Experimental and Ethnoarchaeological Approaches to Indus Seal Production: Modeling Variation in Manufacturing Techniques

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Abstract*: Inscribed steatite seals are among the most well-known and emblematic forms of material culture from the Indus or Harappan Civilization (2600-1900 BCE). As the primary medium of the Indus writing system, which has yet to be deciphered, they have been the focus of numerous studies for over a century. Most of this research has examined the script, iconography, or basic morpho-metric properties of seals. Comparatively little attention has been paid to the tools, technologies, and labor used to produce Indus seals since the original site reports from Harappa and Mohenjo-daro, both of which provided detailed discussions of how production may have been conducted. This paper presents a summary of my experimental and ethnoarchaeological studies of Indus seal carving technologies and techniques. In replicating specific aspects of production technologies using tools and techniques that would have been available to Indus craftspeople, it has been possible to model the labor involved in seal manufacturing. These data can be tested against archaeological materials through detailed comparative analyses with seals recovered at sites throughout the Indus. Examining different tool types that may have been used to produce seals and comparing them with examples from Indus material assemblages indicates that certain types of tools are more effective for carving seals than others. Working with professional steatite carvers in Udaipur, India, to replicate aspects of Indus seals, it has been possible to model specific aspects of labor involved in production, as well as clear patterns of variation amongst different carvers. Taken together, these studies represent an innovative and multi-faceted approach to the study of Indus seal production, one that contributes to our understanding of one of its most important craft traditions.*

Keywords: Inscribed Steatite Seals, Indus Civilization, Ethnoarchaeology, Experimental Studies, Udaipur, Harappa, Mohenjo-daro

Introduction

Inscribed steatite seals are among the most important artifacts of the Indus or Harappan Civilization (2600-1900 BCE). Today these small, finely carved stone objects are considered diagnostic features of Indus material assemblages and are often used to identify the Harappan character of a site (fig. 1). Inscribed steatite seals come in a variety of shapes and sizes and would have served a number of purposes during the

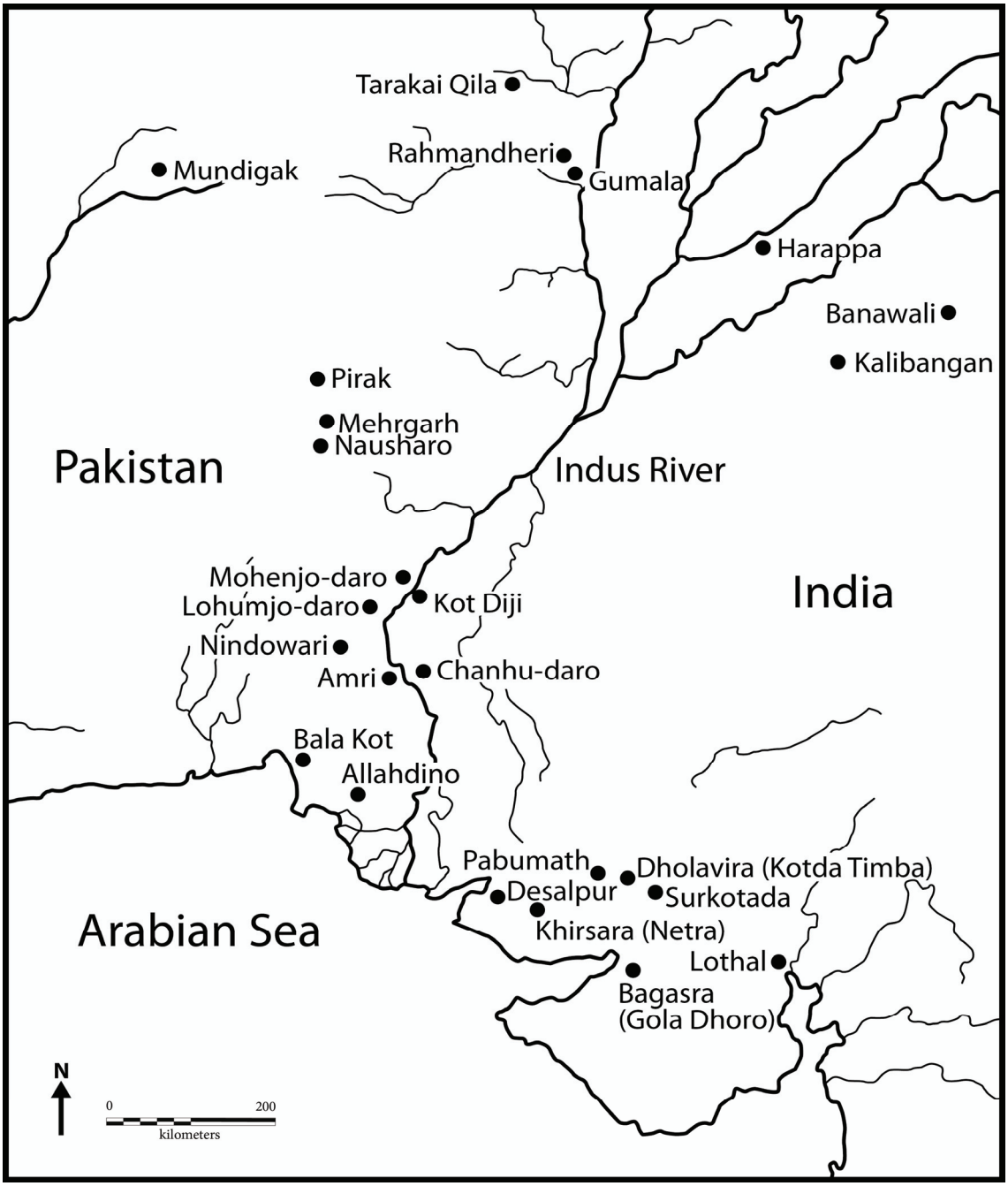

Figure 1: Map of Indus Civilization sites in India and Pakistan

Harappan Phase. In addition to codifying and recording important economic transactions, ritual narratives, and personal property and ownership, seals would have also served as emblems of wealth and power, used by ruling elites to legitimize and reinforce the social order within the Indus cities and other settlements (Kenoyer 2000). In this context they can be viewed as symbols of elite control, and in studying them we can learn much about ancient Indus culture. Yet despite the importance of seals in Harappan society, many unanswered questions remain concerning how and where they were made, and how production would have varied within and among different

sites. At first glance they appear to be highly standardized and homogeneous, but upon further inspection differences can be seen in the ways in which they were carved, even amongst those carved with the same iconographic motifs. This study aims to address this issue through experimental studies and ethnoarchaeological investigations of contemporary steatite crafting in India, including replication of specific aspects of Indus seal production. Using replica carving tools to engrave steatite seals has revealed that certain types of tools are more effective than others, and different tips and edges on these implements are more efficient for specific carving tasks than others. Ethnoarchaeological research with professional steatite carvers in Udaipur, Rajasthan, indicate that there are numerous sources of variation among different artisans, but individual carving styles and varying skill levels create visible differences in finished products, even when all other aspects of production are controlled. This suggests that through systematic stylistic and metric analyses it is possible to "fingerprint" seals and group them based on shared attributes. The application of this method to archaeological materials will provide new insights into the organization of this important craft tradition and can ultimately be used to evaluate our understanding of larger aspects of social and political organization and control. Future research focusing on these issues will undoubtedly increase our understanding of one of the world's earliest urban societies.

Background

As the south Asian subcontinent's earliest civilization, the Indus also represents one of the world's earliest manifestations of urbanism, contemporary with ancient state-level societies in Egypt and Mesopotamia (Kenoyer 1998). The Indus Valley Tradition (Table 1) is one of the chronological frameworks used to document the history of cultural adaptations in the region where the Harappan Civilization flourished. While the sophisticated urbanism that characterizes the Indus reached its apex during the Integration Era of the Harappa Phase (2600-1900 BC), the processes responsible for these developments have their antecedents during the Early Food-Producing and Regionalization Eras. In addition to large, well-planned urban centers, the Integration Era is also characterized by material homogeneity, although recent and ongoing studies (Kenoyer 2008; Possehl 2007) indicate that regional variation is present in many forms of material culture. Because of this and the lack of other salient features usually associated with early states there is still considerable disagreement over Indus social and political organization, specifically whether it represents an ancient state or chiefdom (Kenoyer 2008).

Kenoyer (1994, 2000) and others (Wright 2010) have argued that the Indus cities were ruled by competing groups of elites; likely composed of merchants, land owners, and ritual specialists. Some of these elites would have been literate, using writing on pottery and inscribed seals to record economic transactions, important rituals, and communicate over great distances. This form of sociopolitical organization can be characterized by a city-state or decentralized state model. These competing groups of elites, as well as the majority of the rest of society, were likely integrated at multiple

levels, including economic interaction and a poorly understood ideological system (Kenoyer 2000). Conversely, Possehl (2003, 2002, 1998) and others (Fairservis 1986, 1989; Shaffer 1982, 1992) claim that the Indus civilization represents a non-state or chiefdom level of sociopolitical organization. Such arguments are based primarily on the absence of features usually associated with state-level societies, including palaces, royal tombs, and overt evidence of centralized authority.

Table 1: Indus Valley Tradition (after Kenoyer 2008)

Era	**Phases**	**Time Period**
Foraging Era	Mesolithic and Microlithic	10,000-2000 BCE
Early Food Producing Era	Mehrgarh	7000-5500 BCE
Regionalization Era	Early Harappan Phases: Ravi, Hakra, Balakot, Amri, Sheri Khan Tarakai, KotDiji, Sothi	5500-2600 BCE
Integration Era	Harappan Phase: Harappa Site Period 3A Harappa Site Period 3B Harappa Site Period 3C	2600-1900 BCE 2600-2450 BCE 2450-2200 BCE 2200-1900 BCE
Localization Era	Late Harappan Phases: Punjab, Jhukar, Rangpur	1900-1300 BCE

Regardless of these uncertainties, it is clear that the Indus represents a complex, urban civilization that is unique in comparison with contemporary polities in the Old World. The similarities in material culture and urban planning suggest the presence of a complex administrative body that would have integrated major urban centers and smaller settlements alike (Kenoyer 2008). This integration would have been accomplished in part through the production and use of numerous craft items, including inscribed steatite seals.

Indus Seals

As the primary medium of the Indus writing system, seals would have played a variety of important roles. While there is a considerable amount of variation in the types and sizes of inscribed seals from the Indus Civilization, the most common are often referred to as stamp seals (Mackay 1931) because they were used to stamp wet clay and possibly other soft materials, evidenced by the discovery of seal impressions and sealings. Within the category of Harappan stamp seals there are two principal types: square seals that usually depict a line or two of script with an accompanying

animal motif, and rectangular seals that often depict only script (Rissman 1989). Square seals with the unicorn motif are the most common type found at most Harappan sites, and will therefore be the primary focus of this study (fig. 2).

The motif has been called a unicorn because it appears to represent a single-horned bovid that is characteristic of the mythical unicorn, and its representation on Indus seals is the earliest known example anywhere in the world (Kenoyer 2010). Other representations of the unicorn can be seen in terracotta figurines, which indicate that it was meant to be distinct from other bovids and does not depict a two-horned animal shown in profile. Indus seals engraved with animal motifs that clearly represent bulls and other bovids with two horns support this idea as well. Engravings on seals are often finely decorated with numerous trappings, and it is through the careful study of them that variation in carving styles can be seen. The large number of recovered seals carved with this motif indicates that it was important to the Harappans and their ideologies and beliefs (Kenoyer 2010). Currently there is no archaeological evidence to suggest the existence of a living, breathing unicorn during the Harappan Phase. Regardless, its presence in carved steatite seals and terracotta figurines serves as evidence of its importance during the Indus civilization.

Steatite, or soapstone, is a soft and easily workable stone comprised primarily of the mineral talc (Deer et al. 1992). It usually ranges between 1-3 on Moh's scale and its composition and hardness are influenced by inclusions and parental formations. Due to its softness, it has been a favored stone for carving in south Asia and elsewhere for thousands of years, and continues to be used today. It is infusible with heat but will become much harder after firing, a practice employed by ancient Indus artisans (Kenoyer 1998). The combination of ease in carving and increased durability after firing made steatite a very important raw material to the Harappans, who used it to encode and transmit culturally significant information throughout the region in part through the medium of an inscribed script.

Among their many functions, inscribed steatite seals would have served as symbols of wealth and power, used by ruling elites to legitimize and reinforce the existing social order within the Indus cities (Kenoyer 2000). It follows then that they can be viewed as symbols of elite power. By studying seals it should be possible to learn more about social and political organization and control by testing current models that characterize both. Modeling the organization of seal production and use under varying forms of socio-political organization and testing against current archaeological evidence provides a method for evaluating current frameworks for explaining Indus social and political organization and control. A critical examination of spatial and temporal distributions of seals, as well as comparative analyses with other important administrative types of Indus material culture, will further refine our understanding of seal production and its relationship to larger issues of social and political organization. Identifying and understanding the sources of variation in seal carving techniques and traditions will allow us to isolate groups of seals that would have been carved in

different workshops. In order to accomplish this it will be useful to identify potential sources of variation among different carvers.

Methodology

To examine and understand potential sources of variation among different producers, detailed ethnoarchaeological investigations of contemporary steatite carvers were undertaken. Ethnoarchaeology can be described as material-based ethnographic studies of living communities, consisting of complementary approaches used to examine the relationships between materials and culture in its entirety (David and Kramer 2001). Ethnoarchaeological research has a long and fruitful history of employment in anthropological archaeology (David and Kramer 2001; Gould 1978; Hardin 1979; Kent 1987; Kramer 1979, 1996; White and Thomas 1972), utilizing analogies to construct inferences about prehistoric human behavior (Wylie 1985). These studies have been used to develop models that can be tested using archaeological data (David and Kramer 2001; Gould 1978). Research on modern carnelian bead making in India has provided useful models for understanding the organization of Indus bead production (Kenoyer et al. 1991; 1994). The current study attempts to build upon this body of ethnoarchaeological knowledge through the detailed analysis of a craft tradition that until now has only been marginally documented (Ascher 1995, 2003; Vidale and Shah 1990).

After selecting Udaipur as a field site, based on its steatite carving industry, much of which relies on traditional, non-mechanized forms of production similar to those that would have been available to Indus craftspeople, we met and contracted three stone carvers to replicate various elements of unicorn seals. This included fashioning replica carving tools, based on designs published in early site reports, and providing the carvers with three-dimensional and photographic models of Indus seals to use in the experiments. To ensure that we did not unintentionally create or foster a market for illicit replicas, inscriptions, bosses, and whitening and firing of the seals were not included in the study. Raw materials were provided by each informant from his own stores. We worked with all three of our informants individually and as a group, observing and recording their carving techniques. For the most part we did not provide them with any instruction; we merely recorded how and why they carved the replicas the ways they did. We made a total of four visits to Udaipur over a period of six months. Finished products were recorded and labeled with unique numbers for ongoing analyses, and all stages of the experiments were documented using digital photography, detailed field notes, and informal informant interviews. The last component of the research consisted of working with all three informants simultaneously in a workshop simulation. As mentioned above, these studies were undertaken in order to identify and model potential sources of variation among different artisans.

Ethnoarchaeological investigations were supplemented by experimental studies to investigate the cut-marks created using different carving tools. Experimental research

has a long history of use in the field of archaeology, dating back to at least the 19th century (Forrest 2008). Though lacking a formal, unified theoretical base, experimental studies have been used to address numerous archaeological problems on a global scale, using many different methodologies. I prefer the definition proposed by James Skibo, who concisely explains it as "the fabrication of materials, behaviors, or both in order to observe one or more processes involved in the production, use, discard, and deterioration, or recovery of material culture" (Skibo 1992:18). This research was undertaken in the Laboratory for Experimental Archaeology in the Department of Anthropology, University of Wisconsin Madison, under the supervision of Professor J. M. Kenoyer. After using different replica carving tools to engrave various elements of the unicorn motif, silicone casts were made and examined under the scanning electron microscope (SEM) to identify differences in the engraved surfaces created using these tools. The results of these investigations are discussed in detail below.

Results

The results of the ethnoarchaeological investigations have provided new insights into the types of tools that may have been used to craft Indus seals. As noted above, replica tools were made and used for all of the carving experiments. Each of these tools had at least one and in most cases two different tips that were tested by each informant to evaluate its effectiveness for carving Indus seals (fig. 3). The raw materials selected included bronze, bone, copper, shell, and stone. All were made by local artisans in Udaipur. The raw materials chosen for tool fabrication, as well as the different tips and edges, were chosen based primarily on published examples from the sites of Harappa, Mohenjo-daro, Chanhu-daro, and Lothal ((Mackay 1938, 1943; Marshall 1931; Miller 2000; Rao 1985; Vats 1940). These consist of chisels, burins, awls, needles, and other pointed tools that may or may not have been used in seal carving. As there are no stratigraphically excavated seal workshops with seals, manufacturing debris, and tools found in context, it is not possible to determine whether these types of tools were used in seal production. However the fact that they have been found at these sites suggests that it is a possibility.

All five raw material tool types were successfully used, and macroscopically there are no major differences among the finished products created by our informants with each in terms of cut-marks, engraved surfaces, and overall carving style (fig. 4). It is necessary to examine engraved surfaces created with each tool type microscopically in order to determine if and what any potential differences are, which is discussed below; but this suggests that tool raw material type (e.g. bronze, copper, bone) is not as important as other factors as a potential source of variation. Our carvers all agreed with this statement as well, claiming that light, steatite quality, and model choice (three-dimensional to scale versus blown up photograph) were much more significant in terms of being able to carve successfully. However, not all tool types were preferred equally.

All three informants in Udaipur preferred tools fashioned of bronze over the other raw

Figure 2: Inscribed Indus seal with unicorn motif (Courtesy J. M. Kenoyer)

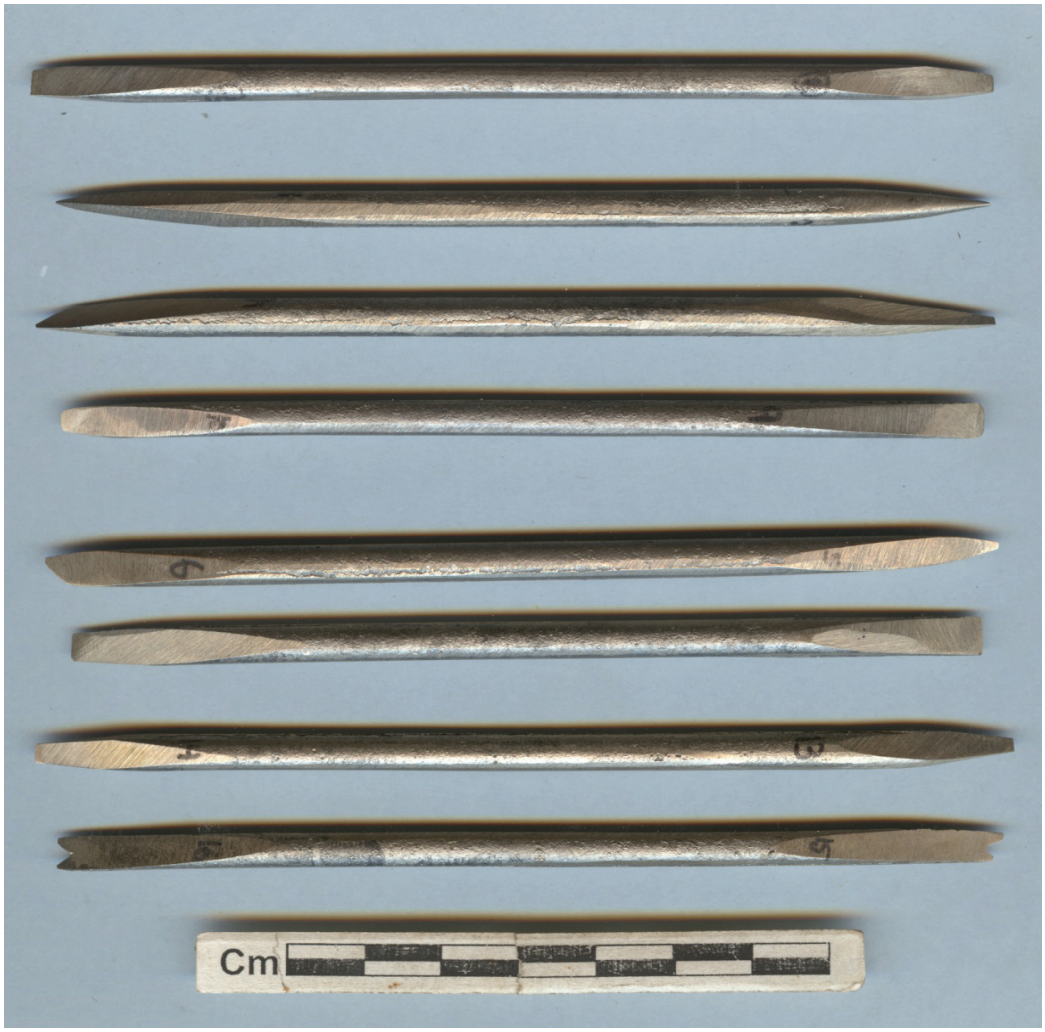

Figure 3: Bronze replica carving tools

material types. This was because the bronze tools were harder and more durable than the other materials, and therefore required less sharpening. After bronze, bone was favored, because it maintained a better edge than the copper and stone implements

and was far less brittle than those made of shell. Although copper and stone tools were effective for crafting the replicas, all three informants agreed that they did not maintain sharp edges as well as bronze or bone. The copper tools required frequent sharpening as their tips and edges became quickly dulled through use. The uneven and jagged edges of the stone tools, which included drills and burins, made it more difficult and time-consuming to produce fine, smooth engraved surfaces. Since none of the artisans regularly work with stone tools, they were not familiar or comfortable with rejuvenating the tips and edges through pressure flaking techniques. Shell tools did not need to be re-sharpened as frequently as copper or stone, but they were the most brittle, and two of them broke during the carving experiments. These differential preferences in tool raw material types, based primarily on very practical, functional choices, may have also influenced tool selection of Indus seal carvers.

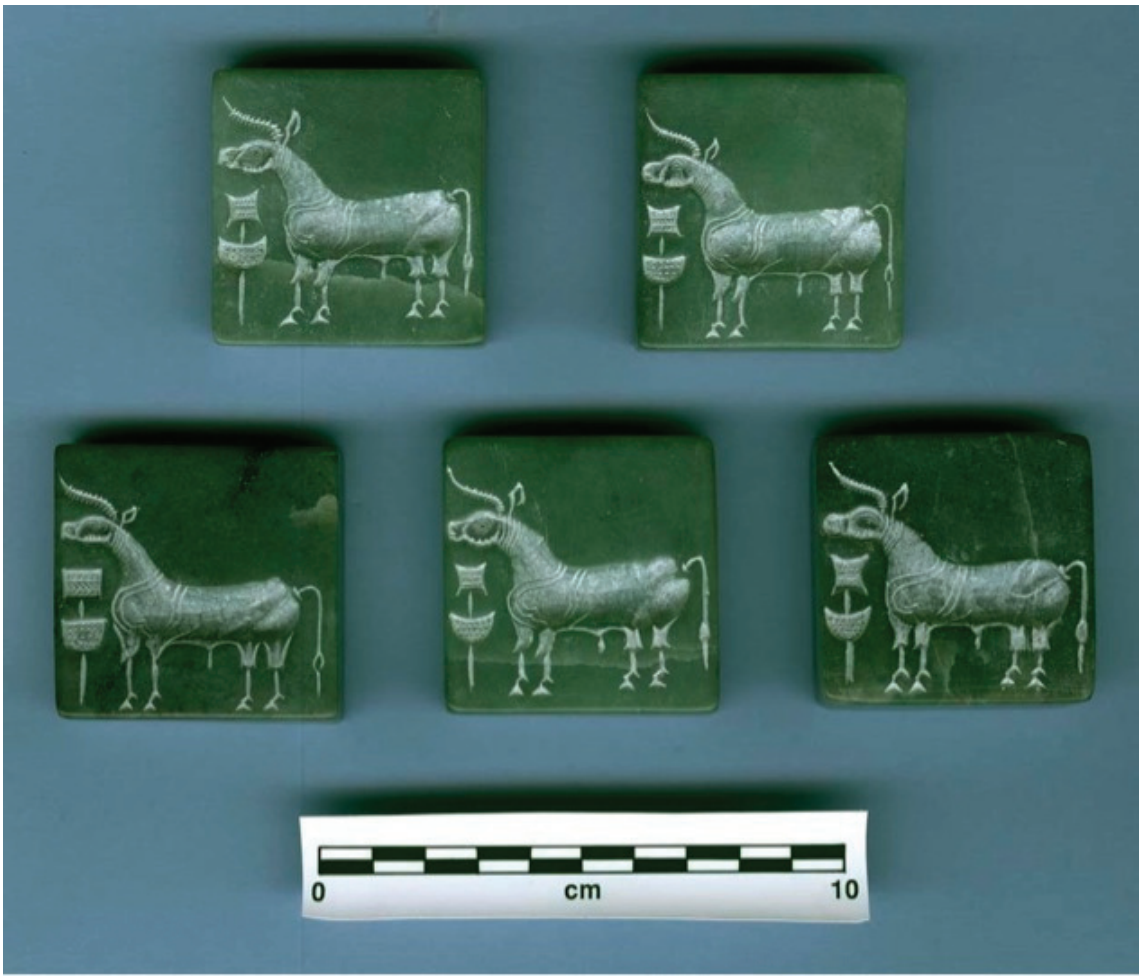

Figure 4: Replica unicorn seals made with tools made from all raw materials

Another important discovery from this study is that tools with different tips and edges are generally speaking more effective for specific tasks than others. For example, tools with pointed tips (fig. 5) are useful for drilling small, fine details of the unicorn, such as the eyeball or decorative elements on the offering stand, than those with flat or beveled

edges. Implements with beveled, or sharpened edges are much more effective for linear engraving, particularly the fine incised lines that often adorn the unicorn's head, neck, and body, as well as the horn and ear. For engraving, smoothening, and finishing all other aspects of the motif, tools with flat tips were preferred (fig. 6). It is also worth noting that all three of my informants used tools with either pointed or constricted tips, those with expanding or wide ends (wider than the body of the tool) were primarily excluded because they were too large for carving the unicorn effectively.

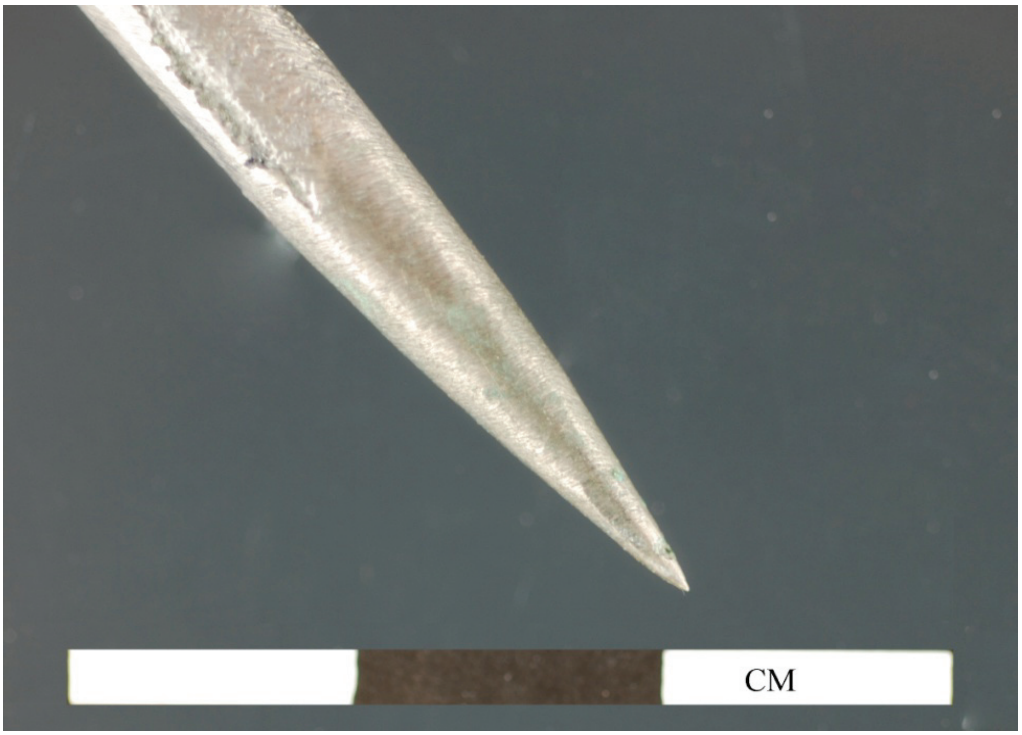

Figure 5: Bronze replica carving tool with a pointed tip

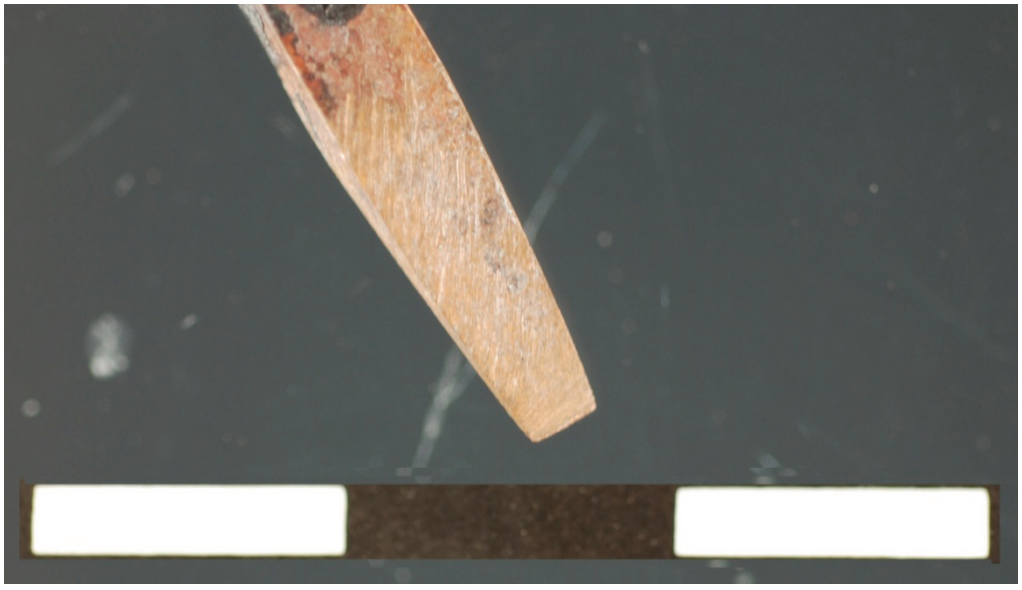

Figure 6: Copper replica carving tool with a flat tip

The results of this study indicate that different raw materials, tips, and edges on carving tools may have been important factors in and influences on Indus seal carving traditions. Though these preferences can't be seen directly, and are difficult to identify macroscopically, they can still be tested against archaeological data. The best way to do this is by examining cut-marks on seals, which reflect the tools that were used to create them. The scanning electron microscope represents a powerful method for studying these issues, and has been used by other researchers in the Indus and elsewhere (Kenoyer 2005, 2006; Kenoyer and Vidale 1992; Sax and Meeks 1995). By comparing cut-marks made with experimental and ethnoarchaeological samples with those from archaeological contexts, it may be possible to identify similarities and differences that will help distinguish the types of tools used to carve Indus seals. These studies are ongoing, and will be published upon completion. It is also important to note that tool selection and use also appears to be correlated to individual carving techniques and style, a subject that we turn towards now.

Individual Carving Techniques and Style

One of the most important results of the ethnoarchaeological studies in Udaipur is that individual artisans craft seals differently, even when using the same tools, stone, and model. In this sense seal carving appears to be akin to handwriting, everyone does it a little differently. This statement is based on the discovery that each producer crafted the replicas using a unique, idiosyncratic style that is clearly distinct (fig. 7). Simple visual inspection confirms that seals made by one informant do not look like those carved by another in terms of style and scale, despite the fact that they were made using the same tools and models. In other words, there is marked and easily identifiable variation in the finished products of samples created by each carver. It follows that seals made by an individual are comparable to the others made by the same carver; in fact in some cases they are nearly identical. This indicates that each of our informants had their own unique carving style, but does not provide any real insight into what the sources of variation amongst each are. A closer look at the style and technique of each individual carver may shed further light on this.

Our first informant, Ganga Ram, followed a fairly standardized production sequence after completing his first few seals, and for the most part used the same suite of tools (regardless of raw material type) to craft them. From the outset, Ganga Ram created an outline of the unicorn and offering stand before engraving, which was remarkably consistent in terms of scale, in large part because the steatite blanks that he engraved were of fairly standardized proportions. In most cases he began with the body, starting in the rear and working towards the front. This was followed by engraving the neck, then the head and face, including external elements associated with them such as the horn, ear, mouth, and eye. Legs and tail were carved next, and the ritual stand was done last. When asked about this consistency he told us that following the same sequence and using the same tools allowed him to replicate the models as accurately as possible. Compared to the original models used, his seals were the most accurate in terms of style and scale (fig. 8). In spite of this, there are still clear differences, most

visible in the small, finely engraved details of the unicorn and offering stand. Collectively, his seals also contained the least amount of variation, stylistically and proportionately, and are easily distinguished from those made by the other artisans. It is only through comparative stylistic and metric analyses that it is possible to identify these differences, and they characterize his own unique carving style.

Anil was our second informant in Udaipur, and like the other two he has been carving steatite professionally for over ten years. His production sequence was much less standardized than Ganga Ram's, and his choice of tools was inconsistent and variable. In some cases he created a pencil outline before engraving, in others he simply began engraving. The choice of where to begin carving was not patterned either, on some seals he began with the body, others the head, and in one instance he created the legs and hooves first. In spite of this variation, it is still easy to distinguish his seals from those made by the other artisans. Generally speaking, his carving style is much more bold and angular than either of the other two, reflected in the large, broad elements of the unicorn compared to the others. His seals were more variable than Ganga Ram's when compared with the original models, but less so than those of the third carver (fig. 9). These evaluations were made on the basis of the stylistic and metric similarities between Anil's seals and those of the original models, as well as the amount of variation in both categories within the full sample created by him. As with Ganga Ram, the signatures of Anil's unique carving style are most visible in the small, finely engraved details of the unicorn, including the eye, ear, legs, and hooves.

Figure 7: Replica seals carved by three artisans from Udaipur

The last artisan we worked with in Udaipur is called Virma, he is related to both Ganga Ram and Anil by marriage (purportedly most of the steatite carvers there are) and has

been carving professionally for twelve years. We spent the least amount of time working with him, and therefore he crafted the smallest sample of seals (n=30). His seals were the least accurate compared to the original models (fig. 10) in terms of style and scale. The bodies of his unicorns are much shorter and more stout than the other carvers, and they also lack the elongated, skinny necks that characterize most of the seals made by Ganga Ram and Anil, as well as the original models. There are also clear differences in most other elements including the head and face, horn, ear, and legs and hooves. All of these together characterize his unique carving style. Within the sample of thirty seals he created, there is less stylistic and metric variation than observed in Anil's, but more than Ganga Ram's. Virma only used a single tool to carve most of his seals, and rarely referred to the models after completing the first few samples. It was clear from the outset that he was not very interested in the project, and after just a few weeks he claimed he did not have time to continue.

The results of this study clearly suggest that different artisans have their own unique carving styles, and that it is possible to distinguish or fingerprint their seals through simple stylistic and metric analyses. However, these first experiments did not reveal exactly what factors are responsible for variation in carving styles. Since each informant had a different operational sequence, used different tools, and relied upon models to varying degrees, it is possible that at least some of the diversity seen in their carving styles is related to these issues. Other reasons may include raw materials, relative sharpness and effectiveness of tools, and time spent in production, to name but a few. For this reason we decided to undertake additional experiments with all three informants working together, regulating as many of these variables as possible in a workshop simulation to determine if there were still differences in their finished products.

Workshop Simulation

The workshop simulation took place over a period of three days at Ganga Ram's home in Udaipur. All three artisans worked together simultaneously, but each still carved seals individually. They were instructed to use the same tools, model, and production sequence, which they developed themselves before commencing the carving experiments. Only bronze and copper tools were chosen, with the same six tips and edges used to make each seal. They also used the same steatite source to craft all thirty replicas (10 made by each carver). The production sequence was initiated by cutting, smoothening, and shaping blanks of a uniform size, followed by a pencil outline created by Ganga Ram to try and standardize as much as possible the dimensions of the unicorn and offering stand on each sample. Carving proceeded from the rear part of the body to the front, followed by the neck, head, legs, and tail. The offering stand was carved after these elements, and only after all of these features were engraved were the horn, ear, and other small details added. In this manner it was possible to control for nearly every aspect of production. We hypothesized that if the final products were still variable, in terms of scale or style, then individual carving styles and skills would likely be the reason for any differences observed.

Figure 8: Replica seal carved by Ganga Ram with original model

Figure 9: Replica seal carved by Anil with original model

Figure 10: Replica seal carved by Virma with original model

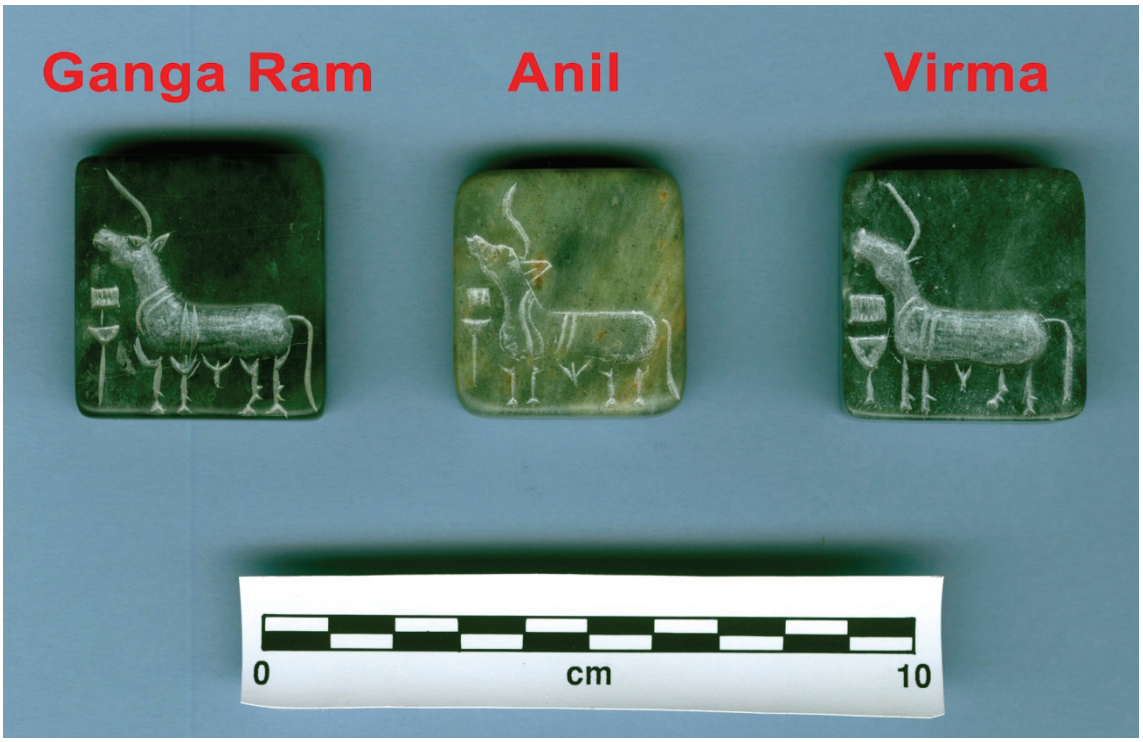

Figure 11: Replica seals carved by all three Udaipur artisans in the workshop simulation

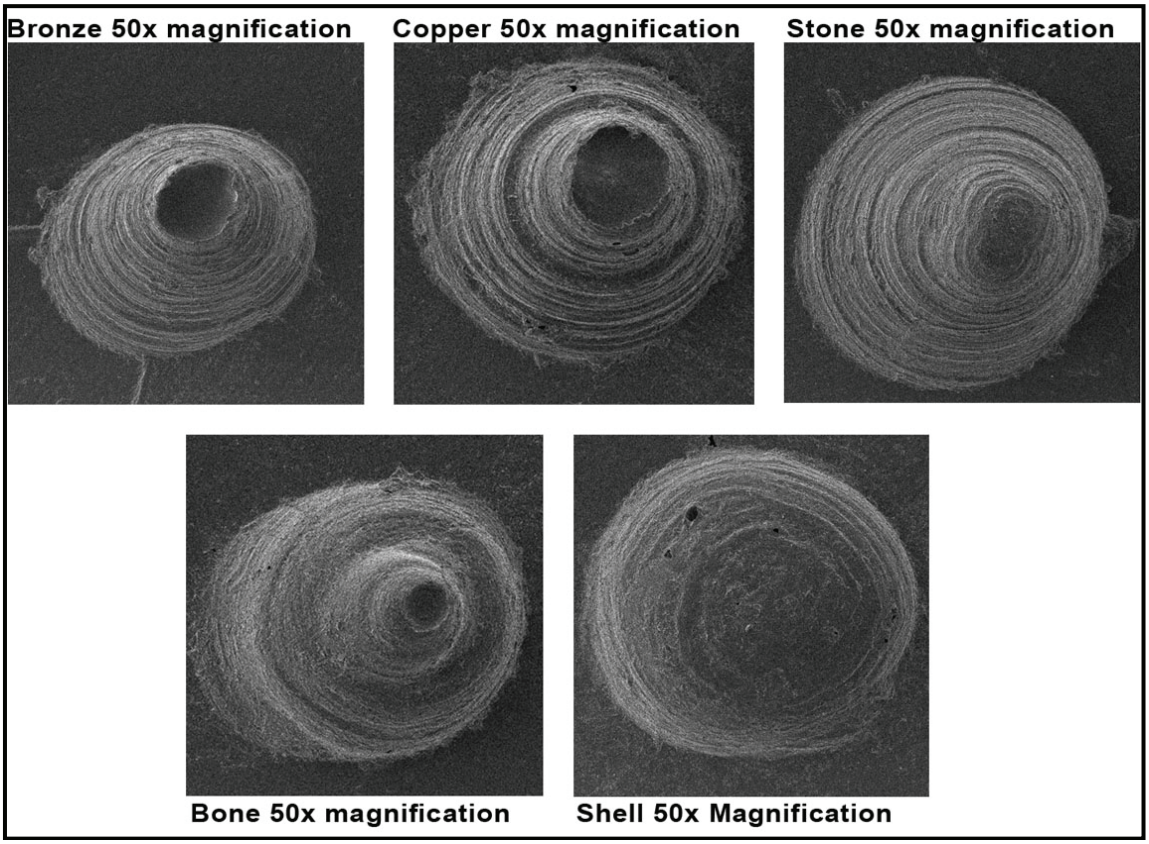

Figure 12: Scanning electron microscope images of cut-marks made with replica tools

Despite all of these controls and regulations, there are still visible differences among the seals produced by each individual (fig. 11). While they are certainly more similar than the others that have already been discussed, a number of differences still remain, despite our attempts to control for every aspect of production. These are most clear in the small, finely-carved details of the unicorn motif, specifically legs, body decorations, head and facial elements, and the ritual stand. Variation can be seen in the placement, orientation, and morphology of these elements, and are identified only through comparative analyses of the full sample of seals produced in the workshop simulation. These results support the interpretation presented above, namely that the signatures of individual carving styles are best seen in small, fine details of the unicorn motif and offering stand. On the other hand, metric analysis reveals that the overall dimensions and shape of the animal motif on the seals produced in the workshop simulation experiments are less variable than those carved in the individual study, and considering that Ganga Ram created outlines on all of the blanks to be used, this is neither surprising nor unexpected. What is relevant here, however, is that each of our informants still carved with a unique style, and that these can be identified through comparative analysis of the finished products. Most of the variation identified during this study was macroscopically visible, but in order to identify further evidence of these experimental and microscopic studies were also undertaken.

Experimental Studies

One of the more interesting results of the initial ethnoarchaeological study was that different tools did not produce major disparities in the appearance of the finished product, at least in terms of the raw materials from which they were fashioned. As mentioned above, previous studies have revealed that different tools do create distinct cut-marks, which can often be distinguished microscopically. To test this I conducted experiments using tools with the same tips but made from different raw materials, and carved various elements of the unicorn with each one. I sharpened all of the tools before using them, and followed the same carving sequence for each sample. Pointed, beveled, and flat-tipped implements, the full suite of replica tools made and used in Udaipur, were utilized in the experiments. Following this I made casts of some of these samples and examined them under scanning electron microscopy to analyze the cut-marks made with each tool.

The images produced by the microscope demonstrate clear differences in the engraved surfaces made with tools made from variable raw materials (fig. 12). The metal and stone tools depict surfaces with clear, sharp edges, and a series of prominent, circular or irregular striations caused by the edges of the tools. Although the tools made from bronze, copper, and stone are similar in this regards, there are still differences in the number and orientations of the striations. The striations indicate that the engraved surfaces were cut by tools with fine, sharp or jagged, uneven edges. In the case of the metal tools, the former is probably the reason, whereas with the stone tools, the jagged, uneven edges and tips are likely responsible for the striations.

In contrast, the scans of cut-marks made with the bone and shell tools are quite distinct from the metal and stone ones. The edges of the surfaces created with these implements are much less sharp, more rounded, and less distinct than those created with stone and metal. This is related to the fact these tools are less sharp than the others, in spite of the fact they were also rejuvenated before use. The cut-marks also lack the distinct parallel striations created with the other implements. Though they are present, they do not occur as frequently or clearly as those made with metal and stone implements, likely a reflection of the fact that the tips and edges of the shell and bone tools are smoother and less jagged. These patterns support the idea that it is possible to distinguish cut-marks on engraved surfaces made with tools fashioned from different raw materials, which has important implications for the study of tools used to make Indus seals.

Discussion

Ethnoarchaeological studies of contemporary steatite crafting in Udaipur, Rajasthan, India, focusing specifically on replicating aspects of Indus seals, have provided new insights into potential sources of variation among different carvers. A number of potential sources have been discussed, including tools, raw materials, production sequences, skill, and carving styles. Controlled experiments aiming to further isolate these potential sources were also conducted through regulated workshop simulations. Analyses of the finished products of three artisans suggest that despite our attempts to regulate various aspects of manufacturing, there are still clear and easily identifiable patterns of variation in the ways in which the animal motif is carved, in terms of both scale and style. While it is not possible at present to eliminate any of the variables mentioned above as sources of variation, we can confidently state that based on these experiments, idiosyncratic carving styles do account for at least some of the differences seen in the seals produced by these artisans.

This interpretation is based on a number of observations. First, tool selection did not seem to play a major role as a source of variation, macroscopically there are no differences in the engraved surfaces carved by different tools, either within or among the samples carved by our informants. Further testing through experimental studies described above does suggest that different tools create distinct cut-marks on engraved surfaces that can be distinguished using scanning electron microscopy, but these are not visible to the naked eye. The same can be said for raw materials and models, neither of which appeared to be major sources of variation among our carvers. Having eliminated these as significant sources of variation in our experiments, we chose instead to focus on production sequences and idiosyncratic carving styles. As the results of this study clearly indicate that these are potentially very significant sources of variation, it is necessary to discuss the role that unique carving styles play in terms of variation among carvers, and what the implications for the study of archaeological materials may be.

Considering that all three of our informants have similar backgrounds in crafting steatite, used all of the same tools, models, and raw materials to make the replica seals for us, and the finished products still look very different, it is reasonable to infer that individual skill and style play a significant role as a source of variation among producers. It follows then that through detailed analyses of finished products it may be possible to "fingerprint" individual seals. Our study indicates that a number of elements of the "unicorn" motif were carved differently by each artisan, despite our instructions to replicate the models as accurately as possible. Specifically, smaller, finely carved details such as the head and face, legs, hooves, and body decorations were carved differently by each informant and can easily be distinguished through comparative analysis. If the products of different artisans can be identified through analysis of finished goods, it should be possible to examine Indus seals and identify seals carved by different individuals, workshops, schools, or guilds. This will undoubtedly provide new insights into the nature and scale of seal production during the Harappan period.

Through a detailed analysis of Indus seals, focusing specifically on stylistic and metric attributes of the unicorn motif, we should be able to identify patterns of attribute co-occurrence that represent individual, idiosyncratic carving styles. In this manner we can distinguish groups of seals that would have been carved by different individuals in the Indus cities. Continued experimental studies focusing on replication using tools that would have been available to Indus craftspeople will refine the patterns presented here, and also facilitate the creation of a larger comparative data set that can be used to identify similarities and differences in the cut-marks on Indus seals. This method of analysis is completely non-destructive, can be easily replicated, and also encourages preservation and the creation of duplicate records (through the process of making casts) that protect these critical data against future damage or loss. Most importantly, studying the cut-marks on Indus seals made with different tools provides another line to evidence to help identify patterned variation that likely represents different artisans and workshops.

Examining the distribution of these different seal groups will provide important information about the organization of seal production and consumption, as well as trade and exchange networks. For example, if "type A" seals are found only at one site, we can infer that they were likely made and used locally. If they appear at multiple sites, this pattern may represent trade and exchange, multi-site production dynamics, and would ultimately suggest a strong level of integration among different settlements. Considering that seals would have been used as symbols of wealth and authority (Kenoyer 2000), they can also be seen as markers of elite power. Thus the analysis of seal production and use can also be used to evaluate current models of Indus social and political organization. We firmly believe that future studies using the models for explaining variation in seal carving techniques will further our understanding of this important craft tradition and its relationship to larger issues of socio-political organization and control.

Conclusion

Despite the significance of inscribed steatite seals in the Indus Civilization (2600-1900 BC), our understanding of how this industry was organized and varied among different producers remains uncertain. Detailed ethnoarchaeological studies of contemporary steatite crafting in Udaipur, focusing on replicating selected aspects of Indus seal manufacturing technologies and techniques, have provided new insights into potential sources of variation among different carvers. These studies suggest that although any number of factors may be responsible for differences in carving techniques, individual, idiosyncratic carving styles and skills can also account for variation, even when all other aspects of production are controlled. Further, current evidence suggests that it is possible to identify these differences through comparative analysis and that they occur in patterned, regular ways, likely a reflection of the carver's individual skills and style. It follows that through analysis of finished seals it may be possible to "fingerprint" archaeological seals and group them based on shared stylistic and technological attributes. High-precision analytical techniques, such as scanning electron microscopy, provide additional methods to investigate the tools used to craft Indus seals, and differences in these may reflect different artisans and workshops. In examining the scale and breadth of different seal carving traditions, it will be possible to gain new insights into the organization of Indus seal production and its relationship with larger issues of social and political integration and control.

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