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Landscapes, soils, and mound histories of the Upper Indus Valley, Pakistan: new insights on the Holocene environments near ancient Harappa

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Abstract

The site of Harappa in central Pakistan has been the primary source of information on Indus Valley cultural and natural landscapes in the Upper Indus Basin. While the site has been excavated for over 100 years, little was known of the pre-occupation history and environments responsible for the culture's emergence in the third millennium BC. Recent geoarcheological investigations of sites sharing the same landform as Harappa—the Bari Doab—along the ancient Beas River have synthesized sediment, soil, and cultural stratigraphies that place Harappa in the context of a regional landscape history. Two key sites—Lahoma Lal Tibba and Chak Purbane Syal—illustrate that larger floodplains of the Indus system stabilized sometime in the early Holocene, when soil development exceeded rates of alluviation. The site of Harappa was revisited to procure radiocarbon dates beneath initial occupation horizons. The stratigraphy and dates established the Pleistocene/Holocene interface and confirmed coeval trends of diminished Early Holocene floodplain accretion and sustained soil formation. Pedogenesis continued at least to the beginning of the fifth millennium BP when occupation began to intensify along the Beas and elsewhere in the Upper Indus. Site formation sequences at Lahoma Lal Tibba and Chak Purbane Syal mirror those of Harappa proper, albeit on a smaller scale.

Keywords: Pedo-stratigraphy; Holocene; Indus civilization; Geoarcheology

1. Introduction

Together with Mohenjo-daro, the ancient city of Harappa was the center of the Indus civilization in the third millennium BC in parts of what are now Pakistan, India, and Afghanistan. The achievements of that civilization were on a par with those of ancient Mesopotamia and Egypt, and its rise, florescence and decline in the second millennium largely paralleled those of the other hubs. As in the Near East, Indus settlements flanked the plains of major drainage nets (the Indus River and Ghaggar–Hakra system). Compared with the Near Eastern centers, however, relatively little is known about the environmental history of the Indus civilization, despite obvious connections between alluvial chronology, site formation histories and human paleoecology. In the Upper Indus, where the city of Harappa is located, extensive excavations have been undertaken [35], producing a well documented culture chronology (Table 1). Inter-disciplinary studies—including fauna [26], fish [3], and paleobotany [15,48]—have linked cultural chronologies to reconstructed subsistence environments. An extensive pedo-stratigraphy has been developed for the site and immediate environments [2,33], but efforts have not expanded regionally.

This paper presents the results of geoarcheological investigations along the Beas River, a buried channel of the upper Indus in Punjab province, Pakistan. The Beas

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Table 1
Culture chronology for the Indus Valley after Possehl [35] and Kenoyer [21]

Years B. P.	Period	Harappan	Phase	Period Intervals
3500				
			Localization Era	
	Period 5	Late	Late Harappa Phase	(1800-1300 B.C.)
4000	Period 4	Late	Harappa/Late Harappa Transitional	(1900-1800 B.C.)
		Mature	***Integration Era***	
	Period 3C	Mature	Harappa Phase C	(2200-1900 B.C.
4500	Period 3B	Mature	Harappa Phase B	(2450-2200 B.C.)
	Period 3A	Mature	Harappa Phase A	(2600-2450 B.C.)
			Regionalization Era	
	Period 2	Early	Kot Diji (Early Harappa) Phase	(2800-2600 B.C.)
5000		Early		
	Period 1	Early	Ravi (aspect of Hakra) Phase	(>3300-2800 B.C.)
5500				
5800				
			Early Food Producing Era	

is the first trunk drainage south of the Ravi, the setting of the site of Harappa. Along the reported reach of the buried Beas, eighteen Harappan mound sites were investigated to develop regional landform histories, pedo-stratigraphies, and mound sequences that could inform on ancient environments (Fig. 1). The study focuses on two settlements closest to Harappa. They share the same landform and general cultural sequence, thus offering an opportunity to formulate hypotheses on regional Holocene geography.

2. Background and objectives

The ancient Indus landscape is known largely from artifacts and mounds exposed across an erosional landscape. The rivers of the upper Indus—the Chenab, Sutlej, Jhelum, Ravi and the Indus trunk stream—have incised surrounding surfaces, currently flowing beneath the general levels of their floodplains. The reasons for this are complex, but appear to be related to a combination of tectonics and climatic forcing [37]. In the vicinity of Harappa, Pleistocene interfluves or "doabs" are typically only several meters above mean annual flood levels and they separate the river channels, floodplains and terraces. They represent relict surfaces that may have supported the agricultural fields of the Harappans. The mounds that dot the Punjabi landscape were built on or at the margins of doabs, which were formerly well drained segments of the alluvial plain.

Two of the more prominent mound sites, Lahoma Lal Tibba and Chak Purbane Syal, are located 23 km and 19.5 km (respectively) southeast of Harappa (Fig. 1). While these sites are best considered satellite settlements, they are extensive and contain stratified

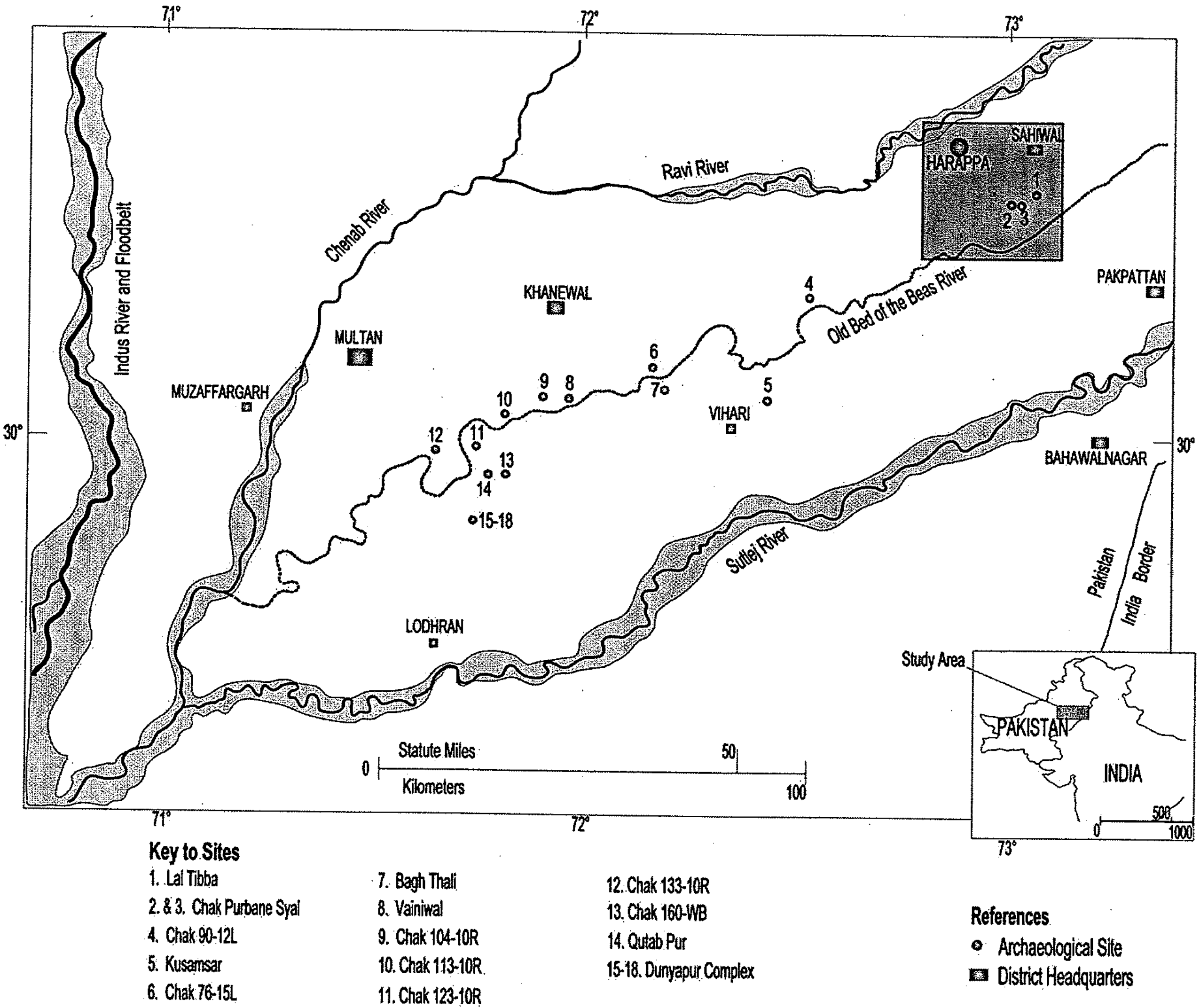

Fig. 1. Site distribution map, Beas River Survey Project. Shaded area highlights locations examined in this study (see Fig. 2).

sequences that bridge pre-occupation alluvial histories with occupation chronologies. Both sites were originally discovered by an earlier government survey of the Punjab [31]. The subsequent Beas River Survey was structured to examine parameters of urban and rural interaction between Harappa and smaller sites along the Beas for the critical protohistoric period. Synthesizing landscape histories became a major goal, since these were key to unraveling the environmental changes associated with the evolving, agriculturally based economies. The 18 sites parallel a 200 km stream segment of the discontinuously buried trunk stream (Fig. 1).

The Beas drainage is a convenient unit for a landscape based study, since it is a first order tributary to the Indus that features larger settlements, and relatively shallow and accessible stratigraphic interfaces between cultural and floodplain deposits. Ancient flow lines are recognizable along much of the stream's former course (Fig. 1), in part because the channel trench is relatively well incised (often to depths of 3 m). Channel morphology is preserved by periodic water flow attendant to irrigation scheduling and/or monsoon forced discharge. The placement of Harappan-age sites, flanking the inner and outer channel banks, is evidence that during the Holocene, the Beas was an active stream and lifeline for settlements in much the same way that the ancient Ravi was for Harappa [4]. Lahoma Lal Tibba and Chak Purbane Syal on the Upper Beas are most comparable to Harappa because of analogous alluvial contexts and proximity to that primary site (Figs. 1 and 2).

3. Geology, geomorphology, and soil landscapes of the Upper Beas

Numerous Harappan mounds in the upper Indus Valley are located either on doabs or the gentle scarps grading to lower alluvial surfaces [37] (Fig. 2). The doabs are locally referred to as "bar upland" [23].

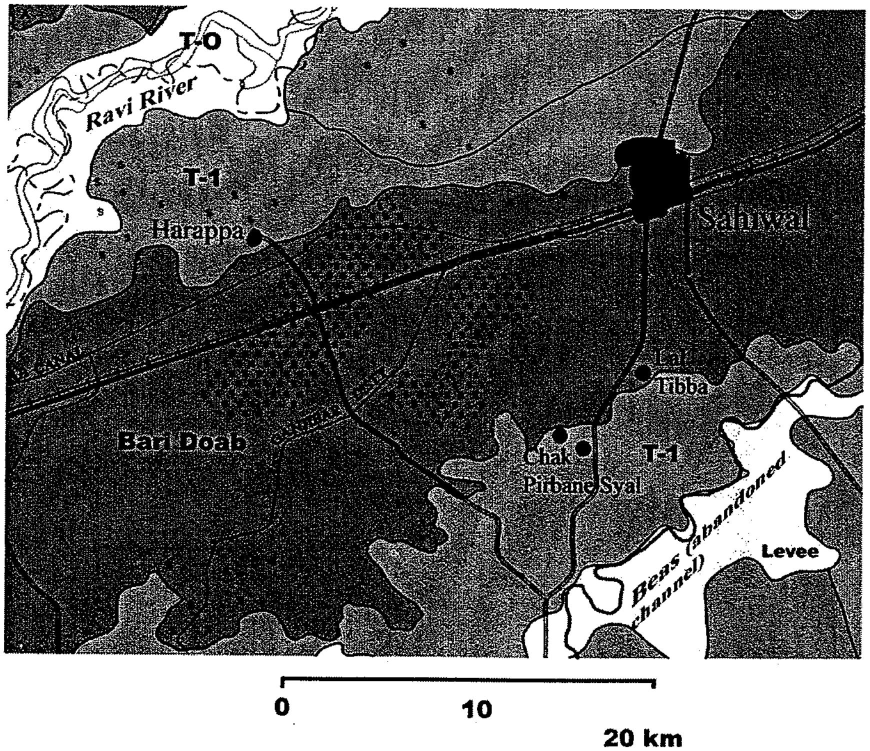

Fig. 2. Bari Doab between Ravi River (active) and Beas channel (abandoned). Note first terrace (T-1), floodplain (T-0) and Levee segment flanking the Doab. Present locations of Harappan period sites are shown on margins of Doab and T-1 (modified from [17]).

Fig. 2 illustrates landform relations across the project area. The Bari Doab is the central feature. Harappa site occupies the landform's western margins, while Lahoma Lal Tibba and Chak Purbane Syal are on the opposite edge. The Bari Doab is a relict Pleistocene or Early Holocene feature of the late glacial to early post-glacial Punjabi landscape, rising as high as 15 m above the surrounding terrain [19], but more typically only 4–6 m. Surface gradients have not varied significantly in the past few centuries [18]. Elevations range from 163.5 m amsl (highest elevation of natural Mound AB at Harappa [11]) to 153 m amsl (Lahoma Lal Tibba; based on GPS measurements taken in 2001). All three sites straddle the edge of the doab, extending on to the Early Holocene floodplain, here depicted as the first terrace (T-1) (also known as "Subrecent Floodplain" [28]). Relief on the T-1 is typically 1–4 m above the floodplain (T-0 or "Recent Floodplain"). The abandoned channel of the Beas is flanked on its left bank by an irregularly shaped, southwest trending levee; this is a relict feature attesting to its former course and its northwesterly migration.

Regional Late Quaternary geology and hydrology has been documented extensively and does not vary appreciably near the Upper Beas sites [1,4,5,19,20]. The Bari Doab is underlain by a thin veneer of terminal Pleistocene loess, aeolian sands, and alluvium (Chung Formation). T-0 deposits are mapped as Recent Holocene and consist of clays, silts and sands. T-1 is dominated by Older Holocene fluvial deposits of extinct streams [1]. It is cautioned that the ages of the formations are inferential. Even broad chrono-stratigraphic designations (Pleistocene vs. Holocene) are based on relative landform elevations in alluvial terrain. The T-1 and T-0 chronologies are particularly questionable [37], since the prevailing model projects alluvial surface ages on classic (but regionally untested) cut and fill models [8,14]; elevation differences between the two surfaces are often on the order of only 1 m. It has been proposed that neither morpho-stratigraphic (i.e. landform based) nor litho-stratigraphic (rock formation-based) criteria are sufficiently refined to formulate landscape developmental histories [37].

More definitive chronologies derive from regional soil maps [40]. For the site of Harappa, refinements to the taxonomy were proposed a decade ago as part of a soil-chronology for Holocene environmental change [2,33,34] (Fig. 3). The present studies at Lahoma Lal Tibba and Chak Purbane Syal follow these same guidelines to develop comparative site formation histories.

Table 2 integrates the updated soil taxonomies and chronologies in the immediate vicinities of the sites. Mapping units follow Soil Survey Staff [40], locally modified for Harappa [33] and for the eastern Beas sites (this study). The younger profiles are characterized by

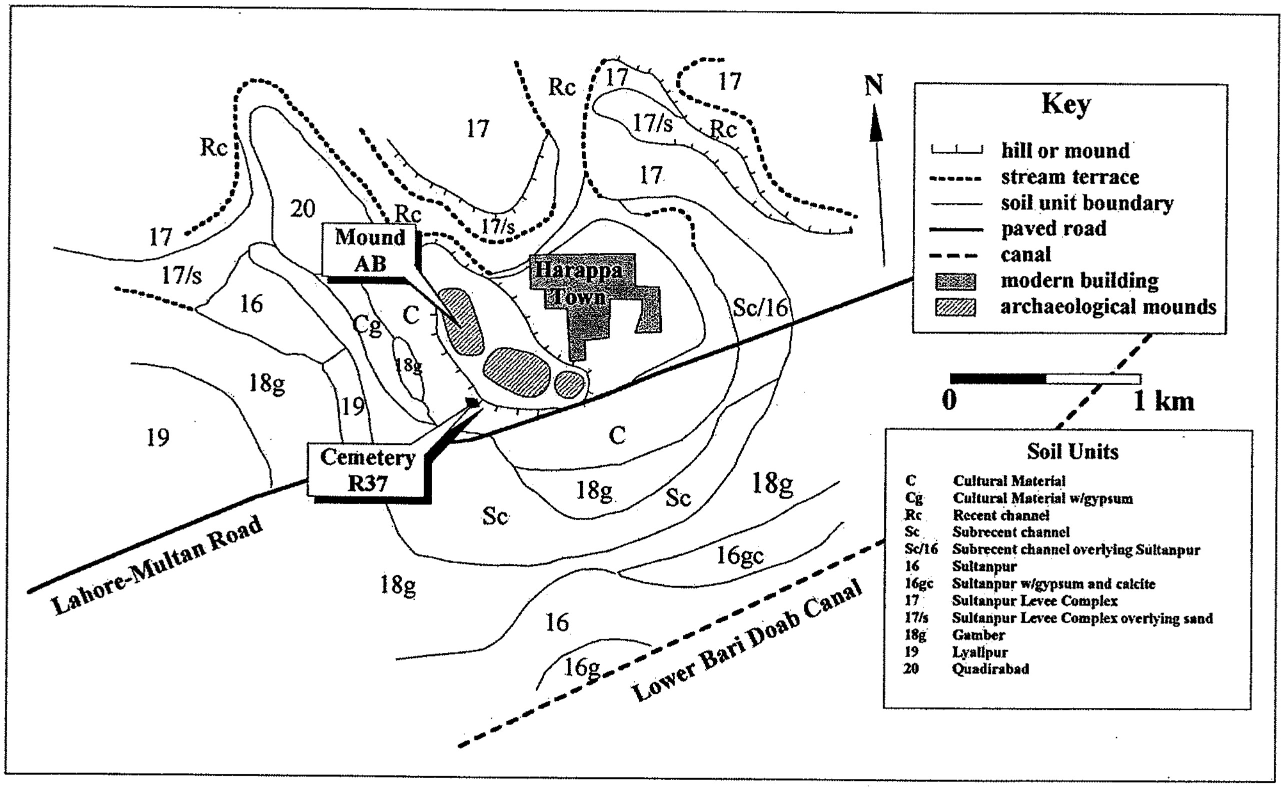

Fig. 3. Soil mapping units across the site of Harappa showing principal archeological locations (after [33]).

A–C sequences which belong to the Entisol soil order; these soils have not been stable for sufficient time to enable sustained soil formation. Progressively older, better developed soils belong to the Alfisol soil order at Harappa [41]; they display deeper, more pronounced weathering patterns in B horizons.

Relative antiquity is determined by degrees of clay translocation and carbonate redistribution and reprecipitation in the B horizon [33]. Thus the oldest soils are of the Qadirabad unit which have an argillic (clay enriched or Bt) horizon and distinct redistribution patterns, sizes, and morphologies of carbonate nodules (or kankars) in calcic (Bk) horizons [16,38]. Table 2 shows the typical profiles for individual mapped units at Harappa. Following these criteria, the Lyallpur and Gamber soils are younger than Qadirabad. Pendall and Amundson [33] claim that these soils are middle Holocene or older because they either underlie the earliest Harappan occupations (Qadirabad) (ca. 4500 BP, uncalibrated) or belong to relict landforms antecedent to the Harappan floodplain (Lyallpur) [4]. The Sultanpur unit, mapped extensively around Harappa, is considered younger still (Late Holocene) because of weaker structural development in the B horizon. Assessments of antiquity must be considered provisional, however, since only a single radiocarbon determination of 7080 ± 120 BP (uncalibrated) from a Bk carbonate nodule at Harappa is the basis for aging the Qadirabad soil [2].

The formally mapped associations at Lahoma Lal Tibba are the Lyallpur and Qadirabad units [40] and would date at least to the Early–Middle Holocene based on projections from Harappa. Chak Purbane Syal is mapped as belonging to the Bagh unit [40] which is not represented at either of the other sites. The Bagh is a calcareous soil with a deep, cambic (Bw) profile that is not as well developed, and therefore not as old as the Qadirabad, Lyallpur, or Gamber. Its age may be equivalent to the Sultanpur (Middle Holocene). As discussed below, the present field investigations bolstered by radiocarbon dates have refined the initial modifications made by Pendall and Amundson [33] to the Harappa sequence. The profiles at the eastern Beas sites confirm that there is some variability in the soil forming processes and chronologies registered along the Bari Doab and its T-1 margins.

4. Investigations

Geoarcheological investigations at Lahoma Lal Tibba and Chak Purbane Syal were undertaken in conjunction with an archaeological survey and limited testing program [52]. The studies at Harappa proper

Table 2
Soil mapping units, representative profiles, and relative ages, Upper Beas project

Site[a,b,c]	Mapping unit	Described profile	Notes	Age
Harappa[a]	Shadara	Ap-C1-C2-2C	Entisol; silt loam developed on silty calcareous alluvium	Recent
Harappa[a]	Sultanpur	Ap-Bw-Bw2-C-2Bw-2C	Alfisol; Cambic B-horizon; developed on silty calcareous alluvium	Late Holocene
Harappa[b]	Recent Channel	Ap-C1-C2-C3	Entisol; fine loam & sand; seasonally high water table; precipitated salts	Recent
Harappa[b]	Subrecent Channel	Ap-C	Entisol; silt-loam formed in poorly drained areas	Late Holocene
Harappa[b]	Sultanpur	Ap-Bw-Bk1-Bk2-BCk1-BCk2-Ck	Alfisol; Cambic and Calcic B-horizon; coarse silty; also has gypsiferous form	Mid–Late Holocene
Harappa[b]	Sultanpur Levee Complex	Ap-Bk1-Bk2-Bky-By-C	Alfisol; Calcic B-horizon; occurs on non-level alluviated surfaces; silty clay loam	Mid–Late Holocene
Harappa[b]	Gamber	Ap-Bw-By1-By2-BCy1-BCy2	Alfisol; Cambic soil with gypsiferous horizon; silt loam	Early–Middle Holocene
Harappa[b]	Lyallpur	Ap-Bw-Bk-Bky1-Bky2-C	Alfisol; Calcic B-horizon; slightly gypsiferous; silt loam	Early–Middle Holocene
Harappa[b]	Qadirabad	Ap-BA-Bk-Btk-BCk1-BCk2	Alfisol; Argillic and Calcic B-horizon; silty clay loam	Late Pleistocene/Early Holocene
Lahoma Lal Tibba[c]	Lyallpur	Ab-Bwk-BC	Alfisol; Cambic B-horizon; silt loam; "upper paleosol"	Early–Middle Holocene
Lahoma Lal Tibba[c]	Qadirabad	2AB-2Bk1-2Btk1-2Btk2-2Btk2-2BC	Alfisol; Argillic and Calcic B-horizon; silty clay loam; "lower paleosol"	Late Pleistocene/Early Holocene
Chak Purbane Syal[c]	Bagh	AB-BCk-Ck1-Ck2	Alfisol; Calcic B-horizon (kankars extend to C); silt to silt loam; "loessic paleosol"	Middle Holocene
Chak Purbane Syal[c]	Bagh	A-Bw-Bk-C	Alfisol; Cambic and Calcic B-horizon; silty clay loam	Middle Holocene

[a] Descriptions from Soil Survey Staff [40].
[b] Descriptions from Pendall and Amundsen [33].
[c] Descriptions modified (this study) from Soil Survey Staff [40].

were confined to refining stratigraphy and dating the interface of pre-occupation soils and sediments.

4.1. Research methods

General descriptions of Lahoma Lal Tibba and Chak Purbane Syal published by the Punjab Archaeological Survey [31] provided baseline data. Updated 1:50,000 Government of Pakistan topographic maps and landform maps [17] were consulted for general identifications of flood basin features. Accessible and minimally eroded mound profiles were selected for stratigraphic observation, sediment description, and radiocarbon sampling (Table 3). The steepest slopes exposed the most separable cultural components. At the mound toe-slope, sampling continued into the natural substrate. Here hand-driven 30 mm diameter cores were extracted to depths of up to 3 m into the soils and alluvium. Cultural stratigraphies extended to within 1–2 m of the base of the mounds, where the natural—typically buried soil—interfaces were encountered.

Sediments from both cultural (anthropogenic) and geo-stratigraphic (soil and geological) contexts were described in the field following the criteria of Soil Survey Staff [41]. Observations were made of Munsell color, texture, structure, consistence, carbonate content (utilizing both effervescence index and carbonate stage morphology), and horizon boundary. For cultural deposits, *field levels* were recognized as discrete bodies of sediment, separated either by grouped artifacts sets, cultural periods, specific features, or activity or fill types. *Geo-stratigraphic units* refer either to sediments laid down by natural agency (e.g. water, wind, or gravity) and/or soils that were weathered in place (containing variants of A–B–C profiles). The geo-strata provide the baseline for synthesizing site sequences since they incorporate the field levels (cultural) and soils in continuous succession (Tables 4 and 5).

Both charcoal and bulk sediments were taken for radiometric dating. For cultural sediments charcoal was always selected. Bulk sediments (processed by humic acid treatments) were procured from non-cultural contexts. Non-cultural sediments have rarely been dated at Harappan sites. These materials are less than ideal because of contamination and taphonomic concerns. However, the refinement of AMS dating techniques coupled with a careful recognition of the sources of potentially datable sediment has enhanced the utility of the method [24,43]. Humic acid dates represent the average age of the horizon formed during soil formation, also referred to as Apparent Mean Residence Time (AMRT) [25,36]. These determinations provide an order of magnitude age for environmental events and buried surfaces preserved in sediments underlying the cultural horizons.

Table 3 summarizes radiometric results by site and in order of increasing age. For pre-cultural deposits, the differences between conventional [^{14}C] and calibrated or calendar [cal yr] years are critical since the former are on the order of 1500–2000 years younger for the terminal Pleistocene time frames [7,13,42]. The differences between calibrated and conventional ^{14}C ages decrease exponentially for later periods. In this study, separate designations for conventional and calibrated dates—[^{14}C] and [cal yr BP or BC for cultural dates] respectively—are reported throughout. Calibrated ages are reported in years BC for occupation deposits only. Calibrated BC ages facilitate comparisons with cultural sequences for other Harappan sites [35]. The four lowermost dates in Table 3 are from pre-occupation alluvial contexts.

4.2. Lahoma Lal Tibba (Fig. 4; Plate 1; Table 4)

Surface elevations at the base of the mound at Lahoma Lal Tibba are approximately 156 m amsl. Mound relief covers an area of nearly 6 hectares [31] and probably spread over a significantly more extensive area, currently encroached upon by agricultural fields and homesteads. The site is located about 4 km north-northwest of a prominent meander loop of the former Beas channel (Fig. 2). The original mound was bisected (northeast-southwest) by a road and power line, creating two unequal sized segments (heretofore North Mound and South Mound). North Mound is conical in shape and accounts for about one-third of the surface area. South Mound is elongate and has a more irregular surface morphology along mid-slopes; it approximates an undulating ridge in profile. Maximum elevation is 4.5 m at the apex of both mounds. Local informants note that both mounds may have been up to 2 m higher a decade ago. Two relatively broad channels (up to 20 m wide) flank the mounds east and west, draining runoff during severe monsoon rains. The eastern channel is more extensive and may have formerly functioned as a tributary to the Beas.

Both mound segments are undergoing severe head-cutting that has resulted in the creation of a series of gullies. The steepest gullies are incised through the mid-slopes and toeslopes of the South Mound. Northward encroachment of neighboring agricultural fields has accelerated runoff on footslopes. Concentrations of Harappan pottery, pyrotechnical refuse, architectural foundation materials, and mud brick fragments are found within the gullied channels of the sideslopes. The more level surfaces on the upper mound elevations have generally preserved artifact concentrations, while mid-slope knolls are generally barren, attesting to the scale of active attrition. The upper surfaces of the mounds appear less susceptible to erosion as they are still steep, often grading as much as 15° downslope.

Table 3
Table of radiocarbon dates, Upper Beas project

Beta Lab no.	Site	Conventional C^{14} age	$\delta^{13}C$	Calibrated age range cal BC[a]	Material	Method	Context
117735	Chak Purbane Syal (126-9L)	3780 ± 70 BP	−25.0	2450 (2190) 1975	Carbon	Radiometric	Burnt feature
117737	Chak Purbane Syal (114-9L)	3800 ± 80 BP	−25.0	2465 (2205) 1975	Carbon	Radiometric	Discrete activity area; two specimens
142267	Lal Tibba	3780 ± 70 BP	−25.0	2455 (2200) 2010	Carbon	Radiometric	South Mound, stratum VI; slump, reworked burnt charcoal
142270	Lal Tibba	3900 ± 40 BP	−24.9	2475 (2430) 2280	Carbon	AMS	South Mound; pyrotechnical feature
142269	Lal Tibba	3960 ± 40 BP	−25.9	2570 (2470) 2340	Carbon	AMS	South Mound, stratum V; sheetwash with cultural materials
142266	Lal Tibba	3980 ± 40 BP	−16.6	2580 (2475) 2430	Organic Sediment	AMS	South Mound, stratum II; charcoal horizon
92216	Lal Tibba	3990 ± 60 BP	−23.8	2610 (2480) 2325	Carbon	AMS	North Mound, stratum VII(?); lowermost discrete feature
142268	Lal Tibba	6900 ± 40 BP	−16.4	5845 (5750) 5710	Organic Sediment	AMS	South Mound, stratum IX; buried A of Lower Paleosol
92217	Lal Tibba	13,050 ± 60 BP	−23.5	14,209 (13,741) 12,687	Organic Sediment	AMS	Buried alluvium beneath Lower Paleosol
133921	Harappa	11,270 ± 40 BP	−19.7	11,490 (11,220) 11,180	Organic Sediment	AMS	AB Mound/low energy humified silts;H97/7768
133922	Harappa	13,090 ± 40 BP	−23.3	14,120 (13,790) 13,380	Organic Sediment	AMS	AB Mound/Paleosol;H97/7769

[a] Calibrated age range based on 2 sigma using INTCAL98 calibration database or CALIB 4.3 program (after Stuiver et al. [42]). Value in parentheses is intercept of radiocarbon age with calibration curve.

Table 4
Field stratigraphic descriptions for Lahoma Lal Tibba composite profile: south mound and core 1

Field layer	Depth (cm)	Unit	Soil horizon	Munsell color	Texture	Structure	Consistence	Carbonates[a]	Boundary	RC dates	Comments
I	0–20	1	Occupation	10 YR 4/3	SiL	1 f gr	fri	Ste	c,s		Ash, abundant charcoal, colluvial
II	20–37	1	Occupation	10 YR 6/3,5/3	SiL	1 f gr	fri	Ste	s,a	3980±40 BP	contains discrete charcoal horizons
III	37–60	1	Occupation	10 YR 5/4,6/4	SiCL	1 f gr	sl hard, fri	Ste	c,s		ash lenses, abundant pottery
IV	60–75	1	Occupation	10 YR 5/4,6/4	LSi	1 f gr	fri	Ste	c,s		abundant decomposed bone, ash
V	75–130	1	Occupation	10 YR 5/3,6/3	LSi	mass strat	hard fri	Ve	a, s	3960±40 BP	local alluvium, few artifacts, ash
VI (A,B)	130–260	1	Occupation	10 YR 5/3,5/4	LSi	1 f gr	fri	Sle	c, s	3780±70 BP	slump, heterogeneous, burnt features
VII	260–305	1	Occupation	10 YR 5/4	LSi	mass strat	hard fri	Ste	c,s		"mud brick horizon", burnt clays
VIII	305–315	2	Ab	10 YR 5/3	FSL	1 w sbk	soft fri	Ste	g,s		"Upper Paleosol" (Middle Holocene)
VIII	315–340	2	Bw	7.5 YR 5/3	SiCL	2 f sbk	hard firm	sle/Stage I	d,s		root casts, diffuse kankars, organic clay films
VIII	340–365	2	Bwk	7.5 YR 5/4	SiCL	2 m sbk	hard firm	ste/Stage I+	d,s		kankers increase in size and frequency parent
VIII	365–385	2	BC	7.5 YR 5/4	SiL	1 w sbk	soft fri	Sle	g,s		alluvium
IX	385–405	3	2AB	10 YR 5/4	FSL	1 w sbk	soft fri	Ste	c,s	6900±40 BP	"Lower Paleosol" (Early Holocene)
IX	405–420	3	2Bk1	10 YR 5/4	SiCL	2 f sbk	hard firm	ste/Stage I+	d,s		small kankars (3–4 m), clay films
IX	420–440	3	2Btk2	10 YR 5/4	CLSi	3 s sbk	v hard	ve/Stage II	d,s		25% kankers (to 40 mm), prominent clay skins
IX	440–460	3	2Btk3	7.5 YR 5/3	SiC	2 m pr	v hard	ste/Stage I+	c,s		continuous clay skins
IX	460–475	3	2BC	10YR 5/4	FSL	mass strat	hard fri	ste/Stage I+	c,s		parent alluvium
NA	475–515	4	3AB	10YR 5/3	SiCL	2 w sbk	sl hard, fri	ste/Stage I	g,c	13,050±60 BP	"Terminal Pleistocene Entisol"; matted organics
NA	515–540	4	3C1	10 YR 6/4, 6/3	SiCL	mass strat	sl hard, fri	Ve	c,s		fining upward alluvium
NA	540–685	4	3C2	2.5 Y 5/3	FSL	mass strat	fri	w	c,s		sandy micaceous alluvium, fining upward
NA	685–710	5	4AC	2.5 Y 5/3	CS	1 w sbk	soft fri	sle	c,s		"Pleistocene Entisol"; laminar beds, dense organics
NA	>710	5	4C	2.5 Y 6/3	FS	mass strat	Loose	sle	NA		coarsest parent alluvium

Texture: Si=silt; L=loam; C=clay; S=sand; F=fine; G=gravel. *Structure*: 1=weak; 2=moderate; 3=strong; f=fine; m=medium; c=coarse; f=fine; gr=granular; mass=massive; strat=stratified; sbk=subangular blocky; ab=angular blocky; pr=prismatic. *Consistence*: fri=friable; sl=slightly; v=very; l=loose; fi=firm; st=sticky; ss=strongly sticky. *Carbonates*: ve=violently effervescent; ste=strongly effervescent; sle=slightly effervescent; we=weakly effervescent. *Boundary distinctness*: a=abrupt; c=clear; d=diffuse; g=gradual; s=sharp. *Boundary topography*: s=smooth; a=abrupt.

[a] Effervescence categories after Birkeland [6]; carbonate stages after Sehgal and Stoops [38].

Table 5
Field stratigraphic descriptions for Chak Purbane Syal: Chak 114-9L

Field layer	Depth (cm)	Unit	Soil horizon	Munsell color	Texture	Structure	Consistence	Carbonates[a]	Boundary	RC dates	Comments
1	0–30	1	Occupation	10 YR 3/2,4/2	Rubble	NA	fri	ste	s,a		Admixture of dense, coarse cultural debris
2	30–82	1	Occupation	10 YR 5/3	SiL	1 f gr	fri	ste	c,s		silty mound fill with Fe, Mn stains
2a	60–65[b]	1	Occupation	10 YR 5/4	SiCL	1 w sbk	soft fri	ste	c,s		band of organic debris, burnt charcoal
3	82–105	1	Occupation	7.5 YR 5/4	SiCL	1 f gr	fri	ste	c,w	3800 ± 80 BP	intensive activity area with burnt debris
NA	105–120	2	AB	10 YR 5/4	SiCL	1 w sbk	soft fri	ste	c,s		"Paleosol" (Late Holocene), intrusive cultural debris
NA	120–140	2	BCk	10 YR 6/4	FSSi	2 m sbk	hard firm	ste/Stage I	d,i		well sorted silts; 1–2 mm kankars
NA	140–165	2	Ck1	10 YR 5/3	SiCL	mass strat	hard fri	ste/Stage I+	d,i		calcareous silts; denser kankars
NA	>165	2	Ck2	2.5 Y 5/4	SiCL	mass strat	sl hard fri	ste/Stage I+	NA		mixed silty clay alluvium

Texture: Si=silt; L=loam; C=clay; S=sand; F=fine; G=gravel. *Structure*: 1=weak; 2=moderate; 3=strong; f=fine; m=medium; c=coarse f=fine; gr=granular; mass=massive; strat=stratified; sbk=subangular blocky; ab=angular blocky; pr=prismatic. *Consistence*: fri=friable; sl=slightly; v=very; l=loose; fi=firm; st=sticky; ss=strongly sticky. *Carbonates*: ve=violently effervescent; ste=strongly effervescent; sle=slightly effervescent; we=weakly effervescent. *Boundary distinctness*: a=abrupt; c=clear; d=diffuse; g=gradual; s=sharp. *Boundary topography*: s=smooth; a=abrupt.

[a] Effervescence categories after Birkeland [6]; carbonate stages after Sehgal and Stoops [38].

[b] Subunit within Unit 2.

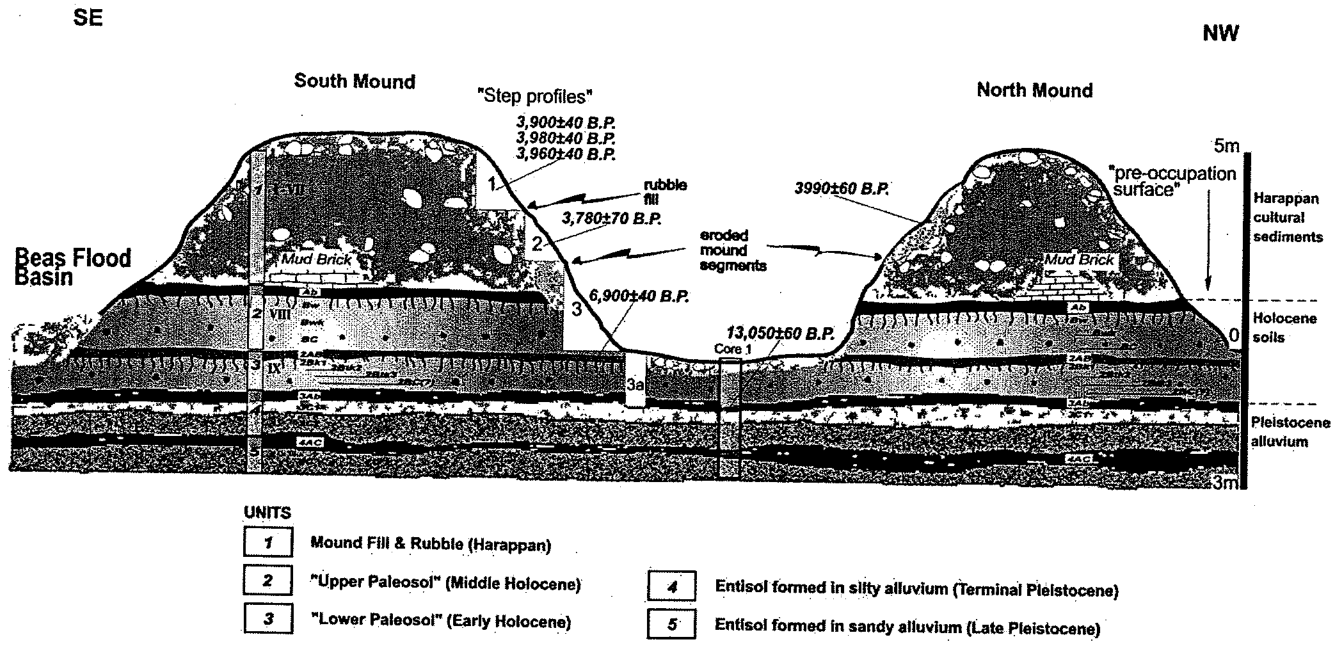

Fig. 4. Schematic cross-section of landform relations and generalized stratigraphy of Lahoma Lal Tibba, South and North Mounds. Locations of step trenches, cores, and radiocarbon dates are approximate. Primary geo-stratigraphic units (Arabic numerals), field layers (Roman numerals) and soil horizons are identified.

Fig. 4 illustrates the landform relations and schematic stratigraphy of the two mounds. The interface between a moderately well developed soil profile and Harappan strata is at between 0.9–1.0 m above the road surface. Cultural materials were visible atop four courses of mud brick representing either a foundation platform or wall. An ash layer above the uppermost course produced a [^{14}C] determination of 3990 ± 60 BP [2480 BC cal yrs] (Beta-92216; Table 3). This Beas date is consistent with collected diagnostic pottery assemblages for Harappa period 3A (Table 1; ca. 2600–2450 BC) [52]. This mud brick feature may be as early as Harappa period 2, if it represents a building episode antecedent to the ash horizon, or as late as period 3 if contemporaneous; the radiocarbon dates from the ash corresponds to Harappa 3a. What is unequivocal is that the mud brick feature was erected directly on an intact cambic paleosol with a diagnostic calcic (Bwk) horizon (Plate 1). Evidence for wall structures was also found at adjacent levels or intrusive into the underlying Bwk horizon.

The general elevations and stratigraphies of the intact mud brick feature and the paleosol were visible on the South Mound, suggesting that the site was originally a single settlement. Radiocarbon dates and artifact distributions confirm their contemporaneity (Fig. 4).

Two cores extracted between North and South Mounds penetrated the Pleistocene alluvium. The composite site profile thus registered 3 m of cultural sedimentation capping 4 m of pre-occupation stream deposits and soils. It is convenient to sort the stratigraphy by sets of components (Fig. 4; Table 4): Harappan cultural deposits (Unit 1); stacked Holocene soils (Units 2 and 3); and Pleistocene alluvium capped by thin organic horizons (Units 4 and 5).

Unit 1, includes layers I–VII. The uppermost, Layer I, was colluvial and consisted of loose, friable silt loams with irregular distributions of ash and charcoal. The matrix disaggregated easily, even when clearly stratified above more cohesive sediments. Layers II and III featured dense pottery, nodules and architectural and pyrotechnical debris. Features were preserved in firmer sediment bodies. Sub-horizontal, abrupt stratification implicates localized activity loci, perhaps associated with living floors. Abundant bone debris and looser loamy silts characterized Layer IV, which may have been a burning feature beneath one of the floors. Layer V was a massive loamy silt with some laminations typical of localized water flow and settling of fines in a minor basin or depression. Layer VI is a deep (1.3 m) slump deposit. It accounts for inverted stratigraphy supported by an early [^{14}C] date of 3780 ± 70 BP [2200 BC cal yrs] (Beta-142267; Table 3). The lowermost cultural sediments of layer VII were the most intact, incorporating the possible mud brick platform and laterally equivalent horizontal burnt clay lenses. Layer VII accumulated directly on the Holocene soil of Unit 2.

Unit 2 is the Upper Paleosol and preserves an .8 m thick Ab-Bw-Bwk-BC sequence. The Bw and Bwk horizons are iron (7.5 YR hues [32]) and clay enriched. The distinctive calcic (Bk) horizon features pedogenic carbonate nodules (locally kankars), sizes (2–5 mm) and frequencies of which increase with

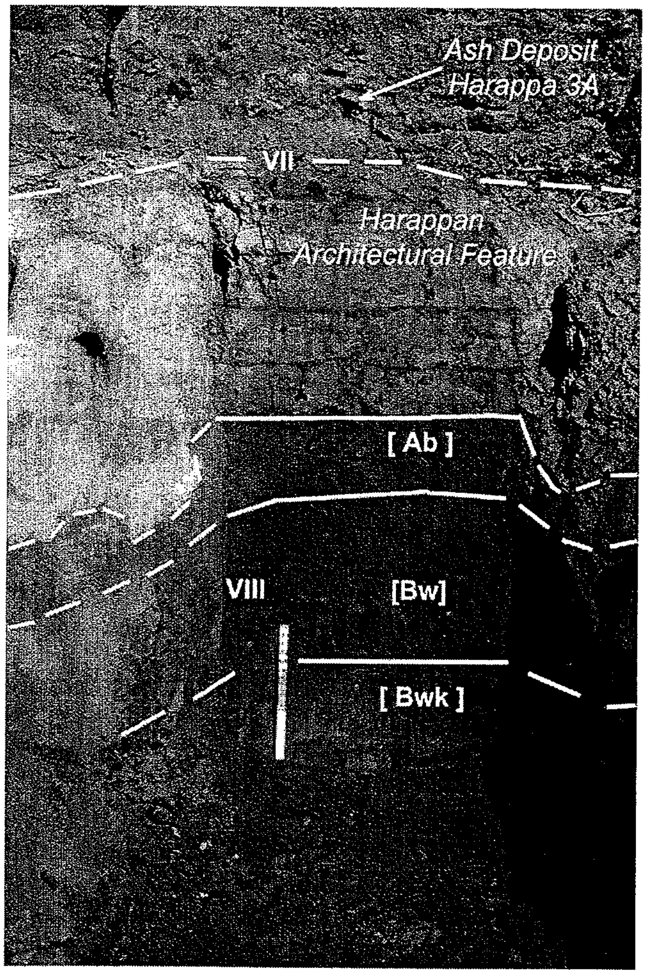

Plate 1. Contact of initial Harappan occupation surface and Mid-Holocene paleosol at Lahoma Lal Tibba, North Mound. Roman numerals refer to field levels. Adjacent soil horizons shown in brackets. Note four courses of bricks associated with Harappan architectural feature. Whitened color at base of profile highlights calcic soil horizon (Bwk). Scale is 30 cm.

depth. Bioturbic action accounts for isolated artifacts, including fragments of salt and carbonate encrusted pottery, extending into the top of the Bw horizon.

Unit 3 (Lower Paleosol) is a deeper (0.95 m), more strongly weathered soil, with a clay enriched (argillic or Bt) horizon and large kankars (up to 40 mm). Carbonate development conforms to the Stage II level of development [6,38], which in non-gravelly alluvium requires about 5000 years to form. The Bt subhorizons were more prominent and had more continuous clay skins with depth. The soil developed over a thin (0.15 m) fine sandy alluvium; it is probable that a considerable thickness of floodplain sediment was stripped away during an earlier phase of channel erosion.

Unit 4 is the deepest sediment package, accounting for 2.1 m of nearly continuous alluviation. The deposits are capped by a moderately well developed AB horizon with limited carbonate development (Stage I). The structure of the pedon is relatively weak, however and there is no apparent B horizon. The alluvium grades from a coarse-medium to medium-fine sand up the sequence suggesting meandering stream behavior.

The base of the succession, *Unit 5* at a depth of approximately 7 m, is draped by couplets of laminar silty organic beds over more massive, coarse sands. These represent short term settling deposits, perhaps laid down during an interval of floodwater retreat. Channel activity may have been dynamic at this time, since grain sizes were the coarsest in the sequence.

Of a total of seven radiocarbon dates, five were from cultural contexts (Unit 1; Table 3). The date from stratum VI, [^{14}C] 3780 ± 70 BP; 2200 BC [cal yrs] (Beta-142267; Table 3), is the only one out of sequence. As noted, it is derived from a slump deposit and materials that were mobilized and redeposited downslope. The other determinations span less than a century, from [^{14}C] 3990 to 3900 BP (2480–2430 BC [cal yrs]). The oldest cultural sediment was obtained from ash immediately overlying the mud brick feature. The latter marks the interface of the Upper Paleosol and appears to date the initial occupation of the site to ca. [^{14}C] 4000 BP The limited occupation window suggests either a rapid sequence of discrete activity loci or a more intensive habitation characterized by multiple, contemporaneous utilization areas. The variation in sediment types from which the radiocarbon samples were procured represents a range of activities and considerable natural reworking (e.g. the water-laid silts of Field Level V). The primary occupation occurred during the latter stages of Harappa Period 3A (Table 1). The out-of-sequence date from stratum VI is correlated with the collected assemblages featuring decorative designs and figurines of period 3B or even 3C [52]. Preliminary indications that the site sustained more limited human activity during its later history is preserved on the upper portions of the mound. The top of the mound was considerably more susceptible to a variety of erosional mechanisms, thus compromising the integrity of the later component and impeding potential for reconstruction of site activity.

Two radiocarbon determinations were procured from soils developed in Units 3 and 4, respectively (Tables 3 and 4). The date of [^{14}C] 6900 ± 40 BP (Beta-142268; Table 3) on the 2AB horizon of Unit 3 is consistent with an Early–Middle Holocene period of low energy alluviation followed by environmental stability. Unit 3 registers the best developed soil. Stage II carbonate nodules and a deep argillic profile are strong evidence for optimal moist/temperate environments during the Early Holocene (prior to 7000 BP). Since Unit 2 is bracketed between that soil and the Harappan 3A occupation, the age of the soil can be reliably dated to ca. [^{14}C] 7000–4000 BP.

The oldest radiocarbon date for the site was from horizon 3AB of Unit 4. The Pleistocene determination of

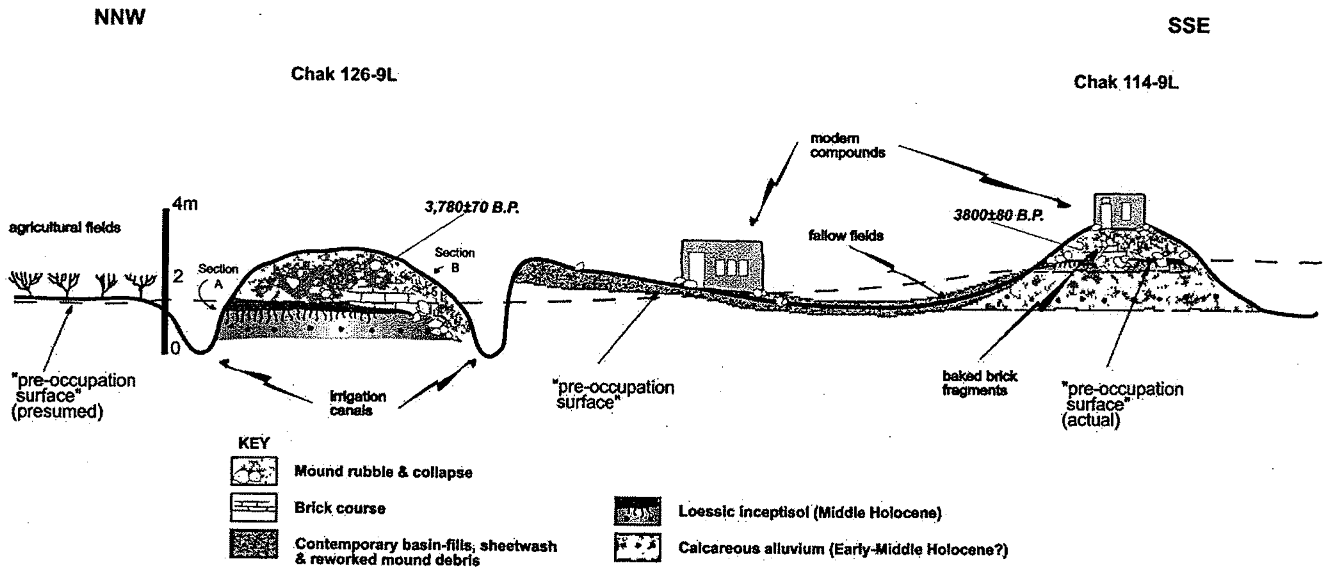

Fig. 5. Schematic cross-section of landform relations and generalized stratigraphy of Chak Purbane Syal, West and East Mounds. Note actual and projected reconstruction of pre-occupation surface. Radiocarbon dates shown in approximate stratigraphic positions.

[^{14}C] 13,050 ± 50 BP (Beta-92217; Table 3) is coincident with initiation of an upward fining sequence that may mark the last stage of lateral stream migration along the Beas floodplain. Mean particle sizes of the alluvium above Unit 4 are chiefly silty while those below are 1–2 *phi* size grades coarser, in the fine–medium sand range. The thinness of the 2 BC horizon immediately above Unit 4 would suggest extensive sediment stripping by a migrating channel, perhaps at the Pleistocene/Holocene interface (i.e. base of Unit 3). For Units 4 and 5, the lack of deep pedons, distinguishable B horizons, and evidence for of semi-arid (i.e. Alfisol) weathering argues for subdued late Pleistocene soil formation.

In sum, five well dated geo-stratigraphic units were identified in the composite section that included: 3 m of separable cultural horizons (Unit 1); a Middle Holocene soil immediately underlying the initial occupation (Unit 2); an Early Holocene soil that is more deeply weathered (Unit 3); a deep alluvial fill of terminal Pleistocene age (weakly weathered) (Unit 4); and an older, coarser Pleistocene flood deposit (Unit 5).

4.3. Chak Purbane Syal (Fig. 5; Plate 2; Table 5)

Chak Purbane Syal is located nearly 6 km southwest of Lahoma Lal Tibba (Figs. 1 and 2) at a surface elevation of about 157 m amsl. The site was originally described by Vats [44] as attaining heights of 15–20 ft (4.67–6.25 m) on its north end, but more typically the site rose only a few feet above surface. There are currently two mounds divided between the villages of Chak 126-9L and Chisti Wala Tibba (alternately Chak 114-9L). Landscape relations suggest that the mounds were originally continuous. Vats attributed attrition of the mound landform to "the southward recession of the Beas ... (which was) seemingly the direct cause of the destruction of the prehistoric [Harappan] site of Chak Purbane Syal" [44:p.7]. Historic accounts confirm that perennial waters flowed along the Beas until about 1750 and that shifts in stream course were linked to the lateral displacement of the Sutlej [18]. Field evidence is consistent with lateral planation, lowering of the original ground surface, and splitting and mound attrition (Fig. 5). Since the nineteenth century farming has altered the terrain between the mounds and produced the concavo-convex surfaces between them.

Chak 126-9L is flanked by parallel irrigation channels, creating a hemispheric profile in section. It is oriented generally north south and is almost perfectly oblong, measuring 260 × 60 m. Chak 114-9L remains as a slightly elongated ridge. The alluvial-colluvial surface separating the two mound segments reflects low angle fan sedimentation, currently visible at the western toeslope of Chak 114-9L. Sediments consist of contemporary refuse and Harappan cultural debris reworked by sheetwash and preserved in a silty sand matrix. Diffuse Harappan age debris has been redeposited in the irrigation canals on both sides of Chak 126-9L.

Fig. 5 illustrates profiles on the west and east sides of the north end of Chak 126-9L and the north side of Chak 114-9L. Chak 114-9L preserved a composite stratigraphy of the Holocene soils that underlie the cultural succession (Table 5). The two mounds contained generally similar sequences, but there is structural and textural variability in the mid-Holocene soil. While one to three cultural levels are recognized in the uppermost meter, the underlying Inceptisol to the west (Chak 126-9L) was a pure silt but at Chak 114-9L it graded to

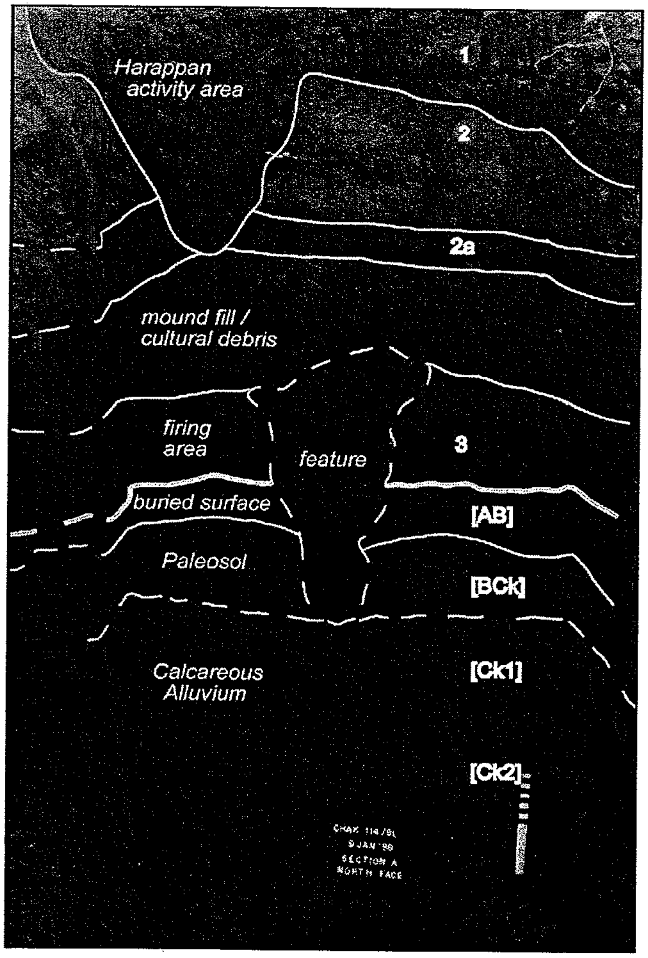

Plate 2. Contact of initial occupation surface (Harappan) and Mid-Late Holocene paleosol at Chak Purbane Syal; section is at north face of Chak 114-9L (Fig. 5). Arabic numerals refer to cultural levels (above paleosol). Adjacent soil horizons shown in brackets. Note whitened calcic horizons (BCk, Ck1, Ck2). Scale is 20 cm.

a mixed sandy silt. Two principal stratigraphic units were identified (Table 5) and cultural horizons were preserved in Unit 1 only.

In *Unit 1* (Plate 2) the uppermost occupation sediment (1) was an admixture of dense Harappan debris including decomposed baked and mud bricks, pottery fragments, and isolated burnt debris. It was underlain by a softer, massive silt (2) with interdigitations of burnt lenses, ash features, and silt-clay lined micro-depressions with identifiable organic mats. Pores within the matting structures preserved mineralized iron and manganese streaks. A prominent, 0.05 m thick band of organic debris with charcoal (2a) and entrained 2–5 mm filaments (seeds?) was intercalated within Field Layer 2. The lowermost cultural deposit was a possible firing area and contained charred pieces of wood, burnt pottery, and fired clay nodules, as well as baked brick, burnt bone and a slumped feature.

Unit 2 at Chak 114-9L was exposed to the base of the soil (C horizon), reaching parent material only 0.35 m below the interface with mound construction debris. The upper weathering horizons—AB-BCk—broke into weak to moderately developed subangular blocky structures and were dominated by silts with limited amounts of translocated clays. These properties are suggestive of a cumulic profile, one in which weathering is ongoing while sedimentation persists. Progressive calcification was persistent well into C horizons, with increased sizes and densities of carbonate nodules. The AB horizon contains a pure silt, indicative of wind-borne loess sedimentation. However, the transition to relatively thick (approximately 0.2 m), poorly sorted fine sandy silts in the BCk horizon suggests probable inputs of alluvium. Moreover, the striking color change (to 2.5 Y 5/4) near the base of the exposed profile is typical of Beas alluvium. Coarsening fine and medium sands marked the top of an alluvial facies beneath the Ck2 horizon. Unit 2 consisted of a basal alluvium which gave way to increased wind-blown contributions on which the Late Holocene soil developed.

On the western mound, the loessic subsoil is defined by an AB horizon with minimal structure and some clay translocation in the underlying Bk. The loess is a typically well sorted, calcareous silt with a 0.4 m thick calcic (Bk) horizon extending into the parent material. That profile is consistent with descriptions of the Bagh soil association [40]. Two cultural radiocarbon dates were taken at depths of 0.5–1.0 m (Unit 1) and provided dates within 20 years of each other ([^{14}C] 3800–3780 BP; ca. 2200 BC [cal yrs]) (Table 3). The determinations post-date the primary occupations at Lahoma Lal Tibba, but are consistent with that site's uppermost component, equivalent to periods 3B and 3C at Harappa (Table 1; [52]).

No radiocarbon determinations were taken from the soils immediately underlying the mound. The weathered profile is only 0.25 m thick. The broad similarity to the "Upper Paleosol" at Lahoma Lal Tibba points to a similar soil developmental sequence, but somewhat different depositional mechanisms. The wind-blown silts account for differential weathering and a somewhat modified chronology. The soil is provisionally dated to the Middle-Late Holocene.

4.4. Pre-occupation stratigraphy of Harappa (Fig. 6)

Amundson and Pendall [2] have furnished the only pre-cultural radiocarbon date from Harappa. They obtained a determination of [^{14}C] 7080 ± 90 BP on a carbonate nodule (i.e. kankar) from the Qadirabad soil at Cemetery R37 on the south side of the site (Fig. 3). The Qadirabad is the oldest soil in the Harappa sequence, underlying nearly the entire main portion of the mound (Fig. 3).

During recent excavations of Harappa Mound AB, Meadow et al. [27] updated an older section of Wheeler's

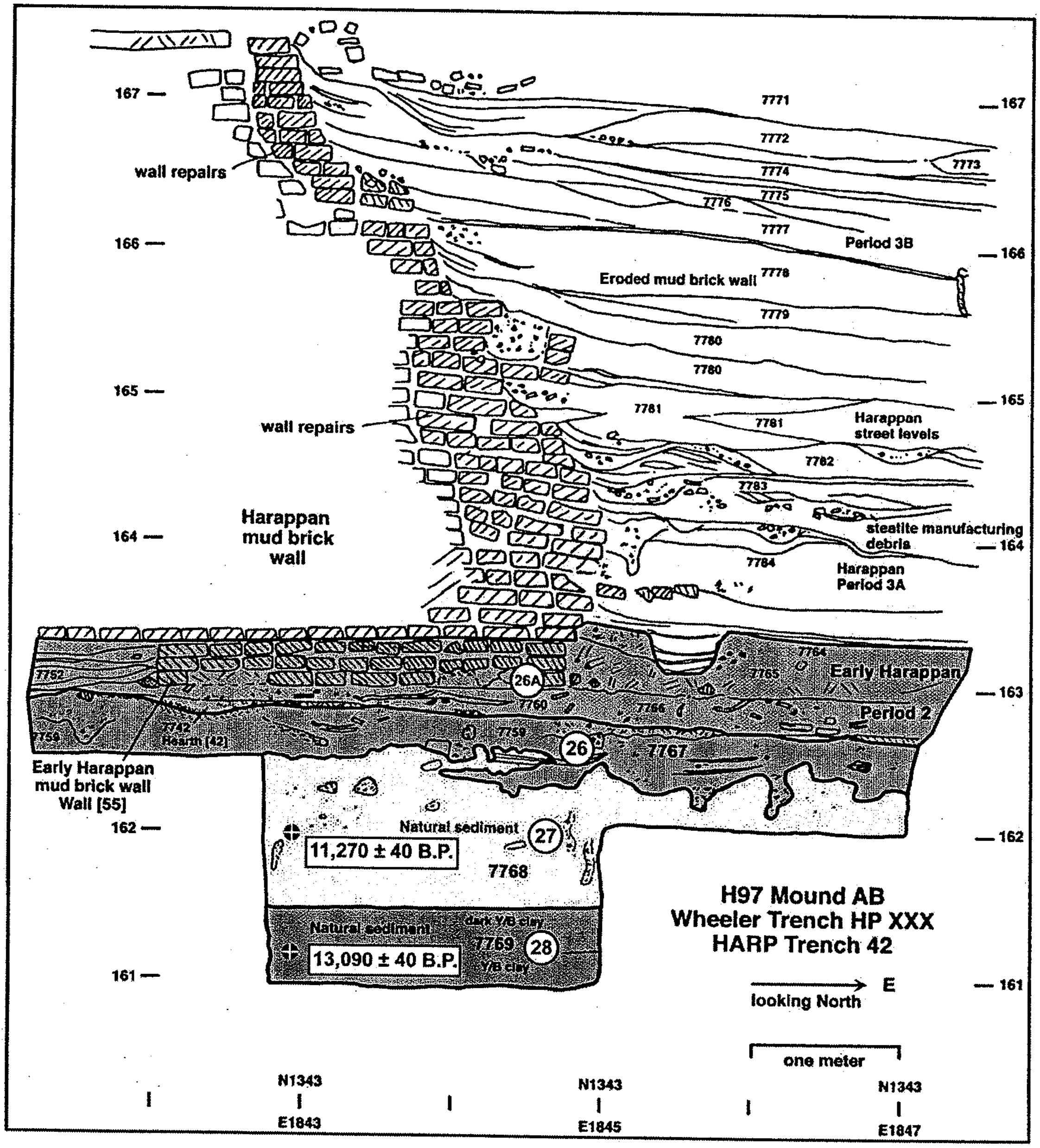

Fig. 6. Detail of section of HARP Trench 42, Mound AB, at Harappa showing provenience of Pleistocene radiocarbon dates at interface of cultural and pre-cultural strata. This is an updated section from Wheeler's [49]: Plate XXII original trench as modified in [27], Figure 5]. Dates are derived from bulk humic samples from two lowermost horizons (labeled "Natural Sediment"); these correspond to field units 7768 and 7769 [27] and layers 27 and 28 [49]. See text for details.

[49] that illustrates the cultural to natural stratigraphic interface at the site. An Harappan (Period 2) wall was erected over the uppermost of three deposits that extend into unmodified alluvium (Fig. 6); stratigraphic schemes include Meadow et al.'s [27] (units 7767, 7768, and 7769) and Wheeler's [49] original layers (layers 26, 27, and 28). There is some question about the cultural vs. natural origins of the uppermost deposit 7767 (layer 26) [[21] and personal communication], but the two underlying horizons (7768/Layer 27 and 7769/layer 28) are considered "natural sediments" by Meadow et al. [27]. Wheeler [49] considers the upper of the two to be an "alluvial deposit" (his layer 27) and the lower a "dark brown earth" (his layer 28), perhaps even an ancient plow zone. Neither stratigraphic scheme offers suggestions of the age of these deposits other than that they pre-dated occupation.

HARP Trench 42 at Mound AB was revisited in 1997. Sections were redescribed and bulk humic samples were dated as follows:

Humic Low Energy Flood Silts (Unit 7768/Layer 27) ABk horizon 0.65 m thick. 10 YR 6/4 silty clay loam, weak prismatic structures; fine sandy and organic linings around ped faces and in root veins; abundant fissures, roots and rootlets; diffuse, small (1–2 mm) kankars; clear, smooth lower boundary. Radiocarbon dated to [^{14}C] 11,270±40 BP [11,220 BC cal yrs] (Beta-133921; Table 3)

Paleosol (Unit 7769/Layer 28) Bt1k-Bt2-Bt3y-C horizons 0.50 m thick 7.5 YR 5/3 silty clay (clay increases with depth); firm, medium prismatic structures; angular ped faces; dense root impressions; discontinuous to continuous clay skins; stiff and very plastic; kankars in upper third of horizon; gypsiferous coatings in lower third; clear, abrupt lower boundary (to unweathered alluvium). Radiocarbon dated to [^{14}C] 13,090±40 BP [13,790 BC cal yrs] (Beta-133922; Table 3)

The two units are part of a single soil profile, with the composite horizonation expressed as A-Bk-Bt1k-Bt2-Bt3y-C. Interestingly, Wheeler implies an alluvial origin for Layer 27, since the sediment was modified by Harappan-age plowing above the flood deposits of Layer 28. Pedo-stratigraphic observations suggest that Layer 27 is a *cumulic soil horizon* in which intermittent low energy stream deposits gradually accreted while the lower portion of the paleosol (Layer 28) continued to weather.

This revised soil chrono-stratigraphy at the base of Mound AB broadly conforms to the modeled sequences at Harappa [2,4,33] with some qualification. First, the previously identified soil units at Harappa contain either gypsiferous (By) or argillic (Bt) horizons but never both, as is the case in the present pedon. Second, in semi-arid environments gypsiferous (By) horizons typically signify drier conditions than those in which calcic (Bk) horizons form. While Pendall and Amundson [33] define one soil, the Sultanpur, as containing both horizons, that profile is considered Late Holocene because of its Bw horizon. The Bw was not identified here where the Bt is more consistent with the substantially older soil dates.

The Gamber and Qadirabad soils are the pedons containing the By and Bt weathering horizons respectively. A key for establishing correlations with the present profile rests, however, in the thickness of the sequence and the recognition of the cumulic (AB) horizon. Only the Qadirabad profile contains an overthickened cumulic above an argillic (Bt) horizon whose thickness generally corresponds to that of the present profile. Next, the presence of the gypsiferous horizon in the profile is confined to its lower third, a possible by-product of capillary action, as evaporites settled out of solution during a former period of higher groundwater.

Finally the dates are in correct vertical position and argue for terminal Pleistocene cessation of flooding prior to initial settlement at Harappa. They may actually signify the Pleistocene/Holocene interface and would depress the posited ages of the Qadirabad and Gamber soils [33] by several thousand years, consistent with Late Pleistocene deposition of parent material. Soil morphology supports a Qadirabad classification, but firmer chrono-stratigraphic assignment necessitates additional dating of the terminal alluvium at Harappa.

5. Synthesis: developmental histories at Upper Beas sites and relationships to Harappa

Landscape reconstructions for the pre-cultural and Harappan periods in the Upper Indus Valley have been impeded by a lack of chrono-stratigraphic data. While the cultural sequence at Harappa proper since the third millennium BC is reasonably well understood, Holocene soil chronologies and alluvial histories have only just begun to provide broad paleo-environmental context. No other sites in the Upper Valley had provided comparative information until the present investigations. It is now possible to expand the reach of Harappa-based landscape history to nearby sites with documented soil chronologies, alluvial sequences, and occupation successions.

5.1. Soil chronologies and alluvial history

Baseline soil chronologies and geomorphic histories can be provisionally correlated across Harappa, Lahoma Lal Tibba, and Chak Purbane Syal, as the Bari Doab (Fig. 2) has been a relatively stable landform since the early Holocene. Fig. 7 links stratigraphies at the three locations, underscoring the pivotal Early to Middle Holocene unconformity which marks the transition from the earliest cultural to terminal natural sequences at each site. For each site column, only the key soil, alluvial and occupational stratigraphic breaks are shown, together with dates obtained for sediments and/or cultural features. In the case of Harappa, dates for individual cultural periods are averaged from recently published determinations and the column is taken from Mound AB, HARP Trench 42 [[27]; see also Fig. 6]. Only the lowermost 2 m of cultural deposits at Harappa are illustrated.

The new late Pleistocene determinations from Harappa confirm that, at the very least, the deposits on which the oldest (Qadirabad) soil formed date to [^{14}C] 11,300–13,100 BP (see Table 3). The soil is typically preserved on the margins of the landform only, since northward migrations of the Ravi (away from the doab) resulted in younger landscapes—and soil chronologies—closer to the present abandoned channel. Lahoma Lal Tibba's equivalent profile is dated [^{14}C] 7000–13,000 BP (see Table 3), based on ages from the bracketing A horizons between Units 3 and 4. Amundson and Pendall's [2] only published pre-cultural date from Harappa, ca. [^{14}C] 7100 BP, is also from the Qadirabad

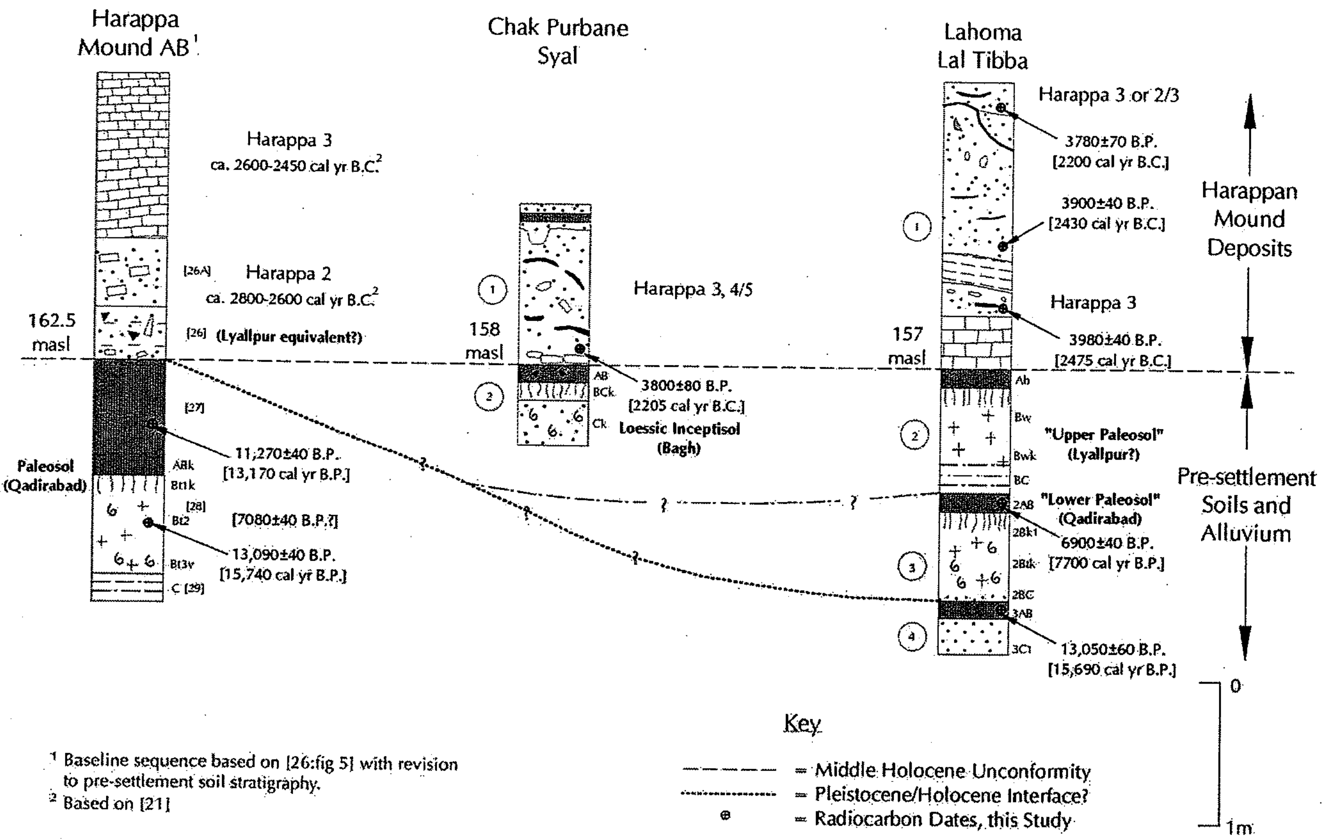

Fig. 7. Site-specific and regional stratigraphies of Upper Beas sites and Harappa. Note Middle Holocene unconformity marking interface of cultural and natural sequences (also indicated by absolute elevations). Conventional [^{14}C] and calibrated [cal yrs BP or BC] dates are presented, as available. Geo-stratigraphic unit designations are on left side of column (Lahoma Lal Tibba and Chak Purbane Syal only). Pedogenic horizons for pre-settlement soils shown on right side of column. Harappa column denotes original layer designations [49] in brackets. See additional notes for Harappa section, HARP Trench 42, Mound AB. [22]

soil and falls within the upper end of this time range. The date appears young compared to the Pleistocene ages for the present column. Three potential factors account for age discrepancies. First, the Harappa radiometric soil samples were taken from a buried Abk horizon at the base of Mound AB. This location is 400 m to the north and up to 3 m lower than the equivalent context sampled by Amundson and Pendall [2], at cemetery R-37 (Fig. 3); the extent and prominence of the buried A horizon was variable at the base of the site. Second, humic acid specimens were processed whereas Amundson and Pendall dated carbonate nodules [2]. In the latter instance, introduction of younger carbonates could potentially reduce the age of the nodules. Third, contamination of the humic soil matrix is possible and could include influx of older organic matter. At Harappa incorporation of older carbon may have depressed ages in the cumulic horizons. Sources include alluvially redeposited plant matter or post-depositional rises in groundwater that might have adsorbed colloidal carbon on to the parent matrix by capillary action. Some indication of groundwater effect is signaled by the precipitation of gypsum in the lower third of the paleosol [50].

Fig. 7 illustrates that the top of the Qadirabad soil at Lahoma Lal Tibba conforms with the determination of the [^{14}C] 7100 BP date at Harappa, while the top of Unit 4 is consistent with the recently obtained Harappa determinations. Again, the possibility of older carbon contamination may compromise the reliability of pre-cultural dates within and between the sites.

More dates are required to ascertain the ages of these events and to calibrate the rates and patterns of sedimentation and soil formation. Nevertheless, the [^{14}C] 11,300–13,100 BP time frame is co-incident with the Pleistocene–Holocene transition, marked as a discontinuity at both Lahoma Lal Tibba and Harappa (Fig. 7). It is provisionally proposed that the upper portion of the Qadirabad soil dates to at least [^{14}C] 7000–10,000 BP and that it marks the first Early Holocene soil for the region. It may extend into the Pleistocene (i.e. older than [^{14}C] 11,500 BP) because of the apparent antiquity of the Qadirabad at Harappa proper.

The second major paleosol is that registered by Unit 2 at Lahoma Lal Tibba. Its correlate at Harappa is either the Sultanpur or Lyallpur although these soils at Mound AB at Harappa may be obscured by the earliest cultural debris. A provisional equivalence with the Lyallpur is suggested for several reasons. First, the Sultanpur is less developed and is mapped within a meander loop of the former Ravi south and north of Harappa [33]. Since the Ravi appears to have migrated north around 4500–3500 BP [21,33] and the Lyallpur soil caps the older landscapes south of the meanders, the Lyallpur appears to pre-date these events. Second, at Lahoma Lal Tibba, in contrast with Harappa, the Unit 3 (Qadirabad) soil underlies the cambic profile of Unit 2, which in turn underlies the initial (4000 BP) Harappan occupation. This Middle Holocene soil clearly dates to the interval [^{14}C] 7000–4000 BP, is older than the Sultanpur and is therefore considered to be the Lyallpur unit. Finally, the soil profile at Chak Purbane Syal developed on parent materials somewhat different from those at Harappa and Lahoma Lal Tibba, including a significant, albeit thin, loess contribution. The chronosequences are not immediately transferable, but the fact that the soil is weathered and underlies the occupation everywhere suggests that it is only slightly younger that the Lyallpur.

The most compelling evidence for dating the changing alluvial regimen is obtained by comparing the Lahoma Lal Tibba (see also Fig. 4) and Harappa sequences. Beginning with the base of Lahoma Lal Tibba, Units 5 and 4 are evidence of the dynamism of the Late Pleistocene Beas. Both are capped by Entisols, signifying limited soil formation and dominant alluviation. Both sequences have relatively coarse materials (fine–medium sands) consistent with channel sedimentation and stream migration. The transition from Unit 5 to 4 was dynamic insofar as it marked the onset of a lateral accretion depositional regime characterized by fining upward deposits (at Unit 4). The uniformly migrating stream was trending to stabilization and entrenchment within the Beas channel, only irregularly discharging sediments on to the higher doab surfaces (in Unit 3). Soil formation dominated over flooding, signified by the more strongly developed profiles of Units 2 and 3. The transition from active alluviation to soil formation coincides with the earliest Holocene (ca. [^{14}C] 10,000 BP).

The alluvial chronology is somewhat more complex at Harappa, where the Ravi drained a broader catchment (even in earlier Holocene times), and changes in its fluvial regime were more dynamic than the Beas. Moreover, the size, logistic placement of Harappa and land use practices by the (presumably) greater population would have resulted in larger scale landform changes above and beyond vertical buildup of floodplain surfaces in a smaller local center, such as Lahoma Lal Tibba. Nevertheless, at Lahoma Lal Tibba, most of the main mound is underlain by the Middle Holocene (Lyallpur) soil. At Harappa overhaul of the site meso-environment also occurred during the Middle Holocene, when meanders formed oxbows, channels were laterally migrating, and the primary drainage-way moved north. The concentric banding of progressively younger soils and weakly developed soil profiles, away from the primary mound are evidence that the Ravi channel shifted nearly 20 km over the past 4000 years [4]. Finally, the limited exposures at Chak Purbane Syal show that deflation was probably a considerable factor later in the Holocene. It is possible that the ongoing displacements of streams exposed large silty tracts along the freshly abandoned floodplain, thus providing fresh sources of sediment that were mobilized by wind action.

Taken together, the alluvial histories of all three sites provide a unique window on Holocene developments. Both Harappa and Lahoma Lal Tibba illustrate a stabilization of landscapes in the Early Holocene, when the Pleistocene stream courses gradually adjusted to new channel geometries. Finer sediments in post-Pleistocene deposits are deeply weathered in both sequences (Qadirabad soils) providing reinforcing evidence for optimal climatic conditions (e.g. stabilized rainfall regimens; moderate evapotranspiration rates) during the Early Holocene. Thinner middle Holocene soils (Lyallpur) and renewed channel migration (principally registered in the Ravi) is evidence of some destabilization of environments at around the time of the initial Ravi Phase and Kot Diji Phase occupations (Table 1).

5.2. Occupation history and site formation

The sequence at Lahoma Lal Tibba offers preliminary indications that an initial occupation may have involved the construction of a mud brick feature that stabilized the site and provided a semi-permanent structural foundation. Butzer [9] has noted that during phases of site formation, architectural form and layout, in addition to construction materials, control the form of a mound [29]. This is not a model that has been widely followed for south Asian mound sites (Meadow, personal communication). Preliminary observations indicate that the ridge-like south mound at Lahoma Lal Tibba was constructed around a base consisting of architectural features (e.g. mud brick foundation platform, house walls). These structures were, ironically, sealed in and reinforced by compact sediment matrices derived from large scale natural events—flooding, sheetwash, localized ponding or combinations thereof—that created a reinforcing cap at the base of the mound. Additional fine grained sediment contributions further fortified the structural core of the mound. In contrast, the upper levels contained evidence for progressively smaller scale activities (e.g. discard areas, preparation facilities) which were housed in looser sediment matrices that were exposed to accelerated runoff and slope stripping. The more conical shape of the mound reflects accelerated slope wearing associated with lower levels of human activity. The uniform shape of Lahoma Lal Tibba's North Mound could represent more limited, less intensive occupation overall, but with a similar drop-off in site utilization through time. The concentration of early dates in the basal levels supports this contention.

The compressed 1–2 m thick exposures of cultural materials at Chak Purbane Syal inhibit comprehensive reconstructions of site function through time. Several activity-specific horizons were identified, but no clear evidence of large scale structural features were traced, perhaps because they have been eroded or destroyed. Contemporary landscape relations suggest significant impacts to the site because of the displacement of the Beas at this location, perhaps as recently as the eighteenth century [18]. Initially, the site was bisected by the river, or one of its distributaries. Subsequently, sheetwash and lateral planation wore back the site slopes and produced undulations in the surrounding terrain. Recontouring of agricultural lands created the current concavo-convex basin between the two mounds and accounts for the irregular distributions of artifacts along all but the northernmost apexes of either mound.

6. Conclusions: implications for regional Holocene paleoecology and future research

The environmental reconstructions and site formation histories at the Beas sites have broader implications for the human paleoecology of the Upper Indus Valley. Recent studies have consolidated information about the climatic and environmental changes across South Asia, with particular emphasis on the critical Early–Middle Holocene period [37]. Key data sets for the Upper Indus Harappan regions include the Ghaggar–Hakra plain for aeolian, and alluvial sequences [10]; Thar Desert paleolake chronologies [12,30,39,46]; and laminated (varved) sediments from marine cores off the Makran Coast [45]. The present study is one of the few based on paleosol chronologies.

Most striking is the evidence for Early Holocene moisture regimes in the wake of post-Pleistocene monsoon circulation. Reduction in aeolian activity (in the Ghaggar–Hakra) is consistent with higher lake levels in Rajasthan. This trend would be reinforced by the revised dating of the well weathered Qadirabad soil to 10,000–7000 BP coupled with the attendant reduction in alluviation for the Beas and Ravi. The Early Holocene soil marks the threshold between dominant late Pleistocene alluviation and the onset of optimal moist and temperate conditions in the upper Indus.

A gradual turn to desiccation, ca. 7000–6000 BP, may be signaled by resumption of loess sedimentation in the Ghaggar–Hakra plain, reduction in the scale of alluviation and incision in some of the main river valleys, and stabilization (and initial lowering) of lake levels. Soil chronologies cannot isolate this time frame reliably. Wasson [47] has inferred that lowered lake levels across the southern hemisphere's monsoon belts is proxy evidence for the decline of southwest monsoon intensity.

For the period centered around Harappan occupation (ca. 4700–3700 BP), the South Asiapaleoenvironmental record is somewhat ambiguous. Cessation of dune activity in the Ghaggar–Hakra and optimal fresh water influx at Didwana may be measures of increased moisture, but channel avulsion, westward drainage displacement, and abandonment and desiccation of the Ghaggar–Hakra plain are more equivocal. If extant reconstructions of channel migrations are a guide [51], then desiccation during 4000–2500 BP may account for net displacements of flow lines on the order of 100–150 km northward. Courty's [10] study of the abandoned depressions in the Ghaggar–Hakra plain argues for reduced seasonal flooding, dune encroachments, and a turn to drier conditions during the same period. Flam [14] argues for geomorphically based realignments of the lower indus channel before 4000 B.P. Coring off the Makran coast [45] shows that monsoon generated varves signal greater precipitation; two peaks within the period 4000–3500 B.P suggest high and widely fluctuating levels of precipitation at around the transition to the Late Harappan. Total rainfall budgets and seasonal precipitation distributions may have varied to a greater degree than at any other time. The thicker sediments, but less pronounced weathering sequences, of Unit 2 at Lahoma Lal Tibba, the mixed alluvial and deflated sediment components at Chak Purbane Syal and, most significantly, the obvious acceleration of channel migration along the Ravi (at Harappa), suggest that realignments of Upper Indus drainages occurred early in the Mid Holocene, and that soil development ensued. Regionally asynchronous alluvial events succeeded by localized sedimentation and weakly developed soils may point to destabilized environments in the later Middle Holocene, when the Harappan cultures were in decline. This theme warrants further investigation.

Studies linking mound stratigraphies with geomorphic histories and soil chronologies are pivotal to the understanding of human ecology across the greater Harappan landscape. Ongoing work along the downstream reaches of the Beas will expand the scope of the reconstructions proposed in this study. Such interdisciplinary ventures are a sound basis for structuring models of human and landscape interaction in greater South Asia.

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