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

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HARAPPAN GEOARCHAEOLOGY RECONSIDERED: HOLOCENE LANDSCAPES AND ENVIRONMENTS OF THE GREATER INDUS PLAIN

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ABSTRACT

The emergence of complex societies in the Indus Valley is largely documented through the archaeological records of its two primary urban centers: Harappa in the north and Mohenjo-daro in the south. The dynamic geography of linked settlement and subsistence environments remain incompletely understood. This presentation begins with a summary of fundamental site and landscape relationships across the Harappan culture core. A baseline landscape chronology for the pivotal middle to late Holocene is generated. Reconstructions are synthesized by merging geological and archaeological sequences for the Lower and Upper Indus floodplains and terraces. Lower Valley Harappan sequences are characterized by changing settlement distributions in response to migrations of the main stem of the Indus channel. Recently developed Upper Valley chronologies have integrated depositional and soil-forming sequences with stable surfaces, climate change, and periods of intense settlement in the Harappan hinterlands. Convergent upstream and downstream landscape records for the Indus point to discrete climatic intervals that may have influenced the broader course of Harappan settlement. A period of Middle Holocene desiccation, based on monsoon circulation patterns, preceded initial Harappan occupations prior to 5000 BP. Significantly, the interval of Harappan-era florescence is accompanied by mixed climatic signals, based on equivocal interpretations of the geomorphic and paleoenvironmental record. The decline of the Harappan heartland may be related to a change in the precipitation regime as well as more intensive human manipulation of the floodplain environment.

INTRODUCTION AND OBJECTIVES

It is widely recognized that the earliest state societies of the Old World flourished in part because of their locations on the fertile floodplains and terraces of the world's most extensive rivers. Between 5500 and 3500 years ago, complex societies emerged in the valleys of the Nile (Egypt), Tigris-Euphrates (Mesopotamia), Yangtze (China), and Indus (Pakistan and India). The archaeological record of the evolution, fluorescence, and collapse of these societies is as varied as it is complex, but the chronicle of the Harappan civilization is perhaps the least known because its script remains undeciphered.

Archaeological explorations of the Indus civilization of Pakistan, India, and northeastern Afghanistan, are rich and compelling, but uneven. Although the major urban centers of Mohenjo-daro and Harappa are generally included in evolutionary syntheses of state societies, much less is known about the greater landscapes and environmental backdrop to Indus cultural developments. Until recently, paleoecological approaches were not widely incorporated in Indus studies, unlike the case in Mesopotamia (Adams 1965; 1978; 1981; Adams and Nissen 1972) where site–landscape relations were at the core of developing an understanding of the regional settlement network of irrigation-based economies and polities. Reconstructions of the human and environmental dynamic of the Indus culture have been hindered in part because landscape studies have not extended beyond its major urban areas.

Over the past decade, geoarchaeology has shown promise for modeling settlement and landscape dynamics for the Indus civilization. Geoarchaeology explores systematic relationships between sites using methods and techniques of the earth sciences (for instance, in the study of soils, sediments, drainage nets, and topographic settings) (Butzer 1982; M. R. Waters 1999). For complex societies, geoarchaeology examines broad parameters of climatic and environmental change, but even more importantly, it sheds light on how natural terrain and landscapes were modified by polities confronting population pressure and resource stress. Adaptive hallmarks of the Indus culture include water management systems, complex mound construction, and use of domesticated plants and animals. The relatively sudden collapse of the Indus civilization remains a mystery but is likely attributable to combinations of climatic, hydrographic, geological, and human impacts. Geoarchaeology is a means for sorting out these factors, linking them chronologically, and tracking landscape changes that may help account for cultural transformations in South Asia during the Middle Holocene.

This paper reviews the current state of Indus geoarchaeological research. The chronology of Indus occupations is initially considered with respect to the calibrated radiocarbon record. Extant site–landform correlations are then viewed as a backdrop to deciphering Middle Holocene site geography. Sites are unevenly distributed across the landscape and reflect complex geomorphic processes that have biased the site distribution records. Geomorphic maps provide some insights on site distributions, but the most ancient sites with information on human ecological dynamics are those that can be tied to alluvial geomorphology and the linked soil and occupation stratigraphies of the greater Indus floodplains. Stream behavior and sedimentation regimes differ between the Indus's Upper and Lower Basins, and each is discussed in terms of its archaeological implications. For the pivotal Middle Holocene, floodplain histories that order cycles of environmental stability and settlement geography suffer from a lack of radiocarbon dates and inattention to soil chronologies and sediment stratigraphies. A recent pilot study of an Upper Indus Valley sequence points the way to filling this gap (Schuldenrein et al. 2004; R. P. Wright, Khan, and Schuldenrein 2002; R. P. Wright et al. 2005a; 2005b). Finally, some hypotheses exploring the climatic and environmental evidence for Middle Holocene cultural expansion and Late Holocene collapse are entertained.

GEOGRAPHY AND ARCHAEOLOGY OF THE INDUS HEARTLAND

Indus Chronologies

The Harappan or Indus culture has traditionally referred to the complex of sites centered on the Indus River and tributaries that culminated in urban adaptations between ca. 3200 BC and 1900 BC (Allchin and Allchin 1982; Possehl 1997b; 1999; 2002). Key settlements are also centered along the Ghaggar-Hakra in Cholistan (Mughal 1997) and northwest India (Francfort 1986). Figure 21 illustrates key sites by cultural component, with respect to primary drainages, geographic features, and regions of the greater Indus culture area. Harappan manifestations are densest in semiarid Pakistan but extend well into India. They are also culturally related to early agricultural communities in the western piedmont of Baluchistan and Afghanistan (Jarrige and Lechevallier 1979). At least seven regional Harappan core areas have been identified (Joshi 1984; Possehl 1999), with the result that cultural chronologies vary between areas. For the purpose of this paper, an overarching cultural sequence is utilized (Table 1). The major developmental divisions are between the Early Harappan (Period 2/ Kot Diji phase) and Mature Harappan (Period 3/Harappan Phases A, B, and C). Early Harappan marks the transition from village farming communities into "formative urbanism," an adaptive shift that included the building of walled settlements, the growth of regional trends in pottery manufacture and ornamentation, the development of writing, and the spread of trade networks (Kenoyer 1998). The subsequent

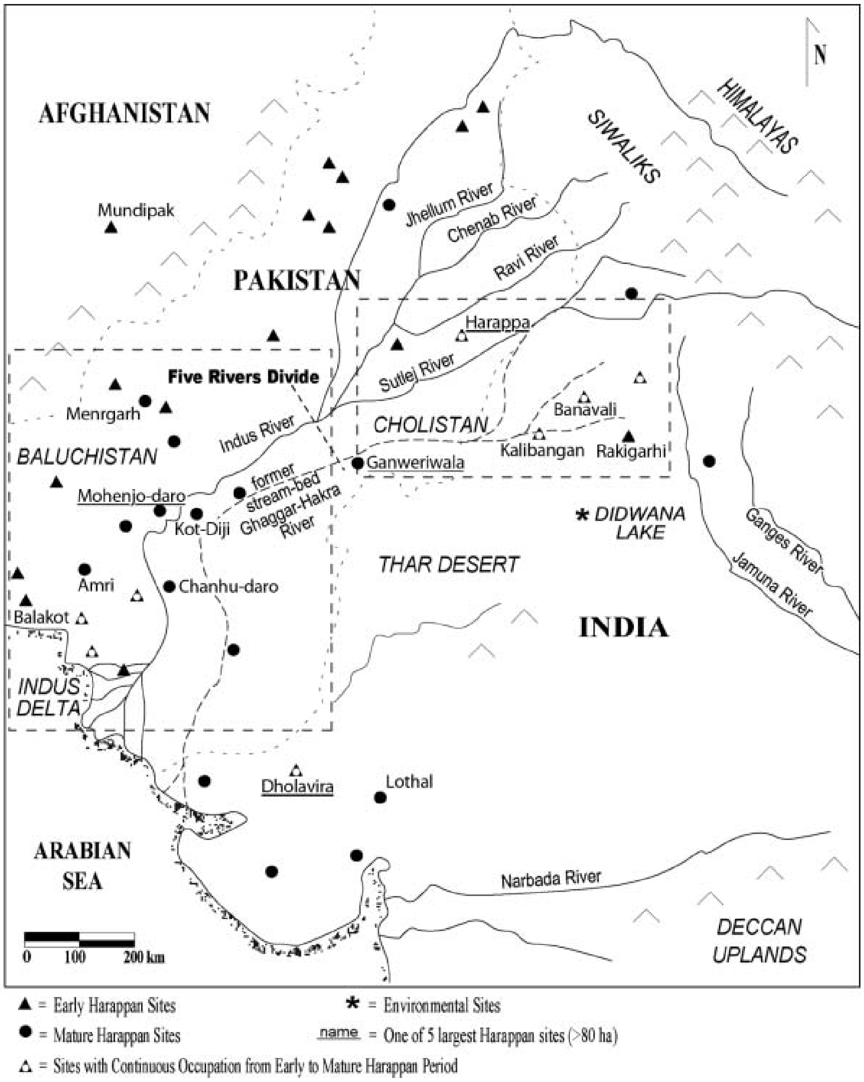

Figure 21. Location of principal archaeological sites, paleoenvironmental sites, and geographic regions mentioned in the text. The Upper Indus refers to the area east of the Five Rivers Divide, while the Lower Indus is the area to west and south.

Mature Harappan signaled the integration of regional traditions into systems of networked cities with satellite communities, and the emergence of socio-economic and political hierarchies that managed industrial-scale production, a standardized system of writing, systems of weights and measures, and increased trade. The Early Harappan lasted to ca. 2600 BC, the Mature

TABLE 1. Indus Valley Chronology for the Harappan Era

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

Source: After Possehl (1999) and Meadow et al. (2001)

Harappan was eclipsed by ca. 1900 BC (Late Harappan), and the civilization was in decline by 1700 BC

In the past decade, Harappan chronologies have been substantially refined on the strength of calibrated Holocene ^{14}C determinations that accommodate the disjuncture between radiocarbon years and solar years (de Vries effects; see Stuiver et al. 1993; Taylor 1997). The significance of the calibrated sequences cannot be underestimated, since together the Early and Mature Harappan lasted only about 1400 years, and correlating sequences within such a limited time frame is dependent on the accuracy and convergence of absolute dates and cultural sequences. Harappan-age radiocarbon dates have been compiled in several publications (Allchin and Allchin 1982; Kenoyer 1991a; Possehl 1997b; 1999), but the majority of samples (> 60 percent) are derived from only three sites—Harappa, Mohenjo-daro, and Kalibangan (Schuldenrein 2002).

The dates largely corroborate successions generated from typological and archaeological analyses and attest to the pan-regional reach of the culture. Harappan civilization spans the Middle to lower Late Holocene, with site frequencies highest for the Mature Harappan, between 4600 and 4000 BP (ca. 2600–2000 BC). A recent inventory of Harappan-age sites assigns

976 to Mature and 477 to Early phases, approximately a 2:1 ratio (Possehl 1999: 714 and app. A).

Combining the absolute chronologies with the archaeology underscores several spatio-temporal trends:

1. There is sparse evidence for occupation in the Indus prior to 3300 BC; radiocarbon evidence suggests that earlier sites are most likely to have occurred in the Upper Indus Valley (Schuldenrein 2002).
2. The end of Harappan occupation is dramatic, given the fall-off in radiocarbon dates after 1900 BC
3. Deterioration of both the northern and southern urban centers—Harappa and Mohenjo-daro, respectively—may have preceded the decline in satellite communities, which may have outlasted the two hub communities by 200 to 400 years (Kenoyer 1991a' 1991b; Schuldenrein 2002: fig. 2).

HARAPPAN LANDSCAPES AND SITE GEOGRAPHY

The Indus River is the central geographic feature for the distribution of Harappan sites. It rises in the Himalayas, initially flowing north and west through its mountainous segments, then turns southwest to drain the foothills (Siwaliks) and ultimately flows the length of Pakistan before emptying into the Arabian Sea through the Indus Delta (Figure 21). The densest Harappan distributions begin south of the Siwaliks, where the greater Indus tributary net begins; site clusters intensify progressively downstream, in the graded terrain of the Punjab and in the Lower Indus in Sindh.

Separation of the Upper and Lower Indus Basins is a function of a major structural fault, the Sulaiman Foredeep, at the Five Rivers Divide (Figure 21). The Upper Basin refers to the catchment north and east of the confluence of the Five Rivers (Jhellum, Chenab, Ravi, Beas [buried and not shown], and Sutlej), while the Lower Basin extends to the stream mouth at the modern Indus delta and coast (Figure 21). Large sites are dispersed along coastal reaches north and south of the Indus Delta as well. The highest site densities occur in the abandoned desolate segments of the Ghaggar-Hakra Plain (in Cholistan; Figure 21), a landscape greatly altered by channel abandonments and subsequent dune activity (Courty 1995; Mughal 1992). Early researchers recognized that the present alignment of sites does not necessarily conform to either the Harappan-age Indus alluvial geography or the reach of the culture core (Mackay 1945; Mughal 1990; 1992; Raikes and Dales 1977; Wilhelmy 1969). Further impeding systematic reconstruction of site–landform relationships is the absence of a reliable site inventory as a result of disparate regional and local records, limited dissemination of much of the Pakistani and Indian literature, and lack of documentation for inaccessible areas (although see Possehl 1999). Such considerations notwithstanding, the available site distributions suggest that alluvial histories are linked to site formation chronologies. As discussed below, the alignment of earlier Harappan sites in the Upper Valley and later Harappan settlements in the Lower Valley argues that the Holocene histories of each segment account for human–landscape interactions constrained by more localized cultural and environmental influences.

More generally, landform chronologies suffer from a lack of pre- and non-cultural radiocarbon dates and a near absence of soil development histories (paleo-pedology). For the Middle Holocene, the identifications of stable surfaces, through soil sequences, establishes those periods of landscape stasis when flooding was minimal and extensive floodplain reaches were available for settlement (Schuldenrein et al. 2004; R. P. Wright, Khan, and Schuldenrein 2002; R. P. Wright et al. 2005 a; 2005b). Thus the establishment of soil-based timelines is a critical barometer of the environmental and climatic conditions favoring settlement at around 5500 BP. Dating difficulties have been partially overcome by LANDSAT- and aerial photograph-based mapping and paleochannel modeling of the Lower Indus near Mohenjo-daro (Flam 1993; Harvey and Schumm 1999; Jorgensen et al. 1993), and by site formation and soils investigations at both Mohenjo-daro (Balista 1988; Cucarzi 1984; Jansen 1999) and Harappa (Belcher and Belcher 2000; Pendall and Amundson 1990a; 1990b; Schuldenrein et al. 2004; R. P. Wright, Khan, and Schuldenrein 2002; R. P. Wright et al. 2005 a; 2005b).

A broad picture of settlement and landscape patterning can be obtained with the help of two separate maps of surface geology (Government of Canada 1956; Mian and Syal 1986). These maps complement each other, as the former links landforms topographically and the latter utilizes soil groups as an organizing principle. Table 2 correlates landform categories and cultural chronologies, presents an assessment of site expectation, and summarizes the characteristics of the seven primary landform complexes. The main depositional processes for each complex are identified, along with estimates of age based on the limited geomorphic, sedimentological, and soil studies performed to date. The antiquity of the landforms generally grades to younger in a seaward direction, a function of increased downstream alluviation compounded by rising sea level along the coastal plain. While it might be expected that age-dependent geomorphic dynamics are also reflected in the site distributions—younger sites expected closer to the coast and better preservation upstream—such an assessment is premature.

Table 2 is thus at best a crude guideline for site expectation. This is because the ages of the landforms are unreliable, based on relative landform elevations and on scaled degrees of soil development on the more stable and

TABLE 2. Landforms of the Indus and Harappan Site Distributions *(facing pages)*

Landform	Description	Depositional Process	Age
Sandy deserts	Laterally zoned complex of dune and terrace meso-environments	"Alluvial valleys dominated by flooding and stream migration, but punctuated by protracted intervals of aeolian activity and tectonic displacements"	Pleistocene to Holocene
Bajadas	Coalescent aprons and alluvial fans	"Fan progradation of coarse, stony gravels and sandy gravel sedimentary suites"	Late Pleistocene to Holocene
Undulating sandy terraces	High escarpment interfluves with irregular surfaces	Interglacial and post-glacial outwash intercalated with massive angular boulders (tectonic origin?) and capped by loess	Middle to Late Pleistocene
Bar uplands (doabs)	Extensive terraces 2–9 m high; also referred to as tablelands since they span extensive interfluves between drainages	Massive outwash deposits laid down by post-glacial melting and resorting of coarser fills from Himalayan core area	Late Pleistocene–Early Holocene
Terrace (T-1)	Low-relief terrain generally used for contemporary agriculture and flood control	"Protracted seasonal and irregular overbanking; episodic sheetflooding, meandering, and braiding"	Middle to Late Holocene (Early Harappan to post-Harappan)
Floodplain	Near level to mildy undulating surfaces. These are ellipsoid to more laterally extensive segments of alluvium dispersed irregularly along proximal margins of active drainages	Cut and fill deposits inset into T-1 banks	"Late Holocene, contemporary to Historic (post-Harappan)"
Indus delta and estuarine plain	Coastal plain aggradation of pro-deltaic and marine sediments	Level surfaces dominantly silty; basins are infilled with clays; tidal flooding and riverine sedimentation attest to highly variable geomorphic process in littoral setting	Holocene

older terraces. Thus, in the Five Rivers area (see Figure 21), the prevailing alluvial chronology projects floodplain and terrace surface ages on classic cut and fill models (Brinkman and Rafiq 1971; see discussion in Flam 1993). The Bar Uplands—the higher areas (or interfluves) between the rivers—are considered to be Pleistocene terraces that were downcut, their margins subsequently aggraded in the Early Holocene to create what will be referred to here as Terrace T-1 (see Figure 22 for the area around Harappa; elsewhere called subrecent floodplains; see Flam 1993). A second cycle beginning with the dissection of the T-1 landform and culminating with construction of the

TABLE 2. Landforms of the Indus and Harappan Site Distributions *(cont.)*

Upper Basin	Lower Basin	Harappan Site Expectation
Southeastern margins of Ghaggar Plain in Cholistan	Similar to Cholistan in upper Thar Desert; southern reaches not widely known	H
Discontinous fan complexes along piedmont edge (to western margin of Indus)	"More extensive, semi-continuous fans grading directly onto alluvial terrain"	M
Semi-continuous landform between Jhellum and Indus	NA	L
"Older and more extensive at upstream ends of Chenab, Ravi, and Sutlej drainage where they extend across interfluves; irregular remnants near channel confluences"	NA	M
"Semi-continuous bands running parallel to principal flow axes of each of the Five Rivers; Meso-landfoms include level plains and (isolated) infilled channels. Periodic sheet flooding has destoryed/modified landform in recent times"	"Localized basins, levee remnants, and infilled ancient stream channels of the former meandering Indus trunk stream; low relief of basin preserves extensive buried segments between Thar Desert and western mountains"	M–H
"Localized point bar deposits along outside banks of meandering segments of primary drainages; dominant accretion along major confluences (Indus, Chenab, Sutlej, and Jheullum)"	Attenuated in downstream direction; disappears immediately north of Indus Delta where it grades into deltaic sediments	L
NA	"Sediment complex of spill flats, basins, spill heads, meander bars, and levees"	M

floodplains is assigned to the Contemporary/Historic period (or Late Holocene). There are no absolute dates or soil sequences anywhere to confirm these associations (although see Schuldenrein 2002).

Table 2 shows that the highest concentrations of sites are contained in sandy deserts and first terraces (T-1 landform). Preservation conditions and contexts are different for the two. In the sandy deserts of the Ghaggar-Hakra region, for example, site exposure is the product of Cholistan's dynamic geomorphic environment in the recent past. Landscapes now consist of a series of low-relief dune and desert landforms that did not exist in Harappan times

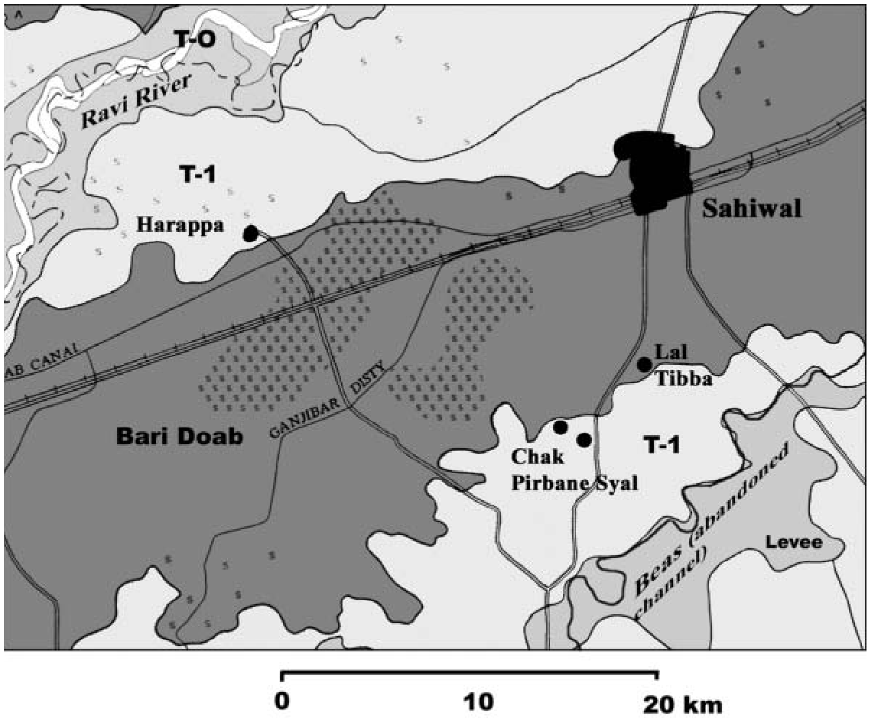

Figure 22. The Bari Doab and landforms in its immediate vicinity. Note the first terrace (T-1), floodplain (T-0), and levee segment flanking the Doab. Present locations of Harappan-period sites are shown on margins of Doab and T-1 (modified from Government of Canada 1956).

when this part of the Ghaggar-Hakra drainage sustained a lush alluvial biome. Aeolian sedimentation has overridden the former riparian environment, virtually masking it and obscuring the evidence of a biotically differentiated floodplain that sustained an environment suitable for agriculture and broadly based subsistence economies.

The other context, T-1 landforms, is more typical for well-preserved Harappan sites. These are former floodplains whose archaeological environments are either sealed by later Holocene alluvium or consist of mounds built on that older floodplain. In the Upper Basin, the more prominent topography underscores the correspondence between mounds and elevated terrace environments. A typical setting is shown in Figure 22. Here Harappa and two smaller satellite mounds, Chak Pirbane Syal and Lahoma Lal Tibba, occupy the terrace landform (T-1) positioned between more dynamic, currently active floodplain (T-0) segments which are now subject to extensive inundation (Schuldenrein et al. in 2004). The T-1 is also known locally as a *doab*, and in the Upper Basin it refers to elongated Late Quaternary terraces, parallel to stream flow and forming the interfluves between adjacent trunk streams; elevations can extend to 15 meters above floodplains (T-0) but are more typically less than 5 meters high. Site positioning on the doab between the Ravi and Beas Rivers was optimal for exploiting riverine resources and for farming the well-drained raised fields of the flanking rivers. The present topography preserves evidence of the Middle Holocene physiography. Elsewhere in the Upper Valley, bajadas, gently sloping plains of unconsolidated rock debris at the mountain fronts—effectively desert pavements that are resistant to erosion—are likely to preserve nonstratified evidence for recurrent Harappan occupations. The more complex depositional features (Indus Delta) contain clustered landscape segments of variable age with similarly variable preservation potential. Low site expectation is characteristic of areas where both landforms and sites are poorly investigated or where there is no apparent relationship between landform and site selection. Table 2 indicates that the highest expectation for preserved, stratified sites is in the T-1 landform category. Moderate to high site expectation is noted for the Upper and Lower Basins because of the unique geomorphic processes associated with the channel geometry and flooding behavior of each segment, as summarized below.

As previously stated, the absence of an absolute Holocene landform chronology remains an impediment to understanding the environmental history of the Harappan landscape. However, it is still possible to systematize associations between Harappan site clusters and landform complexes on a broad scale (refer to Figure 22 and Table 2). Accordingly:

1. There is a high density of Early Harappan (Kot Diji phase) sites on the bajadas grading down from the Piedmont Plain. Major sites generally occur along major drainages but smaller ones do not. The coalescent alluvial fans upon which the latter sites are found are difficult to bracket stratigraphically, since such fans are erosional surfaces of uncertain Pleistocene age.

2. Markedly lower site densities in the Upper Valley may reflect the dynamism of the Upper Indus drainage system and the dearth of systematic archaeological and geoarchaeological exploration of this region. The discrepancy in site frequencies between the Lower and Upper Valley is pronounced. The majority of known Upper Valley sites are associated with either Bar Uplands or T-1 surfaces.

3. Early and Late Harappan sites along the distributaries emptying into the mouth of the Arabian Sea attest to extensive deltaic progradation (buildup) during the Middle to Late Holocene. The Harappan coast may have been

tens of kilometers inland of its present location, although coastline configurations of the Harappan-age littoral landscape remain speculative.

4. The proliferation of lineally configured Late Harappan sites in the Lower Valley signifies pronounced channel migration along the downstream reaches of the Indus in the Middle and Late Holocene. At Mohenjo-daro, the Indus flowed up to 25 kilometers to the west of its present course. Sites span several geomorphic units, including the T-1, bajadas, and undifferentiated piedmont segments. Former channel courses have been extensively mapped and relatively dated based on geomorphic features.

5. The preservation of extensive Harappan site complexes in the sandy deserts of Cholistan—the Ghaggar-Hakra Plain—reflects a major paleogeographic shift during the Late Holocene. The primary landscape modification involved stream capture and the westward migration of the drainage net, most dramatically the Sutlej, between ca. 1500 BC and AD 1500. Both climatic and tectonic mechanisms account for attendant landscape overhauls.

In sum, while the geomorphic record is useful for sorting out relationships between site selection, preservation, and landform types, its potential for establishing the synchroneity of occupation and landscape history is constrained by the lack of dated subsurface stratigraphic evidence. The impact of tectonics may be the most difficult to chronicle. Nevertheless, the aforementioned landform complexes (Table 2) accommodate nearly 90 percent of known Harappan sites, based on a general correspondence between landform units and recent site distribution maps (in Possehl 1999). Primary sources for environmental and Harappan-aged sequences are stratified alluvial records whose deep flood sets are separated by developed soils signifying stable landforms with archaeological potential.

ALLUVIAL GEOMORPHOLOGY OF HARAPPAN SITES

As the above discussion stresses, the key measures of landscape change for the critical protohistoric period are extant landform configurations and stratigraphic sequences. Landform configurations (and by extension, site–landform correlations) are only indicators of preservation. Stratigraphic sequences preserve depositional histories and are more complete, finer-scale proxies for environmental succession. The alluvial geomorphology of the Indus is therefore an optimal backdrop for ordering human ecological events.

Pre-Quaternary dynamics of Indus stream flow, hydrography, and topography were initially fashioned by structural elements (Friend et al.

1999) and, as noted above, the Sulaiman Foredeep is the feature that separates the Upper and Lower Indus Basins (Kazmi and Rana 1982; Haghipour, Ghorashi, and Kadjar 1984; Biswas 1987) (Figure 21). However, there is considerable debate as to the influence of tectonics versus other environmental factors—climate, paleohydrology, runoff, erosion, stream migration, and alluvial landform construction—in modifying those Late Quaternary landscapes contemporaneous with earliest settlement. Lateral channel migration is characteristic of most of the Indus, such that meter upon meter of Late Quaternary sediments have built up extensive, low-relief, alluvial plains (Harvey and Schumm 1999; Jorgensen et al. 1993). It is often impossible to differentiate buried channels because of the depth of sediment burial and the uniformity of sediment type (typically in the fine sand or silt loam size grade). Depositional uniformity has obscured Harappan settlement topography and complicated attempts to synthesize stream and valley histories. Massive flooding, breaches in channel flow due to monsoon-generated runoff, and overhauls of the contemporary and perhaps earlier irrigation networks (Wescoat 1998) have collectively reduced gradients to the point where visible landform separation is possible only in select reaches of the drainage. The vast majority of Harappan sites are situated within this typically undifferentiated alluvial terrain, with sites occupying terrace or basin segments at elevations below 1200 meters (Schuldenrein 2002). It has been estimated that the Harappan civilization encompasses nearly half a million square kilometers (Agrawal 1992).

In general, the rivers above the Five Rivers Divide flow below the levels of the adjacent floodplains. This is not so for the Indus trunk stream to the south. The Upper Basin is characterized by a series of high-order tributaries separated by the low-relief *doabs* cited earlier (Figure 22); these were the loci of mound sites immediately flanked by laterally extensive alluvial basins (Khan 1991). In contrast, the Lower Basin has sustained a more freely migrating stream—between the Thar Desert and the Western Mountains—that eventually progrades into the coastal delta (Figure 21). The differences between Lower Valley and Upper Valley landscape relations and associated geomorphic processes are discussed below.

Lower Valley

Early attempts at modeling relationships between site location and environment were begun at Mohenjo-daro in order to address the reasons why this enormous, 250-hectare city was abandoned. It was thought that the site was either obliterated by a series of floods that created a semipermanent dam or lake, or that frequent channel shifts depleted soil moisture recharge and agricultural productivity of the fields fronting the floodplain. Arguments in support of the dam theory were given prominence in the 1960s and 1970s, with the recognition of presumed alluvial and paludal (that is, swamp or marsh-related) deposits ranging 8 to 12 meters above the existing floodplain (Raikes 1964, 1965; Dales and Raikes 1977; Raikes and Dales 1977). Damming of the Lower Indus that resulted in such sedimentation was attributed to tectonism. An alternative hypothesis raised doubts that field relations and sedimentology implicated a relict dam landform (Lambrick 1967). Instead it was argued that the disposition of the deeply stacked fine sands, silts, and clays was of aeolian origin.

The Raikes hypothesis has subsequently been questioned on a variety of grounds, most notably whether the impermeable source alluvium could retain floodwaters without dam failure (Jorgensen et al. 1993; Harvey and Schumm 1999). Revised assessments are based on geomorphological work that has linked lateral stream movement to depositional suites near Mohenjo-daro, effectively confirming the Lambrick hypothesis. By quantifying rates of sedimentation, stream slope, and channel displacements through time, they concluded that Indus River dynamism is best explained by channel migration, perhaps initiated by tectonics but ultimately perpetuated by segmentation of the various reaches of the lower drainage basin. Segmentation of channel reaches may have accounted for the partitioning and zonation of agricultural fields for finite durations, thus accounting for limitations on Harappan settlement, patterns of land use, and longevity.

LANDSAT and aerial photographic mapping of relict paleochannels and levee remnants in lower Sindh bolsters this hypothesis (Flam 1993; 1999). Flam mapped two major and numerous minor courses of the former Lower Indus between 4000 and 3000 BC. Figure 23 shows that both the major channel courses—the Sindhu Nadi to the west and the Nara Nadi to the east—flank the present locations of major Harappan sites. The complex migrations of the ancestral stream left meanders that isolated landscape segments which may have been functional over several decades or longer. Such extensive meandering at Mohenjo-daro resulted in the long-term displacement of the active Indus channel to its present position, approximately 25 kilometers southeast of its original course, during peak Harappan occupation. Changes in the flow regime of the major channels would have promoted sheet flooding whose effects extended throughout the drainage net in Sindh. The relatively short and irregularly dispersed irrigation channels suggest that only limited irrigation agriculture was practiced (Flam 1999) and its role at Mohenjo-daro has been minimized (Jansen 1999). Ultimately full-scale abandonment of complete settlement networks may have occurred as flood subbasins were reconfigured and cultivable tracts inundated. Lower Basin research has also demonstrated that progradation of the delta has systematically extended the shoreline southwestward into the Arabian Sea. The complex alignments of the primary Harappan centers south and west of

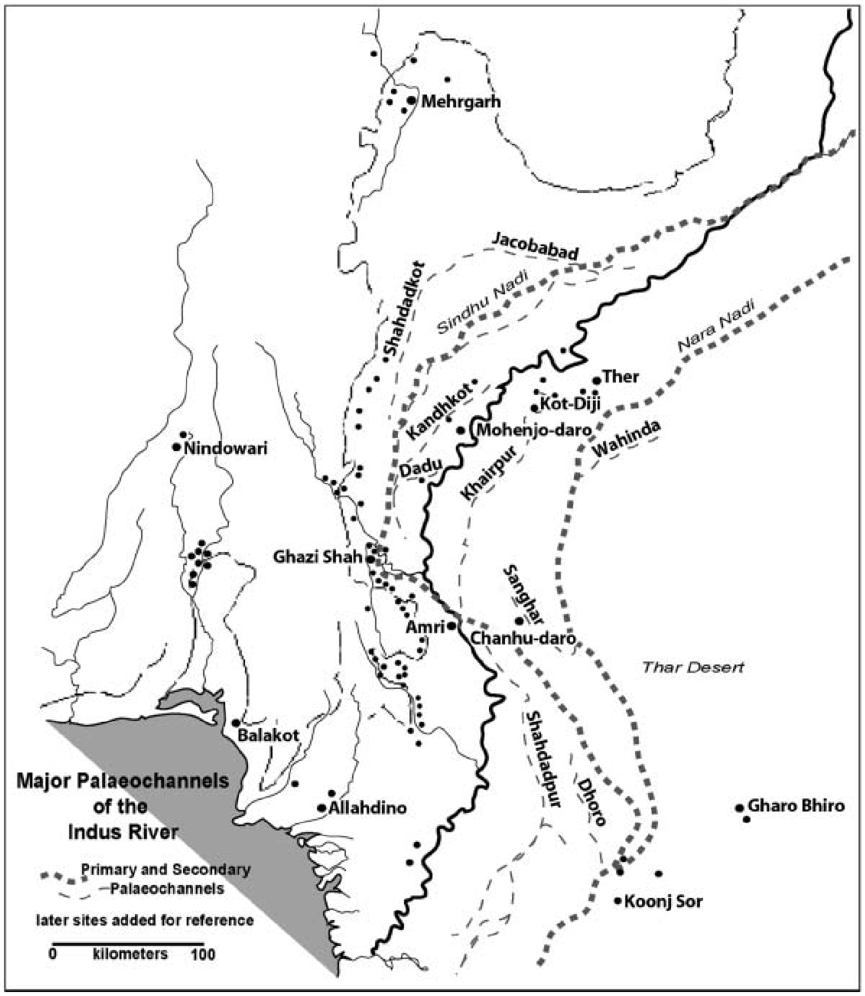

Figure 23. The ancient drainage net of the Lower Indus Valley in the vicinity of Mohenjo-daro. Principal paleochannels—Sindhu Nadi and Nara Nadi—as well as key tributary segments are shown. Key archaeological sites are depicted. (Map modified from Flam 1993 and Possehl 1999: 296, 309).

Mohenjo-daro are consistent with arguments tying progressive channel migration to shoreline displacements (see Figure 23).

This hypothesis has not been verified by either landform relations or by the stratigraphic record. A critical gap is the chronology of Holocene terraces and the cut and fill cycles that produced the *doabs* (Figure 22 and Table 2). In the Lower Valley, lateral migration produced relatively shallow terraces, on the order of < 1 meter, but it remains difficult to establish firm landform associations with Harappan sites aligned with such subdued surfaces flanking contemporary channels (Schuldenrein 2002). Terrace chronologies remain uncertain and must be considered relative in the absence of more refined mapping bolstered by radiocarbon dates and soil sequences. Beg (1993: 258–263), for example, has proposed a soil taxonomy for the terraces and subrecent floodplains that postdates the landform chronology of Mian and Syal (1986; see Table 2).

Some critical chrono-stratigraphic information can be gleaned from Mohenjo-daro itself. Jansen (1999) noted that the replacement of mud brick by burnt brick for retaining walls between the Early and Mature Harappan was a technology designed to stabilize foundations against rising groundwater. It is now estimated that original (Early) Harappan landforms were up to 10 meters below present surfaces, while groundwater is only 5 meters below. Groundwater would have migrated from excess discharge laterally (by channel movements, as noted) or from increased discharge from the Indus. It is known that siltation increased drastically during the Holocene—on the order of 10 centimeters per century (Haitken 1907). The variable location of water sources is also indicated by the proliferation of over 600 wells in the city. Such needs were clearly related to a time when the river was considerably more distant from its present position.

Upper Valley

As in the case of the Lower Valley, both climatic and tectonic mechanisms were major influences in fashioning Upper Valley landscape histories, but the lines of evidence are more varied and several areas have been investigated.

The Ghaggar-Hakra Area. It is striking that the highest densities of sites in the Upper Valley were associated with the Ghaggar-Hakra Plain in Cholistan (Figure 21; Mughal 1982; 1989). That area is now traversed by a series of dry distributaries linked to the primary channel bed. An early study (Wilhelmy 1969) offered initial indications that site abandonments were related to stream capture of the Sutlej during the Late Harappan and the culture's subsequent collapse (1500 BC–AD 1500) when the Indus and Ganges drainages assumed their present configurations. Flam (1999) suggests that an upstream change of this magnitude resulted in the increased flow to the Sindhu Nadi.

The Ghaggar-Hakra research has benefited from contributions from archaeology, historiography, geomorphology, and sedimentology, much of which has been recently summarized by Possehl (1999: 359–387). The density of Harappan sites and their intricate associations with complex stream migrations is illustrated in Figure 24. Some researchers have associated the Ghaggar-Hakra drainage with the ancient Sarasvati, which was the holiest of Indian rivers in Vedic times (Wadia 1966). References to the stream's significance during the time of Alexander the Great are noted historically (Tod 1829). Archaeologically related investigations of the dry streambeds have been undertaken since the late nineteenth century (Oldham 1893; S. Bhan 1973; Pande 1977).

There is some question as to the chronology, morphology, and evolution of the Indus and Ganges systems and the pivotal role of the Ghaggar-Hakra in explaining such developments. It has been proposed that, at various times in the Holocene, the Ghaggar belonged either to the Jamuna/Ganges watershed, or to the Indus—via the ancient Hakra—since the modern river Sutlej is located between them (Figure 21). The preponderance of the evidence now favors a west-southwest (that is, Indus net) flow during Harappan times. The primary channel was gradually displaced northwestward, initially captured by the Sutlej, and then by the Beas, subsequently emptying into the primary Indus stem (Mughal 1997; Pande 1977; Possehl 1999; 2002; Wilhelmy 1969). By 1500 BC the stream channels shown in Figure 24 were effectively bereft of water, except for pockets sustained by recharge during seasons of intense monsoon rains.

The emergence of stream networks since the Middle Holocene has been modeled on alignments of sites whose assemblages are Early Harappan (Figure 24). Site distribution data for the Cholistan Desert sites along the abandoned bed of the Hakra are presented in Table 3. The data report provides information on site size and more detailed measures of settlement frequency by site category (such as camp, residential, industrial, cemetery) for the periods from 3500 BC through 1000 BC (data assembled from Mughal 1982; 1990; 1992). While a comprehensive analysis of site function and settlement trends is beyond the scope of this study, the data illustrate that site densities (by count) and site sizes (by area) are highest during the Mature Harappan.

TABLE 3. Distribution of Sites: Sindh and Cholistan

	4th millennium BC	3100/3000–2500 BC	1500–2000/1900 BC	1900–1500 BC	1100/1000–500 BC
Site category	Hakra	Early Harappan	Mature Harappan	Late Harappan	Painted Gray Ware
Camp sites	52	3	10		13
Residential sites	45	23	50	14	14
Industrial activity	2	14	33	14	
Exclusively industrial			79	9	
Cemeteries			2		
Total number of sites per period	99	40	174	50	14

Source: After Mughal 1990, 1992.

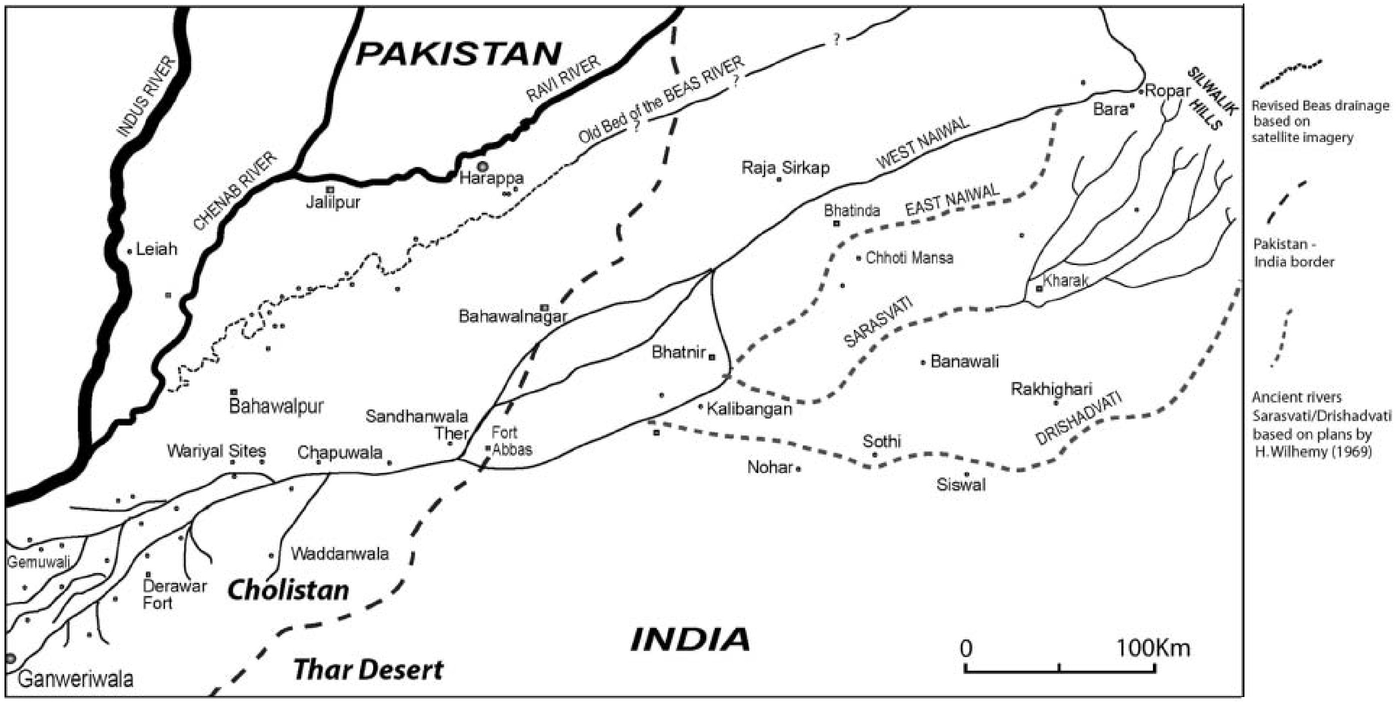

Figure 24. The ancient drainage of the Upper Indus Valley in the vicinity of Harappa and south and west to Cholistan. Note the complex streambed and settlement configurations of the Ghaggar-Hakra along margins of defunct channels. The old Bed of the Beas is shown along with principal sites investigated during the recent Beas Survey (see text). (Map redrawn from Possehl 1999: 382).

They are preceded and succeeded by lower site densities and smaller site sizes during the emerging and declining phases of the Harappan culture. The exception to this trend is during the Early Harappan, where high site frequencies but relatively small site sizes mirror pre-state, nomadic-pastoral settlement patterns that favored clustering in well-watered settings not tied to perennial stream flow (Kenoyer 1998). Thus the high stream density (larger proportion of stream arteries relative to land area) modeled for the Mature Harappan reflects a dynamic stream network that must have been, in part, manipulated by polities of a stabilized state society. To what extent this development represented human engineering (drainage and irrigation nets) versus climatic influences (higher or better distributed rainfall) or tectonic shifts (displacements of the entire drainage net) remains uncertain. What is clear is that the landscape was such that the available rainfall and water sources, including springs and seasonal aquatic basins, favored the long-term survival of the state-based organization. The Mature Harappan represented the era of optimal balance between human exploitation and availability of water resources.

To date, the only studies of the subsurface geological record are those of Courty (1995) who addressed the chronologies of sedimentation and soil formation as proxies for the interplay between dynamic flood-prone environments and stable landscapes that would have preserved soil horizons and archaeological sites associated with their upper profiles. She concluded that the widely accepted Early Holocene moist phase in South Asia initiated the multiple channel configurations in the Ghaggar-Hakra. The last major phase of alluviation ended prior to 5000 BP. Subsequently, progressive narrowing of floodplains created the segmentation of discrete river reaches (shown in Figure 24). By Harappan times the various stream segments sustained small lakes, seasonal swamps, and minor basins. Thus, scarcity of water accounted for the general configuration of the earliest Harappan sites. Floodplain terrain prone to systemic flooding promoted clustering of populations on rises above the seasonal impoundments and in interdunal settings. The appearance of aeolian sands and loess and layered silts and clays in the upper sediment columns are indicative of siltation and encroaching dune migration (Courty 1995: fig. 5). Irrigation canals have been identified (Courty 1990), suggesting that some flooding occurred and that, as in the Lower Valley, small-scale diversions were built in response to high-frequency, high-impact climatic events. The lowest-lying settings (marshes) were also drained by Harappan farmers. Salinization became a serious problem, again (as in the Lower Valley) because of rising water tables and increasingly poor drainage. Winter wheat may have ceased to be a major crop. The belief is that devegetation may have promoted slope stripping, erosion, and the acceleration of dune development. The decrease in soil moisture content was the main finding for the Harappan-period sediment analysis (Courty 1995). Progressive desiccation and salinity eventually forced the abandonment of the Ghaggar-Hakra Plain.

Harappa. The only other area in which significant geoarchaeological studies have been performed is at the site of Harappa itself. Here there is excellent evidence for a different landscape concurrent with the original settlement. The site occupies a relict Pleistocene terrace overlooking an abandoned reach of the Ravi River (Whitehead 1932; see also Schuldenrein et al. 2004). Site stratigraphy (Kenoyer 1991a: figs. 4.5, 4.10, 4.11, 4.14) reveals precultural deposits at depths in excess of 4 meters below surface. Recent studies of the geomorphology indicate that, like the Ghaggar-Hakra, the earliest Harappan occupants settled on a landform within a meander channel that eventually became an oxbow lake (Belcher and Belcher 2000). The landscape evolved into a terraced river plain overlooking a rich aquatic setting.

A robust program of paleosol mapping in the late 1980s by Amundson and Pendall (1991; Pendall and Amundson 1990a; 1990b) produced a map of the Holocene soils that surround the site and demarcate the ages and magnitudes of weathering environments radiating away from the mound proper (Amundson and Pendall 1991: fig. 3.4). Their research determined that after stabilization of the late Pleistocene terrace, a succession of soils formed on varied landscape segments and parent materials which was tied to the migrating channel and its surrounding floodplain. Stable isotope analysis (for carbon and oxygen) offers the possibility that during Harappan times an extensive tropical grassland was sustained by cooler and moister climates (Amundson and Pendall 1991). The oldest (Pleistocene) soils were recognized on the strength of the diagnostic calcic soil horizon (Bk, chara characterized by carbonate nodules or *kankars*) and were dated to > 7000 BP. Buried soils implicated four intervals of weathering at 5000–15,000 BP; 2000–5000 BP; < 4500 BP; and recent. Since then, new radiocarbon dates have been obtained for the terminal alluvial episode preceding the Early Harappan occupations. Age determinations of 11,270 ± 40 BP (Beta-133921; organic sediment; $\delta^{13}C$ = –19.7‰) and 13,090 ± 40 BP (Beta-133922; organic sediment; $\delta^{13}C$ = –23.‰) date a well-developed soil formed on overbank alluvial silts (Schuldenrein et al. 2004). The dates confirm that stable environments and well-drained landforms emerged at the end of the Pleistocene in the better-drained segments of the Upper Valley.

In contrast with that at Mohenjo-daro, geoarchaeological work at Harappa has stressed the chronology of stable environments (through soil studies) while underplaying reconstructions of the depositional environments. Thus there is an excellent baseline study of the surfaces contemporaneous and even predating the Harappan occupation, but there is minimal information on the changing stream environments during the Middle

Holocene. More extensive geomorphological studies are warranted to develop a more comprehensive landscape chronology.

Beas River. Harappa's setting on the Bari Doab (Figure 22) indicates that at various times its resource environment would have incorporated both the Ravi and Beas floodplains (Figure 24). Reconstructions have demonstrated Harappa's logistic dependence on the Ravi, but the magnitude of Holocene channel migrations underscores the potential significance of the Beas as part of an economic landscape for Harappa and its satellite communities. Earlier studies suggested that subsequent to the Harappan collapse, the Beas—as the ultimate conduit for the Sutlej—may have functioned as the trunk stream for the Upper Valley (Mughal 1997: see fig. 4). A recent survey of the Punjab province disclosed a broad representation of prehistoric, protohistoric, and historic sites (Mughal et al. 1996), dispersed on various landforms aligned with the ancient Beas. The Beas Survey was designed to link a population of Harappan-age sites with their landforms, occupation chronologies, and landscape histories using dates and sedimentological histories derived from stratigraphic profiles.

RECENT DEVELOPMENTS IN UPPER VALLEY GEOARCHAEOLOGY

The Beas Survey

The Beas River Survey was the first study in the Upper Indus designed to establish a regional stratigraphic framework bridging environmental and mound formation histories. The survey focused on a population of eighteen Harappan sites spanning the buried margins of the ancient channel for a 200-kilometer stream segment (Figure 24) (R. P. Wright, Khan, and Schuldenrein 2002; R. P. Wright et al. 2005 a; 2005b; Schuldenrein et al. 2004). The Beas alluvial setting lent itself to modeling baseline stratigraphies because the Harappan sites are relatively large and alluviation was shallow, facilitating access to stratigraphic interfaces between cultural and floodplain deposits. Moreover, the Beas is the trunk drainage intermediate between the Ghaggar-Hakra, the axis of the densest cluster of known Harappan sites, and the Ravi, the location of Harappa.

While currently defunct, the Beas preserves numerous stratigraphic exposures even though most of its ancient course and floodplain margins have been infilled, overridden, and sealed. The disposition of sites flanking the inner and outer channel banks is evidence that during the Holocene, the Beas was an active stream and the lifeline for settlements in much the same way that the ancient Ravi was for Harappa (Belcher and Belcher 2000). Two sites in the upper end of the drainage—Lahoma Lal Tibba and Chak Purbane Syal—facilitate chronological connections between occupations and environmental histories. They are the basis for comparisons with Harappa because of their proximity and geomorphic setting (Figure 22).

Developmental Histories at the Upper Beas Sites. A guiding principle for structuring the environmental chronologies for the Beas sites was the use of the available Harappan soil stratigraphy to document periods of landform stability (Amundson and Pendall 1991; Pendall and Amundson 1990a; 1990b). A second strategy was to probe, and subsequently date, the interface between the natural surface of the mounds (that is, the alluvium) and the initial intact occupation horizon. This was designed to enable identifications of the time frame between the stabilization of the floodplain (namely, the soil formation) and its initial settlement.

Cultural chronologies were established by test excavations within the mounds (R. P. Wright, Khan, and Schuldenrein 2002; R. P. Wright et al. 2005a), and continuous stratigraphic records—from occupation through the latter phases of floodplain alluviation—were assembled by extending mound profiles into the natural substrate. Here hand-driven 30-millimeter-diameter cores were extracted to depths of > 3 meters into the soils and alluvium. It was thus possible to bracket the periods of terminal alluviation, initial soil formation preceding the cultural occupation, and the nature of the occupation. Finally, alluvial sequences subsequent to occupation were obtained by sampling and dating floodplain segments away from the mounds. The composition of that alluvium would inform on the channel geometries and flooding patterns that resulted in site abandonment. Most significantly, radiocarbon dates were secured from soil horizons within these sites, a strategy that had not been utilized before for ordering environmental events.

Detailed descriptions of site archaeology are presented elsewhere (R. P. Wright, Khan, and Schuldenrein 2002; R. P. Wright et al. 2005a; Schuldenrein et al. 2004). For present purposes, it is noted that Lahoma Lal Tibba consists of two mound segments, located about 4 kilometers north–northwest of a prominent meander loop of the former Beas channel (Figure 22). Maximum elevation is 4.5 meters at the apex of both mounds, and assemblages consist of dense concentrations of Harappan pottery, pyrotechnical refuse, architectural foundation materials, and mud-brick fragments. The assemblages suggest an initial Early Harappan occupation (2800–2600 BC) that extends to the Mature phase (Period 3A; 2600–2450 BC) (Table 1; Meadow, Kenoyer, and Wright 2001). Exposures revealed the interface between a moderately well-developed soil profile—an intact Cambic paleosol with a diagnostic calcic ("Bwk") horizon—and initial Harappan occupation, at approximately 0.9 to1.0 meter above the general levels of the alluvial plain

(Figures 25 and 26). The composite profile registered 3 meters of cultural sedimentation capping 4 meters of pre-occupation stream deposits and soils. Analysis of sediments supplemented by radiocarbon dates identified five stratigraphic units for the composite section as follows: 3 meters 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).

The second site, Chak Purbane Syal, 6 kilometers southwest of Lahoma Lal Tibba (Figure 22), is variously eroded and has been known for over half a century (Vats 1940). The two surviving mound segments are 1 to 2 meters high, and both mounds are capped by one to three cultural levels in their uppermost meter. The cultural stratigraphy is subtle, and microstratigraphic analysis indicates local episodes of sheetflow and mound collapse over the course of occupation. As at Lal Tibba, the lower exposures disclosed a sharp stratigraphic boundary between the initial occupation and a moderate to weakly developed paleosol (Figures 25 and 27). The western mound was underlain by a silty inceptisol that graded to a coarser, mixed sandy but still weathered silt exposed at the eastern mound section. Soil horizonation varied considerably across the site. The upper weathering horizons—AB–BCk featured weak to moderately developed subangular blocky structures that were dominated by silts with limited amounts of translocated clays (Figure 27). These properties are suggestive of a cumulic profile, one in which weathering dominates over reduced sedimentation. Progressive calcification was persistent in the soil profile, well into C horizons, and carbonate nodule sizes and densities increased. The nearly pure silt composition in the AB soil horizon is indicative of single-source wind deposition typical of a loess profile. Radiocarbon determinations postdate the primary occupations at Lahoma Lal Tibba, but are consistent with that site's uppermost component and are equivalent to the Mature to Late Harappan transition at Harappa (Schuldenrein et al. 2004; R. P. Wright, Khan, and Schuldenrein 2002. R. P. Wright et al. 2005a.).

It is possible to bridge the soil chronologies and geomorphic histories across Harappa, Lahoma Lal Tibba, and Chak Purbane Syal, as the Bari Doab is their common landform (Figure 22) and has been relatively stable since early Holocene times. Figure 25 presents composite site stratigraphies for each of the three locations, indexed by key radiocarbon dates. The section underscores the significance of the Early to Middle Holocene unconformity which marks the passage from the earliest cultural to terminal natural sequences at each site. 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

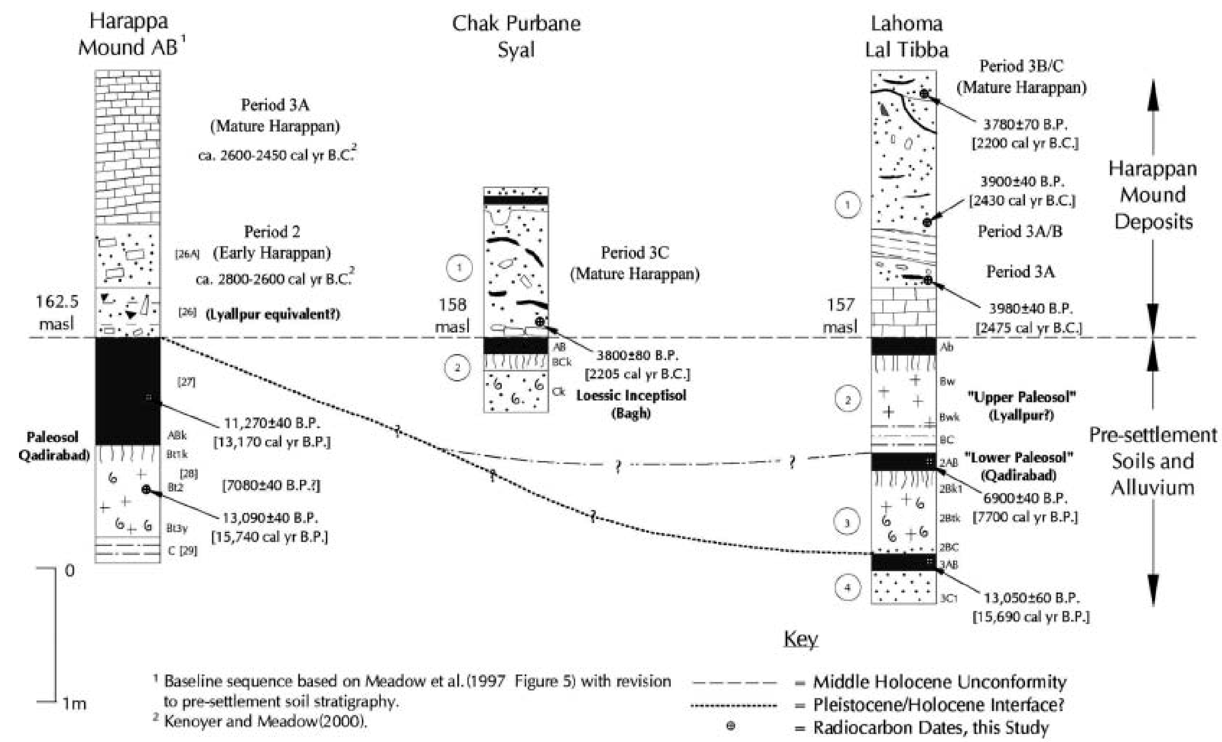

Figure 25. Site-specific and regional stratigraphies of Harappa, Lohoma Lal Tibba, and Chak Purbane Syal. Note the Middle Holocene unconformity marking the interface of cultural and natural sequences (also indicated by absolute elevations). Conventional (^{14}C) and calibrated (cal BP or BC) dates are presented as available.

averaged from recently published determinations, and the column is taken from AB Mound, HARP Trench 42 (Meadow, Kenoyer, and Wright 1997). Only the lowermost 2 meters of cultural deposits at Harappa are illustrated.

Figure 25 places the age of the soil at the interface of the earliest occupation (Early Harappan) and terminal alluviation ([^{14}C] 11,300–13,100 BP [13,200–15,800 cal BP]). The soil, also known as the Qadirabad (after Pendall and Amundson 1991), 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 soil is dated [^{14}C] 7000–13,000 BP [7,800–15,700 cal BP] based on the ages obtained from the bracketing A-horizons between Units 3 and 4. The terminal alluvial soil at Harappa—at [^{14}C] 11,300–13,100 BP—is coincident with the Pleistocene–Holocene transition and is marked as a discontinuity at both Lahoma Lal Tibba and Harappa, despite some uncertainty as to the reliability and correlation of dates. For these reasons, 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 initial phase of regional landscape stabilization during the Early Holocene. It may extend into the Pleistocene (that is, > [^{14}C] 11,500 BP) because of the apparent antiquity of the Qadirabad soil at Harappa proper.

The second major paleosol is that registered by Unit 2 at Lahoma Lal Tibba (Figure 25). It is probably equivalent to the Lyallpur soil of Pendall and Amundson (1991) which underlies the initial (4000 BP) Harappan occupation at that site. This is a Middle Holocene soil that dates to the interval [^{14}C] 7000–4000 BP. 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 chrono-sequences are not immediately transferable, but the fact that the soil is weathered and underlies the occupation everywhere across the terrain suggests that it is only slightly younger than the Lyallpur.

Changing channel flow and alluvial geography are implicated by the contrasting sedimentary suites at Lahoma Lal Tibba and Harappa (Figure 25). At the base of the Lal Tibba sequence, the deposits of Unit 4 are substantially coarser than the overlying alluvial fills and provide evidence of the dynamism of the Late Pleistocene Beas. It and the terminal alluvium at Lahoma Lal Tibba are capped by entisols. This is evidence of limited soil formation and dominant alluviation. Such a pattern is consistent with channel sedimentation and considerable lateral migration. It has been discussed elsewhere that Unit 4 marked the onset of a fining upward sedimentary suite that is a signature depositional index of a meandering stream (Schuldenrein et al. 2004). Eventually, the migrating stream moved toward stabilization or eventual channel entrenchment within the Beas channel, only irregularly discharging sediments

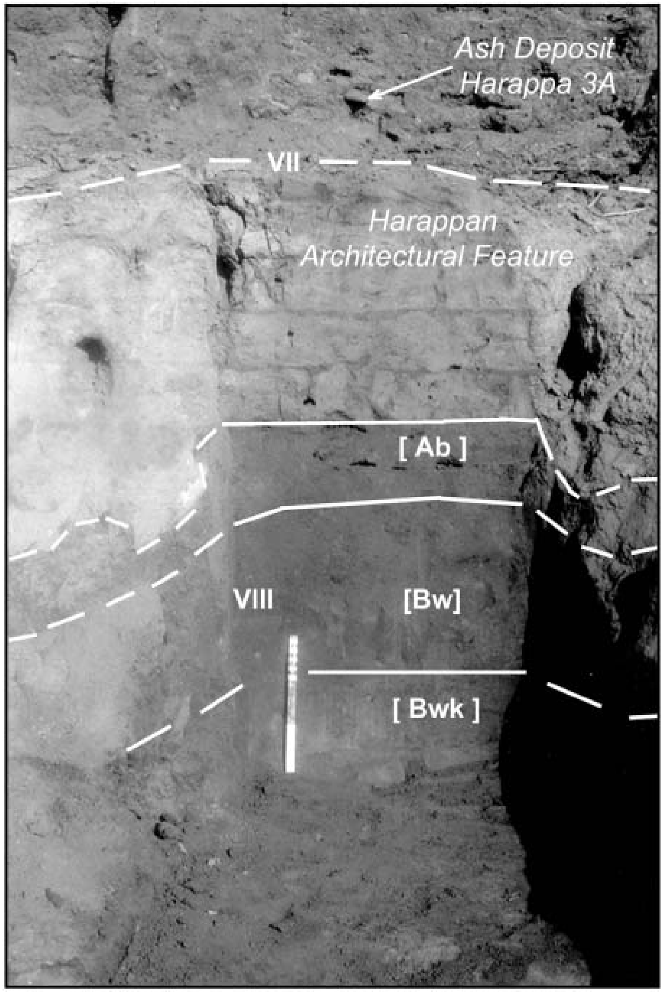

Figure 26. Contact of initial occupation surface Period 3A (Mature Harappan) and Mid-Holocene paleosol at Lahoma Lal Tibba, North Mound (see Figure 24). Roman numerals refer to field levels. Adjacent soil horizons are shown in brackets. Note the four courses of bricks associated with the Harappan architectural feature. The whitened color at the base of the profile highlights calcic soil horizon (Bwk). Scale 30 cm.

onto the higher *doab* surfaces (in Unit 3). Soil formation then dominated over flooding, signified by the more strongly developed profiles of Units 2 and 3. The transition from active alluviation to dominant soil formation would appear to coincide with the earliest Holocene (ca. [^{14}C] 10,000 BP)

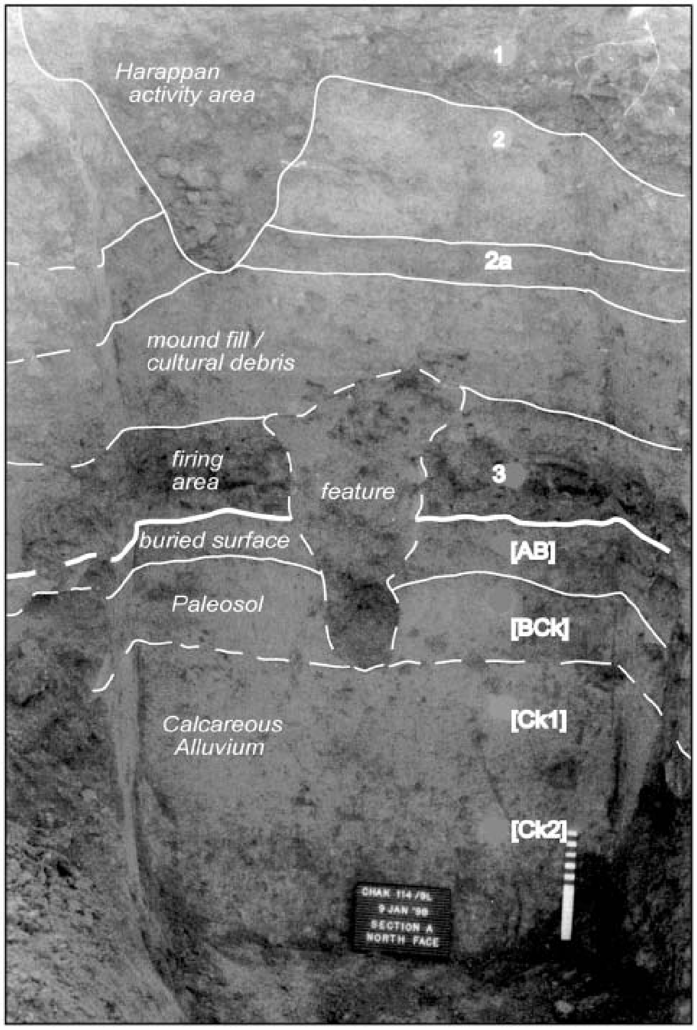

Figure 27. Contact of initial occupation surface Period 3 (Mature Harappan) and Mid-Holocene paleosol at Chak Pirbane Syal, also referred to as Chak 114-9L (see Figure 24). Arabic numerals refer to cultural levels (above paleosol). Adjacent soil horizons are shown in brackets. Note the whitened calcic horizons (BCk, Ck1, Ck2). Scale 20 cm.

The alluvial chronology is somewhat more complex at Harappa since the Ravi probably drained a broader catchment (even in earlier Holocene times), and changes in its fluvial regime were more dynamic than those of the Beas. Moreover, the size, logistic placement of Harappa, and land use practices of the (presumably) greater population would have resulted in larger-scale stream migrations and more complex landform configurations than at Lahoma Lal Tibba, whose smaller size may be consistent with a less dynamic stream and more subdued floodplain topography. Nevertheless, at Lal Tibba, most of the main mound is underlain by the Middle Holocene (Lyallpur) soil. At Harappa, an overhaul of the site 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 soils of progressively younger age and weakly developed soil profiles away from the primary mound are evidence that the Ravi channel shifted nearly 20 kilometers over the past 4000 years (Belcher and Belcher 2000). 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 displacement of streams exposed large silty tracts along the recently abandoned floodplain, thus providing fresh sources of sediment that were mobilized by wind action.

Taken together, the alluvial histories of all three sites provide unique windows on regional Holocene developments. Both Harappa and Lahoma Lal Tibba illustrate a stabilization of landscapes in the Early Holocene as 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 (such as stabilized rainfall regimens and moderate evapotranspiration rates) during the Early Holocene. Thinner Middle Holocene soils (Lyallpur) and renewed channel migration (principally registered in the Ravi) are evidence of some destabilization of environments at around the time of the initial pre-Harappan (Period 1[Ravi phase]) and Early Harappan (Period 2) occupations (Table 1).

SYNTHESIS OF LANDSCAPE RECORDS

The landscape records for both the Upper and Lower Indus converge around full-scale overhauls of the drainage basin in the postglacial period. These developments can be expected to mirror broader climatic and environmental changes for most of South Asia because of the pervasive impacts of the Asian monsoon. The key element in understanding climatic succession is the variability, intensity, and periodicity of monsoon circulation patterns over the duration of the Holocene (Bryson 1996; Swain et al. 1983; Wasson 1995). The effects and the timing of climatic cycles are variously registered across the physiographic regions of South Asia. To obtain a measure of understanding of landscape transformation bearing on Harappan landscapes, it is appropriate to summarize the reconstructions that focus on (1) the semiarid and arid Indus landscapes in which the Harappan sites are clustered; and (2) the critical later Middle Holocene period during which climatic and environmental changes bear most directly on Harappan settlement.

Table 4 is a synopsis of Holocene landscape and paleoclimatic trends across the Indian subcontinent with data sets associated with the Harappan phases highlighted (ca. 5000–3000 BP). The types of settings for which information has been assembled include aeolian mantled terrain; coasts (estuaries and drainage mouths); lake beds; fluvial features and valleys; buried soil (paleosol) localities; and low-lying areas with evidence for structural movements (tectonics). Because the monsoon was such an overarching mechanism for climatic change across the subcontinent, its manifestations should be represented across most geographic subdivisions (although see Wasson 1995 for an alternative viewpoint).

It cannot be overstressed that the stratigraphic records across South Asia are spotty and uneven because of the relatively recent incorporation of the latest paleoclimatic and environmental methodologies. Soil sequences remain woefully undocumented, and the tectonic record has not been widely investigated (compare columns in Table 4). It is nevertheless possible to discern converging lines of paleogeographic evidence. Most striking is the evidence for Early Holocene moisture associated with the establishment of post-Pleistocene monsoon circulation. Reduction in aeolian activity (Ghaggar-Hakra) is consistent with renewed alluviation and submerged coastlines for many regions of the subcontinent, highest lake levels in Rajasthan, and subsequent delta progradation as rising base levels reflect stabilization of transgressive coastlines. The formation of the most deeply weathered soil profiles in the Harappa area (Amundson and Pendall 1991; Schuldenrein et al. 2004) signifies that well-drained surfaces flanked the major rivers of the Punjab at that time.

A gradual turn to desiccation, ca. 7000–6000 BP, may be indicated by resumption of loess sedimentation in the Ghaggar-Hakra Plain, a reduction in the scale of alluviation and incision of some of the main river valleys, and stabilization (and initial lowering) of lake levels. Soil chronologies have not been documented for this time frame, although it is not clear whether or not this is a function of increased erosion or insufficient research. Wasson (1995) infers that reduction in lake levels across the southern hemisphere's monsoon belts is proxy evidence for the decline of southwest monsoon intensity coupled with high evapotranspiration ratios.

For the 2000 years of peak Harappan settlement in South Asia, the paleoenvironmental record is somewhat ambiguous (Table 4, shaded rows). Cessation of dune activity in the Ghaggar-Hakra and optimal freshwater influx at Didwana and coastal transgressions (+3 to +6 meters) may be measures of increased moisture, but such developments as channel migrations, westward drainage displacement, and abandonment and desiccation of the Ghaggar-Hakra Plain midway through the interval are more equivocal. Here again,

TABLE 4. Synopsis of Holocene Landscape and Paleoclimatic Trends in the Indian Subcontinent Landscape History (with Harappan era highlighted) *(on facing page)*

Years BP	Aeolian Activity	Coastal Changes	Lacustrine Record
0			
1000	Moderate aeolian activity, Ghaggar	2m regression in Saurashtra; accelerated pro-deltaic aggradation at mouth of Arabian sea (lower Indus)	Progressive desiccation and salinity: Didwana
2000			
3000	Cessation of dune build-up: Thar Desert; localized sand dunes, Ghaggar	Maximum sea levels (+3 to +6 m transgression)	Optimal fresh water influx and highest lake levels: Didwana
4000			
5000	Loess sedimentation Ghaggar plain	Onset of marine transgression	Moderately deep freshwater, Didwana
6000			
7000		Southwestward migration and sedimentation of Indus delta	Fluctuating dry/saline and deep/freshwater conditions, Didwana; high water levels and freshwater Bap Malar, Thob
8000	Limited extent and reduced rates of dune construction: Thar Desert		
9000		Still-stands, submerged terraces in Goa (–92m, –85m, –75m and –55m)	
10000	Terminal loess deposition in interior Gujarat		Rising lake levels: Didwana

References

Aeolian: Gujarat loess (Chamyal and Merh 1995); Ghaggar (Courty 1995)

Lacustrine: Thar Desert and Didwana (Chawla et al. 1991; Misra, 1995; Singh et al. 1972, 1974, 1990; Singhvi et al. 1982; Wasson et al., 1983, 1984; Wasson 1995); Kajale and Deotare (1997); Deotare et al. (1998)

Sea levels: (Juyal et al. 1995); Sarma (1971); Marathe (1995); Flam (1993); Snead (1993a, 1993b)

the degree to which tectonics account for drainage realignment is both pivotal and uncertain. If existing reconstructions of channel desiccation are correct (Possehl 1999; Wilhelmy 1969), then the 4000–2500 BP interval resulted in net displacements of flow lines on the order of 100 to 150 kilometers northward, coupled with desiccation in abandoned channel lines. Evidence for north and westward channel migration has been noted for the Ravi at Harappa (Belcher and Belcher 2000), for the Sutlej-Beas (Wilhelmy 1969; Possehl 1999; 2002; this study), and along the Lower Indus at Mohenjo-daro (Flam 1993). However, even extensive structural dislocations should not have resulted in realignments of topography and drainage to such a degree that all

TABLE 4. Synopsis of Holocene Landscape and Paleoclimatic Trends in the Indian Subcontinent Landscape History, *Continued*

Years BP	Fluvial Sequences	Soil Chronology	Tectonics	Climate
0 / 1000	Reduction of swamps and channel activity; lowered water tables, Ghaggar incision in Deccan Uplands; aggradation exceeds subsidence in lower Indus		Upwarping promoting stream capture and westward drainage (lower Indus) with episodes of eastward avulsion	Reduced precipitation / High precipitation levels with contemporary rainfall patterns
2000	Peak flood stages-Narmada R.; reduced seasonal flooding and siltation of channels, Ghaggar	Soil formation in Nepal		
3000 / 4000	Sandy alluviation of Belan River; moderate aggradation in Deccan Uplands. Reduction in aggradation and channel avulsion along lower Indus	Sultanpur soils at Harappa (Bk, Bw horizons)	Structural deformation leading to eastward and westward stream capture in Punjab (Ghaggar-Hakkra)	Generally decreased monsoonal precipitation punctuated by moister pulses
5000	Incision of Belan River into Pleistocene fills; reduced alluviaton; slackwater formations, Ghaggar			Stabilization and gradual decline of southwest monsoon intensity; high evapotranspiration
6000				Maximum winter monsoons
7000 / 8000	Rejuvenation of alluviation in valleys of Deccan uplands; massive seasonal flooding, Ghaggar plain	Nevasa; soil formation in Nepal; Gamber, Lyallpur soils at Harappa (Bk, Bw, By horizons); weathering of E. Indian		
9000	Rapid aggradation of lower Indus			Establishment of post-Pleistocene monsoon circulation
10000	Alluviation at foot of Siwaliks			

Fluvial sequences: Narmada River (Baker et al. 1995); central India (Williams and Clark 1995); Pappu (1974; 1995); Korisettar (1979); Ghaggar plain (Courty 1995); Indus (Jorgensen et al. 1993)

Soils: Nepal & Siwaliks (Corvinus 1995); Nevasa soils (Misra 1995); "red dunes" (Gardner and Martingell 1990); Pendall and Amundson (1990a, 1990b)

Tectonics: Wilhelmy (1969); Jorgensen et al. (1993); Agrawal and Sood (1982)

Climate: Nigam & Hashimi (1995); Von Rad et al. (1999); Bryson (1996); Brinkman and Rafiq (1971); Singh et al. (1974) Swain et al. (1983); Wasson (1995)

signs of hydric conditions in the ancient depressions are absent. Courty's (1995) sedimentological study of the abandoned depressions in the Ghaggar-Hakra Plain argues for reduced seasonal flooding and dune encroachments and a turn to drier conditions, an argument that is in opposition to widely held concepts of increased moisture during the Harappan (Singh et al. 1974; Bryson and Swain 1981). Courty's position is that Harappan environments and rainfall distribution patterns were analogous to those of the present. This argument is compelling insofar as traditional landscape indicators of reduced moisture (such as lowered water tables and broader dune expanses) are linked to agricultural practices during the Harappan period. But a major concern in Courty's analysis is the absence of any consideration of tectonic influence as a mechanism accounting for the initial displacement of the drainage lines despite the fact that the stream displacements near Harappa and Mohenjo-daro during the Late Harappan would appear to lend some credence to structural displacement mechanisms. The soil reconstructions at the Beas sites do not offer unequivocal indications of stable environments after 7000 BP, although identifications of two cycles of low-magnitude alluviation capped by thin soils is indicative of a controlled floodplain environment for the period 7000–4000 BP.

Recent offshore coring on the Makran coast sheds new light on the ambiguous climatic proxy data (von Rad et al. 1999). Here marine cores were used to infer paleoclimatic conditions based on relative thicknesses of turbidite varves (that is, continentally derived monsoon deposits) (Figure 28). Thicker varves signal greater precipitation, while thin varve deposits denote less precipitation and drier circulation patterns. Figure 28 shows that during the Harappan phases, mean varve thicknesses spiked twice within the period 4000–3500 BP, suggesting that high and widely fluctuating levels of precipitation may have characterized the latter part of that occupation. High periodicity may also indicate that the distribution of rainfall or the frequency of overbanking would have accelerated at that time. It may have been that the successes of the Harappan agriculturalists in managing the rainfall—specifically constructing and maintaining effective irrigation and drainage systems—extended their ability to function in a climate in which rainfall was

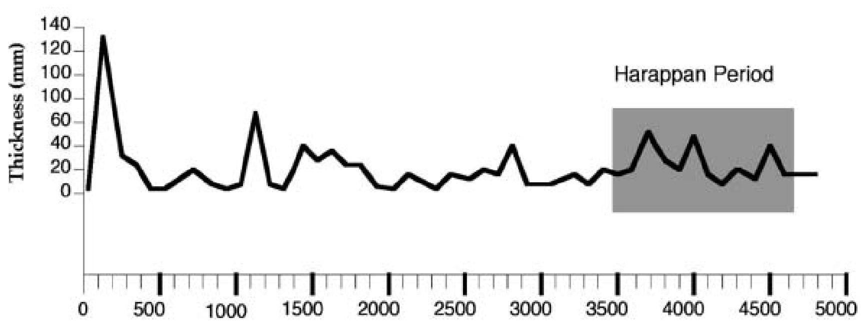

Figure 28. Late Holocene climatic signals inferred from the thickness of turbidites in the oxygen-minimum zone off Makran Coast, Pakistan (after von Rad et al. 1999). Note the pronounced variations for turbidite thicknesses during the Harappan period.

abundant but erratic. However, erratic precipitation, salinization, and mismanagement of the irrigation systems may have hastened the civilization's downfall. It is not clear whether or not moister climates are implicated (as varve thickness may also reflect human-induced mobilization of sediment), but precipitation intensities and regimes may have been different then than at any other time. Increased rainfall may have disrupted water management systems and dictated changes to Harappan adaptive strategies.

Depositional records of the past 3000 years suggest that the effects of human modifications to the landscape may have been as critical as any natural processes of sedimentation. The Late Holocene lake records suggest increased desiccation as water levels decrease, while reinitiation of dune activity also points to higher wind activity and less vegetation cover. Shoreline regression (by 2 meters) is also consistent with the reduction in available moisture. Von Rad et al. (1999) imply that over the past few thousand years, low precipitation values are characteristic and are interspersed with aperiodic rainfall regimes that have minimal effects because of their limited durations. Paleo-circulation models argue for high precipitation after 3000 BP, the effects of which are tempered by the stabilization of contemporary seasonal rainfall distribution patterns. Thus, despite increases in net moisture, the distribution of precipitation may have had deleterious environmental effects—for example, catastrophic inundations of farmed fields—conceivably exacerbated by population increases and stress on natural landscapes. Here again, the paleoclimatic record is not unequivocal.

CONCLUSIONS

An abundance of geoarchaeological and Quaternary research across South Asia is beginning to make possible broad environmental chronologies across a range of physiographic zones. Regional investigations focusing on the locations of sites along landforms and the assembly of alluvial histories for the Upper and Lower Valleys of the Indus enhance understanding of the critical Middle Holocene period in this key cultural area. Larger-scale climatic events—immediately antecedent to Harappan occupation—are preserved in the depositional histories of the valleys sealed beneath Harappan mounds. Soil sequences distinguish those periods favorable to settlement. It is thereby possible to document changing thresholds in stream energy levels and floodplain morphologies, to date them, and link floodplain histories along the length of contemporary drainage lines. In this way, it may also be possible to calibrate the relative impacts of tectonics and climatic mechanisms regionally, thus structuring chronologies for Holocene floodplain transformations.

In summary, the following working hypotheses can be generated regarding Holocene paleo-landscapes and circulation patterns for the greater Harappan countryside:

1. Continental and littoral geomorphic histories and soil sequences converge around moister climates during the Early Holocene (ca. 10,000–7000 BP), during which time post-Pleistocene monsoon circulation patterns were established; they stabilized toward the end of this period.
2. There is more limited stratigraphic evidence for the lower Middle Holocene, although general indications are that southwest monsoon intensities diminished and drier climatic cycles were initiated (ca. 7000–5000 BP).
3. The record for the Middle Holocene contemporaneous with peak Harappan occupation (ca. 5000–3000 BP) is ambivalent; mechanisms accounting for fluvial cut and fill cycles, moisture budgets, coastal terrace cutting, and aeolian events may reflect tectonic influences and human manipulation of alluvial and even perimeter environments (due to agricultural practices).
4. The Later Holocene stratigraphic record (prior to 3000 BP) preserves increasing evidence for anthropogenic sedimentation, underscoring human landscape manipulation; critically, present patterns of rainfall (seasonal precipitation) had been clearly established, although there are some indications of greater precipitation between 3000 and 2000 BP.

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