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History of Stone Beads and Drilling: South Asia

Jonathan Mark Kenoyer

INTRODUCTION

Stone beads are an important object produced by human communities throughout the world during the gradual transition from foraging and hunting to settled agro-pastoral adaptations. Decorative arts were already well established in other media beginning in the Upper Palaeolithic period in Europe, Africa and Asia as early as 30,000 years ago (Kenoyer 1992b), and South Asia has a long record of rock art that can be traced in all parts of the subcontinent (Sonawane 2002), along with bone carving and the modification of natural stone to create symbolic objects (Kenoyer et al. 1983a). Beads and pendants are grooved or perforated objects that can be worn on a cord, or in the hair, or attached to clothing as a form of decoration. The oldest known beads in South Asia were made of marine and riverine shells, ostrich egg shell (Francis 1981), animal teeth and, in some cases, antler and bone (Mandal 1997), as these materials were relatively soft and easy to perforate. The earliest stone beads were also made of relatively soft stone, but over time, humans developed ways to perforate and polish harder stone, creating exquisite ornaments that came to reflect status, power and ritual meaning. Eventually, raw materials used to make stone beads were traded over vast distances and stone bead workshops were established at many small and large settlements to cater to the needs of local populations. Stone beads also came to be used for regional and external trade during the period of the Indus Civilization

(2600-1900 BCE) (Kenoyer 2015b) and the later Indo-Gangetic Tradition (800BCE to 400 CE) (Kenoyer 2015a), linking distant resource areas to production centres and then to consumers who lived throughout the subcontinent and beyond. During the Medieval and Historic periods, stone bead production at sites in Gujarat and peninsular India supplied global markets that stretched as far as East Asia, Africa, Europe and eventually to the Americas (Arkell 1936, Kenoyer and Bhan 2004).

Even though stone beads began to be produced only later in human history, the raw materials that were used to make beads have a long and complex story that begins with the formation of various types of rocks during the initial geological formation of the Indian Subcontinent and South Asia in general. Rocks suitable for making stone beads are found throughout the world, and the collision of tectonic plates that resulted in the creation of mountains and eroded rocky gravels in different regions of South Asia also created unique opportunities for humans to access coloured rocks and minerals in many different locations. Over time, human communities developed appropriate technologies to use these rocks to create stone tools needed for basic survival and eventually for making ornaments. Some individuals began the long process of experimentation and discovery that led to important technological developments such as the use of fire to modify rock and flaking, grinding and polishing that are essential for stone tool and ornament manufacture. These technologies have continued to evolve and are today an important part of modern technologies and science.

More than two million years ago, hominin species began to flake rocks using various types of percussion techniques as revealed from stone tools at the site of Riwat in the Potohar region of what is now northern Pakistan (Dennell 1990) (Fig. 1). Later stone tools associated with more refined flaking technologies including bilaterally symmetrical tools such as handaxes, have been found during the Lower Palaeolithic period in South Asia, dating as such as early as 1.07 to 1.5 million years ago at the site of Attirampakkam in South India (Pappu et al. 2011) and in the Hunsgi Basin to around 1.2 million years ago (Paddayya et al. 2000). Stone working technologies evolved gradually throughout the Middle and Upper Palaeolithic period and by around 12,000 years ago heat treatment was being used to prepare chert and agate for making blades at the site of Baghor I Madhya Pradesh (Kenoyer et al. 1983b) (Fig. 2). During this same time period, there is evidence for the production of ringstones

Fig. 1. Flaked stone tool, Riwat, Pakistan (*Courtesy* Department of Archaeology and Museum, Govt. of Pakistan).

Fig. 2. Heat treated blade cores, Baghor I, Madhya Pradesh, India (*Courtesy* Department of Ancient History and Archaeology, Allahabad University).

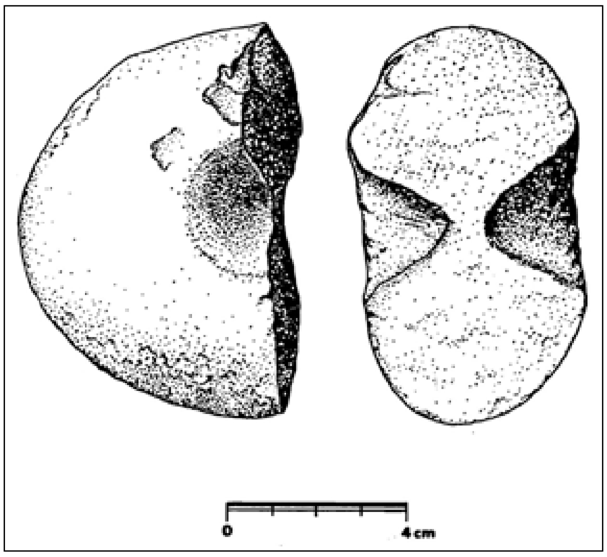

Fig. 3. Broken Ringstone Blank, Baghor I, Madhya Pradesh.

or digging weights that involved the perforation of stone using a pecking technique (Kenoyer et al. 1983b: Fig. 17.4) (Fig. 3). This innovative method of perforation continued to evolve and was the basis for the perforation of hard stone such as carnelian to make beads in the later Neolithic and Chalcolithic periods. Heat treatment is also documented from the site of Bagor, Rajasthan along with the important technique of pressure flaking (Inizan and Lechevallier 1995). By around 7000 to 5000 BCE, Neolithic and Chalcolithic cultures throughout the subcontinent were developing multiple techniques for flaking, pecking, grinding, perforating and colouring rocks to make tools and ornaments (Barthélemy De Saizieu and Rodière 2005, Jarrige 2008, Rao et al. 2005). The site of Mehrgarh provides a long sequence of bead manufacturing during the Neolithic and subsequent Chalcolithic that includes soft shell and stone beads as well as harder varieties of agate and jasper beads (Vidale 1995) (Fig. 4).

Later, during the Indus Civilization (*c*. 2600-1900 BCE) there is evidence for major developments in bead production that involved innovative techniques for drilling, shaping, colouring and mounting beads into ornaments (Kenoyer 2005a). In the Late Harappan period (*c*. 1900-1300 BCE), additional developments are seen in stone bead drilling and also the elaboration of techniques used to enhance the colour of bead raw materials

Fig. 4. Stone beads, Mehrgarh, Pakistan (*Courtesy* Department of Archaeology and Museum, Govt. of Pakistan).

(Kenoyer 2005b). During the subsequent Indo-Gangetic Tradition and associated Early Historic Period (800 BCE to 400 CE), we see the introduction of iron and steel tools and eventually the use of diamonds for drilling beads (Kenoyer 2007). A brief discussion of some major features of stone bead production and use will be presented below in order to provide an overview of the ways in which stone beads have been intimately linked to human adaptive strategies in South Asia both in the past and in the present.

STONE BEAD PRODUCTION

Stone bead production involves the shaping and perforation of stone in order to create a bead or pendant that can be strung on a cord or attached to clothing or the hair. Depending on the type of bead that is being produced, numerous sequential and sometimes interchangeable steps or sequences are required. First there is the selection of the raw material, then shaping and grinding, polishing and perforation, followed by stringing the bead or pendant onto an ornament.

RAW MATERIAL SELECTION

South Asia has a very wide variety of coloured rocks that were used for making beads at different times in its long history (Fig. 5). The selection of raw materials for making a stone bead is closely related to the availability of locally available rocks as well as

Fig. 5. Major Stone Bead Raw Materials (1. Limestone, 2. Fossiliferous Limestone, 3. Orbicular Jasper, 4. Carnelian - yellow orange to deep red, 5. Banded Agate, 6. Dyed Agate, 7. Onyx - black to brown banded agate, 8. Chalcedony - white to gray, 9. Sardonyx - red orange to red and white, 10. Moss Agate, 11. Grey Steatite - soapstone, 12. Talc, 13. Bloodstone - green with red spots, 14. Malachite, 15. Lapis-lazuli, 16. Sodalite, 17. Aventurine - Fuchsite, 18. Serpentine - light and dark green, 19. Amethyst, 20. Rock crystal, 21. Smoky and Rose quartz, 22. Ruby, 23. Nephrite (Jade), 24. Basalt, 25. Basalt with quartz bands, 26. Coral - orange and red, 27. Turquoise).

the availability of tools necessary to shape, perforate and polish the rock. These limitations may have impacted some of the earliest human communities, but over time, people in areas with no rock at all were able to obtain a wide variety of materials to produce exquisite varieties of stone beads and ornaments. Some of the earliest stone beads may have been made by collecting stone with natural perforations that can be found in streambeds or along the seashore. These perforations are often the result of natural features of the stone or from the borings of marine species. Humans also may have made beads from natural shaped rocks by simple perforation using pecking or abrasion. No examples of such beads have been found at sites in the subcontinent, but they may turn up in future research of Upper Palaeolithic or early coastal settlements.

At the site of Mehrgarh, in the later Neolithic period (Period 1B), most local production of stone beads involved the use of locally available soft limestone. Shell and stone beads made from exotic materials were primarily produced in more distant regions and brought to the site in finished form, presumably having been manufactured in areas closer to the source of the raw material (Barthélemy De Saizieu 2003, Kenoyer 1995). However, by around 5500 BCE and later, during the Chalcolithic period (Period II and III) at the site, many raw materials were being brought to Mehrgarh and local production of some types of beads was undertaken (Barthélemy De Saizieu 2003). At the site of Harappa, which is located in the middle of the alluvial plain where there are no local rock resources, and even from the very earliest levels of the Ravi Phase (*c.* 3700 BCE) all raw materials such as agate, jasper, carnelian and lapis-lazuli, were brought to the site from resource areas that were between 150 and more than 800 km away from the settlement, (Kenoyer and Meadow 2000, Law 2011a).

SHAPING BEAD ROUGHOUTS AND BLANKS

Shaping a natural rock to create a bead involves several stages of heating, flaking and grinding and the basic techniques are closely related to the production of stone tools, specifically blade tools (Fig. 6). Direct percussion using hard or soft hammer, and indirect percussion using a punch or even pressure flaking has been documented for rocks such as agate and jasper that have conchoidal fracture. The use of inverse indirect percussion, where a stake is placed in the ground and the core is held against the point of the stake and then struck from the opposite side, is also documented at many Harappan sites (Kenoyer et al. 1991). For rocks that do not have conchoidal fracture, such as lapis-lazuli and amazonite, the initial bead roughouts were created by cutting grooves in the stone using chert or quartzite flakes and then snapping the fragments off the core (Bhan et al. 2002, Vidale 1987). In the case of steatite, which is relatively soft, the earliest techniques involved grinding small flat bead blanks or sawing sheets from the blocklets using chert blades. Later, with the development of copper or bronze says, bead preforms or roughouts were made by sawing and then chipping or grinding the edges of the bead to create the basic shape (Vidale 1995). The transition from a bead roughout to a bead blank is simply a process of refining the shape to approximate the final form of the bead. A bead roughout can be shaped into many different final bead shapes, but a bead blank can be considered the final shape before polishing and drilling.

During the prehistoric and Early Historic Period, most of the grinding of stone beads was done by hand or while holding the bead roughout or bead blank in a wooden vice. The wooden vice was probably made with a split piece of wood that allowed the bead grinder to use both hands to hold the bead and the whole body weight to help with grinding. Some very tiny beads were probably

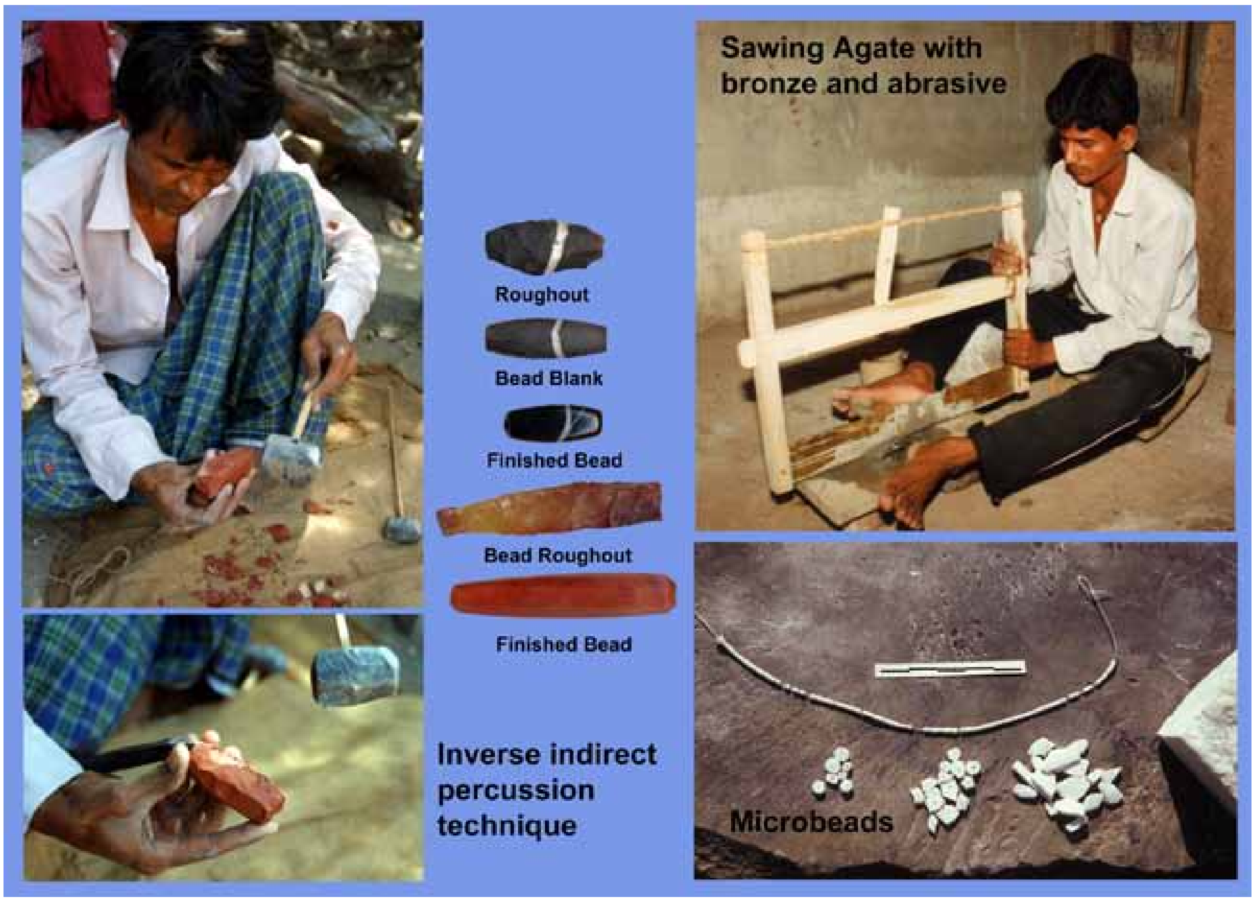

Fig. 6. Bead roughout and blank manufacture.

mounted on a dop stick using lac or insect resin so that each edge of the bead could be ground separately. Then the bead was turned over and the other side was ground. This technique results in the common short biconical shape that is common in many of the early bead forms. Longer biconical or barrel shapes would result from the use of the hand-held vise. Flat and concave grinding stones with parallel grooves have been found at Harappan and Early Historic sites, which demonstrate that most grinding was done by hand and without the use of a rotary grinding wheel. However, the discovery of perfect spheres made from agate or carnelian indicates that the Indus craftsmen also may have developed some mechanical means for rotating the bead in a continuous manner that resulted in a perfectly spherical object. The use of rotary grinding wheels may have been introduced on a larger scale during the later part of the Early Historic period as the number of spherical stone beads increases dramatically during the Kushana period (2nd to 4th centuries CE). This is also the time period when there is evidence for faceted beads and engraved gemstones that were carved using a lathe drill as well as lathe turned abrasive wheels (personal observation).

POLISHING

After the bead has been shaped, it is ground on fine-grained sandstones and siltstones to gradually smooth and eventually polish the surface (Fig. 7). The number of stages involved in grinding and polishing is highly varied and changed significantly over time. During the Indus period, most beads were polished in such a way that all traces of earlier flaking and grinding were removed. This can only be achieved by multiple stages of grinding and polishing on finer and finer grained surfaces.

Fig. 7. Bead polishing techniques.

The final polishing may have been done using a wooden polishing surface and fine brick dust, which is basically silica clay with iron in it. This would achieve the highly reflective polish that is seen on some Indus beads. Some beads from the Indus period were flaked, partly ground and then polished, leaving traces of all earlier stages. These beads can be considered of lower quality in terms of the time and energy involved in production, but they may have had other special symbolic value that we cannot understand. Normally beads were not included in Harappan burial goods, but in one burial at Harappa, a female was buried with five roughly shaped and polished beads at her waist (Dales and Kenoyer 1991: 195, Kenoyer and Meadow 2016). These beads were clearly very important for her and accompanied her into the afterlife. In another burial of a male, three stone beads and three tiny gold beads were worn around his neck, including an orbicular jasper bead with natural eye designs (Kenoyer 2014: 8). These beads were finely made with high polish and with no traces of earlier manufacture. Furthermore, they were heavily worn and appear to have been heirlooms that may have been passed down for more than one generation. The fact that they too were buried with the dead indicates that they had special symbolic value.

In later periods, polishing was generally done in fewer steps and earlier stages of production are often clearly visible. During the Early Historical period, at the site of Taxila (*c.* 4th century CE), there is evidence for garnet beads that were mass polished after drilling (Kenoyer personal observation), which was possibly done by putting the beads into a leather bag with fine abrasives and then shaking or rolling the bag for up to two weeks (Kenoyer et al. 1993). During this period it is also possible that large lathe wheels were used for polishing since there is evidence for tiny abrasive wheels for engraving gemstones (see above).

The polishing of a bead is something that goes beyond the necessary techniques used in tool making and represents a new process of creating a smooth reflective surface that has two functions. Polishing allows the natural colour and designs present in a rock to be seen more clearly and it also creates a reflective surface that can enhance the colour and clarity of the rock, drawing attention to the person wearing the ornament. Polishing is well attested on ground stone tools as a way to sharpen the edges of the stone, but eventually ground stone tools in the Neolithic or early Chalcolithic appear to have been polished over their entire surface in a way that is clearly not functional and must have also played a role in visual display.

PERFORATION

As noted above, stone perforation using pecking techniques can be traced quite early in the Upper Palaeolithic and Epi-Palaeolithic in South Asia. The perforation of slate harvesting tools found at sites such as Loebanr, Pakistan (Stacul 1980) indicates that perforation was used to help in tying and hafting the slate blade to a handle. Based on the nature of the holes in these slate knives, it is possible that they were made using hand held perçoirs or drills made from quartzite or chert. Long deep holes have not been documented at this time so drilling could have been done with a pump drill or hand-held drills. Whatever the process, it is clear that people were experimenting with perforation using harder rocks to make holes in softer rocks. In addition to perforation, some stone ornaments were attached to necklaces and clothing by a cord that was secured to the object by means of a groove or simply by wrapping a cord tightly around the object. Such ornaments could be called pendants but are not technically considered beads.

By the Neolithic period at the site of Mehrgarh, shell beads and soft stones were being perforated to make ornaments (Fig. 4a-b). At Mehrgarh, white limestone was being ground and shaped to create flat tabular beads that were used to make anklets and bracelets (Fig. 4b). Other soft materials were also being used at Mehrgarh, including lapis and turquoise (Fig. 4c). Additional soft stones, such as talc (steatite) or serpentine were also used to make beads. While in the earliest levels at Mehrgarh, the steatite was left unfired, in later levels there is evidence for the firing of the steatite to turn it white and also to harden it (Barthélemy De Saizieu and Bouquillon 1994, Vidale 1995). The earliest Neolithic beads were probably being perforated using chert perçoirs or hand-held drills. However, at Mehrgarh there is also evidence for the perforation of harder stones such as jasper and agate. These raw materials could be perforated using similar types of chert of jasper drills used in perforating softer stone, but would have required the use of a bow drill in order to allow heavier pressure in drilling and more vigorous rotation. A bow drill was also necessary for perforating long beads, as pump drills are not effective for perforating deep and narrow holes.

Based on the excavations at a wide number of sites in South Asia, it is now clear that multiple types of drills and many different drilling practices were being developed to perforate different types of stones (Fig. 8). A brief summary of the major types is presented below.

PECKING OR PERCUSSION DRILLING

The perforation of a stone bead blank using percussion is a technique that is found in the earliest Neolithic levels at Mehrgarh, dating to around 7000 BCE. Pecking is found on both carnelian and on rare example of garnet beads (Barthélemy De Saizieu and Rodière 2005: 45). Pecking is also found in the later Chalcolithic period at Mehrgarh and is well documented at other Early Harappan sites, such as in the Ravi Phase at Harappa (Kenoyer 2005a). Pecking also continues into the Harappa Phase at sites such as Chanhudaro, where pecked

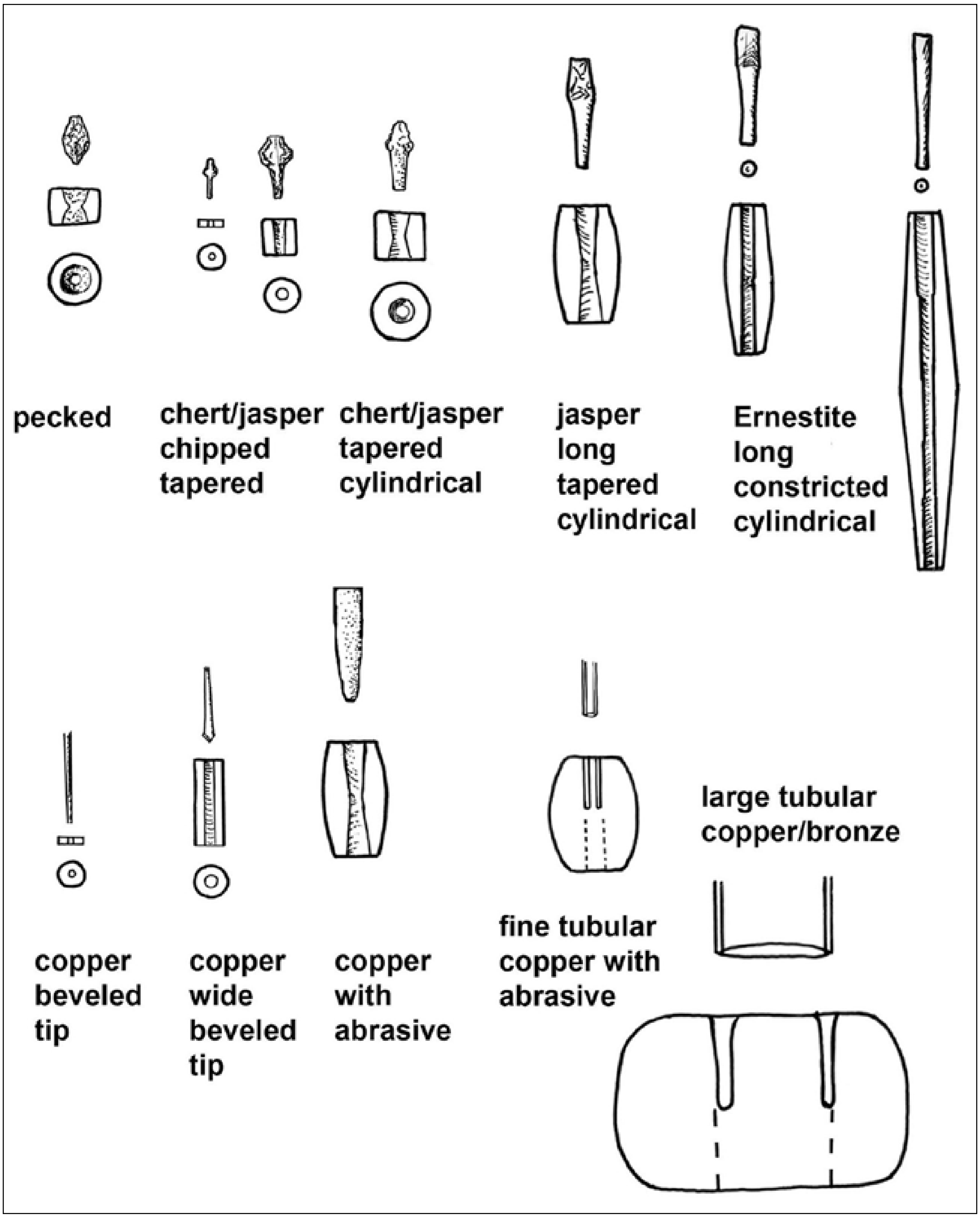

Fig. 8. Major bead drilling techniques.

perforation was taking place alongside other stone drilling techniques. This indicates that there were different qualities of beads being produced in Indus workshops and that the perforation technique may have been an important indicator of the overall time and energy, as well as skill needed to make a bead.

Fig. 9. Ravi phase percussors and drills, Harappa.

Pecking involved the manufacture of a pointed stone tool that could be either made using pressure flaking to create a long tapered cylindrical point or by notching a blade to make a short point. The long tapered cylindrical points were made using jasper, chert, and even carnelian at the site of Harappa during the Ravi Phase (Fig. 9). In Chanhudaro, the common pecking tool was made by retouching or notching a blade on two edges to create a point (Fig. 10), which is also seen at sites such as

Fig. 10. Percussors made from chert blades, Chanhudaro.

Fig. 11. Experimental perforation by pecking.

Hierakonpolis in Egypt (Endo et al. 2009, Hikade 2004) and the site of Tayma, Saudi Arabia (Hausleiter 2011) and at other sites in West Asia (Chevalier et al. 1982). Based on the large numbers of broken beads at Chanhudaro as well as the other sites mentioned above, it appears that this technique resulted in considerable bead breakage. I have tried various techniques to perforate carnelian using the pecking technique and have been most successful using a hafted percussor and a horn hammer so that the pecking can be precisely directed to a single spot to perforate the carnelian (Fig. 11).

The pecking technique is also found in East Asia and is found at sites of the Lower (4200-1600 BCE) and Upper Xiajiadian (1000-600 BCE) Culture of Inner Mongolia and Liaoning Province in Northeastern China (personal observation) (Shelach-Levi 2015: 20). These pecked beads were often curated and used by later communities such as the Shang tomb of Fu Hao and in some of the elite burials of the Western Zhou of Central China (personal observation). Pecking results in a conical drill section when done from one side, and an inverted biconical shape when done from both ends of the bead (Fig. 8).

TAPERED CYLINDRICAL CHERT DRILLING

Another technique used to perforate hard stone involved the use of tapered chert drills that eventually became ground and polished into long tapered cylindrical form through the drilling process (Fig. 12). Chert and jasper have a hardness of around 7 on the Moh's scale, but the microcrystalline structure is granular while that of carnelian is fibrous (Luedtke 1992). The difference in microcrystalline structure allows the chert and jasper to withstand heat and pressure more effectively and this allows for the gradual breakdown and abrasion of carnelian. The drilling process is quite tedious and many drills are broken and worn down in the process, but eventually a hole can be perforated through the carnelian. The shape of the drill hole is long and tapered conical or cylindrical if drilled from one side and long tapered inverted biconical or cylindrical if drilled from two sides (Fig. 8). The rates of drilling carnelian using a chert or jasper drill are quite varied depending on the skill of the craftsperson, and whether or not additional abrasives are used. Stocks (1989) was able to perforate quartz and amethyst to a depth of around 0.5 mm in 10 to 15 minutes of drilling with a chert drill. According to another recent publication report on experiments using a flint drill to perforate carnelian, 'The penetration rate accomplished using a pump-drill with sand was about 1 mm per 3 min' (Groman-Yaroslavski and Bar-Yosef 2015: 81). This later rate would mean that a 1-cm bead could be drilled with a stone drill in around 30 minutes.

In my own experiments using a bow drill, I have had a very difficult time drilling carnelian using a chert or jasper drill and continue to experiment with different types of chert and jasper to try to improve my drilling time. In one of the early attempts, the drilling rate for green jasper on carnelian was 0.83 mm per hour. This includes time required to cool the drill tip and to regrind the tip of the drill (Kenoyer and Vidale 1992: 513). More recent attempts have been able to slightly improve this rate of drilling, but have not improved that much. Based on the very different results of the experiments noted above, further studies supplemented with video documentation are needed to better

Fig. 12. Tapered cylindrical chert drills, Harappa.

understand the ways in which ancient stone drills were made and used.

CONSTRICTED CYLINDRICAL DRILLING

The types of drills used to perforate stone evolved significantly during the Indus Civilization, and can be correlated to the need to create long and narrow beads of hard carnelian or jasper. The most important development was the discovery of a very hard material that we have named 'Ernestite' (Kenoyer and Vidale 1992) in honour of Ernest J.H. Mackay, who is the first person to report the discovery of drills at the site of Chanhudaro (Mackay 1943). Constricted cylindrical drills are only found during the Harappa Phase of the Indus Civilization, circa 2600-1900 BCE and recent excavations at Dholavira indicate that they were most common during Stage IV and V (2500-2000 BCE) (Bisht 2015: 104, Prabhakar et al. 2012) at that site, which roughly corresponds to the Harappa 3B and 3C Phases (2450-1900 BCE) (Meadow and Kenoyer 2005). Constricted cylindrical drills have a long cylindrical shape that is wide at the tip and constricted in the midsection (Fig. 13). This shape allows for water or oil to flush out the abraded materials resulting from the drilling process and also make it possible to drill a relatively straight cylindrical drill hole (Fig. 8). As smaller drills are

Fig. 13. Constricted cylindrical ernestite drills and beads, Chanhudaro (Photo Courtesy of the Boston Museum of Fine Arts).

used to drill deeper into a bead, the drill hole section reveals a stepped profile. This is a very distinctive feature of Indus drilling and is not possible with tapered cylindrical drills. In the Indus region, constricted cylindrical drills were made exclusively from Ernestite and have not been found made from chert or jasper. However, recent studies of beads from Bactro-Margiana show stepped cylindrical drilling profiles and much larger holes than are common in Indus beads, so it is possible that constricted cylindrical drills were also being used in other regions, possibly made from chert or jasper. Future excavations may reveal such drills, but so far the Indus is the only region that has reported this type of drill.

METAL DRILLS

The use of metal to make drills is documented indirectly based on the drilling striae found on the inside of steatite beads at Harappa. The tiny holes and the straight cylindrical drill holes suggest that the drilling was done using a thin metal rod, probably of copper or bronze with a hammered and bevelled tip that was slightly wider than the shaft. This allowed the drills to efficiently perforate long narrow tubes of steatite to create long cylindrical beads. During later periods, there is evidence for the use of tubular copper drills that were used with abrasives (see below) (Fig. 14). The tubular drills were probably made by rolling a thin sheet of

Fig. 14. Experimental tubular and solid copper drills with abrasive.

copper into a tube and hafting this to the tip of a wooden shaft. Tubular drills made from brass have been used historically in Khambhat for drilling out the centre of rings or other large holes. The sheet of brass is hafted on the tip of a wooden drill leaving a narrow gap so that abrasives and water can flow into and out of the drilling area. This may have been how the ancient tubular drills were created, but so far no preserved ancient drills have been found. During the Early Historical Period, iron and steel eventually came to be used for drilling soft stone and as the shaft for mounting diamond chips for diamond drilling, which will be discussed in more detail below.

DRILLING WITH ABRASIVES

Another technique used for perforation involves the use of abrasives made of quartz, garnet, corundum or even diamond sand. When drilling with abrasives, there are three major variables that need to be considered—the hardness of the bead raw material, the hardness and grain size of the abrasive material, and the nature of the raw material and shape of drill itself. In order for an abrasive to cut through a bead, it must be harder and have a more resilient microstructure than the bead raw material. Quartz and carnelian both have hardness of Moh's 7, but as noted above with chert and jasper, quartz has a granular microstructure and can therefore cut through the fibrous microstructure of carnelian. The drill material needs to be softer than the abrasive so that the abrasive can become imbedded in the drill and grind against the bead. If the drill is too soft it will abrade faster than the bead. Using bamboo, wood or bone with quartz abrasive is extremely time-consuming as the softer organic material of the drill must be replaced repeatedly as it is worn away. While this technique may have been used in antiquity for drilling softer stone such as nephrite or serpentine, the earliest evidence for drilling hard stone such as carnelian or jasper with abrasive is seen during the Chalcolithic, when copper would have been available. Copper is resilient and strong enough to withstand the intense heat that is produced in drilling. Even when cooled with water, the tip of the drill and the abrasive slurry becomes quite hot. Ongoing studies by the author suggest that part of the drilling process is heating the underlying stone to help break it down and weaken the crystal bonds so that the bead surface is gradually worn way. Experiments using stone drills with quartz abrasive do not appear to be that effective since the stone drill and bead surface are the same hardness and the abrasive ends up being ground into a fine powder rather than effectively grinding away the bead surface. Copper and bronze drills allow for the abrasive to be pressed into the softer metal and in this way continue to abrade and eventually drill through the bead surface.

The only evidence for abrasives was found at the site of Mehrgarh during Period VII, which is during the pre-Indus or Early Harappan period (note that their Figure label has a typographical error and should read MR Period VII and not NS Period VII) (Barthélemy De Saizieu & Rodière, 2005: Fig. 4.6). The authors have not stated that this is abrasive drilling, but based on my own SEM analysis of similar beads, the distinctive collaring that is seen in this drill impression was probably created by a copper drill with abrasives. This would need to be confirmed by studying the impression at higher resolution but copper drills often flare out when too much pressure is applied during the drilling process. This is seen in the collar that is seen in the drill profile. The main abrasive that would be present at this time would be quartz. This abrasive leaves a relatively polished surface compared to corundum or emery, which leaves a rougher surface. During the Harappa Phase (2600-1900 BCE), studies of beads from Harappa and Dholavira indicate that there is evidence for drilling using quartz abrasive and some other harder material that could be garnet or possibly corundum or emery. Further studies are needed to determine the nature of the harder abrasive.

Most of the drilling of hard stone beads with abrasives during the Harappa Phase appears to be with solid copper drills, but there is possible evidence for the use of tubular copper drills (Fig. 13). During the Late Harappa Phase (*c*. 1900-1300 BCE), tiny tubular copper drills with abrasive are well documented from Harappa (Kenoyer 1997, 2005a).

DIAMOND DRILLING

The use of diamond for drilling stone beads is one of the most significant and transformative technologies related to bead production in South Asia. From one perspective, this technique made it possible to drill faster and more efficiently, but in another context it resulted in a change in the overall value of hard stone beads. Whereas in the past, a stone bead required a lot of time to perforate, with diamond drilling, many beads could be made very quickly and the value of these objects was changed forever.

The use of tiny diamond chips for drilling dates to around 600 BCE in western India (Kenoyer 2003: 17-18) and further studies may show that it started even earlier. The source of the diamonds used for drilling is not known but would have to be derived from diamond producing regions of peninsular India. The use of diamond drills is documented on the basis of comparative studies of drill hole analysis from modern and ancient beads. The

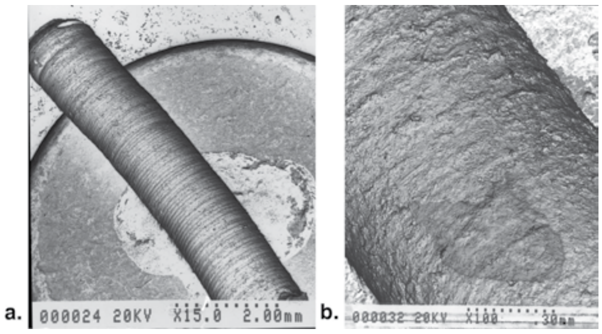

Fig. 15a. Ancient double diamond drilling, Nagara, Gujarat (a. 15 x magnification, b. 100X magnification).

site of Nagara near modern Khambhat presents examples of beads that were clearly drilled using double diamond drills (Fig. 15a). The earliest beads may date to the 6th and 5th centuries BCE while others date to between the 3rd century BCE and the early centuries CE (Mehta and Shah 1968). Although no examples of early diamond drills have been recovered from excavations, by studying the drill hole impressions from sites such as Taxila, it is possible to note that at least two forms of diamond drills were being used (Fig. 15b). Single diamond drills were made by crimping a rounded diamond chip at the tip of the drill, exposing two edges of the diamond. The metal used for the drills may have been bronze or iron. This technique is still used by Afghan bead drillers in modern Afghanistan where drills were made by using a single diamond chip that was crimped to the end of a narrow bronze of iron drill shaft (Kenoyer 1992a). The double diamond drill was made by crimping two rounded diamond chips at each edge of the widened metal tip of the drill. This allows the externally projecting diamonds to cut the stone bead in a circular motion, much like a tubular drill. This technique was used in Gujarat and throughout much of peninsular India and is still practiced in Gujarat today. It appears that this technique may have spread to Thailand and Southeast Asia along with the spread of Indian craftsmen during the Early Historic

Fig. 15b. Modern double and single diamond drilling techniques.

Period (Carter 2013), but more studies are needed to document the nature of this technological diffusion. Diamond drilling is also evident from the study of Achaemenid period beads and those of later periods in Iran (personal observation), but more research is needed on well-dated beads to properly document this spread to the West.

DECORATED AND DYED STONE BEADS

The final discussion of beads relates to the decoration of beads using artificial colours that leave a permanent design, or the dying of beads to enhance or change the colour of the original rock. In the later part of the Neolithic period at Mehrgarh, white stone beads that included the mineral *anthophyllite* along with talc were thought to represent early heat treatment of talc (Barthélemy De Saizieu and Bouquillon 1994: 51). However, experimental studies have not been able to replicate this type of composition, and Law argues that "the heat-treatment of steatite during Period I at Mehrgarh must, at present, be considered unconfirmed" (Law 2011b: 257). Steatite was definitely being heat treated by Mehrgarh Period IIB and then in Period III (*c*. 5000-4500 BCE) (Law 2011b: 257), and is widespread at other sites during the Early Harappa Phase (5500-2800 BCE). Extensive studies of Harappan steatite and replicative experiments by Randall Law have shown that the Harappans selected specific types of Dolomitic steatite that would fire to a white colour (Law 2011b: 259), and that the soft "talc decomposes to *enstatite* (magnesium silicate) and amorphous silica between around 900°C and 1000° C. At temperatures above 1100°C the amorphous silica will begin to crystallize as *cristobalite* (the high-temperature polymorph of quartz)" (Law 2011b: 256). The whitening of steatite can also be enhanced by using a fluxing agent, such as plant ash that is rich in sodium carbonate and potassium (personal observation). The plant ash that is commonly used to make glazes in Pakistan

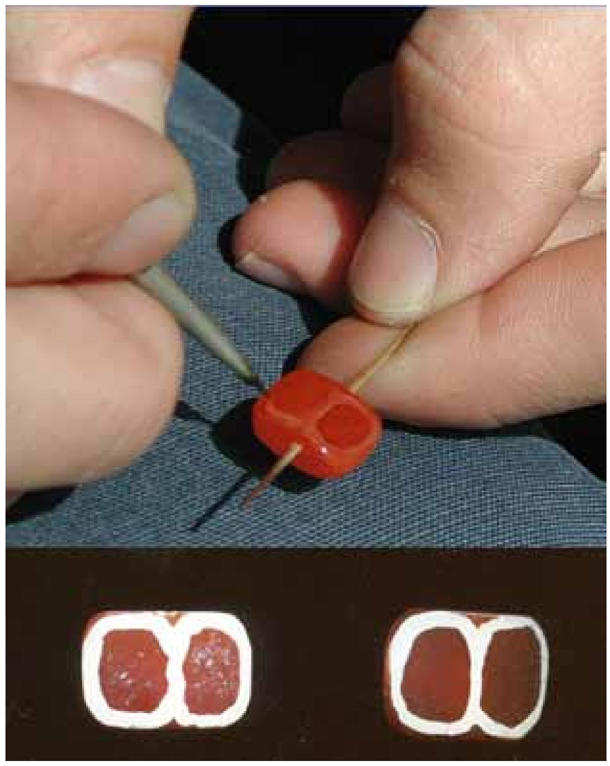

Fig. 16. Experimental bleaching and replica beads.

and India today is called *sajji* or *sajji-khar*, and is made by burning the plant *Salosola stocksii* or other species of Amaranth. This same flux is used to produce white lines on the surface of carnelian, again through a process of slow heating.

The technique of decorating carnelian using a sodium carbonate based paint was first noted by Mackay (Mackay 1937), who also noted the use of the leaves of the caper or *kirar* tree. I have been able to replicate this technique to recreate Harappa designs on carnelian using a simple hearth with glowing coals to gradually heat the bead and fuse the paint on to the surface of the bead (Fig. 16). This technique does not etch the bead, but causes micro fractures of the carnelian so that the surface appears white. I have referred to this technique as bleaching rather than etching (Kenoyer 2003). The Harappan bead-makers developed this technique and were able to make extremely fine lines and designs on carnelian beads but if the firing was done incorrectly, or the bead was subsequently burned,

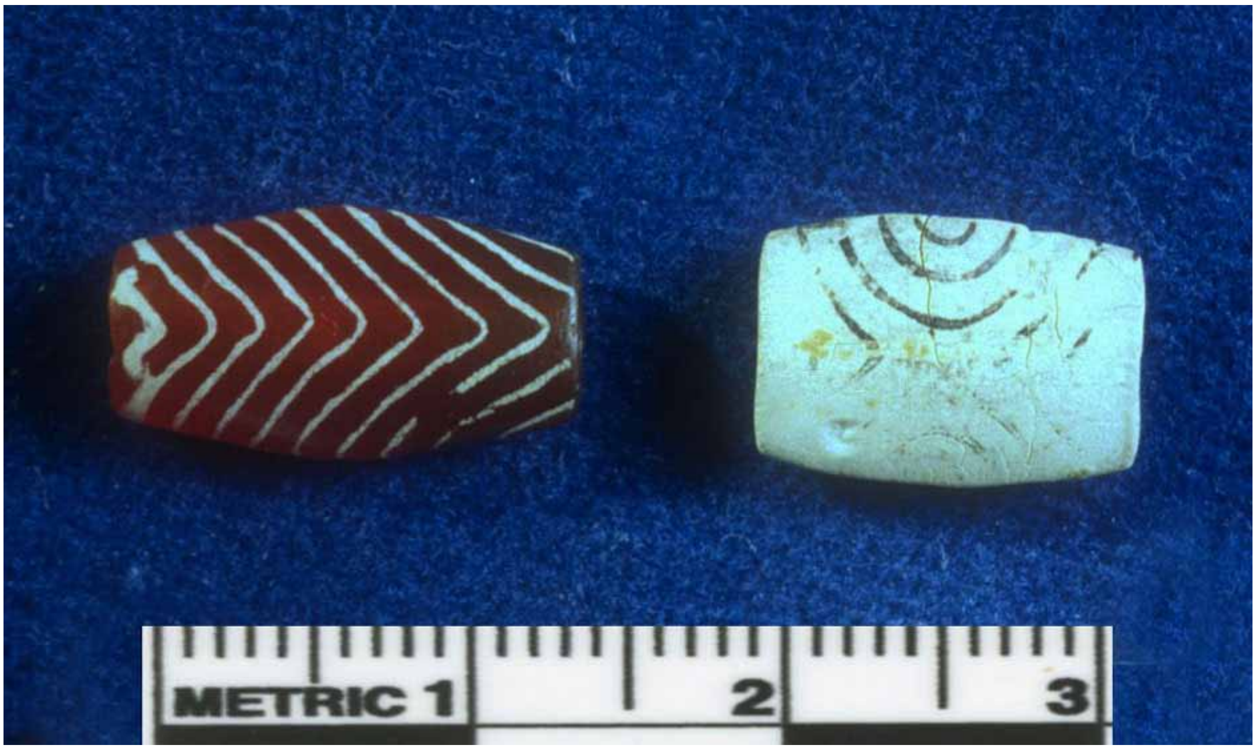

Fig. 17. Bleached carnelian and burned bleached carnelian beads, Chanhudaro (*Courtesy* Boston Museum of Fine Arts).

the white design often took on carbon and turned black, while the red carnelian was burned to a white colour (Fig. 17). Harappan beads with bleached designs have been found as far as Mesopotamia in Ur (Zettler 1998) as well as Egypt (Grajetzki 2012) and even in Greece (Aruz 2003). This technique also spread to Mesopotamia with Harappan craftsmen and eventually spread throughout Peninsular India and on to Southeast Asia. The technique continued on into the Late Harappa Phase, and appears in the Early Historic Period where it is used throughout the Indian subcontinent and surrounding regions.

Another technology that may have begun during the Harappan period but was possibly expanded during the Late Harappan is the colouring of agate using carbon to create a dark black or brown-banded agate (Fig. 18). Due to the fact that the silica that accumulates to form agate is built up in layers, each layer has a slightly different consistency and porosity. Some layers are naturally coloured with minerals such as iron or manganese, and some are extremely compact or slightly porous. With heating, the iron will turn red to form carnelian and manganese can turn slightly darker. By soaking agate in honey or sugar water, the porous layers can take on the organic sugars, and by later heating the stone, the sugar can be carbonized to turn brown or black. This colouring technique is known to have been used historically (Russell 2008), but the first use appears during the Harappa and Late Harappa Phases (Kenoyer 2014). The technique continued to be used during the Early Historic period and was combined with the bleaching technique to create new designs on beads that were

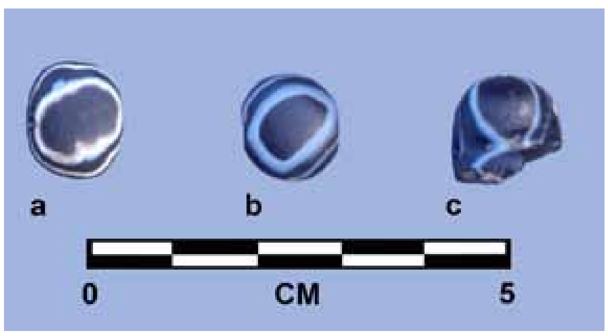

Fig. 18. Black and white dyed agate, Late Harappa Phase, Harappa (a. single eye, b. single eye, c. double eye) (*Courtesy* Department of Archaeology and Museum, Govt. of Pakistan).

Fig. 19. Carnelian belt, stone bead necklaces and gold jewellery, Mohenjodaro (*Courtesy* Department of Archaeology and Museum, Govt. of Pakistan).

Fig. 20. Early Historic period dyed and decorated beads, Shorkot (*Courtesy* Jamil Bhatti, Jhang, Pakistan).

black and white rather than red and white (Fig. 20). Further studies are needed to better understand the origin and spread of the technology to blacken stone and how it might have changed over time. This new style of bead decoration may have had some specific ideological association as it is first found at sites in the northern subcontinent associated with Buddhism but eventually spread to the entire subcontinent along with similar shapes and designs made with bleached carnelian.

CHANGING STONE BEAD STYLES

Stone bead shapes and styles changed dramatically from their first appearance during the Neolithic Period around 7000 BCE to the Early Historic Period. The major changes in shape can be correlated to the technologies available for perforation and the use of rotary drilling and eventually wheel grinding and polishing. The early beads at Mehrgarh and during the Early Harappan period of the Indus Valley region were generally short cylindrical or disc shaped, long cylindrical, flat circular or quadrangular, short bicones or short barrel shapes (Fig. 4). Flattened shapes such as lenticular or oval barrel shapes were also created using different coloured stones that were designed to accentuate the banding or natural patterns of the stone. This overall trend continued into the Harappa Phase (2600-1900 BCE), but the new style to emerge during this period was the very long and slender biconical or barrel-shaped carnelian bead (Fig. 13). The long carnelian beads were specifically designed to be worn in massive belts (Fig. 20) that had six rows of beads that would clink against each other to create a unique tinkling sound. These same beads were traded to regions outside the Indus but they have never been found to be used in belts outside the Indus. With the introduction of the Ernestite drill, it was also possible to drill harder stones that were not used in earlier periods. During the Harappa Phase, bloodstone, which is much harder and more difficult to drill than carnelian was also used to make long biconical beads. Another hard stone was grossular garnet or vesuvianite, a light green stone that has a hardness of around 7 and could only be drilled using Ernestite drills or hard abrasives such as corundum (Fig. 21). Many new styles of bead ornamentation were probably developed during the Harappa Phase, but the ones that are preserved archaeologically are those using copper or gold wire. With the aid of these metals, beads could be combined together to create pendants or placed on metal headdresses or mounted in unique ways to create exquisite ornaments (Figs. 20 and 21).

Fig. 21. Green vesuvianite beads and pendant beads of jasper and gold, Mohenjodaro (*Courtesy* Department of Archaeology and Museum, Govt. of Pakistan).

Fig. 22. Early Historic period raw materials for bead making, Taxila Museum [1. Beryl (Emerald), 2. Beryl (Sapphire), 3. Topaz, 4. Tourmaline. (*Courtesy* Department of Archaeology and Museum, Govt. of Pakistan].

At the end of the Harappa Phase, the use of the Ernestite drill disappears and along with this technological setback, the production of long carnelian beads disappears in most regions of the Indus. The only place where long carnelian beads continue is in the north, where they are found at the Late Harappan site of Sanauli (Sharma et al. 2004), but these beads are drilled with tapering stone drills or with abrasives, and not the constricted cylindrical drills of the Harappa Phase.

The main changes in bead styles during the Early Historic Period are seen in the introduction of spherical garnet beads, amethyst, faceted amethyst, topaz and eventually emerald and ruby beads (Fig. 22). These later could only be drilled using diamond drills and reflect a totally new trend in hard stone beads.

CONCLUSIONS

The use of stone to make beads and pendants continues to be an important industry today, and many regions of South Asia and the world continue to produce distinctive forms of stone ornaments using a combination of both old and new techniques. One of the important challenges to the study of stone beads is to understand the complex technologies that were created to mine, shape, decorate and perforate stone. The symbolic value and economic value of beads is also a topic that can be explored in relation to the overall cultural context in which beads are found. Due to the fact that cultural contexts change over time, it is important to try and sort out the changing role of beads in human adaptive strategies and how they were used to enhance social, economic and political power as well as to be used as important ideological symbols. Stone beads are extremely durable and have been passed down from generation to generation, but they have been used in different ways over time. The only way to try and sort out the period of bead manufacture and to trace its use from one period to the next is through the detailed analysis of its production and traces of use wear that show how it was used. Each bead has a unique story, and innovative techniques and larger samples of well-excavated and chronologically documented beads are needed to increase our understanding of this important type of artefact.

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