Prehispanic human ecology of the Río Verde drainage basin, Mexico

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Abstract

This article discusses the results of ten years of interdisciplinary archaeological research along the Río Verde drainage basin, Oaxaca, Mexico. In the highland valleys of the upper drainage basin we have documented six periods of significant geomorphic change. The first two were probably the result of climatic change during the mid-Holocene. The four subsequent periods of landscape change are correlated with major shifts in demographics and human land use; we argue that these factors may be causally related. Erosion in the highland valleys led to modification of stream channel dynamics, alluviation and expansion of the agriculturally rich floodplain in the lower Río Verde Valley. Increasing agricultural productivity in the lowlands may explain in part the rapid increase in population and social complexity beginning in the Late Formative. However, increased flooding also created risks for people living on the floodplain. The research demonstrates the dynamic nature of prehispanic ecology in the Río Verde drainage basin of Oaxaca.

Keywords

Mesoamerican archaeology; human ecology; geoarchaeology; human impact; Pre-Columbian agriculture; erosion.

Introduction

Over the past thirty years Mesoamerican archaeology has witnessed an increase in interdisciplinary research examining prehispanic human ecology. This work initially focused on problems of subsistence, settlement and land use (e.g. Coe and Flannery 1964; Flannery 1982; Harrison and Turner 1978). In recent years the focus of research has shifted towards an interest in the ecological impact of prehispanic agriculture (Abrams and Rue 1996; Deevey et al. 1979; Metcalfe et al. 1989; Rue 1987). However, paleoecological research in Mesoamerica has been hampered by a relative scarcity of paleoenvironmental data (Brown 1985). Oaxaca, in particular, has yielded little data on paleoenvironments despite years of ecologically oriented research (e.g. Flannery 1976, 1986). Until recently, this lack of data forced Oaxacan archaeologists to assume that geomorphic and climatic

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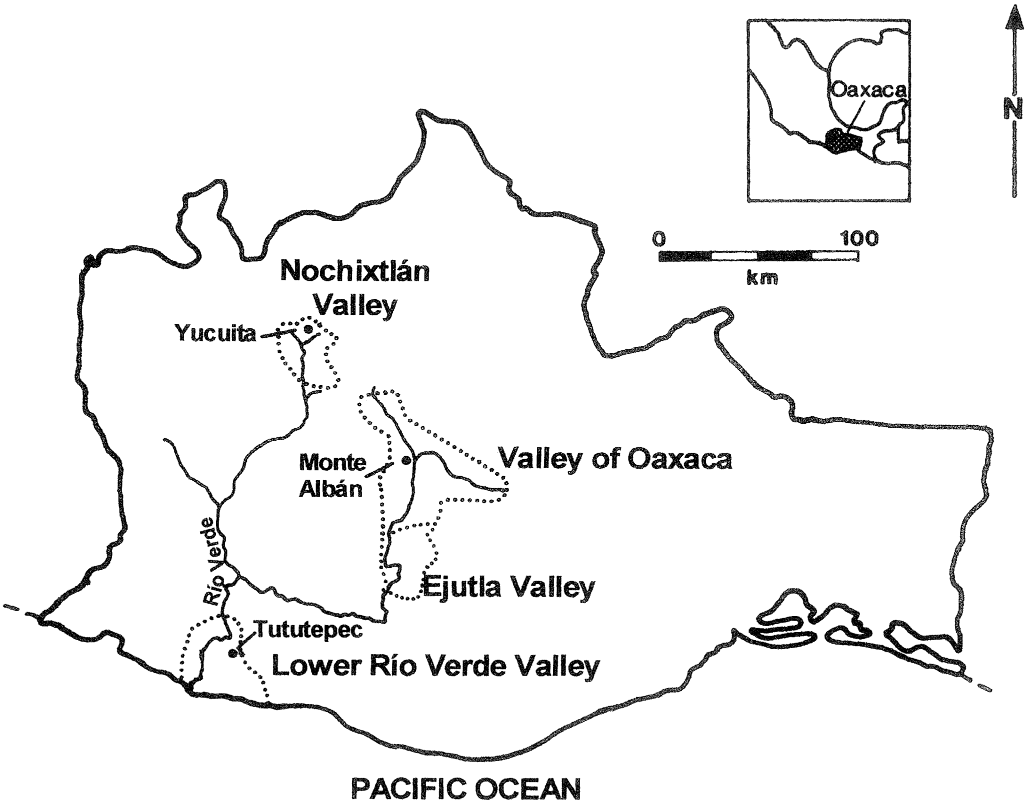

Figure 1 Map of Oaxaca, Mexico, showing the Río Verde drainage basin.

conditions have been largely stable over the past several thousand years (Smith 1978; Smith and Hopkins 1983).

This article discusses the results of ten years of interdisciplinary research in the Río Verde drainage basin of Oaxaca (Fig. 1). Our research shows that geomorphic conditions have been extremely dynamic with paleoenvironmental change linked to both climate and human impact (Joyce 1991a, 1991b; Joyce and Mueller 1992, 1995). Most research on the environmental effects of Pre-Columbian agriculture has focused on local environmental degradation (e.g. Abrams and Rue 1988; Deevey et al. 1979; Metcalfe et al. 1989). Our research in Oaxaca demonstrates that the environmental impact of highland populations had both local and macro-regional effects resulting from geomorphic changes in the drainage system of the Verde. We discuss the results of our research and their implications for prehispanic human ecology and cultural evolution.

Methods

The Río Verde is one of the largest rivers on the Pacific Coast of Mesoamerica in terms of both drainage area and discharge (Tamayo 1964). The upper drainage basin of the Verde, which is the major zone of sediment production, consists largely of several highland valleys including the valleys of Oaxaca, Ejutla, and Nochixtlán (Fig. 1). The Oaxaca and Ejutla Valleys lie at elevations of 1500m to 1700m above sea level, while the Nochixtlán Valley varies from 2000m to 2500m. Mean annual temperature in the highland valleys is about 16°C to 20°C and average annual rainfall varies from about 400mm to 1000mm. The lower Río Verde Valley is the major zone of deposition for the drainage system. The coastal climate is hot and humid with mean temperatures ranging from 25°C to 28°C and mean annual rainfall between 1000mm and 2000mm near sea level (Rodríguez et al. 1989). Intervening sections of the drainage basin that link the highland and lowland valleys consist almost entirely of deep gorges that cut through the high mountains of the Sierra Madre del Sur (peaks reach 3000m). The gorges of the mid-basin provide almost no area for sediment storage which means that environments in the lower valley are sensitive to changes in geomorphic variables in the highland valleys (Leopold et al. 1964; Schumm 1977). Therefore, changes in climate and land use in the valleys of the upper drainage could have had a significant impact on the geomorphology of the lower Río Verde Valley.

The ecological links between the upper and lower drainage basins of the Verde have led us to adopt an innovative sampling strategy designed to examine both geomorphic changes in the highlands and how they may have affected people and environments in the lowlands (Joyce 1991a; Joyce and Mueller 1992, 1995). Our research has included sedimentological sampling in three valleys of the upper drainage basin as well as archaeological and sedimentological work in the lower valley. In particular, we have been interested in identifying periods of highland erosion that resulted in increased alluviation and flooding in the lower valley. Alluviation in the lower Río Verde Valley in large part controls the area of the active floodplain which is where productive agriculture can be carried out.

Highland research

The archaeology of the upper drainage basin of the Río Verde is as well known as any area of Mesoamerica. The valleys of Oaxaca, Ejutla and Nochixtlán have all been the focus of regional settlement pattern studies (Feinman and Nicholas 1990; Kowalewski et al. 1989; Spores 1972). The Valley of Oaxaca, in particular, has been the focus of some of the most important archaeological projects investigating Mesoamerican cultural evolution (Blanton 1978; Flannery and Marcus 1983; Winter 1989). These projects have shown that both the Oaxaca and Nochixtlán Valleys gave rise to the precocious development of complex societies in the Early Formative (1800–900 BC) and urban, state polities probably by the Late/Terminal Formative (400 BC–AD 250). The Ejutla Valley was not as central to highland cultural developments (Feinman and Nicholas 1990), but supported large populations from the Terminal Formative (100 BC–AD 250) to the Postclassic (AD 800–1520). The rich archaeological database from the highlands has been crucial to understanding changing land-use patterns that may have affected the drainage system of the Río Verde.

To examine the geomorphic record in the Verde's upper drainage basin we investigated the incised cuts of four rivers: the Río Tlacolula in the Oaxaca Valley, the Río Ejutla in the Ejutla Valley and the Ríos Yanhuitlán and Yucuita in the Nochixtlán Valley (Joyce and Mueller 1995). These drainages were selected because reconnaissance showed that each

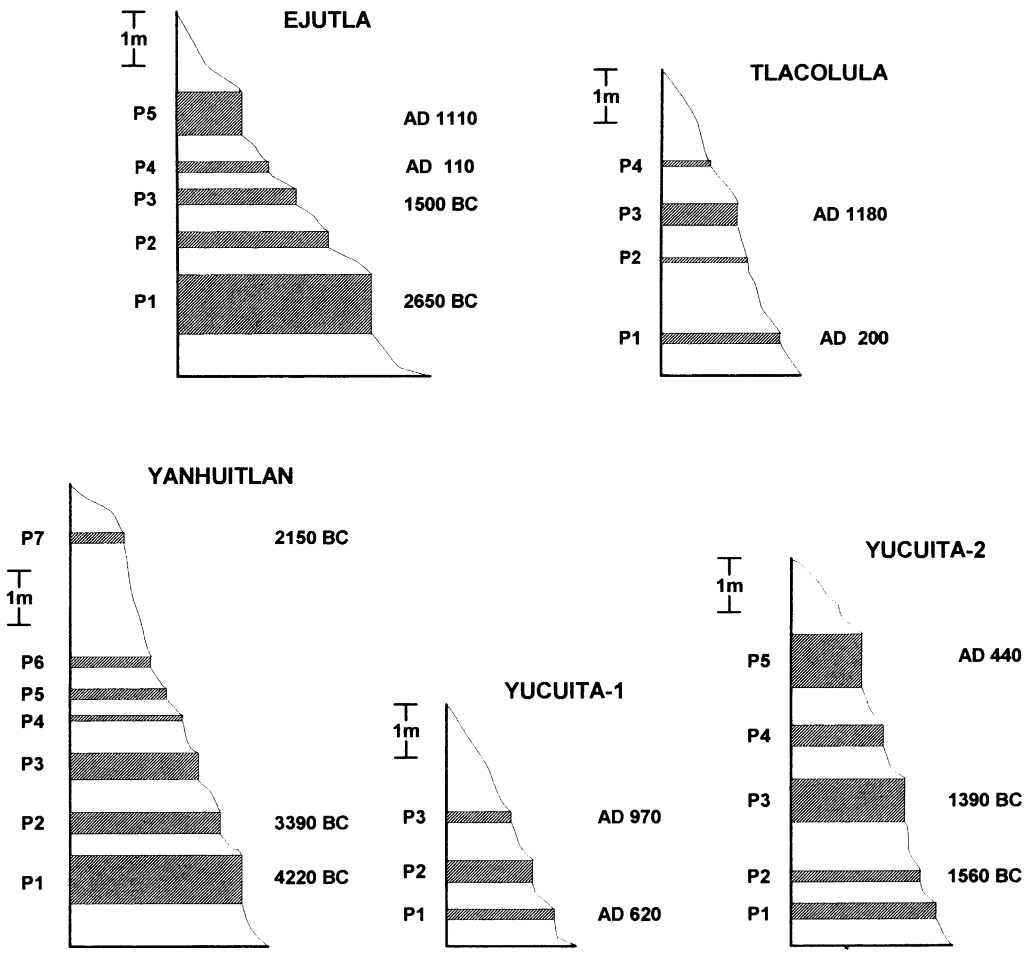

Figure 2 Highland stratigraphic sequences from the Yanhuitlán, Yucuita, Tlacolula and Ejutla rivers (dark bands are paleosols, with radiocarbon dates if available).

had significant lengths with deeply incised cuts that exposed thick sedimentary sequences. We surveyed long stretches of each drainage before selecting sampling sites to ensure that samples typified the region.

Sedimentary deposits in all of the drainages consisted of many organic-rich soils formed in fine-textured overbank or backswamp deposits (Fig. 2). Evidence of soil formation was typically shown by soil structural development and the presence of argillans (clay skins) formed by clay translocation. These paleosols were separated from one another by higher-energy overbank and/or channel deposits. Soils are important because they represent periods of landscape stability and are distinct from sediments formed by depositional events. Soils are also important because their high organic content allows them to be radiocarbon dated, thereby providing a chronology of stable land surfaces. However, radiocarbon dating of soil humate materials usually does not give as precise a date as that from wood, charcoal or bone. Since soil organic matter accumulates over time and has

Table 1 Paleosol radiocarbon dates, with standard deviations, for highland Oaxaca (all radiocarbon dating by Beta Analytic, Inc.).

Valley of Oaxaca		
Tlacolula – P3	770 ± 70 YBP	AD 1180
Tlacolula – P1	1750 ± 80 YBP	AD 200
Valley of Ejutla		
Ejutla – P5	840 ± 60 YBP	AD 1110
Ejutla – P4	1840 ± 80 YBP	AD 110
Ejutla – P3	3450 ± 60 YBP	1500 BC
Ejutla – P1	4600 ± 100 YBP	2650 BC
Valley of Nochixtlán		
Yucuita 1 – P3	980 ± 100 YBP	AD 970
Yucuita 1 – P1	1330 ± 80 YBP	AD 620
Yucuita 2 – P5	1510 ± 60 YBP	AD 440
Yucuita 2 – P3	3340 ± 80 YBP	1390 BC
Yucuita 2 – P2	3510 ± 80 YBP	1560 BC
Yanhuitlán – P7	4100 ± 80 YBP	2150 BC
Yanhuitlán – P2	5340 ± 90 YBP	3390 BC
Yanhuitlán – P1	6170 ± 80 YBP	4220 BC

varying rates of decomposition and translocation, soil radiocarbon dates yield an age called the Apparent Mean Residence Time (AMRT). The absolute age of the soil (i.e. the time when organic matter began to accumulate) is always older than the AMRT. The soils dated for this study showed little evidence for disturbance during burial and were overlain by relatively low organic matter alluvial deposits. These conditions increase the probability of accurate dating.

In our sample, the presence of paleosols indicates that valley alluviation was punctuated by land-surface stability and associated soil formation. Radiocarbon dates have been obtained for fourteen paleosols in the highlands which, along with associated pottery from some sampling locations, provide the chronology for our paleoenvironmental reconstruction (Table 1).

Stratigraphic profiles from the highland drainages should record geomorphic changes resulting from climate, human land use, and tectonics. We expect that major pan-regional changes in climate or land use would produce evidence for geomorphic responses in multiple drainages, especially in two or more valleys, while tectonic activity would probably result in more localized changes. However, geomorphic responses at our particular sampling locations may have varied in intensity and timing depending on a variety of physiographic properties, such as local topography and position along the drainage (Schumm 1977). While some of these factors can be anticipated, we expected some variability in the radiocarbon dating of geomorphic transitions (Fig. 3). A large number of dated soils from different points along multiple drainages will be required to confirm the patterns that we have identified.

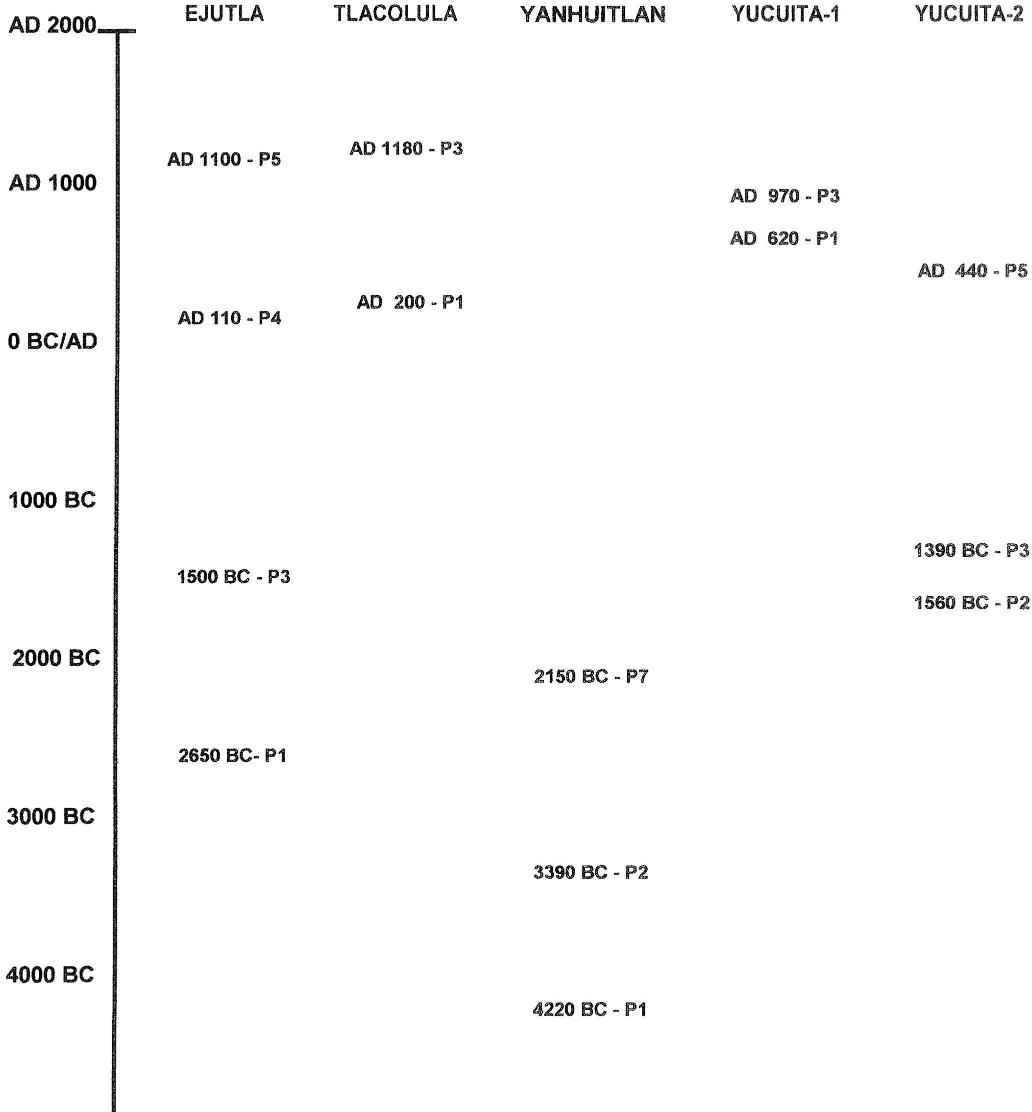

Figure 3 Timeline of radiocarbon-dated paleosols from highland Oaxaca.

Lowland research

Interdisciplinary archaeological research in the lower Río Verde Valley (Fig. 4) over the past ten years has begun to describe regional social developments and paleoecology (Joyce 1991a, 1991b, 1994; Joyce et al. 1995a, 1995b). Field research included a regional site reconnaissance, intensive surface survey over $70km^2$ of the floodplain and excavations at eleven sites. This research shows that the lower Verde supported large populations and complex society from the Late Formative (400–100 BC) to the time of the Spanish conquest.

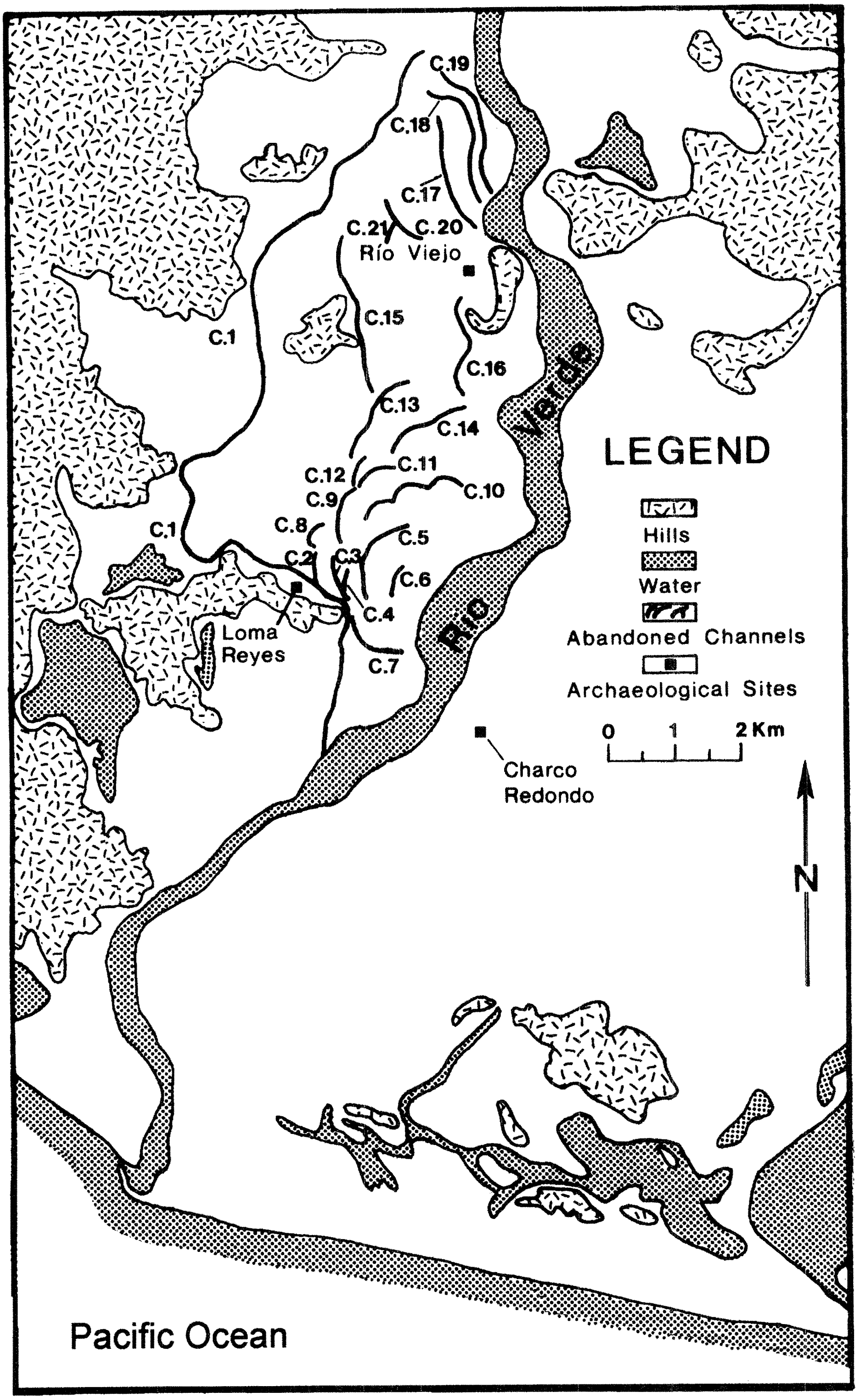

Figure 4 The lower Río Verde Valley showing abandoned river channels and archaeological sites mentioned in the text.

In the lower valley geomorphic research has examined changes in alluvial deposition and in river morphology potentially triggered by highland erosion (Joyce and Mueller 1992, 1995). The focus of the geomorphic sampling in the lower valley has been the excavation of approximately fifty-five non-archaeological tests designed to examine the sedimentological history of the floodplain (Joyce 1991a). Non-archaeological test-pits and auger-cores were excavated to a maximum of 8m below the ground surface; most were carried out along six sampling transects in the floodplain. Due to the highly active depositional conditions of the lower Verde, few soils have formed, making it difficult to date natural deposits. We have had to rely on radiocarbon dates from only two paleosols, two organic lacustrine deposits and wood deposited in one abandoned channel. In addition, we have used archaeological deposits to provide terminal dates for underlying natural strata.

Geomorphic change in highland Oaxaca

The results of our sedimentological research in the valleys of Oaxaca, Ejutla and Nochixtlán show that geomorphic conditions have been extremely dynamic since the mid-Holocene. We have tentatively identified six periods when the data suggest a change from stable to unstable geomorphic conditions. We discuss each of these periods of environmental change according to the cultural period in which they occurred.

Archaic Period (8000–1800 BC)

Our data indicate two periods of significant geomorphic change during the Archaic. The stratigraphic data from the Ejutla and Yanhuitlán rivers show that during the Early/Middle Holocene fine-grained, fluvial sediments of overbank deposition accumulated as valley fill. Landscape stability allowed the formation of a well-developed soil with high organic-matter content which is represented by the Yanhuitlán P1 and P2, with radiocarbon dates of 6170 ± 80 BP, 4220 BC (Beta-37863) and 5340 ± 90 BP, 3390 BC (Beta-37864), respectively. Floodplain aggradation that buried the Yanhuitlán P1 and P2 was followed by a period of geomorphic stability, forming the Yanhuitlán P7, dated to 4100 ± 80 BP, 2150 BC (Beta-66290), and perhaps the Ejutla P1 soil, radiocarbon dated to 4600 ± 100 BP, 2650 BC (Beta-66284). These soils were buried during the Late Archaic by further alluviation resulting from upland erosion.

Characteristics of the Yanhuitlán P1 and P2, and the Ejutla P1, call into question models of Archaic Period environments in Oaxaca which project current natural vegetation characteristics into the past (Kirkby 1973; Smith 1978; Smith and Hopkins 1983). These models argue for the presence of forested communities, especially along major drainages. However, the paleosols from the highlands show very strong, prismatic soil structure with translocation of clay. This structure, along with the thick (>1m), high organic-matter content of the paleosols, suggests formation beneath grassland vegetation. If floodplains were dominated by grasslands or savanna, it would suggest that climatic conditions were drier than today. River aggradation at 4200–3300 BC is consistent with rising precipitation, resulting in increased upland erosion. The Yanhuitlán P7 and Ejutla P1 indicate a second period of geomorphic stability that ended about 2650–2150 BC. The most likely explanation for the formation of these later soils is that slopes in the highlands stabilized in response to the earlier climatic change. Alluvial and fluvial deposits that overlay the Yanhuitlán P7 and Ejutla P1 suggest that another period of rising precipitation may have triggered increased upland erosion by the Late Archaic.

We cannot eliminate human impact as a potential factor in upland erosion during the Archaic because subsequent alluviation could have buried floodplain sites and biased population estimates. Based on current evidence, however, extremely low population densities are indicated for this period (Flannery and Spores 1983). Drier climatic conditions might have contributed to the low population densities that have been inferred for Archaic Period Oaxaca and beyond. A drier climate would have limited the productivity of both wild resources and early domesticates. The gradual shift towards agriculture during the later Archaic and Early Formative could have been accelerated by greater precipitation which probably would have increased the growing season and crop productivity.

Early Formative Period (1800–900 BC)

The third period of landscape instability that we infer dates to the Early Formative Period and is represented by the Ejutla P3 dated to 3450 ± 60 BP, 1500 BC (Beta-85021), the Yucuita-2 P2 soil dated to 3510 ± 80 BP, 1560 BC (Beta-85024) and the Yucuita-2 P3 dated to 3340 ± 80 BP, 1390 BC (Beta-91138). These are moderate-to-strongly developed soils, suggesting some geomorphic stability during the Late Archaic/Early Formative transition. However, the dates suggest that about 1500 BC there was a shift to unstable geomorphic conditions resulting in river aggradation. While we cannot exclude climate as a contributing factor, this geomorphic transition occurs during a period of population growth and major changes in human land use. The Early Formative marks the period of the first permanent sedentary villages in the highland valleys, along with a much greater commitment to agriculture than is apparent during the Archaic (Flannery 1976). Population densities inferred for the Early Formative are also far greater than those of the Archaic (Kowalewski et al. 1989: 55–68; Spores 1972: 173). Accelerated erosion usually follows land clearance for agriculture, especially where some topographic relief is present (Harden 1991; Leopold et al. 1964; Ritter 1978). Anthropogenic erosion may account for the geomorphic instability that is evident for the Early Formative.

Late/Terminal Formative Period (400 BC–AD 250)

A transition from a stable land surface to alluviation during the Late/Terminal Formative is indicated by the Tlacolula P1 soil radiocarbon dated to 1750 ± 80 BP, AD 200 (Beta-66286) and the Ejutla P4 dated to 1840 ± 80 BP, AD 110 (Beta-66285). In the highlands the Late/Terminal Formative was a time of dramatic population growth and changes in land-use practices that could have triggered large-scale upland erosion, resulting in river aggradation. Estimates from settlement pattern data suggest that during the Late Formative the

Valley of Oaxaca experienced a twenty-eight-fold increase in population (Nicholas et al. 1986), while population in the Ejutla Valley increased thirteen-fold (Feinman and Nicholas 1990). Settlement pattern data from the Nochixtlán Valley suggest at least a doubling in population during the Late/Terminal Formative (Spores 1972).

Population growth was marked by a dramatic increase in settlement in the piedmont (Blanton et al. 1982: 70; Kowalewski et al. 1989; Spores 1972). The piedmont expansion in the highlands was driven by the development of some of Mesoamerica's earliest cities such as Monte Albán in the Valley of Oaxaca and Yucuita in the Nochixtlán Valley. These urban centers were built on hilltops or ridges and had populations numbering in the thousands, often residing on artificial terraces. Monte Albán was the largest of these early cities, covering 442ha by the Late Formative with an estimated population of 10,200–20,400 (Blanton 1978: 44).

Accelerated runoff and erosion into the upper drainage basin of the Verde would have resulted from clearing for settlement and farming in piedmont zones of the highland valleys (Joyce and Mueller 1992). These zones lie at higher elevations and have steeper gradients than do the valley floors. Agricultural intensification in the piedmont, including small-scale irrigation, may have accelerated erosion and soil depletion (Flannery 1983: 326–8; O'Brien et al. 1982; Winter 1985). Kowalewski and his colleagues (1989: 126) argue that in the Valley of Oaxaca small-scale irrigation was probably used throughout the piedmont at this time to produce two annual harvests. Evidence indicating large increases in erosion concurrent with agricultural intensification has also been documented in Bronze Age Europe (Davidson 1980; Richter 1980), the New Guinea highlands (Golson 1977), the continental United States (Knox 1977; Nelson 1966) and areas of prehispanic Mesoamerica beyond Oaxaca (Deevey et al. 1979; Metcalfe et al. 1989; Rue 1987).

Beginning in the Late Formative, cycles of piedmont expansion and collapse in the Oaxaca Valley (Kowalewski et al. 1989) were probably the result of anthropogenic erosion. For example, in the Valley of Oaxaca a dramatic decline in piedmont settlement during the Terminal Formative was probably caused by depletion of the shallow soils due to intensive agriculture. Evidence for moderate to heavy erosion is common for Late Formative piedmont sites (Kowalewski et al. 1989: 154–61). Hillside agricultural terraces, the earliest of which were built in the Late Formative, are used today to limit soil erosion (Kirkby 1973: 35; O'Brien et al. 1982: 82).

In the Nochixtlán Valley the potential for erosion is an even greater problem than in the Oaxaca and Ejutla Valleys. Large-scale erosion control techniques have been a major component of agriculture in the Nochixtlán Valley since at least the Postclassic (AD 800–1520) (Spores 1969). Evidence from the Río Yanhuitlán suggests that erosive processes in the Nochixtlán Valley were even more dramatic than in the Oaxaca and Ejutla Valleys. The uppermost or P7 paleosol at Yanhuitlán was dated to 2150 BC (see above). Lying on the surface just above the P7 we discovered Postclassic pottery. The stratigraphy suggests that in this area the severe erosion, so evident today in both upland and floodplain settings, removed all sediments that had accumulated after 2150 BC, but before the Postclassic (Plate 1). We suggest that most of the erosion at Yanhuitlán was initiated during the Late/Terminal Formative since land-use changes at that time appear to have been on a much larger scale than during earlier periods.

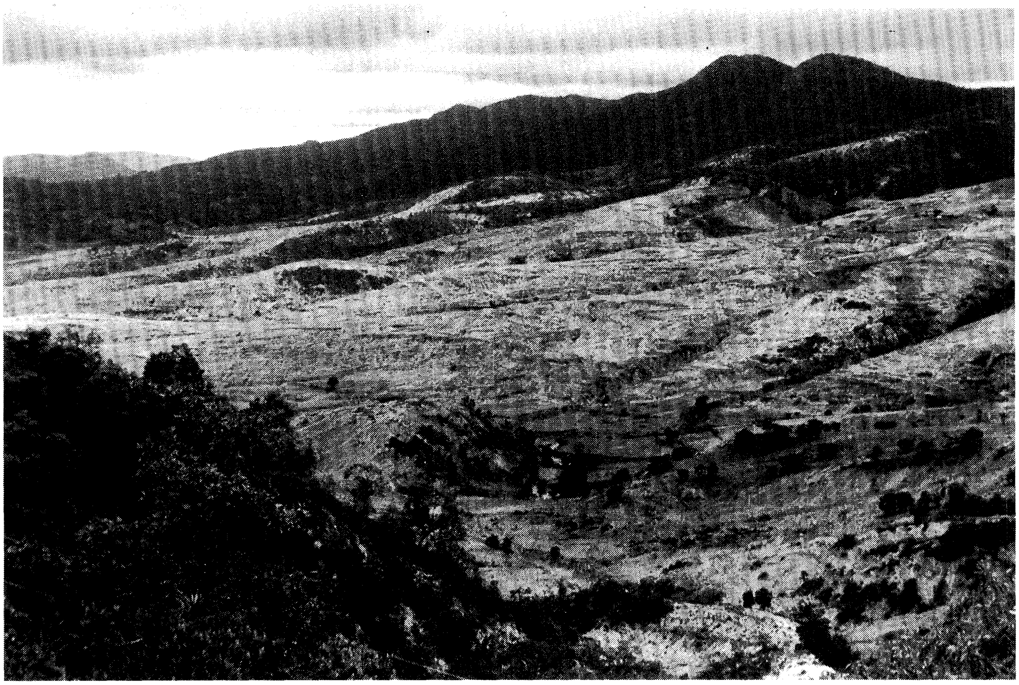

Plate 1 Erosion in the Nochixtlán Valley.

Postclassic (AD 800–1520) and Historic Periods (AD 1520–present)

Soils data from Tlacolula and Ejutla suggest another period of geomorphic change during the Postclassic. Before discussing the evidence for the Postclassic we should note, however, that two radiocarbon-dated soils from the Río Yucuita fall into the Classic Period (AD 250–800): Yucuita-1 P1 dated to 1330 ± 80 BP, AD 620 (Beta-66287) and Yucuita-2 P5 dated to 1510 ± 60 BP, AD 440 (Beta-85025). We do not feel that these soils reflect a major geomorphic transition because they are located only c. 3km apart on the same river and the Yucuita-2 P5 was only weakly developed, indicating only a short period of stability. We cannot, however, rule out the possibility of local geomorphic changes in the Yucuita river basin during the Classic Period.

Geomorphic change during the transition from the Early Postclassic (AD 800–1100) to the Late Postclassic (AD 1100–1520) is suggested by the Yucuita P3 dated to 980 ± 100 BP, AD 970 (Beta-66288), the Tlacolula P3 dated to 770 ± 70 BP, AD 1180 (Beta-85023) and the Ejutla P5 dated to 840 ± 60 BP, AD 1110 (Beta-85022). These soils suggest geomorphic stability during the Early Postclassic (AD 800–1100), perhaps resulting from a reduction in anthropogenic landscape change following the Classic-Period collapse. The collapse involved the decline of the Classic-Period urban centers and political decentralization probably coupled with some degree of population loss (Kowalewski et al. 1989; Spores 1972). However, the specific nature of cultural developments immediately following the collapse has been hotly debated (Marcus and Flannery 1990; Winter 1989). Alluviation at about AD 1100 probably resulted from upland erosion, but, given the controversies over cultural developments during the Oaxacan Postclassic, it is difficult to assess the relative contribution of people or climate to this geomorphic transition.

The final period of major geomorphic change occurred during the historic period and resulted in the deep incision of drainages throughout the highlands (also see Kirkby 1973: 13–14). We assume that aggradation abated and rapid downcutting began in the sixteenth century, concurrent with the Spanish conquest, massive depopulation and presumably a decline in agricultural impacts on the landscape.

Cultural and ecological effects in the lower valley

In the lower Río Verde Valley (Fig. 4) our interdisciplinary research over the past ten years has examined the human response to periods of increased alluviation and floodplain expansion triggered by highland erosion (Joyce 1991a, 1991b; Joyce and Mueller 1992; Joyce et al. 1995a). The five erosional episodes inferred for the prehispanic period in the Oaxacan highlands would have caused changes in the hydrology and geomorphology of the entire drainage basin. If the magnitude of change in the input of sediment and runoff in the upper basin exceeded geomorphic thresholds, then a variety of geomorphic changes would be expected in the lower valley (Chorley et al. 1984; Richards 1982; Schumm 1977). An increase in discharge, seasonal range of discharge and alluvial deposition across the floodplain would be expected. The increase in discharge would also have resulted in the deposition of larger-grained alluvium in the floodplain and more severe flooding during the rainy season. Larger floods would have deposited alluvium over a wider area and at higher elevations, effectively increasing the size of the active floodplain. An increase in the range of discharge and sediment load would also have caused a shift from a more meandering to a more braided river pattern, a shift which involves an increase in meander wavelength, decreased sinuosity and an increase in the width–depth ratio (Fig. 5). Braided rivers are less stable than meandering rivers and tend to migrate across the floodplain at a faster rate. Lateral accretion would have been the dominant process in the area of the floodplain where the river was migrating. In areas where the river did not migrate, increased flooding and alluviation would have caused an increase in vertical accretion.

Our data indicate that geomorphic conditions have been extremely dynamic in the lowlands as well as in the highlands (Joyce 1991a; Joyce and Mueller 1992, 1995). We have distinguished two distinct regional depositional regimes for the lower valley. The earlier regime is associated with a single meandering channel, C.1, that runs along the western edge of the floodplain up to 5.5km from the present-day river (Fig. 4). The more recent regime is associated with increased rates of alluviation and with most of the abandoned channels in the floodplain, especially those east of the site of Loma Reyes (channels C.2 to C.12). These channels, like the river today, exhibit a braided pattern which is consistent with an increased discharge and sediment load relative to a meandering river. The predominance of lateral accretion deposits and the relatively small build-up of overbank deposits (<2.5m) in channels C.2 to C.12 show that the river has been moving back and forth across the floodplain in the area east of Loma Reyes since the shift in depositional

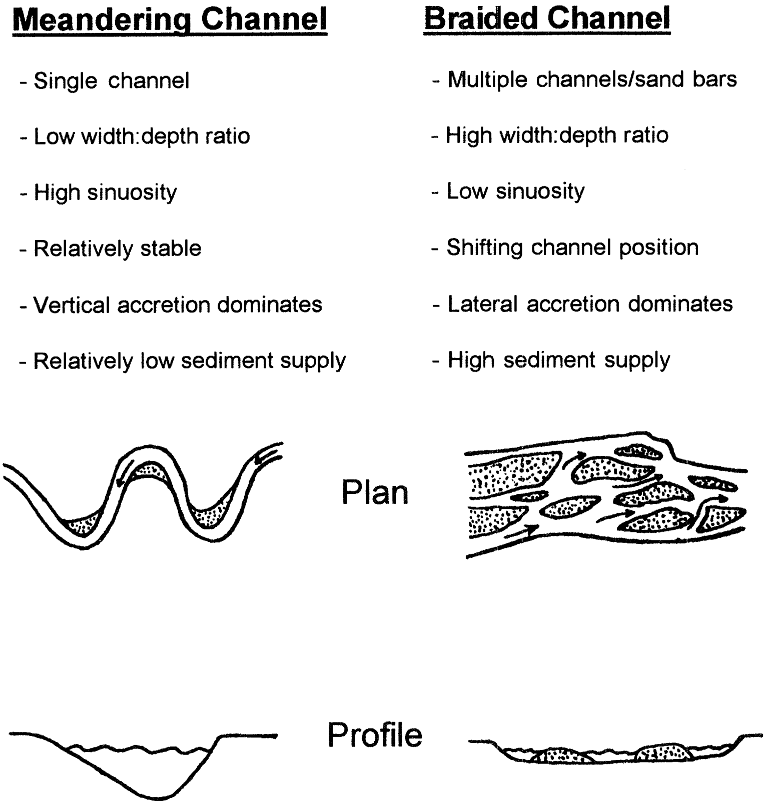

Figure 5 Channel characteristics: meandering vs. braided rivers.

regimes occurred. Wood deposits recovered from channel sands in C.4 yielded a radiocarbon date of 210 ± 70 BP (Beta-26220) indicating that as recently as AD 1670–1810 the Río Verde was located there, roughly 2km from its present position.

North of Río Viejo, after the abandonment of C.1, the river migrated across the floodplain from west to east and alluviated its bed. Sedimentological sampling in this area shows that, during the more recent depositional regime, the river has been relatively stable and aggrading because it is constrained both by the piedmont proper and by a series of bedrock hills in the floodplain. This effect is most pronounced at the southern end of Río Viejo where hills on both sides of the Verde constrict the river. Therefore, the river in the area east of Loma Reyes was free to migrate across the floodplain, while north of this area the Verde was stabilized by hills. Overall, the data are consistent with Late Holocene alluviation in the lower valley caused by erosion in the highlands.

A key question that remains is to determine the degree to which the various geomorphic transitions in the highlands contributed to ecological changes in the lower valley. While our chronological control of lowland geomorphic change is not as precise as for the highlands we can make some tentative correlations.

Until recently we argued that the transition between the two depositional regimes occurred rapidly during the Late/Terminal Formative as a result of human impact in the highlands (Joyce 1991a, 1991b; Joyce and Mueller 1992). This date was based on correlations between natural and archaeological strata at Loma Reyes. However, we recently obtained a radiocarbon date of 6190 ± 70 BP, 4240 BC (Beta-85027) from lacustrine clays deposited shortly after the abandonment of channel C.1. This suggests that the abandonment of C.1 was triggered by the transition in the highlands recorded by the Yanhuitlán P1 dated to 4220 BC.

We have good evidence that the more recent depositional regime in the lowlands was in place by the Terminal Formative. Excavations at Río Viejo show that a structure (Mound 5) was cut into by channel C.20 during the Terminal Formative as the Verde migrated slightly south from near its present position (Fig. 4). Sediments from auger testing in C.20 suggest that it had a braided pattern. There are no major geomorphic changes indicated for the lower Verde after the Terminal Formative. Therefore, the shift from a meandering to a braided river pattern and, presumably, the largest expansion in the floodplain occurred between 4200 BC and AD 250. Sedimentological data from excavations at floodplain and barrier island sites show that a significant increase in alluviation occurred during the Late/Terminal Formative (Joyce 1991a: 465–97). These data suggest that anthropogenic erosion in the highlands during the Late/Terminal Formative may have triggered the most significant ecological changes in the lower Verde.

The precise relationship between demographic change and the rising agricultural potential of the lower valley cannot yet be established. However, a smaller and less productive floodplain may explain, at least in part, why we have identified only a single site earlier than 500 BC. The numerous archaeological and sedimentological excavations in the floodplain and piedmont, along with the survey and reconnaissance results, suggest that the small number of Early/Middle Formative sites is not simply the result of sampling bias or alluvial burial. Only at Charco Redondo have excavations recovered Early/Middle Formative sherds and figurines (Gillespie 1987) that probably reflect sporadic settlement of the site between 1800 and 500 BC. The small number of early sites in the lower Río Verde Valley is surprising in that the Pacific Coast of southern Mesoamerica was a focus of population during the Early/Middle Formative (Blake et al. 1995; Bove and Heller 1989; Voorhies 1989). The lower Verde is located within 350km of two areas containing important Early Formative sites: Puerto Marqués on the Guerrero Coast (Brush 1969) and Laguna Zope in the Southern Isthmus of Tehuantepec (Zeitlin 1979). Rosenthal (1960–2: 14) reported Early Formative figurines from her survey and excavations along the Costa Chica of southeastern Guerrero, a mere 75km north-west of the lower Verde.

By the Terminal Formative the modern depositional regime was in place, characterized by an aggrading, braided river that was migrating across the floodplain except in areas obstructed by bedrock. Regardless of the precise dating of the shift in depositional regimes, agricultural productivity would have increased as topsoil was eroded from the highland valleys and deposited along the lowland floodplain (Joyce 1991a, 1991b). Organic materials washed down from the highlands, especially plant material from land clearing, would also have contributed to greater fertility in the lowlands. The migration of the river created oxbow ponds supporting populations of fish and waterfowl, as well as low-lying areas where the water-table was high, allowing maize to be grown through the dry season. Many of the largest sites on the floodplain are located adjacent to abandoned channels that would have been oxbow lakes. Aggradation of the Verde would have raised the water-table in the lower valley and increased the moisture content of the soil.

By the Late/Terminal Formative productivity in the region was sufficient to support rapidly growing populations and a developing urban center at Río Viejo (Joyce 1991a; Joyce and Workinger 1996). The largest increase in absolute site numbers occurred during this period and the size and internal complexity of sites also increased. In the 70km^2 of the floodplain that were intensively surveyed, site totals increase from four during the late Middle Formative (500–400 BC) to twenty-five by the late Terminal Formative (AD 100–250). A two-tiered settlement hierarchy was in place by the Late Formative with Río Viejo and Charco Redondo as first-order centers. By the Terminal Formative other large and architecturally complex sites developed creating a four-tiered settlement hierarchy. Río Viejo emerged as the regional center with monumental architecture and settlement over approximately 150–200ha.

Population growth and increasing social complexity continued during the Classic Period. By the Late Classic (AD 550–800) Río Viejo had reached 250–300ha with massive public architecture (Joyce and Workinger 1996). The civic-ceremonial center of Río Viejo was defined by Mound 1, a huge acropolis measuring 350m × 200m at its base. The remainder of the site is dominated by approximately fourteen residential platforms ranging in area from c. 0.1ha to 16ha. A total of sixteen carved stones has been recorded at the site, including six that appear to depict rulers accompanied by their hieroglyphic names (Urcid and Joyce 1996). Río Viejo was an urban center at the apex of a four-or-five-tiered settlement hierarchy. The increase in the size of Río Viejo may have been at the expense of nearby communities as the number of sites in the region declines for the first time. By the Late Classic Río Viejo may have been the capital of a state that dominated the lower Verde region and perhaps other small valleys along the Oaxaca Coast.

At Río Viejo and other Classic Period sites in the floodplain people used abandoned channels as part of the site geography. At Río Viejo, channels C.20 and C.21 formed both external and internal site boundaries. Monumental buildings at Río Viejo and other floodplain sites were often built with their sides along levees of abandoned channels, which increased the apparent height of structures.

While the ecological changes in the lower valley increased agricultural productivity, the dynamic geomorphic conditions proved to be unpredictable and created risks for people. The largest Late Formative occupations are found near hills in the floodplain, such as at Río Viejo, Charco Redondo and Loma Reyes. The largest Terminal Formative and Classic Period floodplain sites are dominated by impressive residential platforms (Joyce 1991a; Joyce et al. 1995a). The use of natural hills and residential platforms in the floodplain was probably an adaptation to flooding. Mound 5 at Río Viejo was cut into by the Río Verde as it migrated across the floodplain, demonstrating that channel changes were also sometimes unpredictable.

By the beginning of the Postclassic Period population declined and monumental building activities ceased at Río Viejo, as well as at most other large Classic-Period sites. While regional population continued to grow, there appears to have been a shift in settlement during the Postclassic with sites moving from the floodplain into the piedmont and secondary valleys (Joyce 1991a: 436–7). The shift in settlement could have been related to environmental factors such as increased flooding, but probably also resulted from the rise of the city-state of Tututepec located in the foothills about 16km east of Río Viejo. Since Tututepec was often at war with other polities (Spores 1993) the shift in settlement towards the piedmont may have been motivated in part by defensive concerns.

Conclusions

Our interdisciplinary research along the Río Verde drainage system demonstrates the dynamic nature of prehispanic ecology in Oaxaca. In the highland valleys of the upper drainage basin we have documented six periods of significant geomorphic change (Table 2).

Table 2 Summary of geomorphic transitions and hypothesized causal factors for highland Oaxaca.

*Dates**	*Geomorphic transition*	*Hypothesized causal factors*
4220–3390 BC	upland erosion/ floodplain aggradation	climate change
2650–2150 BC	upland erosion/ floodplain aggradation	climate change
1560–1390 BC	upland erosion/ floodplain aggradation	population growth and land clearance with the establishment of sedentary agricultural villages
AD 110–200	upland erosion/ floodplain aggradation	development of urban, state societies; agricultural intensification, population growth and expansion into the piedmont
AD 980–1180	upland erosion/ floodplain aggradation	poorly defined demographic changes of the Postclassic
AD 1520–?	decreased erosion/ river incision	Colonial Period depopulation and reduction in agricultural impacts

Note
*The range of dates for each transition is based on the AMRT radiocarbon ages without considering standard deviations. This was done to simplify the figure given the relative imprecision of AMRT ages.

The first two were probably the result of climatic change during the mid-Holocene. The four subsequent periods of landscape change are correlated with major shifts in demographics and human land use; we argue that these factors may be causally related. Because of the physiographic properties of the drainage, all of the periods of geomorphic change in the highlands would have had an impact on environments in the lower Río Verde Valley. Erosion in the highland valleys led to modification of stream-channel dynamics, alluviation and expansion of the agriculturally rich floodplain in the lower valley. Increasing agricultural productivity in the lowlands may explain in part the rapid increase in population and social complexity beginning in the Late Formative. Increased flooding also created risks for people living on the floodplain. One response to those risks appears to have been the investment of labor in the construction of large residential platforms to raise houses above the flood waters. In contrast, piedmont communities in the highlands were periodically abandoned due to soil depletion. Thus, the boom in the lowlands may have resulted from a bust in parts of the highlands.

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