

# A TECHNIQUE FOR DETERMINING THE PROVENANCE OF HARAPPAN BANDED LIMESTONE "RINGSTONES" USING ICP-AES

Randall W. LAW and James H. BURTON

Department of Anthropology, University of Wisconsin-Madison

## 1. INTRODUCTION - BANDED LIMESTONE ARTIFACTS AT HARAPPA

Among the largest artifacts recovered at Indus Civilization (ca. 2600 to 1700 BC) cities in Pakistan and northwestern India (figure 1) are limestone "ringstones". Two ringstones found at the northernmost Indus city of Harappa are composed of a distinctive yellow-brown sandy textured



Figure 1. Indus Civilization cities and banded limestone sources.

limestone with reddish-brown bands and patches (figure 2). Several dozen flakes and fragments of this particular variety of banded limestone have also been recovered. For this study, 29 banded limestone artifacts (including the two ringstones) from Harappa were compared with two potential sources of that material using elemental data obtained through partial digestion of powdered samples and analysis using an inductively-coupled plasma atomic emission spectrometer (ICP-AES).



**Figure 2.** Banded limestone ringstones from Harappa. Scale = 0.5 meter.

## 2. POTENTIAL SOURCES OF BANDED LIMESTONE IN THE INDUS REGION

While limestone is found in abundance in each of the major geologic provinces surrounding the Indus Basin, there are few formations where material having the distinctive banding and sandy texture occurs. The most well-known source is in the vicinity of Jaisalmer in western Rajasthan, India, 450 km south-southwest of Harappa (figure 1). The limestone deposits of Jurassic age that occur here have long been exploited as a source decorative building stone (Agrawal et al. 1999) and past excavators at Harappa used the term 'Jaisalmer stone' to describe various artifacts found at those sites (Vats 1940: 358). Twenty five samples from three locations - Mool Sagar Khan, Jethway, and Habur, in the Jaisalmer Formation were analyzed for this study. Another possible source of the banded limestone artifacts from Harappa has recently come to light nearly 800 km to the south-southwest in the Kutch region of Gujarat, India. Here the Pachchham limestone formation of Jurassic age is found on several islands located within the intermittent inland sea known at the Great Rann of Kutch (Merh 1995). The southernmost Indus city

of Dholavira is located on one of these islands called Khadir (Bisht 1990). Twenty nine samples were collected for analysis from an ancient limestone quarry located 3 km north of Dholavira.

### 3. GEOCHEMICAL ANALYSIS OF BANDED LIMESTONE ARTIFACTS AND SOURCES USING ICP-AES

Banded limestone samples were analyzed using the ICP-AES facilities at the Laboratory of Archaeological Chemistry, University of Wisconsin-Madison. Preparation of geologic samples 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. The one gram sample was crushed to provide a homogeneous, representative sample from which a smaller sample could be taken for analysis. For all samples exactly 0.004 g of homogenized powder was weighed out and placed in a polyethylene analysis vial. One milliliter of nitric acid was placed in each vial and the samples were left to dissolve for 24 hours. After that time they were filtered of any remaining mineral particulates and 19 ml of purified water was added. This solution could then be passed through the ICP-AES, which is capable of quantifying a wide range of elements at parts-per-million levels. All samples were analyzed during a single session and data was acquired for the elements Ca, Ba, Sr, Mg, and Fe. Because there was a large component of quartz in these sandy limestones we were uncertain of precisely how much calcium carbonate was dissolved from sample to sample. We therefore divided each element by measured Ca to normalize for variable carbonate content, expressing the results as Ba/Ca, Sr/Ca, Mg/Ca and Fe/Ca. The resulting data were converted to log 10 values and subjected to exploratory canonical discriminant analysis (Baxter 1994) using SPSS 10.1 to evaluate the extent to which the two sources could be distinguished from one another and the degree to which archaeological samples resembled either source.

### 4. RESULTS

Figure 3 shows all samples plotted using discriminant functions derived from measured concentrations Sr Ba Mg Fe (each divided by Ca and log normalized). Geologic samples from the Jaisalmer formation were split into two groups: samples from Jethway and nearby Mool Sagar Khan (MSK) were combined as one group while the Habur samples are another. These were compared to the group of Pachchham limestone samples from the prehistoric quarry Khadir Island. While there is a degree of overlap between the outliers of the Jaisalmer and Pachchham formations, good separation overall between

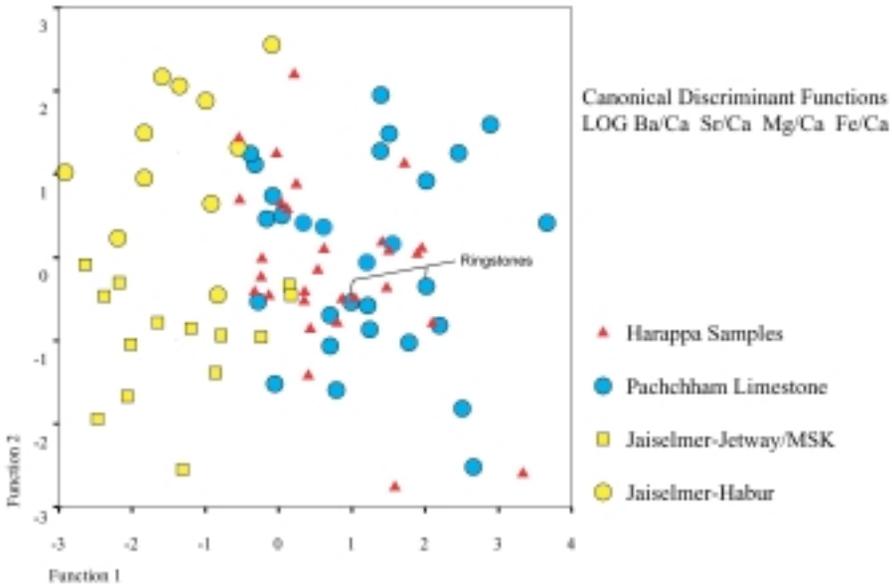


Figure 3. ICP-AES Analysis of Banded Limestone Sources and Artifacts.

the three groups was achieved with nearly 77% of cross-validated cases correctly classifying. When the archaeological samples are superimposed over the sources as ungrouped cases it is evident that they very much tend to cluster with the Pachchham formation samples. Some of the archaeological fragments (red triangles) fall within the overlapping margins of the two formations and, because they are closer to the center of one of the Jaiselmer groups, are classified as belonging to them. However, they may in fact be similar to outliers of the Pachchham formation, which themselves are misclassified as belonging to one of the Jaiselmer groups. Samples taken from the two ringstones (noted on figure 3), however, fall unambiguously in the center of the Pachchham group cluster.

In order to more clearly present the data as a comparison between the two source formations, all of geologic samples from the Jaiselmer formation were compared as single group to the Khadir Island quarry samples using canonical discriminant analysis. The resulting discriminant scores were used generate the box plots of the two formations and plot the archaeological samples (figure 4). Good separation between the two source formations was again achieved even though there is still a small degree of overlap evident. When the archaeological samples are plotted it is strikingly clear that they cluster within the range of Pachchham formation. In this plot even those archaeological samples that could potentially be outliers of the Jaiselmer formation fall closer to the center of the Pachchham cluster. The ringstone samples (noted on figure 4) are once again aligned with the center Khadir Island quarry source.

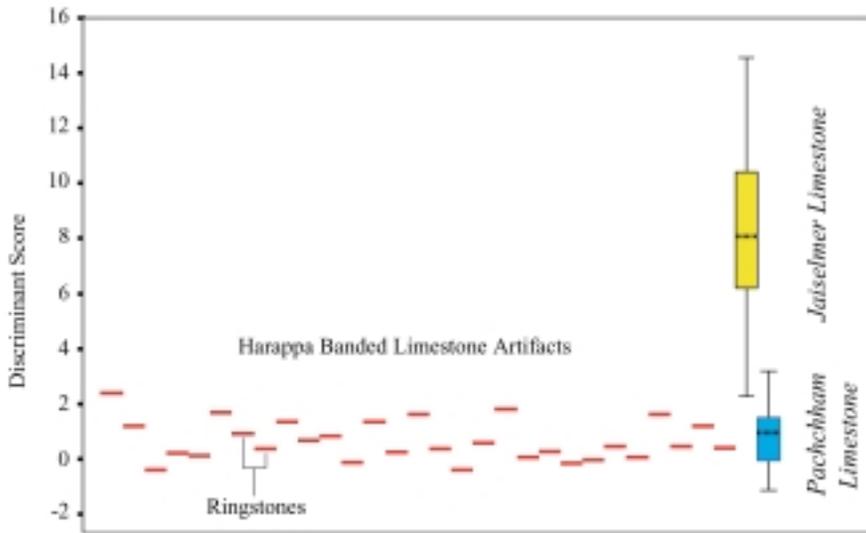


Figure 4. ICP-AES Analysis of Banded Limestone Sources and Artifacts (BOX PLOTS).

## 5. CONCLUSION

This study is ongoing. Additional geologic samples are to be analyzed that will help to generate a clearer picture of geochemical variability in the potential source formations and to provide a larger data set for more statistically secure provenance appraisals. Other potential sources of banded limestone elsewhere in the Indus region may come to light and that will have to be evaluated also. At this time, however, the evidence strongly suggests that, of the two potential sources examined, the banded limestone ringstones and fragments excavated at Harappa most likely derived from the Pachchham formation of northern Kutch, perhaps from the ancient quarry near Dholavira itself.

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