Harappa Excavations 1986-1990

A Multidisciplinary Approach to Third Millennium Urbanism

Edited by Richard H. Meadow

Monographs in World Archaeology No. 3

PREHISTORY PRESS
Madison Wisconsin

Prehistory Press
7530 Westward Way
Madison, Wisconsin 53717-2009

James A. Knight, Publisher
Carol J. Bracewell, Managing Editor

Manufactured in the U.S.A.

ISBN 0-9629110-1-1
ISSN 1055-2316

Library of Congress Cataloging-in-Publication Data

Harappa excavations 1986–1990 : a multidisciplinary approach to third millennium urbanism /
edited by Richard H. Meadow.
p. cm. -- (Monographs in world archaeology, ISSN 1055-2316 : no. 3)
Includes bibliographical references.
ISBN 0-9629110-1-1 : $33.00
1. Harappa Site (Pakistan) 2. Excavations (Archaeology) –
– Pakistan. I. Meadow, Richard H. II. Series.
DS392.2 H3H37 1991
934 - - dc20 91-39504
CIP

Cover art: Bowl on Stand H88-1002/192-17 associated with Burial 194a
in Harappan Phase Cemetery (see Figure 13.18).

3

Pedology and Late Quaternary Environments Surrounding Harappa: A Review and Synthesis

Ronald Amundson and Elise Pendall
University of California-Berkeley

A review and synthesis of pertinent pedological, geological, and paleoenvironmental studies in the vicinity of Harappa (District Sahiwal, Punjab, Pakistan) suggest that a wealth of research opportunities exists for earth scientists interested in contributing to an understanding of the origins and later decline of the Indus civilization.

Harappa lies near the apex of the Holocene alluvial fan of the river Ravi on an alluvial deposit of late Pleistocene age. Soil patterns around Harappa indicate several periods of river meandering and channel infilling.

Stable isotopes in pedogenic carbonates of a soil buried by early occupation offer potential insights into pre-Harappan environmental conditions. Although carbon isotope ratios are difficult to interpret unambiguously, they suggest either a very arid, sparsely vegetated site (matching presumed latest Pleistocene conditions) or a nearly pure C_4 flora, indicative of a tropical grassland (presumed early Holocene conditions). Oxygen isotope ratios in the carbonate are also difficult to interpret due to a lack of knowledge of the isotopic composition of present precipitation. Depending on the temperature at which the carbonates formed, the oxygen isotope ratios in the carbonate could indicate that pre-Harappan conditions were either similar to the present or that a stronger monsoon may have existed.

The ancient city of Harappa, like other cities of the Indus civilization, should be studied in the context of its contemporaneous environment (Butzer 1982), as well as in relation to conditions which preceded its inception and followed its demise. Environmental and geologic factors such as climate, vegetation, flooding, and sedimentation, to name a few, not only determine the suitability of a site for habitation, but can ultimately help shape the culture which evolves (Amundson and Jenny 1991).

Numerous approaches are becoming available to archaeologists interested in reconstructing past environments. In this paper we report on our initial pedological work at Harappa and its relationship to the more regional conditions in the Punjab. In addition, we review some of the important previous studies of the climate and geology of the region to provide a context for our work at Harappa and to provide a general overview of much of the area once inhabited by the peoples of the Indus Valley Civilization.

Climate of the Punjab

The present day summer monsoon circulation of Pakistan is driven by the relative warmth of the South Asian land mass relative to the surrounding oceans (COHMAP Members 1988). Winters are cool to cold, with occasional disturbances originating from the Mediterranean Sea. From April to June, land mass temperatures increase greatly, with maximums of 50°C or more being recorded in the southern Punjab (Pakistan Meteorological Department 1986). These temperatures set up the Indus low, which is associated with a south-westerly, but dry, monsoon. During May, an associated low pressure trough develops over the Ganges, which is fed by moist air from the Bay of Bengal. The upward surging, warm moist air of this trough reaches the Punjab in late June or early July, marking the onset of summer precipitation which commonly continues until late August. From September through November, a transition from the summer monsoon to the cool, dry winter period occurs. At Sahiwal, about 12 km NE of Harappa, the mean annual temperature is about 26°C and the mean annual precipitation is about 260 mm, 70% of which falls between July and September (Greenman et al. 1967).

The general character of the prehistoric climate of South Asia has been debated for many years (see Meadow 1989 for summary). While some scholars feel that there has been little change in climate since the end of the Pleistocene, others suggest that it has varied greatly from the last glacial maximum (18,000 years BP) to the present. Model calculations for the past 18,000 years, based on input parameters of orbitally determined insolation, ice-sheet orography, atmospheric CO_2 concentrations, and sea surface temperatures (as well as other inputs), suggest that during the late Pleistocene, South Asia was colder and drier than the present, with a greatly weakened summer monsoon due to factors such as highly reflective ice sheets (COHMAP Members 1988). This prediction appears to be supported by field evidence in the sediment stratigraphy of several small salt lakes in the arid to semi-arid belt of western Rajasthan, India (Singh 1971; Singh et al. 1974; Bryson and Swain 1981). Pre-Holocene (>≈10,000 years BP) sediments consisting of loosely-packed aeolian sand, indicate that the lakes were dry and that the presently stabilized sand dunes were active. Singh et al. (1974) have interpreted the pre-Holocene conditions to have been extremely arid and possibly windy.

The increased summer, and decreased winter, insolation proposed for the early Holocene would have greatly enhanced the summer monsoon of South Asia. The Asian land mass may have been 2° to 4°C warmer than present, and increased summer rainfall, relative to the present, is predicted to have fallen over South Asia. After 6,000 years BP, the summer insolation appears to have decreased, with the monsoonal winds and associated rainfall predicted to have declined to present levels. Singh's interpretations of the lake sediments of western Rajasthan appear to support these model predictions and also provide a more detailed environmental history of the region. Laminated, pollen-bearing, lacustrine sediments accumulated from the early Holocene until approximately 3,000 years BP, at which time there is possible evidence for desiccation (Singh 1971). Qualitatively, the pollen in all the lacustrine sediments suggests far greater precipitation than at the present time. Using the lake pollen data in conjunction with statistical relationships between present-day pollen and climate, Bryson and Swain (1981) have estimated that the precipitation of western Rajasthan between 10,000 to ≈3,500 years BP may have been three times that of the present. Singh (1971) and Singh et al. (1974) have distinguished several distinct pollen zones within the sediments, with each zone indicative of changing climatic (as well as cultural) conditions.

The early Holocene appears to have been an open steppe rich in grasses, *Artemisia*, and sedges. At approximately 7,500 years BP, the appearance of charcoal and Cerealia-type pollen is believed by these authors to signal the appearance of early agriculture and land alteration. An apparent increase in mesophytic vegetation between 5,000 to 3,000 years BP was interpreted by Singh (1971) and Singh et al. (1974) to possibly represent the moistest period of the Holocene. However, the later analysis of the data by Bryson and Swain (1981) seems to indicate that the period was not greatly different than those that preceded it.

A reduction in annual precipitation rates would have been especially detrimental to the non-riverine settlements in western Rajasthan, and the desiccation of the lakes at approximately 4,000 to 3,000 years BP may correspond to the disappearance of the Indus culture in western Rajasthan (Agrawal et al. 1964; Singh 1971). However, the influence of such a climate change on riverine settlements, such as Harappa and Mohenjo-daro, is more difficult to assess. (See Misra 1984 for a critical assessment of Singh's data).

Geology and Geomorphology of the River Ravi

The present day floodplains of the Indus river system lie atop a sequence of alluvial deposits many thousands of feet thick. The rapidly changing channels of the Indus and its tributaries attracted the attention of many of the early geographers in the region (Raverty 1892; Oldham 1874; Oldham 1887), many of whom recognized the significance to archaeological and historical studies (Wood 1924; Whitehead 1932).

The upper region of the Ravi (as well as other Indus tributaries) is entrenched several or more meters into its own, Pleistocene-aged, alluvium (Figure 3.1) (Abu Bakr and Jackson 1964), while in its lower reaches, prior to entering the Chenab, the older alluvium is buried beneath alluvium of Holocene age. The Pleistocene-aged alluvial terraces which rise prominently above the present floodplains, are locally referred to as *bar* (Whitehead 1932; Mian and Syal 1986) and have been recognized since some of the earliest studies as containing prominent concentrations of *kankar*, or pedogenic calcium carbonate nodules (Wood 1924). It has been recognized that these geomorphically stable terraces are sites for settlements of great antiquity (Wood 1924).

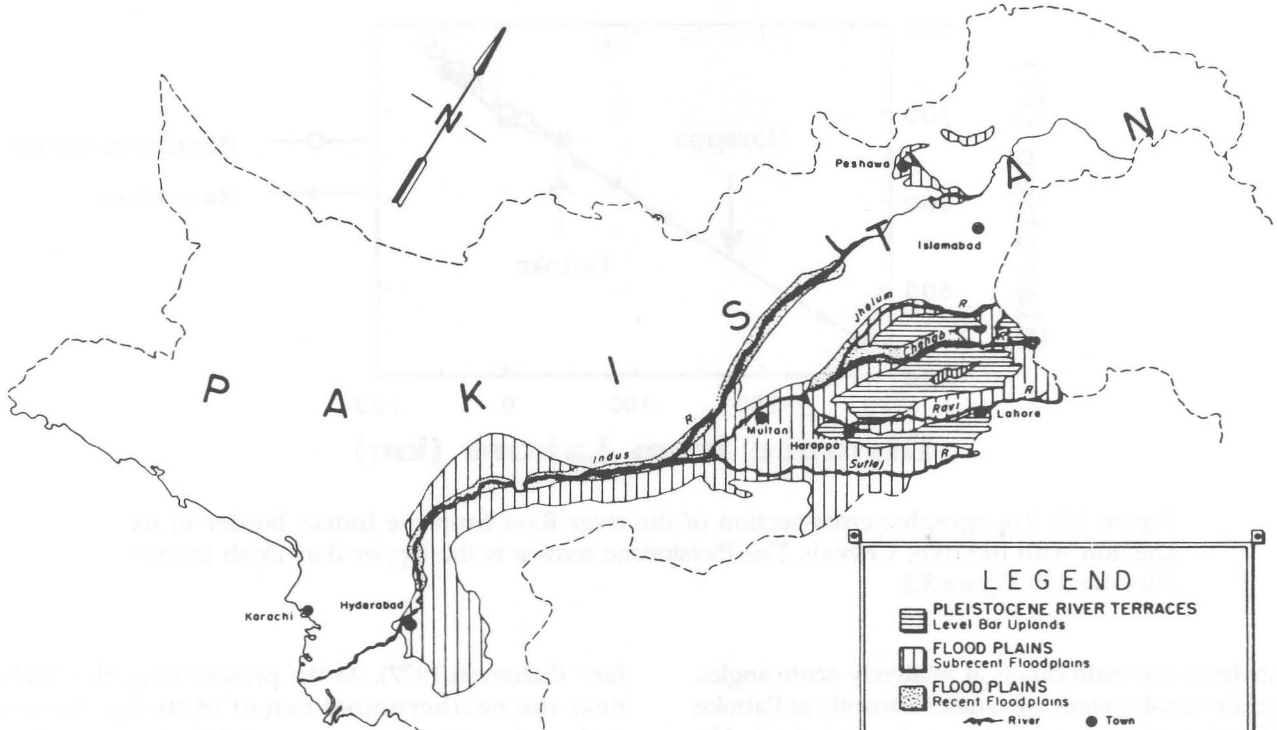

Figure 3.1: Generalized geomorphological map of Pakistan showing major cities, site locations, rivers, and alluvial landforms. Modified from Mian and Syal (1986), taken from Pendall and Amundson (1990a).

Whitehead (1932) suggested that Harappa lies on an old terrace of the Ravi and provided a very general map showing the partial extent of this terrace.

Detailed geomorphic studies of the central section of the river Ravi (including the area around Harappa) have not been made, although a reconnaissance study of the upper section (mainly in India) (Mahr 1986) and general studies of its lower section (near the river Chenab) (Wood 1924; Wilhelmy 1969) have been published. In this paper, we present a preliminary map of a portion of the geomorphology from the Indian border to the river Chenab. The map was constructed based on interpretations of topographic maps published by the U.S. Army Corps of Engineers (1955) and Couchman (1936). Scattered elevation data from the maps were used to prepare topographic cross sections. The pattern of irrigation canal systems, which, as Wood (1924) noted, are mainly the controlled diversions of present rivers into channels that follow old beds, was also used to assess landform patterns.

The present gradient of the river Ravi is roughly linear from the Indian border to the river Chenab (Figure 3.2), with a slope of approximately 29 cm/km (Table 3.1). The city of Lahore lies atop an old alluvial deposit into which the present river Ravi has entrenched approximately 10 m. This *bar*, or terrace, is more steeply dipping than the present Ravi (Table 3.1) and, based on its slope, should plunge beneath the present land surface near the village of Pattoke, approximately 60 km SW of Lahore (Figure 3.3). Major changes in irrigation patterns near Pattoke reveal this geomorphic change. The age of the terrace on which Lahore resides is certainly Pleistocene in age based on *kankar* development in the soil (Mian and Syal 1986) and its height above the present river Ravi. A more precise assignment of age is not possible without detailed fieldwork and radiometric dating.

The major irrigation canal on the Pleistocene terrace is the Upper Bari Doab canal. For the purposes of this paper, we will informally name this terrace the Upper Bari Doab terrace. On this terrace, distributary channels

Table 3.1: Calculated Slopes of some Landforms in the Vicinity of Harappa.

Landform	Slope (m/km)
River Ravi	0.287
Pleistocene Terrace (Upper Bari Doab)	0.340
Chenab River (near Multan)	0.204

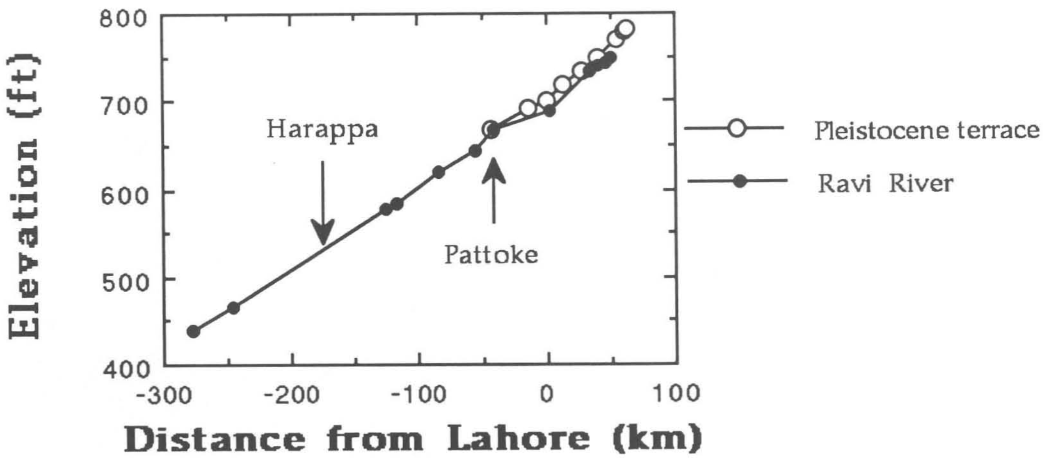

Figure 3.2: Topographic cross-section of the river Ravi from the Indian border to its junction with the river Chenab. The Pleistocene terrace is the Upper Bari Doab terrace illustrated in Figure 3.3.

radiate from the main canals at relatively acute angles. The entire canal system terminates abruptly at Pattoke, marking the point where the terrace becomes buried by younger alluvium.

Just downslope from Pattoke, the lower Bari Doab canal diverts water from the Ravi and distributes it over a relatively low, narrow terrace to the south of the present Ravi floodplain. In this paper, we will informally call this the Lower Bari Doab terrace. The distributary channels from this canal radiate outward at greater angles than those of the Upper Bari Doab terrace. This canal system ends approximately 25 km SW of Sahiwal (formerly Montgomery), which is near Harappa. On the south, the terrace (and the irrigation system) ends at a prominent escarpment that drops down to the abandoned channel of the river Beas. On the north, an escarpment is not prominently indicated on topographic maps. The slope of the terrace is not known due to inadequate elevation data on available maps. The exact age of the terrace is also not known, although generalized geologic (Abu Bakr and Jackson 1964) and geomorphic maps (Mian and Syal 1986) suggest a Pleistocene age. The terrace is younger than the Upper Bari Doab terrace since its alluvium buries that of the older terrace. Whitehead (1932) suggested that Harappa lies on the edge of what we call the Lower Bari Doab terrace, but, as will be discussed in the following section, the relationship is not unambiguous.

To the southwest of Harappa, numerous irrigation canals branch off mainly to the south of the present day river Ravi and extend as far as Multan (Figure 3.3). These canals appear to outline the major area of Holocene deposition by the Ravi or its "wet alluvial fan" (Schumm 1977). At the present time, the Ravi is near the northernmost extent of its fan. Several authors, however, have suggested that, as recently as 1500 AD, the Ravi flowed at the southernmost extent of its fan and entered the Beas, and ultimately the Chenab, far south of Multan (Wood 1924; Wilhelmy 1969). Thus, in roughly the past 500 years, the Ravi has migrated northward almost 70 km.

The rapid and extreme shifts in river courses on the Indo-Gangetic plain are well documented (Cole and Chitale 1966; Lambrick 1967; Wilhelmy 1969). Rapid rises in the base of river beds, due to deposition of alluvium, lead to sudden breaks in levees, particularly during flood events. New channels are then formed in adjacent areas of lower elevation. This process has been termed river avulsion (Schumm 1977).

River avulsion has important archaeological significance. For example, Alexander sailed his barge to the junction of the Chenab and Ravi rivers in 326-325 B.C. The exact location of this event is now difficult to assess given the dynamic nature of these two rivers (Wood 1924). As a second example, archaeological sites of great antiquity may not have been preserved on the Holocene fan of the river Ravi, to the southwest of Harappa, as a result of frequent river avulsion and sediment deposition.

For Harappa itself, the dynamics of the river Ravi may have played a significant role. Although Harappa appears to be upslope of the apex of the Ravi's alluvial fan, the river does appear to have migrated significantly, near Harappa and also upstream, within its relatively narrow valley. Harappa lies some 12 km south of the present Ravi river, but the modern town and ancient site are located on the southern bank of a

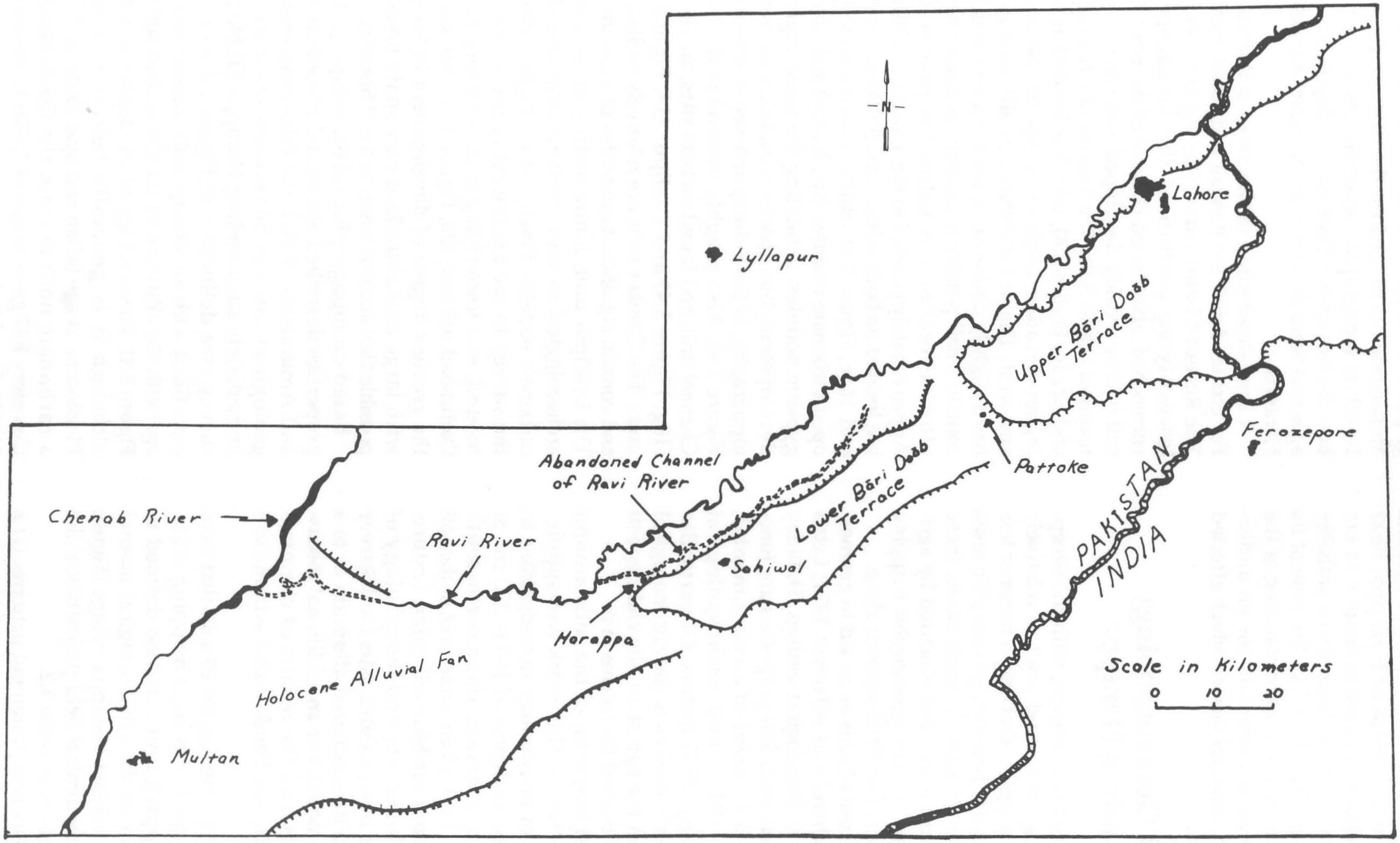

Figure 3.3: A reconnaissance geomorphological map of a section of the river Ravi. The relative age sequence of the alluvial deposits, from oldest to youngest is: Upper Bari Doab terrace, Lower Bari Doab terrace, and Holocene alluvial fan. Both the Upper and Lower Bari Doab terraces are believed to be Pleistocene in age.

conspicuous channel that often carries water during the summer monsoon floods. This channel bifurcates from the Ravi 83 km upstream of Harappa, near Pattoke, and rejoins the river approximately 14 km downstream from the site. This channel was probably once the main course of the Ravi, but the time of its abandonment is unknown. An understanding of the timing of these events is important for an understanding of the environmental factors which affected the people of Harappa.

Soils and Geomorphology Surrounding Harappa

The topography around Harappa, with the exception of the archaeological mound itself, is relatively subdued. Field work suggests that only a meter or less of relief commonly exists between geomorphic units of significantly different ages. In some cases, these topographic differences have been obscured by agricultural activity. Thus, detailed geomorphic mapping is difficult on the basis of surficial features alone.

In recent years, the use of soils as an aid in geomorphic mapping (Marchand and Allwardt 1981; Lettis 1985), particularly in archaeological settings (Holliday 1990), has greatly increased. Soil properties are functionally related to a handful of environmental, geological (Jenny 1941), and anthropological (Amundson and Jenny 1991) factors. Of particular interest in geomorphic studies is the chronological relationship between the age of an alluvial deposit and the properties of the soil that forms in it.

In 1988, a detailed mapping of the soils around Harappa was undertaken. This work was supplemented with results of preliminary investigations in 1987. Soils were cored to depths of 150 to 300 cm, at approximately 200 m intervals, along north–south transects (Figure 3.4). Each 15 cm increment of the soil core was characterized for Munsell color, texture, consistence, and abundance and morphology of calcite, gypsum, and more soluble salts (Soil Survey Staff 1981). Depth to unweathered alluvium or to a water table was also noted. For an additional discussion of the methods and the results of chemical analyses of the soils, see Pendall and Amundson (1990a).

Based on their field properties, the 65 soils that were examined were grouped into eight mapping units. One additional mapping unit was also defined to show the distribution of the archaeological mound and the presently-inhabited Harappa village (Figure 3.4). A summary of the typical field properties of the major soil types are given in Table 3.2.

The soil units display two prominent patterns: (1) a sinuous east-west band to the north of Harappa (abandoned channel of the river Ravi) and (2) a series of parallel, semi-circular bands surrounding the archaeological mound on the east, south, and west. Based on topographic relationships and soil properties, the soil units reflect alluvial deposits of differing ages that were deposited in meander channels around Harappa.

A brief description of the major soil units follows. For greater detail, see Pendall and Amundson (1990a). The Recent Channel unit (Rc, Figure 3.4) is on the lowest-lying portion of the landscape in the entrenched, abandoned channel of the river Ravi. The soil is very weakly developed and relatively coarse-textured (Table 3.2). The Subrecent Channel unit (Sc and Sc/16, Figure 3.4), which is located at a slightly higher elevation, circles Harappa on the east, south, and west. The soil is commonly silt loam in texture, has a slightly darkened A horizon, and was found to contain small pottery fragments in unweathered alluvium several meters below the present surface. Approximately parallel to the Subrecent Channel unit, but located on both sides, is the Sultanpur soil unit (16 and 16gc, Figure 3.4) which contains weakly-developed carbonate nodules (i.e., *kankar*) and occasionally gypsum nodules. Exhibiting the same degree of soil development, but greater variability in texture and topography, is the Sultanpur levee complex (17, 17S, Figure 3.4). Also roughly parallel to the Subrecent Channel unit, and found on both sites, are the Gamber (18g, Figure 3.4) and Lyallpur (19, Figure 3.4) soil units. The Gamber soils are relatively well-developed and contain significant quantities of gypsum nodules. The Lyallpur unit, found mainly to the west of the archaeological mound, contains large and abundant carbonate nodules. Finally, at the highest elevation in the survey to the northwest of the archaeological mound, and underlying it at Cemetery R37, is the Qadirabad soil unit (20, Figure 3.4). This soil exhibits the greatest degree of development in the vicinity, with large and abundant carbonate nodules and possible clay accumulation in the B horizon.

Based on topographic relationships and the soil properties described above and elsewhere (Pendall and Amundson 1990a), the following sequence of geologic events can be reconstructed for the area immediately surrounding Harappa (Table 3.3). The survey area delineated in Figure 3.4 was probably once filled with an alluvial unit contemporaneous in age with the alluvium of the Qadirabad soil unit (20, Figure 3.4). The exact age of the deposit is not known, although it is generally believed to be latest Pleistocene in age (Mian and Syal 1986). A ^{14}C date on a carbonate nodule from the Qadirabad soil in Cemetery R37 gave an age of 7,080±120 years BP (Beta 21520). Considering that it takes at least several thou-

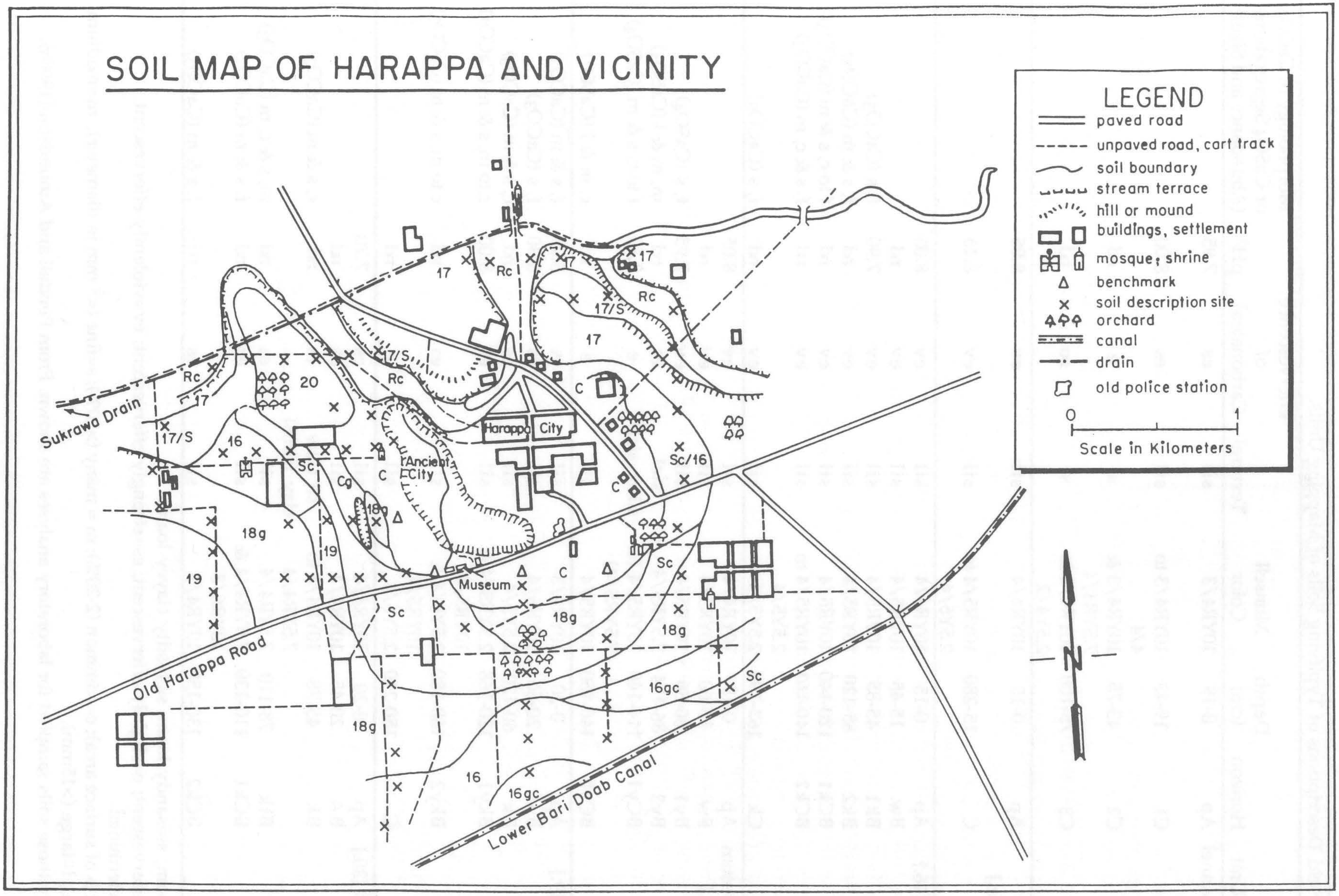

Figure 3.4: Soil map of the region immediately surrounding Harappa. Mapping units are discussed in the text. Abbreviations for mapping units are: C, Cg: Cultural material, Cultural material with gypsum; Rc: Recent channel; Sc, Sc/16: Subrecent channel, Subrecent channel overlying Sultanpur; 16, 16gc: Sultanpur, Sultanpur - gypsum plus calcite phase; 17, 17/S: Sultanpur Levee Remnant Complex, Sultanpur Levee Remnant Complex - shallow over sand; 18g: Gamber; 19: Lyllpur; 20: Qadirabad. From Pendall and Amundson (1990a).

Table 3.2: Field Descriptions of Typifying Soils of Mapping Units.

Mapping Unit	Horizon	Depth (cm)	Munsell Color	Texture[1]	Effervescence of Carbonates[2]	pH[3]	Morphology of $CaCO_3$ or $CaSO_4$ Segregations (Abundance and Size)[4]
Recent Channel [Rc.]	Ap	0-19	10YR4/3	sil	es	7.95	
	C1	19-43	10YR4/3 to 4/4	sil	es	8.00	
	C2	43-75	10YR4/3 & 7.5YR4/4	sl	e	nd	
	C3	75-100	10YR4/2 to 2.5Y4/2	sl	eo	nd	
Subrecent Channel [Sc.]	Ap	0-15	10YR4/4	sil	ev	8.05	
	C	15-280	10YR5/4 to 2.5Y5/4	sil	ev	8.15	
Sultanpur [16.]	Ap	0-15	10YR4/4	sil	ev	8.05	
	Bw	15-45	10YR5/4	sil	ev	nd	
	Bk1	45-85	10YR5/4	sil	ev	7.90	f, s ($CaCO_3$)
	Bk2	85-120	10YR5/4	sil	ev	nd	f, s & m ($CaCO_3$)
	BCk1	120-140	10YR5/4	sil	ev	nd	f to c, s & m ($CaCO_3$)
	BCk2	140-163	10YR5/4 to 2.5Y5/4	sil	ev	nd	f, s & c, m ($CaCO_3$)
	Ck	163-193	2.5Y5/4	sil	ev	nd	f, s ($CaCO_3$)
Gamber, gypsum phase [18g.]	Ap	0-15	10YR4/4	sil	ev	8.05	
	Bw	15-60	10YR5/4	sil	ev	nd	
	By1	60-86	10YR5/4	sil	ev	7.95	f, s ($CaSO_4$)
	By2	86-114	7.5YR5/4	sicl	es	nd	m, m & l ($CaSO_4$)
	BCy1	114-140	10YR5/4 (& 7.5YR5/4)	sil(& sicl)	e	8.10	f to c, s & m ($CaSO_4$)
	BCy2	140-150	10YR5/4	sil	e	nd	c, m & l ($CaSO_4$)
Lyallpur [19.]	Ap	0-20	10YR4/3	sil	es	8.35	f, s & m ($CaCO_3$)
	Bw	20-60	10YR6/4	sil	es	8.30	f, s ($CaCO_3$)
	Bk	60-120	2.5Y5/4	sil	es	nd	c, s & m ($CaCO_3$)
	Bky1	120-168	2.5YR5/4 & 10YR5/4	sil	es	8.00	c to m, s & m ($CaCO_3$)
	Bky2	168-180	2.5Y6/4 & 10YR5/4	sil	es	nd	c to m, s & m ($CaCO_3$)
	C	180-210	2.5Y6/4	sil	e	nd	
Qadurabad [20.]	Ap	0-20	10YR4/4	sil	es	7.70	
	BA	20-45	10YR4/4	sil	es	nd	
	Bk	45-78	10YR4/4 to 7.5YR4/4	sil (few clay films)	es	nd	c, s & m ($CaCO_3$)
	Btk	78-110	7.5YR4/4	sil	es	nd	m, s & c, m ($CaCO_3$)
	BCk1	110-130	7.5YR4/4 & 10YR6/3	sil	es	nd	f, s & m ($CaCO_3$)
	BCk2	130-150	10YR4/3	sil	es	nd	f, s & m ($CaCO_3$)

[1] sil=silt loam; sl=sandy loam; sicl=silty clayey loam.

[2] eo=non-effervescent; e=slightly effervescent; es=strongly effervescent; ev=violently effervescent.

[3] nd=not determined.

[4] f=few (<2% of surface area); c=common (2-20%); m = many (>20%); s=fine (<5 mm in diameter); m=medium (5-15 mm); l=large (>15mm).

Note: Only those soils sampled for laboratory analyses are shown. From Pendall and Amundson (1990a).

Table 3.3: The Relative and Estimated Absolute Ages of the Mapping Units.

		Differentiating Features			
Relative Landform Age[1]	Map Units	Carbonate Morphology[2] (Stage)	B Horizon (Type)	Observable Landscape Position	Estimated Age (Years BP)
1 (Youngest)	Recent Channel	None	None	Entrenched Distributary Channel	<30[3]
2	Subrecent Channel	None	None	Level Floodplain	<4500[4]
3	Sultanpur, $Sultanpur_{gc}$	I to Early II	Bk, Bw	Level Floodplain	<2000 – >5000[5]
4	Gamber, Lyallpur	II	Bk, Bw, By	Level Floodplain	>5000–15,000[5]
5 (Oldest)	Qadirabad	Late II to Early III	Bk, Bt	Stream Terrace Remnant	>7080±90[6]

1 Based on soil morphologic features and landscape position.
2 Based on classification by Gile et al. (1966) and Sehgal and Stoops (1972).
3 Last flood of Recent Channel (M. Saddiq, personal communication, 1988).
4 Approximate date of beginning of Harappan occupation (Kenoyer 1987).
5 Based on rates of pedogenic carbonate redistribution (Gile and Grossman 1979).
6 Radiocarbon date of carbonate on the inside of a nodule from Btk horizon (Pendall and Amundson 1990b).
Source: Pendall and Amundson (1990a).

sands of years to form a carbonate nodule, the ^{14}C age could easily suggest an early Holocene, or even latest Pleistocene, age for the deposit. The relationship of the deposit (now preserved in small portions under and around the mound) to the alluvium comprising the more extensive Lower Bari Doab terrace between Pattoke and Sahiwal is not known with certainty, but they could be the same. More fieldwork and elevation data are needed to work this relationship out.

During Holocene times, the river Ravi (presumably when it occupied the abandoned channel north of Harappa) meandered around Harappa, entrenching and subsequently partially backfilling its channel. At least three meander units of differing ages could be identified on the basis of topography and soil development. The exact timing of these events is not known with certainty. The presence of significant carbonate nodule development in the oldest meander unit suggests that it is at least several thousand years old, while the presence of pottery fragments in the alluvium of the youngest unit suggests it postdates Harappa itself (Table 3.3). It appears that subsequent downcutting by the Ravi (when it occupied the abandoned channel) ultimately bypassed the meander bends around Harappa, creating a more direct route along the north of present-day Harappa. Thus, the soil/geomorphology map (Figure 3.4) and the relative age estimates (Table 3.3) suggest that Harappa was initially built on a slightly elevated landscape in a meander bend of what may have been at least a seasonally active Ravi river channel. It is difficult to determine, without more fieldwork, if the main channel of the Ravi flowed by Harappa during Harappan times. It does appear, however, that the meander bends around Harappa were essentially abandoned at some time after the Harappan occupation.

It should be noted that the "abandoned" channel of the Ravi can still receive flood waters during the summer monsoon season and that even the relatively elevated landscape around Harappa can become inundated by these floods. Thus, by no means is Harappa entirely removed from the influence of the present-day river Ravi.

Stable Isotope Studies of Pre-Harappan Soil

As discussed in the previous section, at least a portion of Harappa was built on a latest Pleistocene or early Holocene alluvial deposit. Thus, the soil that formed in this deposit was at least several thousand years old prior to burial during human occupation and should have had sufficient time to chemically reflect pre-Harappan environmental conditions.

In recent years, a search for soil properties that can be quantitatively correlated with climatic parameters has been underway. One of the most promising avenues has been the work on the stable carbon

($^{13}C/^{12}C$) and oxygen ($^{18}O/^{16}O$) isotope ratios in soil carbonate. A brief review of this work, and its significance to our work at Harappa, is given below.

Isotope ratios in a sample are reported relative to those in an internationally-accepted standard in the notation:

$$\delta(‰) = 1000\left[(\text{R sample} + \text{R standard}) - 1\right]$$

where 'R sample' equals the isotope ratio in a sample and 'R standard' equals the isotope ratio in the standard. The standard for carbon is the Peedee belemnite (PDB) and for oxygen it is standard mean ocean water (SMOW).

Carbon isotope ratios (i.e., $\delta^{13}C$ values) in soil carbonate are determined by that of the soil CO_2 (Cerling 1984). Soil CO_2 is derived from two sources: (1) root respiration/decomposition of soil organic matter (biological) and (2) atmospheric CO_2 ($\delta^{13}C$ = –7‰). Isotopically, there are two main types of plants: (1) C_3 ($\delta^{13}C$ values ≈–27‰) and (2) C_4 ($\delta^{13}C$ values ≈–14‰) (Bender 1968; Smith and Epstein 1971). C_4 plants are mainly restricted to the tropical grasses while C_3 plants make up the remaining grasses and nearly all other plants.

If the $\delta^{13}C$ value of decomposing plant material is known, the $\delta^{13}C$ value of soil carbonate can be used to determine the proportion of CO_2 derived from biological or atmospheric sources. It has been found that the proportion is related to plant density and soil respiration rates (Amundson et al. 1989; Quade et al. 1989) and that atmospheric CO_2 only makes a significant contribution to soil CO_2 in arid regions (Cerling et al. 1989). Thus, soil carbonate can be used to distinguish between semi-arid and truly arid conditions if the $\delta^{13}C$ of biologically-produced CO_2 is known.

In regions where tropical grasses are present and the climate is at least semi-arid, plant cover is usually dense enough so that atmospheric CO_2 makes only a small contribution to total soil CO_2 (Cerling et al. 1989). Therefore, in sites where tropical grasslands or savannas are known to have existed, the $\delta^{13}C$ of soil carbonate can be used to reflect the relative proportion of C_3 to C_4 plants at the site. This is important to know in that the C_3:C_4 ratio is strongly dependent on climate, particularly temperature (Tieszen et al. 1979).

The $\delta^{18}O$ value of soil carbonate is determined by that of the soil water (Cerling 1984), which is ultimately derived from the precipitation. While factors controlling the $\delta^{18}O$ values of precipitation are very complex (Gat 1980), it has been observed that it is commonly correlated to regional temperature (Yurtsever 1975). Thus, the $\delta^{18}O$ values of soil carbonate can serve as a guide to the $\delta^{18}O$ value of past precipitation as long as possible evaporation effects are considered and the effect of soil temperature is taken into account (see Cerling 1984; Quade et al. 1989 for more detailed discussions).

During the 1987 excavations of Cemetery R37, several excellent exposures of the Qadirabad soil (Table 3.2) were made. In some locations, the profile was truncated and buried by several meters of archaeological material, while in at least one other location the upper horizons of the profile were found intact, buried by a few centimeters of archaeological material. Because the soil horizons could be traced easily throughout the cemetery, a complete profile was readily reconstructed.

Calcium carbonate nodules (i.e., *kankar*) were collected in a depth sequence from their uppermost appearance in the profile (120 cm beneath original land surface) to a depth of almost 400 cm (with the aid of a soil auger). From each soil horizon, or depth interval, samples of the bulk soil, the exterior of the nodule, and the interior of the nodule, were analyzed isotopically. In addition, sediments from the present Ravi floodplain were also analyzed (see Pendall and Amundson 1990b for more details).

The results of the carbon isotope analyses are illustrated in Figure 3.5. The carbonate nodules are formed from the dissolution of fine-grained carbonate in the alluvium and its subsequent precipitation in nodular forms. The data in Figure 3.5 illustrate that the $\delta^{13}C$ values of the nodules are distinct from fine-grained carbonate in the soil or from that of fresh river Ravi alluvium (–3.8‰). Recent work has shown that pedogenic carbonate does not inherit its $\delta^{13}C$ values from its parent material, but instead isotopically reflects the $\delta^{13}C$ values of the soil CO_2 (Amundson et al. 1989; Quade et al. 1989). Thus, the $\delta^{13}C$ values of nodules can be used to evaluate environmental conditions that existed when the soil formed. A ^{14}C age of the inner portion of a nodule of the soil yielded a ^{14}C age of 7,080±120 years BP (Beta 21520). We believe this to be a minimum age for the soil since it takes at least several thousand years to develop carbonate nodules of the size we encountered (Sehgal and Stoops 1972). Thus, the soil carbonate of the inner portions of the nodules probably reflects mainly early Holocene conditions, although a pre-Holocene age is also possible (Pendall and Amundson 1990b).

What climatic conditions do the $\delta^{13}C$ values of the carbonate reflect? Since Harappa is presently on the arid edge of the semi-arid belt (Singh et al. 1974), one question might be, were early Holocene conditions similar, or possibly more or less arid, than the present (i.e., does the carbonate contain significant percentages of atmospheric CO_2 due to a low plant density)? To evaluate this, we must know what the $\delta^{13}C$ of biologically produced CO_2 was at the time the nodules formed. We measured the $\delta^{13}C$ values of

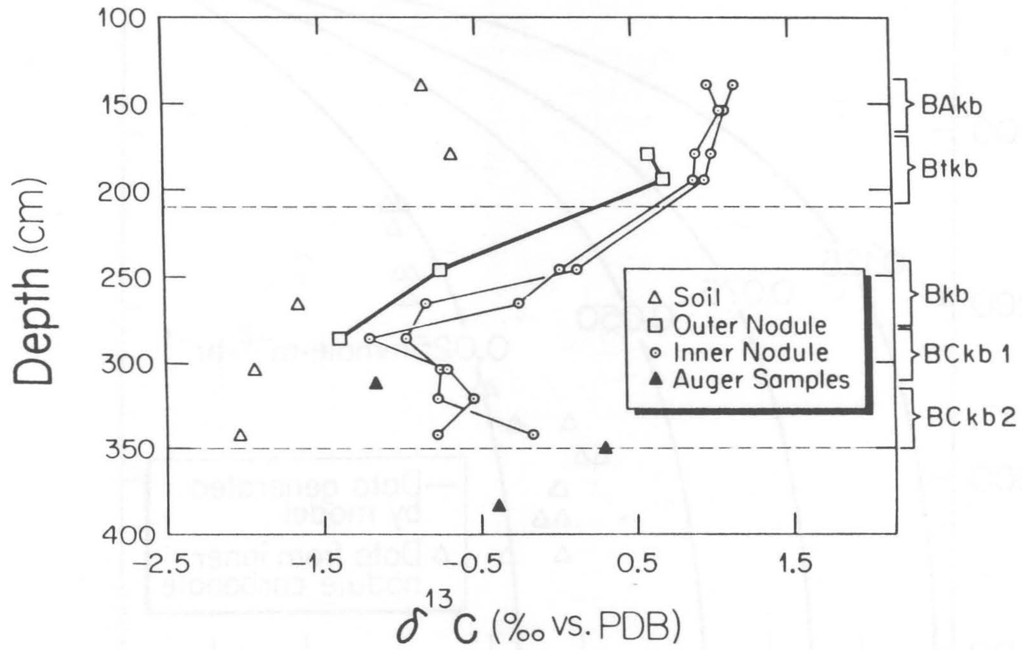

Figure 3.5: Carbon isotopic composition of carbonate in inner and outer nodule layers and disseminated in soil. BAkb and Btkb horizons sampled from profile SC3; Bkb, BCkbl, and BCkb2 horizons sampled from profile NC1. From Pendall and Amundson (1990b).

organic matter in the Ab horizons of the Qadirabad soil. The values ranged from –20 to –22‰, indicating approximately a 60% C_3 and 40% C_4 mix of plant sources. If this organic matter is representative of pre-Harappan vegetation, then the soil carbonates reflect an atmospheric CO_2 contribution of nearly 30% and a soil respiration rate representative of very arid and sparsely vegetated sites (Figure 3.6).

Soil organic is very dynamic, and the present $\delta^{13}C$ values may reflect vegetation altered by human activity and may not be representative of pre-Harappan conditions. Thus, an alternative explanation, as discussed above, can be made. If it is assumed that the site was always under at least semi-arid conditions and that it had a closed vegetative cover, the $\delta^{13}C$ values of the carbonate can be taken as representative of the C_3:C_4 plant ratio at the site. Soil carbonate $\delta^{13}C$ values are about –15‰ greater than the plants that produce CO_2 at a site (Cerling et al. 1989). Using this relationship, the $\delta^{13}C$ values of the carbonate illustrated in Figures 3.5 and 3.6 could be interpreted as having been formed in a nearly pure C_4 flora, such as a tropical grassland or savanna.

Unfortunately, with the available data, we can not distinguish between the two alternatives given above. The limiting factor in the analysis is an inadequate knowledge of the $\delta^{13}C$ of soil organic matter at the time the carbonate formed. The answer to this may lie in the nodules themselves in the form of occluded organic matter. Possible future work may be able to isolate this carbon and solve the dilemma.

The $\delta^{18}O$ values of the carbonate samples are illustrated in Figure 3.7. In contrast to the $\delta^{13}C$ values, there is virtually no difference between the isotopic composition of the fine-grained carbonate in the bulk soil and that of the nodules. The source of the carbonate in the alluvium is not known, but it may contain significant quantities that were formed in a pedogenic environment farther upstream on the Ravi.

The main interest here is whether the $\delta^{18}O$ values of innermost nodule samples reflect conditions significantly different than the present. To evaluate this, the $\delta^{18}O$ value of present-day precipitation must be known. Monitoring stations are few in South Asia. Available data suggest that the average isotopic composition of rainwater in New Delhi is –5.7‰ while that of Karachi is –4.1‰ (International Atomic Energy Agency 1960-1987). At 25°C, which is approximately the mean annual temperature of Harappa, carbonate forming from these waters should range between 22.8‰ and 24.4‰ (O'Neil et al. 1969). The $\delta^{18}O$ values of the inner nodules are slightly less than that predicted from the present rainfall for Karachi and New Delhi, assuming this temperature. We do not know if this represents a real difference or if it is due to our lack of isotopic data for regional rainfall. If real, the difference would suggest slightly cooler conditions than the present or greater rainfall out of

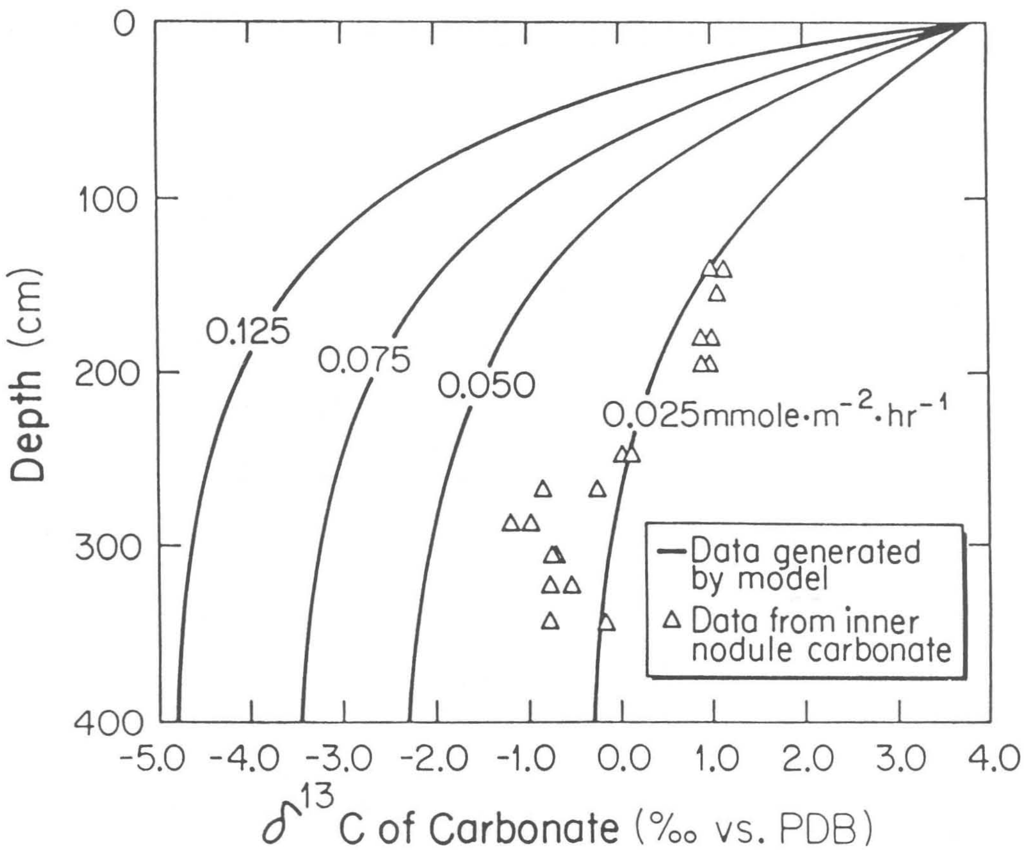

Figure 3.6: Carbon isotopic compositions of inner nodule carbonate in Qadirabad soil (triangles) compared with values calculated by the model of Quade *et al.* (1989). Variables: P = 1 atm, T = 25°C, n = 0.4, production $\delta^{13}C$ = –21.9‰, atmospheric $\delta^{13}C$ = –6.0‰, and various soil respiration rates. From Pendall and Amundson (1990b).

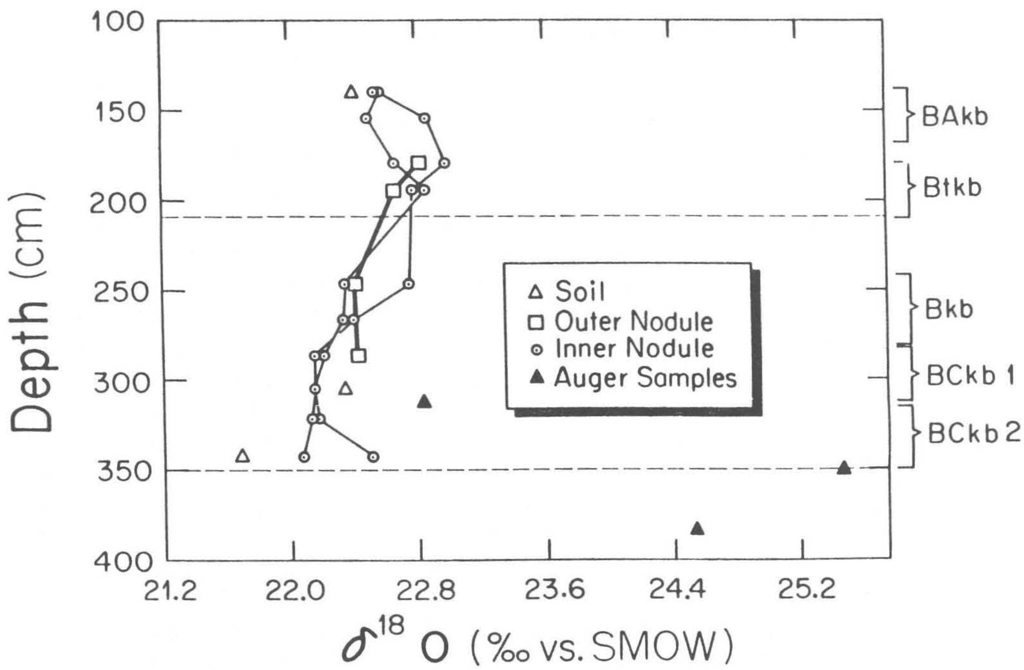

Figure 3.7: Oxygen isotopic composition of carbonate in inner and outer nodule layers and disseminated in soil. From Pendall and Amundson (1990b).

storm fronts that reached Harappa in the past. The latter would certainly seem reasonable based on estimates of early Holocene monsoon intensity for South Asia (COHMAP Members 1988). Alternatively, the carbonates may have formed at a higher temperature than 25°C (for example, during the warm, summer monsoon season). Assuming a soil temperature of 30°C, carbonate forming from present rainwater would range between 21.7 and 23.3‰, which agrees well with the measured values in Figure 3.7. We strongly emphasize that a better understanding of the isotopic composition of present rainfall at Harappa is needed before this issue can be resolved.

Summary

The purpose of this paper was to consolidate previous climatic and geologic research pertinent to Harappa in a manner that would provide a framework for our recent pedological studies, as well as provide a better means of understanding the environmental context of Harappa. We think that it would be fair to conclude that a very intriguing, but sketchy, picture of the environmental and geological history of Harappa emerges from this exercise. The other point that emerges is that an array of important problems and topics remains to be studied and understood. It should be apparent to interested earth scientists that a wealth of exciting research problems are available for years to come if the environmental context of Harappa, and the Indus civilization, is to be understood.

Acknowledgements

The authors thank Ms. Joan Van Horn for preparing the manuscript. The research was supported, in part, by a grant from the University of California Committee on Research and from California Agricultural Experiment Station Hatch funds. Laurie Newman and Joe Jersak reviewed an earlier version of the manuscript.

References Cited

Abu Bakr, M., and R.O. Jackson
1964 *Geological Map of Pakistan*, Scale 1:2,000,000. Government of Pakistan and United States Agency for International Development.

Agrawal, D.P., S. Kusumgar, and R.P. Sarnan
1964 Radiocarbon Dates of Archaeological Samples. *Current Science* 33:226.

Amundson, R.G. and H. Jenny
1991 The Place of Humans in the State Factor Theory of Ecosystems and Their Soils. *Soil Science* 151:99-109.

Amundson, R.G., O.A. Chadwick, J.M. Sowers, and H.E. Doner
1989 The Stable Isotope Chemistry of Pedogenic Carbonates at Kyle Canyon, Nevada. *Soil Science Society of America Journal* 53:201-210.

Bender, M.M.
1968 Mass Spectrometric Studies of Carbon 13 Variations in Corn and Other Grasses. *Radiocarbon* 10:468-472.

Bryson, R.A. and A.M. Swain
1981 Holocene Variations of Monsoon Rainfall in Rajasthan. *Quaternary Research* 16:135-145.

Butzer, K.W.
1982 *Archaeology as Human Ecology*. Cambridge University Press, New York.

Cerling, T.E.
1984 The Stable Isotopic Composition of Soil Carbonate and Its Relationship to Climate. *Earth and Planetary Science Letters* 71:229-240.

Cerling, T.E., J. Quade, and J.R. Bowman
1989 Carbon Isotopes in Soils and Palaeosols as Ecology and Palaeoecology Indicators. *Nature* 341:138-139.

COHMAP Members
1988 Climatic Changes of the Last 18,000 Years: Observations and Model Simulations. *Science* 241:1043-1052.

Cole, C.V. and S.V. Chitale
1966 Inland Delta Building Activity of the Kosi River. *Journal of the Hydraulics Division of the American Society of Civil Engineers* HY2:111-126.

Couchman, H.J.
1936 *Topographic Maps of India, 1:126,720*. Map and Record Issue Office, 13 Wood Street, Calcutta.
Gat, J.R.
1980 The Isotopes of Hydrogen and Oxygen in Precipitation. In *Handbook of Environmental Isotope Geochemistry, 1. The Terrestrial Environment*, edited by P. Fritz and J.C. Fortes, pp. 21-47. Elsevier, Amsterdam.
Gile, L.H., F.F. Peterson, and R.B. Grossman
1966 Morphological and Genetic Sequences of Carbonate Accumulations in Desert Soils. *Soil Science* 101:347-361.
Gile, L.H. and R.B. Grossman
1979 *The Desert Project Soil Monograph*. U.S. Department of Agriculture, Soil Conservation Service, Washington, DC.
Greenman, D.W., W.V. Swarzenski, and G.D. Bennett
1967 Ground-Water Hydrology of the Punjab, West Pakistan with Emphasis on Problems Caused by Canal Irrigation. *Geological Survey Water-Supply Paper 1608-H. Contributions to the Hydrology of Asia and Oceania*. U.S. Government Printing Office, Washington, DC.
Holliday, V.T.
1990 Pedology in Archaeology. In *Archaeological Geology of North America*, edited by N.P. Lance and J. Donahue, pp. 525-540. Geological Society of America Centennial Special Volume 4. Boulder, Colorado.
International Atomic Energy Agency
1960-1987 *Stable Isotope and Precipitation Series*. Active Tape.
Jenny, H.
1941 *Factors of Soil Formation*. McGraw-Hill Book Co., New York.
Kenoyer, J.M.
1987 The Indus Civilization: Unfathomed Depths of South Asian Culture. *Wisconsin Academy Review* 33(2):22-26.
Lambrick, H.T.
1967 The Indus Flood-Plain and the 'Indus' Civilization. *The Geographical Journal* 133:483-495.
Lettis, W.R.
1985 Late Cenozoic Stratigraphy and Structure of the West Margin of the Central San Joaquin Valley, California. In *Soils and Quaternary Geology of the Southwestern United States*, edited by O.C. Weide, pp. 97-119. Geological Society of America Special Paper 203.
Mahr, B.S.
1986 *Geomorphology of the Ravi River*. Inter-India Publications, New Delhi.
Marchand, D.E. and A. Allwardt
1981 *Late Cenozoic Stratigraphic Units, Northeastern San Joaquin Valley, California*. U.S. Geological Survey Bulletin 1470. U.S. Government Printing Office, Washington, DC.
Meadow, R.H.
1989 Continuity and Change in the Agriculture of the Greater Indus Valley: the Palaeoethnobotanical and Zooarchaeological Evidence. In *Old Problems and New Perspectives in the Archaeology of South Asia*, edited by J.M. Kenoyer, pp. 61-74. Wisconsin Archaeological Reports 2, Madison, WI.
Mian, M. Alim, and M. Narvaz Syal
1986 Geomorphology of Pakistan. In *Proceedings of XII International Forum on Soil Taxonomy and Agrotechnology Transfer, Pakistan*, edited by Mushtag Ahmad, Muhammad Akram, M. Shabbin Baig, M. Yasin Javed, and Riaz-ul-Amin, pp. 26-42. Director General, Soil Survey of Pakistan, Multan Road, Lahore-18.
Misra, V.N.
1984 Climate, a Factor in the Rise and Fall of the Indus Civilization: Evidence from Rajasthan and Beyond. In *Frontiers of the Indus Civilization*, edited by B.B. Lal and S.P. Gupta, pp. 461-490. Books and Books, New Delhi.
Oldham, C.F.
1874 Notes on the Lost River of the Indian Desert. *Calcutta Review* LIX:1-29.

Oldham, R.D.
1887 On Probable Changes in the Geography of the Punjab and Its Rivers. *Asiatic Society of Bengal Journal* 55:322-343.
O'Neil, J.R., R.N. Clayton, and T.K. Mayeda
1969 Oxygen Isotope Fractionation in Divalent Metal Carbonates. *Journal of Chemical Physics* 51:5547-5558.
Pakistan Meteorological Department
1986 Climate and Seasons of Pakistan. In *Proceedings of XII International Forum on Soil Taxonomy and Agrotechnology Transfer, Pakistan*, edited by Mushtag Ahmad, Muhammad Akram, M. Shabbin Baig, M. Yasin Javed, and Riaz-ul-Amin, pp. 43-46. Director General, Soil Survey of Pakistan, Multan Road, Lahore-18.
Pendall, E. and R. Amundson
1990a Soil/Landform Relationships Surrounding the Harappa Archaeological Site, Pakistan. *Geoarchaeology* 5:301-322.
1990b The Stable Isotope Chemistry of Pedogenic Carbonate in an Alluvial Soil from the Punjab, Pakistan. *Soil Science* 149:199-211.
Quade, J., T.E. Cerling, and J.R. Bowman
1989 Systematic Variations in the Carbon and Oxygen Isotope Composition of Pedogenic Carbonate Along Elevation Transects in the Southern Great Basin, USA. *Geological Society of America Bulletin* 101:464-475.
Raverty, H.G.
1892 The Mihrn of Sind and Its Tributaries: A Geographical and Historical Study. *Asiatic Society of Bengal Journal*. LXI:155-297.
Schumm, S.A.
1977 *The Fluvial System*. John Wiley and Sons, New York.
Sehgal, J.H. and G. Stoops
1972 Pedogenic Calcite Accumulation in Arid and Semi-arid Regions of the Indo-Gangetic Alluvial Plains of Erstwhile Punjab (India). *Geoderma* 8:59-72.
Singh, G.
1971 The Indus Valley Culture Seen in the Context of Post-Glacial Climatic and Ecological Studies in North-West India. *Archaeology and Physical Anthropology in Oceania* 6:177-191.
Singh, G., R.D. Joshi, S.K. Chopra, and A.B. Singh
1974 Late Quaternary History of Vegetation and Climate of the Rajasthan Desert, India. *Philosophical Transactions of the Royal Society of London* B267:467-501.
Smith, B.N. and S. Epstein
1971 Two Categories of $^{13}C/^{12}C$ Ratios for Higher Plants. *Plant Physiology* 47:380-384.
Soil Survey Staff
1981 Examination and Description of Soils in the Field. *USDA-SCS Soil Survey Manual (in revision)*. Issue 1, Directive 430-V-SSM, May 1981. U.S. Government Printing Office, Washington, DC.
Tieszen, L.L., M.M. Senyimba, S.K. Imbamba, and J.H. Troughton
1979 The Distribution of C_3 and C_4 Grass Species Along An Altitudinal and Moisture Gradient in Kenya. *Oecologia* 37:337-350.
U.S. Army Corps of Engineers
1955 *Maps of India and Pakistan*, 1:250,000. U.S. Army Map Service, Washington, DC.
Whitehead, R.B.
1932 The River Courses of the Punjab and Sind. *Indian Antiquary* LXI:163-169.
Wilhelmy, H.
1969 Das Urstromtal am Ostrand der Indusbene und das Sarasvati-Problem: *Zeitschrift für Geomorphologie, Supplementband* 8:76-93.
Wood, W.H.A.
1924 Rivers in the Indus-Ganges Alluvial Plain. *The Scottish Geographical Magazine* XL:1-16.
Yurtsever, Y.
1975 *Worldwide Survey of Stable Isotopes in Precipitation*. Rep. Sect. Isotope Hydrology, International Atomic Energy Agency. Vienna.