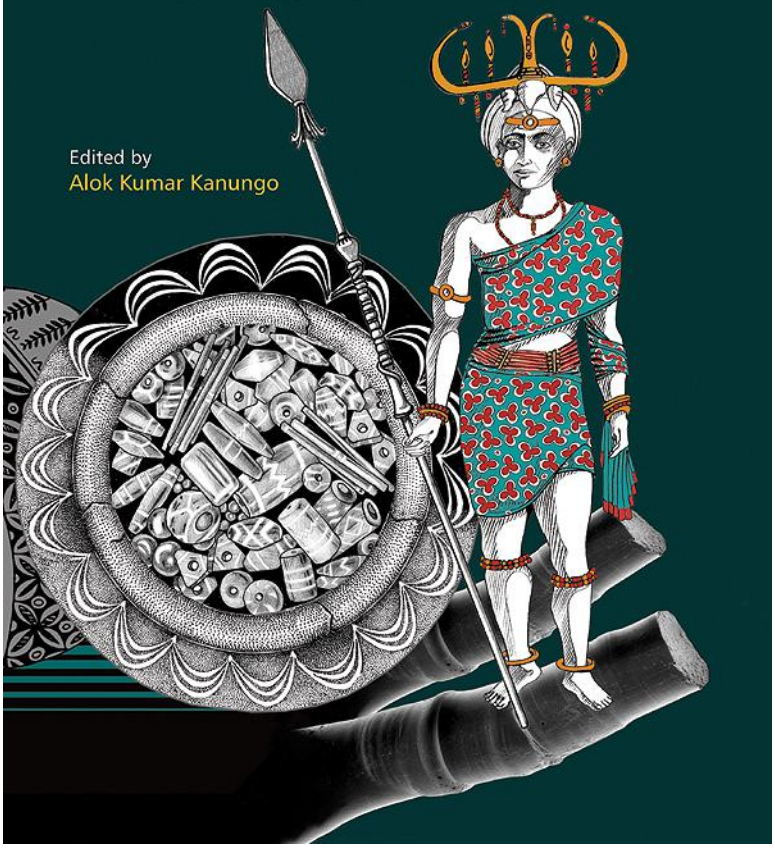
Stone Beads of South and Southeast Asia

Archaeology, Ethnography and Global Connections



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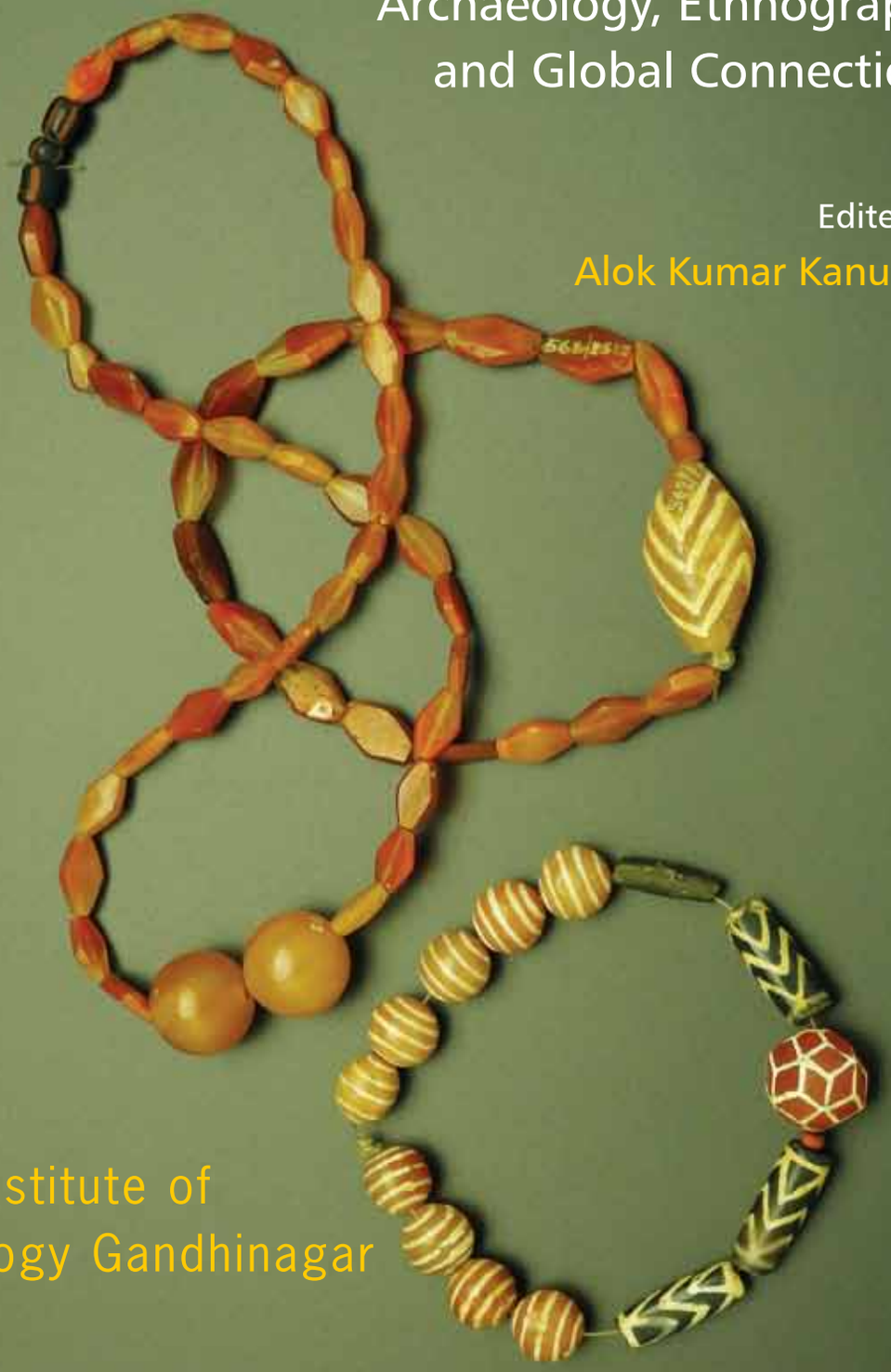

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Archaeology, Ethnography and Global Connections

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Contents

BEADS: CASE STUDIES FROM SOUTH ASIA

BEADS: SCIENTIFIC STUDIES

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Documentation and Analysis of Stone Drills from Dholavira

V.N. Prabhakar

The site of Dholavira (District Kachchh, Gujarat) was excavated by the Archaeological Survey of India (ASI) for thirteen field seasons between 1989–90 and 2004–05. The results of these excavations have been a revelation. Seven stages of cultural occupation have been documented at the site spanning over a period of 1500 years, starting from *c.* 3000 BCE onwards. The excavations yielded a rich collection of beads right from Stage I. However, the beadmaking industry seems to have proliferated during Stages IV–V (Harappan phase) and VI (late Harappan phase). The evidence that consists of numerous bead blanks, both polished and unperforated simple rough-outs, along with a good number of bead polishers of various dimensions clearly suggests the existence of a flourishing bead manufacturing industry at the site. This is again supplemented by the presence of three beadmaking workshops, two of which belonged to late Harappan phase. Numerous stone drills, which are among the implements associated with the workshop and bead blanks, have been recovered from the site. These stone drills are made predominantly from 'ernestite', a slightly harder material than the agate–carnelian silicates. The geological origin of ernestite has not yet been ascertained. However, scholars like Randall Law suggest that there is a strong possibility of its provenance being north Gujarat. Nevertheless, Dholavira has the distinction of yielding the largest number of ernestite drills so far from any Harappan site, the present number exceeding

1550. This chapter deals with the descriptive and scientific details of these stone drills.[1]

INTRODUCTION

Dholavira, locally known as Kotada, is located in the Khadir Island in the Great Rann of Kachchh of Gujarat (Fig. 1). The excavations at the site brought to light the remains of a highly developed, planned and a model Harappan city (Fig. 2), (Bisht 1989: 266). As can be observed in the layout, the city was distinctively divided into three parts, named as 'Castle', 'Bailey', and 'Middle and Lower Towns' by the excavator. The layout of the city consisted of interesting combinations of ratios and proportions. According to Bisht (2000: 23), Dholavira was a "city par excellence in overall planning, detailed resolution which were done with mathematical precision in all measurements". The overall extent of the city, along with the cemetery to its west, measures around 100 ha, while the built-up area roughly measures around 50 ha (Bisht 2014: 254). The city was replenished with a series of sixteen water reservoirs, estimated to have occupied 20% of the walled area (Bisht 2000: 21-22). Apart from the typical urban features of a Harappan city, Dholavira also has a vast cemetery consisting of funerary structures of various types, the estimated size of which is more than 50 ha (Bisht 2014: 255). The excavated remains record a long and continuous occupation at the site. It has a deposit of around 15 m thickness, which has been divided into seven distinct cultural stages, namely Stage I to VII, displaying an overall chronology of 1500 years spanning between *c.* 3000 and 1500 BCE (Bisht 2014: 255).

The stratigraphy of seven cultural stages (Stages I–VII) can be best observed from a cutting across the rain gully on the southern arm of the fortification of the castle. The material remains from these stages confirm their cultural association with the early

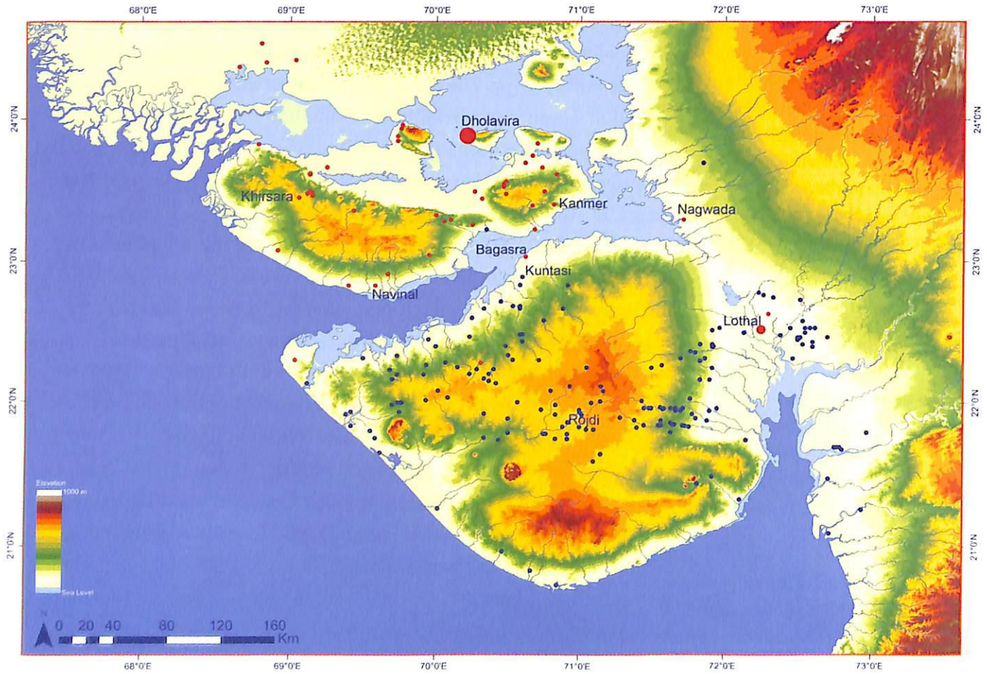


Fig. 1. Map showing the location of Dholavira, Khadir island in Great Rann of Kachchh, Gujarat.

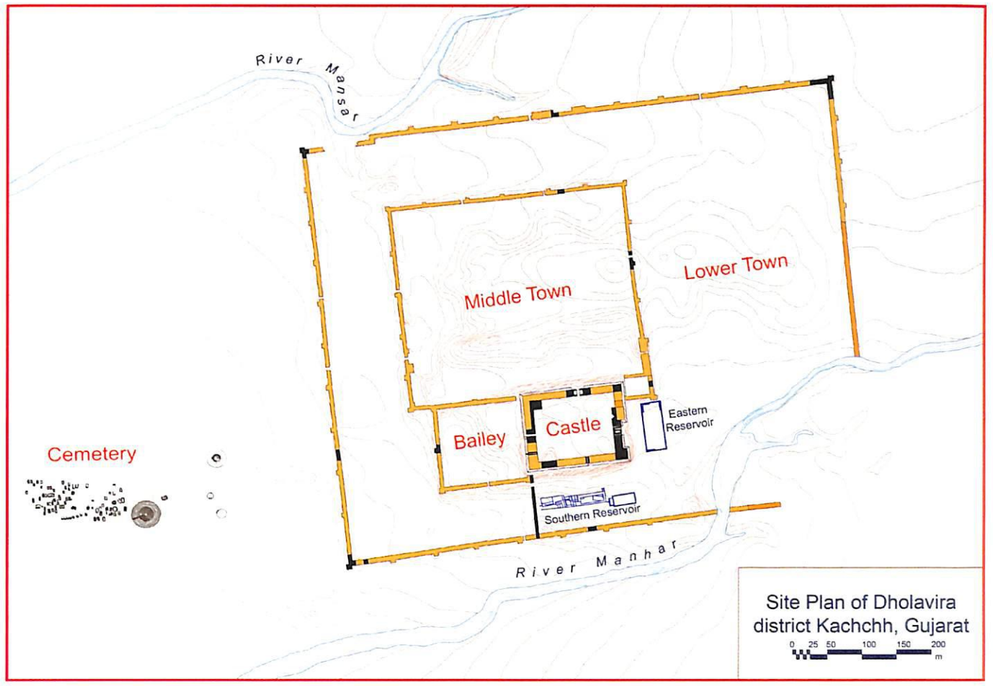


Fig. 2. Layout of the Harappan city of Dholavira showing prominent divisions and reservoirs.

Harappan phase (Stages I–III), Harappan phase (Stages VI–V), Late Harappan phase (Stage VI) and post-urban Harappan phase (Stage VII).

The presence of such a large Harappan settlement in the desolate island of Khadir in the Rann of Kachchh is, indeed, very difficult to explain. One of the reasons for this may be the rich natural resources of Kachchh, which the Harappans might have exploited. Kachchh is rich in chalcedony, chert, ochres, white clay, Fuller's earth (*mung mitti*), glass-sand, salt, gypsum, different rocks and building materials, many of which might have been exploited by the Harappans (Bisht 1989: 267). A recent study (Law 2015: 747-87) on various rocks and minerals from the site has helped in understanding the different zones from which the Dholavira Harappans obtained raw materials and sustained the long and thriving craft activities at the site. This study has helped in identifying various rocks and minerals from Dholavira (Fig. 3), which consist of steatite, chert, haematite, marine shell, basalt, gabbro, limestone, sandstone, quartz crystal, translucent or semi-translucent agates (carnelian, chalcedony, chrysoprase, onyx, yellow agate, brown agate, green agate, moss agate and banded or mottled varieties that are mixtures of these), opaque jaspers (in solid, banded or mottled red, brown, yellow, green, black and other shades including the variety called bloodstone), quartzite, conglomerate, siltstone, amethyst, amazonite, lapis lazuli, serpentine, vesuvianite–grossular garnet, other 'tentatively identified' materials like fluorite, aventurine quartz/fuchsite, turquoise, 'ernestite' (for making drills), and metals like copper, lead, and gold (Law 2015: 747-87). This study has also helped in identifying probable sources of some of the raw materials (Fig. 4), such as steatite, agate, chert, lead and silver (Law 2015: 778-87).

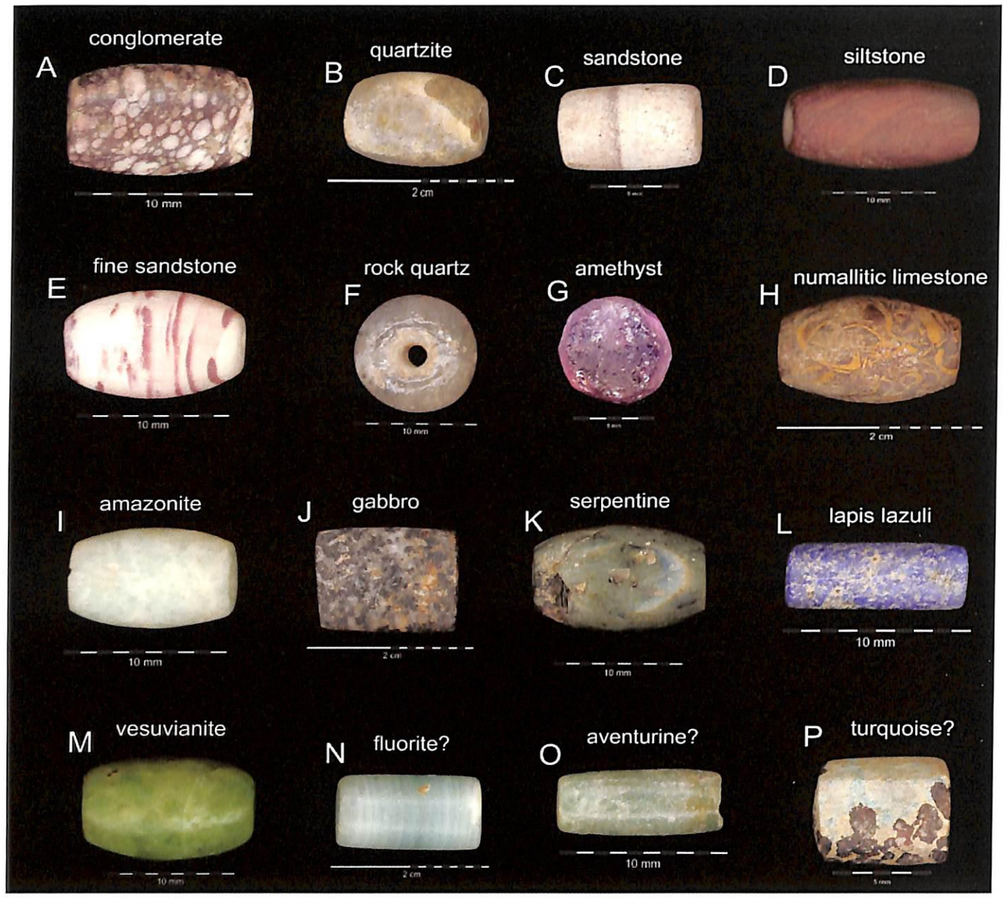


Fig. 3. Examples of various materials used for making beads (after Law 2015).

The evidence for beadmaking at Dholavira has been obtained right from the earliest period and continues to later periods (Bisht 1991: 71-82). The evidence is in the form of only a handful of stone beads, while steatite beads surpass the former. Only one micro bead of carnelian from Stage I and another one of fine sandstone from Stage II could be seen from the collection so far (Fig. 5). The eight stone beads found from Stage III are of materials such as carnelian, jasper, sandstone, banded agate and amazonite (Fig. 5).

The very small number of stone beads from early levels can be attributed to the minimal excavation of these stages and might not represent the overall bead industry at the site. The bead industry which made its humble beginning during the Stages I–III, diversified during the Stages IV–V of the Harappan phase. Bead manufacturing continued during Stage VI at this site. This is further substantiated by the presence of at least three bead manufacturing workshop areas, one of Stage V near the east gate of Middle Town and two of Stage VI (Fig. 6). The workshops of Stage VI are located near the north gate of the Bailey and the east of west gate of the castle. A large number of rough-outs, unfinished beads of various stones, both partly

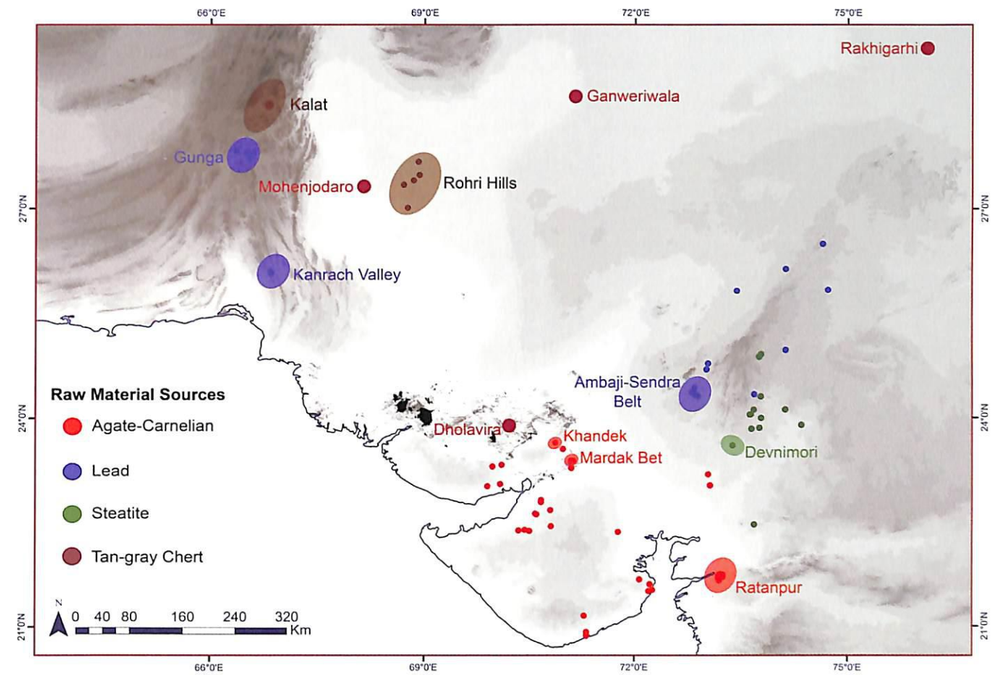


Fig. 4. Tentative raw material sources of steatite (Devnimori), agate–carnelian (Khandek, Mardak Bet, and Ratanpur), lead (Ambaji-Sendra belt, Kanrach valley, Gunga) and tan-gray chert (Rohri Hills, Kalat) for Dholavira (after Law 2015).

perforated and totally unperforated, have also been found from Stages IV–V (Fig. 7), supplemented by numerous bead polishers (Fig. 8).

The number of stone beads of different raw materials increases from the Harappan phase onwards (Figs. 9-10). On an overall estimate, the number comes to around 5,154 consisting of 28 types of raw materials.

Among the raw materials, steatite dominates the collection with 2,065 beads (40.1%), followed by agate–carnelian varieties including chalcedony and jasper (1,614, 31.4%), refractory materials like faience and paste (956, 18.6%), and lapis lazuli (133, 2.6%). The remaining 7.3% is represented by various materials like chert (107, 2.1%), serpentine (75, 1.5%), and others like amazonite, rock crystal, sandstone,

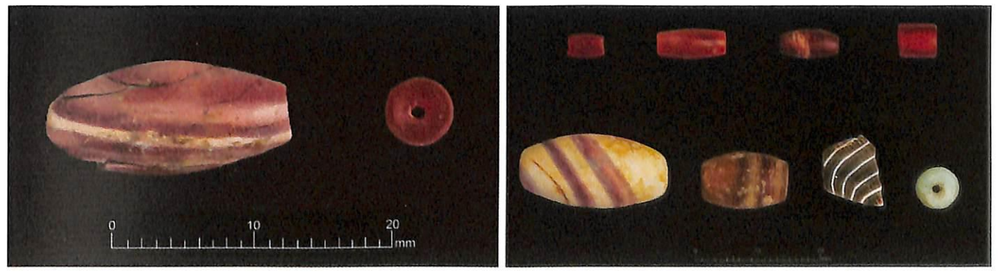


Fig. 5. Bead of sandstone (Stage II), carnelian (Stage I) (left) and Stage III (right) from Dholavira.

Fig. 6. (a) Location of bead workshop, Bailey, (b) Detail of bead polisher *in situ*, Bailey and (c) Bead workshop in Castle.

bloodstone, basalt, turquoise, and so on. The bead manufacturing industry at Dholavira, apart from the bead workshops and numerous bead blanks and rough-outs, is also attested by the presence of more than 1,550 drills of 'ernestite'.

BEAD DRILLING TECHNOLOGY OF THE HARAPPANS

One of the earliest attempts to understand the bead drilling technology of the Harappans was made by Ernest John Henry Mackay while excavating Chanhudaro. The excavation at Chanhudaro yielded a good number of unfinished beads along with stone drills, some broken and some complete, the latter averaging 3.81 cm long, and 2.54 mm to 3.048 mm in diameter (Mackay 1937: 6). Mackay got some of these analyzed through the Geological Survey of India and these "consist of chert, containing a

Fig. 7. Bead rough-outs of various materials, Dholavira.

Fig. 8. Bead polishers, Dholavira.

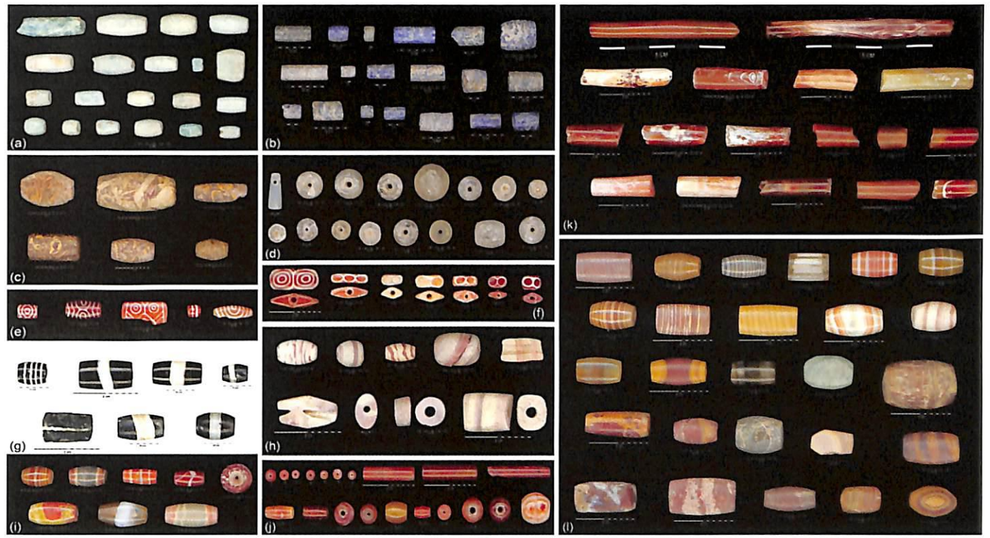


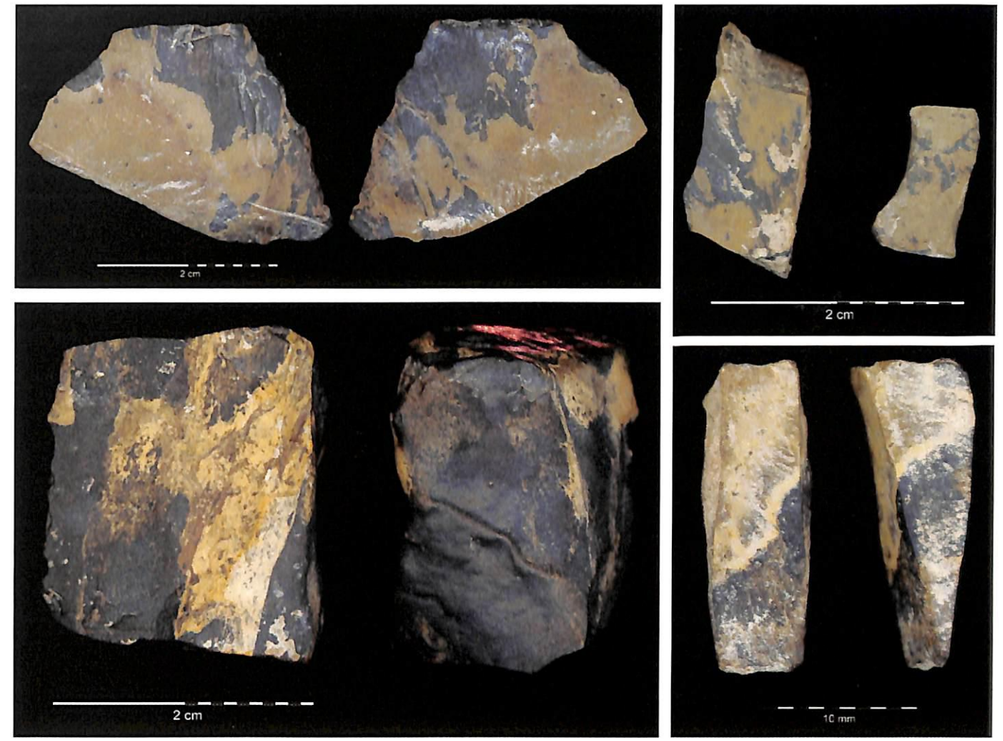
Fig. 9. Beads of (a) amazonite, (b) lapis lazuli, (c) limestones, (d) rock crystal, (e & f) etched carnelian, (g) agate, (h) fine sandstone, (i & l) jaspers, (j & k) agate–carnelian.

Fig. 10. Beads of (a - c) steatite, (d) terracotta.

little magnetite, the hardness of the specimens is 7 [which] 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" (1937: 6). The beads were bored first and then polished (Mackay 1937: 9). The study of contemporary bead drilling techniques at Khambhat, albeit with modernized techniques, has helped in understanding the Harappan methodology. The similarities of the contemporary techniques with ancient ones have been pointed out by Mackay (1937), Rao (1979, 1985) and Possehl (1981). However, a detailed study by Kenoyer et al. (1994) helps in understanding the various stages of bead manufacturing, including raw material acquisition, heat treatment, chipping, polishing, and discard of waste materials. The Khambhat bead manufacturers use a diamond-tipped drill, fitted into a wooden shaft, 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 (Fig. 11). The flow of water and grit to the point of drilling of beads is regulated by a thin wire connected to the pot (Possehl 1981: 44). The use of a drill, a bow, water, and grit as lubricant and abrasion seems to be the same technique that was practised by the Harappans, with the only exception that instead of diamond drill, ernestite and chert drill were used by the latter.

| Fig. 11. Traditional bead drilling at Khambhat.

Thus, the drills form an important component in the manufacture of beads, particularly stone beads. The agate–carnelian beads are hard to perforate and the drills have to be either of same or of better hardness. Various materials have been documented for making drills from different archaeological contexts; for example: stone drills at Shahr-i-Sokhta for drilling lapis lazuli (Kenoyer and Vidale 1992: 499); various colours of translucent chert and jasper for drilling small carnelian beads, short truncated bicones in shape at Shahdad in eastern Iran (Kenoyer and Vidale 1992: 499); pumpelleyite at Mehrgarh (Barthelemy and Rodiere 2005: 46); and grey–black jasper and chert at Harappan sites (Kenoyer and Vidale 1992: 503). The drills recovered from various Harappan sites like Mohenjo-daro, Chanhudaro and Harappa is of a different material of unknown geological origins, which was given a temporary name of "ernestite" by Kenoyer and Vidale (1992). It is "an extremely fine-grained stone that typically has dark-brown to black patches or dentritic veins in a khaki-coloured matrix (Fig. 12). It is hard (easily scratching quartz but not topaz giving it a Mohs hardness of at least 7 but less than 8), very tough (it does not break or fracture easily), and fairly dense (it has a specific gravity ranging from app. 2.8 for khaki coloured matrix to app. 3.2 for the brown–black portion)" (Prabhakar et al: 2012). The detailed microscopic investigation of this material reveals that it is "a fine grained metamorphic rock composed primarily of quartz, sillimanite, mullite, haematite and titanium-oxide phases" (Kenoyer and Vidale 1992). Ernestite is found in many colours and often multi-coloured ones are also found. The XRD analysis on some of the drills from Harappa indicates that the 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: 506-07).



| Fig. 12. Ernestite raw material, Dholavira.

Law (2011: 544-55) carried out XRD and EMPA studies on four ernestite samples obtained from Mound E of Harappa. The diffraction peaks of two samples indicate that the material is composed mainly of quartz and mullite–sillimanite along with minor presence of haematite (iron oxide) and rutile (titanium oxide). The remaining two samples showed the presence of cystobalite and mullite while quartz, haematite and rutile were absent. He also speculates that ernestite may actually be a variety of claystone known as tonstein that was heated by the Harappan beadmakers to high temperatures so that they become extremely hard to allow drilling of stone beads of high hardness. Two ernestite raw material samples from Dholavira were also subjected to XRD analysis, indicating a pattern similar to other sites (Prabhakar et al. 2011).

CLASSIFICATION OF DRILLS

The classification, typology and documentation of the ernestite drills from Dholavira are based on a methodology developed by Mark Kenoyer (Prabhakar et al. 2012).

Tapered cylindrical drills

The tapered drills of ernestite from Dholavira have a typical tapering (Fig. 13) on the bit portion, the condition of surface of which varies according to

| Fig. 13. Examples of tapered drills of ernestite, Dholavira.

the amount of drilling that it was subjected to. The surface is also chipped, faceted, or ground smooth due to various degrees of drilling. The tang or the base portion retains the original surface of the drill bit, which is usually faceted, chipped, or ground faceted in nature, and preserves evidence of surface modifications due to its fashioning to desired shape.

For the sake of documentation purposes, the broken tapered cylindrical drills were given a separate category and recorded separately from the complete ones. These types were then sub-divided depending upon the surface conditions. A coding system for recording the drills, which was devised by Kenoyer, was used to document them (Prabhakar et al. 2012). The tip portion of tapered cylindrical drills has various morphological features depending upon the degree of drilling. In some cases, the tip portion is found to be broken due to wear and tear and excessive pressure developed during the drilling.

Constricted cylindrical drills

Another prominent type noticed among the ernestite drill bits is constricted cylindrical drill. It "has a long cylindrical shape that is wide at the tip and constricted at the midsection" and is classified into three parts, namely (i) the distal tip, (ii) the constricted medial portion, and (iii) the proximal tang portion (Kenoyer and Vidale 1992: 508).

The constricted cylindrical drills from Dholavira (Fig. 14) fit very well with the description and morphology provided by Kenoyer and Vidale. The surface morphology and the changes that occur on the drill bits due to drilling have been dealt in detail by both of them (Kenoyer and Vidale 1992: 495-518). Here, for recording purposes, the drill bits with and without base have been categorised separately and recorded.

Cylindrical drills

These types of drills have, more or less, a round or faceted section (Fig. 15), while the surface condition varies according to its nature and working. Even

Fig. 14. Examples of constricted cylindrical drills of ernestite, Dholavira.

though a distinct basal/shaft portion can be identified, the tip portion can be recognized on the basis of surface modifications and different tip profiles. The cylindrical drills recorded at Dholavira also include the rough-outs and unused ones, which

Fig. 15. Examples of cylindrical drills of ernestite, Dholavira.

Fig. 16. Examples of re-used drills of ernestite, Dholavira.

are long and faceted without any tip modification. The surface of cylindrical drills may, therefore, depending on the stages of drilling and finishing, appear chipped, chipped and ground or ground faceted.

Re-used and re-sized drills

Apart from the three major categories of drill bits noticed at Dholavira, there are a few types which are not represented in large numbers but are unique in shape and surface morphology. These drills were the ones that were modified and reworked from the already broken and substantially longer drill bits so that they could be reused again. The broken tips were then worked again, smoothened, and made flat for re-use. In some cases, the base portion was worked upon and used as a drill bit. Both tapered and constricted cylindrical drills were utilised for such type of re-used drills (Fig. 16).

The re-sized drills (Fig. 17) form a category in itself. The difference is that the re-sized drills were totally altered and modified into new ones. The bit profile of these drills is also very much different from others, and the sides are more or less straight. This is also a state in which, due to the continued

Fig. 17. Examples of re-sized drills of ernestite, Dholavira.

Fig. 18. Example of pointed drill.

drilling of the beads, the profile of the drill changes completely into straightened edges.

Pointed drills

This is a unique drill type noticed at Dholavira (Fig. 18); albeit only one such piece has been documented. The tip portion of the drill bit is pointed and triangular in profile, while the base portion retains a cylindrical shape. The exact function of this drill type is unknown at this point of time. However, it may be deduced from the working observed on the surface of the drill bit that it had been subjected to drilling extensively and could have produced a bi-conical profile in a bead. It can also be deduced that this particular variety could have been used for small beads.

DOCUMENTATION OF DRILLS

The documentation of the drills consisted of a methodology and coding system to record various parameters such as: (i) state of the drills, (ii) condition of surface of the drills, (iii) drill type, (iv) tip profile, for the morphological recordings (Figs. 19-20); and various metrical measurements like (i) base length, (ii) one set of base width, (iii) shaft length, (iv) one set of tip width, (v) one set of width at minimum constricted portion in the case of constricted cylindrical drills, and (vi) one set of proximal widths (Fig. 21).

A typical recording sheet with all the measurements is shown below:

Acc. No.	Trench	Layer	Depth	Bit Profile (1)	Tip Profile (2)	State (3)	Drill Surface (4)	Max. Length (5)	Max. Width (6)	Max. Thick (7)	Average Width	Bit Length (8)	Base Length (9)
2276	ZA 12 Qd 2	3	0	407	8	1	4	16.04	3.30	2.75	3.03	9.80	6.24
3801	A 17 Qd 1	11	-220 to -235	407	8	1	4	10.25	2.24	2.15	2.20	5.28	4.97
6584	47 X 48 X 4	18	-328 to -340	407	8	1	4	16.29	2.95	2.84	2.90	8.87	7.42
7303	48 X 92 X 4	39	-718	407	8	1	4	20.36	2.59	2.50	2.55	10.83	9.53

Acc. No.	Tip Width1 (10)	Tip Width2 (11)	Ave Tip Width	Base Width1 (12)	Base Width2 (13)	Ave base Width	Min Width1 (14)	Min Width2 (15)	Ave Min Width	Proximal width1 (16)	Proximal width2 (17)	Ave Prox Width	Material	Period
2276	2.18	2.08	2.13	2.02	1.93	1.98	2.60	2.16	2.38	2.60	2.00	2.30	Ernestite	IV
3801	1.41	1.39	1.40	1.36	1.39	1.38	2.17	2.05	2.11	2.18	1.84	2.01	Ernestite	V
6584	2.30	2.21	2.26	2.22	2.26	2.24	2.86	2.79	2.83	2.73	2.46	2.60	Ernestite	V
7303	1.95	1.93	1.94	1.18	1.77	1.48	2.50	2.42	2.46	2.12	2.01	2.07	Ernestite	IV

The state of the drills is recorded using a coding system from 1-8 depending upon the preservation of the drill, whether it is complete or broken, and if broken, which part of the drill is preserved, and so on (Fig. 19). Depending upon the preservation of the drill, a suitable number is entered in the coding system. Similarly, the types of drills and tip profiles (Fig. 20) have been given different codings and, depending on the morphology, a suitable code is entered in the recording system. After recording the state, condition, and typology codes, detailed measurements are recorded from different portions of the drill bit, as show in Fig. 21.

STATE	1 = COMPLETE 2 = MEDIAL 3 = PROXIMAL 4 = DISTAL 5 = NOT DETERMINED 6 = PROXIMAL-MEDIAL 7 = DISTAL-MEDIAL 8 = BROKEN / CHIPPED
DRILL SURFACE	1 = CHIPPED 2 = CHIPPED AND GROUND (FACETED) 3 = GROUND-FACETED 4 = GROUND GROUNDED (NON-FACETED)

Fig. 19. Coding for recording state and surface of drill.

Thus, it can be observed that a detailed documentation of the drill bits has been carried out, recording as many as four parameters for morphology and 13 measurements. The morphological parameters were often aided with the help of a handheld jeweller's magnifier with magnification up to 30x. The metrical measurements were carried out with the help of a pair of digital vernier calipers. A pair of 6" digital vernier calipers was used for recording the metrical measurements (Fig. 22).

The recordings also included contextual details such as the accession number, trench, layer, depth,

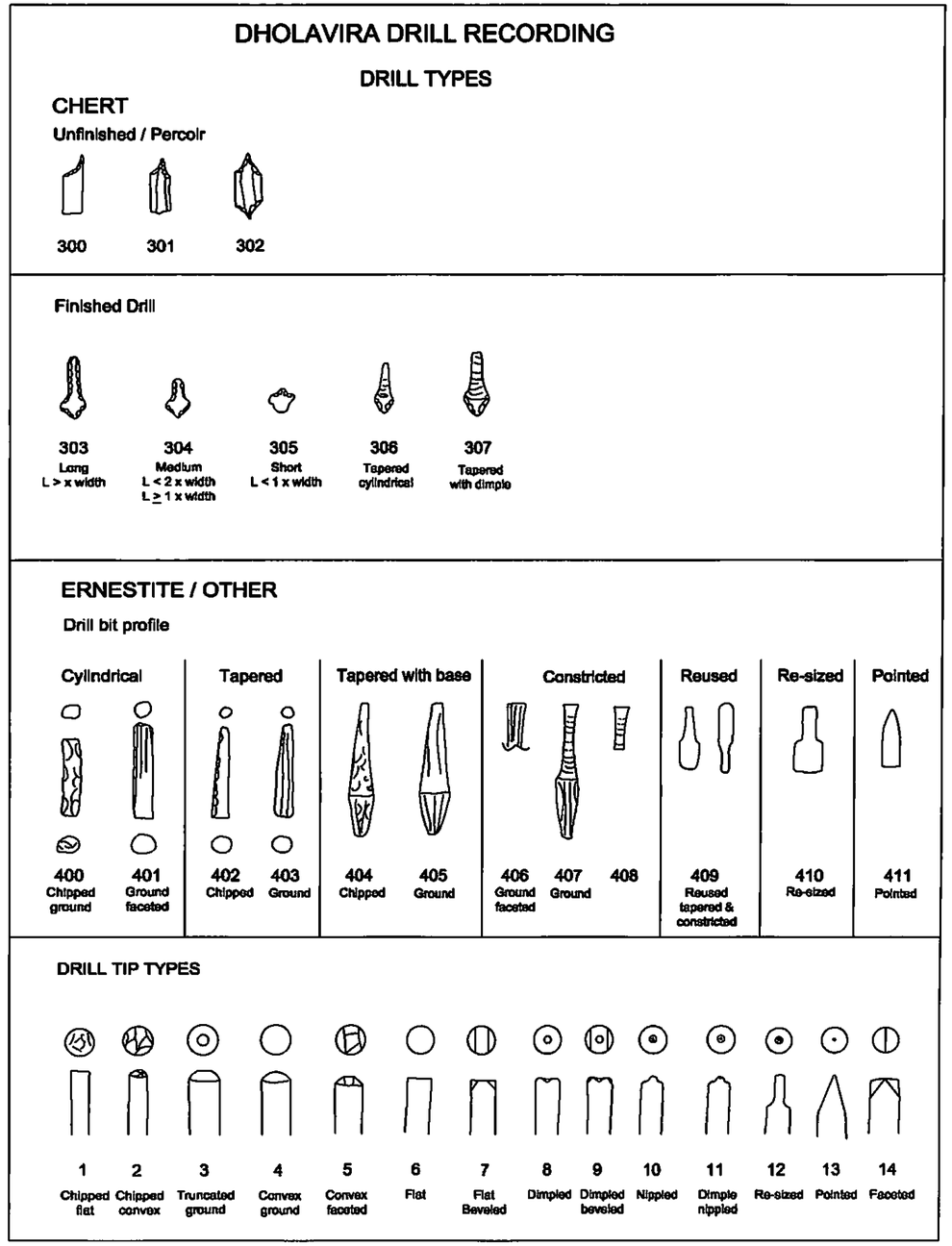


Fig. 20. Coding system for recording the drills.

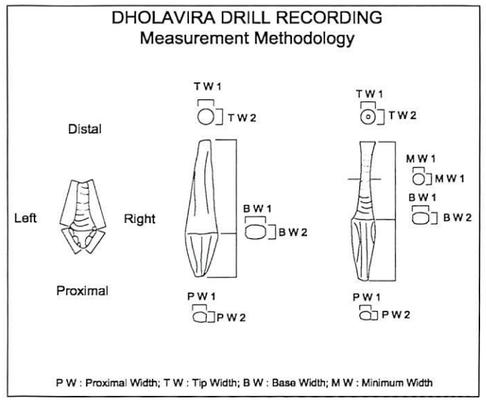


Fig. 21. Drill bit recording methodology for measurements.

location, period along with other measurements. All these details were entered in Microsoft Excel worksheet. Once all the measurements were recorded, the available data was used for detailed analysis.

ANSWERING VARIOUS QUESTIONS USING THE RECORDED DATA

The available data was used to answer various pertaining questions and, thus, to arrive at a broad-based conclusion regarding the ernestite drills from Dholavira. The data was used to understand the spatio-temporal distribution of drill bits from various locations of Dholavira belonging to different periods. This helped understand the period in which the ernestite drills were dominant and from which locality they were predominantly used. The concentration of drill bits from a particular locality in Dholavira may help in identifying probable bead workshops and, thus, provide a good indicator for future planning of excavations. Similarly, the analysis of 'state' indicates the completeness of the drills and, thus, if a major percentage of the drills are broken, it can be concluded that it may represent an industrial waste, and so on. Therefore, the statistical analysis of these drills provided various clues to arrive at broad-based conclusions; some of the results are given here as examples. The detailed results from the preliminary analysis can be found in Prabhakar et al. 2012 and the results from the complete analysis are under publication separately.

Fig. 22. Example of a digital vernier caliper.

Percentage of various drill materials

A total of 1,603 drills have been documented so far from the collections stored at Purana Qila, New Delhi. Out of these, 12 are of chert, 2 of vesuvianite and 1 of agate, while the remaining 1,588 are of ernestite (Fig. 23). The dominance of ernestite over other materials is a clear indication of the preference of a harder material for drilling beads of agate–carnelian and other similar harder materials.

The analysis of 1,603 drills indicates that ernestite drills represent 99.2% of the total collection, while chert and vesuvianite represent 0.7% and 0.1%, respectively.

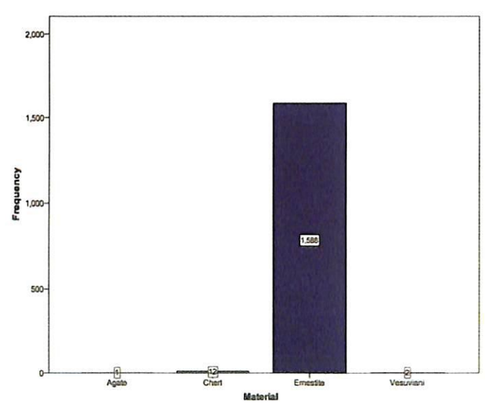


Fig. 23. Broad drill types based on material.

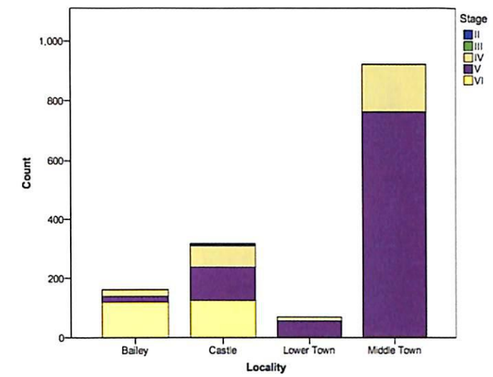


Fig. 24. Spatio-temporal distribution of ernestite drills.

Spatio-temporal analysis of the drills

The remaining 1,588 ernestite drills were analyzed on the basis of periods (Stages in the case of Dholavira) vis-à-vis the location from where they were found during excavations. The analysis could be carried out for 1,470 drills, for which the contexts from where they were recovered such as the Castle, the Bailey, and the Middle and Lower Towns, were available. These localities broadly constituted the occupational area. The remaining finds from other localities may be due to re-deposition or erosion and other causes, although the possibility cannot be ruled out that other spaces like the banks of water tanks or other open areas might have also been in use for beadmaking purposes. Of these 1,470 drills, five each belong to Stages II and III, 271 to Stage IV, 947 to Stage V and 243 to Stage VI. In terms of the locality of these drill finds, 161 are found from the Bailey, 318 from the Castle, 69 from the Lower Town, and 922 from the Middle Town (Fig. 24). This clearly indicates that the bead manufacturing industry using ernestite drills was dominant during Stages IV and V in the Middle Town locality. This also holds good in terms of the amount of manufacturing debitage. Further, the location of a bead manufacturing workshop very close to the east gate of the Middle Town is another testimony to the large-scale occurrence of drill bits from this area. Future excavations can be planned keeping in view the larger concentrations of drill bits and correlating them with a probable bead workshop in the vicinity. The presence of a good number of drill bits (243) in Stage VI is another indication of continuation of bead manufacturing at Dholavira even after urbanisation came to an end.

State

The analysis of the state of drills is a good indication of completeness of the drills. The analysis (Fig. 25) indicates that the complete and finished drills constitute 39.4% of the total collection, followed by proximal-medial (32.6%), distal (17.3%), medial (6.9%), distal-medial (3%), not determined (0.6%), proximal (0.3%) and broken-chipped (0.1%) ones. The complete ones are followed by the proximal-medial drills which represent 32.6% of the total collection. However, if we take into account the incomplete and broken ones accounting for 60.6%, it clearly indicates that they are used and broken drills. Many of these drills show breakage due to extreme pressure or twisting while drilling. While these varieties can be interpreted as remains of extensive industrial activities, the complete ones are excellent examples of various stages in the usage of

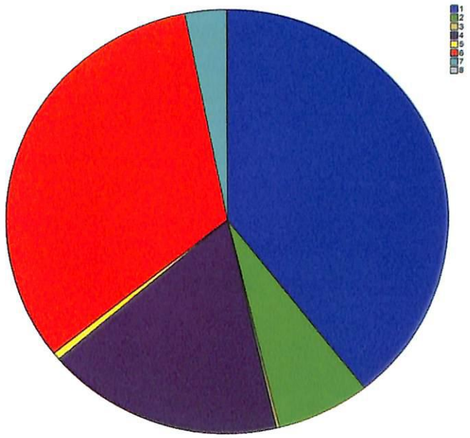


Fig. 25. State analysis of ernestite drills.

drills. Among the complete ones, there are examples of unused faceted drills, which is an indication of the first stage in the finishing of a drill before it is put into use. The subsequent drilling mechanisms clearly left a mark on the surface of the drills corresponding to the perforation made on the bead blanks. The continous to-and-fro mechanism left erosionary marks on the surface of the drills as well as on the tips; the latter facing the brunt of drilling mechanism.

Maximum length

The analysis for finding the maximum and minimum length of a drill bit is an interesting part of the findings. The analysis could be carried out for 625 complete drills, the remaining being broken or partially broken.

The length of the complete drills varies from 6.07 to 45.11 mm. The mean length of the complete drills is 12.62 mm with a standard deviation of 4.15 mm. The histogram of the maximum length of complete drills (Fig. 26) indicates that most of the drills have a length between 8 and 14 mm and nearly 135 drills have a length between 11 and 12 mm.

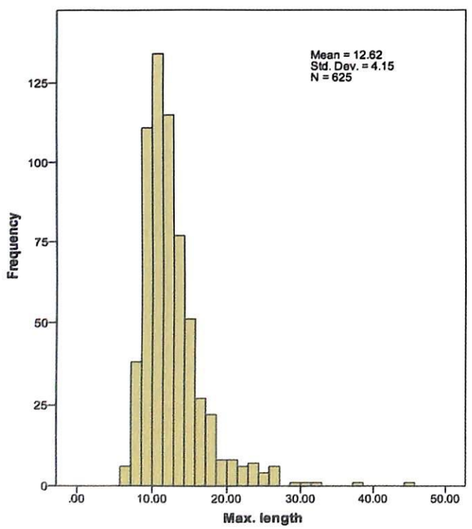


Fig. 26. Histogram of complete drills for maximum length.

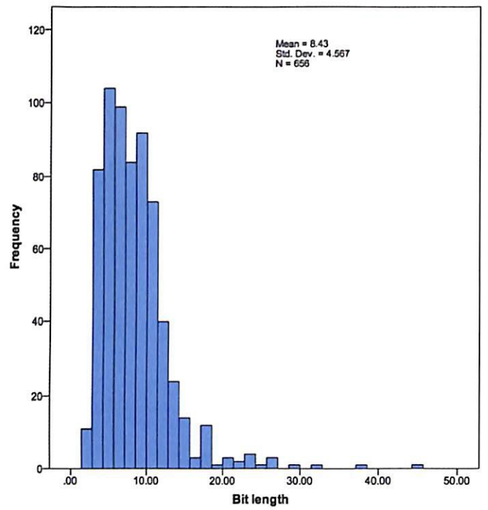


Fig. 27. Histogram of bit length.

Bit length

The bit length is the portions of drill bit which shows evidence of a drilling surface and is distinctly separate from the basal portion that is hafted. The complete drills constitute 39.4% of the total drills recorded from Dholavira and those having a conspicuous bit were utilized for the analysis (Fig. 27). A total of 656 drills having such evidence could be found. The mean bit length of the analyzed drills comes to 8.43 mm with a standard deviation of 4.567 mm. The bit length varies from a minimum of 2.44 mm to 45.11 mm. It is pertinent to mention here that the maximum bit lengths are observed from the cylindrical drills, as the length of complete drill has been assumed as the bit length in such cases in the absence of a clear-cut bit surface.

Base length

The basal portion of the drill bit is hafted in the wooden shaft, and normally it is of a faceted cross-section, which helps to have a better grip in the shaft. The base length is measured from the point where the evidence of drilling ends and un-worked surface emerges up to the proximal end. A total of

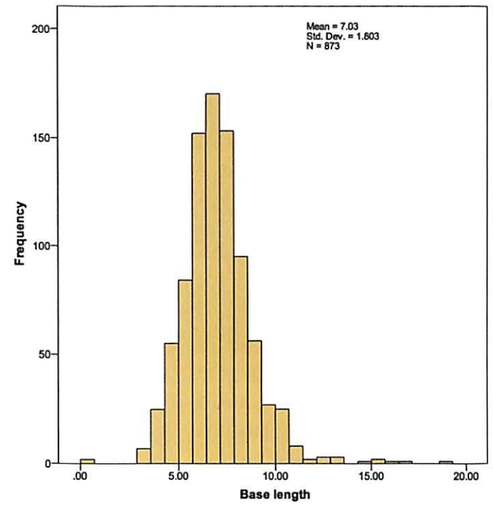


Fig. 28. Histogram of base length.

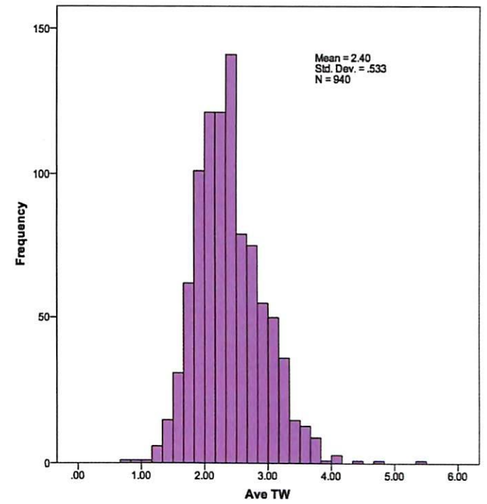


Fig. 29. Histogram of tip width.

873 drills showing evidence of a clear base length were utilized for the analysis and a histogram is created (Fig. 28). The base length varies from a minimum of 0.31 mm to a maximum of 18.77 mm.

The mean base length is 7.03 mm with a standard deviation of 1.803 mm. A majority of the drills have a base length ranging between 5 mm and 10 mm, with a clear presence of drills having a base length between 7 mm and 8 mm. Drills having a base length of 15 mm and above are very few and constitute a minor percentage in the collection.

Tip width

Another important criterion from the analysis of drill bits is the measurement of their tips. The width of tip of a drill bit provides a crucial evidence of width of perforation in a bead, and can also be helpful in identifying whether they were used to manufacture smaller or larger beads. The tip of a drill is the actual working edge and it clearly demonstrates the evidence of various working stages involved in the actual perforation of various mediums. A total of 940 drills with a tip are used for carrying out the analysis of the variations in the tip width. Here, too, two readings perpendicular to each other at the tip end are taken and the mean of these are taken for creating the histogram (Fig. 29).

The analysis indicates that the mean tip width of 940 drills is 2.4 mm with a standard deviation of 0.533 mm. The tip width ranges from a minimum of 0.79 mm to a maximum of 5.37 mm. The tip widths ranging from 1.8 mm to 3.6 mm constitute a major percentage of the drills and this is also a clear indication of the diameter of the perforation made on the actual bead. Tip widths of 4 mm or above constitute less than 1% in the collection.

OBSERVATIONS ON THE SURFACE MODIFICATIONS OF DRILLS DUE TO MANUFACTURE AND ITS USE

Another area in which various surface modifications can be documented and analyzed is the usage of a simple USB digital microscope. In the case of drills from Dholavira, a Dino Lite digital microscope (Fig. 30) was used for documentation of the surface conditions from various parts like shaft, drill portion, tip, and so on. The detailed examination of drill rough-outs under the microscope indicated that the chips were removed along their longer axis (Fig. 31 a-b) and were ground-facetted longitudinally.

Fig. 30. Example of a dinolite USB digital microscope.

The evidence for creating a faceted side is clearly found on the surface of the drills in the form of striations due to various angles of grinding on a harder surface (Fig. 31 c-e).

Further, it can be observed that these striations do not follow any regular pattern and this indicates a grinding as per the necessity to meet the requirements of a faceted drill blank. The presence of a stone fragment with negative grooves from Dholavira (Fig. 32) also suggests its usage for grinding drills, most probably of ernestite.

The USB microscope was also utilized to investigate the nature of unworked tip of drill bits, with a chipped-flat edge (Fig. 33a), a raised edge (Fig. 33b), a faceted edge having triangular cross-section (Fig. 33c), and a pointed tip with prismatic cross-section (Fig. 33d). That the tip of drills was grounded and fashioned to have a desired shape (Fig. 33e) is clearly understood through the microscopic analyses, which could not have been observed through the naked eye.

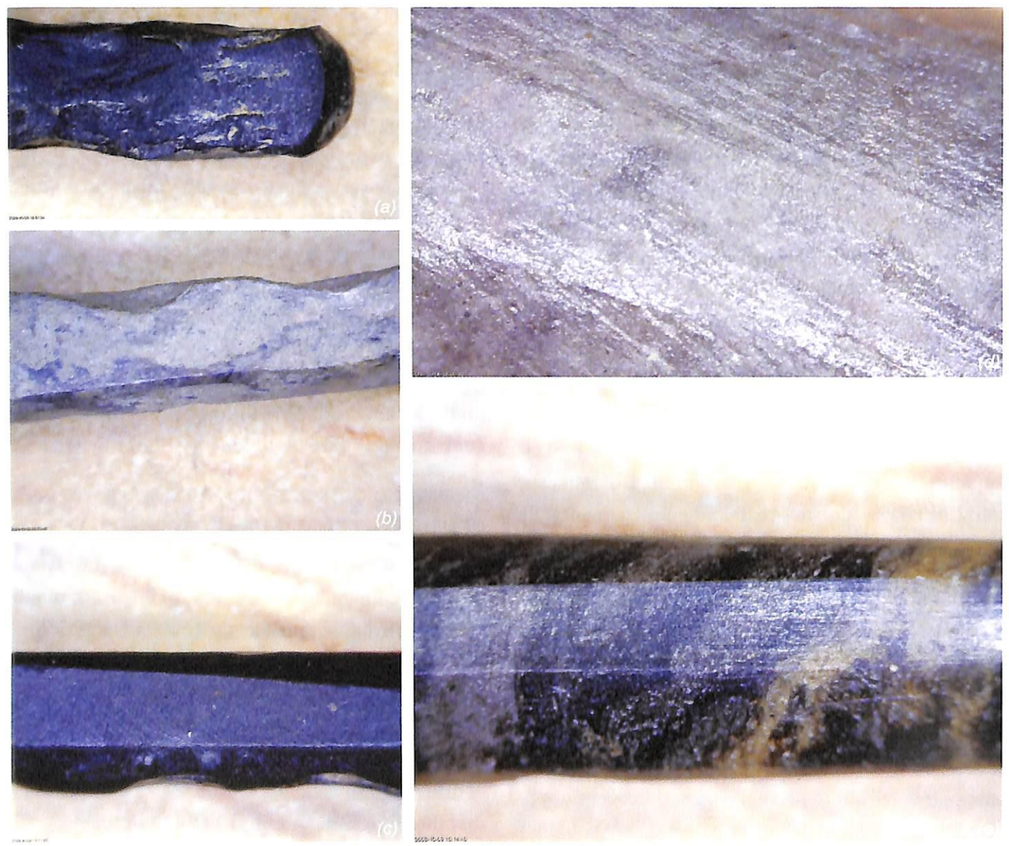


Fig. 31. Drills showing removal of chips (31a: Drill No. 122k; 31b: Drill No. 1325) and grounded surface and facetted profile (31c: Drill No. 3112; 31d: Drill No. 105 and 31e: Drill No. 4420).

Fig. 32. Grinding stone for shaping the ernestite drill bits, Dholavira.

It is also indicative from the microscopic examination that the shaft of the drill might have been fashioned with a faceted cross-section in order to have a clear grip with the hafting tool. Some of the drill shafts also display deliberate chipping on at least two facets (Fig. 33f). The rough edges thus created could have facilitated a firm grip with the hafting tool in order to have a smooth drilling of beads.

The investigations of the tips of drills also provide very good evidence of surface modifications

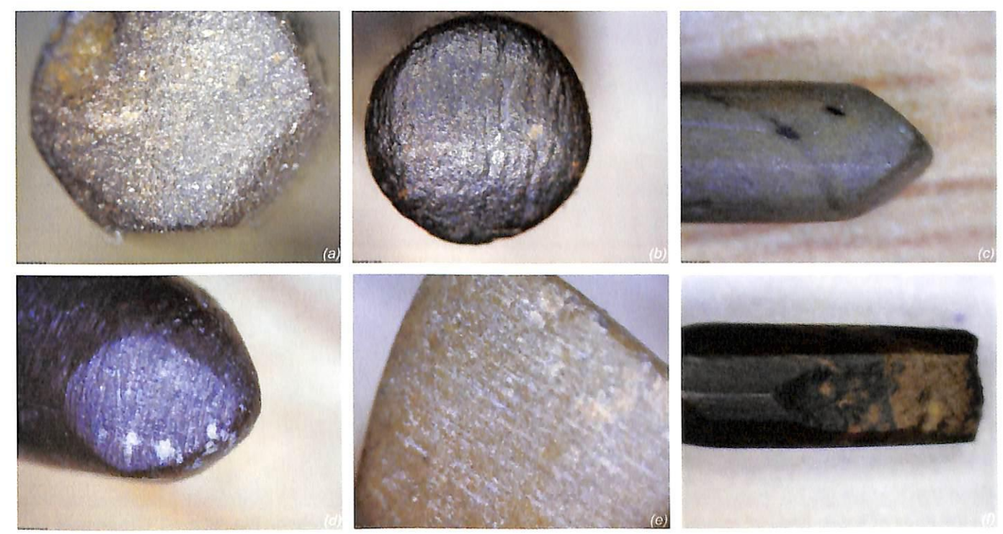


Fig. 33. Drill tip with flat edge (33a: Drill No. 4144); raised edge (33b: Drill No. 3113); faceted with triangular cross-section (33c: Drill No. 4832); pointed with prismatic cross-section (33d: Drill No. 3205A); showing purposeful grinding to fashion the desired shape (33e: Drill No. 4832); removal of chips to facilitate hafting (33f: Drill No. 26170).

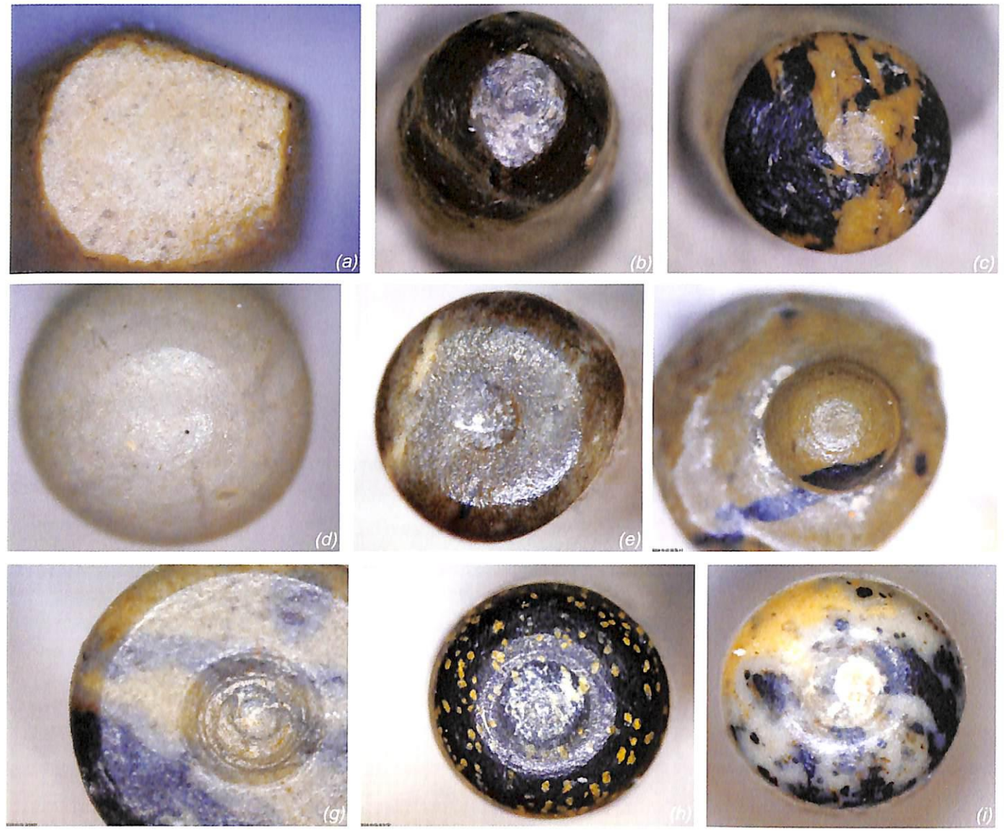


Fig. 34. Drills with different tip profiles, Dholavira
34a: Flat tip (Drill No. 1178); 34b: Truncated ground (Drill No. 4170); 34c: Truncated ground approaching a convex ground (Drill No. 10515A); 34d: Convex ground (Drill No. 1999); 34e: Dimpled (Drill No. 116 (1999)); 34f: Nippled (Drill No. 1490F); Dimpled tip profiles (34g: Drill No. 4093; 34h: Drill No. 4762 (2002); 34i: Drill No. 9400B).

as a result of a to-and-fro drilling mechanism. Surface modifications could also be due to the intensive heat emanated while drilling. The surface of the drills also underwent wear and tear during the course of surface modifications, some of which could be seen clearly under a microscope. The order in which the formation of these different tip profiles happened is yet to be understood clearly due to the absence of a detailed experimental analysis of ernestite drill manufacturing as well as the drilling of agate beads. The different surface modifications of the tip that have been noticed and documented are flat, truncated ground, convex ground, nippled, and dimpled (Fig. 34 a-f). From the analysis of drill tips, it is also surmised that the dimpled tip could be the final stage of a continuous usage of drill before it is broken/snapped (Fig. 34 g-i).

The drill record from Dholavira indicates nearly 60% of broken drills and, therefore, provides several examples of breakage at the tip point when the dimpled stage is reached (Fig. 35 a-c). The breakage happening while the tip profile is a dimpled one is an indicator that this profile was produced probably at the end of the one lifetime of a drill

bit. The drills, after breakage, were then grinded again, re-fashioned and re-used. The microscopic analysis also helped in understanding the imprints of internal dynamics from rotary motion of drills inside the bead holes in the form of deep striations, both clockwise and anti-clockwise, tallying with the similar movement of drills (Fig. 35 d-f). The breakage of spalls starting from the tip portion and proceeding in a radial pattern along the length of the drills indicates the event while it is in use in a rotary motion (Fig. 35g). The evidence of breakage at the central portion of the drills indicates a sudden snap, caused again by the rotary motion of the drills, the snap being due to the intense pressure on the drills, which is stuck inside the bead holes along with byproducts of drilling and abrasives (Fig. 35 h-j).

IMPLICATIONS AND SCOPE OF DETAILED DOCUMENTATION OF DRILL BITS

The foregoing discussion on the detailed documentation and analysis of drill bits based on a coding system and methodology catering to the specific needs of a category of artefacts from archaeological records indicates the success of such analysis. The development of recording system, a pioneering effort of J.M. Kenoyer has helped in understanding various parameters of an artefact category, in this case ernestite drill bits from Dholavira. The recording and analysis is further important due to the availability of a large number of a specific type of artefact. The presence of 1,588 ernestite drill bits from a single site itself adds to the importance of this material, that too if it is not available even in hundreds from contemporary

Fig. 35. Various stages of breakage patterns observed on the dimpled tip profiles of drill bits, Dholavira
(35a: Drill No. 9237; 35b: Drill No. 9857A; 35c: Drill No. 6229); Dimpled tips showing striations due to drilling action (35d: Drill No. 2239; 35e: Drill No. 3801; 35f: Drill No. 12364); Broken spalls which move in a radial pattern (35g-h: Drill No. 9857A); Drill bits broken at the shaft portion (35i: Drill No. 12390; 35j: Drill No. 4192; 35k: Drill No. 3425[2000]).

urban centres, much larger than Dholavira. It also implies the mastery over this particular technology by the Harappans, that too from the Gujarat area.

An attempt has been made to analyze the drills of Dholavira in terms of statistics, typology, and surface morphological changes happening due to the drilling mechanism. The methodology evolved by Kenoyer has been adopted here for the description of morphology of the drills, classification and coding, taking various measurements. A total of 1,603 drills were recorded and documented, which included 12 of chert, two of vesuvianite, one of agate and 1,588 of ernestite. An overwhelming preference for ernestite drills can be observed. The collection at the National Museum, New Delhi, could not be taken up for analysis. The spatio-temporal analysis indicates that the bead manufacturing industry using ernestite drills was dominant during stages IV and V in the Middle Town locality. The Middle Town at Dholavira thus comes up as a clear manufacturing hub of beads of various kinds.

The broad drill types noticed consist of cylindrical, tapered cylindrical, constricted cylindrical, re-used, re-sized and pointed drills. Only one specimen of pointed drill type is noticed in the collection. Chert drills are also very few in number; hence the findings are not repeated here. The break-up of the ernestite drill types is as follows: tapered cylindrical (55.9%), cylindrical (22.5%), constricted cylindrical (19.4%), re-used (1.6%), re-sized (0.4%), and pointed (0.1%). Of these, 39.4% are complete drills, while the remaining 59.6% are broken and incomplete. The larger percentage of broken and incomplete drills is a clear indication of industrial waste.

Of the drills, 40.2% do not have tips; they are either broken or partially broken. The dimple tip variety dominates, which has a presence of 23.6%, followed by convex ground tip (12.4%), truncated ground tip (5.6%), nippled tip (5.8%), and chipped flat tip (4.5%). The other types such as chipped convex, convex faceted, flat bevelled, dimple bevelled, dimple–nipple and faceted represent a very small percentage. The larger percentage of broken tips as well as dimple tips clearly shows that 63.8% of the drills were extensively used and might have been discarded when rendered inoperative.

The maximum length of the complete drills varies from 6.07 mm to 45.11 mm. Out of the 1,588 drills, 625 drills are complete. The width of the drills varies from 1.245 mm to 6.885 mm with a mean of 2.861 mm. Bit lengths in case of 656 drills are complete, which range from 2.44 mm to 45.11 mm, with a mean of 8.43 mm. Evidence of a clear tip could be noticed in the case of 940 drills with the tip width varying from 0.79 mm to 5.37 mm, with a mean of 2.4 mm.

The study also indicates that the prominent working areas were complemented by the presence of bead workshops. The large collection of drills with evidence of re-used and re-sized ones indicates large-scale utilization of ernestite material even to its smallest possible level, possibly due to its rarity and the fact that it is a remarkable drilling tool when compared with other stone drills. The morphological studies with the aid of a microscope were most revealing in understanding the various stages, starting from the manufacture of drills to its usage and discard.

Thus, the detailed documentation, recording, and the microscopic and statistical analysis of the drill bits of Dholavira has helped in understanding the various drill types, their sub-variants, tip types, bit and base lengths, as well as tip, base and proximal widths. This has so far been the most comprehensive and exhaustive analysis of ernestite drill bits from any Harappan site, which is also helped by the fact that Dholavira has the distinction of yielding the largest collection so far from any excavation of Harappan sites. Detailed documentation on similar lines from other excavated sites in Gujarat may help in arriving at a holistic picture of the entire bead manufacturing technology of the Harappans.

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NOTE

1. The preliminary analysis of 1202 drills was published as a joint paper in *Man and Environment* 37(1): 8-25, and has been partly reproduced here.

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Antiquity of Semi-precious Stone Beads from Deccan

Rabindra Kumar Mohanty

Ornaments and ornamentation have a long cultural past; they manifest personality, beautification, technological attainment and human appreciation along with a sense of possession. They are used to enhance and also satisfy the natural instinct of human beings to look beautiful. Ornaments found in archaeological contexts help in understanding the use of different type of ornaments, material used, manufacturing technique, preference as well as the individual ideology and aesthetic sense of the user of the period. They also highlight the contemporary socio-economic conditions, even religious connotations, trade and exchange systems, prevailing social norms and appreciation of a particular period. Besides these aspects, ornament and ornamentation have very wide perceptions.

Among the adornments and decorations, beads made of both organic and inorganic materials have fascinated the human imagination from a very early stage of human civilization. A bead, as we understand, necessarily must have a perforation to be hung or sewed or stringed. The shape or the presentation requires a presentable and appealing feature, except the ones used for occult purposes. Hence, the most important aspects of bead production revolved around the nature of raw material, their visual appearance, their socio-cultural relevance, the technological advancement of the period that included the ultimate external fashioning and the way a bead could be perforated. Among all these aspects, to make a hole or perforation by drilling or punching remained a nagging point