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Alluvial archives of the Nochixtlan valley, Oaxaca, Mexico: Age and significance for reconstructions of environmental change

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ABSTRACT

A reconnaissance of the Nochixtlan valley confirms that thick alluvial deposits of the late Quaternary are both well preserved and well exposed along the heavily incised modern streams. Their geometry and age were ascertained by logging representative cutbank exposures and radiocarbon dating buried palaeosols. The last four cut-and-fill cycles recorded cover the period since 14,000 BP, but older alluvial insets are also present. Contrary to previous reconstructions, the streams have had an arroyo-type morphology throughout the late Quaternary. The climatic oscillations at the transition from the Pleistocene to the Holocene seem to be expressed in the alternating formation of clayey organic-rich cumulic A horizons, and the precipitation of secondary carbonates. Rapid though intermittent aggradation set in after 10,300 BP in response to the establishment of a rather dry, warm and strongly seasonal climate and of open canopy forest or scrub on slopes. The unstable arroyo floodplains offered a favorable niche for the establishment of secondary vegetation and foragers exploiting annual and heliophilous plants. After 4000 BP sedentary farmers cleared the valley of its natural vegetation increasing sediment transfers and the frequency of local cut-and-fill cycles. They modified streams intentionally by building long flights of cross-channel agricultural terraces known as *lama-bordos*, the remains of which are preserved in many cutbanks. The oldest specimen dated goes back to ca. 3000 BP. A remarkably synchronous incision swept through the fluvial system close to 800 BP, possibly as a result of a marked climatic shift or valley-wide changes in land use. The widespread gullying of the latest pre-Conquest settlements and fields suggests the introduction of grazing or the collapse of hillside terraces as cause, but coeval alluvial fills have not yet been positively identified.

1. Previous research

The Mixteca Alta of northwestern Oaxaca is known for its spectacular erosional landforms. The barren slopes, deep gullies, dry streambeds, and the generally small and poor villages, all add to the rugged relief to create an impression of an isolated and inhospitable country. However, the region also has a reputation for the abundance of prehispanic ruins and artifacts, and the sumptuousness of its early Colonial architecture. This contrast has been noted by even casual visitors, and many have tried to link environmental change and cultural history. Scholarly attempts at explanation go back to the Berkeley researcher Sherburne Cook (1949), who observed the severity of erosion in different valleys and sketched the stratigraphy of cutbanks near the bridges of the Pan-American highway. He assigned tentative ages to the deposits on the basis of artifactual inclusions, the degree of development of buried palaeosols, and ideas he held about the general pace of erosion and soil formation. After comparing these to Colonial records that suggested much higher populations before the introduction of European diseases, he concluded that the countryside scarred by erosion bore testimony to its over-exploitation by prehispanic farmers. Most of Cook's frames of reference are outdated, which makes his conclusions questionable, but he is to be credited with recognizing the alluvial deposits of the Mixteca as an important archive of environmental change.

This article focuses on the Nochixtlan valley (Fig. 1), which holds the largest expanse of alluvial bottomlands in the Mixteca Alta. The valley has been explored more thoroughly by archaeologists than by natural scientists. Excavations at several sites documented occupations from 4500 BP to Colonial times (Caso, 1938; Lorenzo, 1958; Spores, 1974; Zárate, 1987; Robles García, 1988; Winter, 1994; Blomster, 2004). A valley-wide survey of archaeological sites was conducted by a Vanderbilt project (Spores, 1972), complemented by surveys covering smaller areas (Plunket, 1983; Byland and Pohl, 1994; Kowalewski et al., 2009). We know that the valley was frequented by hunter–gatherers, had sedentary farming villages by 3600 BP, and urban centers by

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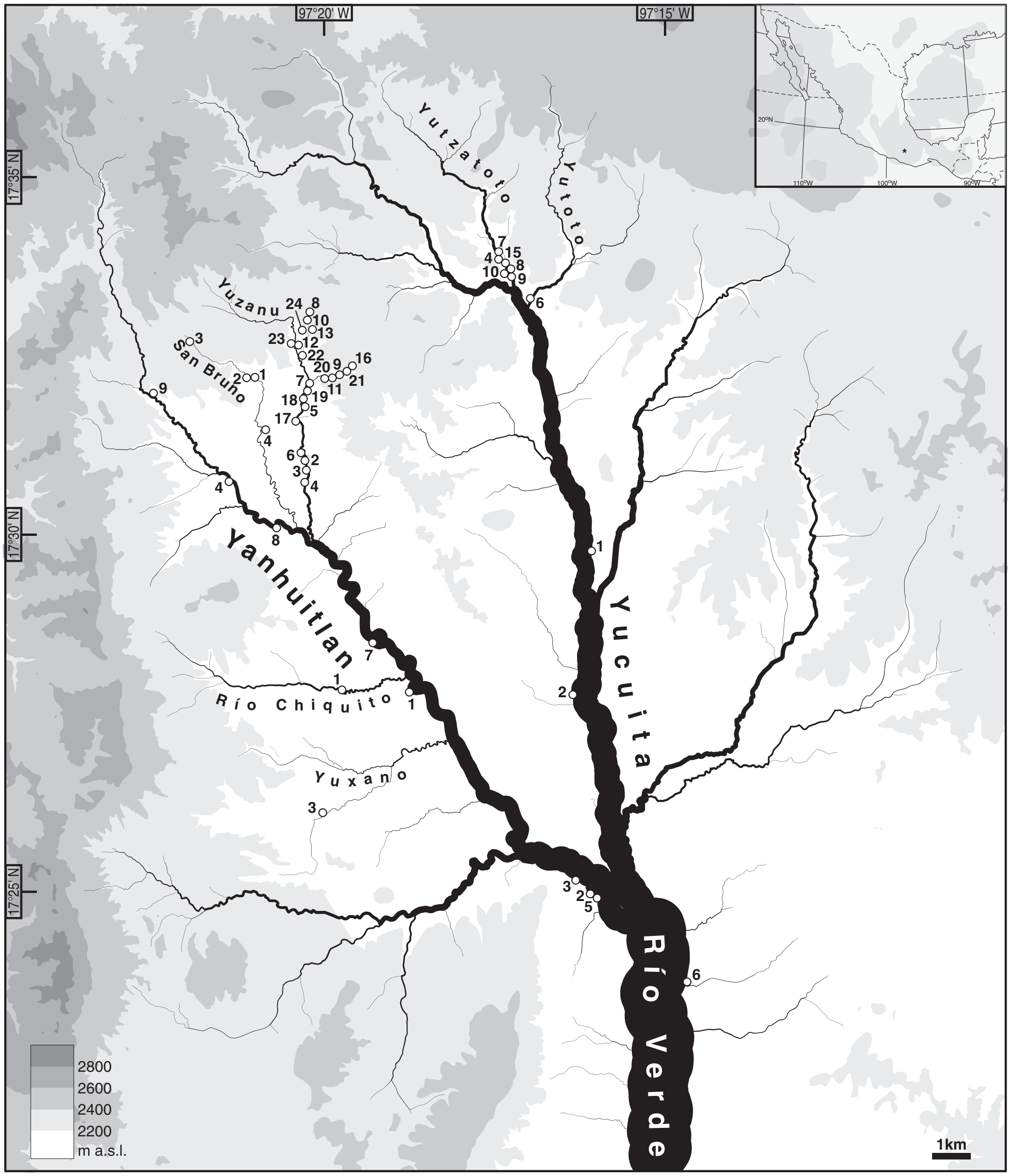

Fig. 1. The stream network of the Nochixtlan Valley and cutbank exposures mentioned in the text. Line thickness is proportional to stream magnitude. First-order streams and streams disjointed from the main network are not shown.

2200 BP. The Vanderbilt project involved natural scientists who produced thoughtful discussions of the changes in vegetation, hydrology and soilscape that the valley had undergone with more than 3000 years of farming (Spores, 1969; Kirkby, 1972; Smith, 1976). Michael Kirkby's report went far beyond Cook's observations, as it included an exhaustive consideration of geological, climatic, and human factors that shaped stream behavior. He also made an ingenious attempt to identify episodes of most severe erosion by observing stratigraphic relationships between erosional landforms, alluvium, the remains of prehispanic settlement, and Colonial waterworks.

Our aim below is to carry Kirkby's research one step further, by providing the foundations for a radiocarbon-dated chronology of alluviation in Nochixtlan, to relate it to what is currently known about natural and anthropogenic environmental change in highland Mexico, and to formulate hypotheses regarding the causes and effects of soil erosion and variations in stream behavior over the last 15,000 years. A few of our dates from Nochixtlan were previously referred to in a more general article on land degradation in Oaxaca (Joyce and Mueller, 1997), but here we offer a detailed report of new findings, and a substantial revision of previous conclusions.

2. Geographical setting

The Nochixtlan valley encompasses some 500 km^2, to the west of the continental divide, at altitudes that vary between 2000 and 2900 m a.s.l. It has a temperate climate, with mean annual temperatures on the valley floor close to 16 °C. Precipitation is markedly seasonal, with more than 80% falling between May and October. It is also highly unpredictable, with extreme local and interannual variation. It averages between 450 and more than 1000 mm, displaying a positive but relatively weak correlation with altitude (CLICOM, 2006). These parameters place the valley in the oak-and-conifer forest zone of potential vegetation (Rzedowski, 1978), though close to an ecotone to xeric scrub, especially at its eastern edge. Today the only vegetation that could be described as 'natural' consists of patches of pine and oak at high altitudes.

The most extensive bedrock in the valley center is the Tertiary Yanhuitlan Formation (YF) (Ferrusquía Villafranca, 1976; INEGI, 1984). Its properties are crucial to understanding the character of erosion and stream behavior in Nochixtlan. It consists mostly of red shales, with some intervening beds of sandstone, conglomerate and limestone. The YF is fine-grained, very weakly consolidated, permeable, and rich in bases. It offers little resistance to channel incision, which can proceed for tens of meters of its thickness and yields few large clasts, so that streambeds never become armored with gravel. It gives rise to regosols, cambisols, castanozems, and calcisols with A–C, A–Bw–C, or A–Bk–C profiles. A horizons are rarely more than 20 cm thick. Only occasionally do these soils remain stable long enough to develop into luvisols with Bt horizons, or to form a weak layer of caliche that hardens after subaerial exposure. In contrast to most soilscapes of the Mexican highlands there is thus no duripan-forming subsoil (see Etchevers et al., 2003) that would set a local base level to gullying. Different conditions obtain at the edges of the valley, where andesitic lavas or limestone crop out. Both are less erodible than the YF, and the volcanics also less permeable. To the east, the conglomerates become more prominent within the YF, offering more resistance to erosion and a ready source of gravel.

The valley is drained to the south by the Río Verde, which forms at the confluence of the trunk streams of its two main arms that we refer to as the Yucuita and Yanhuitlan rivers. Drainage density is notably higher over the shales, reaching astronomical figures of 100 km^{-1} in the heavily gullied headwaters of the Yuzanu stream (Kirkby, 1972; Fig. 2). The Río Verde, lower Yanhuitlan, and higher-order reaches elsewhere maintain a baseflow throughout the year, though it dies down to a trickle during the dry season. The system receives practically no input from springs, and is governed mostly by flash floods of the wet season. Stream channels at nearly all points of the network are heavily incised, with narrow floodplains confined between either near-vertical walls of older alluvium, or steeply sloping walls of bedrock (Fig. 3). To judge by the palaeochannels exposed and the overall geometry of alluvial deposits that we describe in this article, they have maintained this arroyo-like morphology throughout the late Quaternary. Like their counterparts elsewhere (Elliott et al., 1999), the arroyos have gone through several cut-and-fill cycles. Instead of forming stepped terraces, they tend to leave insets 'nested' within one another and only fragmentarily preserved (Waters and Haynes, 2001). The proximate controls of either incision or aggradation, and of their pace, are stream discharge and sediment load (Schumm, 1999). In the Nochixtlan case, and on the timescales we deal with, these will be determined in turn by climate, vegetation cover, land use, and, perhaps, occasional tectonic disruptions of local base levels and sediment supply.

We are not aware of any gauging stations in the valley, but some remarks on the proximate controls of stream behavior can be made on the basis of field observations and the interpretation of maps and air photos. As an imperfect substitute for measured discharge we have calculated link magnitude (Knighton, 1998) for all stream reaches depicted in INEGI (2000, 2001a–c) maps and made line thickness proportional to it in our Fig. 1. Strong lithologic control complicates the picture. As pointed out by Kirkby, the lower drainage density and the scarcity of areas of highest altitude and rainfall in the Yucuita arm mean that, at comparable magnitudes, its streams have lower discharges and sediment loads than those of the Yanhuitlan arm. Moreover, during periods of intensive agriculture, discharge was likely dissipated in watering fields, making some reaches influent and favoring local sediment storage. On the other hand, beyond the lowest-order streams, there are practically no bedrock knickpoints and few topographically conditioned sediment traps that would disjoint the fluvial system.

3. Methods and conventions

Our fieldwork was intended as a reconnaissance of the deposits available for study without recourse to remote sensing, coring or excavation. We walked the reach of the Río Verde shown in Fig. 1, the entire Yanhuitlan river, the Yucuita river downstream of the mouth of the Yutzatoto, as well as major portions of the Yutoto, Yuzanu, San Bruno, Chiquito, and Yuxano streams. Cutbanks where stratigraphic sequences seemed most representative or more complete than elsewhere, as well as those where walls and other cultural features were exposed, were selected for study. These are named combining sequential numbers with the acronyms Ver (Río Verde), Yan (Yanhuitlan), or

Fig. 2. Headwaters of the Yuzanu drainage. A. Gullied slopes underlain by red shales of the Yanhuitlan Formation. B. Alluvial insets of different ages. C. Ridge underlain by more resistant bedrock.

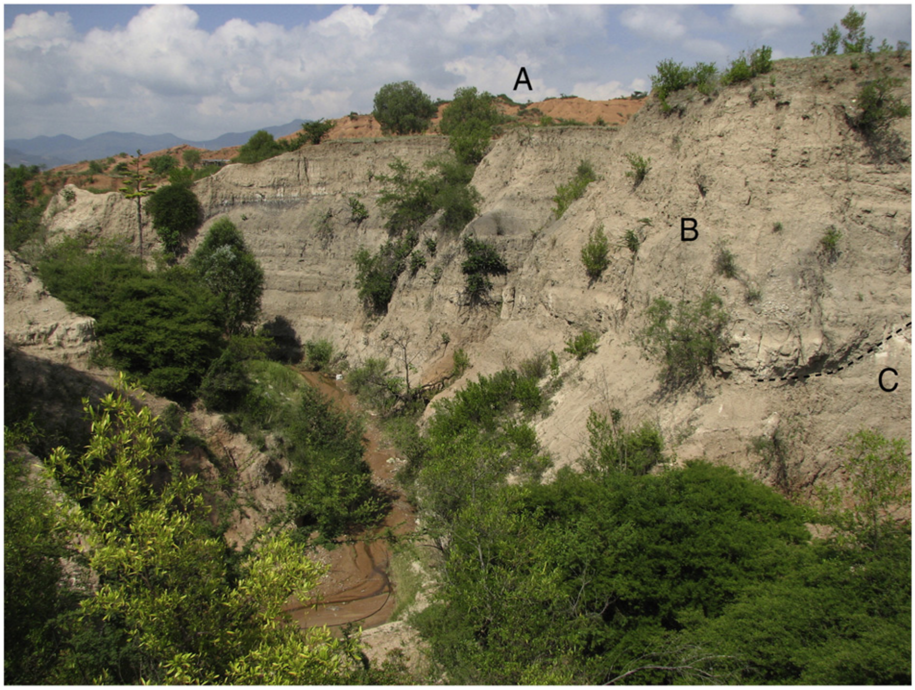

Fig. 3. Stream reach near Yuz22. A. Active gullies in the Yanhuitlan Formation. B. Inset of fill cycle 3. C. Inset of fill cycle 4.

Yuc (Yucuita) if situated along one of these streams. Others are identified by reference to the highest-order tributary of these three: Yutz (Yutzatoto), Yuz (Yuzano), etc.

Stratigraphic zones were defined on the basis of sedimentary and pedogenic attributes, and described using mostly the Soil Survey Staff (1993) nomenclature. Special attention was paid to palaeosols, as the most readily datable elements. The accumulation of organic matter on momentarily stable or slowly aggrading floodplains seems to have proceeded rapidly under most climates, while the development of soil structure and secondary carbonates was slower and more conditioned by climate, topography, and other factors. This means that most alluvial sequences display a vertical succession of several weakly developed A horizons with short residence times, ideal for direct radiocarbon dating, but of little use in correlation, or as regional indicators of landscape stability (*pace* Joyce and Mueller, 1997). There are nonetheless a few palaeosols whose advanced development and peculiar attributes do warrant such inferences.

Our chronology rests on the dating of bulk organic matter of buried A horizons, or of organic-rich alluvium (Table 1). All samples were cleaned of rootlets, and subjected to acid but not alkali washes, as our main interest lay in the age of soil burial, not the inception of soil formation (Matthews, 1985). We also took advantage of time-diagnostic ecofacts and artifacts, as well as buried walls of cross-channel terraces. Care was taken to distinguish sequences belonging to different cut-and-fill cycles, and to identify the unconformities separating them. Composite cross-sections (Figs. 5, 8, and 9) were drawn to summarize complex stratigraphic relationships along key reaches, and a selection of measured stratigraphic columns is presented in Fig. 10. We are not yet in a position to map alluvial surfaces of different ages, but in anticipation of this task are numbering fill cycles with Arabic numerals rising from youngest to oldest, with 0 marking fills under modern floodplains. The chronology is discussed in terms of calibrated years BP. For their uncalibrated equivalents the reader is referred to the data in Table 1 and to the right-hand timescale in Fig. 4. Below we describe deposits along three reaches that we judge to have been shaped by discharges and sediment loads of increasing magnitude. We then discuss the overall timing of changes in stream behavior and point to their possible causes.

4. Geometry and age of alluvial deposits

4.1. The Yutzatoto stream

The Yutzatoto drainage (Fig. 1) covers 18 km^2 and contains a large proportion of resistant, mostly volcanic bedrock. Its headwaters lie at ca. 2500 m, its mouth at 2120 m. The most informative exposures are along the 1.5 km above its mouth. Along this reach the valley is only 100 m wide, hemmed in by hills. The modern streambed is strewn with gravel and incised ca. 7 m below the well-preserved though discontinuous surface of a fluvial fill-terrace (Fig. 5). The topography of adjoining fields and isolated exposures near Yutz4 hint at the presence of a slightly higher terrace that contains mostly coarse-textured alluvium of the preceding fill cycle, but the contact between the two is not well exposed. All alluvium stored along this reach is set into landslide deposits with matrix-supported boulders and other colluvia from a hill to the west.

Yutz4 is the most representative exposure of the 7 m terrace. It contains a series of six different A horizons, separated by packets of buff-colored overbank muds. The bottommost palaeosol is an A horizon markedly overthickened by aggradation synchronous with strong enrichment in organic matter that imparted it a dark brown color. It breaks neatly into prisms conspicuously coated with clay. It is 50 cm thick at Yutz4, but since it has been scoured by channels 1–2 m wide and 0.2–0.5 m deep, it must have originally been even thicker. Given the cumulic properties and truncation, the date of 13,990 BP obtained on it corresponds to a moment during its formation, not that of its burial. The next higher palaeosol is similar in its macroscopic attributes, but only 0.25 m thick. At Yutz4 it can be distinguished from its predecessor only due to the presence of the intervening rills or channels, filled with medium-sized gravel. In other exposures, presumably those corresponding to the most distal floodplain, the two appear welded together. The upper one shows no signs of truncation prior to its burial by about 0.5 m of alluvium, capped in turn by a weakly developed, 0.25 m-thick grey A horizon dated to 5520 BP. The aggradation that followed raised the floodplain at Yutz4 by another 1.8 m. It stopped for a timespan sufficient for the development of a 0.3 m-thick dark grey A horizon with moderately strong prismatic structure, this one dated to 2990 BP.

Table 1
Radiocarbon dates from alluvial contexts.

Lab no.	Cutbank	Depth reference	Method	$\delta^{13}C$	^{14}C age BP	cal 2σ range	Midpoint
YUTZATOTO							
Beta248943	Yutz7	soil 1/1.6 m	AMS	−19.7	870 ± 40	910–700	800
Beta206256	Yutz7	soil 2/5.0 m	LS	−19.5	8500 ± 70	9600–9310	9450
Beta248942	Yutz4	soil 1/1.7 m	AMS	−19.8	2730 ± 40	2920–2760	2840
Beta189677	Yutz4	soil 2/2.6 m	LS	−21.2	2840 ± 70	3200–2780	2990
AA51074	Yutz4	soil 3/4.4 m	AMS	−19.5	4839 ± 58	5710–5330	5520
AA51073	Yutz4	soil 5/5.6 m	AMS	−19.1	12,134 ± 64	14,160–13,810	13,990
YUZANU							
Beta232658	Yuz8	soil 4/7.1 m	AMS	−21.7	2460 ± 40	2710–2360	2530
Beta232655	Yuz12	soil 1/7.7 m	AMS	−21.3	12,110 ± 70	14,150–13,790	13,970
Beta232656	Yuz9	upper soil/3.9 m	AMS	−22.6	7400 ± 50	8360–8050	8200
Beta232657	Yuz9	lower soil/7.4 m	AMS	−22.9	11,410 ± 60	13,410–13,140	13,270
Beta174199	Yuz7	lowest soil/4.3 m	LS	−25[a]	11,450 ± 80	13,460–13,140	13,300
Beta248941	Yuz5	soil 1/0.9 m	AMS	−19.3	4320 ± 40	5030–4830	4930
Beta269780	Yuz5	soil 3/4.5 m	AMS	−16.9	6970 ± 40	7930–7700	7810
Beta66290	Yuz2	soil 1/1.7 m	LS	−25[a]	4100 ± 80	4830–4430	4630
Beta66289	Yuz2	soil 5/5.6 m	LS	−25[a]	5920 ± 120	7150–6440	6800
Beta37864	Yuz2	soil 6/7.3 m	LS	−25[a]	5340 ± 90	6290–5930	6110
Beta37863	Yuz2	soil 7/9.0 m	LS	−25[a]	6170 ± 80	7260–6810	7040
Beta248940	Yuz3	bottom of paleochannel—0.1 m	AMS	−19.8	3510 ± 40	3890–3650	3770
Beta131039	Yuz4	bottom of paleochannel—0.1 m	LS	−25[a]	3560 ± 60	4070–3690	3880
YANHUITLAN							
Beta207568	Yan4	soil 2/4.1 m	LS	−16.7	9040 ± 70	10,390–9920	10,160
Beta232654	Yan8	soil 3/4.0 m	LS	−21.4	10,200 ± 60	12,110–11,630	11,870
Beta174201	Yan7	soil 1/1.9 m	LS	−25[a]	[6910 ± 110]	[7950–7580]	[7760]
Beta174202	Yan7	soil 6/5.1 m	LS	−25[a]	10,590 ± 130	12,730–12,080	12,400
Beta248937	Yan1	soil 1/0.9 m	AMS	−18.5	4570 ± 40	5450–5050	5250
AA45088	Yan2	soil 2/2.9 m	AMS	−17.9	1102 ± 33	1060–940	1000
AA45089	Yan2	soil 2/2.9 m	AMS	−25[a]	[post-bomb]	n/a	n/a
Beta174200	Yan2	soil 3/3.7 m	LS	−25[a]	2480 ± 70	2730–2360	2540
AA45087	Yan2	lower soil 5/6.3 m	AMS	−18.7	9246 ± 66	10,570–10,250	10,410
AA45086	Yan5	soil 3/1.6 m	AMS	−22.2	717 ± 33	720–570	640
RÍO VERDE							
AA45085	Ver6	soil 1/2.0 m	AMS	−15.7	2378 ± 34	2680–2340	2510
Beta248938	Ver6	paleochannel/5.1 m	AMS	−16.1	5030 ± 40	5900–5660	5780
YUCUITA							
Beta66288	Yuc1	soil 1/2.3 m	LS	−25[a]	980 ± 100	1120–690	900
Beta66287	Yuc1	soil 3/4.2 m	LS	−25[a]	1330 ± 80	1380–1070	1220
AA51072	Yuc1	auger hole/8.9 m	AMS	−20.5	5774 ± 67	6730–6410	6570
Beta85025	Yuc2	soil 1/1.6 m	LS	−25[a]	1510 ± 60	1520–1310	1410
Beta91138	Yuc2	soil 3/4.3 m	LS	−25[a]	3340 ± 80	3820–3390	3610
Beta85024	Yuc2	soil 4/6.1 m	LS	−25[a]	3510 ± 80	4060–3580	3820
YUXANO							
Beta248944	Yux3	soil 1/1.1 m	LS	−17.5	900 ± 40	920–740	830

AMS = accelerator mass spectrometry.
LS = liquid scintillation.
a = assumed, not measured.
[ ] = age thought to be unreliable.
Calibrated using IntCal09 curve in CALIB6.1.0. See Stuiver and Reimer (1993) for previous version of program.
The calibrated ages are rounded to the nearest 10 years.

The energy of the stream was at that time low enough to allow the building of a wall that crossed the channel, trapped waterborne muds, and turned the floodplain behind it into a cultivation surface. The Yutz4 cutbank has sectioned this 0.9 m-high wall at an oblique angle, exposing several courses of unfaced masonry, probably piled up gradually as the tread behind it rose (Fig. 6). Its use is bracketed by the mentioned date of 2990 BP, and one of 2840 BP, on the weakly developed A horizon draping over the uppermost course. Farther downstream, at Yutz8, Yutz9, and Yutz15, there are more walls of this type, at comparable elevations, in both left and right cutbanks (Trogdon, 2010). They indicate that close to 3000 BP this reach was turned into a flight of agricultural terraces known in the modern Mixteca by the term *lama-bordo* (Spores, 1969; Pérez Rodríguez, 2004, 2006). The left tributary of the Yutzatoto that joins it near Yutz4 contains a functioning set of these terraces (Fig. 7). Their Formative predecessors are difficult to relate to any site in particular, though substantial Cruz phase settlement has been documented a few kilometers downstream along the Yucuita (Spores, 1972; Plunket, 1983; Robles García, 1988).

After its abandonment, the Yutz4 wall was buried by another 1.6 m of silty clays, prior to the incision of the stream that breached the terrace walls and removed their fills. The Yutz7 cutbank, 200 m upstream from Yutz4, seems to correspond to the same terrace, though it is difficult to correlate with Yutz4 on pedostratigraphic grounds alone. We think this is due to the fact that it exposes a facies very close to the main channel axis, and is correspondingly dominated by coarse-textured deposits, including cross-bedded gravels. Near the base of the cutbank, however, one can recognize the same cumulic palaeosol as at Yutz4. The tooth of an extinct camelid embedded in its fine-grained matrix adds plausibility to the Pleistocene age of this

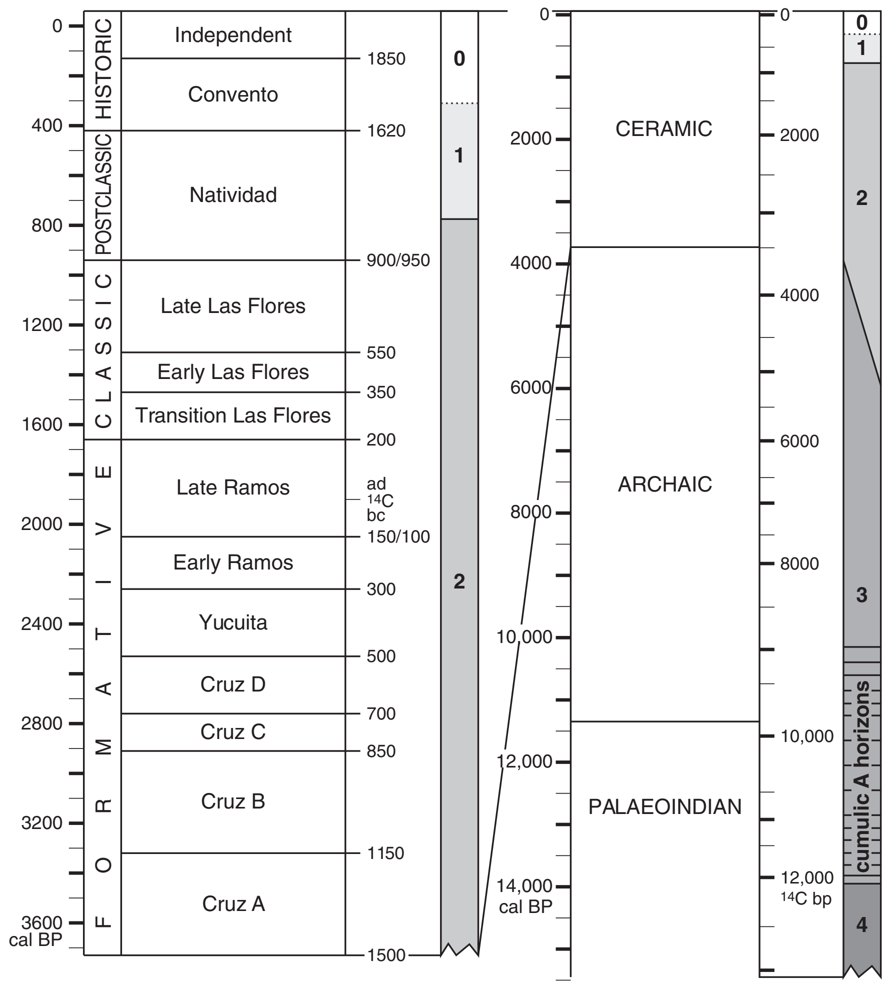

Fig. 4. Archaeological periodizations referred to in the text. Based on Blomster (2009) and Kowalewski et al. (2009). The right-hand columns mark the alluvial fill cycles defined (see Fig. 5).

palaeosol. Higher up, above a 1.5 m-thick unit of channel gravels, there is a moderately developed clay-rich palaeosol that may be the proximal floodplain equivalent of the undated dark brown soil at Yutz4. Here, its surface was strewn with charcoal and angular rock fragments, several of them knapped pieces of chert. The soil was dated to 9450 BP, which makes this an early Archaic occupation surface. In contrast to Yutz4, the topmost soil at Yutz7 is effectively buried and thus was considered worth dating. The result, 800 BP, may be considered a maximum age for the incision that created the 7 m terrace.

Younger insets are rare and poorly exposed along the Yutzatoto. The only exception is the fill retained behind the remains of a dam at Yutz10. This dam originates from a surface much lower in elevation than the Formative lama-bordos. It is visible on both sides of the arroyo as a slanted line of large cobbles and stones forming a wall. We do not know its age or function, but the several meters of alluvial fill backed up before it was breached, point to an interval in the last 800 years when the stream carried large sediment loads.

4.2. The Yuzanu stream and its tributaries

Following Lorenzo (1958) we refer to the stream draining the areas north and east of the Yanhuitlan monastery as the Yuzanu. At its confluence with the Yanhuitlan river it receives runoff from 17 km^2, but seems to carry discharges and sediment loads larger than the Yutzatoto, because it is largely contained within the area of the most gullied YF shales. The stream descends from altitudes close to 2700 m at its westernmost sources. Its upper reaches are confined in narrow valleys, but south of Yuz7 it exits into an area where its alluvium merges with those of the neighboring San Bruno and upper Yanhuitlan to form a wide plain. The three merge their waters at an altitude of 2100 m.

The stream is deeply incised into older alluvium and the YF, creating excellent cutbanks that are typically 10–15 m tall. The insets of at least four different fill cycles are visible upstream of Yuz2 (Figs. 3 and 8). The most readily identifiable fill is under a constructional fluvial terrace that usually rises more than 10 m above the streambed. Upstream of Yuz2 and at least as far as Yuz21 and Yuz22 the terrace is almost continuous, except in places where it has been sheared by slip-off slopes on the inside of recent meanders or by cut-terraces (*sensu* Bull, 1991), such as at Yuz7. The alluvium of this terrace tends to be dominated by either grey and buff or reddish sands and muds. It contains several soil A horizons of varying thickness and organic matter content. Two of them stand out, as they represent timespans when soil development on the floodplains of the drainage was strong enough to overprint sedimentary structures and major differences in the textures and other macroscopic attributes of the parent material. Their attributes can thus be related with more confidence to drainage-wide factors such as climate, rather than local vagaries of alluviation imposed by different sediment source areas and distances from the channel axis. The older palaeosol sits at the base of the cutbanks, either directly on a sharp boundary to the YF, or separated from it by organic-rich bedded muds. It is a cumulic soil, with marked enrichment in organic matter over 0.5–2 m. It is a dark brown to dark grey clay, breaking into large prismatic peds with prominent clay coats. In places two or more such

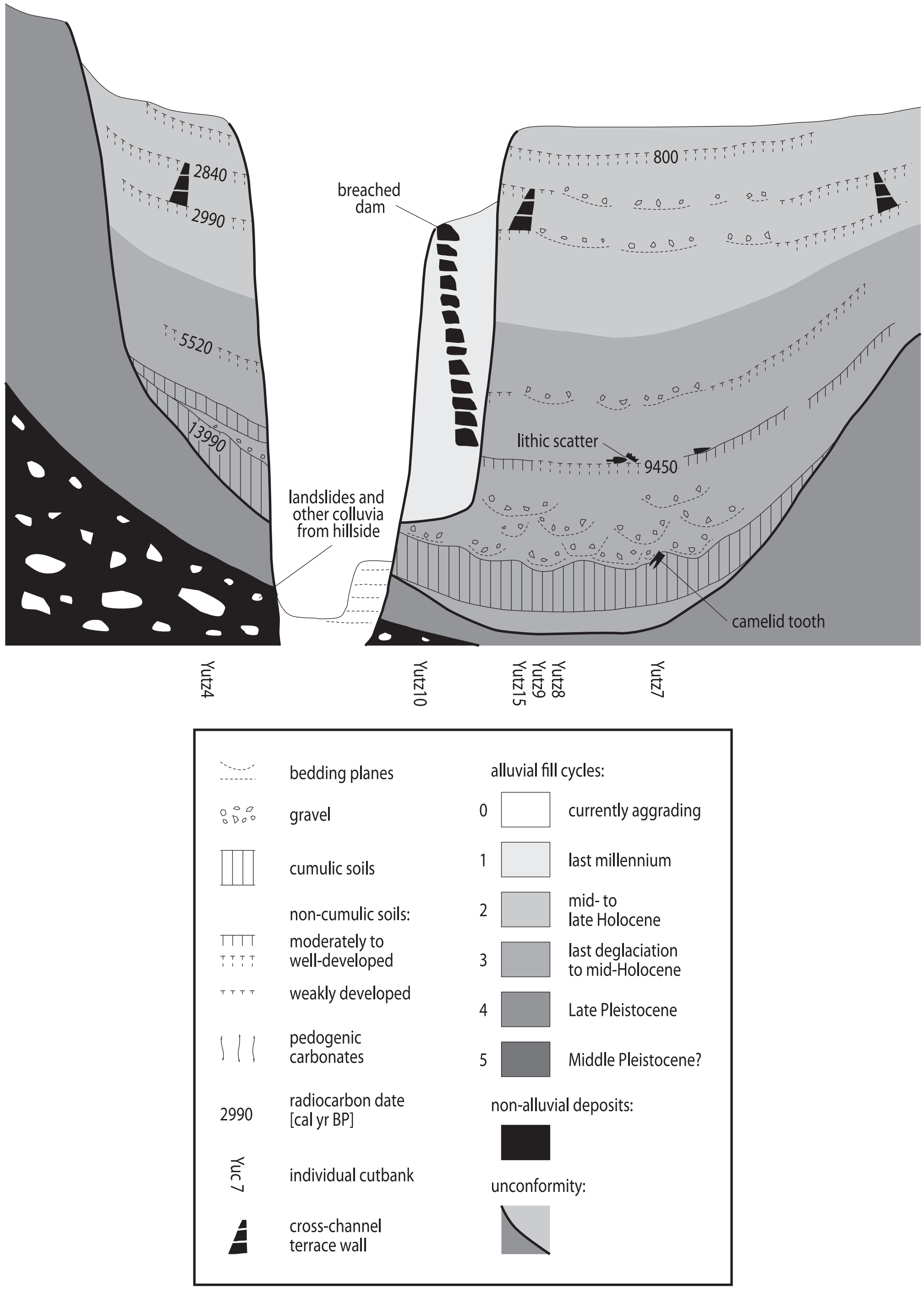

Fig. 5. Composite cross-section of the Yutzatoto stream. Not to scale.

horizons are separated by thinner layers of bedded alluvium of different textures. This palaeosol has been independently dated at Yuz12, Yuz7, and Yuz9, to 13,970, 13,300, and 13,270 BP. The incision that initiated the fill cycle must have occurred before these dates.

The other marker soil sits several meters higher, about two-thirds of the way up to the top of the terrace. It is 0.3–1 m thick and distinguishable by its very dark grey or black color. It has a silty clay loam or silty clay texture, a moderately strong structure of medium prisms, and remarkable cohesiveness, which makes it stand out in high relief in many cutbanks. It dates to 8200 BP at Yuz9, and 7810 BP at Yuz5. The alluvium in-between the two marker soils tends to be finer in texture and more organic-rich than the alluvium on top of the upper marker soil. In this last part of the sequence there are two or three buried A horizons, sometimes with associated filaments of pedogenic carbonate. At Yuz5 the last of them was dated to 4930 BP. Its burial and the incision that terminated the whole fill cycle must have occurred shortly afterwards.

The sequences observed at Yuz2 and Yuz12 belong to the same fill cycle, as revealed by radiocarbon, but are difficult to relate to other exposures. The ca. 13,500 BP cumulic soil is missing at Yuz2. We may be here at the sloping distal margin of the arroyo, where aggradation could not begin until its center was filled. The 7040 BP palaeosol at Yuz2 may be a rough equivalent of the upper marker soil upstream, but the correlation must remain tentative, especially in view of the stratigraphically inverted dates of 6110 and 6800 BP higher up. The date of 4630 BP on the topmost soil gives a maximum age for the

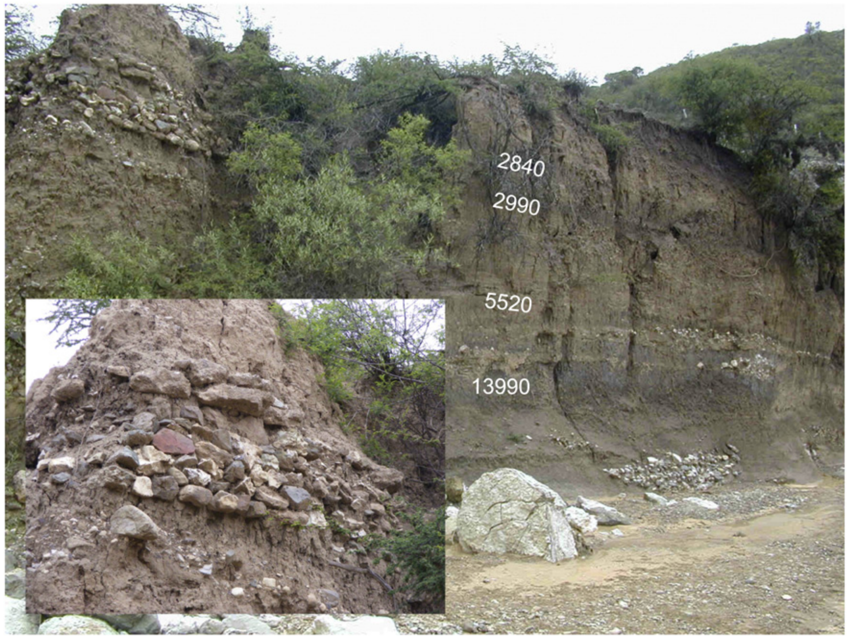

Fig. 6. Yutz4. Inset shows close-up of the wall of the Formative *lama-bordo* terrace.

incision terminating the fill cycle that is in fairly good agreement with that inferred at Yuz5. At Yuz12 the cumulic soil is overlain by some 10 m of coarse-textured reddish alluvium with little indication of any pedogenic development. Within a few hundred meters upstream Lorenzo (1958) excavated a late Archaic maguey (*Agave* sp.) roasting oven, buried 6 m under the top of a cutbank. Two radiocarbon dates placed the occupation at 4500BP. In contrast, surfaces of this age are close to the top of cutbanks such as Yuz5 or Yuz2. This points to an additional incision in the early Holocene that made the later history of this branch diverge from that of the rest of the drainage.

At Yuz21, Yuz22, and a few other exposures the ca. 13,500–4500 BP fill is set into older alluvium, dominated by grey colors and relatively coarse textures (Fig. 3). At Yuz21 there is a hint of a corresponding older fluvial terrace, while at Yuz22 younger alluvium seems to lap over and bury all pre-13,500 BP deposits. In contrast, alluvium aggraded after the ca. 4500 BP incision is common, especially along the Yuz10 and Yuz16 tributaries. At the latter locale the stream has wrought a topographic inversion, leaving a pedestal of alluvium in the middle of the modern streambed. A thick organic-rich deposit at the base of it is overlain by coarse-textured alluvium in which many of the gravel-sized clasts are rolled prehispanic sherds. The latter is representative of the alluvium aggraded in this fill cycle, which is dominated by grey or yellowish brown sands and muds. It typically preserves its original bedding planes and is interrupted by multiple but incipient A horizons. It appears in narrow fluvial terraces bordering the modern channel, as at Yuz8, or in V-shaped infilled gullies perpendicular to it and marking

Fig. 7. Headwater reach of Yutzatoto drainage infilled by currently cultivated *lama-bordos*.

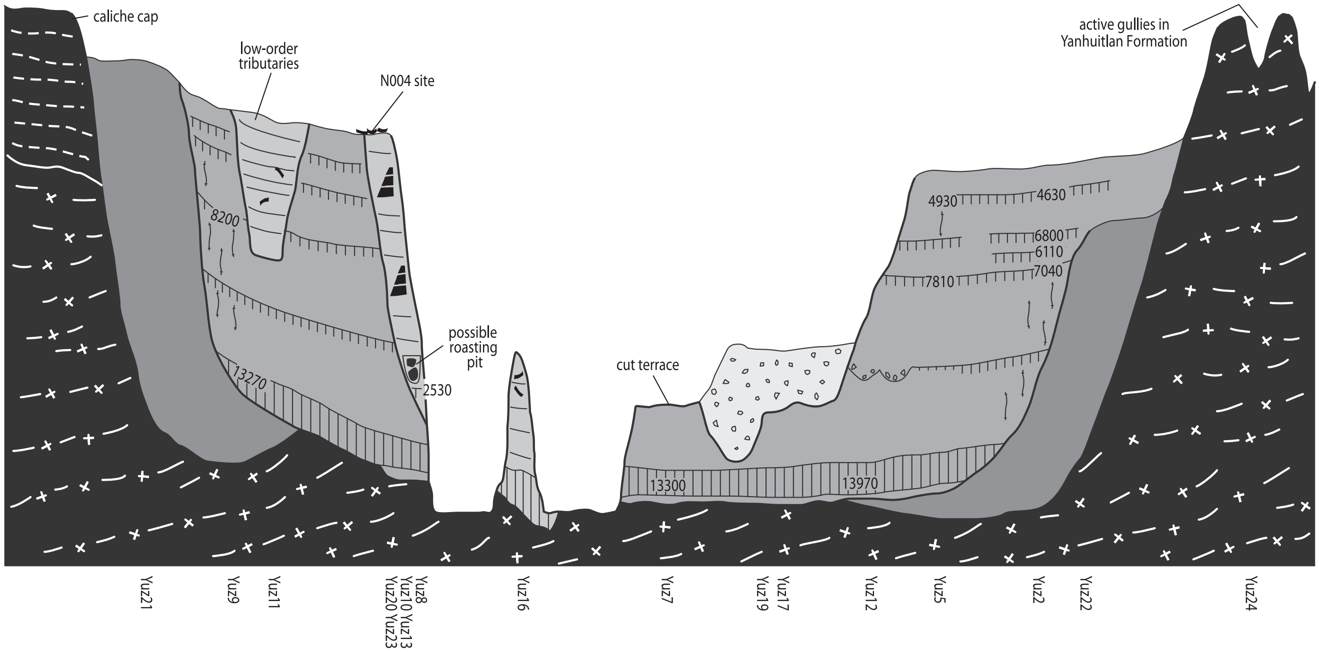

Fig. 8. Composite cross-section of the Yuzanu stream. Not to scale. See Fig. 5 for key.

the former mouths of lower-order tributaries, as at Yuz11. In the former it may be more than 8 m thick, in the latter it is usually much thinner and laterally confined. Apart from sherds it contains a lot of charcoal. At Yuz8, Yuz10, Yuz13, Yuz20, and Yuz23 it also buries, at different depths, the walls of cross-channel terraces. The only date we have for this fill is one of 2530 BP, on an A horizon at 7 m depth at Yuz8. A concave pit dug from a surface 0.4 m higher up the same cutbank and filled with cobbles and large charcoal fragments may be an another roasting oven. The surface of the fluvial terrace at Yuz8 is littered with large unabraded sherds. They mark the southern edge of a Natividad phase village (N004; Spores, 1972), which we would imagine built on a stable surface out of the reach of floods. We thus surmise that aggradation had run its course and been followed by an incision by Natividad times. Overall, we would place this whole fill cycle between ca. 4500 and 1000 BP.

Examples of younger alluvium exist in the form of isolated insets near Yuz17 and Yuz19. They consist of channel gravels capped by reddish sands and silts. They fill concave undulating surfaces carved into older alluvium and form discontinuous terraces at an average 5 m above the modern streambed. We have seen no artifacts within this alluvium, but since it shows practically no signs of pedogenic alteration, we think that it is very young. Its intensely red color points to the erosion of intact YF beds. It is intriguing to contrast this with Spores' (1972) and Kirkby's (1972) descriptions of archaeological remains of the Natividad and Convento phases in the vicinity. Sites on slopes underlain by red shales that were terraced for agriculture or habitation

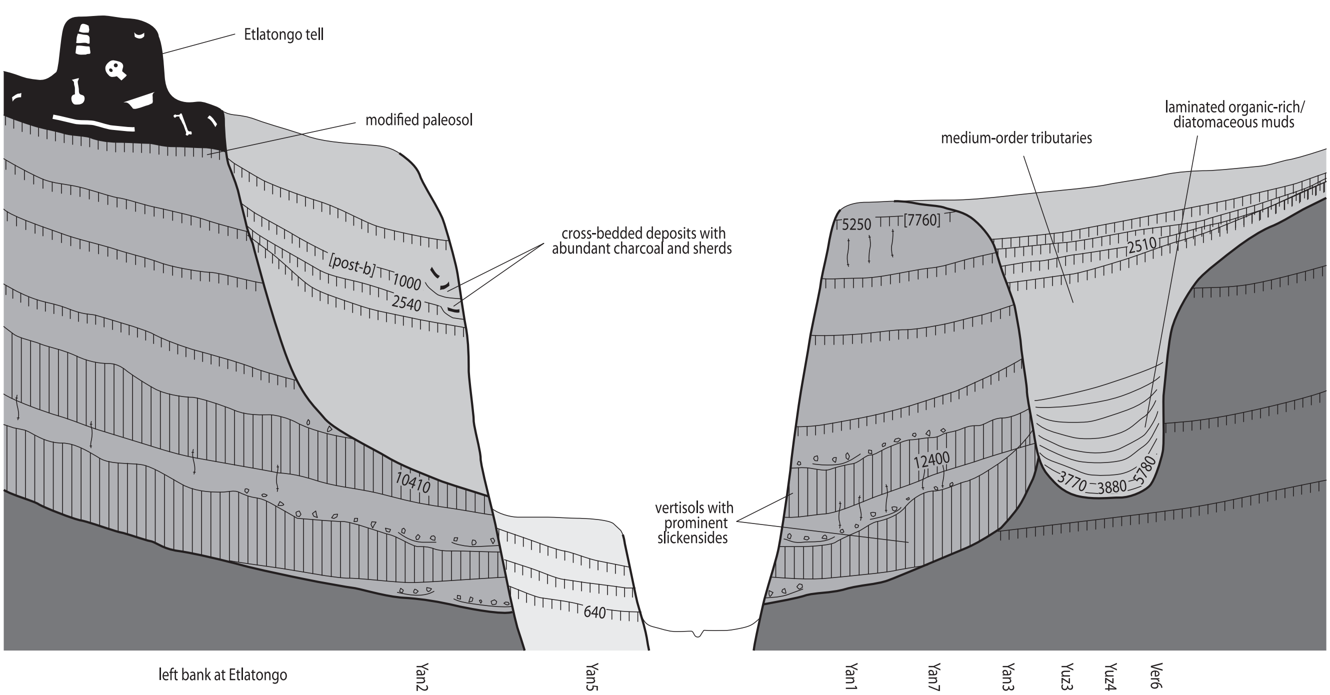

Fig. 9. Composite cross-section of the lower course of the Yanhuitlan river. Not to scale. See Fig. 5 for key.

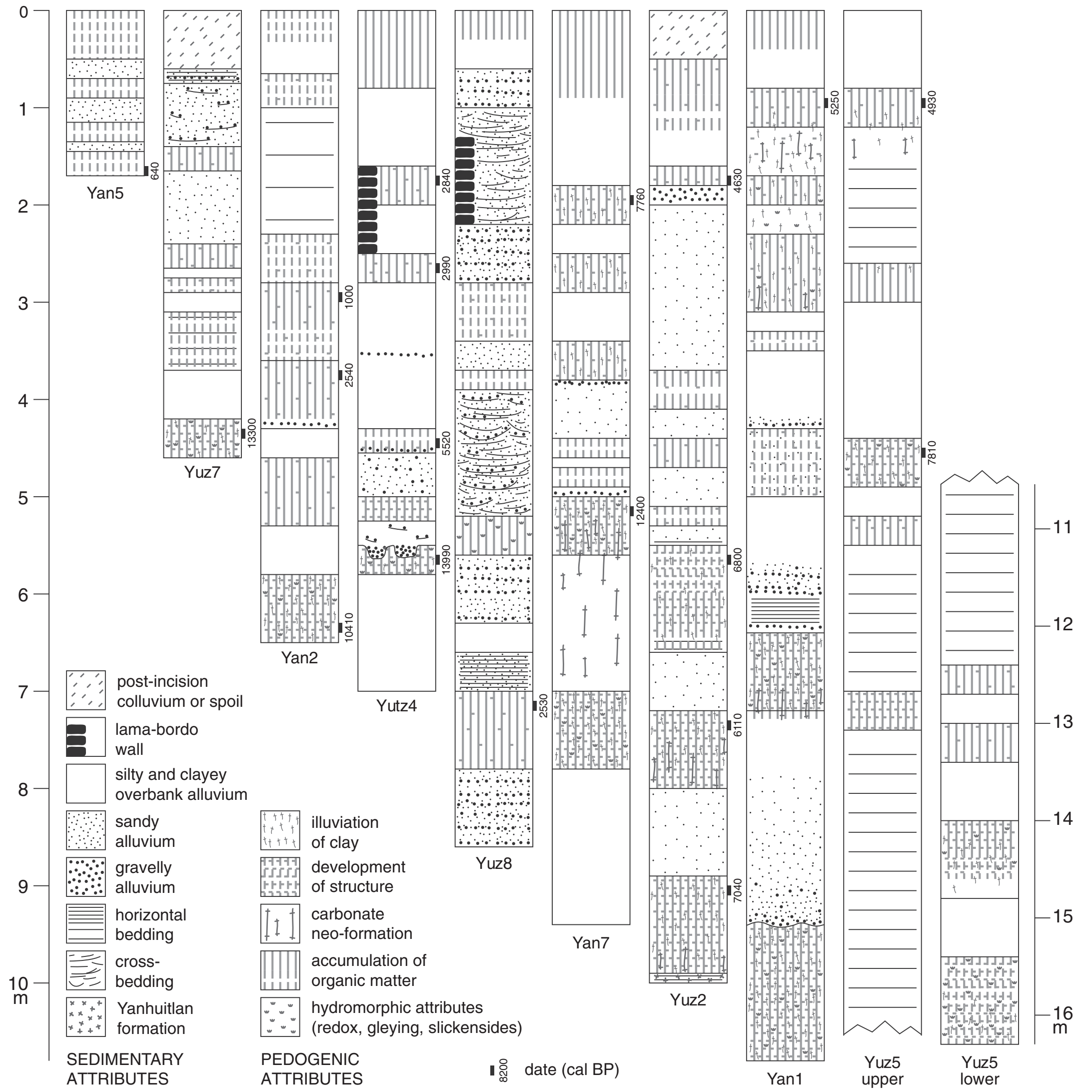

Fig. 10. Selection of stratigraphic columns recorded in measured cutbanks.

are today severely eroded badlands where gullying impedes movement, let alone farming. We therefore suspect that our last alluvial fill was deposited after the abandonment of these sites in the Colonial period, prior to the current incision of the stream.

4.3. Lower course of the Yanhuitlan river

The third reach to be considered is the lower course of the Yanhuitlan river, downstream of the mouth of the Yuzanu. For ease of comparison, we also include here the two lowermost cutbanks along the Yuzanu, Yuz3 and Yuz4, as well as Ver6, downstream of the confluence of the Yanhuitlan and Yucuita rivers. The streambed drops at a gentle gradient from 2100 m at the mouth of the Yuzanu to 2000 m at Ver6. The Yanhuitlan river is fed by a catchment of 70 km^2 at the mouth of the Yuzanu, increasing to 220 km^2 at the confluence with the Yucuita. The Río Verde at Ver6 receives runoff from close to 500 km^2. This part of the valley is a plain several kilometers wide, where bedrock is concealed by a thick mantle of Quaternary alluvium (Fig. 9). The river can migrate laterally across these unconsolidated deposits, and has developed some high-amplitude meanders.

Very old alluvium is exposed at Yuz3, Yuz4, Yan 3, and Ver6. It displays different shades of red, ultimately derived from the YF. It sometimes contains bands that stand out by virtue of their prismatic structure, and a darker red color. They are palaeosols so old that they have lost their grey or brown hues through diagenetic processes or were formed under a climate markedly different from that of the last glacial-interglacial cycle.

Yan7, Yan1, and Yan3 are representative exposures of the alluvium of a terrace that rises between 8 and 10 m above the streambed. Despite the considerable distances involved all three contain comparable stratigraphic sequences. To judge by the channel gravels at Yan1, it represents the facies closest to the valley axis, whereas finer textures at Yan7 and the strong development of secondary carbonate morphology at Yan3 suggests positions on the better-drained distal floodplain. At Yan1 and Yan7 the sequence starts with two units of bedded alluvium, each of them capped by a well-developed soil. The soils are very dark brown overthickened A horizons. They break neatly into large prismatic or wedge-shaped peds with very prominent clay coats and slickensides. The lower one is thicker than the upper one, and more mature in terms of structure and clay illuviation. At Yan1 the upper boundary of the lower soil is markedly wavy, with depressions and ridges 2 m in length and 0.3 m in amplitude. It is also strewn with gravel. The upper boundary of the upper soil is marked by a relatively smooth line of fine gravel. No features suggestive of channel scouring are present at Yan7, but there is a conspicuous horizon of carbonate filaments originating from the upper soil. At Yan3 there is only one such soil combining cumulic and vertic properties, resting on a wavy unconformable boundary to reddish alluvium of an older fill cycle. The development of clay coats and nodules of pedogenic carbonate associated with this soil is so strong that they both penetrate below the unconformity. The soil may be a polycyclic and welded version of the two distinct palaeosols present at Yan7 and Yan1. The upper soil at Yan7 dates to 12,400 BP. The remainder of this fill is made up of light reddish brown organic-poor overbank muds interrupted by four to five palaeosols. These have not progressed beyond the formation of A horizons and carbonate filaments. The topmost of them was dated to 5250 BP at Yan1 and 7760 BP at Yan7. We believe that only the former date is reliable, and that the incision terminating this fill cycle occurred within a few centuries after 5250 BP.

Other exposures of the same fill were inspected just above the confluence with the Yucuita. The promontory between the two rivers is occupied by prehispanic Etlatongo, one of the major settlements in the Mixteca, used almost continuously between ca. 3600 BP and the Spanish conquest (Spores, 1972; Zárate, 1987; Blomster, 2004). The architectural platforms, superimposed floors, house demolition debris, middens, and other cultural deposits form a series of coalescing mounds, many of which contain well in excess of 5 m of man-made strata. In the vicinity of mound A the base of this tell has been cut into by a meander of the Yanhuitlan river, and can be seen to rest on top of the fluvial terrace described at Yan7, Yan1, and Yan3. At the contact of the alluvial and cultural stratigraphy there is an almost pitch-black palaeosol. It may be the last A horizon of the alluvial fill, but modified by cultivation or other human activity. Upstream of mound A, both the mid-Holocene alluvium and overlying anthropogenic layers are cut by a younger alluvial inset. Its surface is flush with that of the tell deposits, and thus about a meter higher than that of the older terrace.

The younger fill is also visible in the opposite, right bank of the river, and was studied at Yan2. It is made up of light reddish brown sands and muds, interrupted by three moderately developed A horizons. The upper two are scoured by large rills filled with gravel, sherds and charcoal. They were dated to 2540 and 1000 BP. The upper 2 m of the sequence is almost massive alluvium, pointing to very rapid deposition. At the base of the cutbank there is a thick dark brown to black A horizon with strong prismatic structure and clay coats. Its appearance, combined with the date of 10,410 BP, suggests that we are looking at the older fill cropping out at the base of the younger inset (Fig. 9). The soil would thus correspond to the upper cumulic vertisol of Yan1 and Yan7.

A third, even younger inset abuts Yan2 as a low terrace rising less than 2 m above the surface of the water during the dry season. Named Yan5, it contains bedded light reddish brown silts interrupted by three incipient A horizons. The lowermost was dated to 640BP and allows us to bracket the incision separating this fill cycle from the previous one. The alluvial stratigraphy can be logically related to Etlatongo's settlement history described by Blomster (2004). The village stood at first well above flowing water, on a terrace created by the incision of the Yanhuitlan river shortly after 5250 BP. Aggradation throughout the Formative, as indicated by the 2540 BP date at Yan2, eventually raised the streambed closer to the houses, and may have motivated the construction of mound A during the Cruz D or Yucuita phases, as well as the Ramos phase shift of all settlement to the north and uphill. Renewed incision at the close of Las Flores would again reduce the danger of flooding and allow the spread of Natividad occupation over the whole promontory.

Downstream from Etlatongo, along the Río Verde, several long cutbanks are capped by upwards of 2 m of grey-colored alluvium that displays internal banding into lighter and darker horizons. This is due to the welding of several A horizons at the distal margin of the valley. At Ver6, the darkest band within this composite soil yielded a date of 2510 BP, almost identical to one of the dates from Yan2. In a further parallel, the top meter of Ver6 is taken up by lighter-colored and almost massive alluvium. At one end of the cutbank, however, these late Holocene deposits grade down to a palaeochannel several meters wide and deep. It seems too small to be of the Verde itself, and instead may represent a predecessor of a lower-order tributary that enters it from the east at this point. Gravels at the bottom of the palaeochannel are covered by thinly bedded organic-rich muds, the base of which was dated to 5780 BP. Similar palaeochannels are present at Yuz3 and Yuz4, also cut through very old red alluvium. The mud beds in the lower half of the palaeochannels are in the centimeter range and alternate between dark grey, and a pale pink to almost white color that may denote the presence of diatoms. The basal muds were dated to 3880BP at Yuz4 and 3770BP at Yuz3. In all three cutbanks the muds seem to denote a sedimentation style adopted for a time only by medium-order streams in the Nochixtlan valley. The palaeochannels in question must have been graded to the streambed of the higher-order reaches at their mouths, and cut in response to the major Holocene incision of the Verde and Yanhuitlan rivers. Given the wide divergence of the radiocarbon dates, that incision appears to be markedly time-transgressive.

4.4. Other cutbanks

Exposures studied along other reaches are too isolated and too poorly dated to merit detailed description at this stage. Nonetheless, a few of them offer pieces of information that allow us to reinforce or refine some of the inferences made above. At Yan8 and Yan4, we have dated a black clay-dominated palaeosol with a strong prismatic structure to 11,870 and 10,160 BP. If it is a valid correlate of the cumulic A horizons described elsewhere, the dates confirm their persistence into the early Holocene. At Yuc1 the dates of 6570, 1220, and 900 BP were obtained in the same 9 m-long stratigraphic column. It would thus seem that sedimentation was continuous during this timespan, as was the case along the Yutzatoto, but in contrast to Yuzanu and Yanhuitlan, where alluvium pre- and post-dating 5000 BP tends to be found under different terraces. The soil from which the 900 BP date was derived was buried by 2.2 m of almost massive buff-colored sands and silts analogous to the pre-incision packets at Yan2 and Ver6. Yet another analog is at Yux3, where the pre-incision soil dates to 830 BP. Cutbanks along the San Bruno, though so far undated, reveal an alluvial geometry with many parallels to that of the Yuzanu, despite a seemingly different lithological composition of the sediment.

5. Cut-and-fill cycles and their causes

Questions of fragmentary preservation, insufficient chronological control, and equifinality of different controls of stream behavior bedevil most interpretations of alluvial sequences (Butzer, 1980; Frederick, 2000). The Nochixtlan record is no exception, and its interpretation is made more difficult by the exploratory nature of our research and the different scales of our observations. For example, the lower-order reaches presented above probably had shorter response times to external inputs and are more suitable for detecting adjustments to local changes in land use or short-term climatic perturbations. The higher-order reaches may be more useful in detecting longer-term adjustments to major transformations, such as the Pleistocene to Holocene transition, or the valley-wide substitution of natural vegetation communities by an agricultural landscape. We consider that we have accumulated enough data to start eliminating some causes, and to offer interpretations of comparative interest. We discuss them in chronological order, referring to the provisional numbering of fill cycles in Figs. 4 and 5.

5.1. Before agriculture (fill cycles 5 through 3)

Previous accounts of environmental change in the valley have laid great emphasis on contrasting a pristine Holocene ecosystem with one impacted by sedentary farmers. Smith (1976) imagined a landscape almost completely covered by pine and oak forest, with perennial rivers flowing in broad valleys. Alder and willow would have bordered the channels, with oak and pine occupying better-drained soils away from it. He blames erosion induced by the farming of slopes for the lowering of water tables, infilling of the valleys, and transition to narrow incised channels with ephemeral flow. Others mention a soil cover dominated by mature forest soils (Kirkby, 1972) or unincised channels persisting into the Formative and allowing the diversion of water for irrigation (Spores, 1969). Kirkby recognizes, however, significant alluviation before agriculture. Now that we have a first suite of radiocarbon dates, we know that much of the alluvium pre-dates, by several millennia, the arrival of sedentary farmers. Their mobile predecessors may have practiced incipient forms of crop husbandry (Ranere et al., 2009) but can hardly be imagined to have set in motion erosive processes of the magnitude observed. We think that the contrast between a stable and a dynamic landscape before and after agriculture has been overstated, and that notions of 'climax' vegetation communities or 'mature' soils need to be carefully linked to specific time intervals.

The oldest alluvium, grouped for now into cycle 5, is characterized by intensely red hues and the peculiar palaeosols described. These palaeosols may lie beyond the range of radiocarbon dating. The late Pleistocene deposits aggraded along the Yutzatoto and Yuzanu immediately before the incision of the stream network at ca. 14,000 BP are grouped under cycle 4. They seem generally coarse-grained and interrupted by few episodes of floodplain stability. Our working hypothesis is that their coarse texture and great thickness are related to the generally arid associations of stadial conditions in central and southern Mexico, and Guatemala (Leyden, 2002; Lozano García et al., 2005; Piperno et al., 2007; Hodell et al., 2008; Ortega et al., 2010). If more arid conditions prevailed in the millennia before and after the Last Glacial Maximum, the slopes of the Nochixtlan valley would have been covered by even sparser vegetation than today and thus more exposed to the removal of soil and its inherently erodible parent materials.

The dated alluvial record starts with cycle 3. Following an incision reaching well into the headwater areas, floodplains along reaches of varied magnitudes started to aggrade fine-grained alluvium at a moderate pace allowing the development of cumulic A horizons. They were forming at 13,990 (Yutz4), 13,970 (Yuz12), 13,300 (Yuz7), 13,270 (Yuz9), 12,400 (Yan7), and 10,410 BP (Yan2), and perhaps also at 11,870 (Yan 8) and 10,160 BP (Yan4). Previous researchers repeatedly mentioned thick dark A horizons near the base of cutbanks (Cook, 1949; Spores, 1969; Kirkby, 1972) but misinterpreted them as remnants of the generalized 'original' soil cover, or the result of the first stripping of it, induced by forest clearance. They are in fact limited to the floodplains of arroyo-type streams, and to a few millennia at the Pleistocene to Holocene transition. Slow-growing trees would have been ill-suited to permanently aggrading cumulic soils, and we imagine them covered instead by wet meadows dominated by grasses and other hydrophylous annuals whose frequent decomposition allowed rapid enrichment in organic matter. The soils have hydromorphic features – gley colors and mottles – indicative of seasons of waterlogging, but the prominent translocation of clay and development of prismatic or wedge-shaped peds with slickensides means that they alternated with seasons when water drained freely through the profile. The meadows likely required a more sustained baseflow, expected with a denser vegetative cover on slopes that delayed runoff. The delivery of large quantities of coarse sediment from the slopes would be minimized, as indeed reflected in the stratigraphy. All this points to a strongly seasonal climate, but with a lower evaporation to precipitation ratio than today. The incision initiating fill cycle 3 could have been an adjustment to higher discharges, which makes us lean towards an increase in precipitation as primary cause.

Similar palaeosols and causal relationships are reported from Puebla, Tlaxcala, and Guanajuato (McAuliffe et al., 2001; Sedov et al., 2009; Borejsza and Frederick, 2010). There, the incision took place close to the Pleistocene/Holocene boundary at ca. 12,000 BP, a juncture at which a major shift from dry to wet is relatively well documented (e.g., Lozano García et al., 2005; Piperno et al., 2007; Ortega et al., 2010). The soils are limited to the earliest Holocene, and Borejsza and Frederick (2010) make tentative connections with meltwater flood 5 (MWF5) in the Gulf of Mexico (Aharon, 2003). In Nochixtlan the incision occurs at or before 14,000 BP. In some exposures of higher-magnitude reaches, however, there are two levels of cumulic soil formation, separated by organic-poor alluvium and/or channel scouring. In at least two cutbanks (Yan7 and Yan3) that intervening layer and the lower soil bear a dense imprint of carbonate filaments, films, and even small nodules. These are typical of semi-arid climates, in which there is sufficient percolation to mobilize the carbonates, but not enough to remove it completely (Gile, 1975, 1977; Machette, 1985). This may indicate two 'wet' periods separated by a 'dry' one. The channel scouring, if taking place at the second dry-to-wet transition, could be an expression of increased discharges that could not be accommodated by a full-blown incision, because the previous incision had reduced longitudinal stream gradients, predisposing the system towards aggradation. The larger hypothesis would be that in Nochixtlan an earlier bout of deglaciation and precipitation increase resulted in an earlier incision. The Allerød interstadial and MWF-4, lasting from 14,100 to 13,100 BP, would be a plausible candidate for such an earlier wet period, with four of our dates falling within its span. After a return of very dry conditions during the Younger Dryas, the onset of the Holocene would elicit the return of cumulic soil formation. Detailed examination of this part of the sequence is needed, supported by close-interval dating of different fractions of soil organic matter and the carbonate nodules themselves.

Cumulic soils disappear from the record after ca. 10,000 BP. Accumulation of organic-poor alluvium predominates for the remainder of fill cycle 3, and the precipitation of carbonates under soil A horizons is common, though rarely proceeded beyond the formation of filaments and thin, discontinuous films. They seem to reflect the establishment of a relatively warm, dry and strongly seasonal Holocene climate, not unlike that of today. The same transition is recorded in central Mexico at roughly the same date (Borejsza and Frederick, 2010). To judge by the number of exposures, there is more alluvium covering the period from 10,000 to 4000 BP stored than any alluvium post-dating the arrival of farmers. It is not possible to translate this into comparisons of sediment yield, as much alluvium post-dating 2800 BP was likely exported beyond the study area (Joyce and Mueller, 1992, 1997; Goman et al., 2005). The amount and nature of deposits alluviated in the millennia before agriculture point to a slope vegetation that must have included, apart from oak-and-conifer forest, more open communities, perhaps combining thorn scrub with small oaks, junipers, or some legume trees. Charcoal is consistently present in small quantities in alluvium of this timespan and hints at slope vegetation that was more prone to fire than closed-canopy forest. At the same time, the arroyo floodplains under a flash-flood regime would have been a niche suited to the reproduction of short-lived and sun-loving shrubs and herbs that we often think of as indicators of disturbance. They would thus be a setting adequate for the propagation of domesticates (Flannery, 1973). Some environmental oscillations may have diverged from this pattern. The conspicuously organic-matter- and clay-enriched soil formed along the Yuzanu between ca. 8200 and 7800 BP, for example, marks several centuries of floodplain stability unusual for this cycle as a whole.

The incision separating fill cycles 3 and 2 appears to be markedly time-transgressive (Fig. 11A). It may have started as early as 6000 BP on the Río Verde, extended along the lower course of the Yanhuitlan close to 5000 BP, and reached the middle Yuzanu as late as 4000 BP. It is unclear whether the incision traveled up the Yucuita arm, too. It certainly did not reach the Yutzatoto, where fill 2 is stacked on top of 3. The direction of change seems logical: an incision signal will usually be propagated from reaches of higher discharge upstream. Discharges in the Yucuita arm may have been too low because of circumstances of topography and lithology mentioned in Section 3. With the time lag

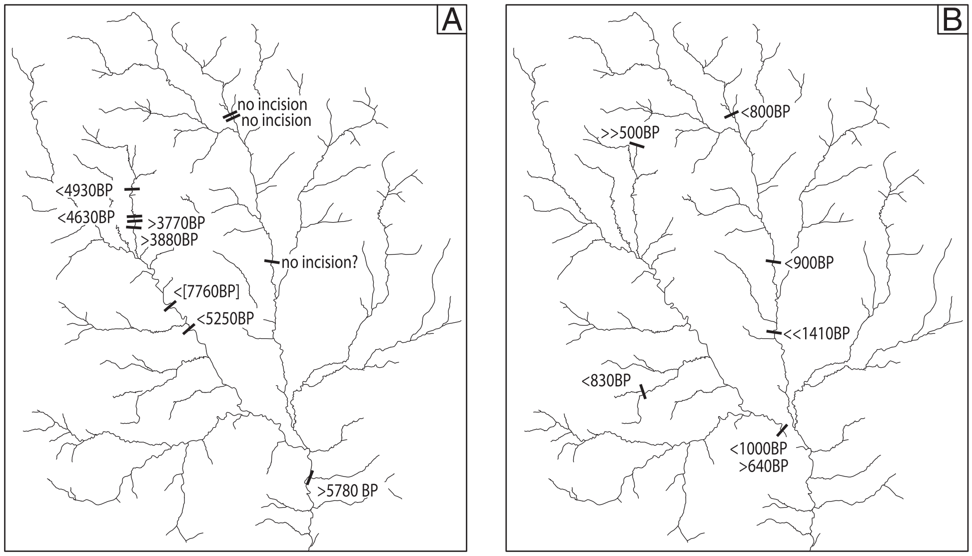

Fig. 11. The timing of two major Holocene stream incisions at different cutbanks. A. Mid-Holocene incision. B. Incision at the transition from the Las Flores to the Natividad phase.

implied it is difficult to see this incision as a response to a return of higher precipitation alone. A lowering of base level somewhere on the Río Verde, due to tectonism or some internal adjustment of the fluvial system, is an alternative to be explored. The last Archaic-period deposits belong already to fill cycle 2 and consist of thin-bedded muds aggraded along medium-order reaches after the incision. They fill markedly concave arroyos and suggest the prevalence of low-energy flows. The high organic content of the muds and the steady water supply might have been an allure for early farmers.

5.2. After agriculture (fill cycles 2 through 0)

There is no doubt that prehispanic agriculture wrought profound environmental change in the Nochixtlan valley and that it influenced sediment transfers between slopes and stream valleys, as well as sediment export out of the valley. There is disagreement, however, as to the timing and causes of the most intense erosion. The issue is closely linked to wider discussions of agricultural terracing, its different morphologies, functions, and unintended effects at different time scales (Córdova, 1997; Fisher et al., 2003; Heine, 2003; Fisher, 2005; Borejsza, 2006; Borejsza et al., 2008). In the Mixteca, as elsewhere, there are two major types of terraces: the already mentioned lama-bordos, an example of cross-channel terracing, and hillside terraces. The fundamental difference is that the latter are not built across surfaces with channelized flow, and tend to be found at higher elevations. Hillside terraces usually cover larger surface areas and on a regional scale retain larger volumes of earth. The Mixteca, however, may be exceptional in this respect, as the lama-bordos have been developed on quite a monumental scale (Spores, 1969; Balkansky et al., 2004; Pérez Rodríguez, 2004, 2006). Examples spanning medium-order stream valleys, forming flights several kilometers long, and retaining fills several meters thick are not uncommon. They no doubt affected stream discharge and sediment load in the entire valley. Localized incision would be expected where sediment-depleted water left functioning sets of lama-bordos, followed by pulses of aggradation generated when their walls failed. Spores (1969) linked the two types of terracing in the following terms:

> …growing pressure on the available level fields […] led first to the development of hillside terracing in Las Flores times and later, in the Natividad phase, to the discovery and development of the *lama-bordo* technique. The erosion of higher elevations was induced during Natividad times in order to fabricate fertile terraces in the lower drainage channels. Then, as population declined after the conquest […] many terraced lands were abandoned and lower slopes were allowed to erode.

Fill cycle 2 corresponds to the latest Archaic, and the Cruz through Las Flores phases. Coarse-grained, charcoal-rich alluvium is common along reaches of different magnitudes, though usually in narrow insets fragmented by more recent incisions. In the lower valley, at Yan2 and Ver6 major alluviation was underway by 2600 BP. At Yuz8, on a first-order stream, some 6.5 m aggraded between 2530 BP and the establishment of a Natividad phase settlement. Research at the mouth of the Río Verde on the Oaxacan coast suggests that sediment influxes from the highlands had increased by an order of magnitude by 2300 BP (Goman et al., 2005) and perhaps as early as 2800 BP (Joyce and Mueller, 1992, 1997; Mueller et al., under review).

The 2990 BP date obtained on the lama-bordo at Yutz4 is surprisingly early and to our knowledge makes it one the earliest agricultural features in Mexico recorded in stratigraphic context and radiometrically dated, contemporaneous with the Las Estacas irrigation canal in Morelos (Nichols et al., 2006). It suggests that the amount of sediment delivered to streams was sufficient to make this technology viable before major slope degradation attributable to humans. It throws a new light on the documented preference of Formative settlers for the lowermost altitudes in the Mixteca. Rather than attracted by wide forested plains, they may have eyed the spatially more limited niche of arroyo bottoms where disturbance-adapted vegetation communities were easily cleared, while sedimentation continuously renewed fertility. The discovery lends credence to early ages assigned to lama-bordos on the basis of their spatial proximity to Cruz D or Yucuita phase settlements (Kowalewski et al., 2009). It also brings the sequence of agricultural change in Nochixtlan in line with theoretical and empirical considerations of the development of terracing, which often point to the ease and probable precocity of cross-channel terracing, as opposed to more labor-intensive and less productive hillside terracing, resorted to only when other farmland became scarce (Flannery, 1983; Wilken, 1987; Borejsza, 2006).

Accelerated alluviation continued unabated after 2500 BP throughout fill cycle 2, to judge by the absence of well-developed soils. It may have assured soil replenishment in lama-bordos, but would also undermine their stability. The technology continued in use: there are specimens that, on the basis of their stratigraphic position, we guess to be of Yucuita, Ramos or Las Flores age. The few lama-bordos in Nochixtlan and neighboring valleys that have been the object of stratigraphic work have been placed in the Late Ramos and Natividad phases (Rincón Mautner, 1999: 678–87; Pérez Rodríguez, 2006; Pérez Rodríguez et al., 2011). More frequent raising of walls may have been required, however, increasing labor inputs. The purposiveness of slope erosion is thus open to debate. Overall, we think that like elsewhere in Mesoamerica, local land use histories had become the primary force determining the pace and style of sedimentation.

The last bout of cycle 2 alluviation seems to have been particularly rapid, and is expressed in exceptionally thick alluvial packets at the top of many cutbanks. The following incision is remarkable in its synchroneity throughout the whole stream network (Fig. 11B). It may have started along higher-order reaches close to 950 BP, expanding into tributaries such as the Yutzatoto or Yuxano by 800 BP. In the Yuzano drainage we have no radiometric date, but know that it occurred before a Natividad-phase settlement spread over the Yuz8 cutbank. With the dates available, we could even posit an incision spreading in a matter of decades, between 800 and 750 BP. The three or four centuries before 750 BP happen to arouse some of the hottest debates among both the archaeologists and palaeoecologists working in Mexico. In many regions, and Oaxaca in particular, it seems to be a time of political turmoil, migration, or at least a major shift in settlement patterns (Flannery and Marcus, 1983; Diehl and Berlo, 1989; Kowalewski et al., 1989; Winter, 1989; Winter, 1994; Kowalewski et al., 2009; Joyce, 2010). A short but possibly the most arid spell of the Holocene has long been placed in this interval (Metcalfe et al., 2000; Stahle et al., 2011). It has been said to have contributed to the demise of Classic Maya civilization (Aimers, 2007, table 1; Webster et al., 2007) and the contraction of the agricultural frontier in north-central Mexico (Braniff, 1989).

Given the dating uncertainties, we can still construct contradictory scenarios to explain our case. Synchroneity of geomorphic response over a wide region is often taken to point to climatic rather than anthropogenic factors. We have seen, however, in the earlier stratigraphic record, that aridity, mediated by scarcer vegetation cover, tends to increase sediment yields and be expressed by more aggradation, not incision. We could assume that the arid spell is reflected by the deposition of the thick pre-incision packets, with a return of moister conditions a century or two later eliciting the incision. An internal adjustment of the fluvial system could have been at play, with large-scale aggradation caused by 2500 years of agriculture and accelerated by the arid spell bringing the streams to a threshold where incision became almost inevitable, due to the choking of arroyos with sediment and oversteepening of headwater reaches (see Schumm and Parker, 1973). If we wanted to focus exclusively on human impacts, we could dwell on a proposed population decline at the Las Flores–Natividad transition (Kowalewski et al., 2009). We would imagine that the abandonment of cross-channel and hillside terraces provoked first a major pulse of sediment and later, an incision driven by sediment exhaustion, the return of vegetation to slopes, and the re-channeling to the fluvial system of the entire volume of runoff previously retained in cultivated fields.

The alluvial record of the last millennium is contained within the few insets of fill cycle 1 or concealed under modern floodplains. It encompasses the Natividad apogee of population densities, and the drastic changes in settlement and land use patterns in the aftermath of Spanish conquest. The alluvial record no doubt holds some clues to the question whether the most severe land degradation in Mexico was due to pre-Conquest land use or to terrace collapse and overgrazing in the Colonial period (Melville, 1994; Fisher et al., 2003; Metcalfe et al., 2007; Butzer et al., 2008). The apparent scarcity of Postclassic alluvium arouses a suspicion that agriculture was intensified on such a scale that most sediment was trapped behind the walls of terraces, as suggested by the recent work of Pérez Rodríguez et al. (2011) on Cerro Jazmín, the hill in-between Yan8 and the headwaters of the Río Chiquito. It also echoes the conclusions reached in Frederick's (1996) and Córdova's (1997) studies of the alluvial records of the Basin of Mexico. We have already signaled a tentative association of undated cycle 1 insets on the Yuzanu with the Colonial period abandonment and degradation of farmland around Yanhuitlan. An association of Colonial land degradation with hydrologic change on an unprecedented scale is argued more satisfactorily by Rincón Mautner (1999) for the neighboring Coixtlahuaca valley, on the basis of both alluvial stratigraphy and archival sources.

6. Concluding remarks

The alluvial records of the Nochixtlan hold the potential to fuel some of the most active debates in contemporary Mexican palaeoecology and archaeology. Like in most terrestrial settings, the records are discontinuous, but in comparison with other highland valleys coverage is excellent for at least the last 14,000 years. Their resolution varies, but with more radiocarbon dates may equal that of lacustrine records at certain key transitions. As elsewhere in Mexico where radiocarbon dating of palaeosols has been used for palaeoecological reconstruction, the lack of data on the residence times of the organic matter introduces noise into the chronology. A systematic program of radiocarbon dating of surface soils would be the only way to eliminate it. There are also ample opportunities to experiment with the radiocarbon dating of pedogenic carbonates (Pustovoytov et al., 2007). In some facies, in particular the sandier fills accumulated behind lama-bordo walls, single-grain optically stimulated luminescence (OSL) dating could provide a check on radiocarbon. It could be particularly useful in studies focused on the last 500 years, a timespan in which the variations in atmospheric ^{14}C render the standard deviations of OSL smaller than those associated with radiocarbon. In this same timespan chronologies could also be tightened by following Kirkby's lead in taking advantage of the stratigraphic relationships of alluvium and the road- and waterworks that appear in archival sources, which are exceptionally rich for the Mixteca Alta (Romero Frizzi, 1990; Terraciano, 2001; Spores, 2007).

Lacustrine records still form the backbone of Mexican palaeoecology and generally offer the advantage of easier chronological control. In the southern highlands of Mexico, however, there are few lakes that held water throughout the late Quaternary. Alluvial archives are one of the few open alternative avenues of inquiry. Apart from our mostly geomorphic inferences they offer an opportunity to extract information from the properties of multiple buried palaeosols. The pre-10,000 BP cumulic soils are particularly interesting in that they do not have obvious modern analogs in the Mexican highlands. The morphology and isotopic composition of pedogenic carbonates in these and other palaeosols could provide a multifaceted source of palaeoecological information (Lal et al., 2000; Kraft et al., 2010). Remains of extinct megafauna embedded in alluvium are uncovered in the valley with some frequency, and the high pH of the soils and sediments derived from the YF bodes well for the preservation of the bone of the ecologically more sensitive meso- or microfauna. We have also signaled the abundance of charcoal in Holocene levels. Its taxonomic identification should be attempted, along with that of phytoliths.

Criticisms of poor coverage cannot be leveled at archaeological exploration. If we are to improve on past settlement surveys, we will need to map geomorphic surfaces of different ages, a task that would require implementing a systematic coring program. Some unrecorded sites may still lie buried on the more distal and less commonly exposed parts of ancient floodplains. Burial under alluvium is also one of the few instances where we can expect the preservation of the ephemeral remains of mobile Archaic bands, as recognized by Lorenzo's (1958) pioneering excavation. The arroyos probably figured prominently in their annual rounds, which increases our chances of discovery. A comparison of the attributes of the floodplain soils of the early and middle Holocene may reveal some attempts at the agricultural management of the latter, prior to the construction of the earliest lama-bordos. In general, we feel that a reassessment of the role of arroyos as a niche in the human ecology of this highland environment is needed. That after 3500 years of anthropogenic soil erosion they are still bordered by fields coveted by farmers is a testimony to the resilience of their and their forebears' land use strategies. As implied by Kirkby's study, for now they seem to have harnessed the massive sediment transfers to their advantage, finding the positive side of soil erosion.

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