CHAPTER 11

LIMESTONE ACQUISITION NETWORKS

CHAPTER INTRODUCTION: LIMESTONE

Limestone – a massive rock predominately composed of calcium carbonate – was, on the whole, used to create objects larger than are typically found at Harappa. Some of those objects are "ringstones" and other big pieces of carved rock that probably had some architectural and/or ritual-symbolic purpose. Large pieces of limestone were also evidently acquired for utilitarian purposes, such as the blocks probably used as sewer drain covers. Like grindingstone (Chapter 5), the heavy and unwieldy nature of comparatively large stone artifacts such as these makes examining them especially useful for detecting subtle and sometimes not so subtle, changes in the ability and/or desire of ancient peoples to acquire difficult-to-transport heavy stone resources. In addition, the likelihood that some of these large objects were important ritual or prestige-related items provides another dimension with which to examine the ways in which social power was expressed through the consumption and display of stone.

Using ICP-AES supplemented by ICP-MS and INAA, I compare 107 limestone artifacts from Harappa (roughly half of the site's assemblage for this material variety) to 160 geologic samples collected from multiple locations in six limestone-bearing geologic formations in Pakistan and India. It is revealed that, mainly during Period 3C, Harappans acquired large limestone objects from multiple sources, some as far away at Kutch in Gujarat. This chapter commences with a discussion of the kinds limestone artifacts found at Harappa and other Indus cities. I then provide details on the material properties and possible geologic sources of the five different limestone types most commonly used to make large objects at Harappa. The primary method that was used to characterize artifacts and geologic source material is new and somewhat experimental (Law and Burton 2006b). I therefore present the provenience results in the same exploratory, step-by-step manner in which the data were obtained and evaluated. The implications that the provenience determinations made here have on our understanding of long-distance trade, inter-regional interaction and changing expressions of prestige and power at Harappa is discussed in the summary section that concludes this chapter. Regions, sites and sources mentioned in this chapter are identified in Figures 11.1, 11.14 and 11.16.

LARGE LIMESTONE OBJECTS AT HARAPPA AND OTHER INDUS CITIES

Around 95% of the objects in Harappa's rock and mineral artifact assemblage are small in size and light in weight. Grindingstones composed of sandstone-quartzite or igneous and metamorphic rocks make up most of the five percent or so of objects that weigh more than one kilogram. After grindingstones, nearly all remaining artifacts in the bulk size/weight category are composed of limestone.

Small ring-shaped objects (whorls, mace-heads, etc.) made from various kinds of stone are not uncommon at prehistoric sites in northwestern South Asia. Large-sized "ringstones" (some weighing over 100 kg) made of limestone, however, are a category of artifact that seems to be exclusive to Indus

Figure 11.1 Sites and regions discussed in this chapter.

Civilization cities (Dales 1984). The styles in which they were carved and types of limestone from which they were made from seem to differ somewhat from site to site. The "typical" ringstone at Harappa has an undulating (or wavy) top and base with a large central hole and is most often composed of a light yellow micritic (microcrystalline) limestone (Figure 11.2 A and B). Ringstones found at Mohenjo-daro are

Figure 11.2 **[A]** Large wavy ringstones at Harappa in front of the tomb of Baba Noor Shah (Naugaza). **[B]** Three ringstones excavated in 2010 west of Baba Noor Shah's tomb. **[C]** Flat-topped micritic limestone ringstones from Mohenjo-daro. **[D]** Ringstones from Dholavira on display in the National Museum, New Delhi.

Figure 11.3 Mould terracotta tablets from **[A]** Mohenjo-Daro and **[B]** Lakhan-Jo-Daro that appear to depict composite columns with flat-topped ringstones.

Figure 11.4 Two large conical objects from Harappa composed of white porcelaneous limestone. Harappa Museum Reserve Collection. Note - 10 cm increments on the scale.

Figure 11.5 Left - Drain at Mohenjo-Daro covered with limestone blocks. Right - Three large rectangular limestone blocks from Harappa. Harappa Museum Reserve Collection. Note - 10 cm increments on the scale.

usually made of a cream-colored micritic limestone and have a flat top and base with a large central hole (Figure 11.2 C). Examples from Dholavira are made from a sandy-textured yellow and reddish-brown banded limestone, have flat tops and bases with small central holes and can have either concave or convex midsections (Figure 11.2 D).

The function of these large ringstones has been disputed. They have been variously interpreted as Shivite "yoni" stones (Marshall 1931d: 58-60), astronomical "calendar stones" (Maula 1984) and ceremonial stones associated with cultic tree-worship (During-Caspers and Nieskens 1992: 94). However, it now seems as if Mackay's suggestion (1938: 597) – that the ringstones found at Mohenjo-daro were elements of composite columns made of stone and wood – is the correct one. In the southern gateway of the citadel at Dholavira, complete ringstones have been found in positions that strongly suggest they were the bases of pillars (Bisht 1989b). Recently, Vidale has pointed out (2010) several examples of moulded terracotta tablets from Mohenjo-Daro that depict column-like objects made up in part of stacked elements that, for all appearances, are identical to the flat-topped ringstones found at that city (Figure 11.3 A is an example taken from Shah and Parpola 1991). In early 2010, another moulded terracotta tablet was recovered during the excavations at large Indus site of Lakhanjo-Daro. That artifact (which is reproduced in Figure 11.3 B with the kind permission of Dr. Qasid Mallah, Chairman, Department of Archaeology, Shah Abdul Latif University, Khairpur) depicts a composite column made up of what appears to be the trunk of a palm tree (note the wavy concentric pattern) topped off with two flat-top ringstones and a capital with prominent volutes. After seeing the Lakhanjo-Daro tablet, Dr. Mark Kenoyer suggested (*personal communication* 2010) that the wavy ringstones of

Figure 11.6 Unusually shaped red, gray and yellow limestone artifacts from Sahni's excavations (Trench "B") on the north side of Mound AB. Harappa Museum Reserve Collection.

Harappa might have been stacked upon one another in order to mimic the pattern of a palm trunk.

Large conical objects that are frequently composed of limestone have been also found at Harappa, Mohenjo-daro and Dholavira. Such artifacts are usually interpreted as "phallic emblems" or *lingams* (Marshall 1931d: 58-61) although some may have actually been grindingstones (Mackay

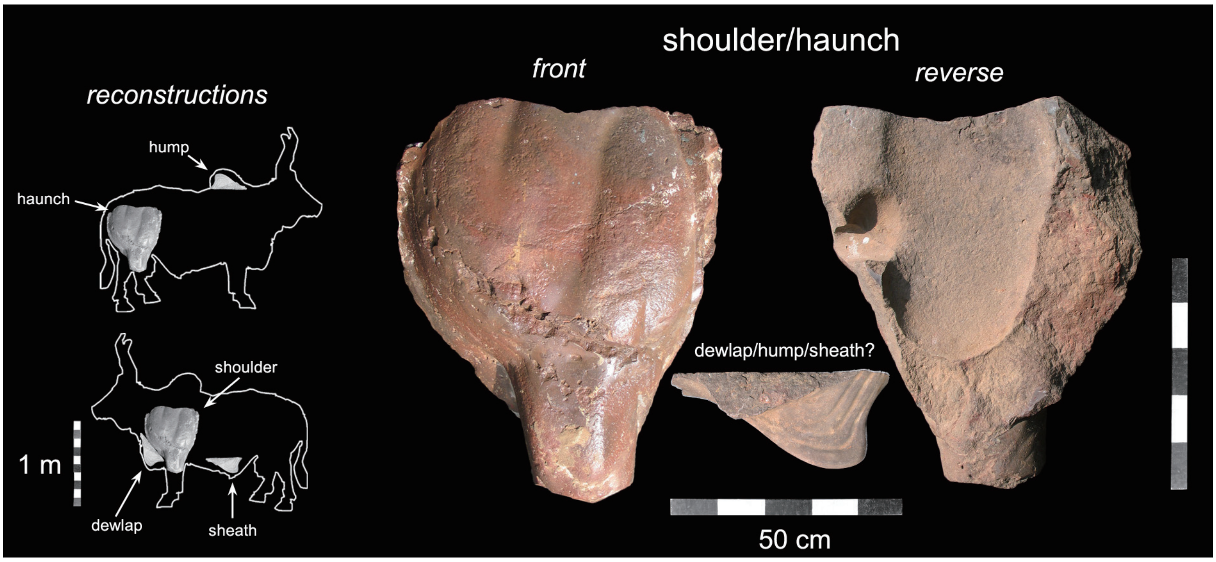

Figure 11.7 Fragments belonging to composite sculpture of a bovid (bull?) from Sahni's excavations on the northeast corner of Mound AB.

1938: 407) or even doorstoppers (R.S. Bisht *personal communication* 2007). Two examples composed of a white, porcelaneous limestone are stored in the Harappa Museum's Reserve Collections (Figure 11.4) and may be the ones mentioned by M.S. Vats in a footnote (1940: 51) as having been recovered in excavations trenches in the central to southern part of Mound AB.

A number of fragmentary as well as several complete large rectangular limestone blocks (Figure 11.5 *right*) from past excavations are stored in Harappa Museum's Reserve Collection. It is possible that these objects were drain covers similar to the ones used at Mohenjo-daro (Figure 11.5 *left*).

A series of red, gray and yellow limestones objects (a selection of which can be seen in Figure 11.6) that may be architectural elements have been recovered on the northeast part of Mound AB. During the excavations of the 1920s, these artifacts were discovered (along with cones and ringstones) by R.B.D.R. Sahni in Trench "B" in levels that would probably be equivalent to Period 3C because of their association with pointed-base goblets (Vats 1940: 139). Many of the objects are fragmentary blocks that are carved with decorative, concentric grooves on one side. On the reverse sides of some pieces there are holes or sockets that may indicate they were meant to be inserted or affixed onto something as if part a molding or composite stone facade. More examples of these unusually shaped fragments were recovered in Period 3C levels in the same general area (Trench 39) during the 1998 season of the HARP (Meadow *et al* 1998: 6). As far as I can tell this particular kind of stone object is unique to Harappa, to this area of the site and to this period. Their presence suggests that a structure or structures heavily adorned with stone may have existed in this part of the city.

In January of 2004, Prof. Mark Kenoyer and I had the opportunity examine the aforementioned large stone artifacts from Sahni's excavations on the northeast corner of Mound AB, which are stored in the Harappa Museum's Reserve Collection. Among them is an object (Figure 11.7) that is recorded as a "block of gray sandstone roughly resembling a (?) tortoise-shell" (Vats 1940: 139, Plate CVXII 8). After closer examination it appears that it is actually a fragment from a life-sized composite statue/frieze of a large bovid, most likely a bull. It is difficult to tell with certainty whether or not the piece represents the front shoulder portion of the animal or its haunch (I have shown the two possible reconstructions on the left hand side of Figure 11.7) but the shaft of a leg descending from the muscled body is clearly evident. During this same field season, a workman at the site brought to Prof. Kenoyer's attention a sculpture fragment that he had found in the modern cemetery at the base of Mound AB, directly below where Sahni's excavations had been. This fragment, which was made of the same type of reddish gray-colored stone that I call "gray sandy limestone" (discussed below), may represent a bull's dewlap, a hump or sheath (see possible reconstructions on Figure 11.7). Also, in the 1940 report but not in the Reserve Collection is another object from Sahni's excavations on the northeast corner of Mound AB, which is described as a "hoof" (Vats 1940: 141, Plate LXXXIII 36). At around 17 cm in length, this "hoof" (if that's what it is) would be roughly proportionate with the other two pieces. Of course, it cannot be certain that these fragments are all part of the same sculpture/frieze. No information on the context of the dewlap/hump is available and, although they were found in the same general area, the "hoof" and the shoulder/haunch were recovered in different "stratum" (note that the "stratum" and "depth" recording system used during the 1920s excavations makes it difficult to accurately judge the chronological relationships). Although the position of Sahni's excavation trench suggests that they could come from late Period 3C levels, it is Prof. Kenoyer's opinion (Kenoyer *in press* a) that the pieces date to the Mauryan Period (ca. 4th to 2nd century BC) or slightly earlier. Regardless of their age, the shoulder/haunch piece alone, at 126 kg, is the second heaviest stone objects (made of limestone or otherwise) ever found at Harappa. Only one ringstone from the site is heavier.

In the following section, I examine the major types of limestones used to make the various large objects discussed above as well as the potential sources for those types.

TYPES OF LIMESTONE USED AT HARAPPA AND THEIR POTENTIAL SOURCES

Limestone is a highly variable rock both compositionally and visually. It is, in addition, widely available in most of the geologic formations surrounding the Indus Basin. For these reasons it may seem that identifying the sources from which Harappans obtained this material variety would be highly problematic, if not impossible. However, as in the case of grindingstones (Chapter 5), a close examination of limestone artifacts indicates that several distinctive material *types* exist within the overall assemblage. Macroscopically some of these types seem to correspond with stone found in a limited number of geologic formations around the Greater Indus region. Although it may not be possible without extensive sampling and analysis to discover the precise location (as in a specific quarry) that one of these distinctive limestones types came from, geochemical characterization can enable us to state, with a reasonable degree of confidence, which of two or more geologic formations an artifact more than likely was derived from.

In this section I discuss the major types and potential sources of the limestones used to make large objects at Harappa. Approximately 200 limestone artifacts have been tabulated since excavation by the HARP recommenced in 1986 and many more from past excavations are stored in the Harappa Museum's Reserve Collection. The types that are discussed in this section were defined based on macroscopic properties of the artifacts alone. Details regarding the texture and color (as determined using a Munsell Rock Color Chart) of all of the archaeological samples analyzed in this study are provided in Appendix 11.1. For that appendix, the macroscopic type names were shortened and noted in uppercase letters - BANDED, GOLDEN, GRAY, MICRITIC and WHITE.

Sandy limestones

The material for a great many of the artifacts that I examine in this chapter was recorded, not incorrectly, as "sandstone." As noted in Chapter 4, limestones are sedimentary rocks that are highly variable compositionally. The geological convention is to call a rock limestone if it is composed of 50% or more calcium carbonate (Rapp 2002: 250). Some types have so much silica that they are essentially a mixture of sandstone and limestone (Lambert 1997: 24). Although no whole rock analyses have been conducted to determine the exact proportions of the major mineral constituents of any of the geological or archaeological samples examined this chapter, I can say that the materials comprising the datasets are quite variable. Within both Harappa's "limestone" artifact assemblage and the various individual geologic formations that I visited and sampled for this portion of the current study, there are a full range of materials that could be called sandstones, "calcareous" sandstones (containing a high amount of calcium carbonate), "siliceous" limestones (containing a high amount of silica) or just plain limestones. For the sake of simplicity, I refer to all of those with moderate to high silica contents as "sandy limestones."

Banded yellow-brown and yellow-brown sandy limestone (BANDED)

In January of 2004, two large ringstones stored in the reserve collection of the Harappa Museum were briefly removed for conservation purposes (Figure 11.8). The smaller of the two ringstones may be the one that the excavator M.S. Vats described as coming from the center of the old Harappa Police Station on Mound ET (1940: 140 & Plate CXVII, 3). Although we do not currently know where on the site the larger one was found, they are both clearly of Harappan design – albeit apparently not a local one. Vats noted (ibid.) that the ringstone found at the old Police Station lacked the wavy undulations typical of those found at Harappa but was similar in style to the flat-topped ones found at Mohenjo-daro (Sahni 1931a: 191). While cleaning these artifacts it was possible to closely examine the material from which they were made, which was a sandy textured limestone that had yellowish orange with pale brown to red-brown banding or patches. At Mohenjo-daro, a ringstone is on display (Figure 11.9) that is identical in style and material as the two banded ones from Harappa. It is possible that these unusual flat-topped ringstones were created at that city and then brought to Harappa. However, in addition to the ringstones, fragments and smaller artifacts made of the same "banded yellow-brown" sandy limestone have been recovered (Figure 11.10). If the fragments represent manufacturing debris (they may actually just be broken pieces of larger artifacts) then it could mean that this type of limestone was brought to the site in large unmodified blocks.

Bright yellow-red sandy limestone (GOLDEN)

Another type of limestone at Harappa with a sandy texture has a distinctive bright yellow, at times "golden" color and is frequently mottled with red or pink patches. Harappans created objects of all descriptions from this stone including wavy ringstones (the largest piece and several of the fragments in Figure 11.11 are clearly from ringstones) and architectural elements (the first left and center objects in Figure 11.6). When past and present excavators at Mohenjo-daro and Harappa encountered artifacts made from this material they often used the term "Jaisalmer" stone (see below) to describe them (Marshall 1931c: 31; Vats 1940: 140, 358; Meadow *et al* 1998: 6).

Gray-red sandy limestone (GRAY)

The final major type of sandy limestone used at Harappa is gray to grayish-red in color and can occasionally have an almost crystalline texture. This type was used to make architectural elements (see the examples on Figure 11.6, bottom and center right), the

Figure 11.8 Large banded flat-topped ringstones (HLS-007 and HLS-008) from Harappa.

Figure 11.9 Flat-topped banded limestone ringstone from Mohenjo-daro.

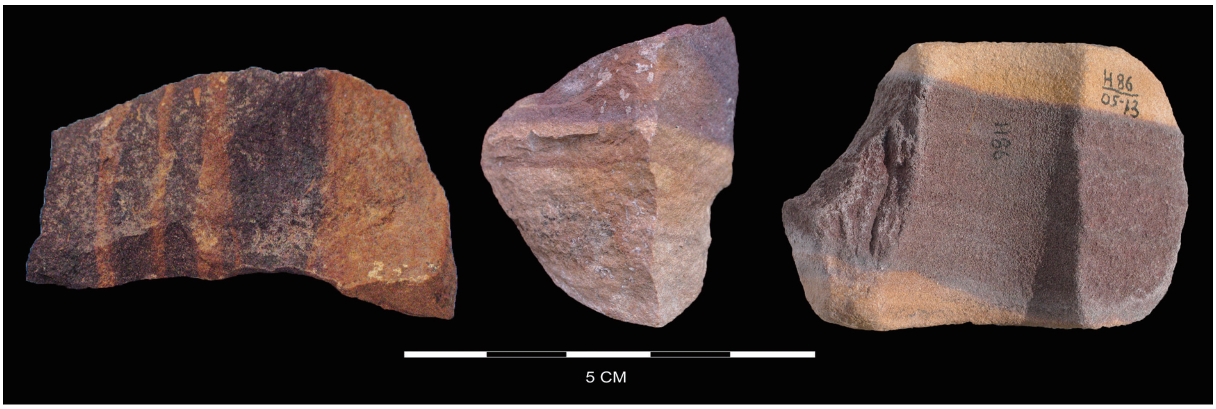

Figure 11.10 Fragments and broken miniature ringstone (far right) composed of banded yellow-brown and yellow-brown sandy limestone.

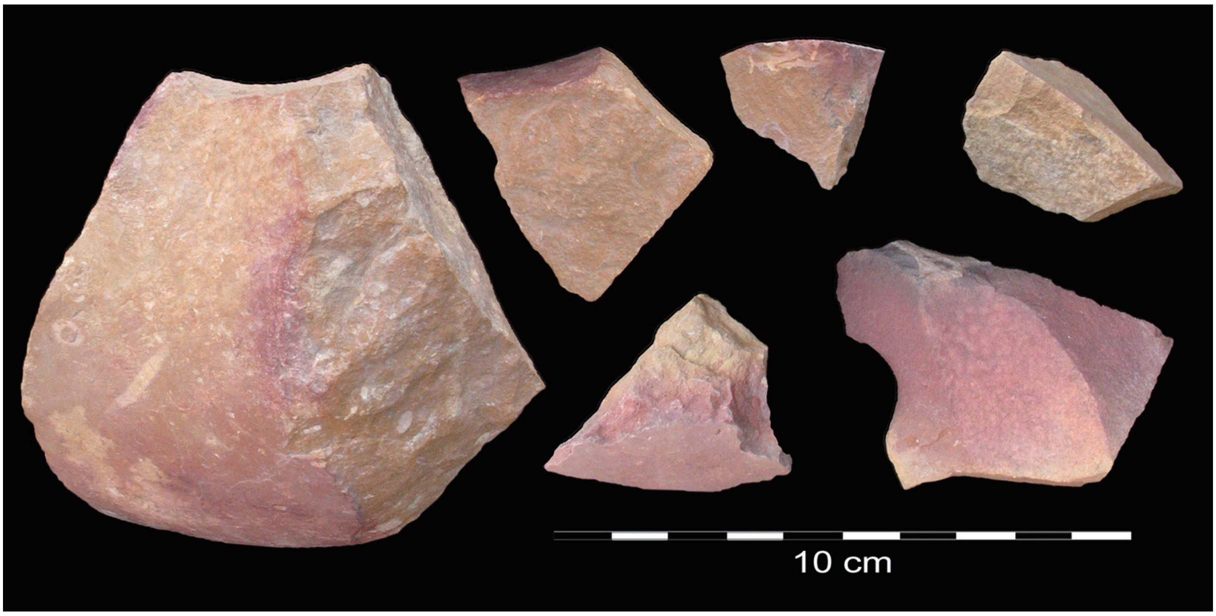

Figure 11.11 Ringstone pieces and miscellaneous fragments composed of bright yellow-red sandy limestone.

Figure 11.12 Ringstone pieces and miscellaneous fragments composed of sandy gray limestone.

bull sculpture pieces (Figure 11.7) and wavy ringstones (Figure 11.12). Of the three sandy limestones this one appears to have the highest silica content. Some examples of this material, which probably more appropriately described as "calcareous" sandstone, are moderately fossiliferous and.

Three possible source formations for the sandy limestones used at Harappa

A review of the geologic literature indicates that there are few formations surrounding the Indus Basin where sandy limestone with these precise textural and visual characteristics can be found, either separately or together. Although extensive bodies of limestone exist in the Himalayas, the Salt Range and regions west of the basin, the material found in those tends largely to be fine grained, micritic or porcelaneous in texture. There are three regions on the margins of the lower Indus Basin, however, where visually varied deposits of sandy textured limestones (or calcareous sandstones) are known to occur.

The closet of the regions is an area of low

Figure 11.13 The "Golden" city of Jaiselmer and details of its limestone architecture.

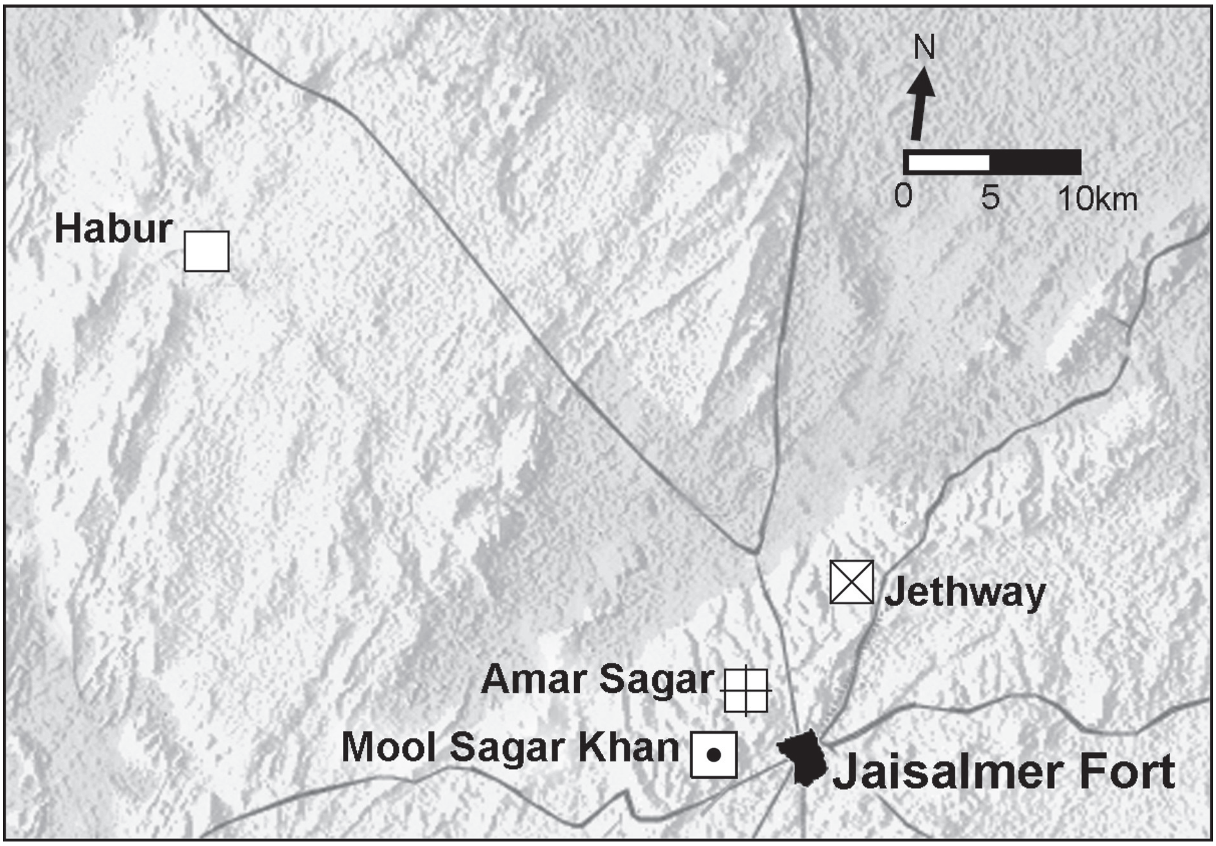

Figure 11.14 Limestone outcrops in the vicinity of Jaisalmer Fort, western Rajasthan that were sampled for this study.

broad plateaus that rise out of the desert sands of western Rajasthan, India. The limestone deposits of Jurassic age that occur in this region have long been exploited as a source decorative building stone (Agrawal *et al.* 1999: 22-24). Here, 450 km south-southwest of Harappa, sits the city of Jaisalmer, famous for its golden-hued architecture (Figure 11.13). Four locations in the region were sampled for

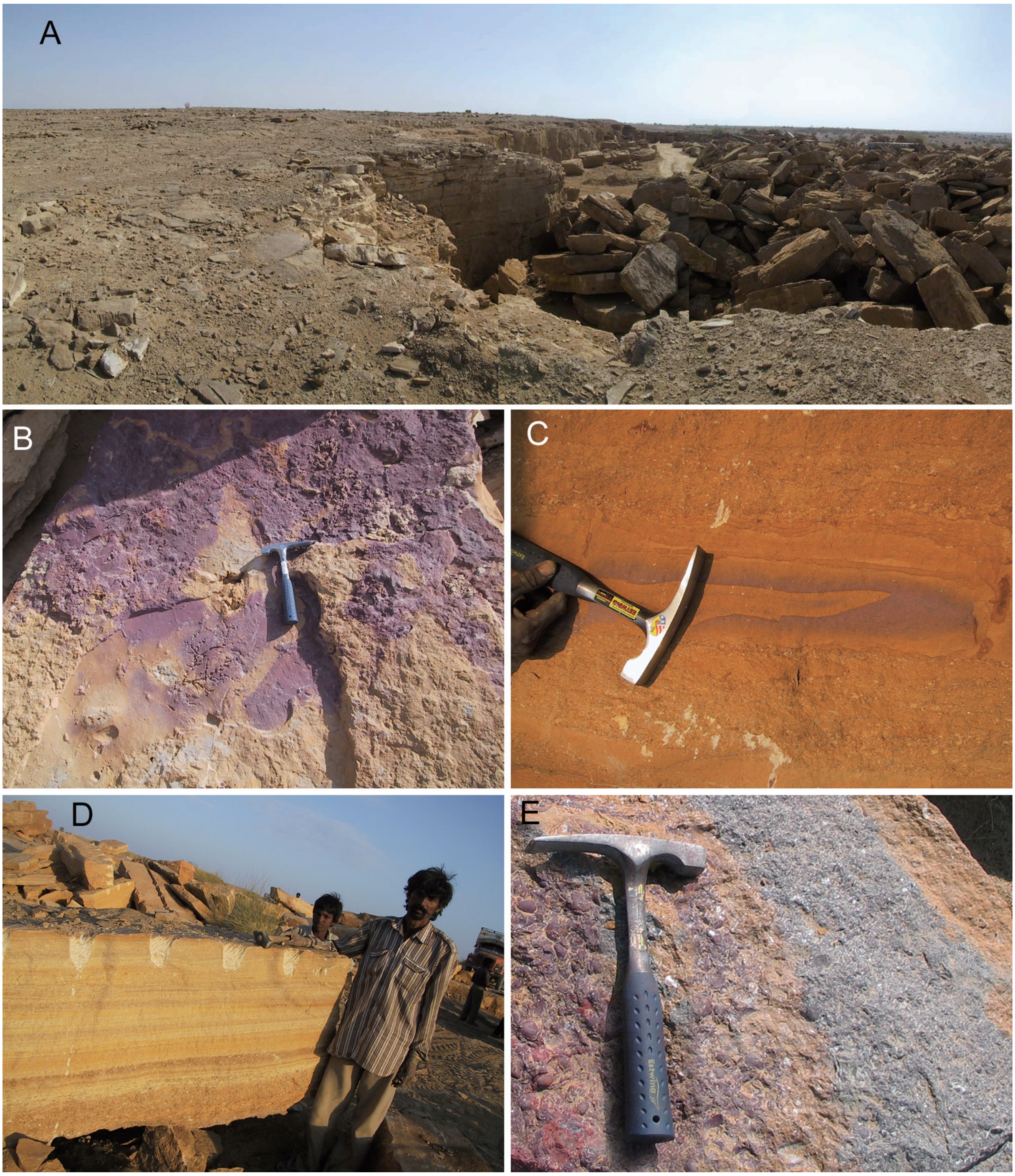

Figure 11.15 Jaiselmer area limestone occurrences. **[A]** Mool Sagar Khan quarry. **[B]** Detail of bright "golden" yellow Jaisalmer limestone with red patches at Mool Sagar Khan. **[C]** Detail of reddish banding in the limestone at Amar Sagar. **[D]** Banded sandy limestone being quarried at Jethway. **[E]** Gray, yellow and red sandy limestone at near Habur, 45km northwest of Jaisalmer Fort.

this study (figures 11.14 and 11.15). The quarries that were exploited for much of the distinctive bright yellow-red sandy limestone used to build the city are found within 10 km of Jaisalmer Fort at Mool Sagar Khan ("MSK") and nearby Amar Sagar ("AS"). Similar material is also found north of the city near Jethway along with a banded yellow-brown type that moderately resembles the banded type found at Harappa. Beginning around 45 km west of Jaisalmer Fort at Habur are limestone outcrops that, although sandy in texture, are more fossiliferous and crystalline. Pockets of gray to gray-red material are found here,

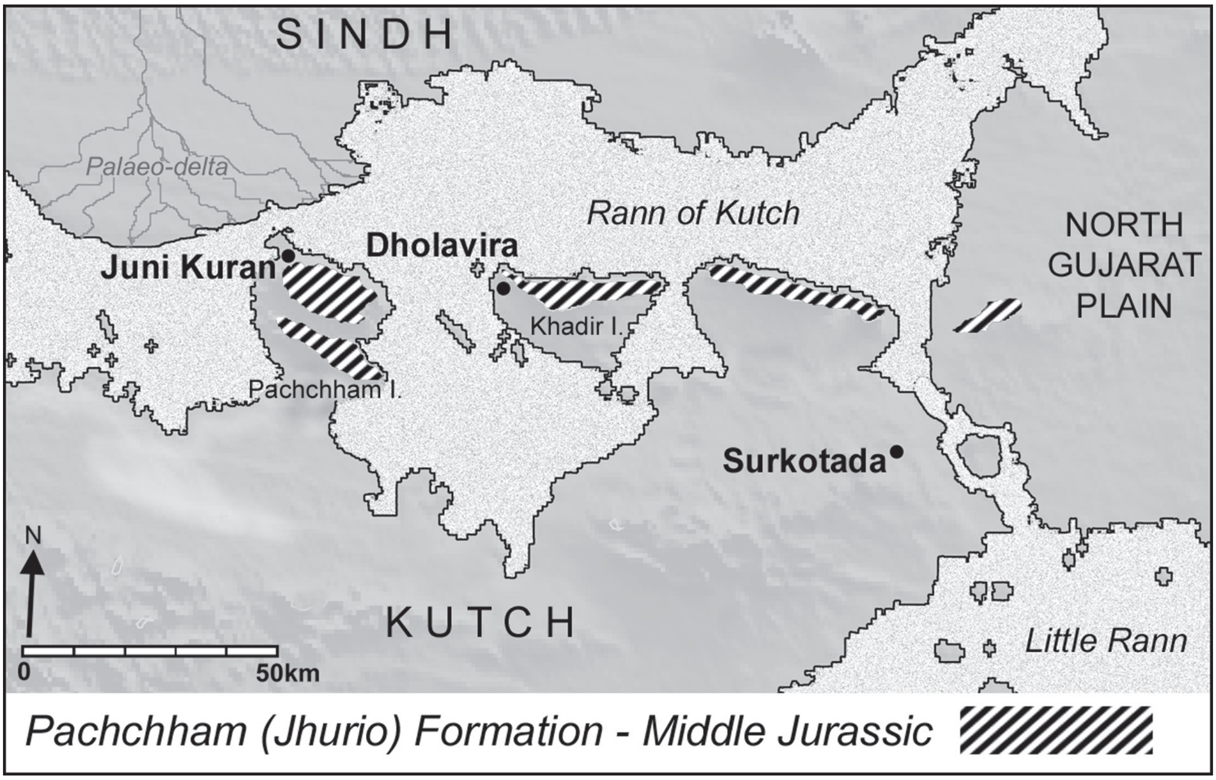

Figure 11.16 Archaeological sites and Pachchham limestone outcrops in northern Kutch.

Figure 11.17 Sandy yellow banded Pachchham limestone masonry and slabs in the northern gateway of Dholavira's citadel.

Figure 11.18 Banded Pachchham limestone quarry 3 km north of Dholavira. Bottom left – Discarded ringstone rough-out. Bottom right – discarded slab.

along with yellow-red types, which are somewhat similar in appearance to the gray sandy artifacts from Harappa – especially the ringstone fragments.

W.T. Blanford noted in his geological survey of western Sindh that stone from the Ranikot beds of the Kirthar Range "closely resembles the very beautiful Jurassic limestone procured at Jaisalmer" (1879: 194). This second potential source formation lies approximately 700 km southwest of Harappa but only around 100 km from Mohenjo-daro. A few small samples were collected for this study near Ranikot Fort.

A third potential source region for sandy limestone is located nearly 800 km south of Harappa. The Pachchham limestone (Figure 11.16) formation of Jurassic age (Fuersich 2001) is exposed

Figure 11.19 Gray Pachchham limestone near the Harappan site of Juni Kuran, Kutch.

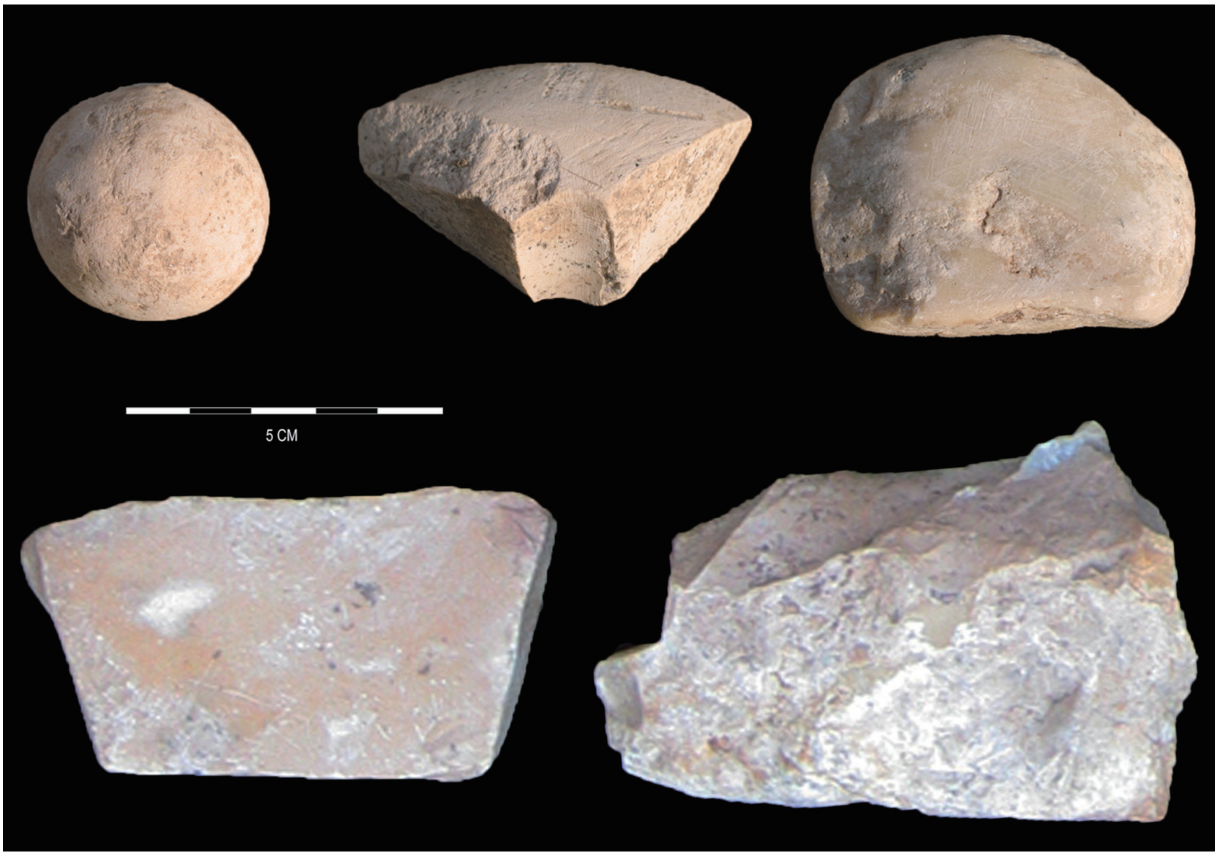

Figure 11.20 Miscellaneous small micritic limestone objects and non-diagnostic fragments from Harappa.

Figure 11.21 Top – White porcelaneous limestone fragments from Harappa. Bottom – White porcelaneous limestone of the Pahr Formation, Loralai District, Balochistan.

on several islands located within the intermittent inland sea known at the Great Rann of Kutch. The southernmost Indus city of Dholavira is located on one of these islands called Khadir (Bisht 1991). Unlike at other Indus cities, stone is used here not only for the gateway ringstones (Figure 11.2 D) that so resemble the two flat-topped ones from Harappa, but also for the city's walls (Figure 11.17), stairs, houses, drains, wells and other public works. Much of this stone seems to have come from a Harappan period quarry (Figure 11.18) located three kilometers directly north of the site (R.S. Bisht 2003 *personal communication*). The Pachchham limestone at this point ("quarry") and at nearby Limdiwali Tari ("LT") is sandy textured and has yellow-brown with reddish-brown bands – again, visually identical to the two ringstones from Harappa. Most significantly for this study are what appear to be ringstone 'blanks' that were discarded during the roughout process (note the large crack splitting the ringstone blank pictured in the *bottom left* image of Figure 11.18). Several of these roughouts as well as discarded slabs (Figure 11.18 *bottom right*) have been found within the kilometer long quarrying area.

Around 45 km west-northwest of Dholavira across the Rann on Pachchham Island lies the Harappan period site of Juni Kuran. Recently excavated by the Archaeological Survey of India (Pramanik 2005), this site appears much like a smaller version of Dholavira, with a rectangular stone perimeter wall and a "citadel" with gateways in which ringstones have been found. The Pachchham limestone in this part of Kutch tends to have a more sandy crystalline texture and, in addition to yellow brown material, there are gray types (Figure 11.19) somewhat similar in appearance to the gray sandy limestone artifacts of Harappa.

Micritic and white chalky-porcelaneous limestones (MICRITIC and WHITE)

Microcrystalline and fine-grained limestones of various colors ranging from white to dark yellow-brown were used by Harappans to create many different kinds of objects both small (Figure 11.20) and large. The two main kinds of large-sized micritic limestone artifacts – wavy ringstones (Figure 11.2 A, B and C) and the rectangular blocks that may be drain covers (Figure 11.6 *right*), have already been mentioned in preceding sections. The potential sources of this type of material are far too numerous to be mentioned in detail. The closest and most accessible geologic formations containing limestone of this type would have been either those of Eocene age found in the Sulaiman Range or the Permian to early Eocene formations of the Salt Range (Bender 1995b: Table 9.4). The Eocene Rohri Hills in Sindh are another possible source.

Only a small number of limestone artifacts over all have been found at Harappa that are made of chalky white to porcelaneous white limestone. The two large conical objects (Figure 11.4) described above and a half dozen or so fragments (Figure 11.21 *top*) represent most of that sub-assemblage. Limestone formations of this kind, although still widespread, are comparatively less common than the micritic ones. In Balochistan, white porcelaneous Parh limestone (Figure 11.21 *bottom*) can be found from the Loralai District in the north part of the state to the Kirthar Range in the south (Ahmad 1969: 104). Chalky white limestone is found in the upper part of Laki Formation of southern Sindh (Jafry and Ahmad 1991; Fatmi and Khan 1998).

Section summary

Many of the large objects created or acquired by residents of Harappa were composed of limestone. The principal types they used were sandy limestone (banded yellow-brown, bright or "golden" yellow-red and gray-red), micritic limestone (of varying shades) and white chalky-porcelaneous limestone. Identifying the regional source(s) of the latter two might prove difficult due to the wide geographic extent across which limestones of those types occur. However it may be possible to determine which of two potential geologic formations is the most probable source of the sandy limestone artifacts found at the site. The Jaisalmer formation is by far the closer of the two possible source areas to Harappa. However, the nearest Indus Civilization sites to that formation lay approximately 150 km away across the desert in either Cholistan (Mughal 1997) or the Thar region of eastern Sindh (Mallah 2000). On the other hand, although Kutch is almost twice as far away from Harappa, there is indisputable evidence that the ancient Indus peoples living in that region exploited the local limestone of the Pachchham formation. Transporting heavy pieces of stone (the larger of the two flat-topped banded ringstones found at Harappa weighs 135 kg) from Kutch to the Punjab, however, would have certainly been a difficult and costly undertaking. In the following section I attempt to shed light on this problem through comparative elemental analyses of limestone artifacts and geologic source materials.

GEOLOGIC PROVENIENCE STUDIES OF HARAPPAN LIMESTONE ARTIFACTS

Past studies, choice of instrumentation and presentation of data

In recent years there have been numerous geologic provenience studies of limestone artifacts, sculpture or building materials. Some studies have employed atomic absorption spectrometry (AAS) in combination with carbon and oxygen isotope analysis (DeVito *et al*. 2004). Others researchers have made petrographic thin-sections of limestone samples and matched them to geologic formations of the same age through palaeontological analysis of microfossils in the stone (Capedri *et al*. 2001). Studies using INAA have been particularly successful in characterizing quarries and sourcing limestone sculpture and building stone in Western Europe (Holmes and Harbottle 2003). Most recently, a geologic provenience study of limestone artifacts and sources using electron paramagnetic resonance (EPR) spectroscopy yielded promising results (Polikreti *et al.* 2004).

Each of the above methods is destructive at some level and has its own particular strengths and weaknesses. For this study of Harappan limestone artifacts and their potential sources, the choice to use the inductively-coupled plasma spectrometers as the primary tools for analysis was largely based on access to those instruments at the LARCH and the experience of Dr. James Burton in using them. To my knowledge no one prior to this time had used ICP-MS or ICP-AES to source archaeological limestone and so the process of analysis was very much exploratory and experimental. I have therefore chosen to present the results of this study in a way that illustrates the step-by-step sequence in which the archaeological and geologic datasets were analyzed and the results evaluated.

The archaeological and geologic limestone datasets

This study began as a small pilot project with a limited number of samples. The materials analyzed for the pilot study, or what I am calling the <u>initial</u> dataset, consisted of six samples of archaeological limestone from Harappa (HLS-001 through HLS-006), 15 geologic samples from two locations near Jaisalmer (JLS-001 through JLS-015) and 15 geologic samples from the Harappan Period quarry near Dholavira (DLS-001 through DLS-015) generously provided to me by that site's excavator, Dr. R.S. Bisht of the Archaeological Survey of India. Five of the archaeological samples were examples of sandy limestones that resembled the geologic source materials. One sample [HLS-003], was a micritic limestone fragment with a texture quite different than the other artifacts or geologic samples in the set. All artifacts are coded using an "HLS" (Harappa limestone) number that corresponds to their official HARP "year/lot-record" numbers listed in the second column of Appendix 11.1.

After the very promising results of the pilot study (discussed below), the number of archaeological and geologic samples was substantially increased. I refer to this as the expanded sample set. The archaeological set grew to include 107 limestone artifacts. Only very small pieces (≈ .005 g) were required for analysis. Half of the samples were taken from flakes or non-descript fragments. The other half were obtained during the examination and cleaning of objects, such as the ringstones from the Harappa Museum's Reserve Collection. In all cases small chips were carefully removed from already damaged areas (note the broken bottom portion of the smaller ringstone in Figure 11.8).

The expanded geologic set grew to include 60 sandy limestone samples from the four locations visited in the Jaisalmer region of Rajasthan along with 65 samples from three areas within the Pachchham Formation of Kutch. Also added to the geologic set were 25 samples of micritic limestone from the Rohri Hills of central Sindh, three samples of chalky white Parh limestone from the Loralai District of Balochistan, five samples chalky limestone from the Junagadh District of Gujarat and two samples of fine sandy yellow limestone from the Kirthar Range near Ranikot in western Sindh. Specifics as to why limestones from these other sources were added to the set are discussed in more detail below. Descriptions of the all samples comprising the archaeological and geologic datasets along with the results and supporting data related to the various analyses conducted on them can be found in appendices 11.1 through 11.7.

Sample preparation, analysis and data evaluation

Three separate techniques were used to characterize either all or a portion of the archaeological and geological limestone samples examined in this study: ICP-MS, ICP-AES and INAA. In this section, I discuss only how samples were prepared, analyzed and evaluated using these techniques. Strategies and factors that affected the

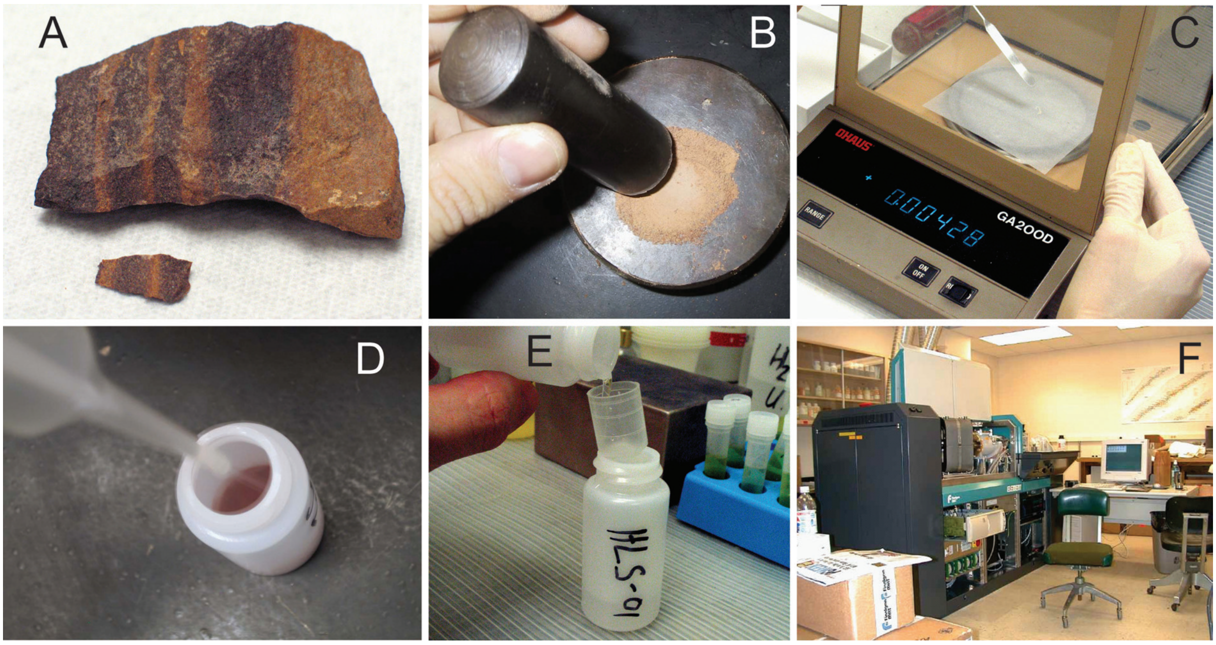

Figure 11.22 Preparing limestone artifacts and geologic samples for ICP-MS and ICP-AES analysis. **[A]** A chip (≈ 1 gram) is removed from a from a cleaned, freshly broken surface. **[B]** The chip is powdered and the powder is mixed. **[C]** 0.004 g of the homogenized powder is weighed and placed into a plastic vial. **[D]** 1 ml of nitric acid is placed on the sample and left to sit 24 hours. 19 ml of ultra-pure water is then added and the sample is left to sit another 24 hours. **[E]** The sample is then filtered of any undissolved mineral particulates. **[F]** The liquid sample is then analyzed with an ICP-MS or ICP-AES.

choice of instrumentation used are discussed as the results are presented.

Limestone samples needed to be dissolved into solution for elemental analysis using ICP-MS and ICP-AES. Preparing the materials for both instruments was the same (Figure 11.22). For geologic samples this involved the removal of one gram of material from a freshly broken surface using a tungsten carbide drill. Depending on the size and condition of each archaeological sample, either the same procedure was used or a small chip (size > 1 g) of the material was powdered by hand in an agate mortar. For all samples, exactly 0.004g of homogenized powder was weighed out and placed in a polyethylene analysis vial. One milliliter of nitric acid was added to each vial and the samples were left for 24 hours. Only the calcium carbonate components of the limestones were dissolved. Quartz, clay minerals and other non-carbonate constituents of the samples did not dissolve. After 24 hours the samples were filtered of any remaining mineral particulates and 19 ml of purified water was added. In approximately one half dozen cases an archaeological sample contained such a high level of quartz that little or none of it appeared to have dissolved at all. These samples were removed from the archaeological set (this accounts for the occasional skipped HLS sample number in the sequence listed in Appendix 11.1).

Prepared solutions were analyzed using one of the inductively-coupled plasma spectrometers in the LARCH. These instruments are capable of quantifying a wide range of elements at sub-parts-per-million levels. Each element that was measured was divided by measured calcium (Ca). This was done because the large component of quartz in these sandy limestones made it unclear precisely how much calcium carbonate was actually dissolved from sample to sample. Let me provide the following illustration: say for instance that two geologic samples came from the same source but less calcium carbonate was dissolved in one of them due to the fact that it contained a higher amount of silica than the other. In the high silica sample 200,000 parts per million (ppm) Ca and 200 ppm barium (Ba) were measured. In the sample containing less silica 400,000 ppm Ca and 400 ppm Ba were measured. Both samples have ratios Ba/Ca of 0.001. Since equal amounts of material were weighed out for both samples the absolute concentrations of Ba per volume of calcium carbonate actually dissolved is the same in both cases. Dividing all measured elements by Ca in effect serves as an internal standard in the ICP.

The preparation, irradiation and count times for those limestones samples analyzed by instrumental neutron activation (INAA) were precisely the same as for other materials examined for this study using this technique and so are not repeated here (see the INAA method section of Chapter 3).

After being log normalized, the data resulting from the ICP-MS/AES analyses and INAA were evaluated in a variety of manners. Bivariate plotting of two elements (divided by Ca and log normalized) in the dataset obtained by ICP-MS/AES was often sufficient to draw distinctions between geologic sources and determine the probable provenience of archaeological samples. Nevertheless, exploratory canonical discriminant analysis (CDA) was also performed to statistically evaluate the extent to which geologic formations could be distinguished from one another and the degree to which archaeological samples could be assigned to one of them. This method was used to examine data resulting from both ICP-MS/AES analysis and INAA. Issues relating to cross-validation of defined geologic sources (groups) and predicted group membership of archaeological samples were previously discussed in Chapter 3. Appendix 11.6 lists the standardized (canonical) discriminant function coefficients for each of the figures that were generated using CDA.

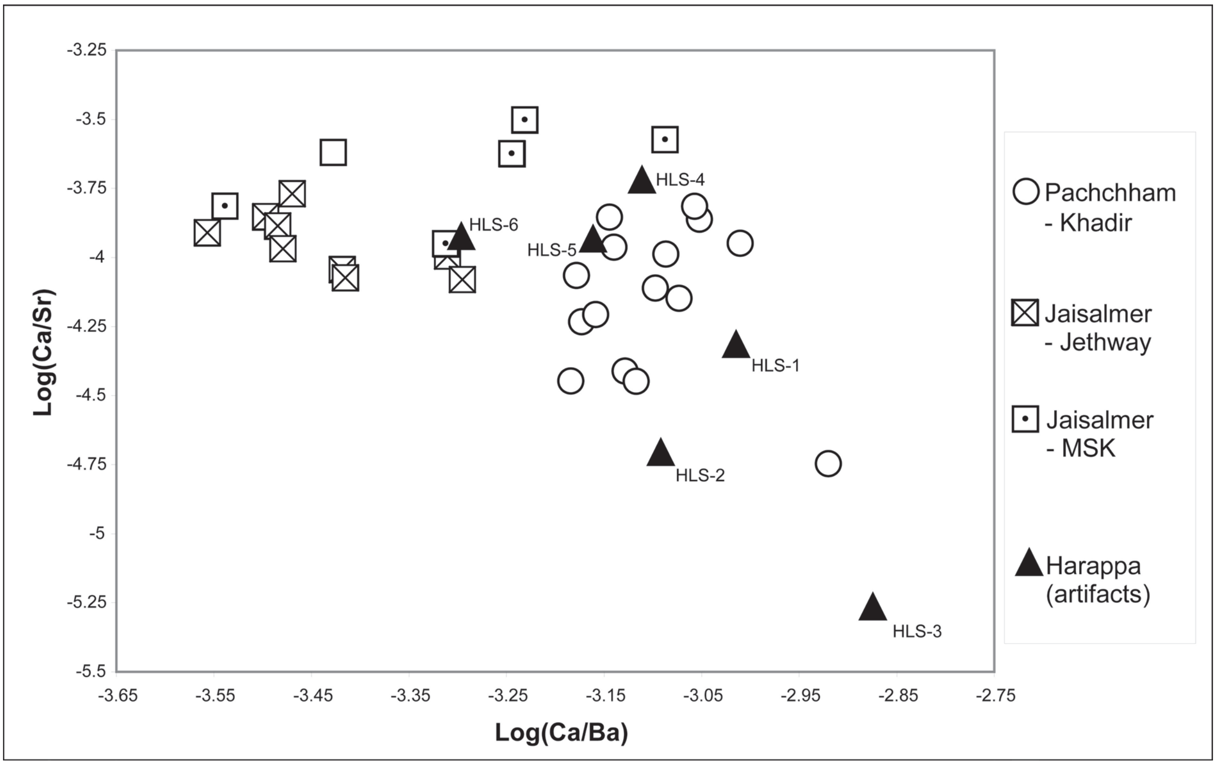

Figure 11.23 ICP-MS analysis of the initial limestone sample set (bivariate plot).

Pilot study using the initial sample set

ICP-MS analysis of the initial set

The first analysis of the initial set was performed on the ICP-MS in the LARCH. Concentrations for the elements Al, Ba, Ca, Ce, La, Mg, Mn, Pb, Sr and U were obtained. However, only Ba, Ce, La and Sr were found to be useful for discriminating between the geologic sources. Except for these and Ca, which was needed to standardize the elemental concentrations, data for the other elements were discarded. The concentrations of the elements that were kept are reported in Appendix 11.2.

When the data were examined using simple bivariate plots of two elements (standardized and normalized) it was found that the best separation between geologic sources is achieved using Sr and Ba (Figure 11.23). When the six archaeological limestones from Harappa are superimposed (as black triangles) on that plot several things are suggested. First, it would appear that four of the samples resemble Pachchham limestone even though some of them fell around the margins of that group. HLS-4 in particular also plotted near the edge of the Jaisalmer group as defined by the Mool Sagar Khan (abbreviated MSK on the figures) samples. One sample (HLS-6) appeared more closely related to the limestones from the two deposits in the Jaisalmer region, both of which overlapped significantly. A final Harappan sample (HLS-3) plotted somewhat away from both groups (although closer to the Pachchham samples). This sample, importantly, is the micritic limestone that visually and texturally unlike the other archaeological fragments.

Next, the data were evaluated using CDA in order to get a statistically stronger sense of how different or alike the geologic sources and archaeological samples were (Figure 11.24). For this Ba, Ce, La and Sr values were used after being divided by Ca and log normalized. Good separation between sources was achieved with almost 87% of cross-validated cases in the three geologic groups classifying correctly. In this analysis, the predicted group membership for HLS-6 and HLS-4 (which straddled the margins of the two sources in the bivariate plot) was the Jaisalmer region.

The remaining samples were assigned membership with the Pachchham group. However, we again see that HLS-3 is a distant outlier. Although it is closest to the center of the Pachchham group (and so was predicted to belong to it) it seems to be very unlike either that group or the other archaeological samples assigned to it.

The results of the ICP-MS analysis were very promising. Good separation between sources was achieved and the provenience determinations seemed to be fairly unambiguous, particularly when the data were evaluated using CDA. However, we (Dr. Burton and I) were cognizant of the fact that this method involved only a *partial dissolution* of samples. A large component of these sandy limestones was being discarded during the preparation process and with it data that might potentially yield very different results. It was decided that the results generated using partial dissolution and the ICP-MS could best be validated through a *whole rock analysis* of the initial dataset.

INAA of the initial set

A whole rock analysis was performed on the initial sample set using INAA. Of the data that were returned, ten elements (Al, Ca, Eu, Fe, La, Lu, Mg, Mn, Sr and V) that were completely free of missing values were judged to be effective for use in discriminating between sources and assigning provenience to archaeological samples (Appendix 11.3). Due to a problem with the sample changing mechanism at the reactor lab, short count data for JLS-10 was not obtained. Therefore this sample had to be excluded. Elemental concentrations were log normalized before statistical analysis of the data.

Canonical discriminant analysis of the INAA data for the initial set (Figure 11.25) produced results that more or less approximated the data obtained through partial dissolution of samples and analysis using ICP-MS. Only around 65% of cross-validated geologic sample cases were correctly classified due to the large degree of overlap between the two sources in the Jaisalmer Formation. Excellent separation between the two limestone formations was achieved however. Once again the single micritic sample from Harappa was clearly much different from the two sources or other archaeological samples. On the other hand, in this analysis, all of the remaining five samples were predicted to be members of the Pachchham Formation group. This is not entirely surprising as the two samples that had appeared more like Jaisalmer limestone in analyses of ICP-MS data had both plotted near the margins of the two groups of geologic samples.

Hierarchical cluster analysis (Appendix 11.7) indicates that a fair degree of overlap may, nonetheless, exist between the two geologic formations. Numerous clustering strategies were employed (the dendrogram in Appendix 11.7 was generated using median clustering and Pearson correlation) and each time there were invariably cases where archaeological samples that had been assigned to the Pachchham group using CDA appeared to cluster with members the Jaisalmer group. Likewise the clusters generated using the various strategies frequently contained examples from both geologic groups. This *may* indicate that demarcation seen between geologic groups when using CDA is not as sharp as it appears in a plot of discriminant functions.

Overall, however, the INAA results appear to confirm the patterns and provenience determinations suggested by the ICP-MS analysis. Based on this it was decided to significantly expand the archeological and geologic sample sets. Unfortunately at this time the ICP-MS at the LARCH was undergoing an extended period of maintenance. A decision was therefore made to analyze the initial sample set for a third time in order to see if the ICP-AES could be used as effectively as the ICP-MS for geologic provenience studies of limestone artifacts.

ICP-AES analysis of the initial set

Details of the detection capabilities of the ICP-

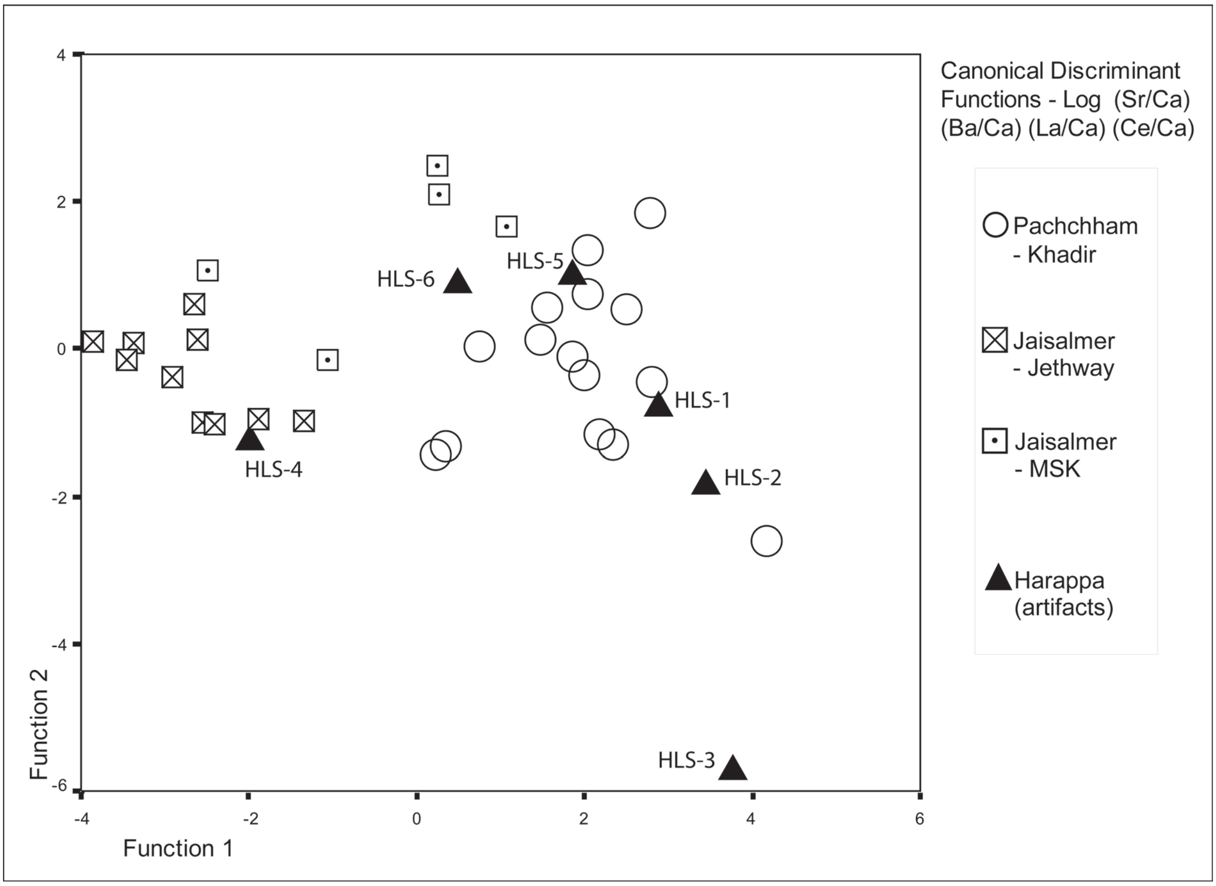

Figure 11.24 ICP-MS analysis of the initial limestone sample set (CDA).

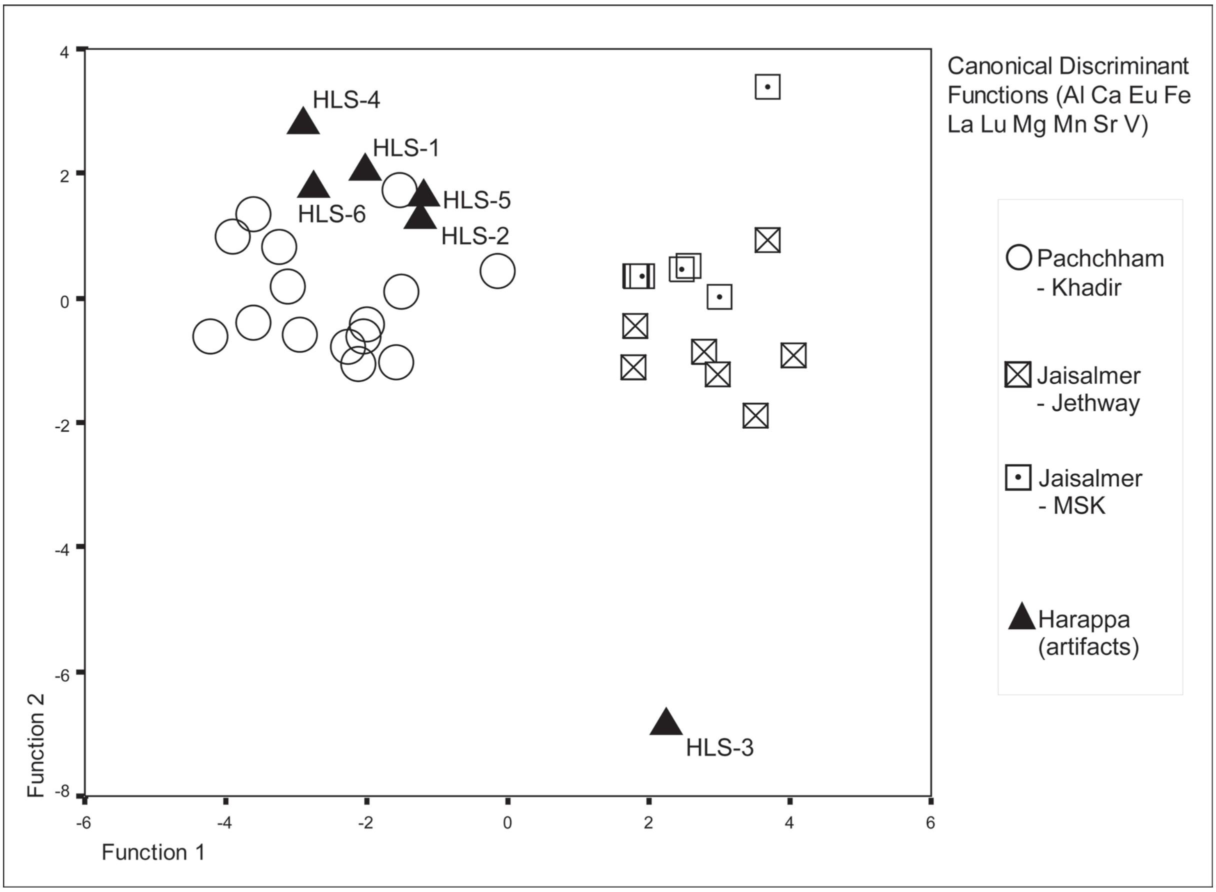

Figure 11.25 INAA of the initial limestone samples dataset.

AES used for this study were discussed in Chapter 3. Out of the various elemental data provided by this instrument, Ba, Fe, Mg and Sr (in addition to Ca of course) were deemed to be most useful for separating geologic sources and assigning provenience to archaeological samples. The absolute concentrations of the selected elements for these samples are listed in Appendix 11.4.

In a bivariate plot of Sr to Ba (standardized to Ca and log normalized) we see that although there is a degree of overlap between samples from the Pachchham and Jaisalmer formations, two reasonably distinct groups are evident (Figure 11.26). Samples HLS-4, 5 and 6 plot near margins of both groups and HLS-3 is again a distant outlier. A fairly similar pattern for the archeological samples is seen when the results of the ICP-MS analysis (Figure 11.23) were plotted in this way.

A degree of overlap again is evident between the two groups when the four measured elements are used in CDA of the sample set (Figure 11.27). In this instance 67% of cross-validated geologic cases classified correctly. The archaeological samples plotted as ungrouped cases repeat the previously seen pattern with HLS-3 yet again being the single distant outlier. Although the same three samples as before fall near the point of overlap between two geologic groups, the group membership predicted for all of the Harappan limestones (except the outlier) is the Pachchham formation.

In summary, reasonably good separation between the two limestone source formations was achieved using both bivariate plotting and CDA of elemental data obtained with the ICP-AES. Archaeological samples plotted in more or less the same manner using either method of data evaluation. In addition and very importantly, the degree of geologic group separation as well as artifact plotting patterns and/or predicted group membership achieved with ICP-AES derived data were largely consistent with the results from the INAA and ICP-MS studies. Therefore, with a high degree of confidence that the ICP-AES could be used effectively for provenience analyses of limestone artifacts, the sample set was expanded to encompass 107 archaeological samples and 160 geologic samples.

Analysis of the expanded set using ICP-AES

Analysis using ICP-AES of the 267 samples comprising the expanded set took place over the course of two days. Data for the geologic samples is found in Appendix 11.4. Data for the limestone artifacts from Harappa, as well as listing of the probable geologic proveniences of those samples, can be found in Appendix 11.5.

Comparisons at the level of geologic formation

I begin the examination of the expanded dataset with comparisons of the Harappan limestone artifacts to source material at the broadest level – that of individual geologic formation. All samples from a single geologic formation are considered as a single group regardless of differences in macroscopic appearance or how far apart they were collected from one another. The Pachchham and Jaisalmer formations are compared with the new group of 25 micritic limestone samples from the Rohri Hills. These samples were collected at the same four locations as the Rohri chert samples analyzed in Chapter 6. It was decided to add this group of Rohri Hills limestone to the set for two reasons: First, over a dozen of the samples in the archaeological set were micritic limestones. Even though there were no samples from other micritic limestone sources available for comparison it would still be informative to know how closely the Harappan samples are to the Rohri limestones. Many Harappan sites, including the city of Mohenjo-daro, are located in the general vicinity of the Rohri Hills. Secondly, in order to create a broad-scale display of data points on an *x-y* axis using CDA a third group was needed in order to generate a second discriminant score.

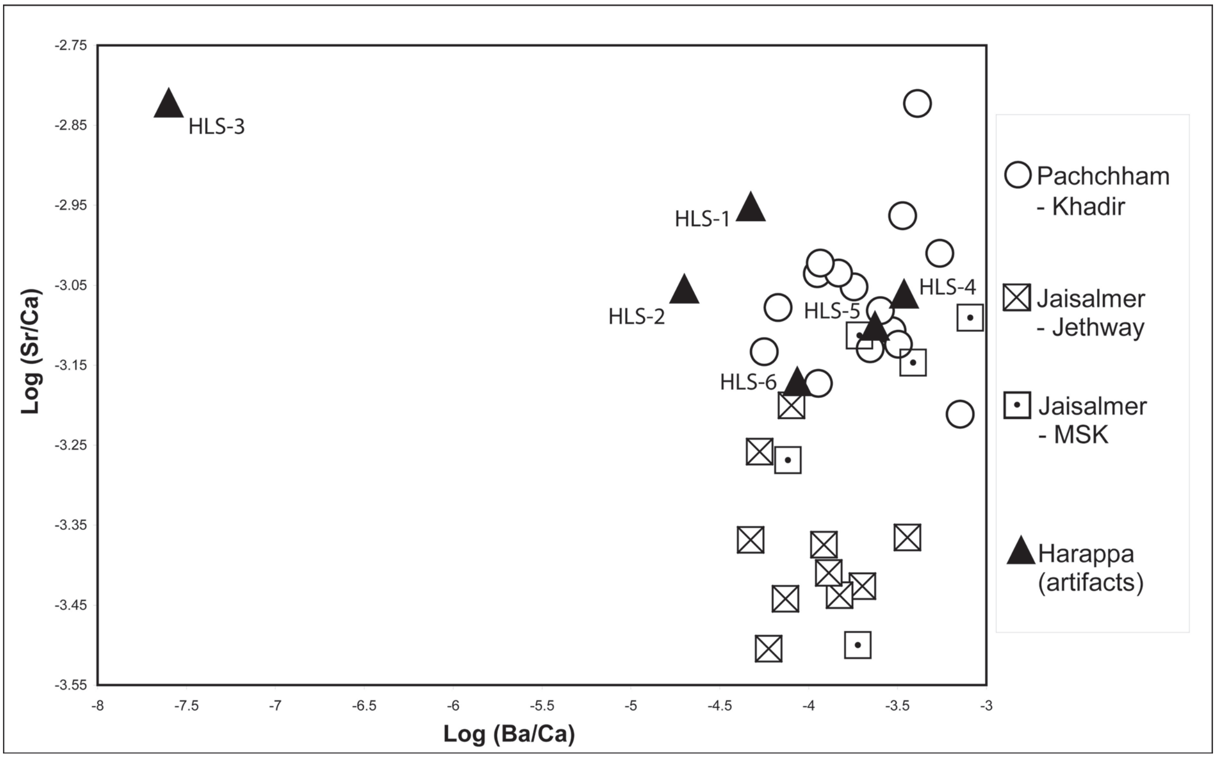

Figure 11.26 ICP-AES analysis of the initial limestone sample set (bivariate plot).

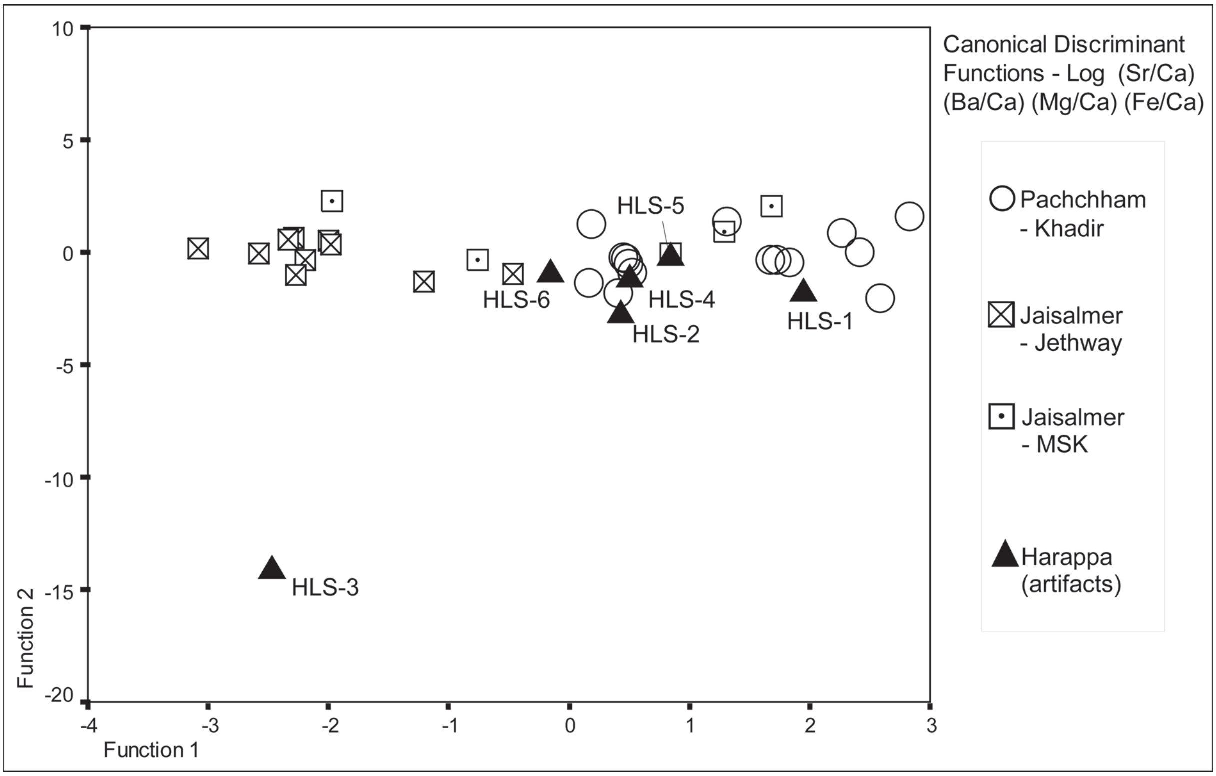

Figure 11.27 ICP-AES analysis of the initial limestone sample set (CDA).

Samples from the three geologic sources alone are displayed in Figure 11.28 using a bivariate plot of their Ba and Sr values (divided by Ca and log normalized). Although there is a fair degree of sample overlap in some areas along the margins the geologic groups, the three sources appear to be reasonably distinct.

In Figure 11.29 the archaeological samples from Harappa are superimposed as black triangles. With

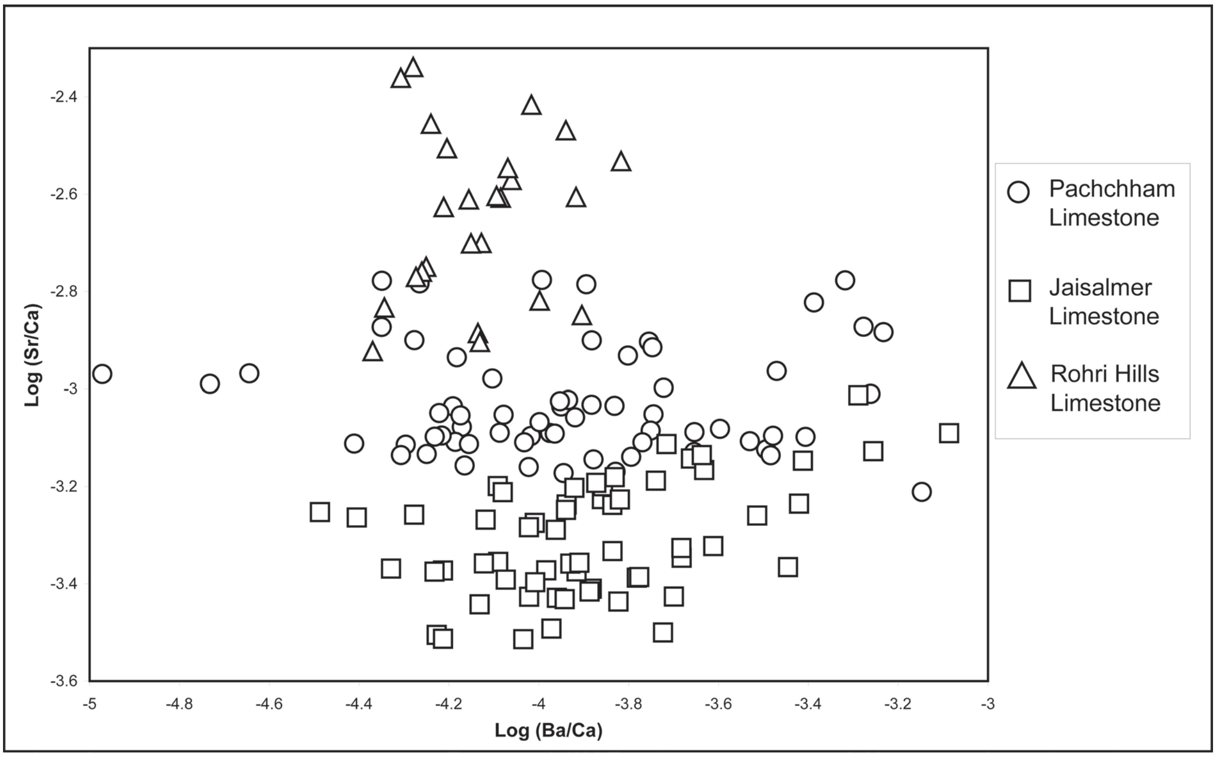

Figure 11.28 ICP-AES analysis of expanded geologic sample set (bivariate plot).

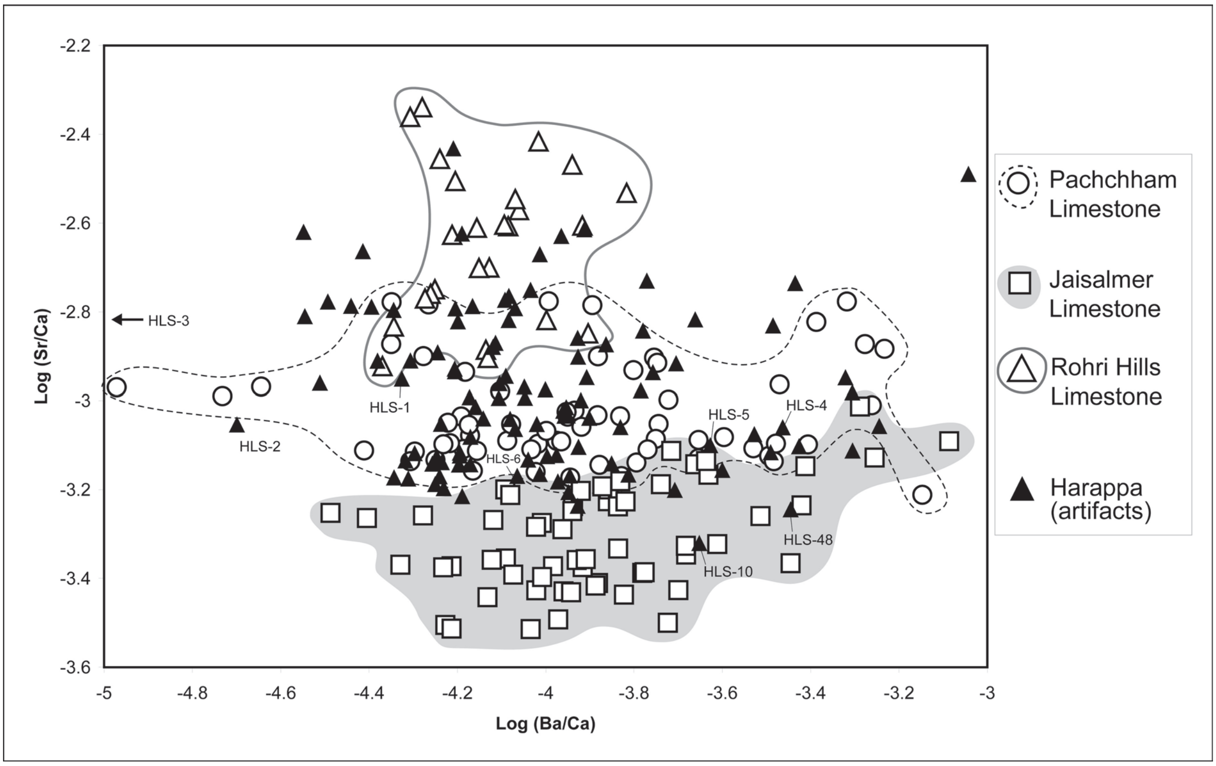

Figure 11.29 ICP-AES analysis of expanded archaeological sample set (bivariate plot).

over 250 points now plotted the figure becomes very *busy* visually. Lines and shading have therefore been added to show the extent of the areas where geologic sources plot. Such additions, which are used frequently in upcoming figures, are only meant to be visual aids and do *not* represent confidence intervals of any kind. In this view, it is evident that the majority of archaeological samples (most of which are types of sandy limestone) fall within the area encompassed by the Pachchham Formation. A significant number of the remaining samples plot either with the Rohri Hills group or outside of all three groups. Two artifacts (HLS-10 and HLS-48) plot squarely within the Jaisalmer group. Many samples fall in and around the area where the Pachchham and Jaisalmer groups overlap. This area is where three of the original six artifacts from the initial set consistently plotted. Those six are identified on the figure in order to provide a sense of how the expanded number of geologic samples might, or in this case might not have, helped to clarify the boundaries between the formations.

Far better separation between geologic sources is achieved when the dataset is examined using CDA (Figure 11.30). The samples from the Rohri Hills, so different in geologic age and appearance than the sandy limestone sources, form very a distinct and separate group. Although a degree of overlap is still present between the Pachchham and Jaisalmer groups, 93.3% of cross-validated geologic cases classified correctly.

When the archaeological samples are considered as ungrouped cases (Figure 11.31), the large majority once again cluster with the Pachchham group. Many samples also fall either in the Rohri Hills group or outside of all three groups. The two artifacts that had plotted in the Jaisalmer group in the bivariate plot now fall away from that group. However, the predicted group membership (based on distance to the Jaisalmer group center point as compared to the other group's center points) of those and four other samples is the Jaisalmer group.

The purpose of this first look at the expanded set was not to assign provenience to archaeological samples. The primary purpose was to determine which method of looking at the data (bivariate plotting or CDA) produced the best results. Best separation between groups was achieved using CDA and, therefore, this method is the one used for all remaining evaluations of the dataset. Another purpose was to get a general sense of how the archaeological samples grouped when compared with the expanded geologic dataset. The majority of artifacts seem to group with the Pachchham Formation. However, many of those fell in the area where that group overlapped with the Jaisalmer Formation. A significant number of others were probably unrelated to either those two groups. In order to determine the probable geologic provenience of the archaeological samples, I now begin to examine the dataset by focusing on the individual material types defined earlier in this chapter

BANDED yellow-brown and yellow-brown sandy limestone

Let us first examine banded yellow-brown and yellow-brown sandy limestone artifacts. The 31 examples from Harappa in this visual type category are plotted as ungrouped cases against samples from the Pachchham, Jaisalmer and Rohri Hills limestone formations (Figure 11.32). The black triangles with white circles on the figure identify samples taken directly from the two banded yellow-brown ringstones from the Harappa Museum's reserve collection (HLS-7 and HLS-8, pictured in Figure 11.4 D). At this level (in which 93% of cross-validated geologic samples classified correctly) the predicted group membership of all samples is the Pachchham Formation. Many of the artifacts do, however, cluster near the area where outliers of the Jaisalmer group overlap with the Pachchham samples.

In the next view (Figure 11.33) we examine the Pachchham and Jaisalmer formations at the level of the individual locations from where geologic samples were collected. The Rohri Hills samples have been discarded while two yellow sandy limestone fragments from the Kirthar Range of Sindh were added. The cross-validation score at this level dropped significantly (to around 62%) due to the high intra-formation overlap between sampled locations.

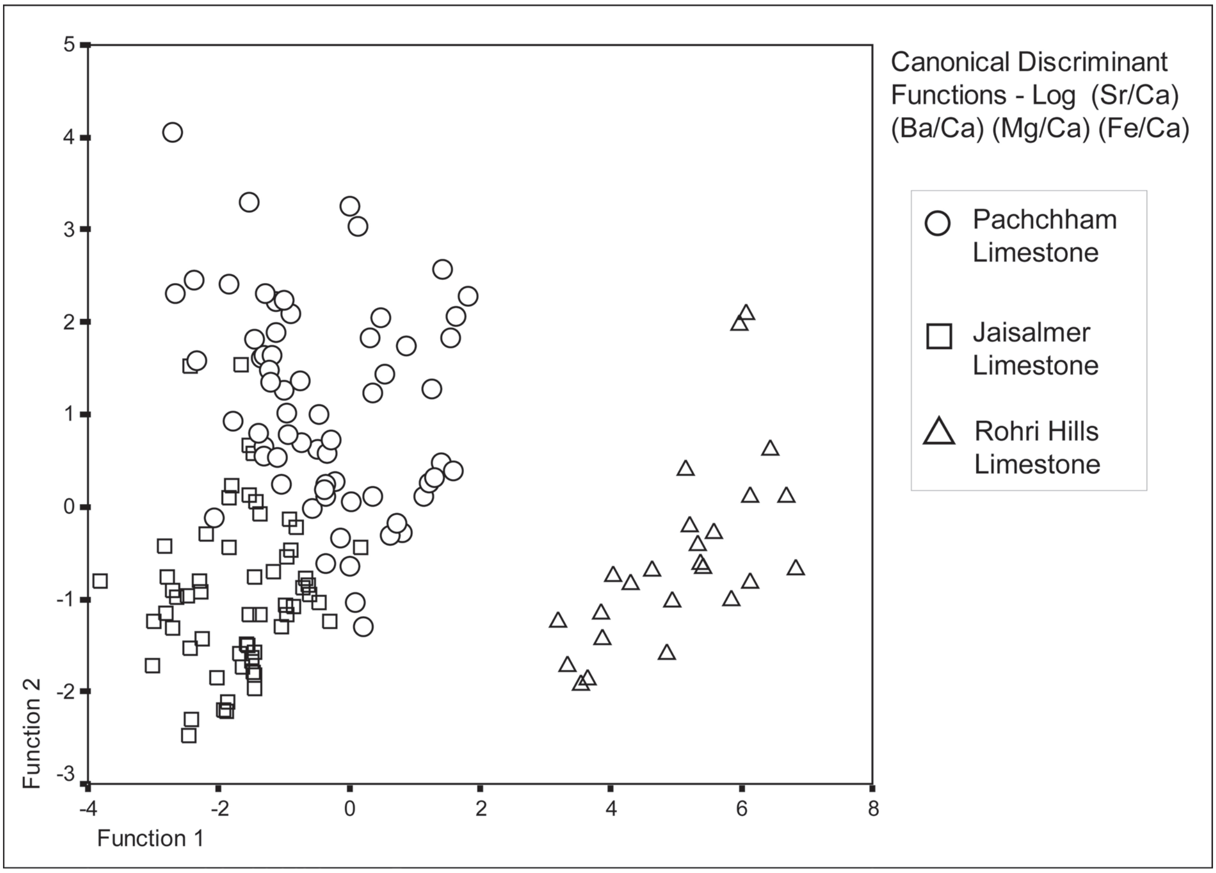

Figure 11.30 ICP-AES analysis of expanded geologic sample set (CDA).

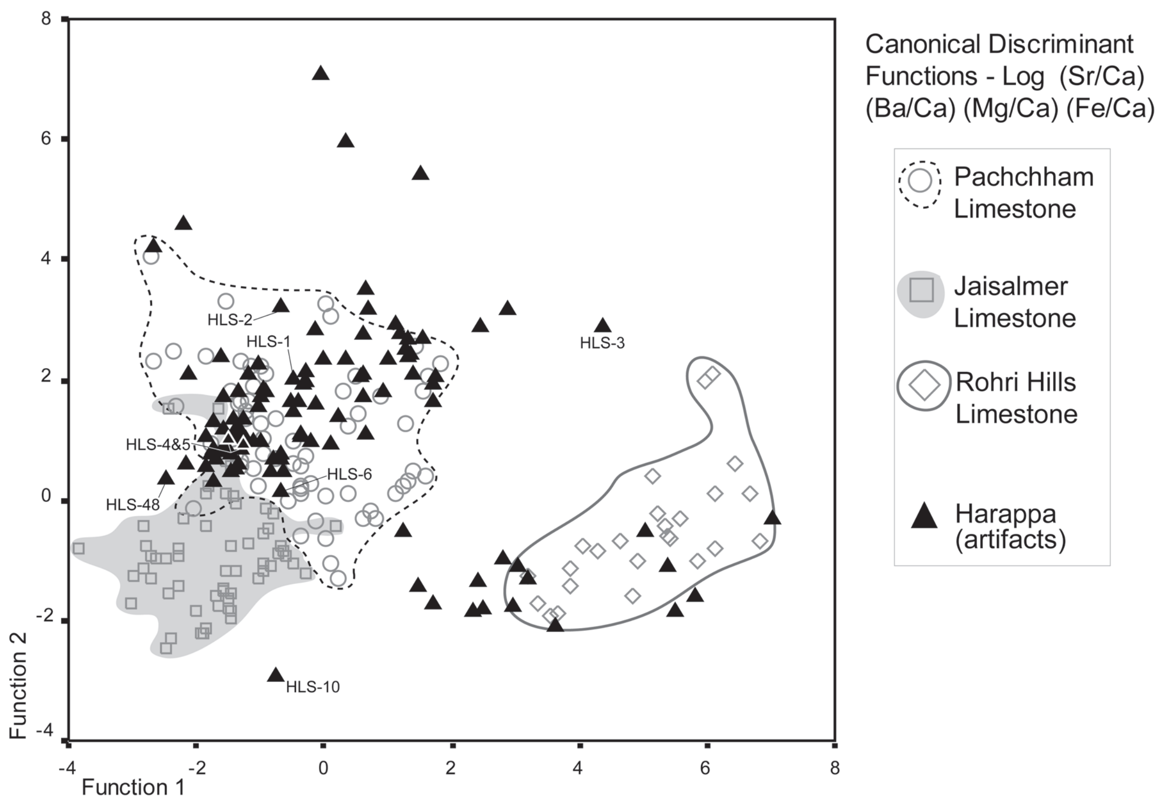

Figure 11.31 ICP-AES analysis of expanded archaeological sample set (CDA)

Nonetheless, 28 of the 31 artifacts had a predicted group membership in the Pachchham formation. Twenty of those 28 artifacts, including the two banded ringstones, were assigned to the Khadir Island Harappan quarry group (Quarry) and the remaining eight to the Pachchham Island Juni Kuran (JK) group. Three samples, however, were predicted to belong to the Mool Sagar Khan (MSK) group of the Jaisalmer Formation. These sample points are marked with the letter "M." Note that three other artifacts group adjacent to those samples. Although predicted to belong to the Pachchham group, those may actually belong with those artifacts assigned to Mool Sagar Khan. On the other hand, all of the artifacts in this area (even the MSK ones) may simply be outliers of the Pachchham Khadir Island quarry group. When the Mool Sagar Khan, Khadir quarry and Juni Kuran sources were compared alone (not shown) only a single sample was predicted to belong the Mool Sagar Khan group.

Although the two yellow sandy limestone samples from the Kirthar Range in Sindh did plot among the Pachchham geologic group, none of the artifacts examined appeared to resemble them. However, it would be imprudent to state that Harappan yellow limestone could not have come from the Kirthar Range, especially after having only analyzed a mere two samples from that region. What is very clear is that the majority of the 31 banded yellow-brown and yellow-brown sandy limestone artifacts examined here more closely resemble Pachchham limestone than they do Jaisalmer limestone or the Kirthar samples.

Bright or "GOLDEN" yellow-red sandy limestone (Jaisalmer stone?)

Now we turn to the category of sandy limestone artifacts that bears a very strong resemblance to Jaisalmer stone. Twenty-two artifacts made up this sub-set of bright yellow to bright yellow-red or "golden" sandy limestones.

The 25 examples in the dataset of this macroscopic category are plotted as ungrouped cases against samples from the Pachchham, Jaisalmer and Rohri Hills limestone formations (Figure 11.34). It immediately is evident that this group and those in the previously examined banded yellow-brown sandy limestone category (Figure 11.32) plot in a very similar way. At this level, 19 of the Harappan artifacts are classified as belonging to the Pachchham Formation. Three are assigned to the Jaisalmer group.

When individual sources in the Pachchham and Jaisalmer groups are compared alone (Figure 11.35), 18 of the Harappan samples are assigned a predicted group membership with Pachchham sources on Khadir Island, Kutch (17 to the Harappan quarry and one to the nearby Limdiwali Tari area) and four are predicted to belong to the Mool Sagar Khan source in the Jaisalmer Formation (noted on the figure with an "M"). When the archaeological samples are compared to those four assigned sources alone (not shown), Mool Sagar Khan looses one member while Limdiwali Tari gains one.

These results would seem to suggest that the many of the artifacts identified as Jaisalmer stone by past excavators of Harappa (and Mohenjo-daro) may in fact have come from sources in Kutch. However, three to four of the Harappan artifacts were predicted to belong to Mool Sagar Khan in the Jaisalmer Formation and I believe that at least some of the other artifacts in this sub-set may have been incorrectly classified as coming from Pachchham sources. For example, sample HLS-044 (noted on Figure 11.35 and pictured in Figure 11.6, *bottom row center object*) is an artifact from Harappa that has the same bright yellow-red of classic Jaisalmer stone (Figure 11.3) but is predicted by CDA to belong to a Pachchham source. None of the stone that I have seen when visiting source formations in Kutch, however, have quite the same "golden" yellow hue of this or many other samples in this category – but granted, I have only visited a handful of located within that region.

Perhaps the possibility that some artifacts

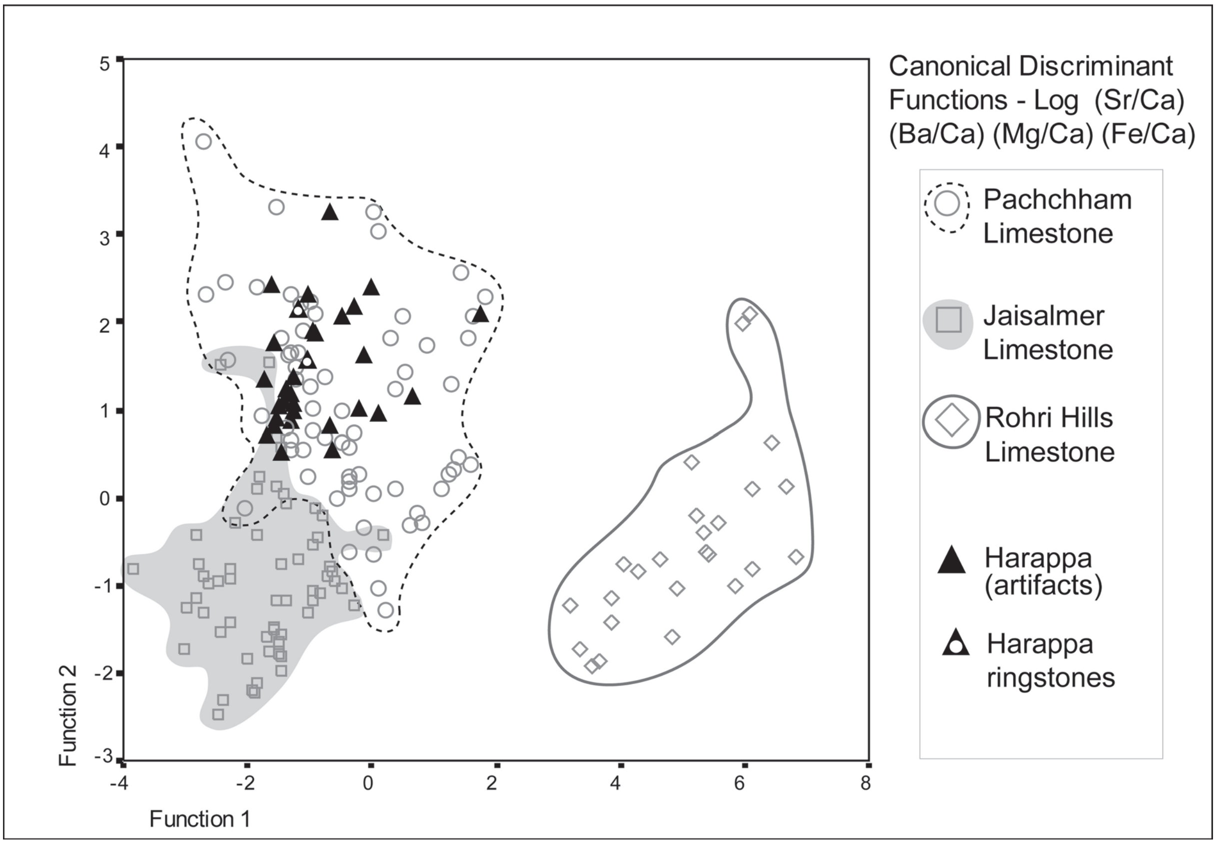

Figure 11.32 ICP-AES analysis of BANDED yellow-brown limestone artifacts (CDA).

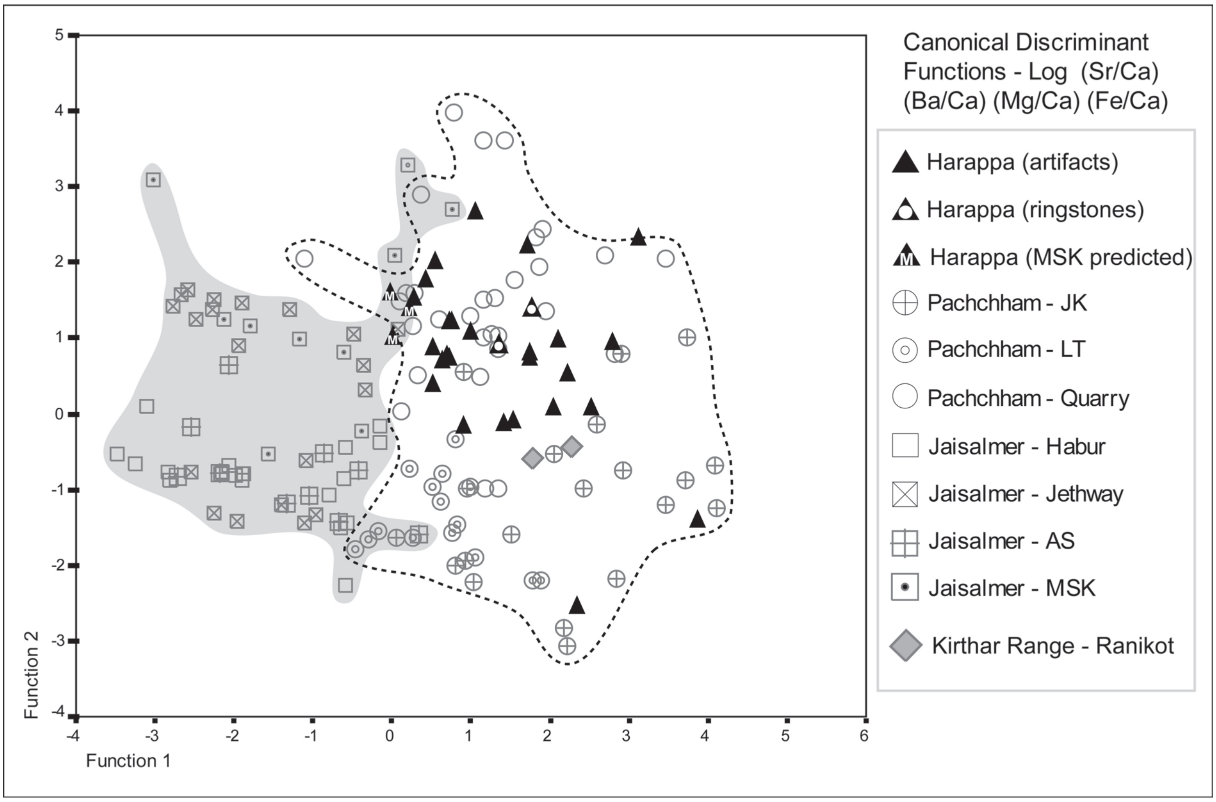

Figure 11.33 ICP-AES analysis of BANDED yellow-brown limestone artifacts vs. select geologic sources (CDA).

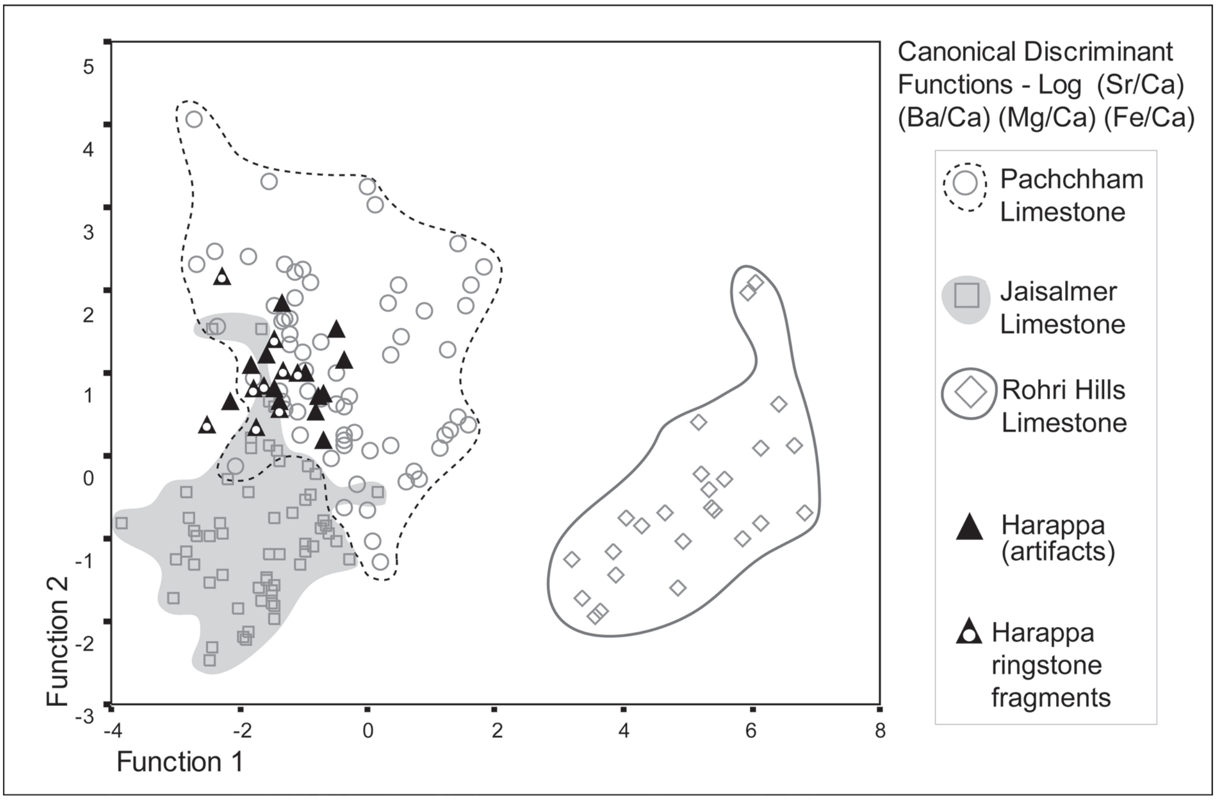

Figure 11.34 ICP-AES analysis of yellow-red "GOLDEN" sandy limestone artifacts (CDA).

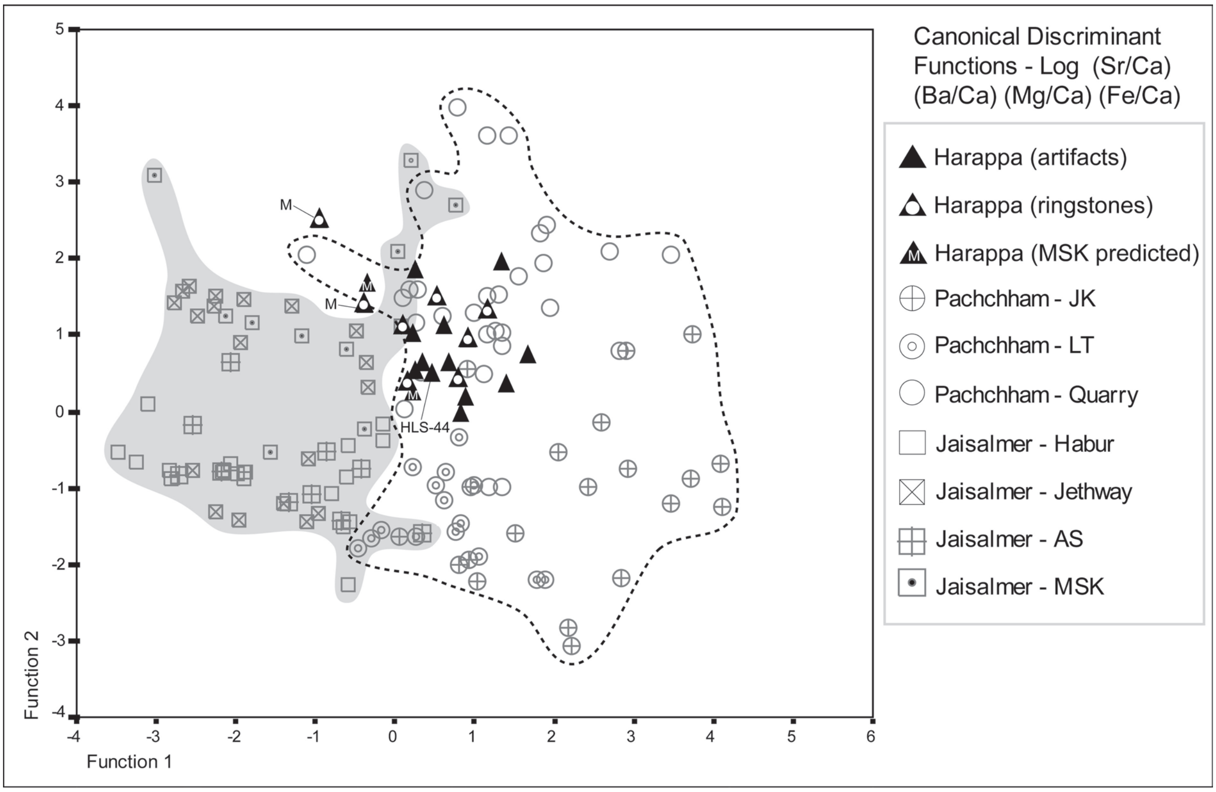

Figure 11.35 ICP-AES analysis of yellow-red "GOLDEN" sandy limestone artifacts vs. select geologic sources (CDA).

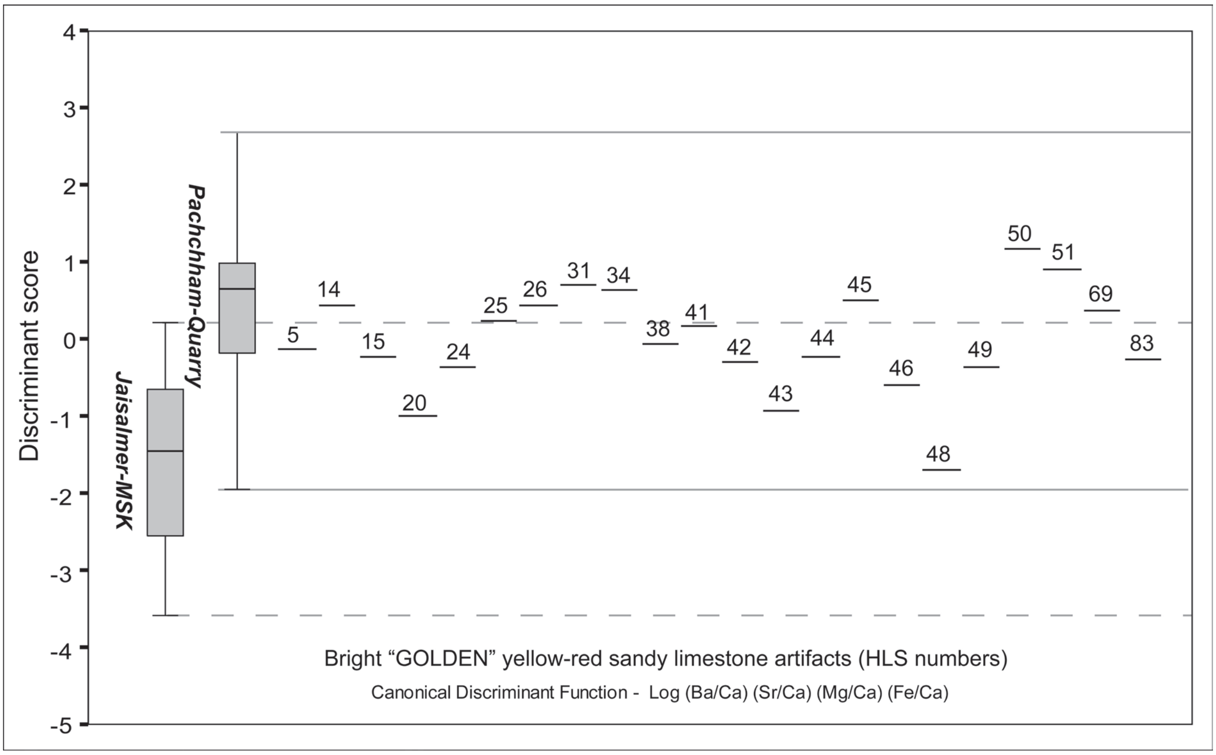

Figure 11.36 Box plot comparison of Pachchham quarry vs. Mool Sagar Khan geologic sources and "GOLDEN" limestones artifacts based on discriminant scores.

may have been misclassified using CDA can be best illustrated by comparing the two overlapping sources alone. Figure 11.36 is a box plot (recall how this was previously used in Chapter 8 to compare agate artifacts to geologic samples from two sources – Figure 8.35) based on the discriminant scores generated when the Mool Sagar Khan (Jaisalmer) and the Khadir Island quarry (Pachchham) were compared alone and the bright yellow-red limestone artifacts were considered ungrouped. I have added horizontal lines indicating where the furthermost outliers of both geologic sources are. Dashed gray lines indicate Mool Sagar Khan and solid ones indicate the Khadir quarry. Artifacts are plotted individually and labeled. The box plots clearly show that a significant amount of overlap exists between the two sources (80% of cross-validated cases were correctly classified) and that all of the archaeological samples plot within the area encompassed by the Pachchham limestone quarry on Khadir. However, 15 of the 25 also plot below the Mool Sagar Khan outlier with the highest discriminant score (marked with the top-most dashed line) and so could *potentially* belong to that group. HLS-044 is among those that plot in this way. Based on this fact and the artifact's appearance I am inclined to re-classify it as Jaisalmer stone. In the fifth column of Appendix 11.5 the probable proveniences of archaeological samples are listed. I have marked the original source assessment of that sample (Pachchham Formation – Khadir quarry) and other artifacts similar to it with the notation "*possibly MSK."

GRAY-red sandy limestone

The final macroscopic category of sandy limestones to be considered is the gray to gray-red type. Among the 33 artifacts in this sub-set are fragments of three large gray ringstones (two of these are pictured in Figure 11.12), many architectural elements and the shoulder/haunch piece of the large bull sculpture/frieze (Figure 11.7) from Mound AB.

When the 33 gray-red sandy limestone artifacts are plotted against the Pachchham, Jaisalmer and

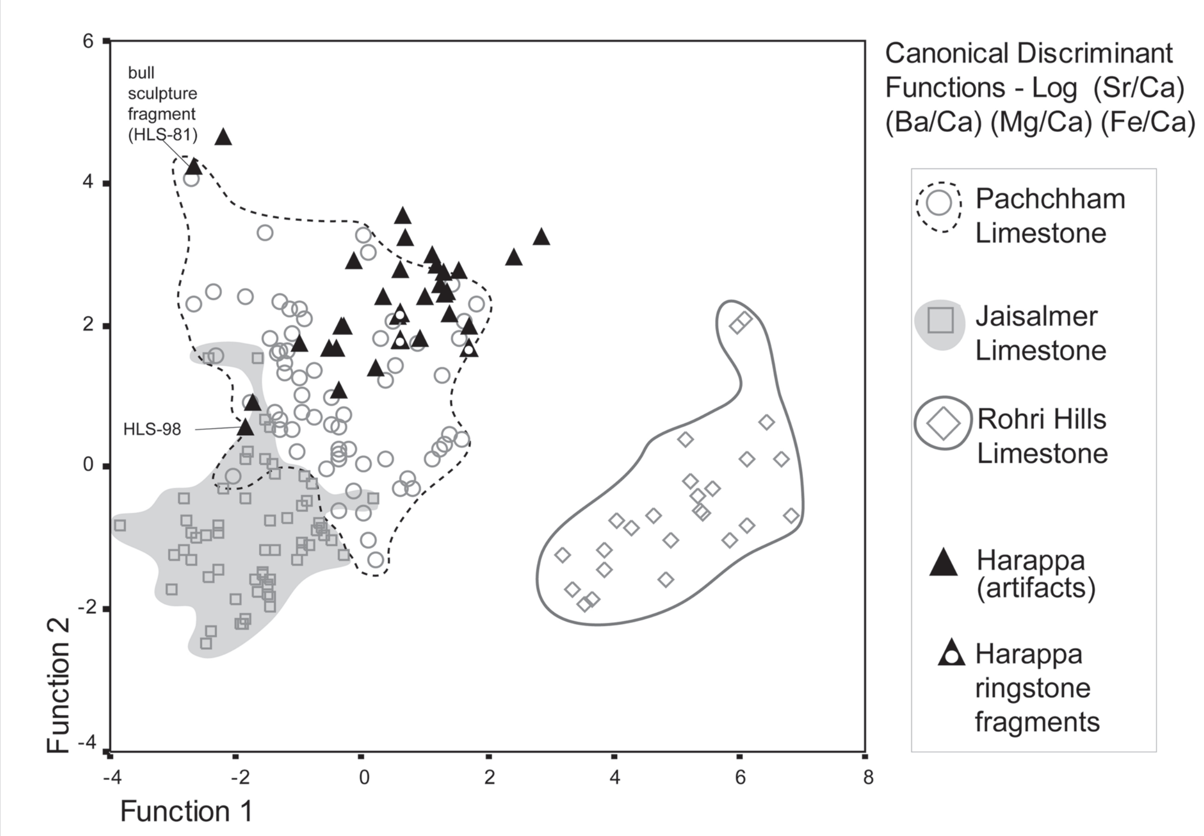

Figure 11.37 ICP-AES analysis of GRAY and red sandy limestone artifacts (CDA).

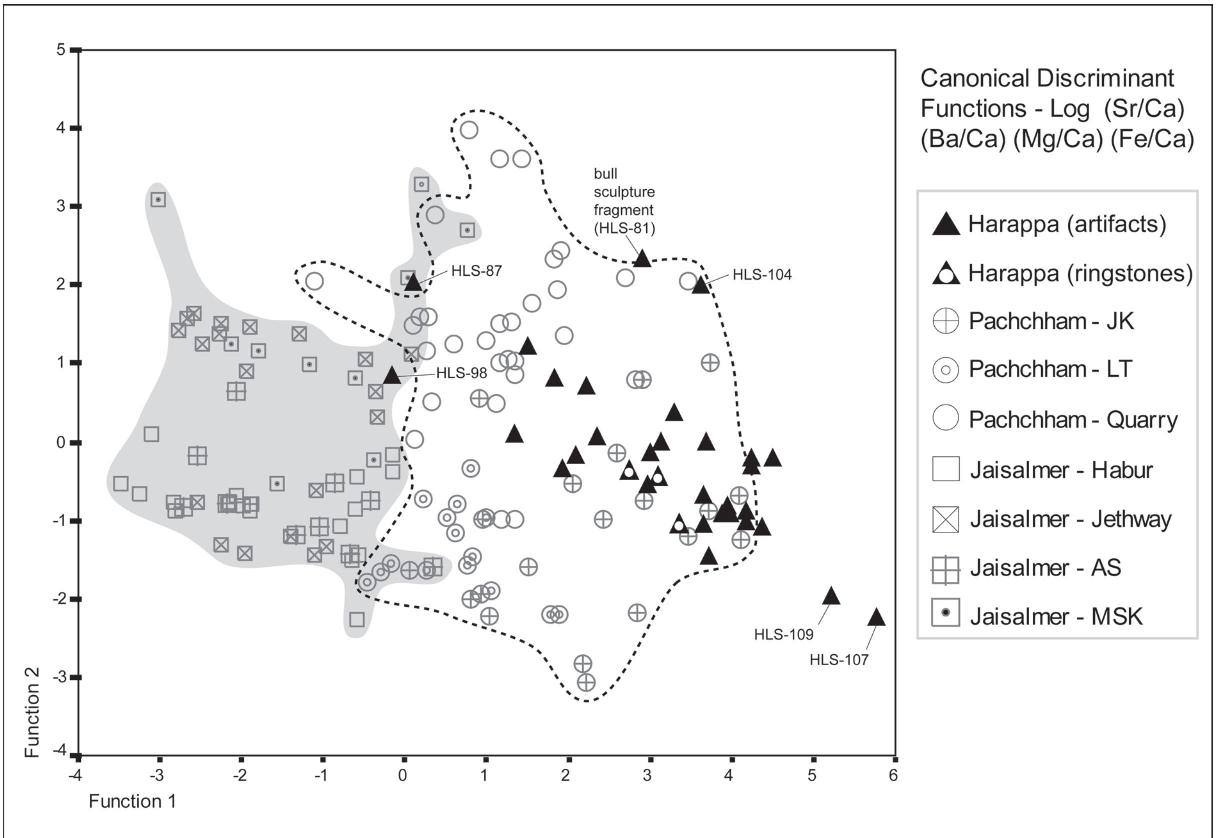

Figure 11.38 ICP-AES analysis of GRAY and red sandy limestone artifacts vs. select geologic sources (CDA).

Rohri Hills formations (Figure 11.37) we see that, like the previous two sub-sets, the majority cluster within Pachchham group. Unlike the previous sub-sets, however, most of these plot well away from the area where the Pachchham and Jaisalmer groups overlap. At this level of analysis the predicted group membership for 32 of artifacts is the Pachchham Formation. Only HLS-98 was assigned to the Jaisalmer group.

Next the individual sources comprising the Pachchham and Jaisalmer groups are compared alone and the archaeological samples are plotted as ungrouped cases (Figure 11.38). It is even more evident now that artifacts of this macroscopic type plot differently overall than the banded yellow-brown and bright yellow-red types. Twenty-five of the 33 samples are predicted to belong to the Juni Kuran group, which is where the gray type of Pachchham limestone is best developed. The three large fragments from the gray wavy ringstones plot squarely in the center of that group. Seven artifacts are closer to the centroid of Khadir quarry group and therefore assigned to it. Some of those, however, samples may be outliers belonging to the Juni Kuran group. More distant outliers (noted on the figure with their HLS numbers) may be from a different sources altogether. One of these outliers is the sample taken from bull sculpture. It appears quite distinct from most of the other samples in thee sub-set. HLS-98 is once again assigned to the Jaisalmer Formation at Mool Saga Khan. This particular artifact is more reddish brown than gray and could conceivably have been carved from a large red patch in a piece of Jaisalmer stone.

Micritic limestone

Micritic limestones are found in numerous locations around the Greater Indus region. For this study, only 25 samples from one source formation, the Rohri Hills of central Sindh, were available with which to compare to the 13 micritic limestone artifacts in the sample set. The majority (n=16) of the micritic limestone samples from the Rohri Hills come from the outcrop directly adjacent to the Early Harappan and Harappan Period site of Kot Diji (Khan 1965). The remaining nine samples are from various outcrops extending from Rohri town in the north to Kandarki in the south (these locations are discussed in greater detail in the Rohri Chert section of Chapter 6). Although having samples from micritic sources in other regions would be preferable, useful information can nonetheless be gained by determining how similar or dissimilar the Harappan micritic limestone artifacts are to samples from the Rohri Hills.

We see that the 13 micritic limestone artifacts from Harappa spread widely when plotted as ungrouped cases against the Pachchham, Jaisalmer and Rohri Hills formations (Figure 11.39). A handful of artifacts fall in or near the Rohri Hills group but the rest, including a large block that may have been a drain cover and the single micritic sample in the initial archaeological set (HLS-3), seem to be unlike limestone from that formation. This would suggest that multiple sources of micritic limestone were used by residents of Harappa.

How similar or dissimilar the Harappan artifacts are to Rohri Hills limestone becomes even more evident when the other formations are discarded and the various sources within the Rohri Hills group are considered alone (Figure 11.40). Again the drain cover (HLS-3) and several other samples plot away from the Rohri Hills group. Seven artifacts, however, do closely cluster with the geologic samples. Until samples from other micritic sources can be analyzed I provisionally suggest that Harappans acquired this type of limestone from multiple sources, one of which was likely the Rohri Hills of Sindh

WHITE chalky porcelaneous limestone

White chalky porcelaneous limestone is the final type of material in the archaeological set and are now briefly examined. This sub-set of consists of samples taken from six non-descript fragments and

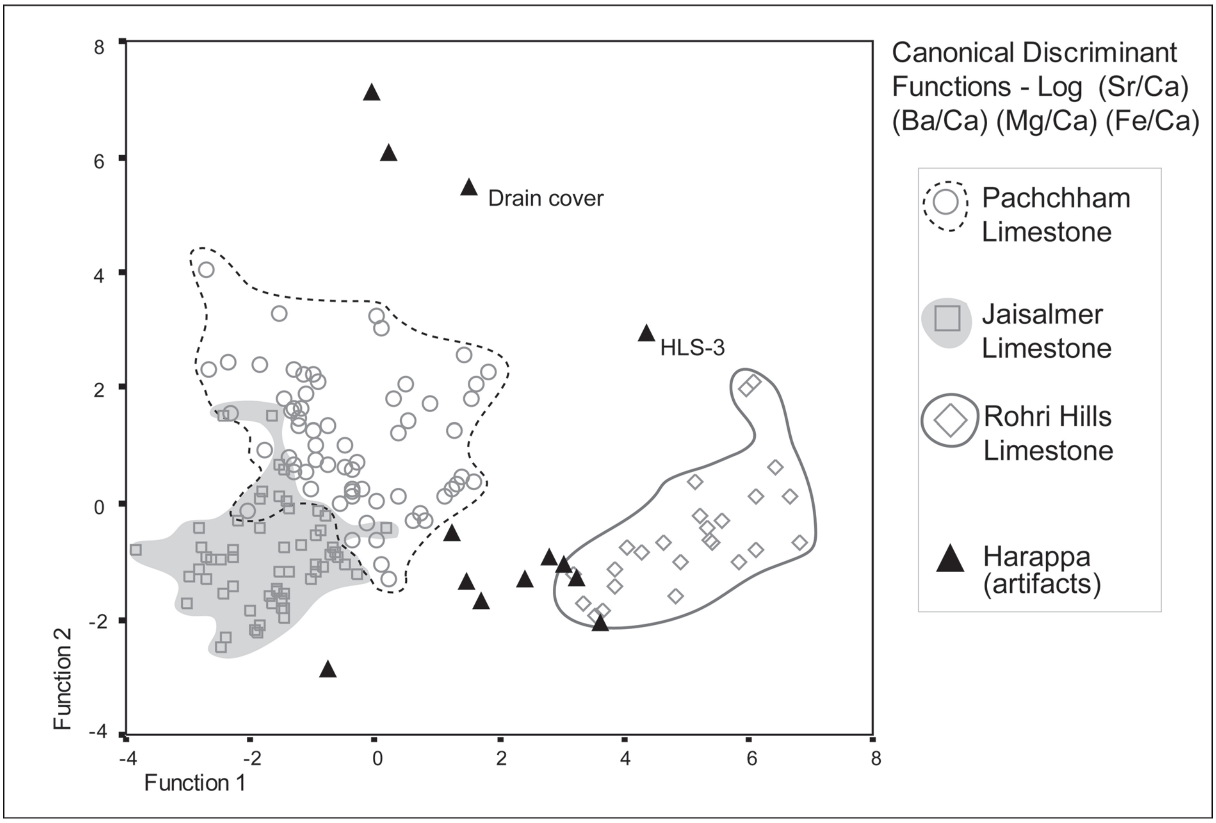

Figure 11.39 ICP-AES analysis of microcrystalline (MICRITIC) limestone artifacts (CDA).

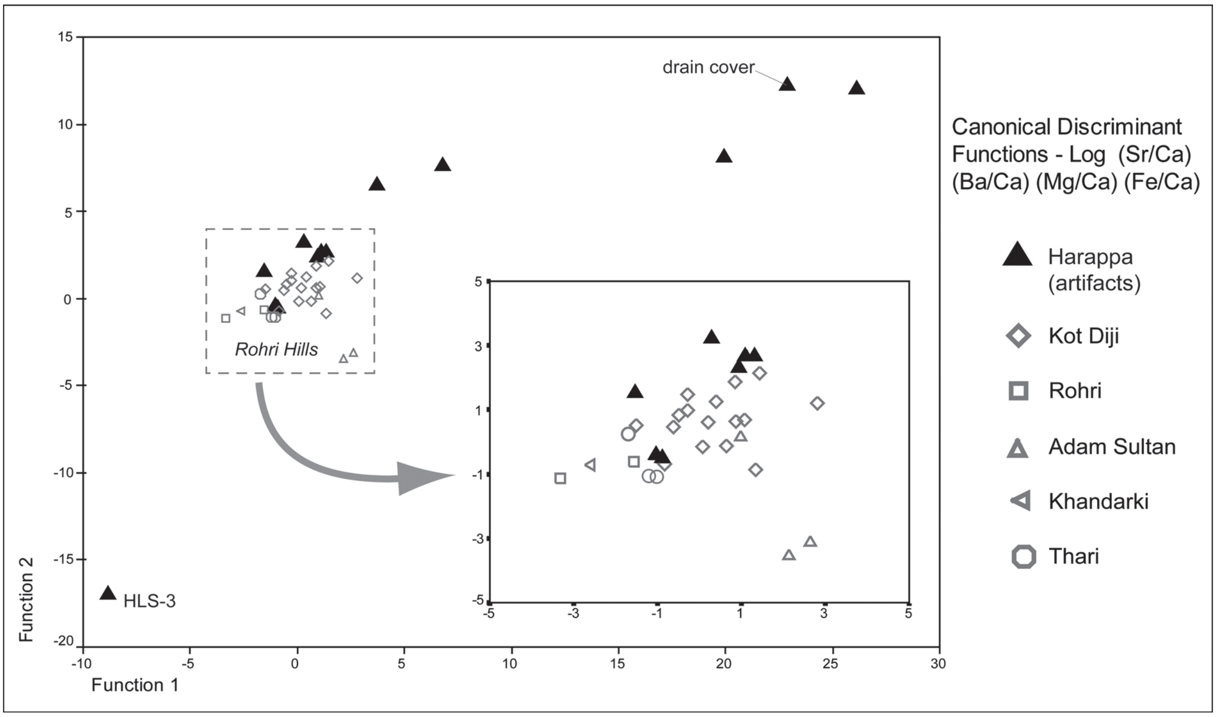

Figure 11.40 ICP-AES analysis of microcrystalline (MICRITIC) limestone artifacts vs. Rohri Hills sources (CDA).

two from a pair of large conical objects. The cones are pictured in Figure 11.4 and are likely same the two reported by Vats (1940: 51) as coming from Trenches III and IV. Although none of the limestones from the three main geologic sources examined in this study much resembles the artifacts, a eight samples from two sources of white limestone have been added to supplement the geologic set. Three of the

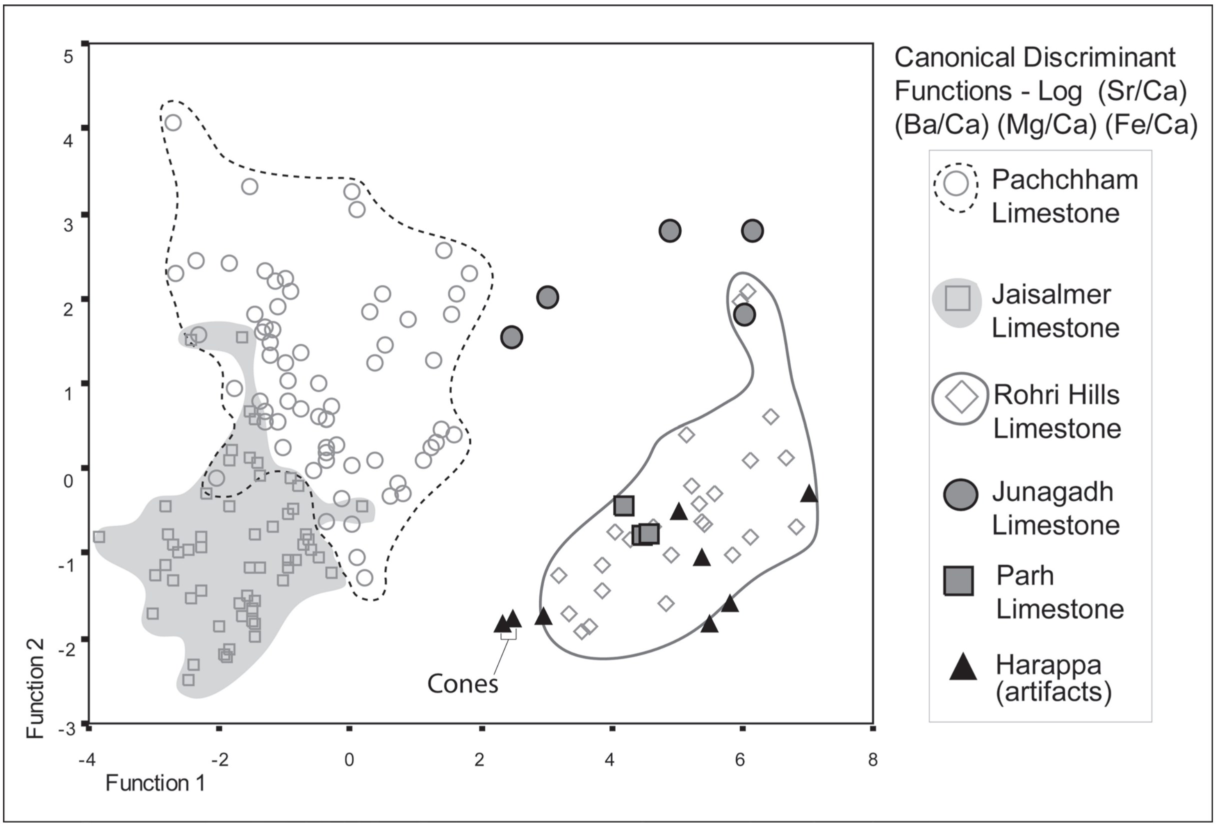

Figure 11.41 ICP-AES analysis of WHITE porcelaneous limestone cones and fragments (CDA).

additional geologic samples are white porcelaneous Parh limestone (pictured in Figure 11.21) collected near the site of Dabar Kot (Fairservis 1959) in the Loralai District, northern Balochistan. Five others are a soft chalky white limestone from Adityana in the Junagadh Distinct of Saurashtra (Desai and Pathole 1979). Although the latter tends to be a much softer material than the white limestone from Harappa, I have included it in this analysis in order to provide another group for comparison.

When plotted against the geologic samples we see that the eight white limestone artifacts cluster in or near the Rohri Hills group (Figure 11.41). Although I have not seen or heard of any chalky white limestone in the Rohri Hills, this is not to say it could not occur at some point along its approximately 80 km length. Interestingly, the three Parh limestone samples plot within the Rohri Hills group and a couple of the Harappan artifacts fall near them. Parh limestone is "exposed extensively in the Kirthar-Sulaiman region" (Kazmi and Jan 1997: 95). It is possible then that the white limestone artifacts may derive from one of these regions west and southwest of Harappa. The samples from the two cones plot very close to one another confirming that were probably made from the same stone, probably at the same time. They are quite distinct from both the chalky white limestone from Adityana, Gujarat and the Parh limestone samples from Loralai, Balochistan.

Section summary

Good separation overall between the geologic sources of sandy limestone (Pachchham and Jaisalmer) was achieved using CDA on ICP-AES derived data, although there was a degree of overlap between the two. When compared as ungrouped cases, many of the archaeological samples fell in and around the area of overlap. Most of the three types of sandy limestone artifacts from Harappa were predicted to belong to sources within the Pachchham formation of Kutch. Some samples of each of the types, however, did fall close enough to geologic groups in the Jaisalmer formation of western Rajasthan to be assigned that provenience. Those that did so may simply be outliers of Pachchham limestone. Or they may actually come from Jaisalmer sources, along with many other artifacts that plotted in or near the area of overlap and were assigned to Pachchham sources. Those bright yellow-red sandy limestones artifacts that that fell within the range of variation for the Mool Sagar Khan source and *look* like Jaisalmer stone, very probably are Jaisalmer stone. So in the end the provenience determination made by past and present excavators based on the appearance of those artifacts was likely correct in most cases.

Most of the banded yellow-brown sandy limestone artifacts analyzed were clearly analogous to Pachchham limestone. The majority (especially the two large ringstones) grouped closely with samples taken from the Harappan period quarry near Dholavira. Similarly the gray-red sandy limestone artifacts largely corresponded with the Pachchham limestone deposits of Pachchham Island – an area that is notable for the gray type that occur there. It is always possible that sources of limestone resembling these types will be identified elsewhere or that fuller characterization of the Jaisalmer Formation may eventually result in the need to reclassify the provenience of those artifacts. The same may be the case when a larger set of samples from the Kirthar Range are eventually analyzed. However, at this time, the results strongly suggest that most examples of these sandy limestones used for large objects at Harappa derived from sources 800 km away in Kutch.

The analysis of micritic limestones in the sample set indicated that materials from multiple sources (three or more) were brought to Harappa. This is not particularly surprising as micritic limestone formations practically line the Indus Basin (particularly on its northern and western margins). A group of the Harappan artifacts appeared to be very similar to geologic samples analyzed from Rohri Hills of Sindh indicating that source *may* have been one of the ones used. However, as no other geologic sources of micritic limestone were available for comparison that conclusion should be considered tentative.

The series of chalky white porcelaneous limestone artifacts analyzed were most geochemically analogous to samples from the Rohri Hills of Sindh, although no occurrences of that type of limestone has been reported from that formation. Three samples of white Parh limestone from Balochistan were analyzed and did appear somewhat like several of the Harappan samples. Although white limestone artifacts at Harappa most probably did come from Balochistan, much more work remains to be done before they can be assigned to any particular formation.

DISCUSSION: LARGE LIMESTONE OBJECTS AT HARAPPA IN CONTEXT

Indus craftspeople used limestone to create many different kinds of objects. Some of the limestone artifacts excavated at Harappa are small in size – cubical weights, beads, inlays, discs, balls and mace heads. The great majority, however, are either bulk stone objects (as defined in Chapter 1), broken pieces that were clearly a part of such objects at one time or non-descript flakes and chunks. The flakes and chunks themselves tend to be comparatively big in size (e.g. bigger than is typical of other kinds of stone debris) and may represent waste produced during the manufacture of bulk-sized limestone objects. Or they might simply be non-diagnostic pieces broken off of already finished items of that kind. Whichever the case may be, after grindingstones (Chapter 5), most of the artifacts in Harappa's rock and mineral assemblage that fall into the bulk size/weight category are composed of one of the types of limestone discussed and analyzed in this chapter. As I have shown, several of these types seem to have been obtained from sources as far away as Kutch. In this final section, I

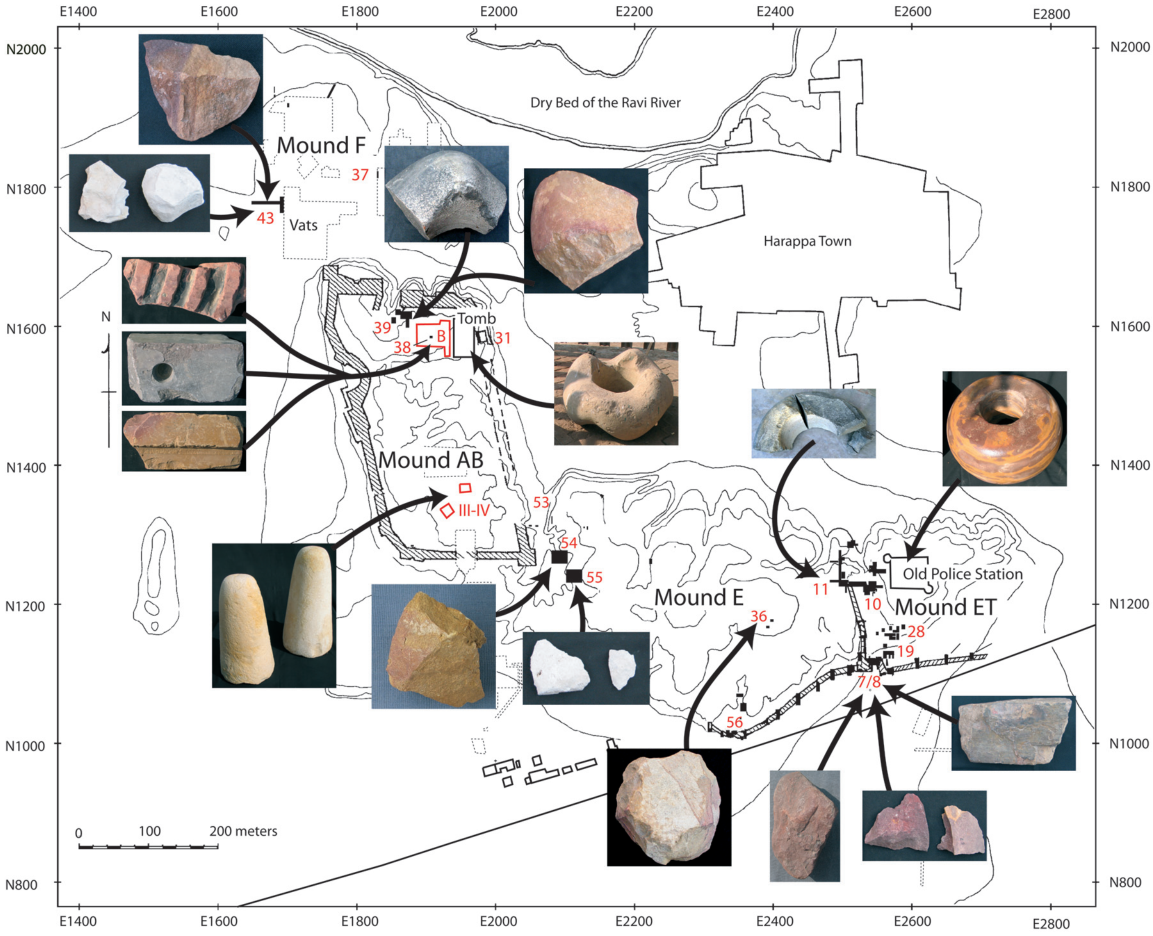

Figure 11.42 Trenches from which the limestone artifacts analyzed in this chapter came and select artifacts representing the distribution of the different macroscopic types.

discuss the spatial and temporal contexts that large limestone artifacts appear in at Harappa, as well as the possibility that their use may have represented a new form of social expression for certain groups of Indus Civilization peoples.

The 107 seven limestone samples analyzed for this study represent a little over one-third of the total assemblage for this material variety. The excavation trenches that those samples came from are marked in red on Figure 11.42. During the period of time that limestone was used most intensively at Harappa (Period 3C – discussed below) it is found on every mound at the site. The photographs on the figure are intended to selectively illustrate how the five main types of limestone do not appear to have been restricted to one area or another. For examples, the relatively abundant type yellow banded sandy limestone is found on multiple mounds. Although there is an especially heavy concentration of limestone artifacts on the northeast corner of Mound AB (Trench 39 and Sahni's Trench B), by and large, all types of this material were available to people in most parts of the site.

All of the limestone objects analyzed for this study came from either Period 3C deposits or unstratified/disturbed contexts that are most likely representative of Period 3C or later phases. In fact, finds of limestone artifacts of any kind in levels earlier than that are comparatively rare. None are found in the Ravi Phase. A handful of brownish micritic-textured limestone artifacts, including the earliest cubical weight (Meadow and Kenoyer 2001: 26), come from Period 2 levels on Mound AB. The material is absent once again from the rock and mineral assemblage during Period 3A. A dozen fragments, a cubical weight and an inlay of some kind have been recovered from 3B levels in various parts of mounds E and ET. The 250 or so objects making up the remaining portion Harappa's limestone assemblage are mostly large in size and come from deposits that date to Period 3C or later. A group of ringstone fragments and some of the blocks that may be architectural elements were found filling a depression in front of a doorway in Trench 39 together with pointed-base goblets, an association which firmly dates them to Period 3C (Meadow *et al*. 1998: 6). Although large limestone artifacts have been recovered in these levels across Harappa, it would probably be inaccurate to think of them as being common at that time – at least not in the sense that every Harappan home had a facade of carved limestone blocks or ringstones adorning their entryways. Rather, items made of this stone were likely used to a limited degree for special buildings or in important areas of the site.

Although it is difficult to say precisely where in Harappa's chronological sequence limestone artifacts from past excavations should be placed, most appear to have come from the site's later levels. For example, when excavating the "Granary" area on Mound F, Vats noted that a Jaisalmer stone mace-head recovered there appeared "to have found its way down from an upper stratum" (Vats 1940: 22). The association of the large limestone objects from Sahni's excavations on the northeast corner of Mound AB with pointed-base goblets definitely dates them to around Period 3C (Vats 1940: 139). Interestingly, at Mohenjo-daro the utilization of limestone for large objects also seems to have been mostly restricted to that site's "Late Period", a time roughly equivalent to the latter part of the urban phase at Harappa. A cache of 18 large limestone ringstones was found in a Late Period side chamber of House V in the HR area (Sahni 1931a: 191) and several more were recovered in the same levels in Area L (Mackay 1931b: 174). Marshall noted that the limestone blocks from the Rohri Hills used for drain covers at Mohenjo-daro, did "not seem to have been introduced before the Late Period" (Marshall 1931c: 31). Even a series of comparatively large stone statues, several of which were made of limestone, came from the later levels at that site (Ardeleanu-Jansen 1984, 1991). It would therefore appear that during the latter part of the Indus Civilization's urban phase (ca. Period 3C at Harappa), limestone began to be utilized at the two largest Indus cities a great deal more than it had been in previous times, especially to create objects that were of larger size than Harappans typical made up to that point. The question then arises – why at that time and not before?

The increased use of limestone at Harappa in the late urban phase cannot be explained by new found access at that time to the source regions examined in this chapter (except *perhaps* Jaisalmer). Evidence presented elsewhere in this book demonstrates that rock and mineral resources were being brought to the site from Gujarat (agate-carnelian), Sindh (chert) and Balochistan (lead) prior Period 3C. Advancements in the ability to transport stone in bulk sizes long distances do not provide a suitable explanation either. Carts capable of handling heavy loads appear to have existed since the Early Harappan Phase (Kenoyer 2004). The use of watercraft to move heavy loads long distances is implied by the finds of large Harappan black-slipped jars (made at cities like Harappa and Mohenjo-daro and capable of holding 30 to 40 liters of oil, wine or some other substance) at sites across the Arabian Sea in Oman (Méry and Blackman 1999).

Rather than changes in source access or transportation technologies, the evident shift at Harappa (and possibly Mohenjo-daro) in limestone utilization likely had more to do with the nature of this particular material variety in combination with the preferences of those who would use it. Although limestone was widely available across northwestern South Asia, it probably was not used a great deal prior to the late urban phase simply because, for the most part, it was a material that did not suit the needs of Indus craftspeople or the wants of consumers during earlier periods. Harappans could have easily used it for grindingstones but sandstone-quartzites and igneous rocks were available and are much superior materials for that purpose. Limestone was sometimes used to make cubical stone weights but harder rocks like chert were clearly preferred (≈ 80% of such weights at Harappa are chert – only ≈ 5% are limestone). The reason it was so seldom used to create personal ornaments or other small items probably was because Harappans had access to rocks that were much more durable and/or aesthetically pleasing to them.

On the other hand, limestone is an excellent material to use when making large objects. It tends to break with a conchoidal fracture and is softer than sandstone, quartzite or igneous rocks such as granite or diorite. Thus, objects like ringstones are more easily roughed out and carved from limestone. At the point in time when Harappans began to feel the need to create larger objects out of stone, it was a natural material for them to choose. Huge formations of limestone were accessible within a distance of 250 km from Harappa in Sulaiman Range and Salt Range and they may very well have used some of the micritic types from those sources. Certain types, although found in more distant locations, were clearly desired for their aesthetic properties just as they are today (e.g. Jaisalmer stone). That different types of limestone from multiple sources were used at Harappa and that some of those sources were quite far from the site simply reflects the great extent of rock and mineral exchange networks in place during Period 3C.

However, the question remains – why, especially if sources were readily accessible and the technologies needed to move heavy stone had long existed, was it not until the latter part of the urban phase (ca. 2200-1900 BC) that large limestone objects began to appear at sites like Harappa and Mohenjo-daro? I believe that this phenomenon probably reflects a new development in the way Harappans (or at least certain Harappans) expressed social power through the consumption and display of stone. Until that point, the creation of small, high-value personal ornaments that signaled the status of those wearing them was one of the principal means through which social and economic hierarchy in the Indus Civilization was marked and maintained (Kenoyer 2000). The wealth-status value of such ornaments is argued to have been largely dependent on two factors – the relative scarcity of the raw materials being used and the level of technological complexity/virtuosity needed to turn them into finished items (Kenoyer 1992a: 45; Vidale and Miller 2000). With bulk stone objects *size* becomes a relevant third factor. A single ringstone weighing 100 kg would have required as much effort, energy and/or expense to bring to Harappa from Kutch as would 100 kg of high quality carnelian nodules. The difference is that with the nodules hundreds, perhaps thousands, of carnelian beads could have been created and dispersed while with a ringstone all of the effort-energy-expense was concentrated within a single item. Bulk stone objects of this kind thus would have probably been important symbols of wealth, prestige and power for Indus Civilization peoples living at settlements located upon the alluvial plains. Their display may have also been a visible marker of a social or territorial relationship held with the distant region where the stone originated. Using such stones in the construction or adornment of religious spaces, private buildings or public areas such as gateways or streets would have been a powerful expression of a person's, a social group's or an organization's ability to expend energy, wealth or influence (probably all three). The timing of the emergence of this new behavior at Harappa and Mohenjo-daro is interesting as it roughly coincides with other changes seen at those cities during the latter parts of their urban phases such as the widespread use of pointed-base goblets and fluctuations in civic control evident as periods of degrading architecture and poor maintenance of public thoroughfares (Dales 1979: 193-194; Kenoyer 1993: 186-187).

CHAPTER CONCLUSION

The acquisition and use during Period 3C at Harappa of expensive-to-transport large limestone objects from multiple sources, some as far away at Kutch, represented a new way for Indus Civilization people living there to express prestige and power using stone. In the following chapter, I attempt to identify the geologic sources of various metals – a category of material the use of which may also have been, at times, prestige-related.