An Overview of the Stone Bead Drilling Technology in South Asia from Earliest Times to Harappans

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Abstract: *The Harappan Civilization is one among the four Bronze Age Civilizations of third millennium BCE that flourished for nearly 700 years (c. 2600 – 1900 BCE) in the river valleys of Indus-Ghagger-Hakra in modern India and Pakistan. The overall site count is well over 2500 now belonging to all the three phases, viz., early Harappan, Harappan and late / post-urban Harappan. The Harappan Civilization is characterized by well-planned out cities, always with a fortification, often with more than two divisions individually fortified, standardized ceramic tradition, weighing system, seals and sealing and a wide variety of craft activities. The knowledge of copper, gold, silver, lead and bronze was widespread and the Harappans exploited more than two-dozen raw material. The beginnings of stone bead manufacturing in Indian sub-continent can be traced to Upper Palaeolithic and Microlithic traditions in South Asia, say some 35000 years ago. It is from the Neolithic Period from Mehrgarh (from 7th millennium BCE) we get evidence of exploitation of various exotic raw materials from distant regions and perforations made using another hard stone. The technology slowly developed during the succeeding Chalcolithic Period before reaching its zenith during the Harappan Civilization. The Harappans gained access to several raw material sources spread around the Indus valley and its tributaries and it has been estimated that they exploited to around 40 minerals for manufacturing jewels and ornaments. The Harappans also developed ornaments of exotic nature from agate-carnelian such as long-barrel cylindrical beads and etched / bleached / decorated carnelian beads, which were exported all the way to Mesopotamia during third millennium BCE. The Harappans also invented a superior drilling technology by using a slightly harder material known as 'ernestite' for making perforations of these agate-carnelian beads. In particular, the Gujarat region dominated in usage of ernestite as drill bits, which indicates its source in this region, which is yet to be identified.*

Keywords: Stone Bead, Drilling Technology, Upper Palaeolithic, Microlithic, Neolithic, Chalcolithic, Harappans

Introduction

The Indus Valley Civilization or Harappan Civilization, one among the four Bronze Age civilizations of third millennium BCE (Fig. 1) was discovered after the excavations at Harappa (1921-21 to 1933-34 onwards) and Mohenjo-daro (1922 to 1931) and announced in the Illustrated London News (Marshall: 1924).The announcement attracted Assyriologists like A.H. Sayce (1924) who noted the similarity of inscribed seals found from Harappa and Mohenjo-daro with Susa from levels datable between *c.* 2600 and 2300 BCE. Since then, Harappan seals have been reported from several sites in West Asia like Ur (Woolley: 1928, 1932), Tell Asmar (Frankfort: 1933), Kish (Mackay: 1925; Langdon: 1931), Nippur (Gibson: 19771). Further, sealing impressions from Harappan seals have been reported from sites like Tell Umma (Possehl: 1996). These evidences along with other exotic artefacts of Harappan origin like long-barrel cylindrical beads, etched/bleached/decorated beads, both of agate-carnelian, flat disc gold beads, and others from sites in West Asia (Fig. 2) (Possehl: 1996) clearly support the conclusion drawn by Sayce as early as 1924 that *'…..intercourse between the Susa and North West of India.* 'The excavations at sites like Mehrgarh (Jarrige *et al*: 1995), Nausharo (Jarrige: 1994), Pirak (Jarrige *et al*: 1979),in the Balochistan area brought to light a long and continuous habitation spread over 8000 years which helped in understanding the evolution of Harappan Civilization since the humans adopted a food gathering-agro pastoral stage followed by settled life and ultimately reaching the pinnacle of civilization through a series of interactions with other settled societies, inventions of various technologies including pyrotechnology, and more importantly surplus in food production.

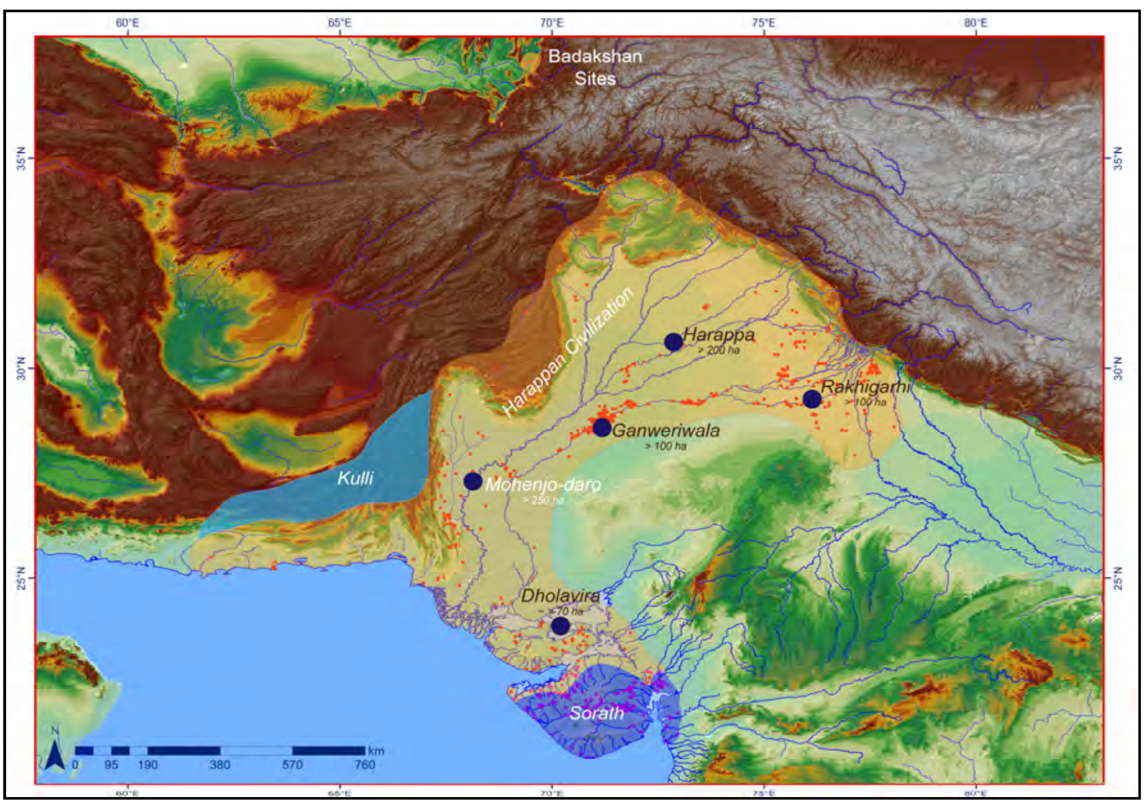

Figure 1: Map Showing the Extent of Harappan Civilization

The investigations carried out by several agencies including governmental and research institutions since 1924 have enabled in the better understanding of Harappan Civilization. The spread of the civilization is also better understood with the available data from nearly 2500 sites spread across diverse geographical zones. The north, south, east and western limits are marked by the sites of Shortugai (Afghanistan)/ Manda (Jammu & Kashmir); Lothal (Gujarat), Alamgirpur (Uttar Pradesh) and Sutkagen-dor (Pakistan), thereby encompassing an estimated area of nearly 0.7 – 1.0 million sq. km. Some of the important sites excavated after Harappa and Mohenjo-daro are Chanhudaro (Mackay: 1943), Rupnagar (Sharma: 1956; 1982), Lothal (Rao: 1979; 1985), Kalibangan (Thapar: 1973; 1975), Surkotada (Joshi: 1990), Kot Diji (Khan: 1965), Dholavira (Bisht: 1991), Rakhigarhi (Nath: 1997-98), Banawali (Bisht: 1987), Bhirrana (Rao: 2004-05), to name a few. These excavations along with a host of others have helped in understanding the origin of Harappan culture, its rise and later slow decline.

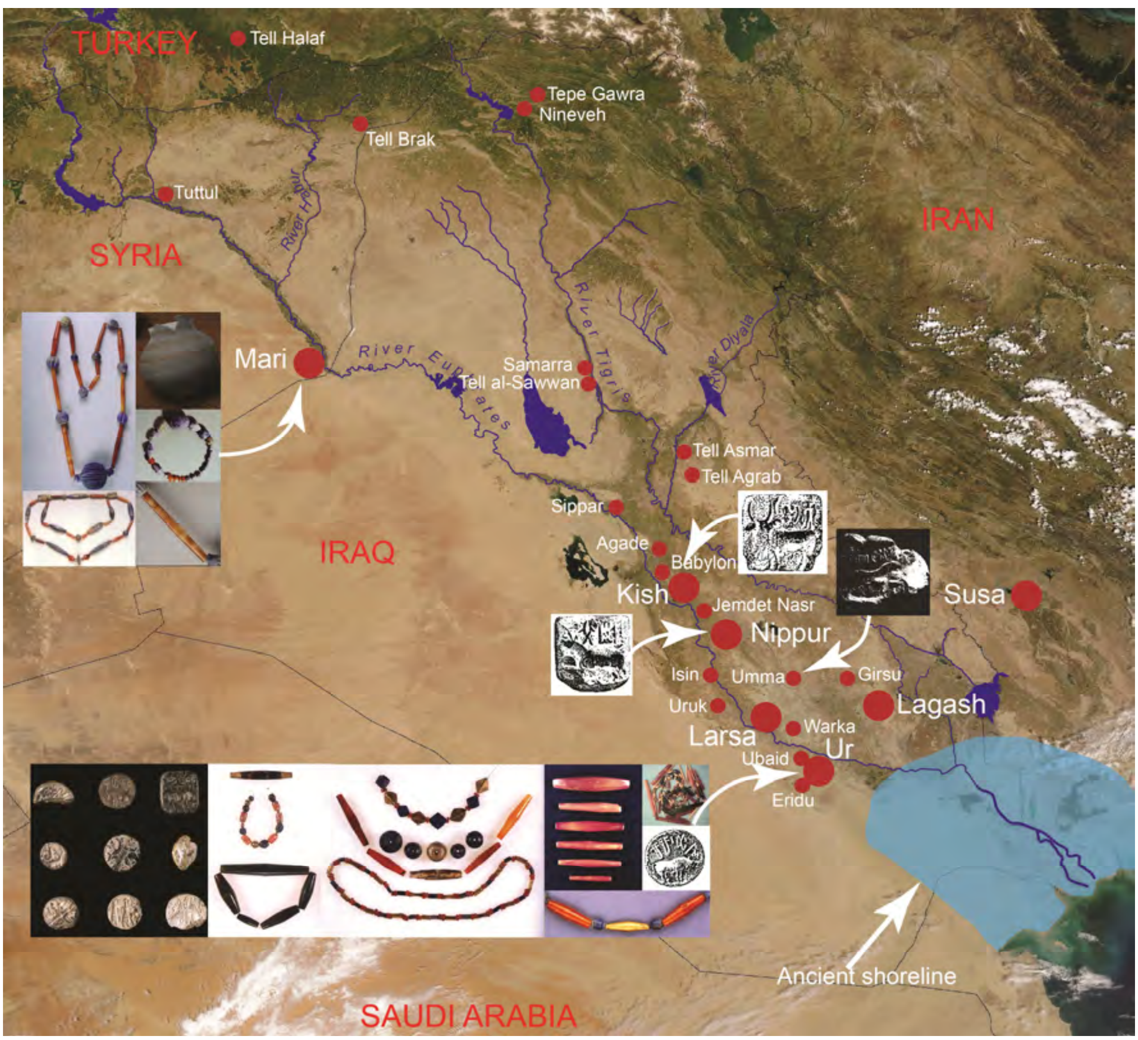

Figure 2: Map Showing Mesopotamian Sites with Harappan Artefacts

The Harappan culture is characterized by several features, including planned cities and towns supported by rural settlements, often encompassed by wide fortifications, standardized ceramics along with local pottery and is supported by a wide range of artefactual assemblage of seals, sealing, variety of ornaments of stone, metal, shell, terracotta and others, weaponry of copper/bronze, toys and amusement items. Among the ornaments, the Harappans dominated the production of certain varieties from agate-carnelian, a hard silicate rock that owes its origin to basalt rock formation of Deccan plateau and Gujarat.

Beads in Prehistoric Context from South Asia (~40 ka[1] Onwards)

The human existence on this planet had witnessed several path breaking innovations and inventions which led them successfully on the growth pattern passing through several stages of hunter-gathering, agro-pastoralism, domestication of plants and animals, urbanism. The growth pattern varies from place to place and continent to continent dependent upon factors like environment, climate, accessibility to raw materials sources, and others. These developmental stages and interrelationship between different groups of humans are identified from the archaeological record through a *"….prodigious quantity of classificatory studies in which artefacts are attributed to 'cultures' and 'styles'* (Miller: 1985)." The human expression and cognitive development is often reflected in the variation of styles in artefacts from cultural to culture. In the international scenario several such examples are found. A fewexamples are Blombos Cave (South Africa, shell beads, engraved ochre, ochre processing kits; 65-75ka), Hohlenstein-Stadel Cave (Germany, part human, part lion standing figurine; 40 ka), Klipdrift shelter (South Africa, engraved ostrich eggshell, 63 ka), Grotte Du Renne (France, fox tooth ornament, 43 ka), Hohle Fels Cave (Germany, griffon vulture bone flute, 40 ka; Venus figurine, 35 ka), Vogelherd Cave (Germany, ivory lion head, 35 ka), Dolni Vestonice (Czech republic, ivory beads, 26 ka), Malta (Russia, ivory flying bird pendant, 20 ka). These individual artefacts being examples of human artistic and cognitive expressions are also accompanied by paintings on rock surfaces. A few prominent ones are Chauvet Cave, Lascaux, Renne, Brassempouy (all in France), Altamira, Monte Castillo (both in Spain), Geissenlkosterle, Hohle Fels, Hohlenstein-Stadel and Vogelherd (all in Germany), Zarayst (Russia).

In the South Asian context, human occupation is attested in several locations. The earliest dated human presence comes from Attirampakkam which is dated to 1.51 ± 0.07 Ma (pooled average) for acheulian (lower palaeolithic) levels (Shanti Pappu*et al*: 2011).The discovery of a partial human skull from Hathnora in 1982 belonging to archaic Homo sapiens is the earliest human fossil from India (Sonakia 1984; Salahuddin *et al:* 1986-87). The remains of human bones of *Homo sapiens* are also found from Jwalapuram Locality 9 datable to a time bracket of 20 and 12 ka (Clarkson *et* al: 2009) and Bhimbetka (Kennedy: 2000). The presence of late Pleistocene human fossil remains from Batadomba lena (Sri Lanka) dateable to 20,239-17,298 cal. years BP and Kitulgala Beli-Lena (Sri Lanka) datable to 15,296-12,980 cal. years BP is an important finding outside India (Patrick Roberts *et al*: 2015). The earliest evidence of human artistic expression from South Asian context comes from sites like Patne (Maharashtra), Jwalapuram (Andhra Pradesh) and from Batadomba-lena, Fa Hien-Lena and Kitulgala Beli-lena (all in Sri Lanka).

The Jwalapuram Locality 9 yielded 25 limestone and bone beads which is claimed to be *"….one of the largest collections of late Pleistocene symbolic items in South Asia"* (Clarkson *et* al: 2009*).* The evidence indicates preference of stone towards bone at the earlier levels along with several unperforated blanks, interpreted as bead blanks. The other evidences of human artistic expression are pierced bivalve shell, grooved reptile tooth, terracotta bead from the same locality. This evidence along with 'striated' red ochre datable to 20-12 kya from the same locality is also an indicator of 'artistic activities' (Clarkson *et al*: 2009). Outside India, the evidences from Sri Lanka from several caves are excellent evidences of the presence of beads from late Pleistocene levels. The findings at Fa Hien-lena dated to *c.* 38-36 kya consist of shark vertebra bead, several perforated marine shells, an *Acavus* shell with multiple perforations (Patrick Roberts *et al*: 2015). The Batadomba-lena evidence indicates the presence of shell bead (*c.* 35 ka), two disc beads made of riverine bivalve (*c.* 20-15 ka).

The evidences from Jwalapuram, Fa Hien-lena and Batadomba-lena from securely dated archaeological levels are the earliest in the context of human artistic expressions and belonging to pre-Holocene era. The onset of Holocene marked remarkable climatic changes, which induced transformation in way of settled human life. Such changes are also visible in South Asian context, the excellent evidence comes from Neolithic levels of Mehrgarh, which formed the basis of later development of Harappan Civilization.

Beads in Neolithic and Chalcolithic Context (7th – Early 3rd Millennium BCE)

The earliest evidence for beads in the Indian sub-continent comes from the Neolithic levels at Mehrgarh (7th – 5th millennium BCE) made from turquoise, steatite, shell, dentalium, calcite, lapis lazuli (Jarrige *et al*: 1995). The exotic raw materials like turquoise and lapis lazuli are not available locally near Mehergarh, which is a clear indication of emergence of long distance procurement, and trade as early as 7th millennium BCE. The available source for turquoise is from Central Asia or Iran, nearly 1500 km away from Mehrgarh. Similarly, lapis lazuli was available only from the Badakshan region of Afghanistan, which is equally far away from Mehrgarh. Further, the presence of marine shells (*Turbinella pyrum* and *Engina* mendicaria) whose origin lies in Gulf of Kachchh and Makra coast respectively is also an indication of long distance contacts of inhabitants of Mehergarh.

There is a further sophistication starting from the Chalcolithic levels at Mehrgarh (4th millennium BCE) asbeads of new materials like carnelian, calcite, garnet beads starts to appear. Further, from this level onwards we start to get the evidence of drill bits, which were used to perforate the stone beads. The presence of unfinished drills made of a stone identified as phthanite also starts to appear. The drills were found in association with debitage of many semi-precious stones like chalcedony, agate, carnelian and turquoise (Jarrige *et* al: 1995). The identification of the material as phthanite has drawn attention of scholars like Kenoyer, who suggests that as phthanite is not an officially recognized scientific term, it should be discarded (Kenoyer: 1992).

While there is marked diversity in the utilization of raw materials from Mehrgarh from Neolithic period onwards, it is also observed that more and more harder stones were introduced, while the length of the beads also increased (Barthelemy de Saiziue and Rodiere 2005: 39). The mineral used for one of the drills is also identified as pumpelleyite.

A detailed microscopic and SEM analysis of bead samples to understand the drilling technology from Neolithic and Chalcolithic levels at Mehrgarh (Barthelemy & Rodiere: 2005) indicates at least four techniques of manufacture. They are (1) carried out from both ends, with a conical drill tip and a hand rotary motion could have driven the borer (Fig. 3), (2) rotary grinding from two opposite ends with quasi-cylindrical boring tips driven by mechanical motion, producing cylindrical or near cylindrical profile and regular grinding rings on inner walls of each opposite hole(Fig. 4), (3) pecking technique, which appears in Neolithic period, indicated by conical holes which were executed from both ends and evidence of small cavities and conchoidal scars. Identified as completely a hand perforation technique, which was exclusively used on hard stones like small carnelian beads (Fig. 5)and (4) pecking from one side and other side drilled by rotatory motion drilling(Fig. 5) (Barthelemy & Rodiere: 2005). The drilling type (1) and (3) appears in the Neolithic period and while type (2) continues and refined further during the Chalcolithic period, technique (1) disappears. Type (2) and (4) emerges during the Chalcolithic period and continues well afterwards also from many other sites with modifications and refinements.

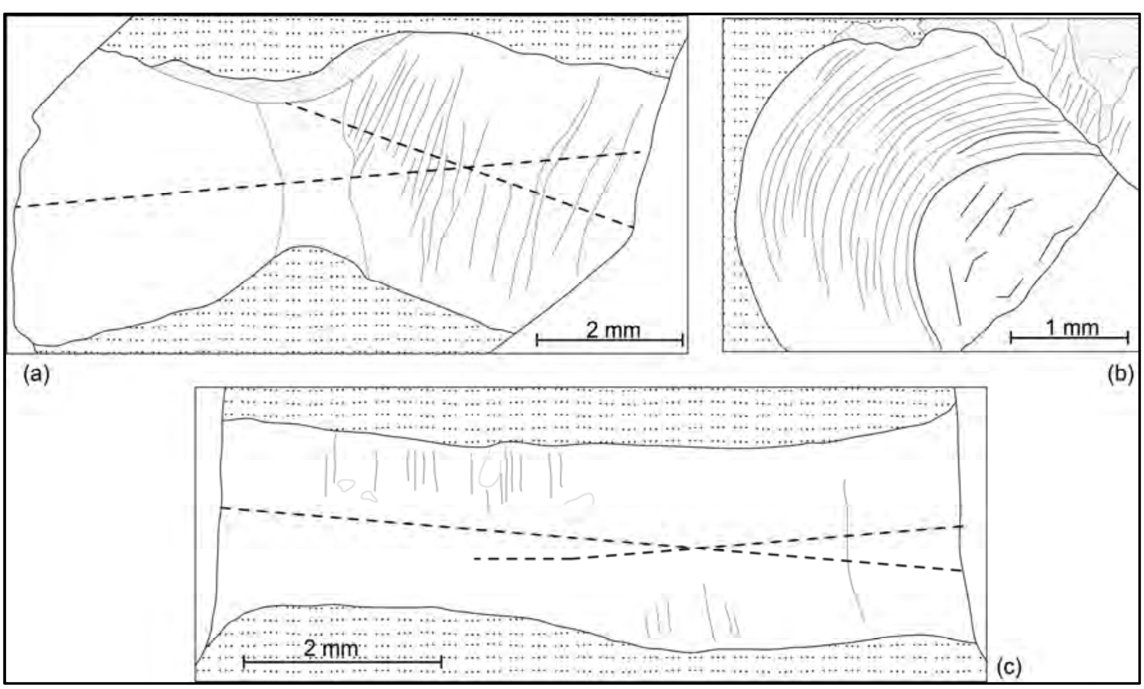

Figure 3: Type 1 drilling technology from Neolithic Mehrgarh; (a) calcite bead, dotted line showing different drilling axes meeting at the junction at centre; (b) calcite bead, showing very strong obliquity and (c) steatite bead, dotted line showing different drilling axes (*after Barthelemy and Rodiere 2005)*

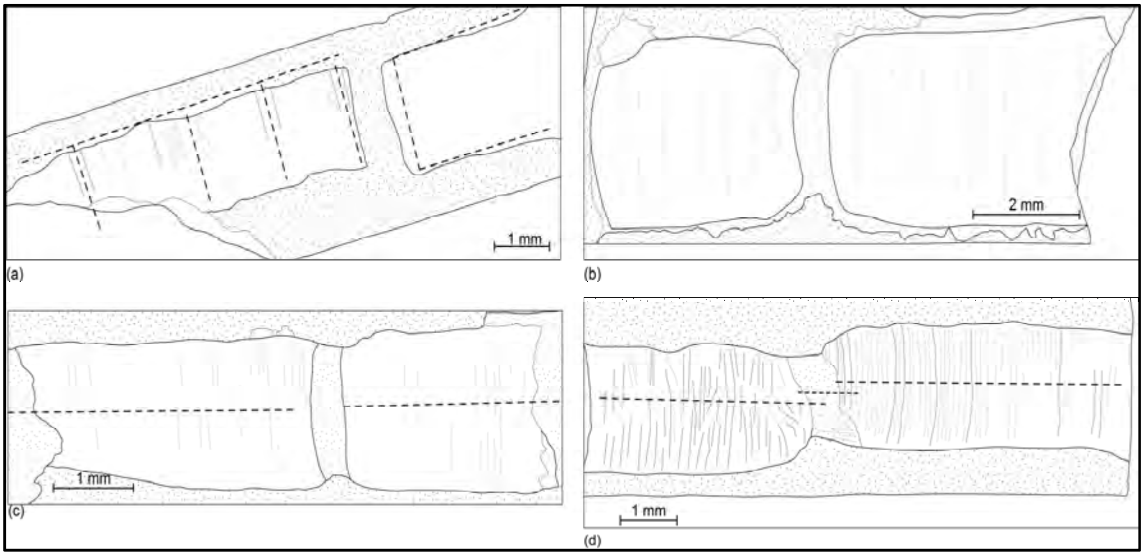

Figure 4: Type 2 drilling technology from Chalcolithic and pre-Indus Mehrgarh; (a) steatite bead, perforation identified in at least four stages; (b) carnelian bead, Chalcolithic (c) carnelian bead, pre-Indus and (d) serpentine bead, pre-Indus *(after Barthelemy and Rodiere 2005)*

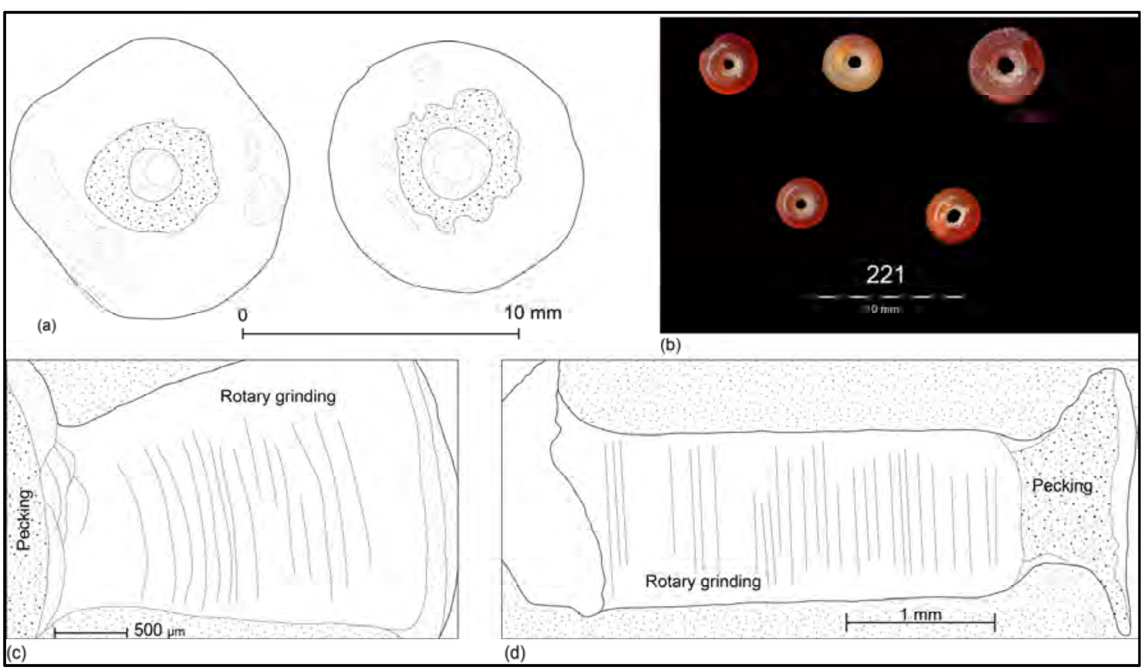

Figure 5: (a) Carnelian bead, Type 3Pecking technology from pre-Indus Mehrgarh; (b) carnelian bead from Harappan period, Karanpura, Rajasthan showing pecking technique; (c) carnelian bead, Chalcolithic, pecking from left and rotary grinding from right; and (d) carnelian bead, pre-Indus, rotary grinding from left and pecking from right *(after Barthelemy and Rodiere 2005)*

From the studies, Barthelemy and Rodiere (2005) concludes that for Type (1) flint stone drills could have been used for drilling and for Type (2) identifies a mineral named pumpelleyite from late Chalcolithic / pre-Indus (Period VII) from Mehrgarh. These stones were used for both harder and softer stones. Bartheley and Rodiere (2005) also observe that the finer particles produced while rotatory grinding could have functioned as abrasive. Thus, it may be observed from the evidence from Mehrgarh a long and continuing tradition of bead manufacturing techniques existed for several millennia. The drilling techniques Types (1) and (3) originated in Neolithic period and all the types are noticed during early Chalcolithic period. The type (1) disappears from late Chalcolithi / pre-Indus period. It may be argued, that these earliest evidences from South Asia helps in understanding the origin of bead manufacturing techniques including the rotatory grinding ones driven most probably by a bow drill, which formed the foundation for the Harappan technology.

Beads as a personal ornament and status symbol were common to diverse cultures in different archaeological traditions. Thus, the presence of beads could be observed from other Neolithic and Chalcolithic cultures in the Indian sub-continent, more particularly from Ganga plains. The presence of stone, terracotta beads is noticed from the Neolithic and Chalcolithic levels at many sites like Lahuradewa, Raja Nal-ka-Tila, Chirand, Malhar, Imlidih Khurd, Waina, Jhusi, Hetapatti in the Ganga plains.

Beads in Harappan Context (4th – 3rd Millennium BCE)

The next stage in the development of bead drilling technology can be witnessed from the context of Harappan civilization; the cultural periods represented by several regional formative phases (*c.* 3700-2800 BCE), early Harappan (*c.* 2800-2600 BCE), Harappan (*c.* 2600-1900 BCE) and late/post-urban Harappan (*c.* 1900-1400 BCE). The foundations laid in the Neolithic and Chalcolithic periods as witnessed from key sites like Mehrgarh helped in further innovations in diversification of raw materials sources in addition to already existing ones. The studies conducted for nearly a century since the discovery of Indus Civilization helps in understanding the increasingly sophisticated nature of raw material procurement from multiple sources, often exploiting the best available raw material in terms of quality, distribution of raw materials to different urban centres, production of various types of beads, amulets, pendants, and their distribution.

This has been attested by a study by Randall Law (Law 2005) at Harappa, which clearly shows the increase in raw material varieties from a mere 11 types in Hakra-Ravi-Kot Dijian phase (*c.* 3700-2800 BCE*)* 40 types during Harappan phase *(c.* 2600-1900 BCE). The various raw material sources have also been investigated by Randall Law, which gives a fair idea of procurement, particularly for the site of Harappa. Later, similar studies were extended to Dholavira and Rakhigarhi as well, which helps us in understanding the pattern of raw material procurement and exploitation of different sources. A comprehensive study of different raw materials from Harappa using analytical and instrumentation techniques (Law 2011) have demonstrated their provenance, e.g. steatite from Hazara (Sherwan) deposits, Prang Dera, Daradar (all in Pakistan) and Alwar deposits (Rajasthan); agate-jaspers from Mardak Bet, Khandek and Ratanpur (all in Kachchh area, Gujarat); vesuvianite from Sakhakot-Qila and Taleri Mohammed Jan (both in Pakistan); lapis lazuli from Badakshan (Afghanistan); serpentine from Mohmand, Las Bela, Zhob and Muslimbagh Ophiolites (all in Pakistan); amazonite from northern areas of Pakistan and northern Gujarat; crystalline quartz (rock crystal and Mari diamond) from Salt Range (Pakistan) and northern Rajasthan. These stones formed most of the bead collection from Harappan sites with agate-jaspers and vesuvianite being the hardest and steatite softest.

Types of Beads from Harappan Context

Tracing the development of beads from the earliest Neolithic period onwards, a gradual evolution in terms of shapes can be discernible. This has been aptly summarized by Kenoyer (2007) that the beads during earliest period were *"……flat disc, tubular forms in geometric shapes and short to long cylindrical beads, using both locally available and exotic raw materials…..beads were made from relatively soft raw materials, shell, limestone, steatite, serpentine, lapis lazuli and even turquoise."*The harder agate or carnelian beads are mostly of short biconical types. The beads manufactured into various shapes and sizes (Kenoyer: 2007) were used mostly as *"….headbands, necklaces, belts, bracelets, and anklets made from shell….colored stones and soft steatite."*

The beads of longer shapes manufactured from jasper, banded agate and carnelian appear from the Chalcolithic period at Mehrgarh in addition to the continuation of disc and tubular shapes, with the most common shapes being lenticular barrel, short bicone, and long bicone (Kenoyer: 2007). Kenoyer (2007) opines that at Harappa, starting from Ravi Phase (>3500-2800 BCE) evidence for local manufacture of beads from both soft and hard stones is noticed. The shape of these beads from early period (Kenoyer: 2007) was *"…small discs, but short bicones, long cylindrical beads, and a wide variety of shapes are common in terracotta."* Kenoyer (2007) also observes that during the Kot Dijian phase (~Early Harappan, *c.* 2800-2600 BCE) while there is an increase in varieties of raw materials like agate, sandstone, carnelian, limestone, there was a *"….decrease in the varieties of shapes and sizes of beads…."*

A 'standardisation' of agate bead shapes was achieved as observed by Kenoyer (1986) and they consist of *"….long tapered barrel beads, short barrel beads, and various tabular shapes along with the standard short cylindrical and short bicones."*The beads of agate-carnelian were probably in high demand as attested by their export to Mesopotamian region. In particular, the long barrel cylindrical beads of reddish orange agate-carnelian beads and etched / bleached / decorated agate-carnelian beads are found in large numbers from several sites in modern Oman, Iraq, Syria, Iran datable to third millennium BCE. A wide variety of stone beads were unearthed from the urban centre of Dholavira, district Kachchh, Gujarat during a thirteen-field season excavation by R.S. Bisht (2014, 2015) of Archaeological Survey of India. It has been estimated that around 12307 beads of various materials have been documented from Dholavira (Bisht: 2015).

The raw materials used in the manufacture of beads are agate, amazonite, amethyst, azurite, bloodstone, carnelian, chalcedony, chert, faience, gabbro, jasper, kaolinite, lapis lazuli, limestone, moss agate, onyx, paste, quartz, sandstone, serpentine, soapstone, sodalite, steatite, terracotta, turquoise, vesuvianite. Steatite as a raw material was the most preferred one with an overall representation of 28.4% followed by terracotta (21%) and agate-carnelian and other silicates (17%). The common shapes among the agate-carnelian are short bicones (Fig. 6), long barrel (Fig. 6), lenticular barrel (Fig. 7), long barrel cylindrical (Fig. 8), tubular. The common shapes made from steatite are disc beads (Fig. 9), micro beads (Fig. 10), tubular. Interestingly, several beads of terracotta (Fig. 11) show replication of stone bead varieties indicating a clear preference for the shapes in stone among the different sections of society.

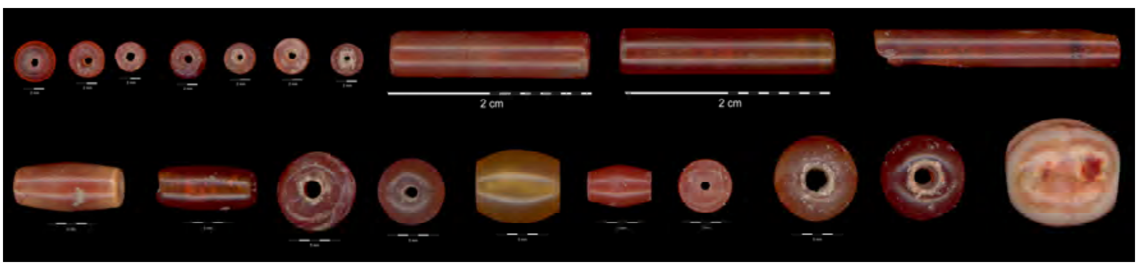

Figure 6: Short Bicone and Long Barrel Shaped Beads, Dholavira

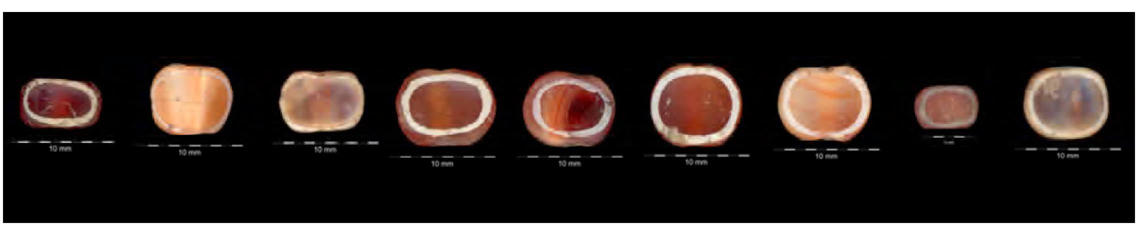

Figure 7: Lenticular Barrel Shaped Eye Beads, Dholavira

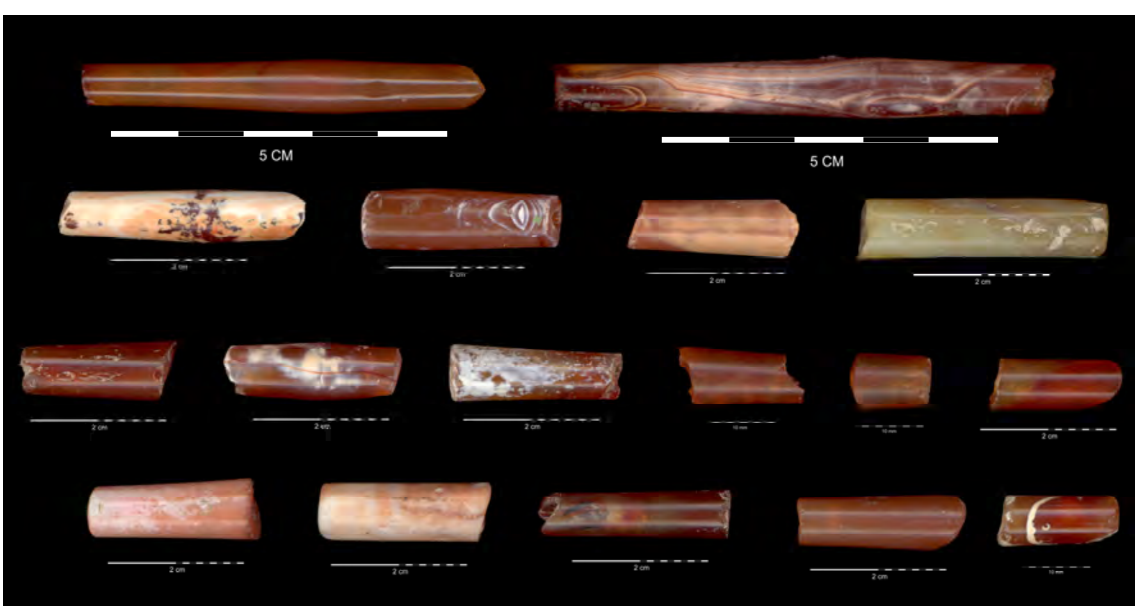

Figure 8: Long Barrel Cylindrical Beads, Dholavira

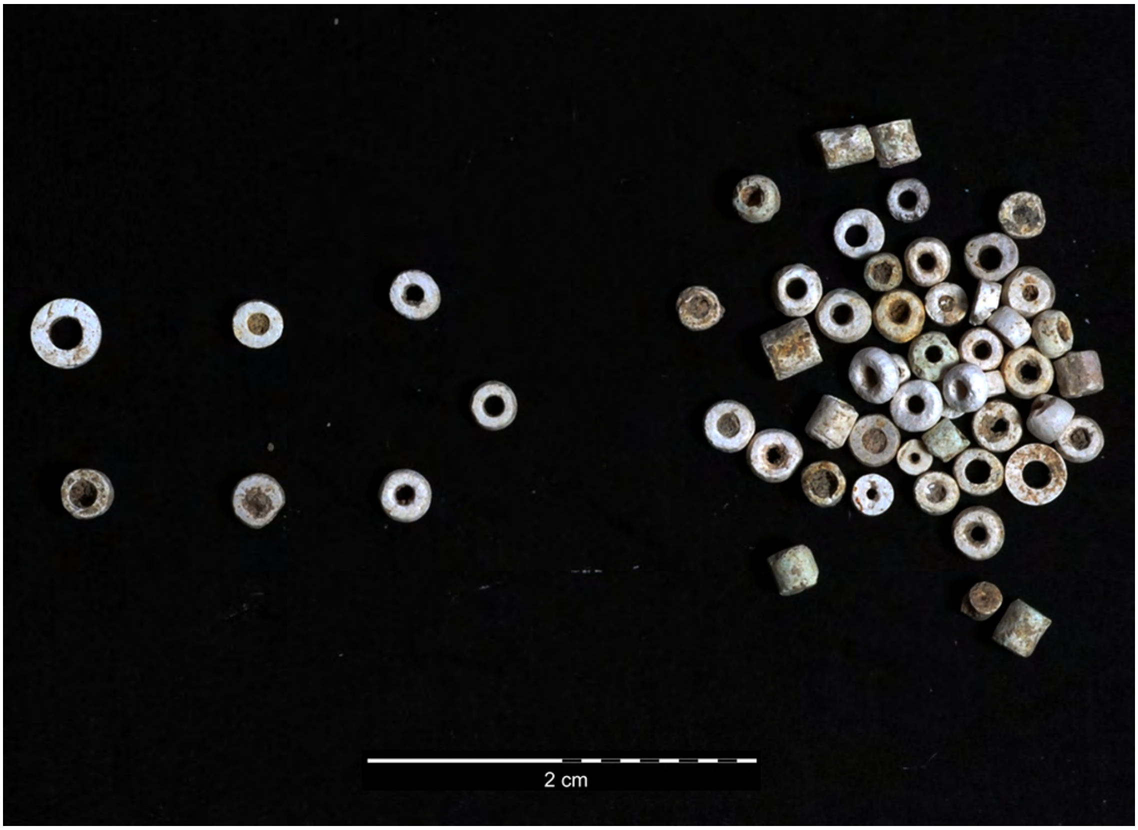

Figure 9: Micro Beads of Steatite, Dholavira

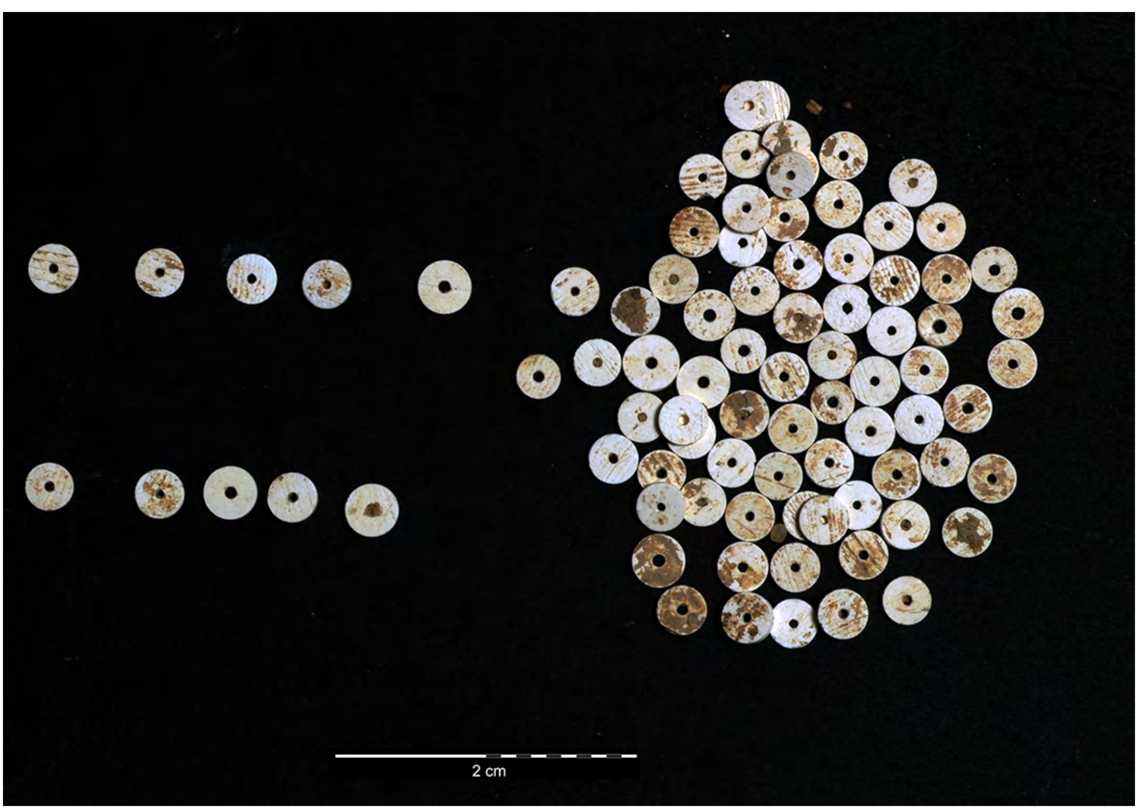

Figure 10: Disc Shaped Beads of Steatite, Dholavira

Figure 11: Terracotta Beads, Dholavira

The etched / bleached / decorated carnelian beads is another category of beads which are found from many Harappan sites and from sites outside the Indus valley. These decorations on these beads were experimentally created by Kenoyer (2007) by the application of *"….a paste of carbonate of soda mixed with water and the pulp of a desert caper plant called kirir in Sindhi "*when completely dry and then heated rapidly on glowing coals, which produces a distinct white colour on a red background. The decorations consist of single (Fig. 7), double (Fig. 12), triple (Fig. 13) and complex patterns (Fig. 14), which are highly characteristic of Harappan Civilization and not produced elsewhere.

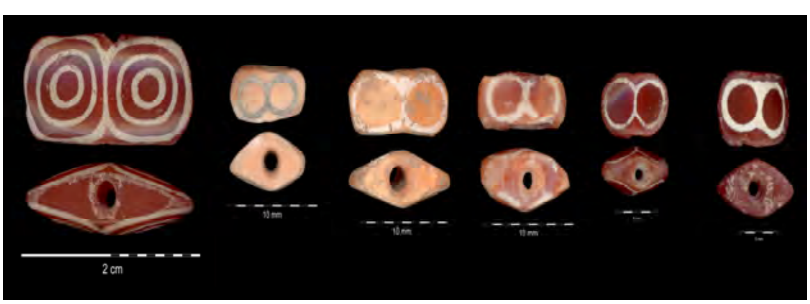

Figure 12: Double Eyed Beads, Dholavira

Figure 13: Triple Eyed Beads, Dholavira

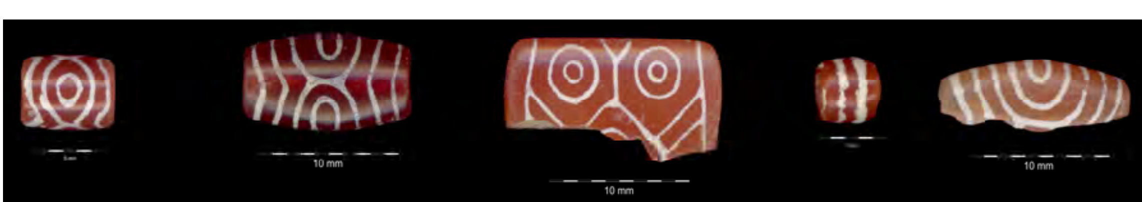

Figure 14: Complex Patterns on Etched Carnelian Beads, Dholavira

The beads made from lapis lazuli (Fig. 15) were mostly short and long tubular in shape and have the distinct bluish colour with occasionally golden coloured streaks.

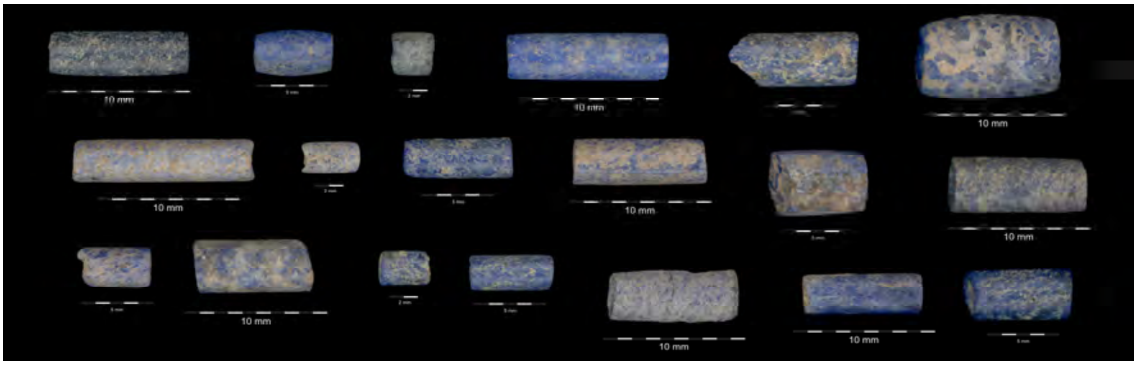

Figure 15: Lapis Lazuli Beads, Dholavira

Technology of the Harappan Stone Beads

E.J.H. Mackay initiated the first detailed investigations of Harappan bead manufacturing and drilling mechanism based on the evidences from Mohenjo-daro and Chanhudaro excavations (Mackay: 1937). While Mackay (1937) observes only little evidence of bead manufacturing at Mohenjo-daro based on the available remains during that time, Chanhudaro brought to light *"….large numbers of incomplete beads but also the raw material from which they were made, and, still more interesting, the actual stone drills by which they were bored."* Mackay concludes that Chanhudaro was a *"great centre of bead-making"* which also contributed for its prosperity. It was also noticed that the finished 'hard stone beads' were fewer in number when compared to the large number of unfinished ones at the site. Among the finished and unfinished beads at Chanhudaro, the ones described as "long barrel-cylinder shape" made of agate and carnelian has been described as favourite among the items worn by people of Harappa culture. The maximum size of one such bead is 12.319 cm (4.85 inch.) is from Mohenjo-daro and "*made of the finest translucent carnelian that it was possible to obtain*" (Mackay: 1937). However, the longest specimen from Chanhudaro is 9.271 cm (3.65 inch.), made of yellow agate and unpeforated.

Chanhudaro also brought to light good number of raw materials including nodules of agate and carnelian from different parts of the city. These nodules were often found with evidence of window chipping in order to determine the quality and colour of stone with an average size ranging between 7.62 and 10.16 cm. Mackay (1937) observes the colour ranging from *"…muddy yellow with red or darker yellow cloudy areas, others were clear agate with occasional dark brown patches."* The evidence for roasting these stones to achieve a reddened surface was also observed from Chanhudaro, which Mackay (1937) compares with the practice still existing in India and other parts of the world. Mackay (1937)also found a great variety of unfinished stone beads in various stages of manufacture from Chanhudaro, which has led to a fair understanding of the bead manufacturing mechanism involved in the production of the long barrel-cylinder beads.

The sources for these stones have been briefly described by Mackay (1937) as Ratanpur in Rajpipla, Ranpur in Ahmedabad, localities in Kathiwar (all in Gujarat), who also mentions about the modern bead industry at Cambay (Khambhat). The earliest account of the Cambay (Khambhat) bead industry was by Summers (1851) who gives a graphic account of the trader community known as *Akkikia Jumat*. Summers (1951) gives details of the stones traded at Cambay (Khambhat) which are jasper, heliotrope or bloodstone (procured near village Tankarra, 19.3 km north of Rajkot), moss-agate (procured near village Tankarra, and at Bud Kotra, 4.8 km from Tankarra), common agate (procured from Mahidpore, 4.8 km from Tankarra), variety of agate known as 'kupperwange' (procured from Kupperwange), veined agate or banded agate (procured from Rhanpore, Darpipla and Ninama), chocolate stone (jasper? / chert?), procured from Rhanpore and Tankarra, crystal (procured from Tankarra), varietaged stone, which appears to be fossiliferous limestone (procured from Dhokavarra (Dhokavada), lapis lazuli (from Persian and Bokhara), jet-stone and obsidian (from Bokhara and Aden), blue-stone known as ferosa (said to be prepared in China), carnelian (from Bowa, B. Abbas and Rajpipla). The other stones that were used in the industry at Cambay (Khambhat) were mora or bowa gori (onyx or dark coloured carnelian), cat's eye. Summers (1951) give a vivid description of the traditional manufacturing techniques of beads from these stones, which consist of the following:

1. The selection of stones are made and broken approximately as per the desired sizes.

2. Rough shaping of the stones thus selected by placing them on an inclined iron spike named *khondia* and struck by horn hammer.

3. These roughouts are polished in groups on a hard polishing stone called *dholia*, which is then repolished again on grooved polishing board known as *pattimar*, the abrasives being a composition of emery and lac, through which the stones achieves a globular form and polished.

4. A stage of final polish given by placing several thousand roughly polished beads in a leather bag (~61 cm in length and ~25 - ~31 cm in diameter) along with emery dust and very fine powder known as *warry*. Two men sitting opposite to each other for nearly ten to fifteen days and moistening the bag in between with water roll the bag. The beads achieve a bright polish in this process.

5. The polished beads are then perforated with a steel drill tipped with a small diamond, the lubrication of bead while drilling achieved by dripping water from a pot transferred by a thin narrow reed or metallic tube.

The next account of the bead manufacturing industry at Cambay (Khambhat), the various manufacturing stages along with the stones used is by A.J. Arkell (1936). The account given by Arkell is in complete consonance and agreement with Summers (1851). The references to of modern agate-carnelian bead industry from Khambhat was also continued by many scholars like Mackay (1937), S.R. Rao (1979), G.L. Possehl (1981), Kenoyer *et al* (1991) have enabled in understanding the different processes involved right from procurement of suitable stone from the mine to final polishing and finishing. Kenoyer *et al* (1991) summarizes these different stages as (1) raw material acquisition from mine and checking the quality by chipping a corner to ascertain required colour, texture and formation, (2) sorting of nodules arriving at the workshop far away from the original mine followed by heating and first slow heating in earthen pots, (3) first stage of chipping of nodule by removing larger flakes thereby producing a rough desired shape of bead followed by second stage of slow heating, (4) second stage of finer chipping by removing smaller flakes followed by grinding with mechanically driven emery wheel, (5) after initial grinding, finer polishing is achieved in the emery wheel and perforation with diamond tipped drill bits and a final heating in earthen pots to achieve the typical reddish orange colour.

Agate-Carnelian sources have been documented in Gujarat from Ratanpur in Rajpipla, Kapadvanj, Jamnagar, Khandek and Medhok (Bisht: 1989) and of these many of the agate-carnelian specimens from Harappa were derived from Mardak Bet (Randall: 2011). The investigation of raw materials from Dholavira indicates its provenance from Mardak Bet, Khandek and Ratanpura (Randall: 2015)

With regard to the drilling technology of hard stones, Mackay (1937) also found a large number of stone drills from Chanhudaro, both broken and complete. The complete ones average 3.81 cm long and 2.54 mm to 3.048 mm in diameter (Mackay: 1937). A few specimen was also analysed by Geological Survey of India and they described the stone drills as, *"….consist of chert, containing a little magnetite, the hardness of the specimens is 7…..do not occur in nature in this rod-like form; they have apparently been worked into shape from material likely to occur in any of the Archaean rock of India*" (Mackay: 1937). The beads were also bored first and then given polish, as has been evidenced from Chanhudaro examples (Mackay: 1937). This is, however, in contrary to the method adopted by the modern craftsmen at Khambhat as reported by Summers (1951). The perforation of the beads is made by diamond tipped drills fitted into a wooden shank and driven by a bow (Possehl 1981: 44). For lubricating the drill movement while in motion, an indigenous arrangement of a small pot with water and grit is made as described elsewhere. The drills driven by bows, the seating arrangement and the usage of water and grit as lubricant and abrasive respectively seems to be the same mechanism adopted by the Harappans with the only exception that instead of diamond drills, ernestite and chert drills were used by them.

Two types of diamond drills were recorded by Kenoyer at Khambhat, namely *tekni* (a single rounded diamond chip to create a depression to facilitate the second drill that makes the actual boring) and *sayedi*, which has two tiny rounded diamonds set at right angles at the tip end (Kenoyer *et al* 1991: 53). As diamond was unknown during protohistoric period, drills of chert and types of mottled green jasper were in use, and much time was consumed in drilling the hard stones using these drills. Kenoyer estimates that at least two to ten hours would have been required to drill a perforation of 1 cm of an agate bead (Kenoyer *et al* 1991: 54).

Kenoyer and Vidale have also studied the evidence for bead drilling from some contemporary sites. The evidence from Shahr-i Sokhta (*c.* 2700 BCE) indicates usage of stone drills with tips larger than 1 mm diameter for drilling lapis lazuli beads and other materials, while beads with holes less than 1 mm diameter are also noticed (Kenoyer and Vidale: 1992). Shahdad in eastern Iran has yielded the presence of various colours of translucent chert and jasper for drilling small carnelian beads, short truncated bicones in shape (Kenoyer and Vidale: 1992). The drills found from Mehrgarh were termed to be of pthanite as mentioned above. These drills were *"…produced from a fine grained jasper-like rock with conchoidal fracture and good chipping properties, distinguished by a uniform light greenish color"* (Kenoyer and Vidale: 1992). The correct identification of the material is yet to be made and Barthelemy and Rodiere (2005) have identified pumpelleyite as the mineral in one of the drills.

From the archaeological context, S.R. Rao describes the presence of a bead factory from the Harappan site of Lothal (Gujarat). This consists of a working platform and eleven rooms along with two earthen jar containing 582 carnelian beads in one and 212 carnelian, shell and steatite beads (Rao: 1985). The complex also brought to light a large number of cores, flakes, ground and unbored beads scatter in the courtyard and the surrounding rooms (Rao: 1985). Rao suggests that the agate for making carnelian at Lothal came from Rajapipla mines. Rao also brings to light the similarities between the modern bead making lapidaries and techniques with that of bead factory at Lothal which yielded a kiln for baking pebble and beads of semi-precious stones along with beads in various stages of manufacture, partly-baked pebbles, fragments of earthen bowls for baking pebbles and finished beads (Rao: 1979; Rao: 1985). Kenoyer and Vidale (1992) carried out a comprehensive study of stone drills and suggested two new terms for the identification and classification of cylindrical drills with a dimpled tip. They are *"tapered cylindrical drills"*(Fig. 16) and *"constricted cylindrical drills"*based on the morphology of the drills (Kenoyer and Vidale 1992: 495). While the former has a very wide distribution and presence in the regions from Mesopotamia to the Indus, the latter is *"a unique form of standardized and specialized tool developed by the artisans of Indus Valley for perforation of long beads made of agate / carnelian and jasper"* (Kenoyer and Vidale 1992: 498). Detailed microscopic investigations were carried out on a stone drill obtained from Mohenjo-daro.

Based on the investigations carried out, Kenoyer and Vidale suggested the name of "ernestite" (Kenoyer and Vidale 1992: 507) to the type of stone drills that were used for drilling agate beads. They describe ernestite as, *"….a fine grained metamorphic rock composed primarily of quartz, sillimanite, mullite, hematite and titanium-oxide phases"*. Of these, mullite is extremely rare in nature, but is produced in modern high temperature ceramic materials (Kenoyer 2003: 73). Kenoyer also suggests that presence of mullite in

Harappan drill bits may be as a byproduct due to intentional heating of the original rock (Kenoyer 2003: 73).

Figure 16: Tapered Cylindrical Drills of Ernestite, Dholavira

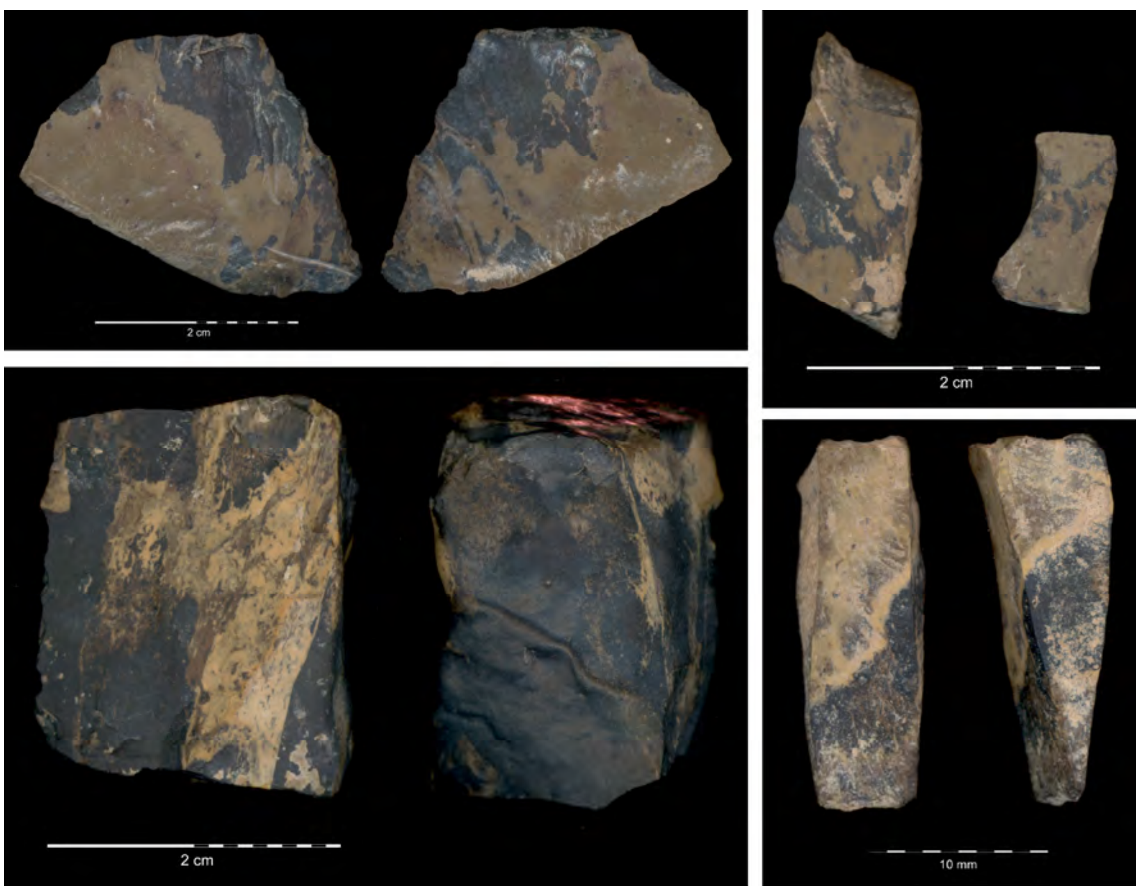

Figure 17: Ernestite Raw Material, Dholavira

Ernestite (Fig. 17) is found in many colours and often multi-coloured ones are also found. The XRD analysis on Harappa examples indicate that yellow brown matrix is composed of quartzite and sillimanite, while the brown-black portion is primarily of quartz with hematite and some sillimanite / mullite (Kenoyer and Vidale 1992: 506-507). Some peaks of mullite or a yet to be identified intermediary phase are also noticed in the XRD analysis (Kenoyer and Vidale 1992: 507). The electron microprobe X-ray analysis on the yellow brown and brown-black portions indicates a matrix of quartz with iron / titanium oxide phase (Kenoyer and Vidale 1992: 507). The studies carried out by Kenoyer and Vidale on ernestite further suggest that:

1. *concentrations of hematite and iron-titanium oxides give cutting and polishing properties;*

2. *matrix of quartz (probably as quartzite) and sillimanite produces a strongly bonded structure that withstood pressures of drilling;*

3. *abraded surface of the drills retains an irregular surface that facilitates drilling the carnelian, which is less strongly bonded;*

4. *the abrasion quality of the drills is due to the toughness of the sillimanite matrix and concentration of iron-titanium oxides in the rough surface of the drills.*

Randall (2011) describes ernestite as, *"ernestite is an extremely fine-grained stone mottled with dark-brown to black patches and dendritic veins in a khaki-coloured matrix."* The XRD and EMPA investigations carried out on four ernestite samples obtained from Mound E of Harappaindicate that ernestite is composed mainly of quartz and mullite-sillimanite along with minor presence of hematite (iron oxide) and rutile (titanium oxide). The remaining two samples showed the presence of crystobalite and mullite and absence of quartz, hematite and rutile. Two ernestite raw material samples from Dholavira were also subjected to XRD analysis (Fig. 18) and it indicates a pattern similar to other sites (Prabhakar *et al* 2011).

Thus it has been observed that no unanimous agreement on the correct identification of the material of these drills has been arrived so far with one exception of Mehrgarh evidence. However, the term "ernestite" has gained currency among the investigators in the absence of a correct geological term. Hence, the same term is also used in the current study of the Dholavira drills also. The site of Dholavira has brought to light the largest assemblage of ernestite drills from any Harappan site. A total of 1588 ernestite drill bits have been recorded from this site and different types were identified. They are cylindrical, tapered cylindrical, constricted cylindrical, re-used, re-sized and pointed drills (Prabhakar *et al*: 2012). A coding system was developed to study these drill bits based on a methodology devised by J.M. Kenoyer which helped in determining various factors like length, width, tip width, base width, proximal width and other calculations. The documentation also helped in understanding the nature of the collection of drill bits, which indicated predominantly broken and discarded ones, an evidence of active drilling industry of hard stones.

These drills have been found in association with bead working workshops also (Fig. 19), and in one case bead polishers were found *in situ* from Baily locality at Dholavira. The presence of a large number of bead polishers of sandstone and limestone (Fig. 20) from Dholavira also attest to the thriving bead industry at this site. The evidence from Dholavira also indicates the continuation of use of ernestite drills in bead workshops even during the late / post-urban Harappan phase (Prabhakar *et al*: 2012). Kenoyer (2003) has extensively studied the evidences from Harappa and other sites in order to understand the actual drilling processes followed by various experimental studies also. The roughouts and bead blanks of various stones from sites like Chanhudaro (Mackay: 1937), Dholavira (Bisht: 2015) (Fig. 21) and Harappa (2003) clearly show the testing of stone nodules, followed by large flake removal, small flake removal, grinding, polishing and drilling.

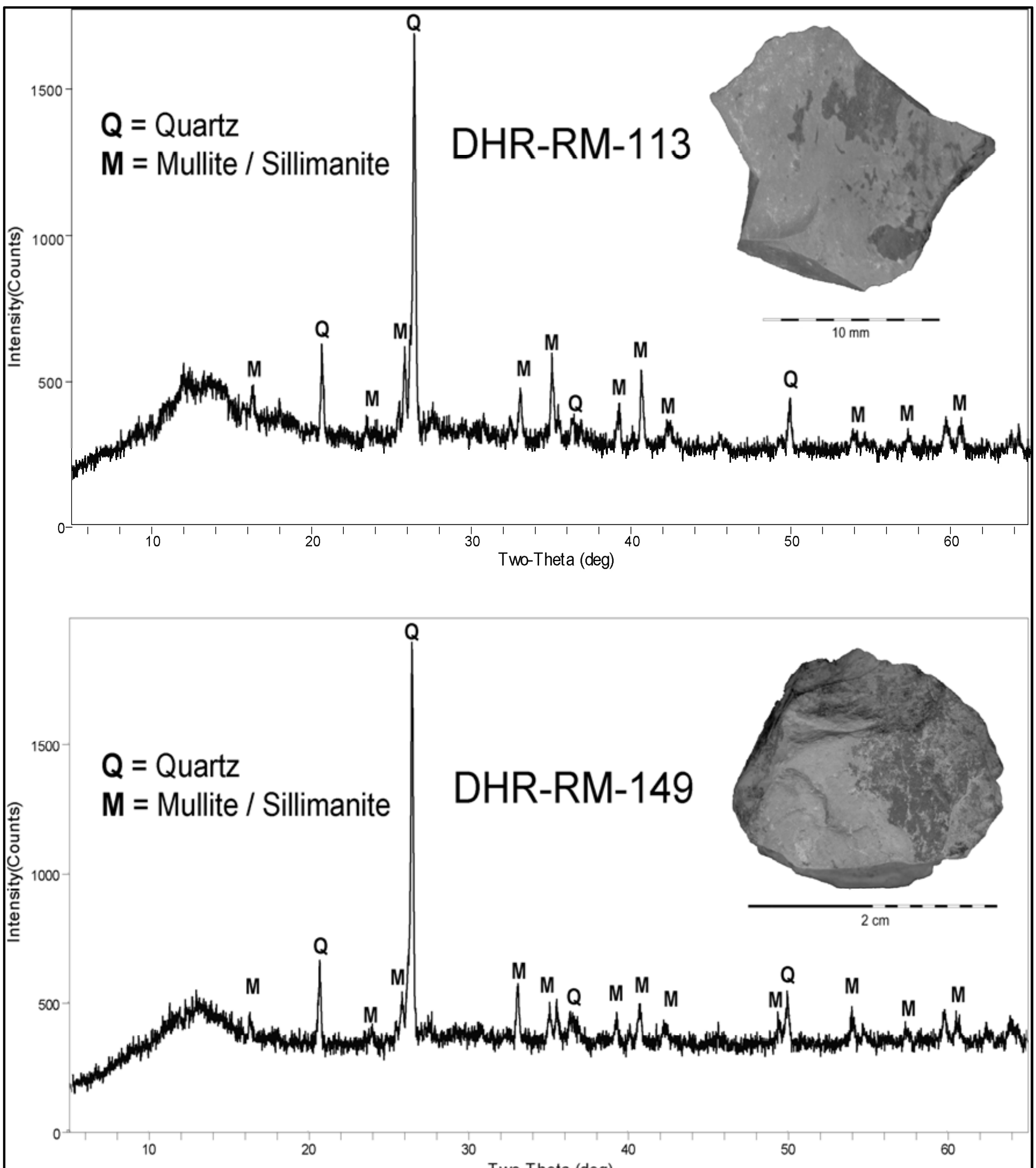

Figure 18: XRD Analysis of Ernestite, Dholavira

The evidence at Dholavira from a bead workshop near the East Gate of Middle Town clearly demonstrates that the bead blanks were grinded and polished before making perforations. Kenoyer (2003) further discusses drilling using a variety of drills both of stone and copper, which were used for pecking, tapered using chert/jasper drills, tapered cylindrical using jasper drills, stepped pattern using ernestite constricted cylindrical, and copper tubular drills(Fig. 22). The drilling patterns due to the use of different materials can be clearly delineated from the drill holes produced by the perforations. These can be then compared with experimental analysis based on similar materials used. The drill holes produced by ernestite have a distinct pattern when compared to other materials. The ernestite drills produce a highly polished surface as it is slightly harder when compared to agates, which can be easily distinguished from the silicone impressions (Fig. 23). Similarly, the drill holes produced by copper drills and copper tubular drills are unique when compared to stone drills (Fig. 23). As copper is a softer material, it wears out easily and has to be removed after short intervals for clipping, modifying the tip and again reusing it. The drill holes produced by diamond tipped drills are very much distinct in comparison with other materials like jasper, ernestite and copper. As diamond is the hardest material it shears off the softer stones and hence produce a grooved interior surface inside the bead, which is easily distinguishable (Fig. 24).

Figure 19: Bead working areas from Dholavira; (a) On top of northern fortification, Bailey; (b) Close up of bead polishing area with bead polisher *in situ*, Bailey; (c) Near west gate of Castle, Dholavira

Figure 20: Bead Polishers, Dholavira

Fig. 21: Bead Blanks and Roughouts, Dholavira

Bead Hole Impression Studies to Understand the Drilling Technology

Tosi and Piperno (1973) carried out one of the earliest microscopic studies of stone drills and stages of bead manufacturing while describing the lapis lazuli trade during third millennium BCE and excavation at Shahr-i Sokhta. Evidence for lapidary working was unearthed at Shahr-i Sokhta with remains of finished, unfinished beads of lapis lazuli, carnelian and turquoise in various stages of manufacture along with microliths. The incised patterns produced by the stone drills were studied with the aid of a microscope in this case.

The first direct application of SEM analysis on artefact impressions was made by Gorelick and Gwinnett while studying the cylinder seals from Mesopotamia (1978). The technique used by Gorelick and Gwinnet (1978) consisted of *"….application of silicone impression techniques used in dentistry makes it possible to provide accurate, duplicated details of both the bore and the surface characteristics…impression could be examined directly or a more durable plastic cast mode, both methods were used after coating with metal for examination in the SEM."*

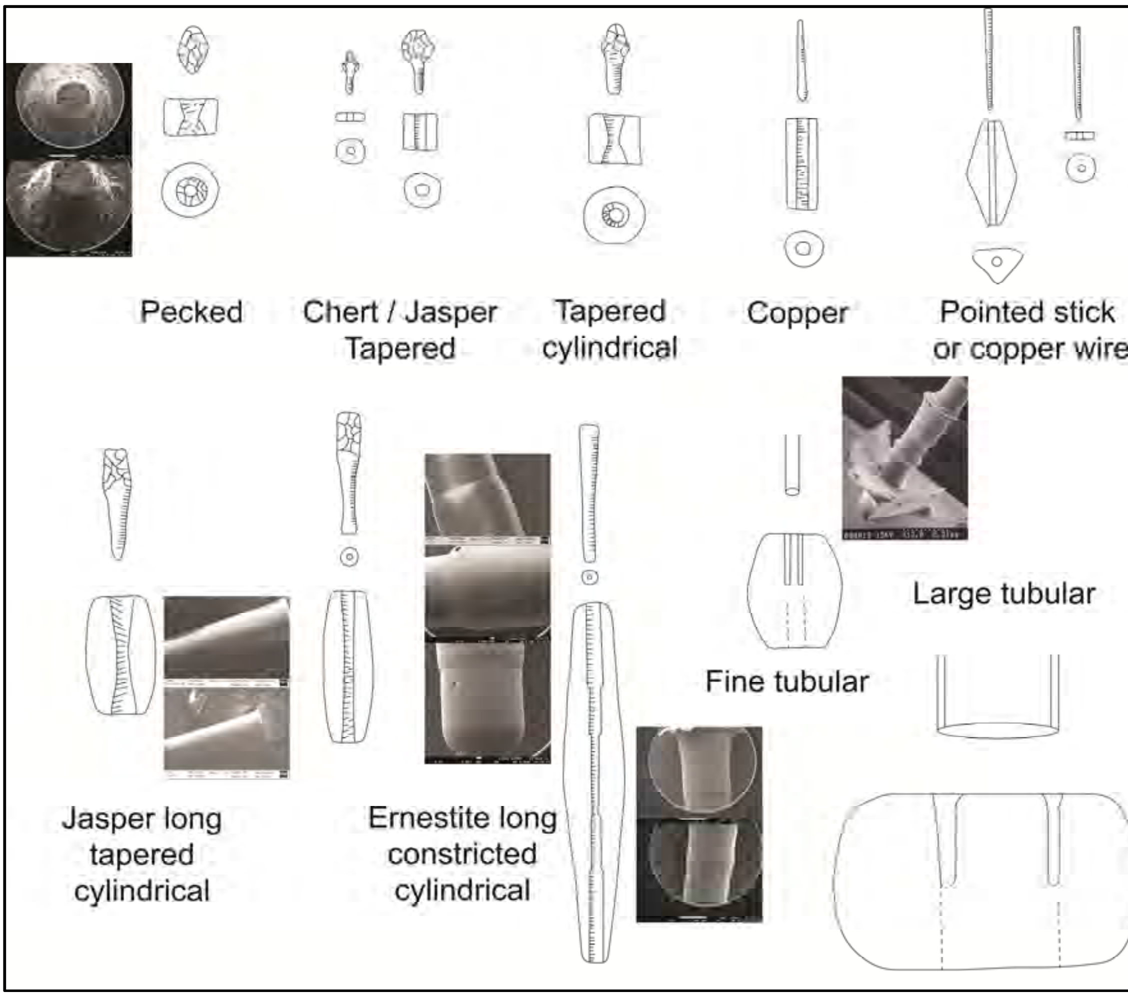

Figure 22: Drilling Patterns from Different Materials (*after Kenoyer: 2003*)

A more direct analysis of artefacts using SEM along with the regular silicone impressions of drill holes from Shahr-i Sokhta was also attempted by Gwinnett *et al* (1981). Further, a detailed methodology of silicone impression technique for anaylising ancient Egyptian stone drilling mechanisms is also elaborated by Gorelick *et al* (1983) which is as follows:

"…..are three separate steps…, all non-destructive to the object. They are (1) silicone impressions of the part to be studied in order to capture the tool marks; (2) examination of the impressions (or epoxy models made from them) in the scanning electron microscope (SEM) and

the fabrication of photomicrographs, and (3) functional analysis attempting to duplicate the tool marks experimentally."

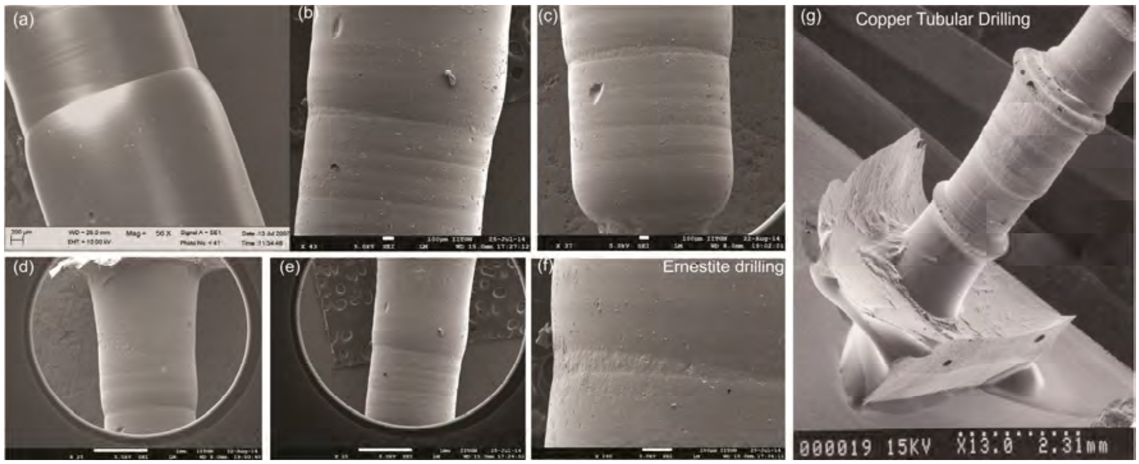

Figure 23: Bead hole impressions analysis using SEM; (a) – (f) bead holes formed by ernestite drills, (a) from Dholavira, (b) – (f) from Karanpura; (g) bead holed formed by copper tubular drill (courtesy J.M. Kenoyer)

The experimental studies carried out by Gorelick *et al* (1983) related to the *"…functional analysis of a granite sarcophagus lid from the Old Kingdom period.."* have enabled to conclude that, *"…1) loose, dry abrasives (except diamond) did not produce concentric lines; 2) fixed abrasives or those in a watery slurry or a lubricant such as olive oil did produce concentric cutting lines; 3) corundum and diamond cannot be ruled out as not having been used to drill granite."*

In the Harappan context, Kenoyer and Vidale (1992) first made the use of SEM analysis for drill impressions. Kenoyer *et al* (1992)also conducted experimental studies and analysed various drill impressions from *"…a carnelian bead perforated by a double diamond tipped drill in Khambhat, India, a carnelian bead perforated by a Harappan stone drill and a pre-Columbian quartz bead drilled with an unknown abrasive."* The drill impressions were viewed under magnifications ranging from 100 X – 300 X and the surface modifications on them were clearly delineated under a SEM (Kenoyer and Vidale: 1992).The studies (Kenoyer and Vidale: 1992) also indicated that the *"….abrading surface of the drill retains a rough irregular surface that helps in cutting the carnelian, which is not as strongly bonded"* and *"…long carnelian beads during the Harappan phase of the Indus Valley tradition reveal that three or four different sizes of drills were used to perforate one half of the bead."*

Several scholars including Kenoyer and Vidale have carried out experimental drilling to understand various patterns produced by different drill materials. The modern beads produced at Khambhat are perforated with the aid of two types of diamond dipped steel drill bits as explained above. One such modern bead was studied by the author under SEM at IIT Gandhinagar (Fig 24). The patterns produced by a diamond tipped drill are very much distinct from those of jasper, ernestite or copper drills.

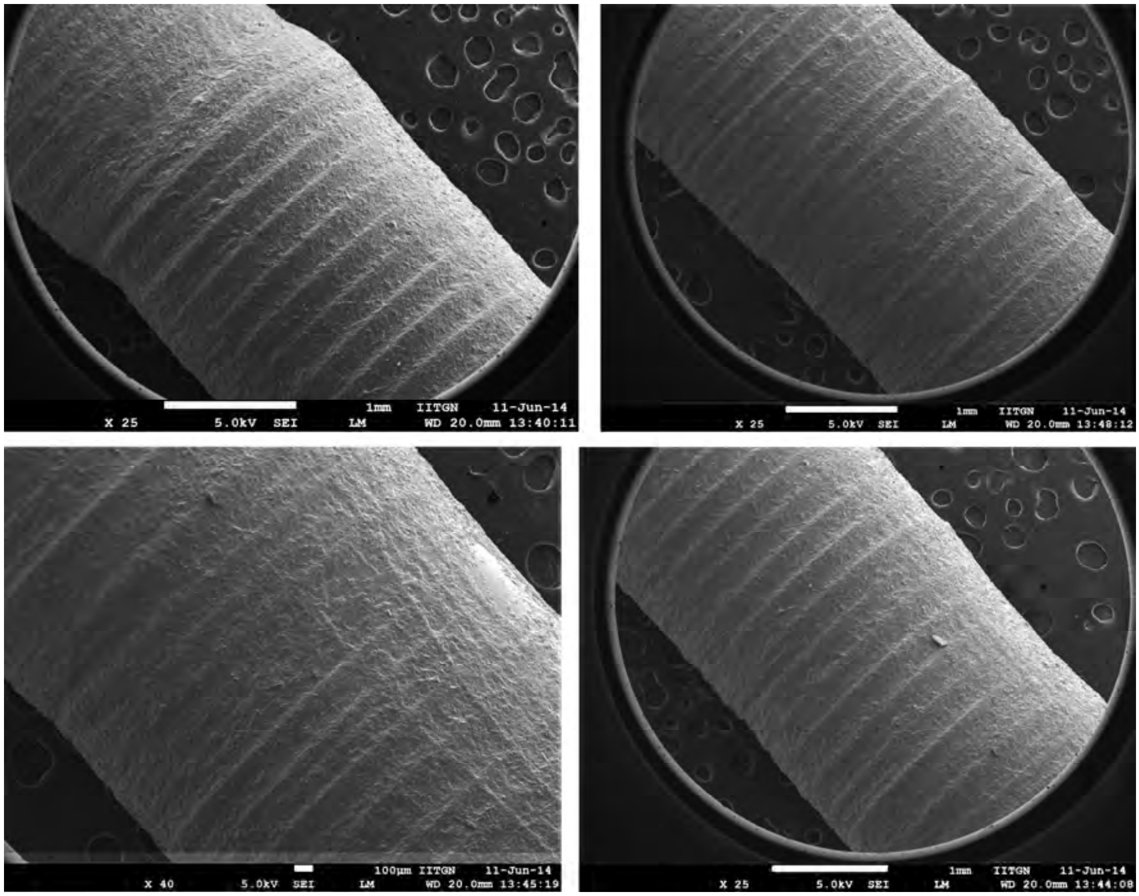

Figure 24: Bead hole impressions analysis using SEM; bead holes formed by diamond tipped steel drill from a modern bead manufactured at Khambhat

Conclusion

An attempt is made in this paper to trace the history of bead making in the South Asian context since prehistoric times up to the Harappan Civilization in order to understand the developments in technology as well as exploitation of various raw materials. Through the growth of civilization, the past humans adopted technologies from simpler to more complex to produce a wide range of artistic products of which beads formed an important component. This is vividly reflected in the context of Harappan Civilization and its preceding phases, the foundations of such complex technologies were based in the Neolithic and Chalcolithic Mehrgarh.

Scholars working on the bead drilling technologies have developed various means and methods to understand them, which have been highlighted in this paper. In particular, these methodologies have largely helped in understanding the Harappan bead drilling technology. The hallmark of this technology is the use of ernestite stone drills. Even though the provenance of this raw material is still unknown, its large presence from Harappan sites in Gujarat is an eye opener and an indication towards its provenance in this region. This is further substantiated by the continuation of bead production at Dholavira employing ernestite drills during late / post-urban Harappan phase. The use of ernestite cease to exist during late Harappan phase from sites outside Gujarat. The modern bead manufacturing industry at Khambhat and its study by enthusiasts and scholars since mid 19th century is a very good evidence in understanding the ancient drilling technology using traditional methods and before the emergence of mechanized drilling and polishing. The traditional bead manufacturers at Khambhat were also instrumental in carrying out different experimental studies by scholars like Kenoyer and Vidale, which helped in arriving at a holistic picture of Harappan bead manufacturing technology. Beads manufactured using Harappan technology have been recognized beyond the Indus Valley from sites in Mesopotamia based on the understanding of this technology using SEM studies of bead hole impressions. Thus, the scientific studies have emerged as an important tool in understanding the past cultural interactions between civilizations and their dynamics.

Explanatory Note

[1]Ka = Kilo years or 1000 years ago

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