The Social Impact of Anthropogenic Landscape Modification in the Río Verde Drainage Basin, Oaxaca, Mexico

Arthur A. Joyce

American Museum of Natural History, Central Park West at 79th St., New York, New York 10024-5192

Raymond G. Mueller

Department of Environmental Studies, Stockton State College, Pomona, New Jersey 08240

This article examines the effects of anthropogenic landscape modification in the upper drainage basin of the Río Verde on environments and populations of the lower Río Verde Valley, Oaxaca, Mexico. Archaeological and geomorphological research conducted by the Río Verde Formative Project indicates that Late Formative (400–100 B.C.) population growth and agricultural intensification in the Oaxaca and Nochixtlán valleys increased erosion and runoff from the Verde's upper drainage. This geomorphic change in the highland valleys altered the drainage system and led to increased flooding and alluviation in the lower Río Verde Valley. The environmental effect in the lower valley may have increased the agricultural potential of the region, leading to population growth, and at least indirectly to social change.

INTRODUCTION

Interdisciplinary research in Mesoamerica is increasingly demonstrating the geomorphic impact of prehispanic agriculture. Evidence of land clearance for agriculture is evident in the palynological record as early as 4000 B.C. in the Basin of Mexico (González-Quintero and Fuentes Mata, 1980; Niederberger, 1979) and by 1500 B.C. throughout much of Mesoamerica (Brown, 1985; Markgraf, 1989:12; Metcalfe et al., 1989; Rue, 1987). Sedimentological research in lakes of both the Peten region of the Maya lowlands and the central Mexican highlands indicates that anthropogenic deforestation triggered large-scale lacustrine siltation around 1500 B.C. (Brown, 1985; Deevey et al., 1979; Metcalfe et al., 1989; Rice et al., 1985; Street-Perrott et al., 1989). Finally, in the Mixteca Alta region of Oaxaca anthropogenic erosion is documented by A.D. 1000 (Kirkby, 1972; Spores, 1969), although recent observations suggest that it may have begun much earlier (see below).

The majority of the research dealing with prehispanic human impact on the environment has focused on environmental degradation produced by local

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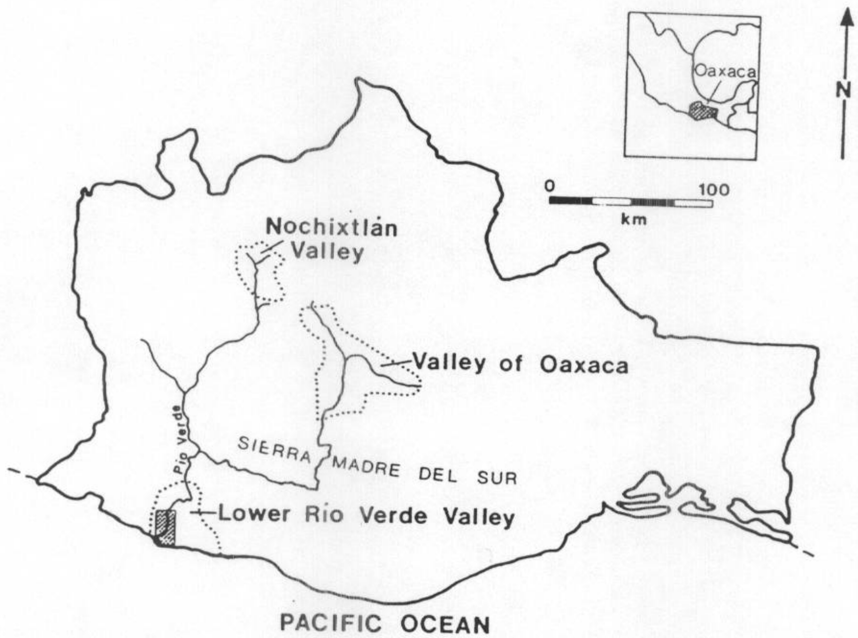

Figure 1. Oaxaca showing the Río Verde drainage basin (shaded area of the lower Río Verde Valley is shown in Figure 4).

agricultural practices. Several studies suggest that environmental degradation caused by human land use had a significant impact on subsequent agricultural productivity (Deevey et al., 1979; Rice et al., 1985) and in some instances compelled people to build large-scale erosion control facilities (Spores, 1969). Some archaeologists have argued that anthropogenic soil depletion was a major factor leading to the Classic Maya collapse (Harrison and Turner, 1978; Sanders, 1973).

This article reports the results of interdisciplinary research by the Río Verde Formative Project (RVFP) on the effects of human land use in the Río Verde drainage basin, Oaxaca, Mexico. The RVFP was designed to examine Formative Period (1500 B.C.–A.D. 250) social development in the lower Río Verde Valley through a program of archaeological and geomorphological research (Joyce, 1991a, 1991b; Joyce and Winter, 1989; Joyce et al., 1989; Mueller, 1991a, 1991b). The research differs from previous studies in that it examines the effects of changing land-use practices in the upper basin of the Río Verde on environments and human populations in the lower reaches of the river (Figure 1). The article argues that shifts in land-use practices in the upper drainage basin during the Late Formative (400–100 B.C.) altered the drainage system and led to environmental change in the floodplain of both the upper and lower valley. In the upper drainage basin, increased erosion in piedmont settings led to soil depletion. However, in the lower valley, alluviation may have increased the agricultural potential of the region leading to population growth, and at least indirectly to social change.

HIGHLAND LAND-USE AND THE RIO VERDE DRAINAGE SYSTEM

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 the Valley of Oaxaca and the Nochixtlán Valley. The Oaxaca Valley lies at an elevation of 1500–1700 m above sea level, while the Nochixtlán Valley varies from 2000 to 2500 m. Mean annual temperature in the highland valleys is about 16–20°C, and average annual rainfall varies from about 600 to 1000 mm. Archaeological research over the last 60 years (Flannery and Marcus, 1983; Spores, 1984; Winter, 1989) has shown that both the Oaxaca and Nochixtlán valleys gave rise to the precocious development of complex societies in the Early Formative (1500–900 B.C.) and urban, state polities probably by the Terminal Formative (100 B.C.–A.D. 250).

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 to 28°C and mean annual rainfall between 1000 and 2000 mm near sea level (Rodriguez et al., 1989). While the lower Río Verde Valley has not been as intensively studied as the highland valleys, recent research in the region has yielded evidence for complex societies as early as the Late Formative (400–100 B.C.; Joyce, 1991a, 1991b; Joyce and Winter, 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 (from the Valley of Oaxaca to the coast, the Verde drops 1600 m in elevation in a stream length of 375 km). These gorges of the midbasin provide no area for sediment storage (Figure 2), which means that environments in the lower valley are sensitive to changes in geomorphic variables in the highland valleys (Friedman and Sanders, 1978; Leopold et al., 1964; Schumm, 1977; Strahler, 1980). Therefore, changes in land-use patterns in the Oaxaca or Nochixtlán Valleys could have had a significant impact on landforms and hydrology in the lower Río Verde Valley.

Archaeological data from the Valley of Oaxaca and the Nochixtlán Valley demonstrate that significant changes in human land use occurred in these regions during the Late Formative. Estimates by Nicholas et al. (1986) suggest that the Valley of Oaxaca experienced a 28-fold increase in population during Period I in the Valley of Oaxaca ceramic sequence (500–100 B.C.). Settlement pattern data from the Nochixtlán Valley suggest at least a doubling in population at this time (Spores, 1972, 1983). Population growth in both regions was marked by a dramatic increase in settlement in the low and middle piedmont

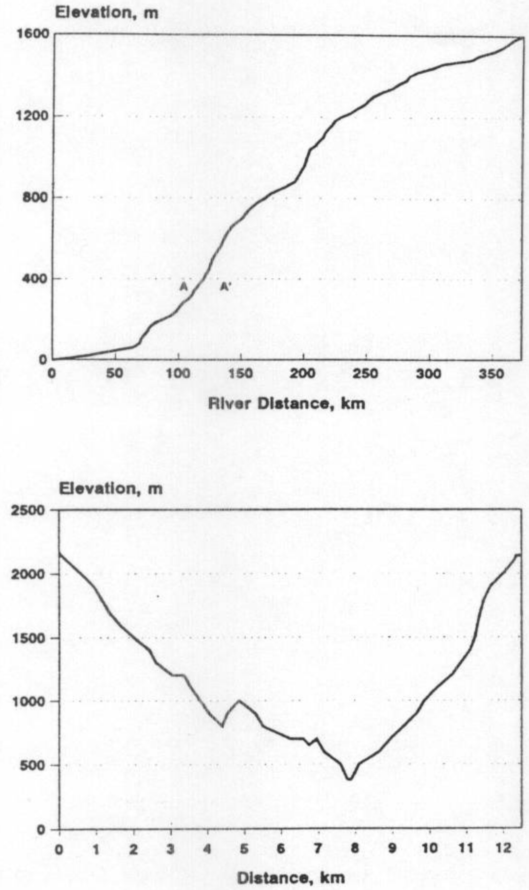

Figure 2. Physiography of the Río Verde drainage basin: (a) slope of the drainage from the Valley of Oaxaca to the coast (A–A′ denotes the location of the cross-section); (b) cross-section of the Verde.

zones, as well as smaller increases in the upper piedmont and mountain zones (Blanton et al., 1982:70; Feinman et al., 1985:346–349; Kowalewski et al., 1989; Spores, 1972).

Accelerated runoff and erosion into the upper drainage basin of the Río Verde would have resulted from clearing for settlement and farming in piedmont and mountain zones in the Oaxaca and Nochixtlán Valleys. These zones lie at higher elevations and have steeper gradients than do the valley floors. Accelerated erosion usually follows land clearance for agriculture, especially where some topographic relief is present (Harden, 1991; Knox, 1977, 1983; Leopold et al., 1964; Nelson, 1966; Ritter, 1978). Evidence indicating large increases in erosion concurrent with agricultural intensification has been documented in Bronze Age Europe (Butzer, 1980, 1982; Davidson, 1980; Richter, 1980), the

New Guinea highlands (Golson, 1977; White and Allen, 1980), the continental United States (Knox, 1977; Nelson, 1966; Wolman, 1967), and areas of prehispanic Mesoamerica beyond Oaxaca (Cook, 1963; Deevey et al., 1979; Metcalfe et al., 1989; Spores, 1969; Street-Perrott et al., 1989).

Evidence for intensive agricultural practices, including the construction of small-scale irrigation systems and hillside terracing, has been recovered from Period I piedmont sites in the Valley of Oaxaca (Flannery, 1983:326–328; Kirkby, 1973:117–122; Mason et al., 1977; Neely, 1967; O'Brien et al., 1982; Winter, 1985). Kowalewski et al. (1989:126) argue that small-scale irrigation was probably used throughout the piedmont at this time to produce two annual harvests. A dramatic decline in piedmont settlement during Period II (100 B.C.–A.D. 200), while possibly linked to a decentralization of political control (Kowalewski et al., 1989:198–199), was probably necessitated by depletion of the shallow soils due to intensive agriculture. A similar sequence of expansion into the piedmont of the Southern Valle Grande during Monte Albán IIIA followed by a dramatic demographic collapse in Period IIIB suggests that intensive piedmont agriculture continued to be unsuccessful as a long-term strategy (Blanton et al. 1982:89–92; Feinman et al., 1985:383–386). Evidence of both recent and ancient erosion is observable today throughout the Oaxaca Valley (Kirkby, 1973:36; Mueller, 1991a; Rodrigo, 1983:77; Smith, 1978:24). Kowalewski et al. (1989:154–161) note that evidence for moderate to heavy erosion is common for Period I piedmont sites. Hillside agricultural terraces, the earliest of which were built in Period I, are used today to limit soil erosion (Kirkby, 1973:35). Geomorphic data indicating the onset of river aggradation in the Oaxaca Valley between 800 and 200 B.C. (Kirkby, 1973:13–14) are consistent with accelerated piedmont erosion. Aggradation abated, and rapid downcutting began in the 16th century, concurrent with the Spanish conquest, massive depopulation, and presumably a decline in agricultural impacts on the landscape.

The potential for erosion is an even greater problem in the Nochixtlán Valley, where large-scale erosion control techniques have been, not surprisingly, a major component of agriculture since at least the Postclassic (A.D. 900–1521; Spores, 1969). While a preliminary geomorphological study in the Nochixtlán Valley suggested that large-scale erosion did not occur until the Postclassic (Kirkby, 1972; Spores, 1969), considerable erosion would nonetheless be an expected outcome of population growth and agricultural expansion inferred for the Late Formative (see Harden, 1991). Preliminary observations by the authors in 1989 indicate that the Nochixtlán Valley has experienced multiple episodes of severe erosion probably over the course of the last few thousand years (Figure 3). In an area which showed evidence of three cycles of deposition and incision as well as a sequence of buried paleosols, the two lowest paleosols had radiocarbon dates of 6170 ± 80 B.P., 4220 B.C. (Beta-37863), and 5340 ± 90 B.P., 3390 B.C. (Beta-37864), respectively. These dates indicate that the initial period of deposition in the valley began sometime after ca. 3390 B.C.

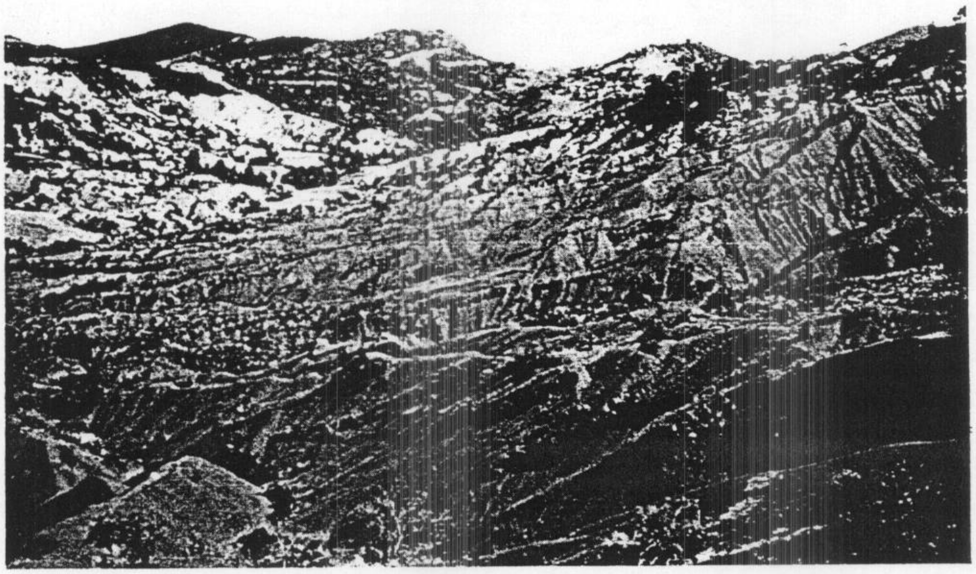

Figure 3. Eroded landscape of the Nochixtlán Valley.

The changes in land-use practices inferred for the Late Formative Oaxacan highlands would have caused an increase in runoff and erosion in the upper drainage basin of the Río Verde. Once land clearance and agricultural intensification began, the increased rates of erosion and runoff would have been considerable and largely irreversible with technologies then available. Under these conditions, a variety of geomorphic changes would be expected in the coastal lowland valley of the Río Verde (see Lewin, 1983; Mueller, 1991a; Richards, 1982; Ritter, 1978; Schumm, 1977). An increase in discharge and alluvial deposition across the floodplain would be expected. The increase in discharge would have caused rainy season floods to be more severe. Larger floods would have deposited alluvium over a wider area and at higher elevations, effectively increasing the size of the floodplain, and possibly raising the water table. An increase in 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. 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.

The hypothesized hydraulic changes in the Río Verde would have had a variety of geomorphic effects which should be observable today in the sedimentological record (Richards, 1982; Schumm, 1977, 1981). Most importantly, increased rates of alluvial deposition should be observable in stratigraphic sequences in the floodplain, datable to the Late Formative (see Ferring, 1986). Alluvial deposits should indicate an increased rate of vertical or lateral accretion, depending on the history of channel migration at a particular sampling point. Larger grains should be observable in post-transition vertical accretion deposits if an increase in the size of grains transported to the floodplain accompanied the increase in alluviation. The morphology of abandoned channels in the floodplain should correspond to the nature of the hydraulic regime under which they were formed. Channels predating this transition should exhibit evidence of a more sinuous pattern and a lower width–depth ratio than later channels. Levee deposits predating the transition should be more developed than later ones since a meandering river is more stable than a braided river. The following section describes the method used to determine whether these shifts occurred, as seen in the sedimentological record of the lower Río Verde Valley, and if so, when.

METHODS

The geomorphological research program of the RVFP was designed to evaluate the hypotheses outlined above, concerning the nature and timing of changes in the depositional regime of the Río Verde. Geomorphological research included mapping of current landscape features, sampling of recent surficial deposits, and sampling of sediments from archaeological excavations. However, the focus of the geomorphological sampling was the excavation of 42 nonarchaeological tests designed to examine the sedimentological history of the lower Río Verde floodplain (for a complete methodological description, see Joyce, 1991a; Mueller, 1991a, 1991b).

Nonarchaeological excavations consisted of sedimentological pits and auger cores (see Appendix). Sedimentological pits (1.5 × 1.5 m) were dug until groundwater was reached (usually at a depth of 2–3 m), and most were further sampled by placing an auger core in the base of the pit, extending the sampling depth to a maximum of 8 m below the ground surface. The auger cores were accomplished using a 4-in.-diameter bucket auger. A detailed description was made for each sedimentological pit and auger core, and sediment samples (500 cc) were taken from each natural stratum for laboratory analysis. Sediment samples were transported to the Environmental Studies laboratory at Stockton State College for grain-size analysis and pH determinations (Mueller, 1991a, 1991b). Four areas of the floodplain were chosen for sedimentological testing, and the strategy that guided the sampling in each area is described in detail below.

One area of the floodplain chosen for intensive subsurface sampling was located adjacent to the site of Loma Reyes on the west side of the river (Sampling Area B). This area was selected because it contained the greatest concentration of old river channels in the valley (abandoned channels [C] were numbered sequentially; see Figure 4). A transect of auger cores (loci B1–B19) was excavated running through channels C.1–C.4 (Figure 5). An archaeological test pit was also excavated at Loma Reyes site (Op. LR88 A) to recover artifacts to provide approximate dates for natural strata sampled in the auger tests. The auger core transect was mapped with a transit to generate topographic profiles of both surface features and the relationships of strata sampled in the cores.

A second area chosen for intensive subsurface sampling (Sampling Area A) was the floodplain between the two archaeological sites, Cerro de la Cruz and Río Viejo, that were the focus of archaeological research during the 1988 field season (Figure 4). A transect was laid out connecting the two sites and a total of 12 sampling loci were demarcated at 200-m intervals along the transect (loci A1–A12). Sampling Area A could not be surveyed with a transit because of problems with lines of sight. However, elevations of sampling loci were taken from detailed (1-m contour interval) topographic maps. Sedimentological pits were excavated at 10 of the 12 points along the transect (loci A5 and A7 were omitted because they promised repetitive results with other tests). Together these samples provided a stratigraphic cross section of the floodplain linking the two sites. In addition, three auger core tests were sampled outside of the transect to examine geomorphic processes near Cerro de la Cruz (A88–A14, A88–A13) and to examine soil profile development on the floodplain west of the river (A88–A15). The only notable surface features observed along this transect were an ancient channel running just east of Cerro de la Cruz (C.15) and several others located just west of the current Río Verde (C.17, C.18, and C.19).

A third place sampled on the west side of the river was the area in and around an abandoned channel (C.16) approximately 500 m south of the village of Río Viejo (Sampling Area C; see Figure 4). These samples consisted of a transect of three sedimentological pits (loci C1–C3) that cut across channel C.16.

Sedimentological sampling on the east side of the river (sampling area D) was much less intensive than for the west side. This inequality in sampling was intentional because observations of land surfaces indicated that the area west of the river had been more directly affected by geomorphic changes during the last few thousand years. Specifically, the east side of the floodplain lacked the large abandoned channels and ridge-and-swale topography that were so characteristic of the west side. Seven subsurface tests were sampled on the east side of the river, primarily to examine soil profile development on the floodplain (Joyce, 1991a; Mueller, 1991a). The next section presents the results of the sedimentological sampling program and discusses their implications for environmental change in the lower Río Verde Valley.

ENVIRONMENTAL CHANGE IN THE LOWER RÍO VERDE FLOODPLAIN

Archaeological data from the Valley of Oaxaca and the Nochixtlán Valley indicate that the Late Formative was a period of marked population growth,

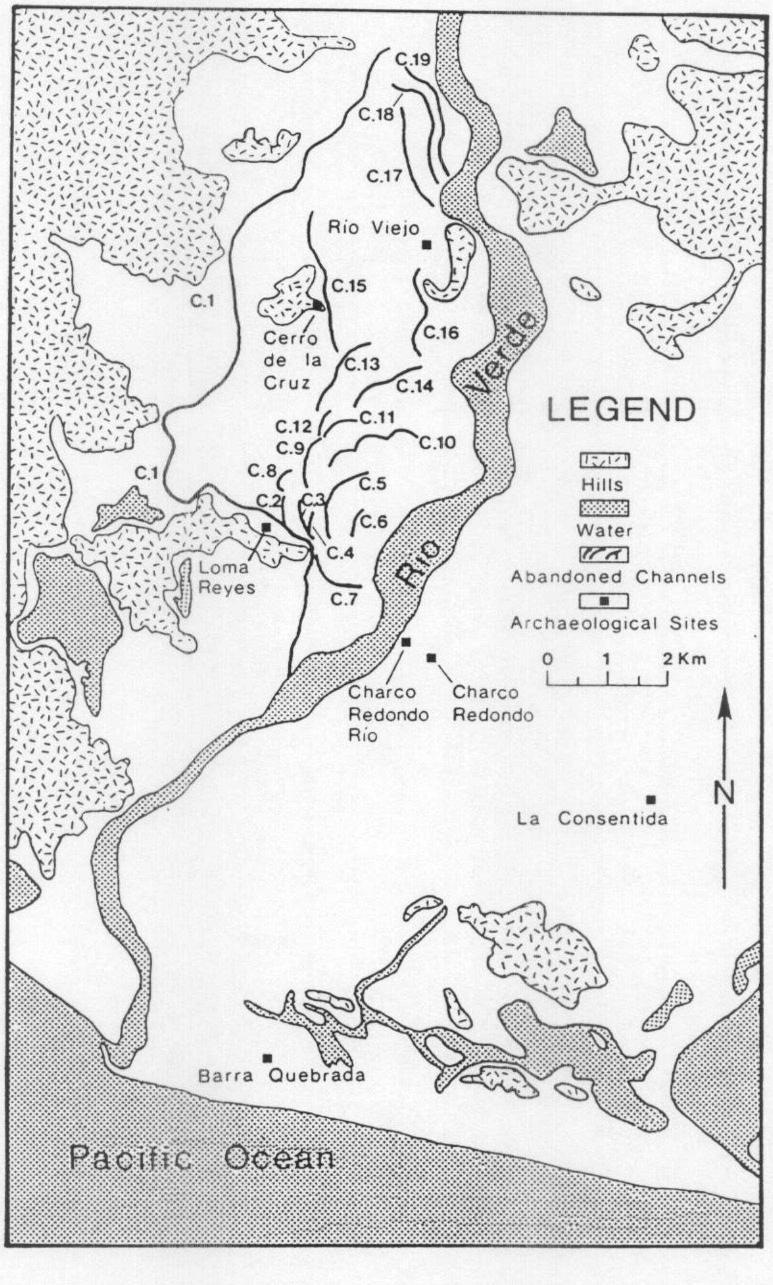

Figure 4. The lower Río Verde Valley showing archaeological sites and abandoned channels.

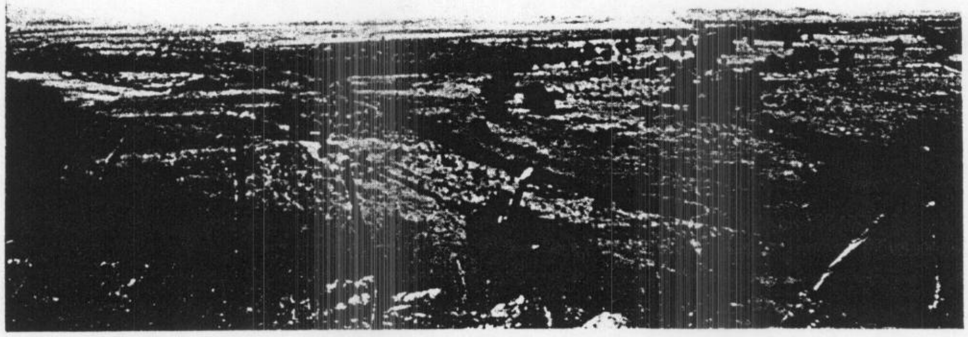

Figure 5. Abandoned channels of Sampling Area B. Channels C.1–C.4 can be seen from left to right in the photograph and are distinguishable by darker vegetation. The site of Loma Reyes can be seen on the far left.

agricultural intensification, and landscape modification. In both regions, the expansion of settlements and agriculture would have accelerated erosion and runoff into the upper drainage basin of the Río Verde. It was hypothesized that accelerated erosion and runoff in the upper basin would have led to an increase in flooding and alluviation in the lower Río Verde Valley as well as a shift in the river from a meandering to a braided pattern.

The geomorphological data collected in 1988 were consistent with the hypothesized shift in the depositional regime of the Río Verde (Joyce, 1991a, 1991b; Joyce et al., 1989; Mueller, 1991a), and are described in this section. Three general sediment types were distinguished in the subsurface testing and were indicative of three distinct depositional environments. The three sediment types were: coarse multimineral sands which resulted from high-energy deposition within the river channel (i.e., lateral accretion); fine silts, clayey silts, and silty clays which resulted from moderate-to-low-energy overbank deposition (i.e., vertical accretion); and dense organic clays which were formed by low-energy deposition due to the gradual infilling of oxbow ponds. The distribution of the three sediment types across the floodplain, their association with abandoned channels, and their stratigraphic relationships allowed two distinct depositional regimes to be distinguished for the Late Holocene in the lower Río Verde Valley. The earlier regime was associated with a single channel, C.1, that runs along the western edge of the floodplain up to 5.5 km from the present day river (Figure 4). The subsurface data demonstrated that C.1 had a

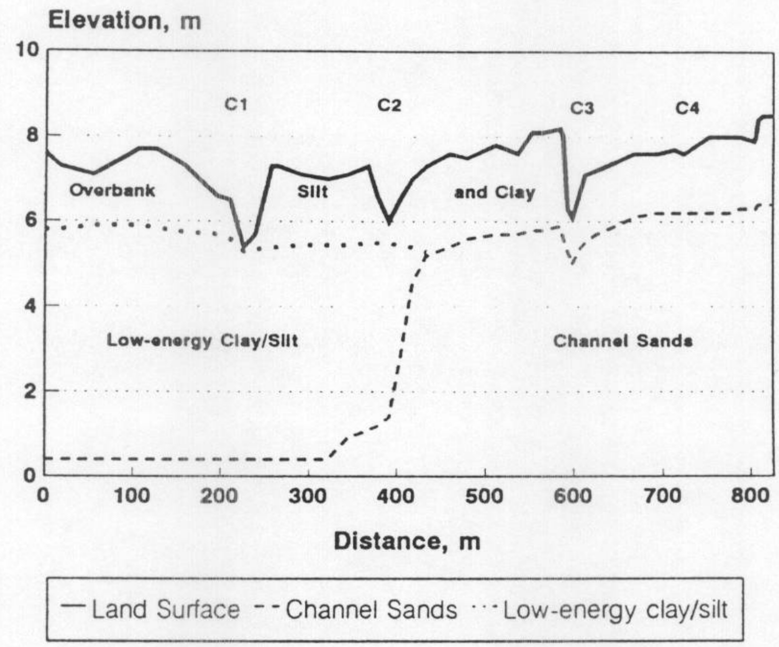

Figure 6. Sampling Area B transect showing abandoned channels and elevation above sea level.

meandering pattern relative to more recently abandoned channels and the river today. The more recent regime was associated with most of the abandoned channels observed in the floodplain, especially the series east of Loma Reyes designated channels C.2–C.10. These channels exhibited more of a braided pattern than C.1 and resembled in form the river today.

Samples West of the River

The data from Sampling Areas A, B, and C record the shift in depositional regimes of the lower Río Verde Valley. These data also demonstrate that the floodplain west of the river has been subjected to considerable geomorphic change over the past few millenia.

Figure 6 shows the surface profile and the stratigraphic relationships of the three sediment types from the Sampling Area B transect east of Loma Reyes. The series of abandoned channels is clearly visible. The westernmost channel is C.1 while the three to the east are C.2, C.3, and C.4. The channel sands associated with C.1 underlay by about 5 m the channel sands of the series to the east which along with the nature of the overlying sediments demonstrated that C.1 was active prior to the other channels in the transect. The deep clay deposits above the channel sands of C.1 demonstrated that after its abandonment this portion of the channel became an oxbow pond that was gradually filled with sediment. The dense, organic clays deposited in the oxbow pond outlined the profile of the channel. This profile shows a deep well-defined channel consistent with a meandering river pattern. Because the clays were deposited under low-energy conditions, it would have taken many centuries to accumulate the 5 m thick deposit that filled the oxbow.

A test pit (Op. LR88 A) was excavated alongside C.1 and adjacent to the large platform of the Loma Reyes site. The uppermost stratum in Op. LR88 A (A-F1) consisted of occupational debris with sherds. The ceramics included late Terminal Formative Chacahua Phase (A.D. 100–250) material in the upper portion of A-F1, changing to early Terminal Formative Miniyua Phase (100 B.C.–A.D. 100) material towards the middle of the layer along with a few Late Formative Minizundo Phase (400–100 B.C.) sherds towards the base. The chronologically correct sequence in A-F1 indicates that the sherd bearing colluvium accumulated as the site was occupied, rather than after its abandonment.

Beneath A-F1 were three strata deposited naturally (A-N1, A-N2, A-N3). The lowermost stratum (A-N3) consisted of weathered granites and gneisses that represented either colluvial deposition from the ridge approximately 250 m to the west of the pit, or weathered bedrock. A-N2 was a buried A-horizon and, given its location and texture, was probably the ancient levee for channel C.1. The formation of an A-horizon on the levee of C.1 indicates that depositional conditions were relatively stable, a situation consistent with a meandering river pattern, but not a braided one. No buried soils have yet been found associated with levee deposits postdating the sedimentological transition. Overlying A-N2 was a layer of clayey silt alluvium (A-N1) which may have represented the first pulse of sediment marking the change in depositional conditions prior to the actual shift in the river. A-N1 must have been deposited relatively rapidly, or it would have been incorporated as part of the levee soil (A-N2). The Loma Reyes site was apparently first occupied shortly after the channel was abandoned. It is unlikely that the mound at Loma Reyes would have been built while the channel was still active since the area would have been subjected to both erosion along the cut bank and seasonal flooding. Since the earliest ceramics were from the Minizundo phase, and the site was apparently occupied shortly after the river shifted its position, the time of abandonment of C.1 can be estimated as approximately 500–200 B.C. The earlier coarse-textured sands into which channel C.1 was incised were probably deposited during the Early Holocene as sea level began to rise (Mueller, 1991a).

The series of channels to the east of C.1 correspond to the more recent depositional regime. These channels have surface and subsurface forms suggesting a high width/depth ratio, much like the present-day river, and consistent with a braided rather than a meandering pattern. The data indicate that the river has been moving back and forth across the floodplain in this area since the shift in depositional regimes occurred, producing a palimpsest of abandoned channels. The predominance of lateral accretion resulting from channel migration was seen in the broad deposits of alluvial sands that occurred near the surface throughout this area, and in the relatively small buildup of overbank deposits (< 2.5 m). Furthermore, detailed topographic maps of the floodplain show only a slight gradient from Loma Reyes to the present-day river. Such a gradient is most consistent with a history of channel migration since the movement of the river through this area of the floodplain would have served to level the land surface, preventing formation of a marked levee. A sediment pit excavated in channel C.4 (S88-B9) exhibited a sequence of two layers of alluvial sands separated by overbank deposits, demonstrating that the river occupied this position at several distinct times in the recent past. A radiocarbon date of 210 ± 70 B.P. (Beta-26220) was obtained from wood associated with the lower deposit of channel sands in this pit. This shows that as recently as A.D. 1670–1810 the Río Verde was located there, roughly 2 km from its present position.

In Sampling Area B the river was free to migrate across the floodplain. North of this area, however, the river is constrained both by the piedmont proper and by a series of bedrock hills in the floodplain. This effect is most pronounced at Río Viejo where hills on both sides of the Verde constrict the river (Figure 4). Sedimentological data from the Sampling Area A transect indicate that these constraints have led to greater stability in the position of the river.

The data indicate that when the depositional regime changed between 500 and 200 B.C., the river north of Río Viejo shifted rapidly from C.1 to its present location. The sedimentological pits in the transect contained up to 7 m of overbank deposits, demonstrating that the primary process in this area has been vertical accretion (Figure 7). The topographic profile for this transect shows a positive gradient towards the present day river in terms of both surface elevation and the buildup of channel sands. This shows that the river in this portion of the floodplain has been relatively stable and aggrading for some time. Channel C.1 must predate the sediments in the transect because in this part of the floodplain it lies approximately 2 km to the west in the direction opposite the gradient (Figure 4).

The data from Sampling Area A also indicate that as the Río Verde migrated across the floodplain from west to east it alluviated its bed, thereby increasing channel elevation (Mueller, 1991a). Rather than thickening towards the river as expected in a natural levee (Allen, 1965; Davis, 1983; Friedman and Sanders, 1978), vertical accretion deposits in the Sampling Area A transect become thinner (Figure 7). Instead, the rise in surface elevation near the river is caused by an increase in elevation and thickness of the underlying channel sands. These data are consistent with alluviation of the channel caused by an increase

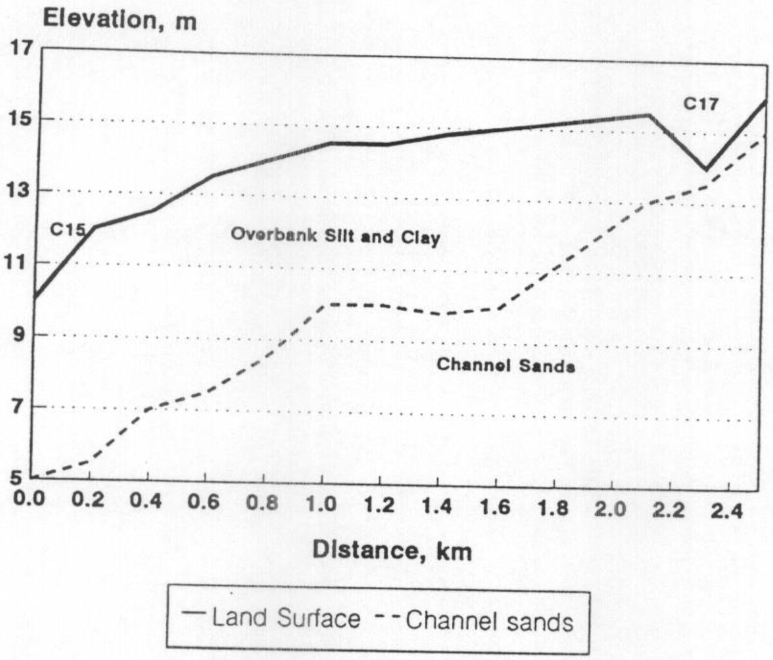

Figure 7. Sampling Area A transect showing abandoned channels and elevation above sea level.

in sediment load delivered to the lower Río Verde from the highland valleys beginning about 500–200 B.C.

Sedimentological data from archaeological operations at the site of Río Viejo (Ops. RV88 B and C) show that a dramatic increase in alluviation occurred there, at about the same time that C.1 near Loma Reyes was abandoned, confirming the timing of the hypothesized shift. Preoccupational strata in Op. RV88 B consisted of alluvial clays and silty clays, including a probable buried paleosol indicative of stable low-energy deposition in the floodplain, probably some distance from the river. The earliest archaeological deposits in Op. RV88 B dated to the late Middle Formative Charco Phase (500–400 B.C.) and were contained in a matrix of silty-clay and clayey-silt alluvium indicative of slightly higher energy conditions. Deposits dated to the Minizundo Phase were primarily features constructed by humans; however, near the base of the Minizundo Phase deposits were two layers of alluvial silts that suggest periodic moderate-energy flooding. Similarly, data from Op. RV88 C, located 50 m north of Op. RV88 B, suggest the onset of alluviation during the Minizundo Phase (Joyce, 1991a:480). Analysis of stratigraphic data from excavations at Charco Redondo and Charco Redondo Río (Figure 4) in 1986 also suggests an increase in alluviation during the Late Formative (Gillespie, 1987; Joyce, 1991a:489–492).

Comparison of sedimentological data from Sampling Areas A and B suggest that the shift in the position of the river probably occurred within a period of a few hundred years. From the Sampling Area B data, it is estimated that C.1 was abandoned between 500 and 200 B.C. Increased alluviation at Río Viejo during the Minizundo Phase (400–100 B.C.) indicates movement of the river at that time to the area east of that site. Despite the rapidity of the shift, an abandoned channel (C.15) alongside the site of Cerro de la Cruz (Figure 4) may represent a location of the Verde during the transition between the two depositional regimes. Sedimentological sampling in C.15 indicates that the channel was active during or prior to the Miniyua Phase (100 B.C.–A.D. 100) and that it probably persisted as an oxbow pond for some time after its abandonment. Preliminary data from another channel (C.16) located south of Río Viejo (Figure 4) suggests that it too may have been a transitional channel (Joyce, 1991a:492–495).

Samples East of the River

Data from Sampling Area D confirmed the preliminary surface observations (see above), indicating geomorphic stability on the east side of the river relative to the west during the last few millennia. A single auger core sampled approximately 3.5 km northeast of Charco Redondo (A88-D1), exhibited a more mature soil profile demonstrating geomorphic stability. Sedimentological data from both an archaeological test (Op. LC88 A) (Winter, n.d.) at the site of La Consentida (Figure 4) and an auger core (A88-D2) about 20 m west of Op. LC88 A also showed moderately well-developed soil profiles. The geomorphic stability indicated by these data is characterized by the gradual accumulation of sediment on the floodplain at a rate that could be incorporated into the soil profile as it developed (Mueller, 1991a). Clay content showed a distinct B horizon indicative of clay translocation. A sample from a similar topographic position (A88–A15) collected from the west side of the river did not show the degree of profile development seen in A88-D1, east of the river. Soil colors east of the river were also slightly darker near the surface, suggesting higher organic matter content, and redder in the subsoil. Therefore, the data from Sampling Area D suggest that the Río Verde has not migrated very far east of its present location during recent millennia.

It is not clear from the available data why the Río Verde has not shifted further east in the area south of Río Viejo (Figure 4), where hills do not constrain the movement of the river. The area of the floodplain east of Charco Redondo is at a relatively low elevation and should offer the river a shorter route to the sea. It is possible that there are resistant rock outcrops similar to the hills at Río Viejo and Cerro de la Cruz lying just below the surface east of the river that prevent the Verde from shifting in that direction. Additional subsurface testing is needed to determine why the river has not shifted to the east.

Overall, the sedimentological data collected by the RVFP are consistent with the hypothesized shift in the geomorphology of the Río Verde. The data indicate that discharge and sediment in the lower Río Verde increased between 500 and 200 B.C. and triggered a shift from a stable meandering pattern flowing through channel C.1 to a braided pattern. North of Río Viejo the river shifted to its present location and vertical accretion was in evidence. South of this point, lateral accretion began as the river migrated back and forth across the floodplain, as it continues to do today. The shift in the drainage dynamics of the river were predicted from and apparently triggered by population growth and land-use changes in the Oaxaca and Nochixtlán valleys. Other factors such as tectonics, climatic change, and sea-level rise cannot be entirely eliminated as having had an impact on the hydrology of the Río Verde. However, given the available data, Mueller (1991a) argues that these factors are unlikely to have had a significant impact on hydraulic changes in the lower Río Verde during the past 3000 years. The next section considers the effects of Late Formative environmental change on populations of the lower Río Verde region.

THE SOCIAL RESPONSE TO ENVIRONMENTAL CHANGE

Today the lower Río Verde Valley is one of the most productive agricultural areas in Oaxaca (Rodríguez et al., 1989). Abundant rainfall combines with the rich soils of the expansive floodplain to create a large area for highly productive agriculture. The paleoenvironmental data suggest, however, that this valley was considerably less attractive under the earlier depositional regime. Specifically, prior to the Late Formative, both the river and its floodplain were smaller. Floods depositing alluvium that replenished soils and maintained agricultural productivity were much less frequent. In addition, the position of the river, hugging the western edge of the valley along the piedmont, would have left only a small area for floodplain development to the west. Furthermore, sedimentological data from the 1986 excavations at Barra Quebrada indicate that the barrier islands along the lower Río Verde coastline had yet to form at that time (Joyce, 1991a; Winter and Joyce, 1987). This suggests that today's large estuaries were then much more open embayments, so that the abundance of estuarine species may have been limited.

The less attractive environmental conditions prior to ca. 500–200 B.C. may explain, at least in part, the paucity in surface survey of sites predating the shift in the river (Grove, 1988; Joyce, 1991a). Only a single site has been dated to the period before the shift in the depositional regime of the Río Verde. Excavations at Charco Redondo in 1986 recovered a small number of Early/Middle Formative sherds and figurines (Gillespie, 1987) that probably reflect sporadic settlement of the site between 1500 and 500 B.C.

The small number of early sites in the lower Río Verde Valley is surprising in that the Pacific coast of southern Mexico and Guatemala was a focus of population during the Early/Middle Formative (Brush, 1969; Clark, 1991; Coe and Flannery, 1967; Lowe, 1975; Zeitlin, 1979). Indeed, the lower Río Verde Valley was originally chosen for investigation because of its current ecological similarity to the environments of early village settlements in Mesoamerica (Grove, 1985). A diverse ecology characterized by the presence of a river with a fertile floodplain and an extensive estuary system is shared by the earliest villages on the Soconusco Coast (Ceja, 1985; Clark, 1991; Coe and Flannery, 1967; Lowe, 1975), the coastal lowlands of Veracruz and Tabasco (Coe and Diehl, 1980; Rust and Sharer, 1988), and Laguna Zope in the southern isthmus (Zeitlin, 1979). Voorhies (1976) has also located several Late Preceramic sites associated with large estuaries on the Chiapas Coast. In addition, the lower Río Verde Valley is located within 350 km of two areas containing important Early Formative sites: Puerto Marqués on the Guerrero coast (Brush, 1965, 1969) and Laguna Zope cited above (Zeitlin, 1979). Rosenthal (1960–1962:14) reported Early Formative figurines from her survey and excavations along the Costa Chica of southeastern Guerrero, a mere 75 km northwest of the lower Río Verde.

The possibility cannot yet be eliminated that alluviation in the lower Río Verde Valley could have buried early sites. It is also possible that sites may have been destroyed by the movement of the river in the area of the floodplain between Loma Reyes and Río Viejo (Figure 4). However, most other areas of the floodplain have not been destroyed by river migration during the last few millennia so that early sites should be intact, although they may be deeply buried by alluvium. The sedimentological sampling program also excavated auger cores and test pits in "nonsite" contexts throughout the floodplain without locating buried sites.

The amount of surface and subsurface coverage in the region suggests that the small number of early sites is not the result simply of sampling bias. The two archaeological projects that have been conducted in the lower Río Verde Valley since 1986 have located 75 sites; eight sites have been excavated, all with occupations dating to the latter part of the Formative between 500 B.C. and A.D. 250 (Grove, 1988; Joyce, 1991a). Several land surfaces in the floodplain and piedmont have also been identified geomorphologically as sufficiently old for Early Formative mounds to be observable on the present surface. One area with a comparatively old land surface is the narrow strip of floodplain between channel C.1 and the piedmont to the west. Even with a smaller floodplain and the meandering river conditions that appear to have prevailed prior to 500–200 B.C., the close proximity of the river should have made the area west of C.1 a relatively resource-rich setting during the Early/Middle Formative. However, surface reconnaissance along C.1 in 1988 failed to locate sites earlier than the Late Formative. Given the scope of this work, the paucity of sites predating the Charco Phase (500–400 B.C.) seems more likely to be indicative of low population density rather than sampling bias.

Therefore, the lower Río Verde does not at present appear to have been a focus of Early/Middle Formative settlement, as had been hypothesized in 1985 from the current ecological characteristics of the region. While alluvial burial and destruction of sites cannot yet be eliminated as a factor explaining the lack of early sites, the present data suggest that the region was sparsely inhabited. Lower agricultural potential in the coastal valley prior to ca. 500–200 B.C. may help explain the scarcity of early sites. Other regions along the Pacific coast appear to have attracted and sustained larger populations because fertile agricultural land made them easier to exploit (e.g., Brush, 1969; Clark, 1991; Zeitlin, 1979).

The increased flooding and alluviation brought on by changing land-use practices in the highlands undoubtedly raised the agricultural productivity of the lower Río Verde floodplain. Such productivity in the lower Río Verde Valley would have increased as topsoil was eroded from the highland valleys and deposited along the lowland floodplain. The fine silts and clays deposited along the floodplain were ideal for agriculture. Moreover, the migration of the river created low-lying areas where the water table was high, allowing maize to be grown through the dry season. The movement of the river to the east also would have opened up additional areas of floodplain land on the western side of the river. Aggradation of the Verde raised the water table in the lower valley and increased the moisture content of the soil (today, at least during the dry season, the Verde is a losing stream with a ground water table gradient away from the river and thus feeding water into the surrounding floodplain). The higher water table would also have increased the irrigation potential of the floodplain (Joyce, 1991b).

While the shift in the position of the river appears to have been relatively rapid (within 100–300 years), the resulting buildup of alluvium and its benefits to agriculture were probably more gradual phenomena. Archaeological excavations at Río Viejo demonstrate that the floodplain was still aggrading during the Late Classic Period (A.D. 550–900; Joyce, 1991a:484). The absence of well-developed soils postdating the Late Formative suggests that the floodplain has been aggrading at a relatively constant rate following the depositional transition.

Given the general poverty of the Oaxaca coast in terms of agriculture (Joyce, 1991a), a significant increase in the agricultural potential of a region would have made it a newly attractive location for human settlement. Population would be expected to rise as a result of increased immigration into the region and/or increased rate of population growth. Increasing agricultural productivity may explain, at least in part, the apparent rise in population in the lower Río Verde region at the end of the Formative Period (Table I). This was the period of most rapid increase in the number of sites as recorded by surface survey in the region. Site totals increasing from 5 during the Charco Phase (500–400 B.C.) to 45 by the Chacahua Phase (A.D. 100–250). When the length of phases are standardized based on a 100-year interval, the number of sites in the region triples from the Minizundo (400–100 B.C.) to the Miniyua Phase (100 B.C.–A.D. 100). Settlement size and societal complexity also increased considerably during this period. Archaeological evidence for a two-tiered settlement hierarchy, ascribed status differences, elite control of prestige goods, and

Table I. Lower Río Verde Valley: absolute and standardized site totals.

Phase/Period and Date	Absolute Totals	Standardized Totals
Charco Phase (500–400 B.C.)	5	5
Minizundo Phase (400–100 B.C.)	20	7
Miniyua Phase (100 B.C.–A.D. 100)	41	21
Chacahua Phase (A.D. 100–250)	45	30
Classic Period (A.D. 250–900)	47	7
Postclassic Period (A.D. 900–1521)	54	9

Standardized totals are based on the assumption that each site was occupied for a 100-year period. Ceramic phases have only been described in detail for the Formative Period so that after A.D. 250 site totals are grouped according to general Mesoamerican time periods (see Joyce, 1991a).

large-scale construction activities suggest that one or more chiefdoms existed in the region during the Minizundo Phase (Joyce, 1991a, 1991b, 1991c). By the Terminal Formative the site of Charco Redondo probably approached 100 ha (Gillespie, 1987). During later periods the absolute number of sites continued to increase at a slower rate, but standardized site numbers actually declined due apparently to settlement nucleation.

In addition to the rich agricultural land within the floodplain, several oxbow ponds that formed in low-lying sections of abandoned channels created attractive locations that offered a year-round water source and populations of fish and birds. Several sites including Cerro de la Cruz and Loma Reyes were located alongside deep deposits of heavy organic clays resulting from the infilling of oxbow ponds. The archaeofaunal data from Cerro de la Cruz, especially the presence of catfish, *mojarra,* and duck, are consistent with the exploitation of an oxbow pond (Joyce, 1991b; Quitmyer, 1991).

CONCLUSIONS

In conclusion, the combined geomorphological and archaeological research indicates that anthropogenic landscape alterations were affecting ecological relationships in parts of Oaxaca more than 2000 years ago. During the Late Formative, changing land-use practices in the Oaxaca and Nochixtlán valleys apparently had a negative local effect as people were forced to abandon piedmont areas due to soil depletion. However, sediments eroded in the highlands were carried downriver and deposited along the floodplain of the lower Río Verde thereby increasing the agricultural potential of that region.

The changing geomorphology of the Verde may have provided at least part of the impetus for Late/Terminal Formative population growth by increasing agricultural productivity and making the region more attractive for human settlement. Rising population during the Late/Terminal Formative provided the necessary demographic conditions for the emergence of social complexity (Joyce, 1991a, 1991b, 1993). The increased importance of the lower Río Verde Valley in terms of population and agriculture may also have attracted attention from people in other regions and stimulated exchange and other forms of social interaction. Archaeological research by the RVFP has shown that people in the lower Río Verde Valley were involved in an extensive network of interregional exchange during the Late Formative involving materials such as fancy pottery, obsidian, and probably marine shell (Joyce, 1991a, 1991b, 1993). Thus, one result of the geomorphic interaction between highlands and lowlands may have been to pave the way for direct social interaction between the regions. The research carried out by the RVFP has demonstrated that intensive agriculture in the upper drainage basin of the Verde affected both local highland populations and people in the lower valley over 150 km to the south. The results of the project highlight the advantages of an interdisciplinary approach for examining the effects of intensive agriculture on prehispanic landscapes in Mesoamerica.

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APPENDIX

A shorthand code was used to designate all sedimentological and archaeological samples. Each sedimentological sampling locus was considered a separate operation. The shorthand code provided information on the methodology, year, and provenience of the sample. The first component of the code designates the sampling methodology (see below) and year (1988). Sedimentological pits, including the auger cores beneath the pits, were abbreviated S88. Auger cores outside of sedimentological pits were abbreviated A88. The notation for methodology and year was followed by a hyphen and a letter and number combination signifying the sampling area and specific sample number within that area. Sampling points were numbered sequentially within sampling areas. For example, a transect of auger cores excavated in the area of the Loma Reyes site was designated Sampling Area B. The first auger core in this area was designated A88-B1 and the second was A88-B2. The ninth sampling point in Area B was a sedimentological pit and was designated S88-B9. Strata within sedimentological pits and auger cores were numbered sequentially and differentiated as naturally deposited strata (N) or archaeological features (F; e.g., A88-B1-N1 refers to natural stratum 1 of auger core B1).

Each archaeological excavation and examination of preexisting natural or artificial exposures (e.g., river cuts, wells) was considered a separate archaeological operation (Shook and Coe, 1961). Proveniences for the operations were designated by site (e.g., LR for Loma Reyes) and year (88) abbreviation, and a letter designating the particular operation. As with the sedimentological operations, strata within archaeological excavations were numbered sequentially and differentiated as naturally deposited strata (N) or archaeological features (F).

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