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Cover image: Ceramic tile depicting an Assyrian scribe, from a desk and *escritoire* by William Burgess, 1865-67 (© Manchester Art Gallery / Bridgeman Images)

Contents

Bleached carnelian beads of the Indus Tradition, 3rd millennium BC: origins and variations

J. Mark Kenoyer[1]

Abstract

The study of bleached carnelian bead production at the site of Harappa and other Indus sites provides a new perspective on early ornament technologies of the 3rd millennium BC. A critical assessment of earlier studies suggests that new terms and new ways of studying and documenting these beads should be developed. The use of experimental replication is also proposed as an important avenue for research in order to develop a more robust interpretive framework for comparing bleached carnelian beads within the Indus region as well as in adjacent regions.

Keywords: Bleached carnelian beads; Harappa; Mohenjo Daro; Indus tradition; experimental archaeology

Introduction

One of the most distinctive and early examples of artificial colouring of stone is seen in the form of carnelian beads decorated with permanent white designs, and as they were the subject of an important paper by Julian Reade,[2] I return to this subject in this volume for him. These beads first appear during the 3rd millennium BC at sites associated with the Harappa Phase (2600–1900 BC) of the Indus tradition of Pakistan and western India as well as at contemporaneous sites in Iran and Mesopotamia (Figure 1).[3] Early scholars referred to these beads as 'etched' carnelian,[4] due to a misconception of how they were originally produced. Due to the manufacturing process and post-depositional weathering the whitened area can break down and erode away, leaving what appears to be an etched pattern as seen on a bead from the site of Balakot, Pakistan (Figure 2). This etching by weathering was not the intended goal of the Indus craftspeople who were trying to create permanent white designs on the bead surface. The term bleaching was used by Woolley to describe the white design on some of the beads from the excavations at the Royal Cemetery at Ur,[5] and this terminology was even cited by Reade,[6] but for some reason no one followed Woolley's terminology. I have argued that the term 'bleached' carnelian is the most appropriate nomenclature for these beads based on careful study of the manufacturing process and use of high-resolution scientific techniques.[7] These beads have been cited as an important indicator of trade between the Indus, Arabia and Mesopotamia during the 3rd millennium BC,[8] but they also continued to be produced and traded in later periods. Even today,

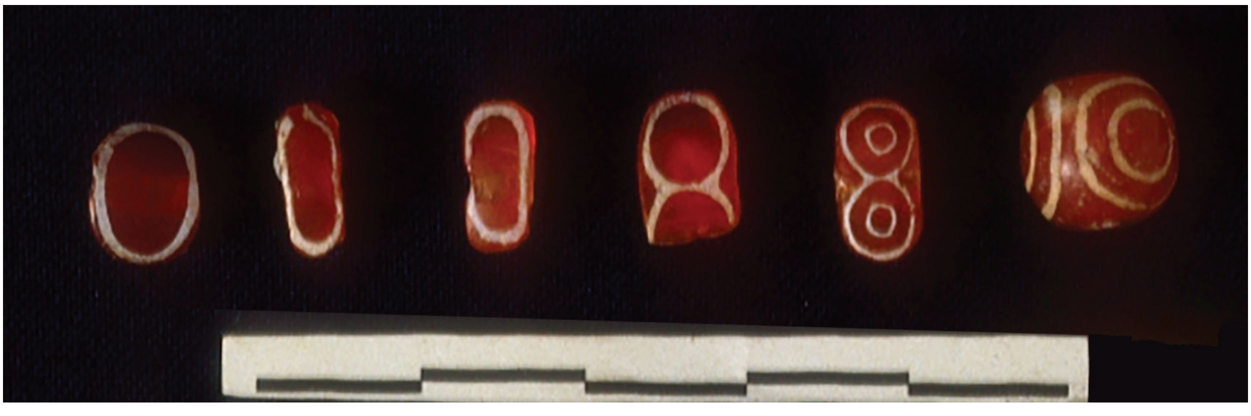


Figure 1. Bleached carnelian beads from Harappa, Pakistan, Harappa Phase, 2600–1900 BC

[1] Department of Anthropology, University of Wisconsin-Madison.
[2] Reade 1979.
[3] Kenoyer 1991; 2015.
[4] Beck 1933; 1940; Dikshit 1949; Mackay 1933.
[5] Woolley 1955: 127, 197.
[6] Reade 1979: 8ff.
[7] Kenoyer 2003.
[8] De Waele and Haerinck 2006; Koiso 2008; Prabhakar 2018; Ratnagar 2004; Reade 1979; 2008.

Figure 2. Bleached carnelian bead showing weathered lines, Balakot, Pakistan, Harappa Phase, 2600–1900 BC

carnelian and many other varieties of rock are coloured with permanent white designs using modern refined chemicals and furnaces.

Issues that will be discussed below include the origin of the technology for creating white designs on carnelian and other rocks, the possible movement of Indus bead makers to regions outside the Indus River Valley and the problems in identifying the diffusion of a technology over time. This last point can only be adequately studied through a comparison of the detailed processes of bead production and decoration, or *chaîne opératoire*, reflected in the finished beads as well as in the workshops where they were produced.[9] Most scholars have assumed that the bleached carnelian beads were made in the Indus region or Baluchistan, but the possibility of production outside the Indus remained a possibility.[10] In my studies of long carnelian beads and some of the bleached carnelian beads from the Royal Cemetery of Ur in the collections at the University of Pennsylvania Museum I found evidence for possible manufacture outside of the Indus.[11] One specific bleached carnelian bead has a unique tapering oval shape and net design that is not seen in the Indus.[12] However, the drilling technology of this bead is identical to the drilling with constricted cylindrical drills seen in the Indus. This would indicate that Indus craftspeople or craftspeople who were trained in Indus styles of production were producing beads for local consumers in Mesopotamian cities using what was probably Indus carnelian, Indus drilling techniques and possibly Indus bleaching techniques. In addition to their distribution in Mesopotamia, bleached carnelian beads are reported from numerous sites in Iran such as Susa and Shahdad,[13] Central Asia,[14] Xinjiang,[15] Arabia,[16] Egypt,[17] and even as far as the Mediterranean.[18] On the basis of published images, most of the beads in these distant regions appear identical to examples found in the Indus and may have been traded and even treasured or heirloomed for hundreds of years. Other beads have distinctive features that may reflect local variations. This could point to the diffusion of the technology beyond the regions where Indus-trained craftspeople were working. A careful reexamination of all of these examples is needed based on the documentation processes that will be discussed below.

The most important approach to the study of these beads is to develop a more refined classification system that takes into account the chemical characterization of the raw material to define its source area, combined with a detailed analysis of the manufacturing processes used to produce the bead shape and specific features of the white designs. Sourcing of the carnelian using chemical characterization with Instrumental Neutron Activation Analysis (INAA) or Laser Ablation-Inductively Coupled-Mass Spectrometry (LA-ICP-MS) can help to determine if carnelian came from South Asia.[19] The analysis of the manufacturing processes such as perforation, shape and styles of decoration can be used to determine if the bead was made using Indus-derived technology.[20]

Identifying the specific techniques used to create these white designs is a challenging problem due to the fact that some do not leave tell-tale traces, especially after long burial in the ground and post-depositional weathering. In 1986 the SEM examination of a 'modern (?) etched' bead by Tite suggested that the white colour of the design was the result of a high concentration of very fine pores 0.5µm in diameter that extend to a depth of 200–300 µm.[21] He explained that the network of pores scatters the light and makes the carnelian appear white. He also noted that there is no compositional difference between the etched areas and the natural carnelian, and there are no detectable amounts of alkali in the etched areas. He assumed the etching was done with a solution of alkali (soda or potash), but it is important to test various types of recipes using samples of alkali or plant ash that would have been available in different regions. The composition of plant ash is highly varied in different

9 Vidale *et al*. 1992.
10 Reade 1979: 24.
11 Kenoyer 1997: 272; 2008: 25–26.
12 Kenoyer 1998: 97, fig. 5.6; Reade 1979: fig. 1, G1.
13 Potts ed. 2013.
14 Kaniuth 2010.
15 Ming 1974; Zhao 2014.
16 Kenoyer and Frenez 2018; 2019.
17 Grajetzki 2012.
18 Aruz 2003; Reinholdt 2008.
19 Carter and Dussubieux 2016; Law *et al*. 2013.
20 Kenoyer 2017*a*; 2017*b*.
21 Tite 1986.

regions of West and South Asia[22] and it is possible that different sources of alkali from plant ash or geological sources might result in different types of micro pores in the carnelian. A more systematic study of the pores formed on different type of bleached beads is needed to determine the range of variation present. Replicative studies to create the white designs on carnelian using these different recipes may provide some answers to the questions of technique, but ultimately we need to find the actual ancient workshops where these beads were being produced. In the meantime, by developing more precise ways of documenting the beads we can begin to classify specific types and variations of beads found during different time periods and their distribution in major regions.

Origins of whitened stone beads

The origin of the technology used to make white designs on carnelian, agate and many other varieties of rock is probably linked with the technology of creating white-fired and glazed steatite using alkaline plant ash fluxes.[23] The earliest fired and whitened steatite beads in the Indus Tradition are found at the site of Mehrgarh Period Ib, dating to around 6000 BC.[24] In the subsequent Chalcolithic occupation at Mehrgarh (Period IIB: circa 5500–5000 BC, Period III: 5000–3500 BC) and at the nearby site of Nausharo (Period I: 3000–2500 BC) there is evidence for the production of whitened steatite beads that were probably glazed with some form of flux made of plant ash.[25] This technology is also well documented at the site of Harappa during the Ravi Phase (Period 1: circa >3700–2800 BC) and the subsequent Kot Diji Phase (2800–2600 BC) (Figure 3).[26] This same technology has been documented at other sites in the northern Indus region, such as Rehman Dheri[27] and Sheri Khan Tarakai.[28] Carnelian beads and other hard stone beads were also being produced at all of the sites mentioned above, but so far there is no evidence that the technique for making white designs on carnelian or other stone beads was being utilised at any of these sites prior to the Harappa Phase, 2600-1900 BC.

Bead production technology and whitening carnelian

The manufacture of early carnelian beads is important to investigate since production technology is an important variable that needs to be considered along with white painted designs. The early carnelian beads at the site of Mehrgarh (7000–5500 BC) were made of thin flakes chipped and ground to form short barrel or biconical bead shapes.[29] They were perforated using the pecking technique by percussion from one or both sides. During the Chalcolithic phase at Mehrgarh (Period III: around 4200 BC) longer barrel beads of carnelian were made and they were perforated using tapered stone (probably jasper) drills.[30] At the site of Harappa during the Ravi Phase, Period 1 occupation (Ravi Phase: >3800–2800 BC) there is evidence for the production of similar forms of carnelian using both pecking and stone drilling techniques (Figure 4).[31] At the site of Rehman Dheri in the northern Indus region there is also evidence for the production of both short and long barrel carnelian beads perforated with the same techniques.[32]

Figure 3. Whitened glazed steatite beads, Harappa, Pakistan, Ravi Phase, >3800–2800 BC

All of the carnelian beads found at these sites have been heated to deepen the colour of the carnelian to a rich red-orange, but prior to the Harappa Phase, none was decorated with any white designs. During the Harappa Phase, pecked and stone drilled carnelian beads continued to be made but, what is quite unexpected, is the presence of many carnelian beads that have been discoloured with irregular white surfaces that do not

[22] Tite *et al.* 2006.
[23] Mackay 1937.
[24] Barthélemy De Saizieu and Bouquillon 1994: 51; Law 2011; Miller 2008.
[25] Barthélemy De Saizieu and Bouquillon 1994: 52; Law 2011; Miller 2008; the dates based on Jarrige 2008.
[26] Kenoyer and Meadow 2000.
[27] Durrani *et al.* 1995.
[28] Khan *et al.* 2010: 268–69, fig 7.32.
[29] Barthélemy De Saizieu 2003; Kenoyer 1992: 88.
[30] Barthélemy De Saizieu 2003; Kenoyer 1992: 88; Vidale 2000.
[31] Kenoyer 2005.
[32] Durrani *et al.* 1995.

Figure 4. Pecked carnelian beads and bead blank, Harappa, Pakistan, Ravi Phase, >3800–2800 BC

Figure 5. Pecked and stone drilled carnelian beads, some with whitened surfaces, Harappa, Pakistan, Harappa Phase, 2600–1900 BC

appear to be intentional (Figure 5). Originally, I assumed that this was the result of long burial and weathering in alkaline sediments. The whitening of the surface of flint artifacts and even natural flint has been identified as being a form of 'white alteration' through desilication and precipitation of silica based on soil chemistry and other taphonomic processes.[33] The whitening of the carnelian beads at Harappan and other archaeological sites may be the result of such natural weathering, but it is also possible that it occurred during the final heating process when the beads were heated to deepen their colour. This interpretation is based on observations made at the modern carnelian bead-producing site of Khambhat, India, where beads are placed in pots covered with ash for a final heating to deepen the colour of the carnelian. Most beads are not discoloured by this process, but some do get whitened, presumably by the contact with the alkaline ash. It is possible that Indus craftspeople observed this phenomenon and since they were already using fluxes to whiten and glaze steatite they may have experimented with ways to produce intentional white patterns on carnelian.

Stone beads with designs

The stimulus for creating white designs in stone can be attributed to the desire by Harappan bead consumers for distinctive patterns in hard stones. This is well documented on the basis of discoveries at Mohenjo Daro and Harappa as well as numerous other Harappa Phase settlements (Figure 6). Beads with circular motifs were specially ground and shaped to bring out the maximum

[33] Caux *et al.* 2018: 215.

Figure 6. Stone beads with natural patterning and eye motifs, Mohenjo Daro, Pakistan, Harappa Phase, 2600–1900 BC

Figure 7. Faience and steatite beads with eye designs, a. faience, b. painted and fired steatite

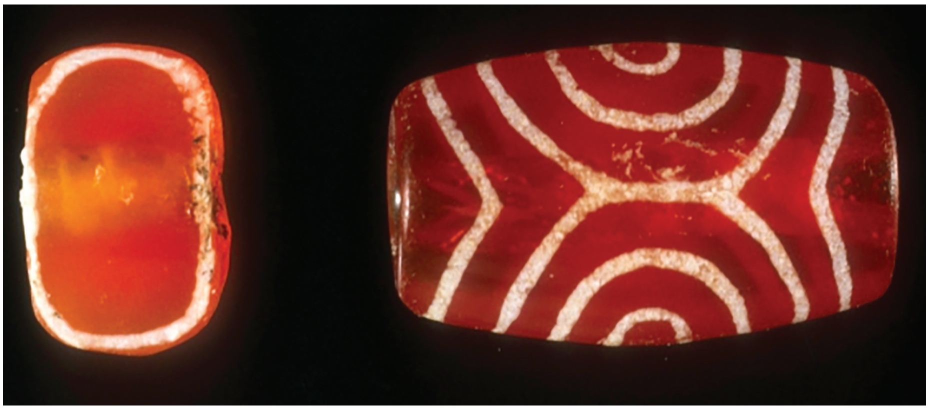


Figure 8. Bleached carnelian beads, a. lenticular short barrel with single eye motif, b. lenticular long barrel with multiple chevron motif, Harappa, Pakistan, Harappa Phase, 2600–1900 BC

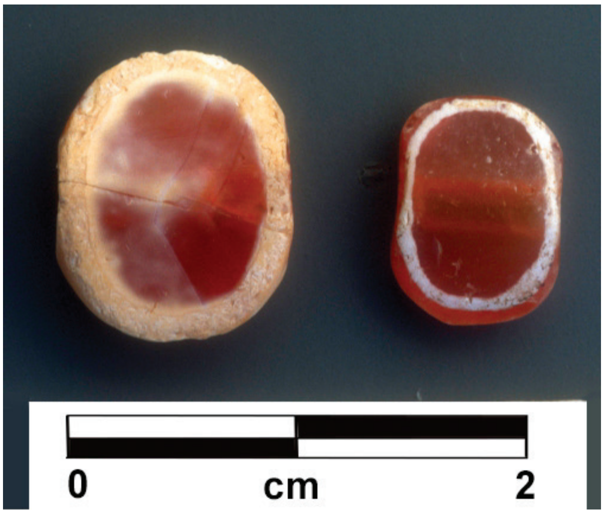


Figure 9. Bleached carnelian beads, a. lenticular short barrel with single eye motif and wide white line, b. lenticular short barrel with fine white line, Harappa, Pakistan, Harappa Phase, 2600–1900 BC

number of 'eyes'. Beads with banding were also ground to produce perpendicular lines that were circular in a linear plane. Steatite beads were also painted with red slip with some areas left white to simulate eye patterns (Figure 7b), and faience beads made with red orange and white glazed faience create the most common single eye pattern (Figure 7a).

Once the Indus craftspeople had developed the technique for creating permanent white lines on carnelian they created a wide range of new motifs that were never seen in nature and developed distinctive bead shapes that would highlight their designs (Figure 8). It is also quite evident that not all bead craftspeople had the same skills or expertise in preparing the white designs. Some beads show very wide and heavily weathered lines, while others are thin and delicate with very little sign of error (Figure 9).

Although the bleaching technique is very effective on steatite and all forms of agate and carnelian there are some dense iron spots found in carnelian that seem to be impervious to the alkaline reaction (Figure 10).

Figure 10. Bleached carnelian bead with red dots in both the red orange and the white area, Harappa, Pakistan, Harappa Phase, 2600–1900 BC

These red spots are found on specific types of carnelian and are found on many agate as well as carnelian beads from Indus sites as well as in later historical period beads. In some cases the bleaching seems to have gone totally wrong with the entire surface of the carnelian turned white from heating except for the area that was being bleached, which is either eroded away or enriched with carbon from the firing (Figure 11). These beads with what appear to be black designs on a white background were originally classified as a specific type of bead by Beck and other scholars,[34] but they are in fact misfired beads and therefore should not really have a separate designation.

[34] Beck 1933; De Waele and Haerinck 2006; Reade 1979.

Figure 11. Bleached carnelian bead that has turned white with black lines, Allahdino, Pakistan, Harappa Phase, 2600–1900 BC

Based on my experiments using a common form of plant ash (*sajji khar*) prepared in rural areas of Pakistan, Afghanistan and India, I have found that some of the plant ash is very effective for whitening while other samples are less strong. This plant ash is made by burning the shrub *Salsola stocksii* (syn. *Haloxylon recurvum*), which is found growing on sandy saline soil through the northwest subcontinent.[35] Studies of plant ash from different parts of Pakistan used in glass making have shown that there is considerable variation in composition that is probably the result of local soils as well as the processes used in making the plant ash.[36] The comparative analysis of various samples from Pakistan shows that most have a high Na content with varying amounts of K, Mg, Ca and Al.[37] Ongoing studies to determine the composition of the different samples that I have been using may provide some clues as to these differences and it is possible that these findings may explain some of the variation in white lines seen in the ancient beads. Another technique which I have been experimenting with is the medium used to create the paste that is applied to the beads. Based on the recipes discussed by Mackay from his observations of bead makers in Sindh,[38] I have collected the tips of the *kirar* plant, *Capparis decidua* (Forsk.) (syn. *Capparis aphylla* Roth) in Sindh, Punjab and Gujarat to experiment with leaves from different regions. Analysis of the chemical components of this plant indicate that it contains lots of medicinal potential, including alkaloids which might contribute to the whitening process itself in addition to its use as a vegetable glue.[39] Mackay noted in his experiments that the use of *kirar* leaves was not necessary and he was able to obtain satisfactory results using no other additives.[40] I have also experimented with various other vegetable glue solutions, including fern tips from the Himalayas and they worked equally well in helping to hold the alkaline mixture to the surface of the stone for heating. Modern goldsmiths in Pakistan make vegetable glue for use in gold granulation by roasting and boiling Fenugreek seeds. This glue is also very effective in holding the alkaline solution to the surface of the bead as it dries. Once the bead surface has been painted and the solution dries the next step involved heating the beads to a temperature that will cause the alkaline layer to leach the silica without peeling off and also without cracking the carnelian.

In my heating experiments I have tried different methods of heating the beads that simulate the ethnographic technique reported by Mackay but adapted to what might be more appropriate for Harappan technology.[41] In my experiments I had my replicas of Harappan style lenticular short barrel beads made in Khambhat, Gujarat by the late Inayat Hussain using partially heated carnelian from Ratanpur, Gujarat.[42] The beads were inserted on long bamboo skewers in order to paint them on both sides. They were dried slowly over a bed of hard wood charcoal and then when totally dry the white design could be clearly seen on the surface of the bead. For heating the beads, I heated them gradually over the glowing embers and gradually moved the beads closer to the heat until the bamboo charred and the beads fell into the embers. If the beads were heated too quickly, they would crack.

Once the beads fell into the embers they were covered with ash and glowing embers and allowed to remain in the fire for variable amounts of time to assess the different effects of the firing. The optimal results were obtained after only three to five minutes in the heat after which the beads were moved away from the glowing coals and left in warm ash to cool slowly (Figure 12).

Ethnographic observations of traditional heating of carnelian in Khambhat, India, have recorded the optimal temperature range of 350° C to 380°C.[43] These temperatures are sufficient to change the colour and remove most of the water in the stone without causing the stone to fracture and spall. Other studies of heat treatment of rocks have shown that microcrystalline silicates such as flint or chert begin changing their colour through the oxidation of iron or other minerals at around 250°–260° C and become highly fractured if they are heated 400° C.[44] My own laboratory experiments in heating carnelian confirm this pattern. When using a

[35] Baden-Powell 1868: 247; Marshall 1951.
[36] Rye 1976.
[37] Tite *et al.* 2006: 1286, table 1.
[38] Mackay 1933: 144.
[39] Joseph and Jini 2011.
[40] Mackay 1933: 145.
[41] Mackay 1933.
[42] Kenoyer *et al.* 1991; 1994.
[43] Kenoyer *et al.* 1991.
[44] Purdy and Brooks 1971.

Figure 12. Experimental production of a common Harappan style bleached carnelian bead

muffle furnace, I gradually increase the temperature by around 50° C per hour until around 350° C and hold that temperature for one or two hours. This will often turn most of the carnelian a deep red, but in some samples it can require two or more additional heating cycles for the carnelian to turn red. If the carnelian is heated over 400° C it becomes fractured and spalls.

SEM analysis of white lines

SEM analysis of beads with different types of bleached surfaces suggests that differences in design features may be due to different recipes used in making the white line itself. As I continue to experiment with different recipes, I am building up a collection of comparable samples that will be analysed to see if there is any difference in the depth, clarity and composition of the white lines. Hopefully other studies can be carried out in other regions of Iran, Mesopotamia, Oman and Central Asia to see if materials in these regions result in dramatically different patterns.

One fragment of a bleached bead from the surface collection at Harappa was polished to prepare a flat surface for SEM analysis at high magnification (3000x). This sample shows the features of the micro pores that were first noted by Tite, but in this sample the pores have many different sizes (Figure 13). SEM-EDS of both the white and the red orange surface showed no trace of any fluxing agent or alkali. Two other examples of beads were examined non-destructively to see what could be determined using backscatter imaging and revealed an interesting feature that is still not clearly understood. On one sample that showed heavy weathered white lines the SEM backscatter image at 23x as well as 500x showed the same basic pattern (Figure 14). SEM-EDS picked up traces of what might be the flux used to make the white lines (Figure 15). The presence of Mg, Ca, K and Al might be traces of plant ash in the area of the white line. There were no similar traces in the unbleached red orange area of the bead. On another bead sample that had a very distinct white design that was not weathered, the altered surface was undetectable using the backscatter imaging at 500x and 1000x magnifications (Figure 16). It is not unlikely that the micro-pores on this bead would be visible if the surface was polished and studied at increased magnification, but it is surprising that nothing is visible at even 1000x. Further studies are needed to see if there are non-destructive ways to compare the white lines and weathered surfaces so that this approach can be applied to archaeological beads from sites throughout South Asia and adjacent regions. This type of research needs to be expanded to include the types of bleached carnelian beads found in later time periods when there is even more variation in terms of bead shapes and white line appearances.

Conclusion

The studies reported here represent an example of a larger study that I am carrying out on beads from Harappa as well as from sites in Oman where I have been able to document similar types of bleached carnelian beads.[45] A selection of carnelian and agate bead samples from the Harappa Phase at the site of Harappa have been analysed using LA-ICP-MS and reveal that most beads derive from known carnelian sources in Gujarat, India, but some samples were from some other unknown source region. At the site of

[45] Kenoyer and Frenez 2018; 2019.

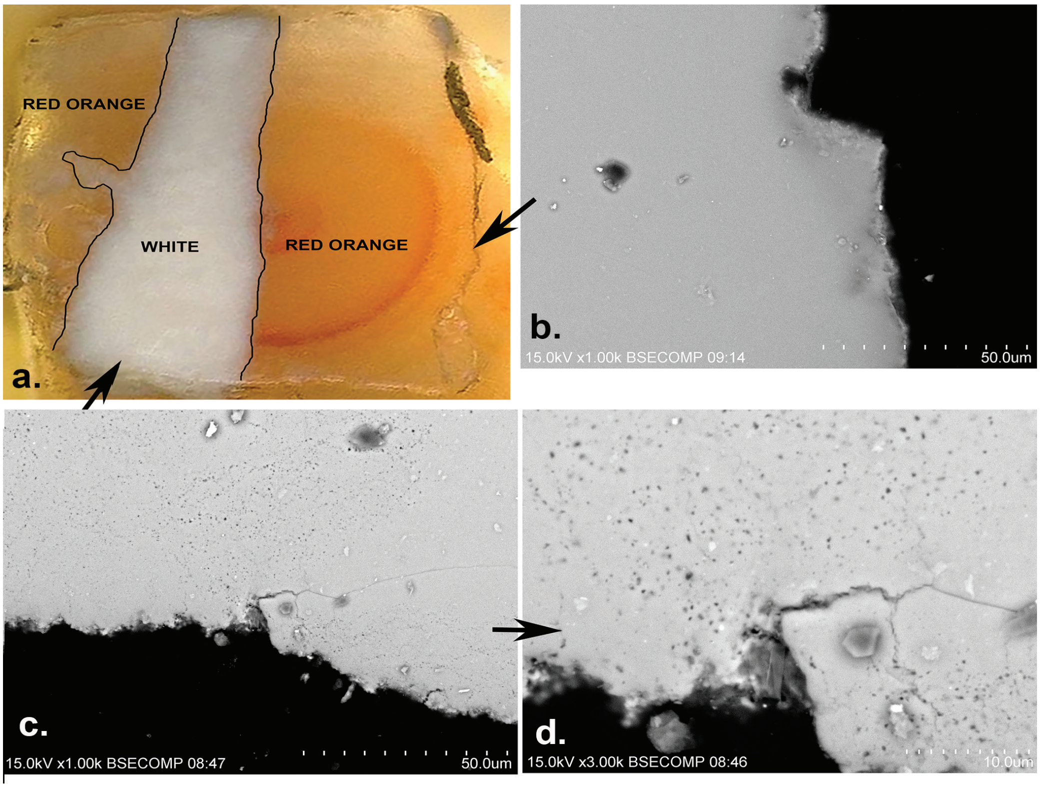


Figure 13. SEM image of white and red orange portions of a bleached bead, surface collection, Harappa, Pakistan

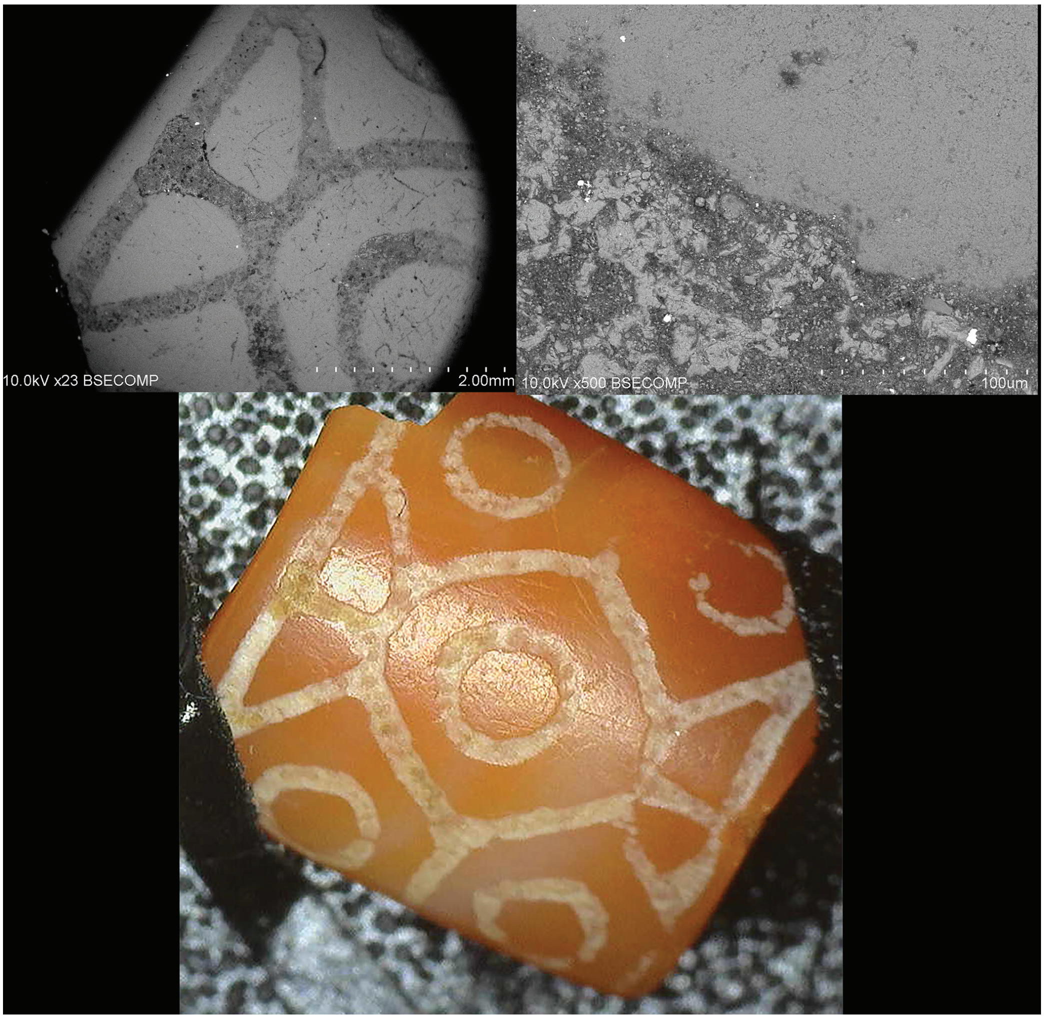
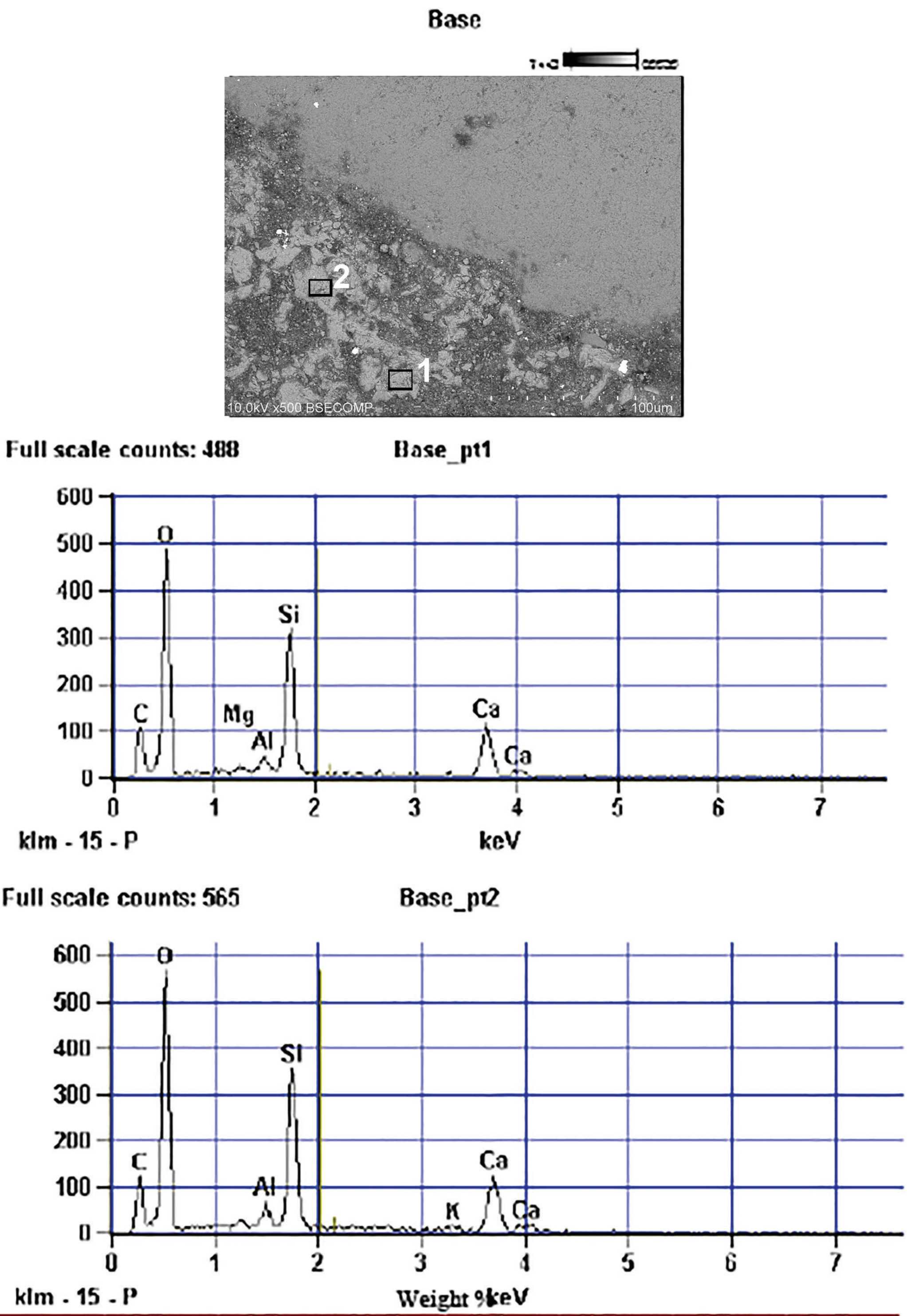


Figure 14. SEM image of bleached carnelian bead, presumably from the Indus (private collection)



Weight %

	C-K	O-K	Mg-K	Al-K	Si-K	K-K	Ca-K
Base_pt1	10.94	51.49	0.55	1.60	16.23		19.19
Base_pt2	10.44	53.49		1.40	15.69	0.75	18.23

Atom %

	C-K	O-K	Mg-K	Al-K	Si-K	K-K	Ca-K
Base_pt1	17.29	61.09	0.43	1.13	10.97		9.09
Base_pt2	16.40	63.12		0.98	10.55	0.36	8.58

Figure 15. SEM-EDS of whitened area bead in Figure 14, showing traces of flux

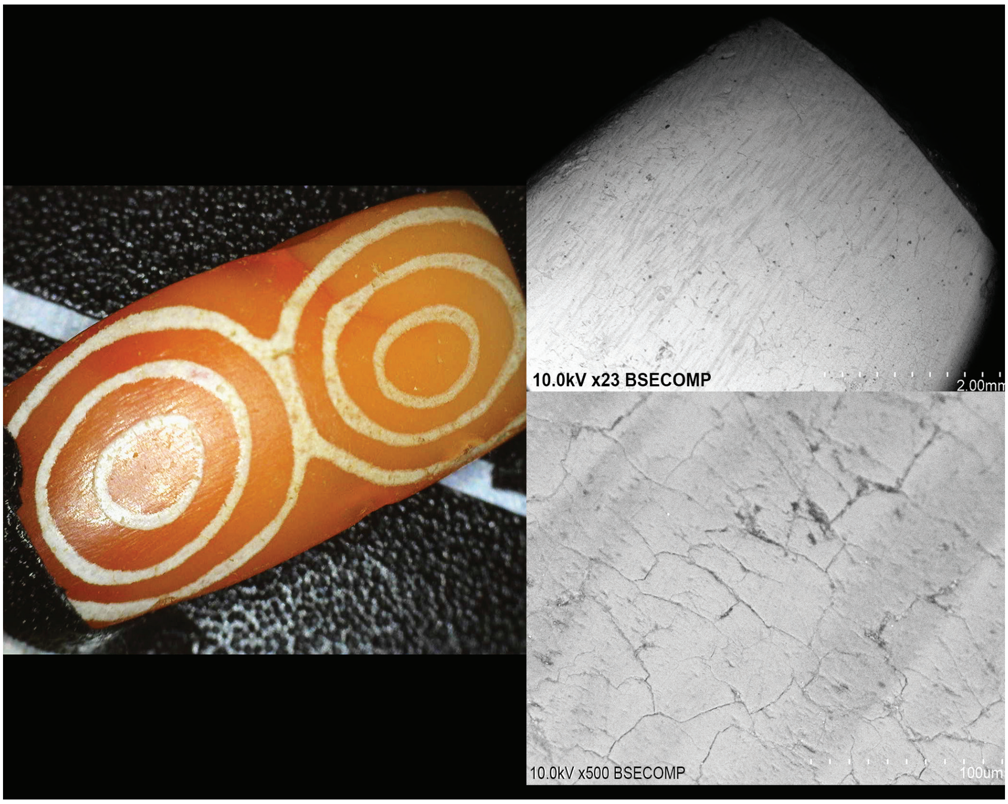


Figure 16. SEM image of bleached carnelian bead, presumably from the Indus (private collection)

Harappa, beads made with very different styles of white lines have been recovered and it is most likely that these were brought to the site from multiple regional workshops in the greater Indus river valley as well as from Baluchistan/Afghanistan and Gujarat. Analysis of the bleached designs on some of the sample beads is still in process and will provide new information on the different features discussed. Detailed documentation of the beads at Harappa and comparisons with beads from other Indus sites will hopefully begin to narrow down where different workshops might be located. Mackay suggested that some of the beads were being made at the site of Chanhu Daro and new excavations at this site by the French Archaeological Mission to the Indus led by Dr Aurore Didier will hopefully discover the actual workshop of these beads.[46] Excavations and surveys at the sites in the upper Ghaggar-Hakra River Valley have also recovered numerous examples of bleached carnelian beads that will help to expand the sample size needed to determine regional variations of these bead types.[47] Another important direction for new research is the continued experimental replication of bleached carnelian using both traditional and laboratory experiments. I hope that this paper will inspire other scholars to begin similar experimental studies in their own regions in order to build a larger comparative sample to better understand the variations in white line features and possible regional patterns of production.

[46] Didier 2017.

[47] Dangi 2009; Shinde *et al.* 2011; 2018.

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Figures: all photographs by the author, archaeological bead photographs courtesy of the Harappa Archaeological Research Project, Department of Archaeology and Museums, Government of Pakistan.

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