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Reconstructing the formation and land use history of the Mound 2 depression at Río Viejo, Oaxaca, Mexico

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ABSTRACT

Archaeological and geoarchaeological work in the lower Río Verde Valley, Oaxaca, Mexico reveal a varied spatial relationship between the prehistoric inhabitants and this dynamic floodplain region over the last 3000 years. Significant demographic expansion occurred by the Late Formative period following floodplain aggradation resulting from a change in stream hydrology and morphology. During the Classic and Postclassic periods, major shifts in settlement and land use occurred, primarily from the productive floodplain to the piedmont. The archaeological site of Río Viejo has played a pivotal role in the political and social history of the valley. Archaeological data indicate the site was occupied from the Middle Formative to the Early Postclassic and was an urban center and the political seat of the region during the Terminal Formative and again in the Late Classic. Four large depressions are associated with mounded architecture at the site. We collected paleoenvironmental and geoarchaeological data from the Mound 2 feature. A synthesis of this multi-proxy data has enhanced our understanding of site formation, occupation, and land use from the Late Formative to Postclassic times. The analysis indicates that the depression associated with Mound 2 was originally a borrow pit on the floodplain that was enhanced and augmented by monumental mound building. The area around Mound 2 was the focus of domestic and agricultural use during the Terminal Formative. An apparent cessation of activity around Mound 2 occurred during the Early Classic, which is consistent with a significant contraction in population at the site at this time. Activity resumed at Mound 2 in the Late Classic and continued until at least the Early Postclassic. These changes in occupation history appear to have resulted from political developments within the valley.

1. Introduction

The lower Río Verde valley of Oaxaca, Mexico has a long and complex history of human settlement (Fig. 1). The earliest evidence for permanent occupation dates to the early Formative period (3900–2755 cal B.P.; Hepp, 2011). However, significant increases in the regional population started in the Middle Formative (2755–2350 cal B.P.), at a time when environmental changes in the valley began to take effect. These changes resulted in the development of a rich ecological setting for human settlement (Goman et al., 2005; Joyce, 2010; Mueller et al., 2013). A politically centralized polity developed during the Terminal Formative period (2065–1620 cal B.P.) with its political seat at the site of Río Viejo (Joyce, 2010, 2013; Joyce and Barber, 2011). Archaeological research over the past thirty years has yielded a detailed history of the site's changing significance through time in terms of cultural and societal development until its ultimate abandonment in the Late Postclassic (740–505 cal B.P.).

An unusual set of architectural features at Río Viejo are large, oval depressions associated with architectural platforms (Joyce, 1999a). Four of these features have been identified, although unfortunately two have been disturbed by recent road construction. These depressions are similar to borrow pits also found at the sites of Charco Redondo and San Francisco de Arriba, both sites with substantial monumental architecture (Gillespie, 1987; Workinger, 2002). The largest of these sunken features covers 2 ha and is associated with Mound 2, a multi-use platform that supported both

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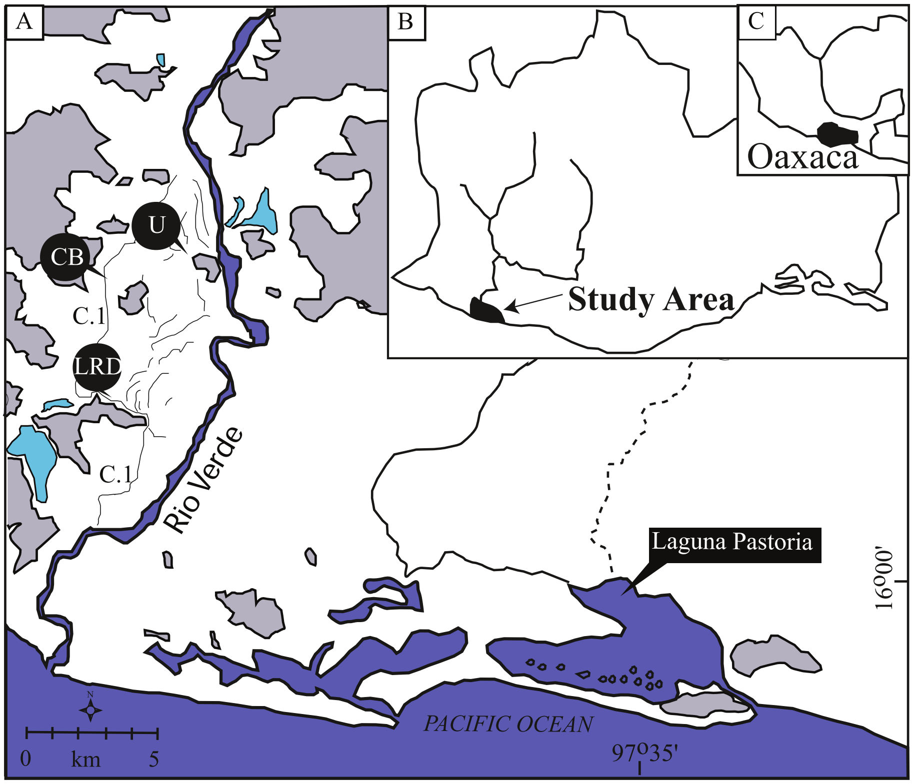

Fig. 1. A. The study region showing paleoecological sites and places mentioned in the text. CB = Charco Barro, LR = Loma Reyes, U = Mound 2 Feature at Río Viejo. Light grey shading reflects terrain above the 20 m contour elevation. The thin lines west of the Río Verde are locations of abandoned channels. C.1 refers to the ancestral meandering channel of the Río Verde (Mueller et al., 2013). B. Shows the state of Oaxaca and the Upper and Lower Río Verde. The Río Verde region is shown in black. C. Indicates the location of Oaxaca (shaded black) in relation to Mexico.

residences and at least one modest public building (Joyce, 1999b). Mound 2 is somewhat unusual because the platform is U-shaped in plan with the depression located between the two arms (Fig. 2).

We present here geoarchaeological and paleoecological data collected to address three questions: 1) What is the origin and depositional environment of the Mound 2 depression, specifically did it act as a year round repository of water or was it only episodically inundated? 2) What is the history of agricultural activity in the vicinity of Mound 2? 3) What is the relationship between cultural and ecological changes at Río Viejo and how are they related to broader regional trends.

2. The lower Río Verde Valley

2.1. Environmental setting

The Río Verde is one of the largest rivers on the Pacific Coast of Mexico in terms both of its overall discharge volume and drainage area (Tamayo, 1964; Alvarez, 2003). The upper drainage encompasses the highland valleys of Oaxaca, Ejutla, and Nochixtlán. It is from these valleys that the river derives the bulk of its suspended sediment load (Joyce and Mueller, 1997; Mueller et al., 2013). Each of the three main tributaries of the Río Verde erode through the Sierra Madre del Sur in narrow canyons. At a river distance of 120 km from the coast the primary canyon is approximately 12 km wide and 1800 m deep. There is commonly an inner canyon that is less than 200 m wide but also 200 m deep. Approximately 20 km from the coastline the Río Verde opens into a broad alluvial plain that is over 1 km wide near the foothills and widens to over 10 km closer to the coast. The river today has a braided form with shallow broad channels and large sand bars. During the summer rainy season, which begins towards the end of May and continues until November, the river overflows its shallow channels and inundates the surrounding low-lying land. Geomorphic analysis of the flood plain deposits and numerous paleo-channels indicates the Río Verde was a meandering river ~5000 years ago (Fig. 1). Soil erosion from the highland valleys is believed to have resulted in floodplain alluviation and a shift in channel form to the current braided condition (Joyce and Mueller, 1997; Mueller et al., 2013). The switch in channel morphology was in place by 2350 cal B.P. (Joyce and Mueller, 1997; Goman et al., 2005; Mueller et al., 2013).

2.2. Archaeological setting

Río Viejo is located in the floodplain of the lower Río Verde just west of the river and 15 km north of the Pacific Ocean. Archaeological evidence for occupation begins in the Middle Formative period at Río Viejo. This site became the major urban center and political seat for the valley during the Terminal Formative and again in the Late Classic (1330–1060 cal B.P.; Joyce, 2008, 2010, 2013; Joyce and Barber, 2011). At its peak, Río Viejo encompassed 250 ha, and included 14 platforms, most of which were residential or multi-use. The largest structure at the site was the acropolis (Mound 1), which was the site's ceremonial center during the late Terminal Formative (1820–1620 cal B.P.). The acropolis was an artificially constructed platform that covered an area of 350 m × 200 m and rose at least 7 m above the floodplain. The platform supported two massive substructures reaching 17 m in height along with a plaza, sunken patio, and numerous smaller buildings (Joyce et al., 2013).

Several large artificial depressions are associated with the platforms at Río Viejo. These features are about 1–2 ha in size and are typically 1 m below the level of the floodplain and as much as 4 m below the associated mounded architecture (Joyce, 1999b; Goman et al., 2010; Joyce and Goman, 2012). It has been assumed that these features are borrow pits, created during the construction

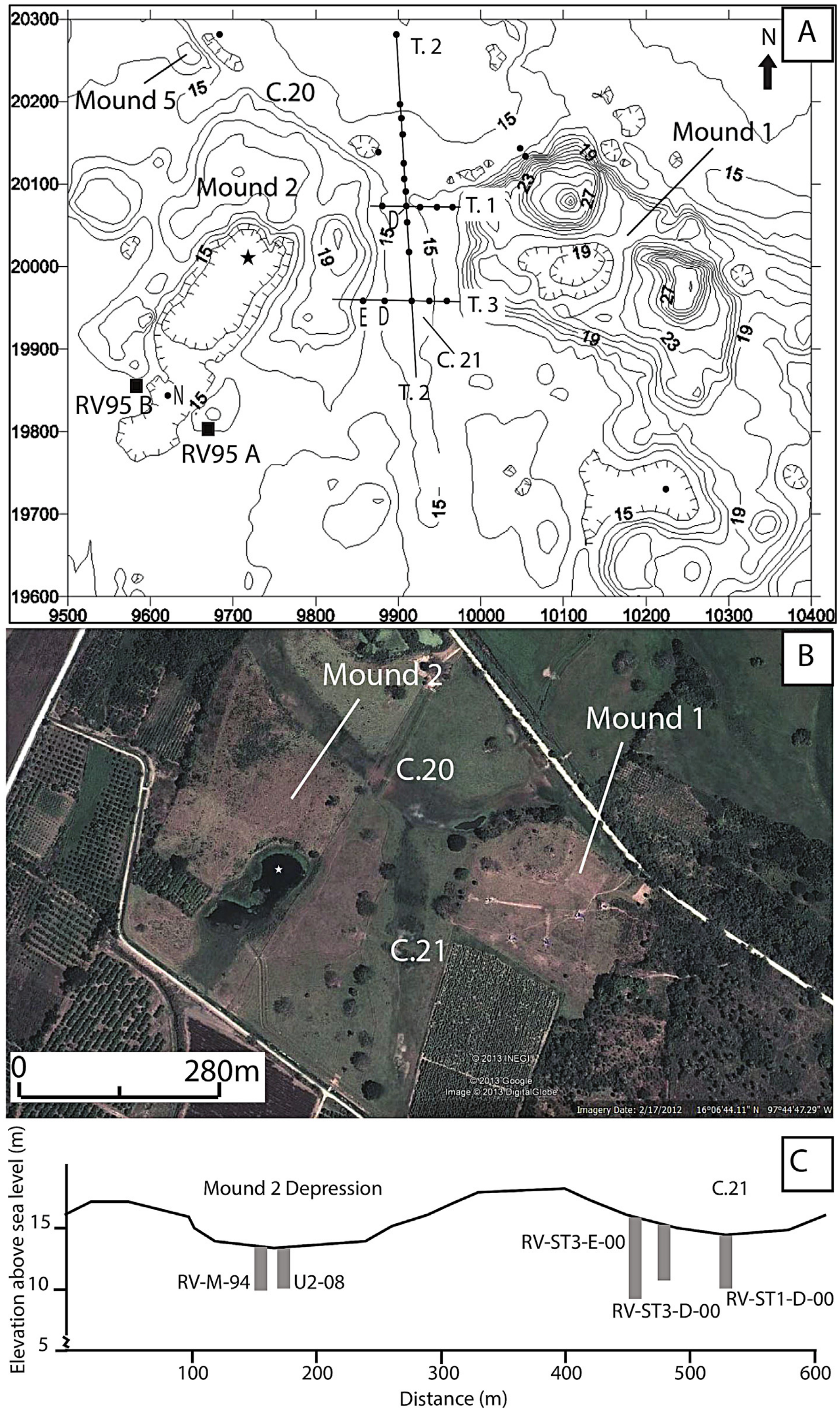

Fig. 2. A. Contour map of the Mound 2 at Rio Viejo (C.20 = Abandoned Channel 20; C.21 = Abandoned Channel 21). Locations of the auger transects undertaken in the 2000 field season are shown as transects T1 (RV-ST1- 00), T2 (RV-ST2- 00), T3 (RV-ST3- 00). Individual auger holes on these transects as well as auger holes 94-N are shown by the appropriate letters and U2-08 and 94-M are indicated by the black star. Black dots represent locations of auger holes not explicitly discussed in the text (for further information see Mueller et al., 2013). Archaeological test pits RV95 A and B are indicated by black squares. B. *Google Earth* image of Mound 1 and Mound 2. Field excavations on Mound 1 are recorded in this image from February 2012. The white star depicts the location of the U2-08 core; notice the site is underwater, which is unusual for this time of year. C. Topographic profile showing projected placement of auger holes onto a line running approximately west to east through the Mound 2 feature and channel C.21 (note: RV-N-94 is not shown). The stratigraphy of the auger sites relative to elevation above sea level is shown in Fig. 3.

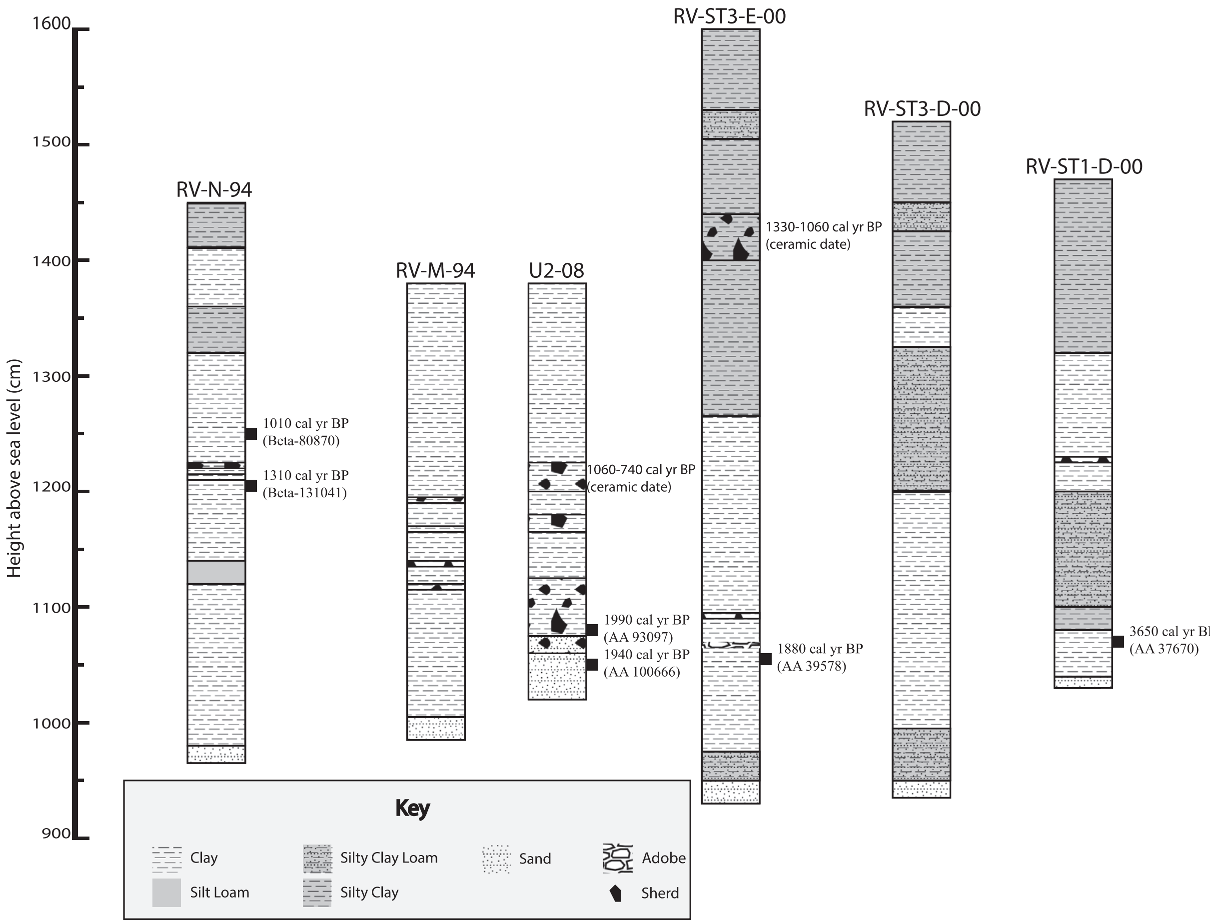

Fig. 3. Lithostratigraphy of pertinent auger holes from the 1994, 2000 and 2008 field seasons. Height in relation to sea level is depicted as is depth below surface. Median calibrated radiocarbon dates are shown; for the full calibrated age range see Table 1 and Fig. 5.

of the mounded platforms; however, it is not clear if these features also served other utilitarian purposes following mound construction. For instance, it has been hypothesized that they may have served as water-control features for aquaculture or specialized agriculture (Joyce, 1999a). The largest of these depressions is the one associated with Mound 2. The depression retains water today well into the dry season. Another large depression can be seen in Mound 8, 100 m south of Mound 1 (Fig. 2).

Several geoarchaeological transects were undertaken during the 1994 and 2000 field season and preliminary paleoecological analysis of 3 auger samples within the depression associated with Mound 2 (Fig. 2) were analyzed for macroscopic charcoal and stable carbon isotopes. Initial findings indicated presence of charcoal along with enriched carbon isotopic values in the lowermost auger samples, indicating the area around the site may have been used for agriculture (Goman et al., 2010). These three samples indicated that it would be beneficial to collect a full sequence of sediment from the feature for further paleoecological analysis, prompting additional sampling in 2008.

3. Methods

3.1. Field methods

During multiple field seasons (Joyce et al., 1998; Joyce, 1999a, 2009; Joyce and Levine, 2009), bucket auger transects were undertaken to determine the approximate age and size of several paleochannels of the Río Verde. Two of these paleochannels (designated C.20 and C.21) were adjacent to Mound 2 and are part of the sample through which we examine the paleoecology of the Mound 2 depression. Previous research has shown that C.21 was abandoned at ca. 3650 cal B.P., while C.20 was abandoned at ca. 670 cal B.P. (Mueller et al., 2013). Fig. 2 shows the placement of discrete auger holes as well as line transects of auger holes across both paleochannels and in the Mound 2 feature (Mueller et al., 1999, 2013; Goman et al., 2010; Joyce and Goman, 2012). Transect 1 (RV-ST1- 00) was aligned at 90° to C.21 and close to the cutbank of C.20. Transect 2 (RV-ST2- 00) was parallel to the axis of the surface expression of C.21. Transect 3 (RV-ST3- 00) was aligned at 90° to C.21 and approximately 100 m to the south of the C.20 intersection. Transects 1 and 3 each had 5 auger drives, while transect 2 had 13 drives. All drives ended either at refusal or more frequently, upon reaching river sands (Mueller et al., 1999, 2013).

Paleoecological samples were collected with a bucket auger during the 2000 (RV-00; Goman et al., 2010) and 2008 field seasons (U2-08) from the Mound 2 depression. The sampling site was located within the base of the “U” formed by Mound 2 (Fig. 2). Lithostratigraphic analysis of the depression was also undertaken in the 1994 field season and these data are also presented here (Mueller et al., 1999; RV-M-94 and RV-N-94 on Fig. 3). In this paper we discuss the paleoecological data from the 2008 field season (the U2-08 auger core); these samples were extracted from and sampled from the central section of the auger head so as to avoid potential contamination. Samples were placed and sealed in labeled plastic bags. The top 55 cm of sediment were not retained due to soil development and recent agricultural activity. The auger drive ended at a depth of 360 cm when wet sands precluded raising further samples. A total of 21 samples were collected that ranged in auger depth from 3 to 37 cm. Beginning at a depth of about 156 cm, pottery sherds became an important component of the sediments brought to the surface.

3.2. Laboratory methods

3.2.1. Initial sample description

Each auger samples was processed for a variety of biological and sedimentary proxies. The general sediment composition was described through texture-by-feel, and by determining Munsell colors; the inorganic, organic and carbonate components were quantified through loss-on-ignition analysis (Heiri et al., 2001). Magnetic susceptibility was measured for each auger sample. Samples of 10 ml were placed in a Bartington Magnetic Susceptibility discrete sampler (MS2B). Three magnetic susceptibility readings were taken per sample and averaged. Magnetic susceptibility assesses the concentration of magnetic minerals within sediments and can be used to determine changes in sediment composition or to infer erosional processes (Nowaczyk, 2001).

3.2.2. Fossil pollen

Each sample was processed for fossil pollen to evaluate floral changes. Extraction followed standard procedures (Faegri and Iversen, 1989) except sodium polytungstate (SPT) heavy liquid extraction was used to float the pollen out of the heavy clay matrix rather than using hydrofluoric acid to digest the clays. We used SPT with a specific density of 1.95. Samples were centrifuged for 10 min at 1800 rpm (Zabenskie et al., 2006). *Lycopodium*, an exotic spore, was introduced to each sample at the beginning of processing (Stockmarr, 1971). Samples were mounted in silicone oil and slides were examined with an Olympus BX51 microscope using 10× and 40× objectives. Pollen concentration was low and despite extensive counting of multiple slides it would have been difficult to reach 100 grains. Therefore, five pollen slides (Horn and Kennedy, 2001) were made per level and each slide scanned for *Zea mays* ssp. *mays* pollen. All *Lycopodium* were counted on every slide examined. *Z. mays* ssp. *mays* was identified based on size measurements, with samples over 70 μm in size categorized as maize (Holst et al., 2007). Many grains were badly crumpled and so accurate measurement was difficult; it is therefore possible that the number of maize grains is underestimated. The maize pollen counts are converted to concentration data following Taylor et al. (2013).

We acknowledge that the grains identified as *Z. mays* ssp. *mays* could be teosinte, as Holst et al. (2007) have shown that there is considerable overlap in the maximum pollen diameter between *Z. mays* ssp. *mays* and teosinte. However, the closest modern teosinte population is that of the Balsas Teosinte (*Z. mays* ssp. *parviglumis*); this plant currently grows at elevations 500–1800 m above sea level and ~400 km from our study site (Doebley, 1990; Matsuoka et al., 2002). While it is possible that the geographic range of the Balsas Teosinte may have encompassed lower elevations and a broader geographic region in the past, current evidence does not suggest this was the case (Matsuoka et al., 2002). Further, *Z. mays* ssp. *mays* is well documented in archaeobotanical samples from the Lower Río Verde region beginning in the Late Formative period and continuing through the remainder of the prehispanic era (Joyce, 1991; Woodard, 1991).

3.2.3. Phytoliths

Opal phytoliths were extracted and analyzed to complement the pollen analysis. Phytoliths were extracted and prepared from 5 g of sediment following standard methodology (Pearsall, 2000). Two portions of each sample were mounted on microscope slides; one with Canada Balsam, which offers a superior mounting medium for counting purposes but can deteriorate over time, and the other with a synthetic acryloid mounting medium for archival purposes. Each slide was scanned for 20 fields at 100× magnification. Diagnostic phytoliths were counted per field, and their relative abundance was calculated as the average number per fields. Non-diagnostic or low-level diagnostic phytoliths are reported qualitatively (e.g., “sparse,” “abundant”; Pearsall, 2000).

3.2.4. Geochemical and isotopic signatures

The carbon isotopic ($\delta^{13}C$) composition of the bulk sediments was determined in order to understand changes in major constituent plant groups through time specifically prehistoric forest clearance and crop cultivation (Lane et al., 2004). Stable carbon isotopic values of $>-18‰$ are associated with maize based agriculture in the Río Verde Valley (Goman et al., 2010). Stable nitrogen isotopes ($\delta^{15}N$) are used to help determine sources of organic material and also productivity. Terrestrial plants have a typical $\delta^{15}N$ value that averages 0.5‰ while most algae have a heavier isotopic value, average 8.5‰ (Meyers, 2003); however, these values can be affected by eutrophication as cyanobacteria directly fix nitrogen from the atmosphere and thus tend to have nitrogen isotopic values similar to terrestrial plants (Gu et al., 1996). C/N ratios provide information on the source of the organic material. Low ratios (4–10) are typically associated with algal sources while ratios higher than 20 are often associated with a strong terrestrial presence (Meyers and Ishiwatar, 1993; Meyers, 2003).

Samples were sieved through a 200 μm mesh and the fine material was acidified with 10% HCl to remove carbonate material. The samples were neutralized, dried for 24 h and finely ground. The finely ground material was then analyzed at the Cornell Isotope Laboratory (COIL) using a Thermo Delta V isotope ratio mass spectrometer interfaced to a NC2500 elemental analyzer. The nitrogen isotopes were standardized to Atmospheric Air, while the carbon isotopes were standardized to the Vienna Pee Dee Belemnite. Note that the stable N isotope analyses were run on the same samples as the carbon isotopic samples (i.e. dual-mode analysis) prior to the results of Brodie et al., (2011a,b). Brodie et al., (2011a,b) show that significant biasing of stable N data can occur with acidification. We therefore consider the overall trend and high amplitude shifts in these data.

3.2.5. Macroscopic charcoal

The local fire history was established by looking at the macroscopic charcoal content of each sediment sample (Goman et al., 2010; Joyce and Goman, 2012). Macroscopic charcoal was extracted from the samples by deflocculating the sediment with sodium hexametaphosphate and sieving through nested sieves of 250 and 125 μm mesh size (Whitlock and Larsen, 2001). Approximately 18 ± 2 g of material was processed for each sample. The samples were examined under a dissecting microscope and charcoal in the different size fractions was tallied. The size fraction <250 to >125 μm is referred to as 125–250 μm. This method was previously successfully used to establish a fire history for a number of sites in the floodplain region of the Río Verde (Goman et al., 2010; Joyce and Goman, 2012). Due to issues with the chronology (see Section 4.2.6), macroscopic charcoal data is presented as charcoal concentration per cm^{-3} rather than particles/cm^2/yr (Whitlock and Larsen, 2001; Goman et al., 2010).

3.2.6. Chronology

Chronology for the 2000 auger lithostratigraphy is based upon diagnostic ceramics from a sherd layer in transect 3 and one AMS radiocarbon date of charcoal as well as previously reported bulk radiocarbon dates (Mueller et al., 2013). A further six samples were submitted for AMS radiocarbon analysis from the U2-08 samples

(Table 1). Four of the samples were of macroscopic charcoal, one a piece of wood and one a charred nutlet which proved to be too small for analysis. All radiocarbon dates were submitted to the NSF-Arizona AMS Laboratory. Pottery fragments were found in numerous auger samples in U2-08. Some of these samples were diagnostic and contributed to the development of our site chronology. The radiocarbon dates were calibrated using IntCal09 (Reimer et al., 2013) through the OxCal 4.2 software program (Bronk Ramsey, 2009). OxCal was also used to construct a rudimentary deposition model for the site.

dominated by clay, although occasional samples were of a sandy silty clay matrix (257–278 cm, 192–201 cm and 156–178 cm below surface). The sample at 192–201 cm had noticeable very fine pieces of shell present as did the one at 156–178 cm. The sample at 156–178 cm was also unusual in that a smoothed gravel-sized river rock was found in the auger drive. The sample at 146–157 cm had pieces of angular rock. Sediment pH values had a very narrow range, clustering around 7.0–7.1.

The magnetic susceptibility readings range from 25 to 127 SI. Basal sediments (360 cm below surface) to a depth of 257 cm returned consistently high readings typically over 100 SI. The readings between 257 and 129 cm typically drop below 40 SI. The remaining samples show a slight increase to readings between 55 and 99 SI (Fig. 4).

Table 1
Radiocarbon data from the auger drives associated with Mound 2 and the depression.

Lab #	Sample/auger ID #	Depth range (cm)	Material	^{14}C Age (BP)	±Error	Calibrated age range (cal yr B.P.)[a]	Median age (cal yr B.P.)	δ^{13}C
Beta-80870	[b]RV94/T3/A4/N8/200 cm	200	Sediment	1120	50	1170–930	1030	Not reported
Beta-131041	[b]RV94/T3/A4/N8/245 cm	245	Sediment	1410	50	1410–1260	1320	Not reported
AA37670	[b]RV00/RV/ST1/D/400 cm	400	Sediment	3401	51	3830–3480	3650	−22.4
AA39578	[b]RV00/RV/ST3/E/545 cm	545	Charcoal	1929	43	1990–1730	1880	−25.4
				U2-08				
AA100663[c]	1	55–68	Charred nut	Insufficient material for analysis				
AA100664[c]	7	146–156	Wood	0.007		Post-bomb		−28.7
AA100665[c]	14	220–257	Charcoal	2810	110	3245–2745	2950	−25.5
AA93097[d]	16	278–289	Charcoal	2037	34	2110–1900	1990	−25.6
AA100666[d]	19	326–341	Charcoal	1988	54	2110–1820	1940	−25.2
AA100667	21	348–360	Charcoal	821	91	930–570	760	−30.8

[a] Radiocarbon dates were calibrated using Reimer et al. (2013) and the Oxcal program (Bronk Ramsey, 2009).
[b] Radiocarbon dates previously reported in Mueller et al., (2013). Note these dates were obtained on bulk samples.
[c] AMS radiocarbon dates.
[d] Used in the construction of the age model for U2-08.

4. Results

4.1. Transect data

Transect 1 lies at 90° to C.21 and roughly parallel to C.20. Radiocarbon dating of organic clays overlying channel sand deposits in both channels shows that C.20 is younger than C.21, by about 3000 years (Mueller et al., 2013; Fig. 2). The stratigraphy of transect 1 auger hole E (the western-most auger drive) displayed the impacts of slope wash from Mound 2 feature (data not shown). Transect 2 lies parallel to the axis of the surface expression of C.21. The low-energy depositional sediments in this channel average about 3 m in thickness. The channel is about 125 m wide but this could not be precisely determined as the western section of the channel disappears beneath the construction material for Mound 2 (Mueller et al., 2013; Fig. 2). Transect 3 lies at 90° to transect 2 and approximately 100 m south of the C.20 intersection.

Transect 3 auger hole D was placed at the eastern base of Mound 2 at an elevation of 15.2 m above sea level (a.s.l.) (Fig. 3). Heavy, dense clay was collected from 320 to 525 cm below the surface. Transect 3 auger hole E was located approximately a third of the way up the side slope of Mound 2; here the elevation was 16 m a.s.l. (Fig. 3). The stratigraphy of this auger hole is complex. A dense ceramic sherd layer occurred between 160 and 200 cm below the surface. A sherd from this depth was identified as Late Classic. Below this was heavy gray clay until 625 cm below the surface. Additional sherds were found at 505 cm and adobe at 530 cm. At about 625 cm the sediments changed to fine sandy clay loam and at 650 cm, channel sands were encountered.

4.2. Paleoecological data U2-08

4.2.1. Magnetic susceptibility, pH, texture and organic composition

The U2-08 auger site is located in the Mound 2-depression at a height of 13.8 m a.s.l. (Fig. 3). Sediment between 304 and 360 cm below surface was sand. The samples above 304 cm were

The percent organic composition of all 21 samples is low with values ranging from 1 to 8%. The auger samples from 156 to 360 cm depth typically comprise about 4–5% organic by dry weight, although there is a slight dip between 220 and 260 cm. From a depth of 156 cm–55 cm percent organic composition is relatively high (6–8%). These values are comparable to percent organics present in oxbow and paleomeander sites within the lower Río Verde Valley (Goman et al., 2010). The percent carbonate averaged 2%, although one sample (from 257 to 278 cm below surface) had very high carbonate content at 9% (Fig. 4).

4.2.2. Macroscopic charcoal

Macroscopic charcoal 125–250 μm in size was prevalent below 146 cm depth with most counts exceeding 100 pieces or +12 fragments/cm^3, and with a maximum of 896 pieces (107 fragments/cm^3) in the sample from 146 to 156 cm depth (Fig. 4). Large counts of macroscopic charcoal in the >250 μm occurred within auger samples between 304 and 279 cm with counts above 100 pieces or +12 fragments/cm^3. The maximum amount of >250 μm charcoal occurred in the sample collected from 257 to 278 cm depth with 467 pieces (56 fragments/cm^3). Unlike for the 125–250 μm size range, charcoal counts in the 250 μm range are low in samples from 220 to 156 cm depth. Both macroscopic charcoal size ranges (125–250 and >250 μm) are very low (total <40 or <5 fragments/cm^3) in the sample at 220–257 cm below surface, and depths above 146 cm also show very low counts for both sample sizes (Fig. 4).

4.2.3. Geochemical and isotopic signatures

The δ^{13}C ranged from −10.5 to −23.4‰ (Fig. 4). There are three clear phases of enriched δ^{13}C, with values from −19 and −10‰. The first phase occurs in the lowermost section of the profile from depths of 360 to 257 cm, samples are consistently enriched through this section. Between depths of 257 and 201 cm, the sediments are markedly depleted with values from −23.35 to −20.52‰. Samples are enriched between depths of 201 and 79 cm below surface (−10.52 to −17.11‰) except between 129 and 146 cm where one auger sample returned a fairly depleted result of −23.34‰. The two near surface samples (55–79 cm) also returned depleted values of −21.14 and −22.92‰. The C/N ratios show a similar pattern to carbon isotopes with most values greater than 20. Particularly low C/N ratios are found between 201 and 257 cm below surface (Fig. 4). The δ^{15}N averages 5.37‰ ± 0.8 (Fig. 4).

4.2.4. Phytolith and pollen data

Phytolith density was moderate (5–10 phytoliths per field) to very high (up to fifty phytoliths per field) in the samples processed. Six major types of phytoliths were identified (the majority of which were of low diagnostic value) whose origin ranged from grasses (including maize) to broadleaf shrubs and trees (Table 2); *Z. mays* c.f. *mays* pollen was found in 5 auger levels all below a depth of 209 cm (Fig. 4). The grains that were identified were often highly crumpled. The calculated concentration of maize grains per sample ranges from 5 to 176 grains/cm^3 (Fig. 4).

Table 2
Phytolith results.

Sample U2-08	Depth (cm)	Phytolith density	Low level diagnostics	Grass totals	Interpretation
1	55–68	High	Abundant scale and globules characteristic of broadleaf vegetation	4	Somewhat open, broadleaf shrubs with sparse grasses Interspersed, including chloridoid grasses
3	79–98	High	Abundant scale and globules characteristic of broadleaf vegetation	9	More open, grasses and broadleaf shrubs
4	98–112	High	Abundant scale and globules characteristic of broadleaf vegetation	14	More open, grasses and broadleaf shrubs
5	112–129	Very high	Moderate scale and globules characteristic of broadleaf vegetation	64	Open with grasses Interspersed with broadleaf shrubs, including panicoid grasses (possibly maize)
7	146–156	High	Abundant scale and globules characteristic of broadleaf vegetation	6	Somewhat open broadleaf shrubs with grasses Interspersed
8a	156–178	High	Abundant scale and globules characteristic of broadleaf vegetation	6	Somewhat open broadleaf shrubs with grasses Interspersed
9	178–192	Moderate	Sparse scale and globules characteristic of broadleaf vegetation	17	Open with grasses interspersed with broadleaf shrubs
10	192–201	High	Abundant scale and globules characteristic of broadleaf vegetation	13	Open grasses Interspersed with broadleaf shrubs
11	201–204	Moderate	Moderate scale and globules characteristic of broadleaf vegetation	0	Closed broadleaf shrubs and trees
12	204–214	Moderate	Moderate scale and globules characteristic of broadleaf vegetation	23	Open grasses Interspersed with broadleaf shrubs
13	214–222	Moderate	Moderate scale and globules characteristic of broadleaf vegetation	3	Closed broadleaf shrubs and trees
14	220–257	Moderate	Moderate scale and globules characteristic of broadleaf vegetation	1	Closed broadleaf shrubs and trees with sparse grasses
15	257–278	Moderate	Moderate scale and globules characteristic of broadleaf vegetation	1	Closed broadleaf shrubs and trees with sparse grasses
16	278–289	Sparse	Light scale and globules characteristic of broadleaf vegetation	18	Open grasses Interspersed with broadleaf shrubs
17	289–304	Sparse	Light scale and globules characteristic of broadleaf vegetation	14	Open grasses Interspersed with broadleaf shrubs
18	304–326	High	Moderate scale and globules characteristic of broadleaf vegetation	20	Open grasses Interspersed with broadleaf shrubs
19	326–341	High	Moderate scale and globules characteristic of broadleaf vegetation	21	Open grasses Interspersed with broadleaf shrubs
20	341–348	High	Moderate scale and globules characteristic of broadleaf vegetation	17	Open grasses Interspersed with broadleaf shrubs
21	348–360	High	Moderate scale and globules characteristic of broadleaf vegetation	15	Open grasses Interspersed with broadleaf shrubs

4.2.5. Ceramics

A total of 42 ceramic sherds was recovered from 7 of the 21 auger samples (Fig. 4). The majority are coarse brownware sherds (typically Munsell 10YR4/4, 10YR5/4 and 10YR6/4) with coarse to very coarse inclusions. There were, however, some fine-paste grayware sherds (Munsell 2.5Y5/1 and 2.5Y6/1). Most of the ceramics were not diagnostic and were badly corroded. There is a clear pattern of deposition within the ceramic stratigraphy. The first sherds were found in low numbers in the auger drives between 257 and 320 cm depth, with quantities ranging from 1 to 4 per drive; none of these pieces were clearly diagnostic but were likely Terminal Formative in age based on paste and incised decorations. Ceramics were absent between 214 and 257 cm in depth but then were abundant between depths of 201 and 214 cm (3–17 pieces) and then from depths of 156–178 cm (13 pieces). The material above 214 cm is likely primarily Classic in age based on paste and incising characteristics. Sherd sample U2-8a-1, from 156 to 178 cm, is about 3 × 4 cm in size and is differentially fired. Differentially fired ceramics are found only during the Early Postclassic (1060–740 cal yr B.P.) in this region (Joyce et al., 2001) and this sherd represents the only one from this period within the auger drive.

4.2.6. Chronology

Table 1 details the AMS radiocarbon results and Fig. 5 shows the depth to age results for U2-08. There are significant age reversals within the samples dated; however, the ceramics found in the auger drives are useful in constructing a chronology of deposition at the site. We believe the reversals in radiocarbon ages are in part a function of younger material inadvertently becoming incorporated into the older matrix during the auger drives (AA100664 and AA100667) and also due to the site's geomorphic history (AA100665) with older material from archaeological contexts

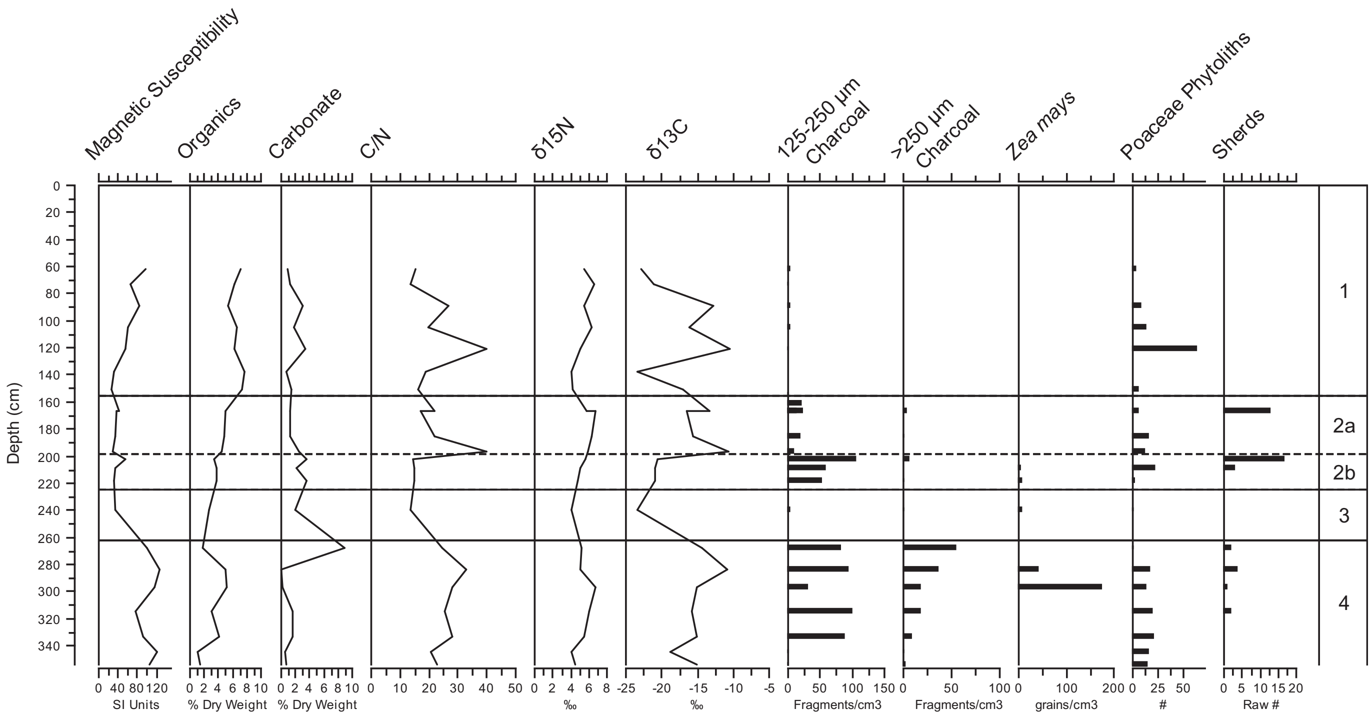

Fig. 4. Geochemical, isotopic and paleoecological proxy indicators of agriculture for U2-08.

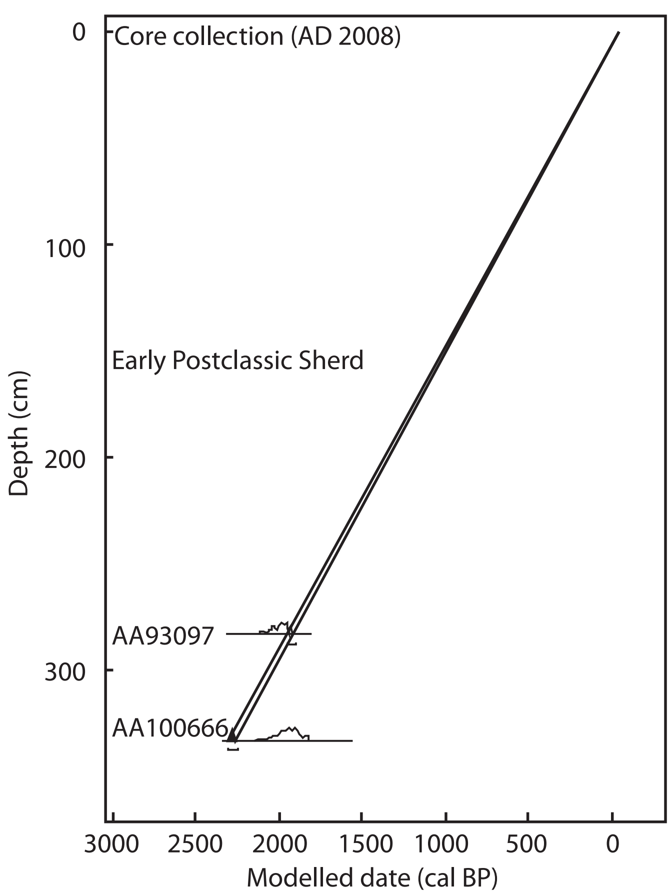

Fig. 5. Depth to age model for U2-08; see Table 1 for further details on the radiocarbon ages used in the model (Bronk Ramsey, 2009; Reimer et al., 2013). One piece of diagnostic ceramic provided a *terminus post quem* age.

incorporated into younger sediment through erosion. Samples AA93097 and AA100666 are used in the construction of our chronology as well as the Early Postclassic differentially fired sherd from sample 8 (156–178 cm depth). This piece of ceramic provides a *terminus post quem* (earliest possible) date within the age model. Due to the complications with the radiocarbon ages, a rudimentary age model was developed and was used to place the data within archaeological periods. However, precise assignments of ages within the different zones of the record are not possible, given the assumptions in constructing the age model.

5. Interpretation

5.1. Site formation

Mound 2 at Río Viejo was a U-shaped platform measuring approximately 380 m × 250 m and reaching an elevation of 4 m above the floodplain (Joyce, 1999b). The arms of the U-shaped platform extend to the southwest with the artificial depression between the arms. Surface survey and excavations indicate that it was a multi-use platform used primarily for residences, although supporting at least one possible public building (Workinger and Joyce, 1999). The excavations consisted of 1 m × 1 m units that penetrated through construction fill into the underlying deposits at the southern end of each arm of the U-shaped platform. Excavation data indicate that this part of the platform was raised during the Late Classic and probably the Early Postclassic periods using basketloads of floodplain sediment as construction fill. As discussed below, the auger core data suggest that the main part of the mound to the north of the excavations may have been raised as early as the Terminal Formative.

The geoarchaeological and paleoecological findings suggest that the prehispanic inhabitants of Río Viejo constructed the Mound 2 platform around a borrow pit. The data collected from the auger transects indicate that channel C.21 was abandoned at approximately 3650 cal B.P. (Mueller et al., 2013; Figs. 2 and 3) and reflects

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the ancestral meandering form of the Río Verde (Joyce and Mueller, 1992, 1997). It is possible that the original width of C.21 and associated floodplain extended to the west below what is now the eastern arm of Mound 2 (Fig. 2). The stratigraphic and radiocarbon data derived from Transect 3 auger holes D and E and U2-08 indicate that a large borrow pit was excavated to the west of and possibly cut into C.21 approximately 2000 years ago. The presence of a borrow pit is indicated by the relative chronologies of these auger cores. Transect 3 auger hole D yielded a radiocarbon age of 3650 cal B.P. for clay deposits overlying channel sands in the middle of C.21. To the west, clays at comparable elevations in Transect 3 auger hole E and U2-08 yielded radiocarbon ages approximately 1700 years younger. The data suggest that in the depression, as well as in the area later covered by the eastern arm of Mound 2, earlier deposits were removed during the digging of the borrow pit. The pit then became a location of quiet water deposition, until at the location of Transect 3 auger hole E it was covered with construction fill used to raise the topographic elevation of the eastern arm of Mound 2. The borrow pit likely provided construction material for Mound 1 and Mound 2. Joyce et al. (2013) estimated that the acropolis (i.e., Mound 1) alone required a minimum 560,050 m^3 of material for its construction, most of which was completed during the late Terminal Formative. Based on the modern dimensions of the depression as well as its depth below the floodplain we estimate that approximately 45,000 m^3 of sediment were removed, although this must be considered a rough estimate, given that we do not know the original dimensions or depth of the borrow pit.

The geochemical and isotopic data from the U2-08 auger are somewhat conflicting; the C/N ratio suggesting a terrestrial source while the $\delta^{15}N$ suggests an algal component (Meyers, 2003; Taylor, 2011). These contrary results are possibly the result of sample acidification during initial preparation (Brodie et al., 2011a,b). Given these caveats and that the $\delta^{15}N$ signal is fairly uniform, we interpret the isotopic data as indicating a seasonal quiet water depositional environment. The borrow pit likely filled with water during the seasonal rains and floods but with waters declining during the dry season. The depth of the water during the rainy season may have been sufficient to provide fish habitat, although oxygen levels may have been too low for most species. The Mound 2 depression would have remained moist during the dry season and coupled with the yearly inundation may have resulted in an important influx of nutrients; thus providing an excellent medium for growing maize or other crops. The depression would also have been closer to the water table resulting in higher soil humidity then on the floodplain generally. It is not clear if the arms of Mound 2 were purposefully constructed to ensure the trapping of water during the rainy season.

This hypothesis is supported by our own observations in the floodplain in the 1980s (prior to the construction of a dam project that raised the valley's water table). We observed subsistence farmers growing crops in the abandoned channels of the Río Verde during the dry season. It is possible that the Mound 2 depression acted in the same way, as both it and the abandoned channels would have been closer to the water table and thus experience greater soil humidity during the dry season.

Thus during the prehispanic era, the Mound 2 depression appears to have filled with water during the rainy season to a greater depth than in the present day. It gradually shallowed through time to the present condition, which typically only experiences shallow surface pooling during the rainy season (Fig. 2).

The test excavations in the southern ends of the arms of Mound 2 indicate initial platform construction during the Late Classic, which was enhanced during the Early Postclassic (Workinger and Joyce, 1999). The magnetic susceptibility data from the U2-08 auger core in the depression, however, suggest an earlier construction date for the main part of Mound 2 located north of the archaeological excavations (Fig. 4). The magnetic susceptibility readings are relatively high at the base of the auger profile with values typically above 100 SI. This is not unexpected as the sediment is dominated by sands. However, above this level, clays dominate. The section between 304 and 257 cm continues to have high magnetic values. This is the time frame that coincides with the late Terminal Formative to onset of the Early Classic. Significantly, the magnetic susceptibility data are relative low (typically below 40 SI) within the clay rich sediments that date to the Early Classic through to the Late Postclassic. This strongly suggests a stable soil surface on Mound 2 and its associated arms and thus minimal erosion into the Mound 2 depression. If the earthen mound and attached arms were constructed or even significantly enhanced during this time, we might expect much higher magnetic susceptibility levels due to the movement of unvegetated and hence highly erodable fill material into the depression. For comparison at the pond site of Charco Barro in the floodplain west of Río Viejo, high magnetic susceptibility readings of >100 SI occur during the Early and Late Classic and Colonial period reflecting land use changes in the region, while samples from recent historic times present low readings of about 40 SI (Goman et al., 2010). The magnetic susceptibility record from the Mound 2 depression thus suggests that major construction of the mound likely occurred during late Terminal Formative times and that no major construction phases occurred later in the site's history.

5.2. Land use reconstruction

The lowest meter of sediment at U2-08 (260–360 cm below surface) is broadly coeval with the early and late Terminal Formative periods. During this time frame, macroscopic charcoal concentrations are very high, indicating significant levels of burning were occurring nearby (see Fig. 4 zone 4). The phytolith data indicate that the vegetation consisted of open grasses interspersed with broadleaf shrubs (Table 2). The carbon isotopic levels are enriched during this period indicating that maize was likely being grown in the direct vicinity of the Mound 2 depression. This finding is supported by the identification of *Z. mays* c.f. *mays* pollen in the upper section of this zone at very high concentrations. Pottery sherds are present throughout the later part of this zone and are tentatively identified as Terminal Formative in age. This finding is complemented by archaeological excavation of domestic remains from two test pits in the southwest part of Mound 2 (Workinger and Joyce, 1999). The unit excavated in the end of the eastern arm of Mound 2 (Operation RV95 A) showed that this area was the focus of domestic activities during the early Terminal Formative period (2065–1820 cal B.P.). The excavation exposed a sequence of house floors and hearths separated by thin resurfacing levels probably designed to raise the occupational surfaces above the level of rainy season floods. Periodic flooding was demonstrated by natural alluvial deposits occurring throughout the early Terminal Formative occupation. The penultimate occupational level of the early Terminal Formative included a burial (Río Viejo Burial 20) consisting of an adult male interred with a greenstone pendant in his mouth and a shell ornament as offerings, which is consistent with low-status domestic interments for this period (Barber et al., 2013:112–116). The excavation in the western arm of Mound 2 (Operation RV95 b) also exposed Terminal Formative domestic remains on the floodplain, including a burial dating to the late Terminal Formative or the very beginning of the Early Classic. The burial included an adult female and the disarticulated remains of another individual, possibly a secondary interment. No offerings were found with the interment. The Terminal Formative occupation was buried by alluvial deposits prior to the construction of Mound 2 in this area during the Late Classic. West of Mound 2, additional test excavations and surface survey also demonstrate the presence of domestic occupations beginning in the Terminal Formative (Workinger and Joyce, 1999).

These findings support and enhance our understanding of the early occupational history of Río Viejo and the floodplain in general. Paleoecological data suggest that incipient agriculture and land clearance was occurring near the coastal zone approximately 4800 cal B.P. during the Late Archaic period, followed by an apparent hiatus until the Middle Formative (Goman et al., 2013). Direct evidence for maize based agriculture does not occur in the region until the Late Formative. Thousands of fragments of charred maize have been recovered from cultural levels (primarily middens) dated by associated ceramics and radiocarbon to this period at the sites of Río Viejo and Cerro de la Cruz (Woodard, 1991; paleobotanical analyses of the few Middle Formative contexts that have been excavated are pending). Further, macroscopic charcoal data from the more southerly floodplain site of Loma Reyes indicate that burning was used to clear agricultural fields (Fig. 1; Goman et al., 2010). The amount of charcoal in both size ranges (125–250 μm and >250 μm) is comparable to that determined at the Mound 2 depression site.

Significantly, the amount of charcoal present in the auger site at U2-08 drops to negligible amounts (zone 3) following the Terminal Formative period peaks, and ceramic sherds are absent. The carbon isotopic signature also plummets to the least enriched levels in the whole record (Fig. 4). These proxies indicate that agriculture and also occupation of the immediate vicinity of the site was diminished. The phytolith data characterize the vegetation as closed broadleaf shrubs and trees with sparse grasses present (Table 2), although the presence of a maize pollen grain indicates that limited agricultural activity was occurring in the vicinity of Mound 2. However, this compares well with our understanding of the site history of Río Viejo which declined in occupational area from 200 ha to 75 ha during the Early Classic (Joyce, 2010). In particular, the acropolis, which was associated with the political elite and attempts to centralize power over the region, was abandoned at the end of the Terminal Formative (Joyce, 2010; Joyce and Barber, 2011; Joyce et al., 2013). The abandonment of the acropolis was part of a broader political collapse that signified a failure by Río Viejo's rulers to institutionalize their authority and possibly the result of conflict with the powerful Central Mexican polity of Teotihuacan (Joyce, 2003, 2008, 2010, 2013; Barber and Joyce, 2007; Joyce and Barber, 2011). The data from the Mound 2 depression is important as it suggests that activity around the structure was also curtailed at this time, concurrent with the overall decline in population at the site.

The evidence for the collapse of the Río Viejo polity is found elsewhere in the paleoecological record of the Río Verde floodplain. To the south at Loma Reyes a similar decline in occupation indicators, particularly macroscopic charcoal, were identified during the Early Classic (Goman et al., 2010). The archaeological settlement data indicate a movement up into the more elevated piedmont region at this time, possibly suggesting regional conflict was occurring and that more easily defended sites were favored for settlement (Joyce, 2003, 2008, 2010; Goman et al., 2010).

Previous studies at the Mound 2 depression (Goman et al., 2010) indicated that the Late Classic likely saw an increase in agricultural activity as well as occupation given the presence of Late Classic sherds in the auger drives. The data from the samples analyzed in the current study confirm this finding. Further, the data derived from U2-08 indicate that following the Early Classic period decline in agriculture and possible abandonment of Mound 2, this area was once again the focus of agricultural activity during the Late Classic. The Late Classic section of the record is subdivided into two zones. The lower zone (Zone 2b) is characterized by a significant rebound in macroscopic charcoal levels from their near absence during the Early Classic and a carbon isotopic signature that gradually becomes more enriched. The pollen record indicates that *Z. mays* cf. *mays* was grown during this time frame. However, the phytoliths from this zone portray a landscape that is dominated by closed broadleaf shrubs and trees and with sparse grasses. This data suggests that the area was not densely populated and that trees and shrubs were either able to persist during the agricultural phases or there was sufficient time between field use and abandonment for them to regrow.

However, in Zone 2a the carbon isotopic signature abruptly rises, suggesting a significant change in vegetation; indeed these samples are much more enriched than material from the same time frame at Charco Barro (Fig. 1; Goman et al., 2010). The macroscopic charcoal is consistently high in zone 2a but not as high as zone 2b or in the earlier zone 4. This, along with the phytolith data, which indicate a much more open landscape dominated by grasses and interspersed broadleaf shrubs (Table 2), suggests that agricultural activity was a significant component of the landscape near the Mound 2 depression at this time. We suggest that there was an intensification of land use for agriculture towards the later part of the Late Classic, which is consistent with archaeological data indicating that the site reached its maximum extent and population at this time (Joyce, 2010). Sherds are found within the sediment matrix indicating that Mound 2 was likely once again occupied. The chronology from U2-08 precludes more precise estimates of when the intensification occurred. However, the archaeological record depicts Río Viejo as experiencing significant growth in the Late Classic with the site occupying 250 ha that represents more than a threefold increase from the Early Classic (Joyce, 2008, 2010). During the Late Classic, Río Viejo reemerged as the regional political seat, and settlement throughout the lower Río Verde Valley returned to the floodplain.

Río Viejo's reemergence as the political focus of the valley lasted less than 300 years. By 1060 cal B.P. the Río Viejo polity collapsed, with Early Postclassic settlement at the site declining by nearly half and regional settlement shifting back into the piedmont. The paleoecological data from the Mound 2 depression reinforces the archaeological data at Río Viejo. Most dramatically, the macroscopic charcoal in zone 1, in both size categories, drops to very low amounts, indicating that burning was not being used for vegetation clearance and points towards a decline in agricultural activity. The overall decline in agricultural indicators during the Postclassic is seen at Charco Barro and in the coastal region at Laguna Pastoría (Fig. 1; Goman et al., 2010, 2013).

However, the decline in charcoal also signals the complete abandonment of Río Viejo by the end of the Early Postclassic, although the limits of the chronology preclude a more precise age extrapolation. Following the Early Postclassic, there may have been sporadic clearance and possibly cultivation occurring near Mound 2. It is also possible that there was a shift in the dominant vegetation type such that a more open landscape prevailed despite the absence of landscape clearance by people. The phytolith data suggest a landscape that was more open and included chloridoid, as well as panicoid grasses, which are also a C4 grass-type and thus would return an isotopically enriched signature similar to panicoid grasses such as maize. This shift in dominant vegetation could be reflective of a drier climate and declining water table. Elsewhere in Mesoamerica, significant demographic collapses, particularly in the Maya Lowlands, are associated with climate change at the end of the Classic (e.g. Haug et al., 2003; Hodell et al., 1995, 2005; Masson, 2012; Medina-Elizalde and Rohling, 2012; Turner and Sabloff, 2012). However, our previous and ongoing paleoecological studies have found no evidence for climate change within the valley, and so we prefer a socio-political cause to explain the marked shifts in

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settlement between the floodplain and piedmont regions (Joyce and Goman, 2012). The collapse of ruling institutions at Río Viejo was part of the Classic-period collapse seen throughout Mesoamerica (E.g., Diehl and Berlo, 1989; Webster, 2002). Although the causes of the collapse are debated, they include warfare, the disruption of trade and alliance networks, environmental change, and social unrest. While the causes of the collapse of the Río Viejo polity are unclear, factors such as internal unrest, warfare, and the disruption of interregional interaction networks are suggested by the data (Joyce et al., 2001; Joyce, 2010).

6. Conclusions

The geoarchaeological and paleoecological data obtained from Mound 2 and its associated depression have been critical in developing our understanding of the timing of the feature's construction, occupation, and the region's agriculture history through time. Land use changes inferred from the U2-08 core data are consistent with patterns of settlement, demography, and political organization based on regional archaeological data. The geoarchaeological data are consistent with the initial mining of the borrow pit during the Terminal Formative concurrent with the construction of the massive acropolis at Mound 1 to the east, the raising of residential and multi-use platforms to the west, and perhaps the initial construction of Mound 2 itself. The paleoecological data demonstrate that the area around Mound 2 was cleared and used for maize agriculture during the Terminal Formative, which is consistent with archaeological survey and excavation data indicating that this part of the site was largely residential. The evidence suggests that people were farming in close proximity to their houses in house gardens or infield settings. Charcoal concentrations and the carbon isotope signal indicate that during the Early Classic the area around Mound 2 was not as intensively occupied or farmed as it had been during the Terminal Formative. These data are consistent with regional archaeological evidence showing that the Río Viejo polity collapsed at ca. 1620 cal yr B.P. and population at the site declined significantly. By the Late Classic Río Viejo had reemerged as the regional political seat and settlement at the site reached its maximum extent of 250 ha. The U2-08 data suggest that the political and demographic reemergence of Río Viejo, however, may have occurred gradually through this period. Deposits pertaining to the early part of the Late Classic suggest an increase in farming in this area, although of lesser intensity then indicated for the latter part of the Late Classic when permanent land clearance and more intensive land use are indicated. A dramatic decline in evidence of farming occurs during the Early Postclassic consistent with the collapse once again of the Río Viejo polity and population decline at the site. Río Viejo was completely abandoned by the beginning of the Late Postclassic, although the phytolith data suggest some sporadic farming at this time. Overall, the data from the Mound 2 depression enhance our understanding of the relationship between vegetation, land use, demography, settlement, and political organization in the lower Río Verde Valley.

Several questions still remain, however. Significantly, whether or not the depression had a secondary purpose following its excavation for mound construction material remains elusive. The placement and construction of the arms that enclosed the borrow pit suggests a functional purpose, but the paleoecological data thus far do not provide unequivocal insights. It is likely that they represent an effort to raise the level of residential structures above potential seasonal flood waters. The construction of the mounds arms may have also been designed to purposefully trap seasonal flood waters. These flood waters would have a twofold impact on food resources: 1) possibly providing fish habitat during the rainy season and 2) securing an influx of nutrient rich sediments thus "fertilizing" the borrow pit surface. This resulted in the development of nutrient rich moist soils for farming during the dry season. This remains speculative and warrants further analysis and consideration.

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