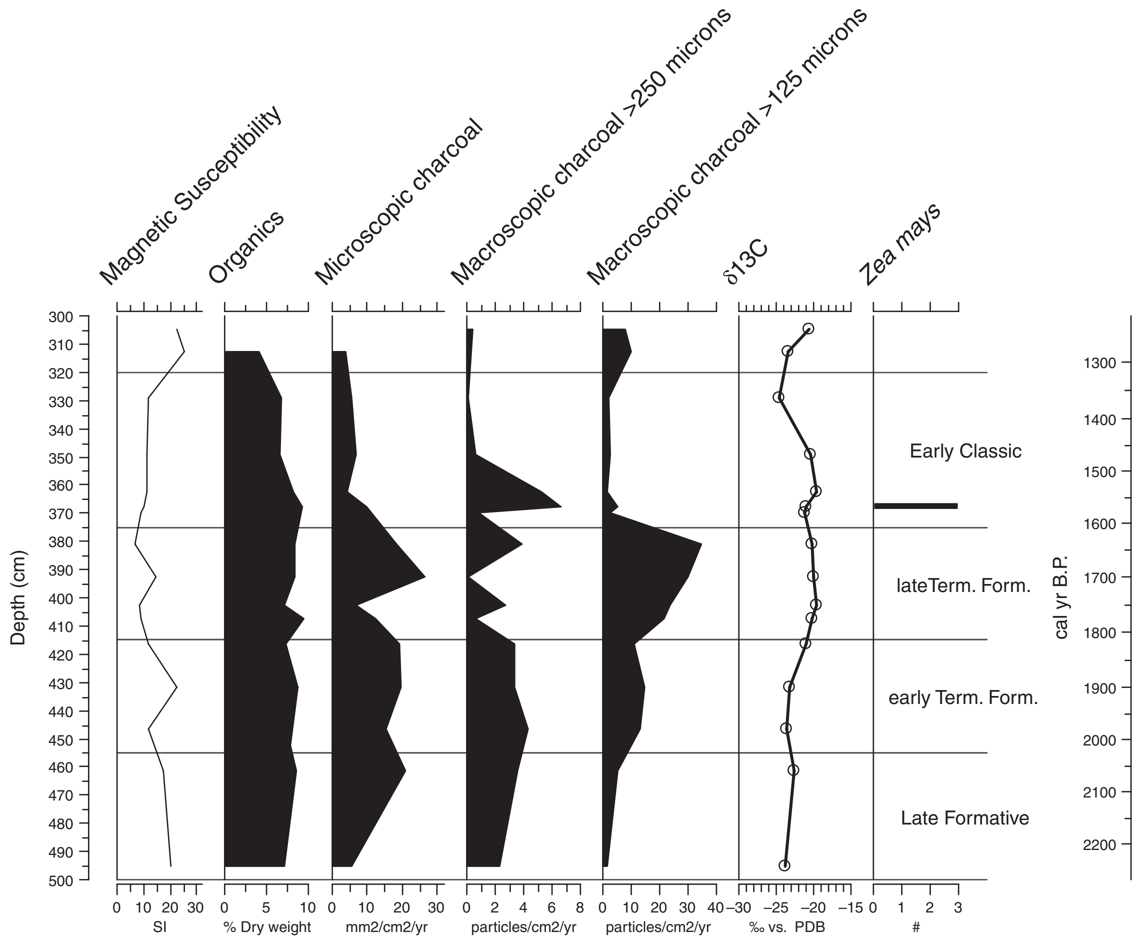

Figure 4. Paleoecological proxy diagram for Loma Reyes

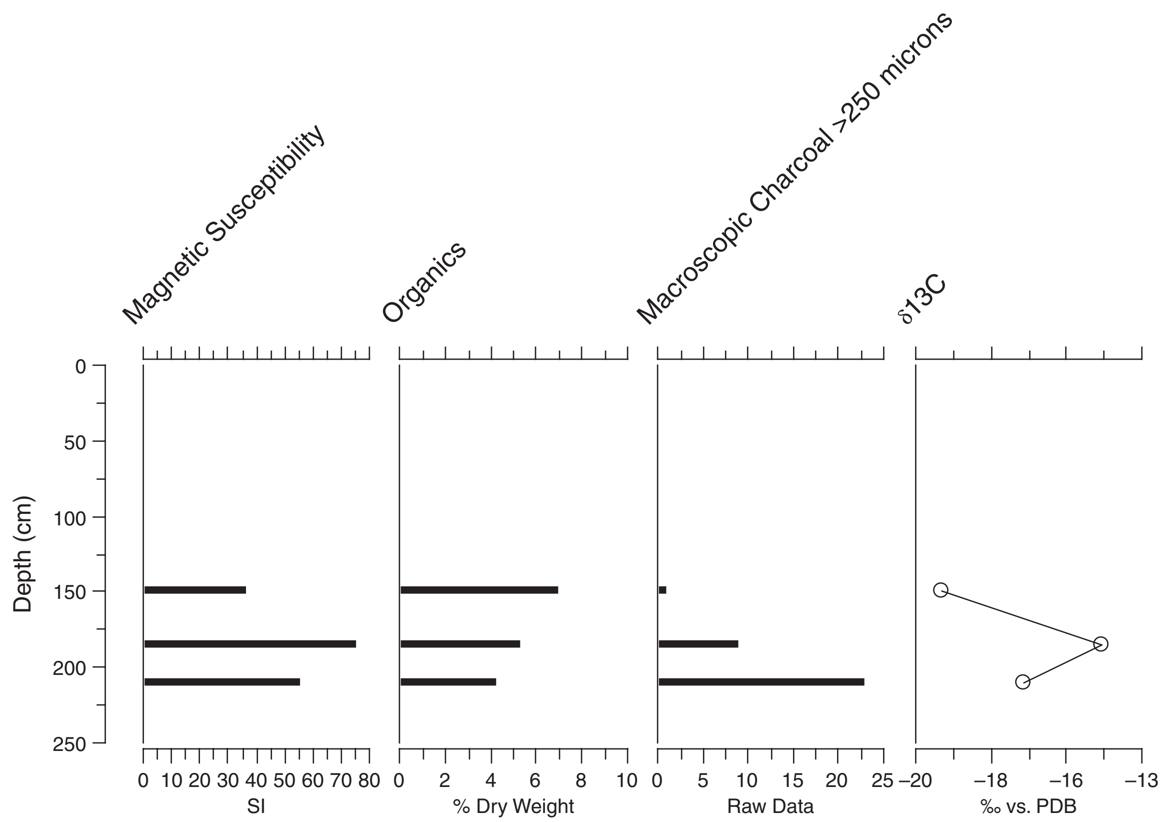

Figure 5. Paleoecological proxy diagram for the Mound 2 Feature at Río Viejo

bay site for a brief ~200 year period (~4700–4430 cal. BP) during the Archaic. Agriculturalists did not return to the region until the Middle Formative when regional forest clearance occurs and pollen of agricultural weeds begin to dominate the record (Goman *et al*., 2010). This is the period of time when the Río Verde's floodplain was expanding (Joyce and Mueller, 1992, 1997) and the coastal bay barriers were forming (Goman *et al*., 2005). The Pastoría pollen record indicates agricultural activity occurred near this lagoon site until the Postclassic when evidence for maize-based agriculture drops out of the record.

The oldest data from the floodplain comes from the site of Cerro del Chivo (Figure 1). The sample dates to 2340 cal. BP, which lies at the transition between the Middle Formative and Late Formative Periods (Table 1). While only a spot sample, the very low macroscopic charcoal amounts are significant as they indicate that there was no major burning occurring near the site at that time. The paleoecological evidence is consistent with settlement pattern data that found no sites from the Middle Formative within a 2 km radius of Cerro del Chivo. Settlement at the Cerro del Chivo site begins sometime in the Late Formative, but was limited to only about 0.1 ha. Likewise, settlement within 2 km of the site also increased during the Late Formative, but was still modest with only 3 ha occupied in the area until the Terminal Formative when settlement at Cerro del Chivo and nearby sites increase significantly.

The earliest evidence for agricultural activity in the floodplain region comes from the site of Loma Reyes. Archeological survey data indicate that the site was occupied beginning in the Late Formative and this is reflected in the macroscopic charcoal record which has high concentrations beginning at this time. Maize was being grown at this time in the floodplain region as the remains of part of a corn cob where found during excavations at Río Viejo (Woodard, 1991). It is however, in the late Terminal Formative and beginning of the Early Classic that we see the most pronounced evidence for maize-based agriculture as the stable carbon isotopes are relatively enriched at this time, suggesting a greater predominance of C4 plants, such as maize and weedy agricultural taxa. The 125 μm macroscopic charcoal fraction indicates that fire was important, most likely reflecting the burning of agricultural fields and scrub in preparation for planting. This corresponds approximately to the major occupation of Loma Reyes since from the Late Formative to the late Terminal Formative a small area (1 ha) around the artificial platform was occupied (Joyce *et al*., 2009). During the Early Classic settlement at Loma Reyes shifted west onto the ridge above the platform; by this time the site had grown to at least 71 ha in size.[2]

Agricultural activity at Loma Reyes declines during the latter part of the Early Classic, as evidenced by the precipitous drop in macroscopic charcoal values after about ~1550 cal. BP and the decrease in $\delta^{13}C$ after *c*. 1500 cal. BP. Microscopic charcoal levels also show a dramatic decline at the same time. These data are somewhat curious. Although settlement at Loma Reyes decreases to 11 ha by the Late Classic (Joyce *et al*., 2009), we should still expect to see significant evidence for agricultural activity and burning from land clearance, cooking, and pottery production. Since macroscopic charcoal and $\delta^{13}C$ again increase in the uppermost two samples from Loma Reyes dating to *c*. 1200–1300 cal. BP, it is possible that the site was largely abandoned during the latter part of the Early Classic and the beginning of the Late Classic. Given the temporal coarseness of our ceramic chronology, we would not have picked up such a settlement change based on pottery recovered at the site.

At Charco Barro the macroscopic charcoal record indicates significant anthropogenic activity about the site throughout the Early Classic. The archeological record for this time period indicates that the polity of Río Viejo abruptly collapsed by ~1620 cal. BP possibly because of regional conflict. The archeological settlement evidence points towards a favoring of the piedmont region over the floodplain at this time. Not surprisingly, archeological sites in the piedmont west and south of Charco Barro grow to the largest size during the Early Classic with one site growing to 20 ha and two others in the 5–10 ha range (Joyce *et al*., 1999). It is likely that people from these communities were burning fields for agriculture in the area around Charco Barro.

The Late Classic (1330–1060 cal. BP) saw a reemergence of Río Viejo as a regional capital and a shift back towards the floodplain as the focus of settlement (Joyce, 2005). Charco Barro provides the only detailed paleoecological record for this period. The macroscopic charcoal indicates that agricultural burning activity near the site was confined to the early part of the Late Classic (peaking for a roughly 100 year period), then showing a steady decline into the Early Postclassic except for a minor peak about 1100 cal. BP. The magnetic susceptibility data indicate an erosive input into the basin in the early Late Classic and a significant curtailment following 1250 cal. BP, perhaps resulting from the rise in settlement on the floodplain at this time. However, the record indicates a strong erosion signal towards the end of the Late Classic which is associated with a minor increase in macroscopic charcoal. Settlement within 2 km of Charco Barro declines by the Late Classic, although the pond was located only 2 km southwest of the western edge of the Late Classic occupation of Río Viejo, which increased from 75 ha during the Early Classic to 250 ha by the Late Classic (Joyce, 2008; Joyce *et al*., 1999). The lowermost two samples from the Mound 2 feature at Río Viejo date to the Late Classic. The enriched stable carbon isotope values and presence of numerous Late Classic pottery sherds are consistent with the increase in population at Río Viejo at this time.

By ~1060 cal. BP the Río Viejo polity again collapsed; this collapse is of comparable timing to other political centers throughout Mesoamerica. This is marked by major changes in settlement patterns and sociopolitical reorganization during the Early Postclassic period. Río Viejo declined in size from 250 to 140 ha (Joyce *et al*., 2001) and there was a cessation in the construction of monumental buildings to house rulers and ruling institutions. The Early Postclassic saw fewer sites than the Late Classic, but on average those sites were larger. There was also a migration of people towards higher piedmont elevations (>60% of the occupational area now occurred in the piedmont). This settlement shift is exemplified by the growth of San Marquitos (Figure 1), located in the piedmont, which increased in size from 7 ha in the Late Classic to over 190 ha by the Early Postclassic (Joyce *et al*., 2001). This trend continued into the Late Postclassic with piedmont settlement increasing to over 90% of the occupational area as defined by the archeological survey (Joyce *et al*., 2004). There was also a shift in occupational focus from the west to the east side of the Río Verde. Settlement in the vicinity of Charco Barro reflects these broader regional trends with only two small sites totaling 0.4 ha present during the Early Postclassic. The area is entirely devoid of settlement during the Late Postclassic.

The local and regional settlement shifts are clearly reflected in the paleoecological proxies at Charco Barro, which is located on the far western edge of the valley and approximately 8 km from San Marquitos. Erosive sediment inputs, as shown by the magnetic susceptibility values, dropped precipitously at the beginning of the Early Postclassic as people moved off the floodplain, and remained low until the end of the Late Postclassic, suggesting land surface stabilization. Concurrently, there is an overall depletion in carbon isotope values at the site reflecting the decline in agricultural activity about the pond. The decline in agricultural activity is also reflected in the fire record as, except for a brief period at the end of the Early Postclassic, the use of fire (presumably for field and shrub clearance) ceased to occur. It would seem that the area near the pond was used briefly for agriculture towards the end of the Early Postclassic but was totally abandoned by the beginning of the Late Postclassic as the settlement focus shifted to the east side of the river and the piedmont.

The spot data from the Mound 2 feature at Río Viejo also reflect this general trend (Figure 5). During the Late Classic (lower two samples) carbon isotope values were enriched at the site indicating a strong C4 source; however, the Postclassic sample shows depleted stable carbon isotope values and an almost complete cessation of macroscopic charcoal inputs. These data are probably reflecting the abandonment of the site of Río Viejo by the Late Postclassic (Joyce *et al*., 2001).

Our understanding of the history of land use for the period following Spanish conquest is restricted to the paleoecological record from Charco Barro (Figure 3). The stable carbon isotope levels show a mixed pattern of relative enrichment and depletion during the Colonial period and the magnetic susceptibility and microscopic charcoal data indicate that there was active erosion and the use of fire in the watershed. One grain of maize pollen was identified towards the end of this period. The macroscopic charcoal record also suggests that there was burning in the immediate proximity of the pond during the Colonial period comparable with Late Classic activity. The most significant land-use change in the Colonial period was the increased importance of cattle (Rodríguez Canto, 1996). In terms of agriculture, maize continued as an important crop for subsistence farmers in the region and cotton became a significant commercial crop. These patterns continued into the nineteenth and early twentieth centuries following Mexican independence.

The data for the most recent period likely reflects the systematic development of fruit orchards within the valley, beginning with coconut plantations in the 1920s, but more recently changing towards lime plantations (Rodríguez Canto, 1996). Initial preparation and clearance of scrub vegetation from the land surface for the plantations would have occurred, and is likely reflected by the significant peak in macroscopic charcoal during this period. The change in land from C4-dominated vegetation to C3-pathway plants is reflected in the stable carbon isotope record with a change towards isotopically lighter values and the decline in sediment erosion as the land surface stabilized with the development of the permanent orchard plots.

Conclusion

Long-term regional paleoecological records are important for discerning broad patterns in environmental and land-use change in Mesoamerica (e.g. Deevey, 1978; Dull, 2007; Goman and Byrne, 1998; Pohl *et al*., 2007). However, human decision making involving land use, subsistence, labor allocation etc. occurs at much finer spatial and temporal scales. Recently, archeologists have called for multiscale approaches that integrate understandings of short-term and local processes with long-term, regional ones (e.g. Fisher and Feinman, 2005; Hill, 2004; Knapp, 2003; McGlade, 1995; Redman, 2005; van der Leeuw, 2005). A multiscaler approach requires paleoenvironmental and archeological data from comparable spatial and temporal scales. The paleoecological data presented here provide a long-term history of agriculture for portions of the western floodplain side of the Río Verde valley and correlate well with our current understanding of changes in demography, land use, and settlement. However, they also represent the first stage of our ongoing paleoecological research within the region. The results from the lower Río Verde's floodplain provide a window into the spatially complex human–land interactions that have occurred through the late Holocene. Current research is focusing towards improving our understanding of finer scale spatial land-use history within the valley as a whole through the expansion our network of paleoecological sites to locations to the south, north and east.

Acknowledgments

We would like to thank Don Thieme and the people of San José del Progesso for their hospitality during our fieldwork. MG would like to thank Christine Nelson, DVM for use of her x-radiography facilities; Dennis Kent and Luca Lanci (Rutgers University) with the collection of magnetic susceptibility for Charco Barro; Robert Dull (University of Texas, Austin) for providing the magnetic susceptibility data for the auger sites; and Bill Watts (Trinity College Dublin) for identifying the *Pistia* seeds. MG would like to thank Sturt Manning for helpful conversations regarding chronology. Paleoecological analysis of these sites was funded in part by NSF BCS-0096012 to AJ and funds from Cornell University and a Grant-in-Aid from the Association of American Geographers to MG. This study was part of a larger interdisciplinary project in the lower Río Verde Valley conducted under the auspices of the Instituto Nacional de Antropología e Historia; we would especially like to thank the president of the Consejo de Arqueología, Joaquín García-Barcena. We thank two anonymous reviewers for their thoughtful comments.

Notes

1. Plastic sample bags were purchased in Mexico and these did not hold the permanent pen used to label the bags. We recommend double labeling, with a label on the bag of the sample, then double bagging with a second label on a different label medium inside the second bag.
2. These estimates are tentative as the site lies on the edge of the current survey zone and so has not been completely surveyed.

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