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Early Beadmakers of the Indus Tradition
The Manufacturing Sequence of Talc Beads at Mehrgarh in the 5th Millennium B.C.

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ABSTRACT

This paper presents a reconstruction of the techniques used by the ancient beadmakers of Mehrgarh (Pakistan) in the 5th millennium B.C. for the production of 'steatite' (talc) disk beads. The raw material was identified through scanning electron microscopy with electron microprobe (SEM-EDA) and X-rays diffraction (XRD). The methods used in the paleotechnological reconstruction include optical microscopy and scanning electron microscopy (SEM) on archaelogical blanks and beads, experimental simulations of the whole manufacturing sequence, and scanning electron microscopy on experimental items. For the experiments were used modern stone samples from Pakistan. The proposed reconstruction is supported by a good match between the micromorphological features of the blanks and beads from Mehrgarh and those observed in the modern experimental items.

Introduction

In the protohistory of the Indus region steatite disk beads are very distinctive artefacts, relatively common from early chalcolithic times to the beginning of the 2nd millennium B.C. Steatite, a commercial term commonly used by archaeologists for different varieties of massive talcose rocks, was perhaps the favourite medium for the jewellers of the Harappan phase of the Indus tradition (about 2600-1900 B.C.) (Vidale 1984; 1989; 1989a). Today, although in simplified forms and in very specific cultural contexts, the making of beads of soapstone or steatite (i.e. rocks with talc and chlorites) still survives in Sindh and Baluchistan, and may be considered one of the traditional industries of the Indo-Pakistani subcontinent (Vidale & Shar 1990).

In 1987 J.F. Jarrige, Director of the French excavations at the site of Mehrgarh (Fig. 1), with his usual courtesy provided me with a sample of steatite debitage from the site of MR 4, datable to early chalcolithic times, i.e. to the 5th millennium B.C. (Fig. 1). The sample included about 300 specimens of steatite blanks, most of which defective, and broken disk beads, evidently left or discarded by one or more craftsmen in a single spot. According to information from the French colleagues and to the published photographs (Jarrige 1981: fig. 4) the sample I studied is a selection focussing on disk bead blanks and beads, whereas the steatite flakes, the larger lumps and part of the roughouts originally associated were not represented. Furthermore, the sample did not include remains in other materials such as flint and shell, reportedly included in the original collection.

As far as I know, this find represents the earliest archaeological evidence of an intensive bead making activity in South Asia. In a regional perspective, the sample offered a precious occasion for observing in detail some aspects of this industry in the early stages of its evolution: a 'technological window' opened on the first forms of interaction between craft specialists and economical power in the protohistory of the Indus basin.

The Activity Area

The beadmaking debitage was found within a single deposit, nearby one of the compartmented buildings distinguishing the neolithic and early chalcolitic architecture of the settlements of Mehrgarh (Figs. 2-3). The building is so described by the excavator:

> [...] ten narrow compartments symmetrically arranged on either side of a central corridor with an additional small room added against the south wall of the complex [...]. The walls of the structure are made of hand-formed bricks, slightly convex in section and rather irregular in size. Overall, the building techniques are very similar to those in the nearby neolithic settlement and different from those of later periods where mould-formed bricks were used. Although the walls are preserved in some parts of the structure to a height of one meter, there are no traces of doorways. The compartments themselves are too small and narrow to have been used for habitation and there is no sign of any domestic activity having been carried out on them [...]. That this building was a granary is an inference supported by the recovery from the compartments of a large number of impressions in clay of wheat grains. In addition, in one chamber were found sickles made of three bladelets each, shafted in a slantwise fashion and set in bitumen. (Jarrige 1981: 97).

East of the structure the excavators discovered a concentration of various types of charred seeds, among which cotton, possibly collected or cultivated for their oil or fibers. In the open area facing the eastern wall were also found piles of bones and burnt pebbles mixed with ash; this deposit contained not less than one hundred bone awls, and other awls were found in the immediately surrounding areas. As suggested by the recovery of one stone sharpener '[...] bone tools were made and used in this area, possibly for working hides' (*ibid.*: 97).

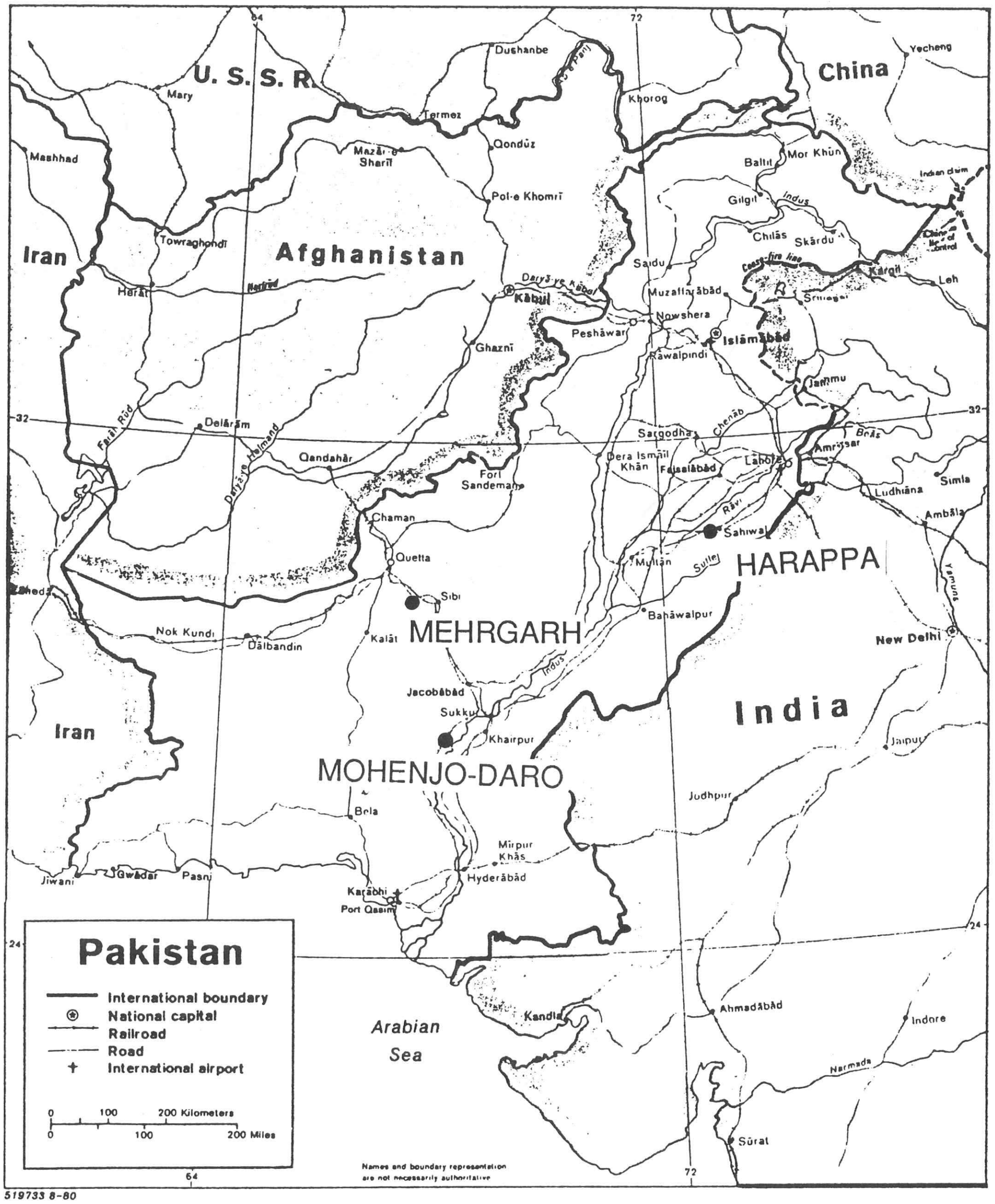


Fig. 1 - Map of the Indus region showing the location of Mehrgarh and other sites mentioned in the text.

Fig. 2 - The compartmented building associated with the steatite activity area of MR2 (courtesy of J.F. Jarrige and R. Meadow).

The beadmaking area was found against the southern wall of the building, in Locus XV. It was formed by a single deposit extending approximately for 4 to 6 sq.m. (R. Meadow, personal communication). The pictures taken during excavation show that the industry was contained within a hard-packed clayey-silty matrix characterized by polyhedral fracture. Always in the words of the excavator, this deposit is described as

> [...] the remains of a workshop where steatite was cut and worked into beads and other objects. Along with the flint drills and flakes used by the craftsmen were recovered several hundred mostly broken or unfinished beads together with beads of dentalium and other shells. The one columella of the sea shell Fasciolaria trapezium found in this workshop is the sole example of a type of shell found in great quantities in a previous sondage made nearby [*ibid.*: 97].

The association of steatite and shell beads suggest that the craftsmen could have produced ornaments with 'black-and-white' alternating beads (see also Vidale 1989a). The production in early chalcolithic times of this type of necklaces required the maintenance of trace relationships capable of furnishing the inland centers of raw material both from the mountain areas of Baluchistan and the sea coasts.

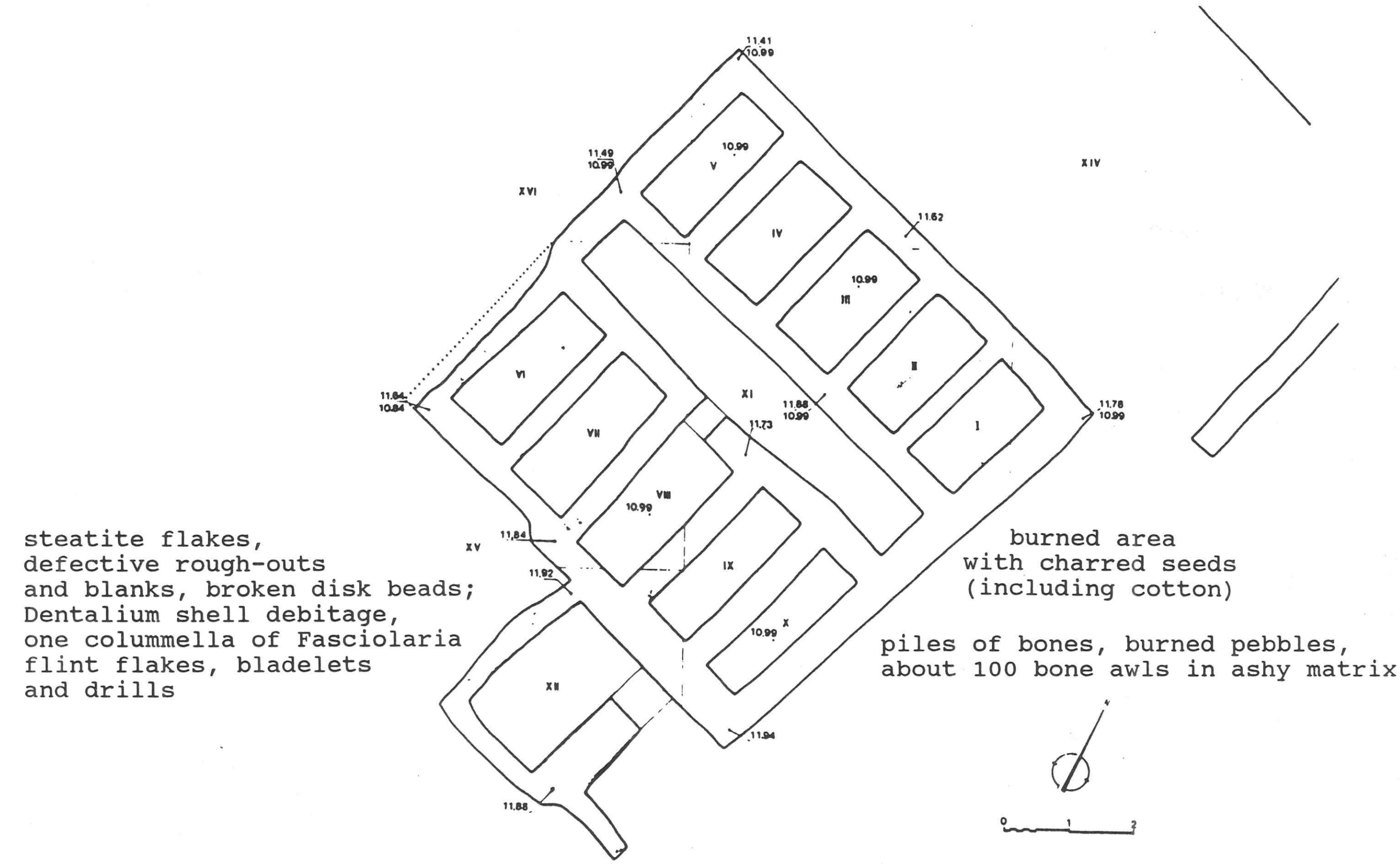


Fig. 3 - Sketch map of the compartmented building with the nearby archaeological finds (from Jarrige 1981).

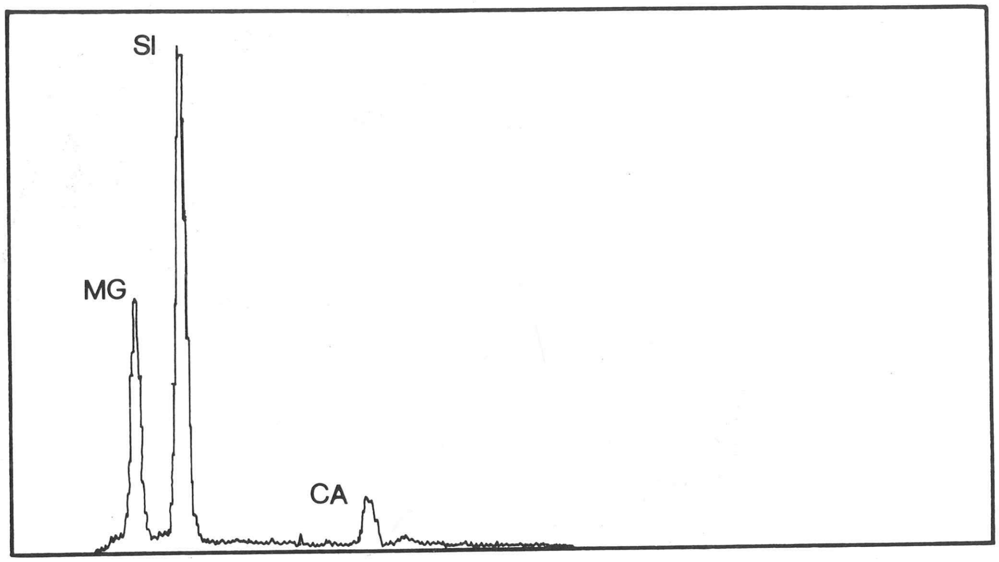


Fig. 4 - SEM-EDA spectrum with peaks of silicon, magnesium and calcium (a rough-out from the activity area).

We may presume that such a homogeneous layer of steatite and shell debitage was dumped or stored and finally abandoned in an open area somehow managed by the same people using and controlling the storage facilities of the compartmented building. The storage building, together with another identical structure excavated at north, seems to have been bounded by other architectural features, and this could support the impression that access to this area was somehow restricted or controlled. The debitage could have been buried intentionally (but this seems unlikely, given the noticeable extension of the deposit), or it could have been sealed by alluvial episodes and/or mudbrick decay processes. The presence of some well defined, individual clusters of objects referable to different crafts would point towards forms of hoarding more than to the localization of specialized dumping areas; but, most probably, the homogeneity of these industrial deposits also depends upon particularly fast dynamics of sedimentation and burial.

Whatever the formation processes of the activity area might be, two factors are stressed in the original report: the presence of spatially segregated piles of raw material and manufacturing residues referable to various industries (steatite and dentalium shell bead making, manufacturing of Fasciolaria shell ornaments, production of bone awls), and the close spatial correlation of these deposits with storage facilities for agricultural goods and tools. Whoever controlled agricultural product was also able to monitor, at least partially, different types of crafts and supplies.

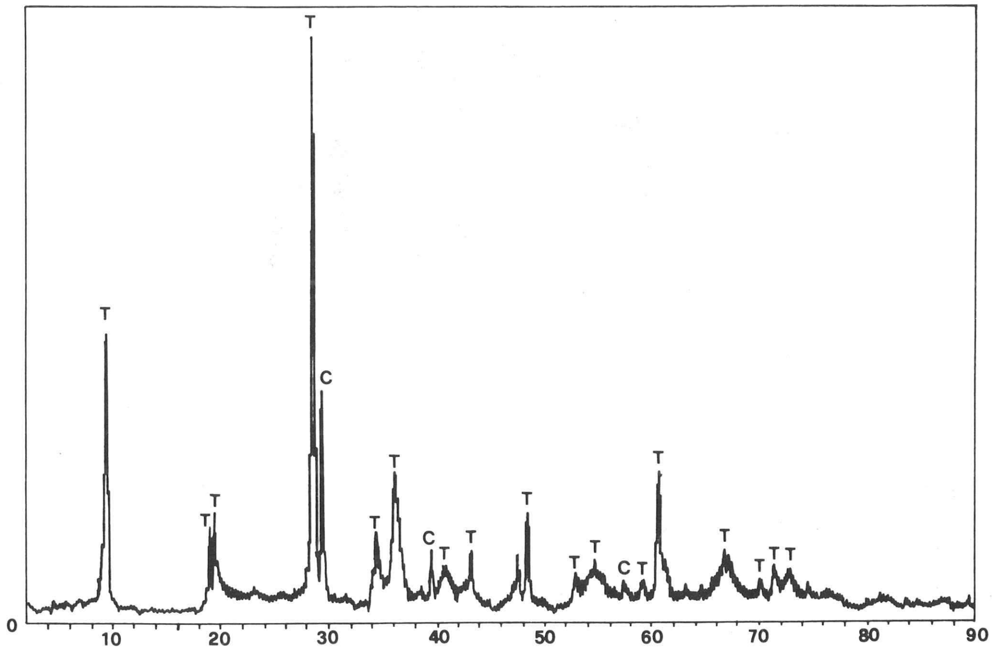


Fig. 5 - XRD spectrum showing peaks of talc (T) and calcite (C) (a rounded bead from the activity area).

Raw Material

All the unfinished blanks, beads and residues found in this activity area belong to a single variety of 'steatite'. The stone is greenish to dark grey, very homogeneous and compact, and only slightly greasy at the touch. The thicker specimens show sometimes a thin layered inner structure. 53 samples of this material were analysed and compared with a preliminary series of 23 samples of so-called soapstones from various parts of Pakistan, both archaeological stone residues and ethnographic items. All the samples were analysed with scanning electron microscopy and microprobe (SEM-EDA) and later with X-rays diffraction (XRD). The samples were cleaned in aceton and with an ultrasonic cleaner to avoid soil contamination.

Analysed with SEM-EDA the samples from Mehrgarh showed peaks of silicon, magnesium and calcium (Fig. 4). The high peaks of silicon and magnesium indicate that the stone is talc, $H_2Mg_3(SiO_3)_4$. The XRD spectra have a good correspondence with PDF 29-143, Talc, and show that calcium is present in form of Calcite ($CaCo_3$) (Fig. 5). The presence of Calcite probably renders this stone slightly harder than the common Talc (1 on Mohs scale).

The other samples from Pakistan I analysed turned out to represent a wide range of rocks and minerals (from pure Talc to Talc with Dolomite, Quartz spinels and minerals of the Serpentine group), for the moment the association of Talc and Calcite was found only in the stone from Mehrgarh. It will be interesting, in future research, to determine if this material might have a more restricted source area of the other talc-bearing rocks of Baluchistan (Vidale & Bianchetti, forthcoming).

The Product

Judging from the specimens broken or abandoned in the last stages of manufacture included in the sample, the range of beads produced in the activity area is almost exclusively limited to a single type of tiny disk bead (Fig. 9). The diameter of the specimens range from a maximum of 11.69 to a minimum of 4.21 mm, with an average value of 6.35 mm (see Appendix B, Table 6). The distribution of the diameter values (always for the finished or almost completed specimens) shows that the beads might fall in two groups, one with diameters between 4 and 6 mm, the other ranging around 7 (see Vanzetti & Vidale 1994). Specimens larger than 9 mm are very rare. All the beads are thinner on one side and thicker on the other, i.e. they have a trapezoidal section: the average maximum thickness is 1.03 mm, the minimum thickness averages 0.89 mm. Disk beads of this type might have been worn in anklets, necklaces or bangles, as they could have been secured to cloth and garments, for embroidery works. Funerary evidence from Mehrgarh and from the later cemeteries of the Harappan phase (2600-1900 B.C.) support the first reconstruction.

The only other type of bead is a carefully shaped flat sub-rectangular element with concave sides, bearing a series of 6 bipolar perforations regularly spaced on its surface (Fig. 9). This unique piece might be a spacer for assembling necklaces with multiple string of beads or another type of ornament.

Study Methods

My goal was to learn as much as possible on the production of early chalcolitic steatite disk beads at Mehrgarh in terms of stages and techniques of manufacture. The first step was a classification of all the items included in the sample. This classification was based on a detailed observation and description of each object, effected at the optical microscope. All the objects were then measured with a 2 decimals digital caliper and the data entered in a database. The debitage showed an evident process of transformation of the beads from polygonal blanks to progressively smaller rounded elements. As a consequence, blanks and beads were divided in groups following the partially empirical criterion of their relative degree of roundness as well as according to the presence-absence of some critical technological features.

In this paper, I shall first describe the morphological-paleotechnological groups resulting from the classification of the industrial debitage. In the following sections, I shall discuss different types and degrees of manufacturing traces around the edge and within the perforation of the beads. This evidence will be used to support the reconstruction of the manufacturing sequence. In this stage, optical microscopy was integrated by SEM micromorphological observation. All counts for morphological-paleotechnological groups and internal indicators are reported in form of tables in Appendix B (see below). It should be kept in mind that such a description in two stages (first by paleotechnological groups, and then by manufacturing wear traces) does not reflect a research path, but represents a conventional, simplified way to explain the progressive transformation of the beads.

The hypothetical reconstruction of the manufacturing sequence was then tested with an experimental simulation of the whole process. As raw material for making disk beads I used a group of modern Talc from Pakistan, currently used all over the country as school drawing chalks. Other materials used in the experiments include a fine-grained sandstone slab, a hand-powered drill with a chert point, and a bundle of rough hemp fibers. All materials were kindly provided by J.M. Kenoyer, University of Wisconsin, Madison, who also assisted me with information and advice.

The beads so obtained, in various stages of transformation, were observed with SEM to compare their micromorphological features with those observed in the archaeological specimens.

Morphological-Paleotechnological Groups

In this section are enlisted and described the morphological-paleotechnological groups in which the sample was subdivided. The order in which the various groups are discussed roughly corresponds to the progressive transformation of the pieces from polygonal blanks to the final rounded beads.

Unbroken Unperforated Polygons (UUP) and Fragmentary Unperforated Polygons (FUP)

These two groups (Figs. 6, 10) together amount to a small percentage of the total (4.5%) and include bead blanks lost before perforation (UUP) or blanks probably broken in grinding (FUP). The diameter of the blanks ranges from a maximum of 10.80 to a minimum of 5.64 mm, with an average of 7.87 mm; the thickness values average 1.33 (maximum) and 1.11 (minimum) mm.

Some information on the shape of the blanks and the original rod-blanks may be gathered considering UUP and FUP together with the groups including blanks which did not undergo the rounding process (PEP; PDB: see below). Their shape may be described, in the majority of the cases, as irregular polygons (55%) and regular polygons (17.5%). In the other cases, they are elliptical or not determinable. Within the small group of well preserved polygonal blanks of the sample, most frequent appear to be octagonal and hexagonal specimens (amounting respectively to about 50% and 25%) (see Appendix B, Table 2).

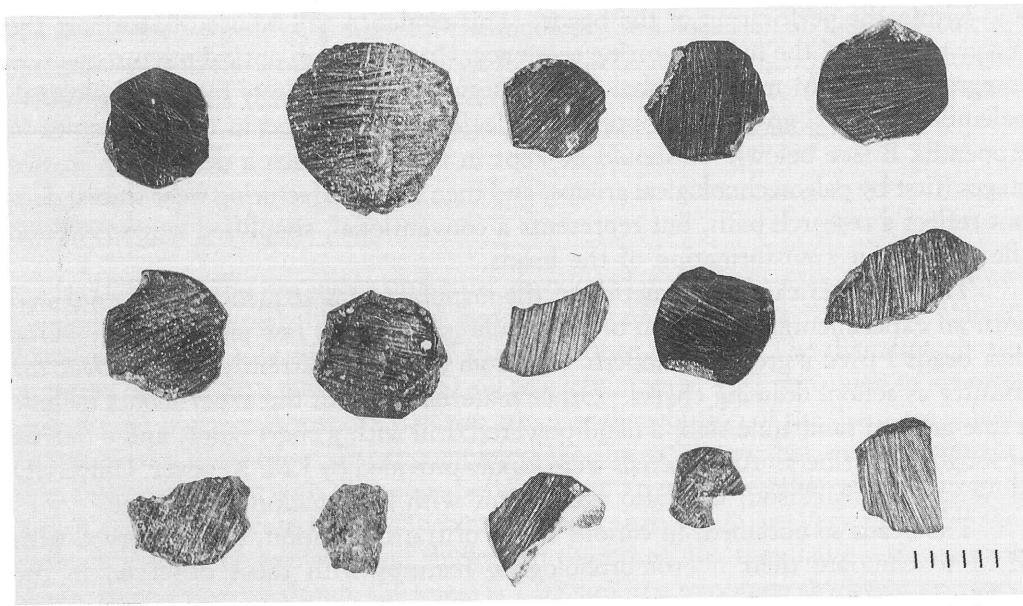


Fig. 6 - Unbroken Unperforated Polygons (UUP) and Fragmentary Unperforated Polygons (FUP) (Dep. CS. 16893).

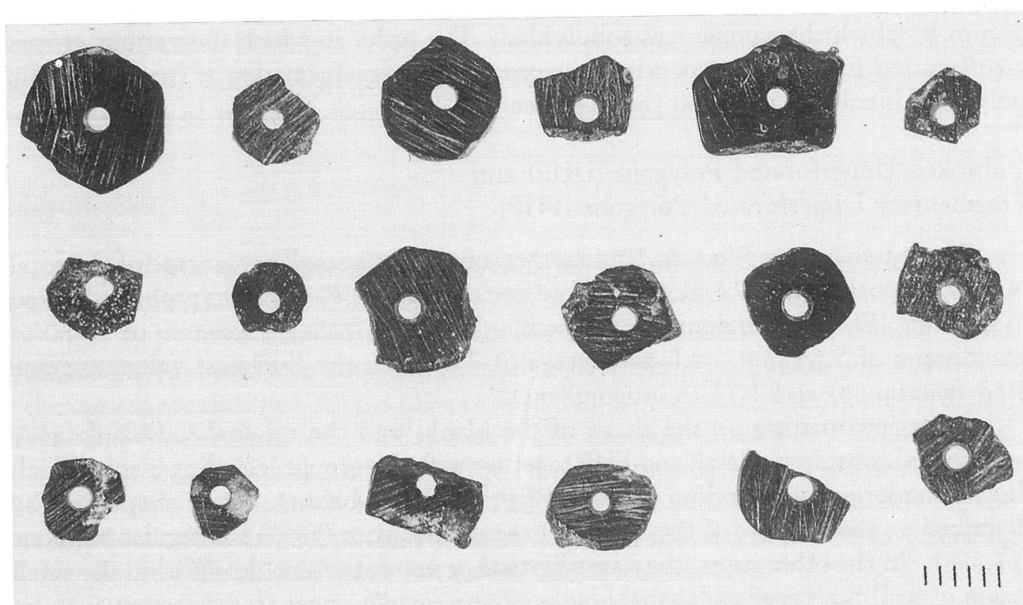


Fig. 7 - Perforated Polygons, from unbroken to slightly damaged (PEP), and Perforated Polygons with missing edges (PME).

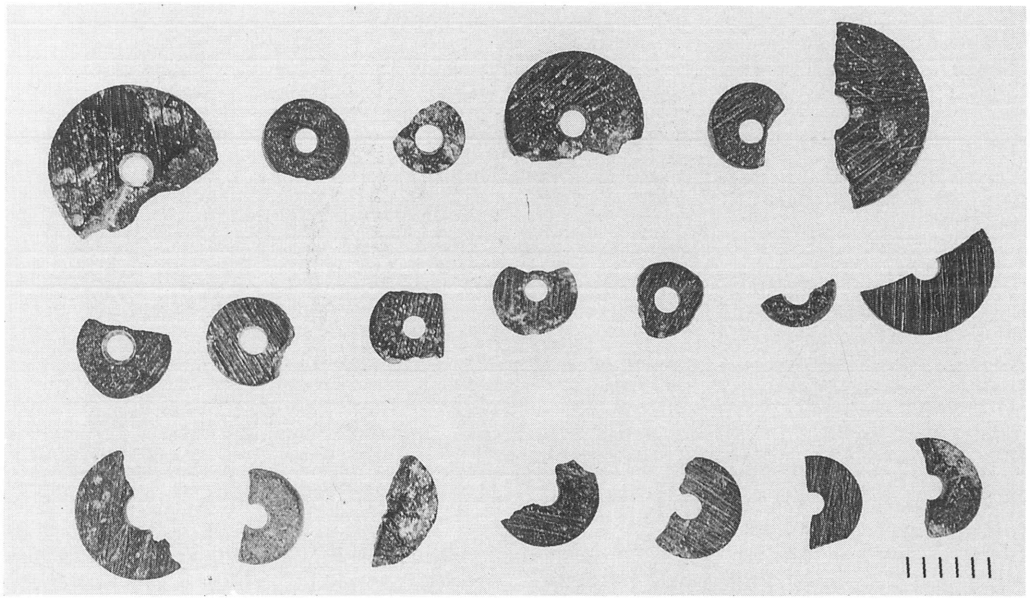


Fig. 8 - Sub-rounded Split Perforated Elements (SSP) and Rounded Split Perforated elements (RSP).

Perforated Polygons, from unbroken to slightly damaged (PEP) (Figs. 7, 11);
Perforated polygons with Missing Edges (PME) (Fig. 7);
Polygons with Defective Bipolar perforation (PDB) (Fig. 13)

These three groups include mostly polygonal blanks discarded or lost after perforation (PEP), a few specimens of perforated polygons badly damaged at the edges, perhaps after the beginning of the rounding process, and a single polygonal blank discarded after a defective bipolar perforation (the two drill holes did not meet: Fig. 13) (PDB).

Split Perforated Polygons (SPP);
Split perforated Polygons with Cutting marks (SPC) (Fig. 12)

Amounting to about 50% of the total, SPP represents the largest paleotechnological group in the assemblage. It is formed by polygonal blanks broken in drilling or during the earliest stages of the ensuing rounding operations. The group SPC includes two specimens of perforated polygons bearing on the surface clear traces of a transversal cut, probably traced with a flint (?) blade. This feature may be intentional or it may represent the byproduct of another operation, and its meaning is presently unknown. A hypothesis is that, as the cut crosses the center of the blank and the hole, it might represent a form of guide-groove for drilling. The average diameter of split perforated

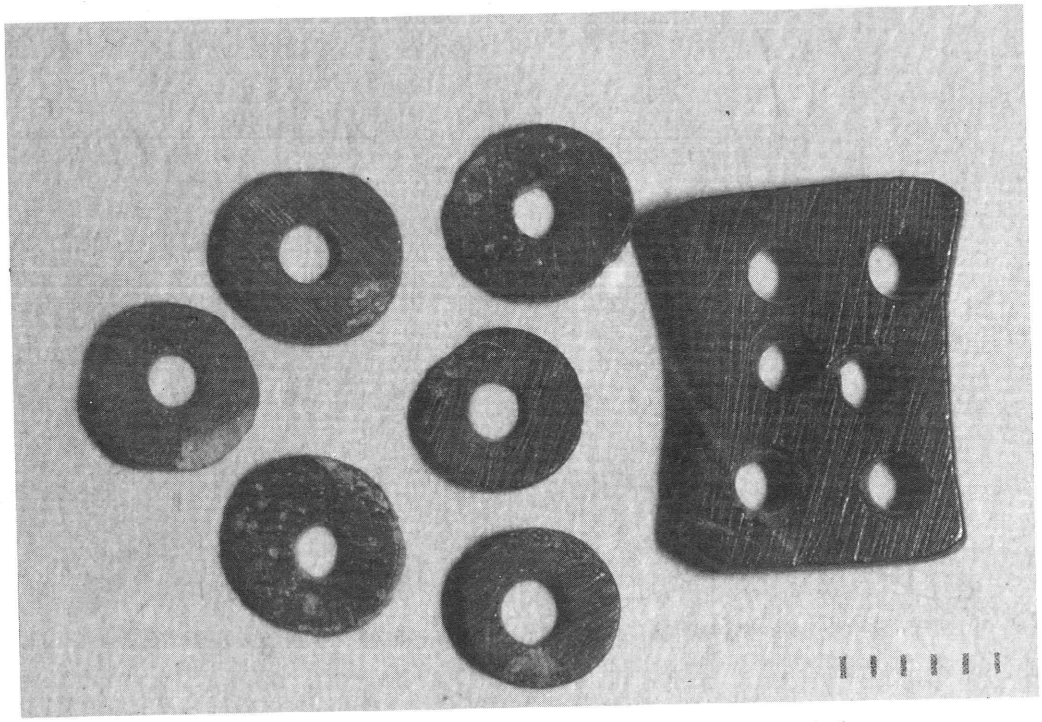


Fig. 9 - Perforated Rounded elements (PRE) and multiple 'spacer' element.

polygons (SPP + SPC) is 7.35 mm; maximum and minimum thickness of the specimens classified as PEP, PME, PDB, SPP and SPC are respectively 1.30 and 1.10 mm.

Sub-rounded Split Perforated Elements (SSP) (Fig. 8)

This group includes a set of blanks (12.7% of the total sample) evidently broken during some advanced stage of the transformation from the original polygonal shape into the final rounded bead. They still show a polygonal contour, while the corners between the facets appear to a great extent smoothed. The average diameter of the blanks belonging to this group is 7.01 mm, the maximum thickness 1.20, while the minimum thickness is 1.01 mm.

Perforated Rounded Elements (PRE) (Fig. 9);
Rounded Split Perforated elements (RSP)

This last set includes finished beads, lost or abandoned as low-quality or defective product (PRE) and a consistent number of beads most probably broken during the last stages of the rounding operation. In these specimens every evidence of the original polygonal blank is lost, and the form of the disk bead is often extremely regular. The dimensional features of the finished product were discussed in a previous section.

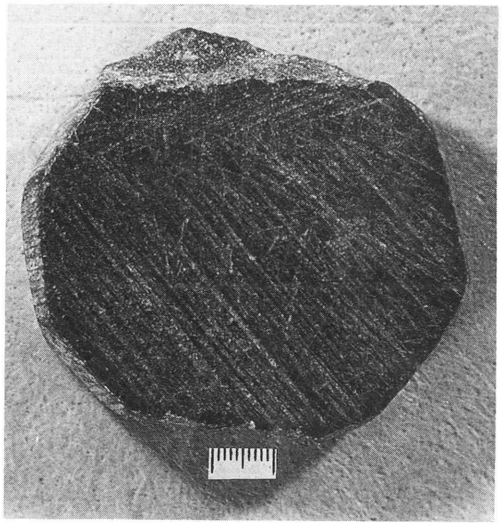


Fig. 10 - Polygonal blank (UUP) showing detail of probable cutting marks. Scale 1 mm.

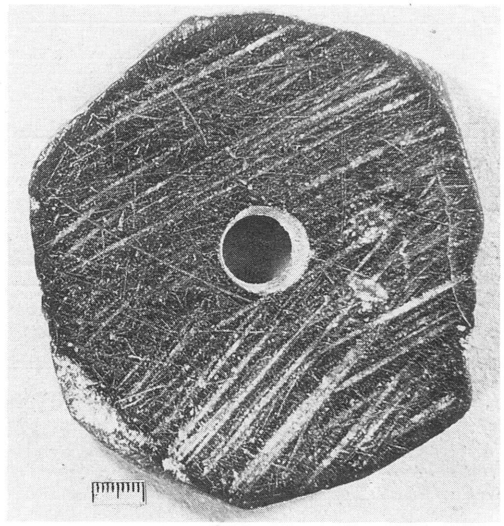


Fig. 11 - Hexagonal drilled blank (PEP). Scale 1 mm.

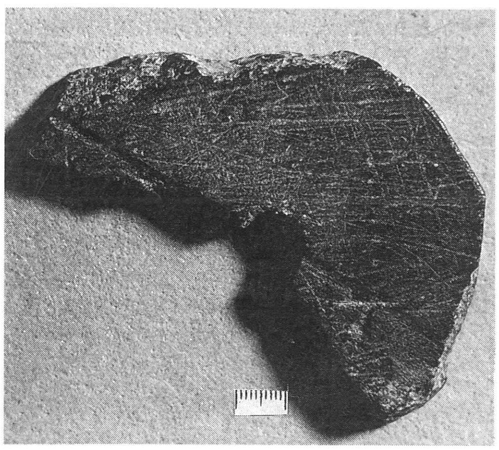


Fig. 12 - Polygonal blank with cutting mark split in drilling (SPC). Scale 1 mm.

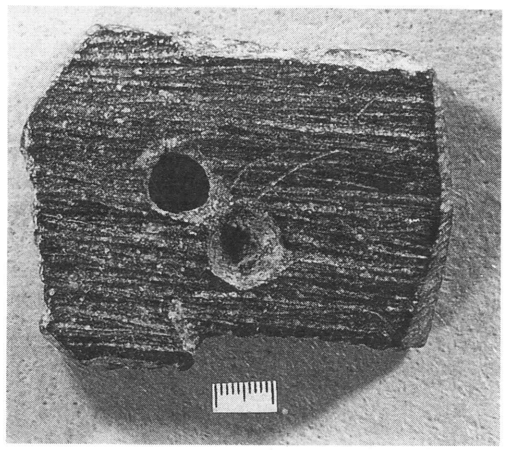


Fig. 13 - Polygonal blank with defective perforation (PDB). Scale 1 mm.

The sample also included a couple of strange blanks apparently perforated on the edge. There is no functional explanation for this feature, nor can I imagine how this excentric drilling could have been unintentionally carried out. One of these pieces is shown in Fig. 15. They were not included in the Tables of Appendix B.

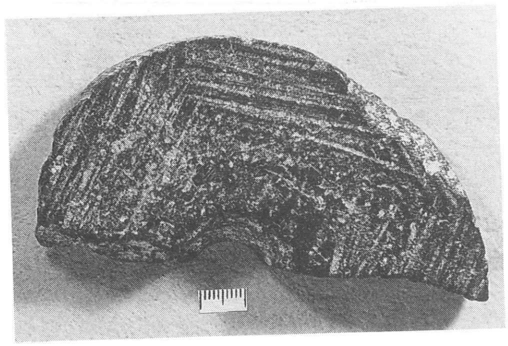
The process of dimensional reduction of the pieces in the course of the manufacturing sequence is clearly represented by the fall of average values (maximum diameter, maximum and minimum thickness) in Appendix B, Table 6.

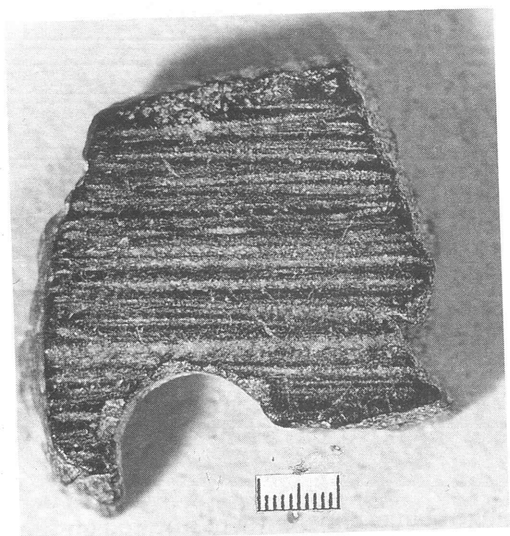
Manufacturing Traces: Micromorphological Observation

The following descriptions are based on observation at the optical microscope of each blank or bead, followed by micromorphological study of a small diagnostic sample carried out with SEM. In the following paragraphs, the term 'faces' refers to the two major parallel faces of polygonal blanks and disk beads; the term 'edge' refers to the surface of the border; 'drill hole' refers to the hole drilled in the center of the bead and to its surface features. The traces of manufacture were both three-dimensional (i.e., distinctive types of edge and drill hole) and by-dimensional (different patterns of abrasion and wear on the edge and on the inner surface of the drill hole). These features were recorded separately, with the purpose of observing the correlation between three-dimensional forms and surface patterns.

Variability of the edge across the manufacturing sequence

The study of the features of the edge of blanks and beads of the various groups described above showed the presence of 5 basic shapes or Types of edge (see Appendix B, Tables 3-4).





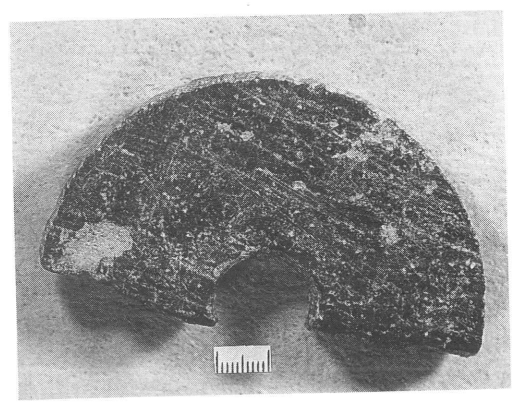


Fig. 14 - Sub-rounded element showing detail of a cutting operation carried out from three sides. Scale 1 mm.

Fig. 15 - Element with an excentric drill-hole.

Fig. 16 - Rounded bead split in drilling.

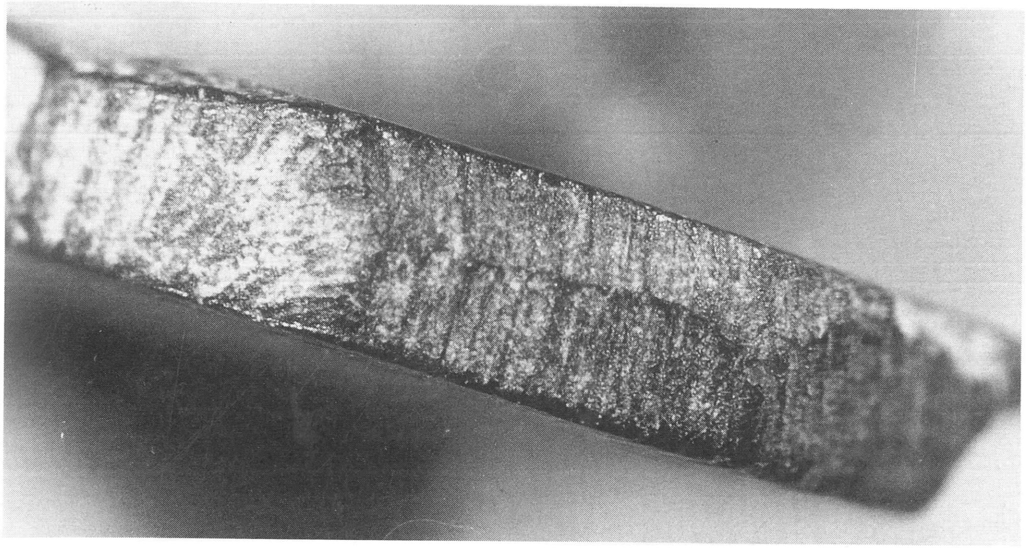


Fig. 17 - Detail of faceting on the edge of a polygonal blank (optical microscope).

Type 1. Edge with flat section. Edges with flat sections occur both on polygonal blanks, in an early stage of the manufacturing sequence, and on rounded beads, at the end of the rounding process. The surface of the edge, anyhow, shows quite different manufacturing traces in the two contexts.

Edge with flat section (on polygonal blanks: UUP, FUP, PEP). Each side of the polygon is a facet with a flat section at the edge. Such edge facets are often obliquely oriented with the two main faces of the blank. On these facets are clearly visible the parallel, coarse grooves left by grinding. The grooves make possible to define the direction of grinding. The grinding grooves run orthogonally or (in most cases) obliquely to the main axis of the facets.

These features were observed in groups UUP and FUP, where they occur together with Types 2 and 3 (see below). In group PEP, flat sections represents the majority of the cases (47.6%). In group SPP, flat sections of Type 1 are also rather common (23.5%).

Edge with flat section (on rounded beads: SSP, RSP). At the end of the rounding process, the edge of the beads, from the initial facets of the polygonal blanks, eventually change into a continuous surface with a regular, flat section. In the rounded elements, anyhow, is visible a distinctive pattern of surface abrasion, i.e. a double pattern of fine striations departing from both the faces of the bead and meeting at the center of the edge with a different angle (Figs. 18, 20-21). The diverging orientation of these striations often gives to these traces a slightly winding trend. This feature does not appear on polygonal blanks, and represents the majority of cases in group SSP and

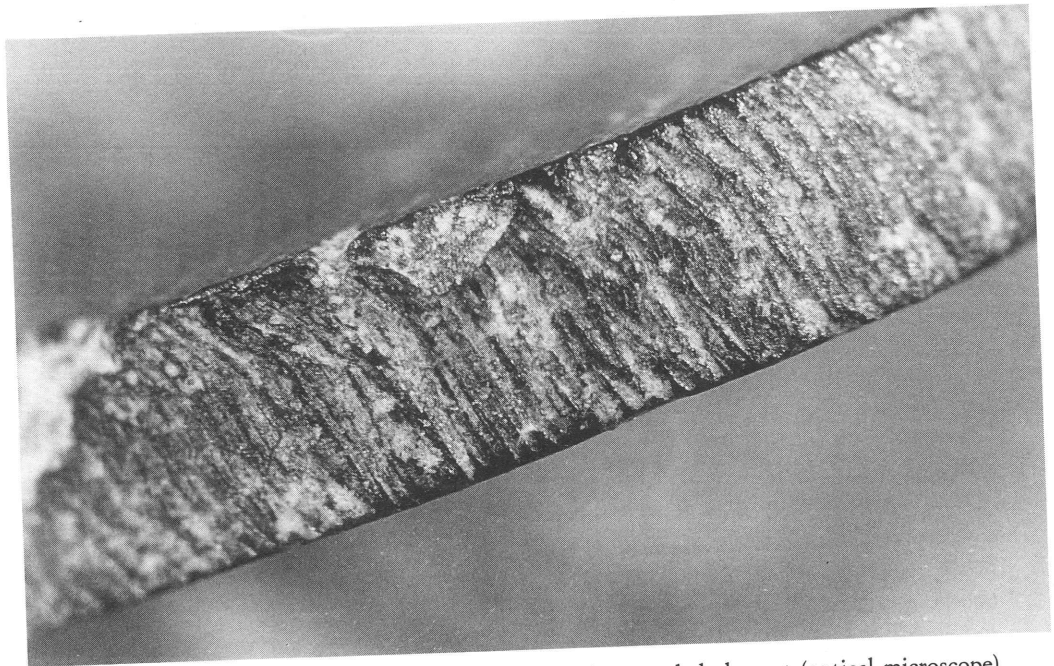


Fig. 18 - Detail of abrasion grooves on the edge of a rounded element (optical microscope).

almost the total in group RSP (the rounded beads). Flat sections with these traces were therefore considered a result of the rounding process.

Type 2. Edge with pointed section. This form was observed only in polygonal blanks. The edge, in these specimens, was often carefully shaped through a series of fast grinding operations resulting into a continuous 'faceting' of the edge of the blank. The oblique facets so obtained are often asymmetric (Figs. 17, 19), because the edge was ground from a single side. The same grinding grooves observed on the facets of Type 1 are visible on Type 2 as well. The hand micromovements required by the 'faceting' result in a higher percentage of oblique versus orthogonal grinding grooves. In a few cases, the superimposition of orthogonal and oblique grooves on the same facet show that the operation was interrupted and resumed from a different angle. The implications of the difference between flat and pointed edges are discussed in Vanzetti & Vidale 1994.

Type 3. Edge with both flat and pointed section. This type of blanks could represent a transitional stage between Types 1 and 2. Edges of this Type were found only on polygonal blanks, both perforated and unperforated (UUP, FUP, PEP, SPP).

Type 4. Edge with rounded section. This modification of the edge is rather rare, and represents an intermediate stage between Type 2 and Type 1. Few instances were observed in groups SSP (7.6% of the total of the Group) and RSP (11.2%). The surface pattern was similar to that observed on edges of Type 1.

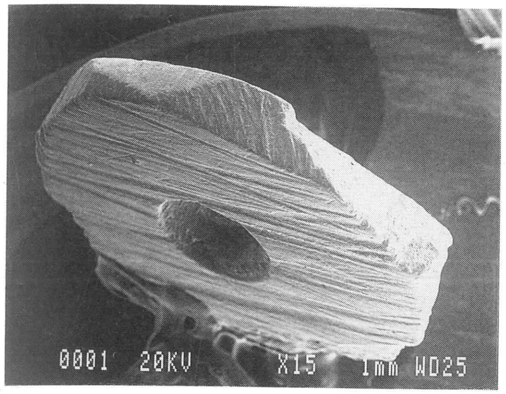
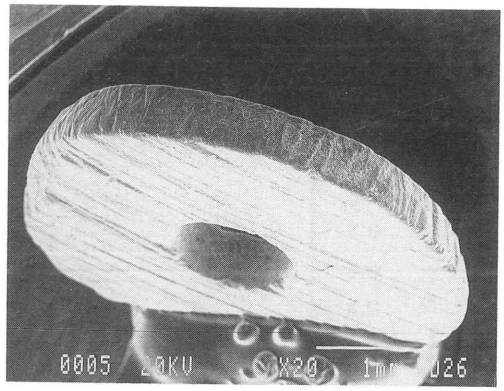


Fig. 19 - SEM image of a perforated polygon with faceted edge (X 15).



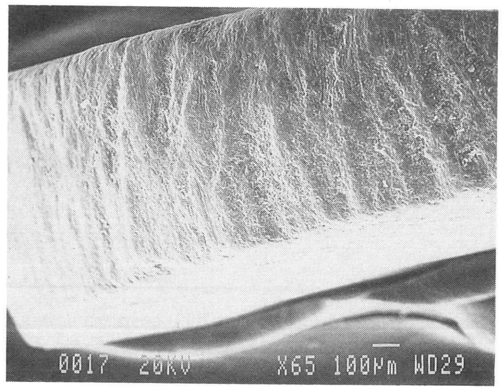


Fig. 20 - SEM image of the grooved edge of a rounded bead (X 20).

Fig. 21 - SEM image of the grooved edge of a rounded bead (X 65).

Variability of Drill Holes

The find in the MR2 activity areas of chert drills, bladelets, flakes and other residues showed that the blanks were perforated with chert drills, whose bits were manufactured and assembled in the site. Chert drills are also indicated by the typical stepped profile of the drill holes (see for example Figs. 26 and the experimental drill hole of Fig. 41). The maximum diameter values for all the drill holes on the best preserved face were measured with a digital caliper, recording two decimals after point. The plot of these values in form of a bar graph (Fig. 22) shows that most probably the bead makers used drill points having the same size. The production of drills in the same working areas or workshops where the beads were made and drilled is also encountered in the much later bead making areas of Mohenjo-Daro and Chanhu-Daro.

The presence of a large amount of blanks and rounded beads broken in half allowed a detailed inspection of the technological features of the drill holes (see Appendix B, Table 9). These holes were divided in two basic categories: those with evidence of

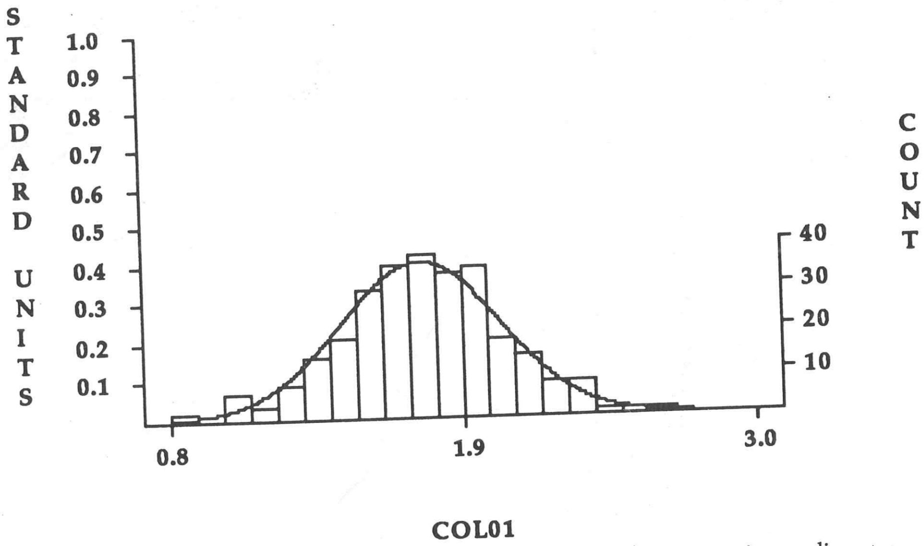


Fig. 22 - Bar graph showing the regular distribution of drill hole maximum diameters.

simple drilling and/or breaking surfaces (Fig. 23: Types 1-5, see list below), and those in which these drilling and breaking surfaces were partially obliterated by more or less intensive wear surfaces (Fig. 24: Types A-E, resulting from modification of Types 1-5, see below). This wear was evidently due to the stringing of the beads on a fiber and to a limited amount of friction between the hole surface and the string. It is important to stress that the blanks were strung together for the rounding stages, and not as finished elements (see below). Unmodified drilling holes were clearly associated with polygonal blanks (PEP, SPP), while, as expected, inner traces of string wear appear in Group SPP, but become common and extensive in Groups SSP and RSP.

1. Bipolar, biconical, symmetrical drill holes (Fig. 23.*1*). In this Type, drilling was carried out from both the faces of the blank, and the holes meet regularly in the center of the bead, so that a 'hourglass' pattern is formed. In the center, sometimes, along the holes' wall remains a small diaphragm, and this feature is easily affected by the wear of the string (see Fig. 24.*D*). This type of drill hole was observed in Groups PEP (33%), PME (2 cases, 50%), SPP (27.3%). The Type occurs sporadically also in some rounded blanks (SSP, RSP).

2. Bipolar, biconical, asymmetrical drill holes (Fig. 23.*2*). In this type, drilling was carried out mainly from one of the faces, and rapidly corrected from the other one, so that the 'hourglass' is asymmetrical. Type 2 drill holes were found in Groups PEP (14.2%) as well as in the split polygonal blanks Groups (SPP, SPC), where they

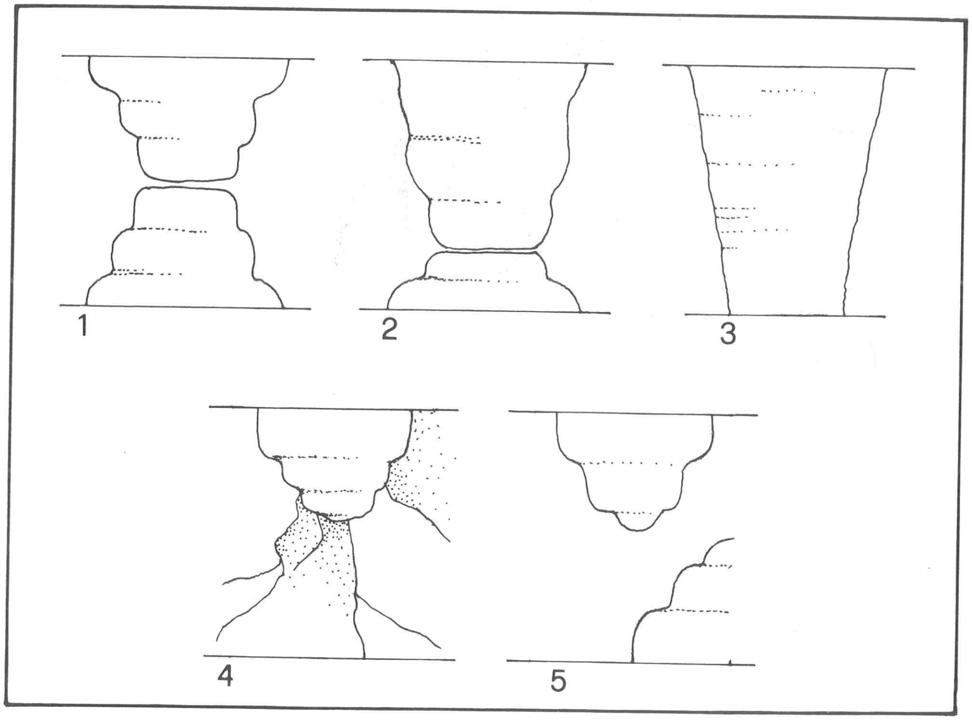


Fig. 23 - Types of unmodified drill holes in the MR2 activity area. *1*: Bipolar, biconical, symmetrical. *2*: Bipolar, biconical, asymmetrical. *3*: Unipolar, conical. *4*: Unipolar ending in breakage. *5*: Bipolar, defective.

amount to 18.4% of the total. Like in the former case, some instances of Type 2 drill holes were found in the rounded blanks groups (SSP, RSP).

3. Unipolar, conical drill holes (Fig. 23.*3*). In these specimens the blank was drilled from a single face. The resulting holes lost the stepped profile distinguishing Types 1 and 2. Unipolar drilling is a variation observed in perforated blanks (Groups PEP, PME, PDB) as well as in the blanks split during drilling (SPP: 5.7% of the Group).

4. Unipolar drill holes ending in breakage (Fig. 23.*4*). While in the previous Types drilling seems to have been completed before the actual breakage of the bead, in these specimens we may assume that the bead broke in half during the first stages of perforation. This Type of drill hole most likely indicates a technological failure. In Group SPP Type 4 is the most common drill hole (31.8%). As we must assume that at least part of the beads broke during the second stage of bipolar drilling, this supports the hypothesis that the whole Group was in fact due to breakage events in drilling. Only two cases of Type 4 were found in Group SSP (5.1%). It is possible that in some cases the fracture of the center of the bead at the end of a unipolar stage of drilling did not cause the breakage in half of the bead, which could therefore be strung for the rounding operation (see also Type E).

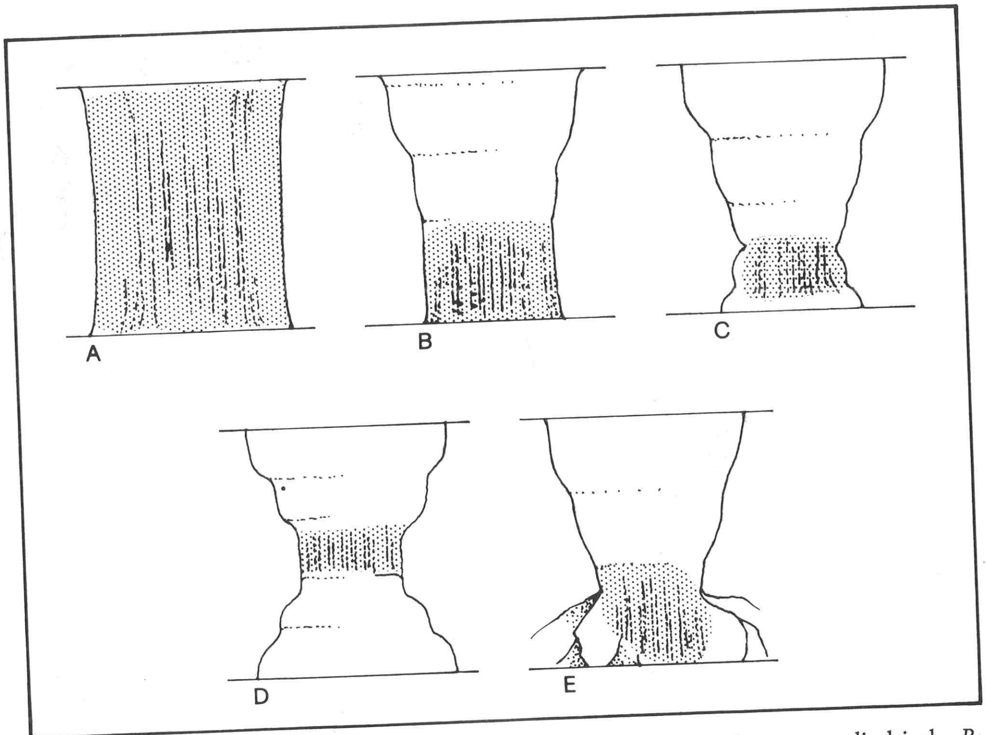


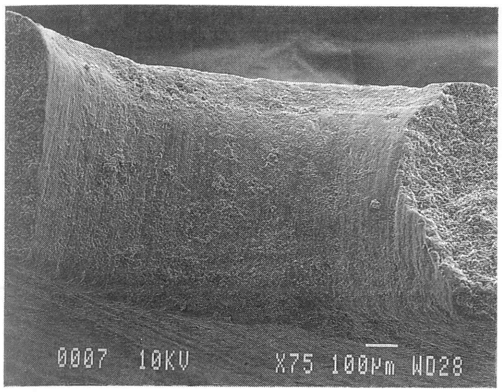
Fig. 24 - Types of drill holes modified by inner wear. *A*: uniformly worn, cylindrical. *B*: asymmetrical or monopolar, with extensive wear in the restricted section. *C*: bipolar, asymmetrical with incipient wear in the restricted part. *D*: bipolar, symmetrical, with central wear. *E*: Unipolar ending in breakage with wear on the fracture.

5. Bipolar defective drill holes (Fig. 23.5). In this Type, the blanks were drilled from both faces, but they were not correctly centered, and the holes did not meet. Three of such cases were observed in group SPP (1.91%) and, like Type 4, document failures in drilling.

The Types of drill holes that appear to have been modified by inner wear caused by a string were the following:

A. Uniformly worn cylindrical holes (Fig. 24.*A*; Fig. 25). In this Type the trace of the original bipolar drill hole are replaced by a uniform, cylindrical wear. SEM images of these wear surfaces show that they are formed by thin, parallel microstriations running along the axis of drilling. The microstriations are rather thin (about 15-20 μ). This type of extensive inner wear is rather common in rounded split beads (RSP: 53.2%) as well as in partially rounded beads (RSP: 41%). Few specimens were also encountered in Group SPP (2.5%).

B. Asymmetrical or unipolar, conical drill hole with extensive wear in the restricted section (Fig. 24.*B*). This Type results from the modification of Types 2 and 3,



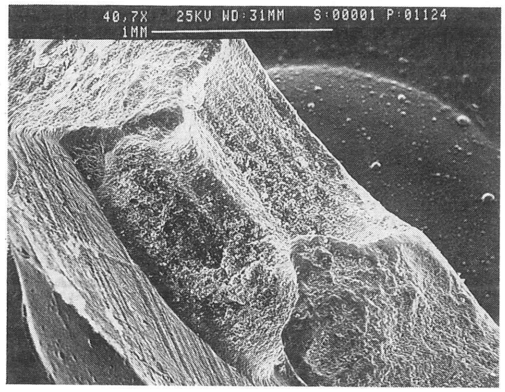


Fig. 25 - SEM image of a drill hole completely worn into a cylindrical, grooved surface (X 75). See Type A in Fig. 24.

Fig. 26 - SEM image of a bipolar, biconical, symmetrical drill hole with central wear (X 40). See Type D in Fig. 24.

when the narrow end of the drill hole is worn by the string. The worn section assumes the cylindrical form of Type A. Like the other Types of worn holes, this Type is only found in rounded or partially rounded beads (SPP, 0.63%; SPP, 12.8%; RSP, 8%). One may note that Type B is more common in Group SSP than in the final rounded beads (RSP).

C. Asymmetrical bipolar drill holes with incipient wear (Fig. 24.*C*). This type is distinguished by limited traces of wear developing in the center of type 2 drill holes. It may be considered as a stage in the formation of the extensively worn Type A holes. This type occurs in the same Groups of Type 2, amounting to 1.9% of SPP, 17.9% of SSP and 20.9% of RSP.

D. Symmetrical bipolar drill hole with central wear (Fig. 24.*D*; Fig. 26). The same pattern of wear developing in the narrowest part of the drill hole appears in the 'hourglass' specimens of Type 1. This type represents 3.8% of Group SPP, 5.12% of SSP, 8% of RSP.

E. Irregular monopolar drill hole ending in a breakage surface, with traces of inner wear (Fig. 24.*E*). This Type includes 1 specimen (Group SSP) in which the wear appears on a fractured surface at the end of a unipolar drill hole.

Reconstructing the Manufacturing Sequence on the Basis of Archaeological Evidence

The presence in the activity area of shapeless stone flakes suggests that also the preliminary forming stages were performed. Stone lumps were brought on the spot and shaped into elongated rod blanks. These rod blanks were carefully shaped by grinding and then orthogonally sliced into polygonal blanks. Some polygonal blanks show parallel marks which are definetly due to cutting, and were not later modified by grinding on the faces. For example, the specimen of Fig. 14 was cut from at least 3 sides, revolving the rod blank. The same technique was used later at Harappa for cutting steatite rods (J.M. Kenoyer, pers. comm.).

The technique of preparing long rod blanks and then slicing them into series of blanks of standardized length is simple and effective, and appears in various cultural contexts: for example, in talc-working sites of north-western Italy in the 3rd millennium B.C. (Sammantino 1990) and in Bantu sites with evidence of serpentine bead making in South Africa (Harger 1940: pl. XLV). In both cases, blanks for disk beads were detached as segments or slices of sub-cylindrical rod blanks. This technique is also conceptually very close to the separation of small disk beads by cutting or slicing the Spondilus shells found in the Mehrgarh activity area.

According to the evidence of the blanks which possibly were not modified after slicing, most of the originary rod blanks had octagonal sections. Thus, the manufacture of the rod blanks required a noticeable care and expenditure of time, but made easier and more efficient the following rounding operations.

Observation of unperforated polygonal blanks (UUP, FUP) showed the presence of edges having flat, pointed and both flat and pointed sections. In unbroken perforated blanks (Group PEP) flat edge sections amount to about half of the Group, the rest being formed by pointed and flat-cum-pointed sections. This rate changes in split perforated polygons (SPP), where flat sections are fairly less common than pointed ones. This evidence supported some conclusions.

1. After separation from the octagonal rod blanks, polygonal blanks underwent a careful operation of faceting at the edges, probably meant to make easier the following rounding operations.

2. As the study of the drill holes indicates that the majority of the perforated polygonal blanks split during drilling, and faceted edges are most common in Group SPP, we may conclude that most of the blanks were drilled after the edge had been faceted.

3. On the other hand, as we know that a minor part of the blanks (about 1/3) were not faceted, we are probably dealing with a form of technological variation within the same manufacturing stage (Vanzetti & Vidale 1994).

Only a very minor percentage of the split blanks (SPP) showed traces of inner wear in the drill hole. The study of the distribution of wear features in the holes showed that their frequency and extent is directly related to the intensity of the rounding process, as well as to the development on the edge of a distinctive double pattern of oblique grooves on flat sections. I think that the inner wear in the drill holes and its correlation with the rounding of the blanks may be explained by the technique of grinding series of blanks threaded on a string or fiber against a fine grained grinding stone. The friction of this string or fiber against the drill hole caused the formation of the thin parallel striations observed in the SEM photographs of Figs. 24 and 25.

This technique (see Fig. 27) has been well described by Foreman (1987: 21) with reference to native American bead making in the southwestern United States:

> [...] the technique of grinding is to hold the rough/strung beads as a columnar unit, then move this unit back and forth with moderate pressure against the grinding stone. This is done by wrapping the spear necklace string around one hand and adjusting the tension so that the thumb and forefinger may exert compressive force on the string of beads. The other hand is used to grasp, by fingertips or hand ridge, the actual beads themselves. Between the compressive force from one hand, and the rigidity imposed by the other hand, the necklace is made to behave as a single unit. The arms are then moved back and forth so that the semistationary bead string is being ground around the rock. Periodically, pressure is relaxed and the beads allowed to drag which rotates them. The pressure is then re-exerted and the grinding continued.

Whenever the pressure is released, the beads may move against the string, and the drill hole can be worn by friction. The back-and-forth movement of the strung beads probably explains also the slightly diverging orientation of the grinding grooves on the flat edge of rounded beads.

After separation, edge faceting, drilling and rounding, the beads underwent some stages of grinding and polishing of the two faces. The progressive decrease of the average thickness values along the manufacturing sequence could be due to the intervention of specific grinding-polishing stages, but it is not easy to define at which stage this processes of abrasion took place.

Grinding could have been carried out on stone slabs of progressively finer texture. Positive evidence of grinding-polishing is illustrated by the SEM images of Figs. 28-32. These images show the micromorphology and dimensions of abrasion grooves in various stages of grinding-polishing. Figs. 29-30 refer respectively to the ridges (dark areas) and depressions (lighter areas) forming the coarse parallel grooves observed in a polygonal blank. Some of the lines visible on blanks are definetly cutting and not grinding marks (see Figs. 10, 11, 14). At present, I assume that most grooves on rounded and subrounded beads come from grinding and not from cutting, mainly on the base of their similarity with experimental replicas, but the question needs further study. The dark areas of the ridges (Fig. 29) are due to the grinding pressure, causing isorientation of the talc microsheets in a continuous, compact surface. In the depressions (Fig. 30), the microsheets of talc, few μ large, are arranged without any order. The width of the grooves is about 70-80 μ.

The image of Fig. 31, taken at the same magnitude, shows a detail of the face of a subrounded bead (SSP). Depressions (light coloured areas) and ridges (dark areas) are now 10 to 30 μ wide, probably because the beads were ground on finer grinding stones. The picture area shows a single grinding orientation. In the following image (Fig. 32), great part of the surface is covered by the dark, flattened areas, bearing a chaotic pattern of very fine striations, only 2-4 μ wide. These striations run in every direction, suggesting a continuous rubbing of the beads against a very fine surface, with multiple movements. These features indicate a polishing rather than grinding stage. The example of a contemporary steatite beadmaker from Khairpur suggests that polishing could have been carried out with leather, and that the beads could have been coated with a vegetal oil to improve their shine (Vidale & Shar 1990: fig. 34).

An ideal reconstruction of the correlation between the progressive rounding of the edge and the formation of inner wear surfaces in the drill hole is presented in Fig. 33. The correlation between edge and drill hole wear and degree of rounding in Tables 3-5 (Appendix B) provides supporting evidence for the sketch of Fig. 33.

Experimental Simulations

In order to further test this reconstruction, I tried to reproduce the whole manufacturing sequence. In this stage I was helped by J.M. Kenoyer, University of Wisconsin, Madison, who provided me with raw materials, tools and substantial information.

The raw material was a set of roughly cut drawing sticks with rectangular sections (Fig. 34). These sticks are commonly used by children for drawing on blackboards. Microprobe and XRD analysis on this stone showed that they are made with pure Talc, and therefore the stone I used was probably softer than that used at Mehrgarh. The average measurements of the Talc sticks were 7.7 × 5.72 mm (in section). Although larger and square-sectioned rods would have been preferable, the blanks obtained from these rods fall in the dimensional range of the Mehrgarh beads.

The rods were ground on a fine-grained grinding stone, removing the corners and grinding the faces to obtain an octagonal section. It is not easy to grind uniformly a complete corner, because the pressure concentrates on a restricted part of the rod; when the operation is interrupted and resumed, the grinding area may shift, and this might explain why the polygonal blanks from Mehrgarh, although often octagonal, have in many cases irregular sections. Grinding the sticks into octagonal-sectioned rod blanks took about 3-5 min., according to the shape and size of each stick. The loss of weight averaged about 20% of the total, but starting from square-sectioned rod blanks this rate should be lower.

To slice or segment the octagonal rod blanks I experimented different tools, such as a bronze saw, a copper blade and finally a modern jeweller saw. The copper blade gave relatively good results, but, although its thickness was 0.55 mm (0.48 at the edge), it appeared too thick and some beads snapped before detachment. None of the blanks in the sample was comparable with this type of failures. It is hard to imagine that the rod blanks of Mehrgarh were sliced with flint blades. The best tool would have been a very thin copper blade, with a very gradual decrease of thickness and a certain degree of flexibility.

With the jeweller saw, a very efficient blade, my rate was about 28 blanks per

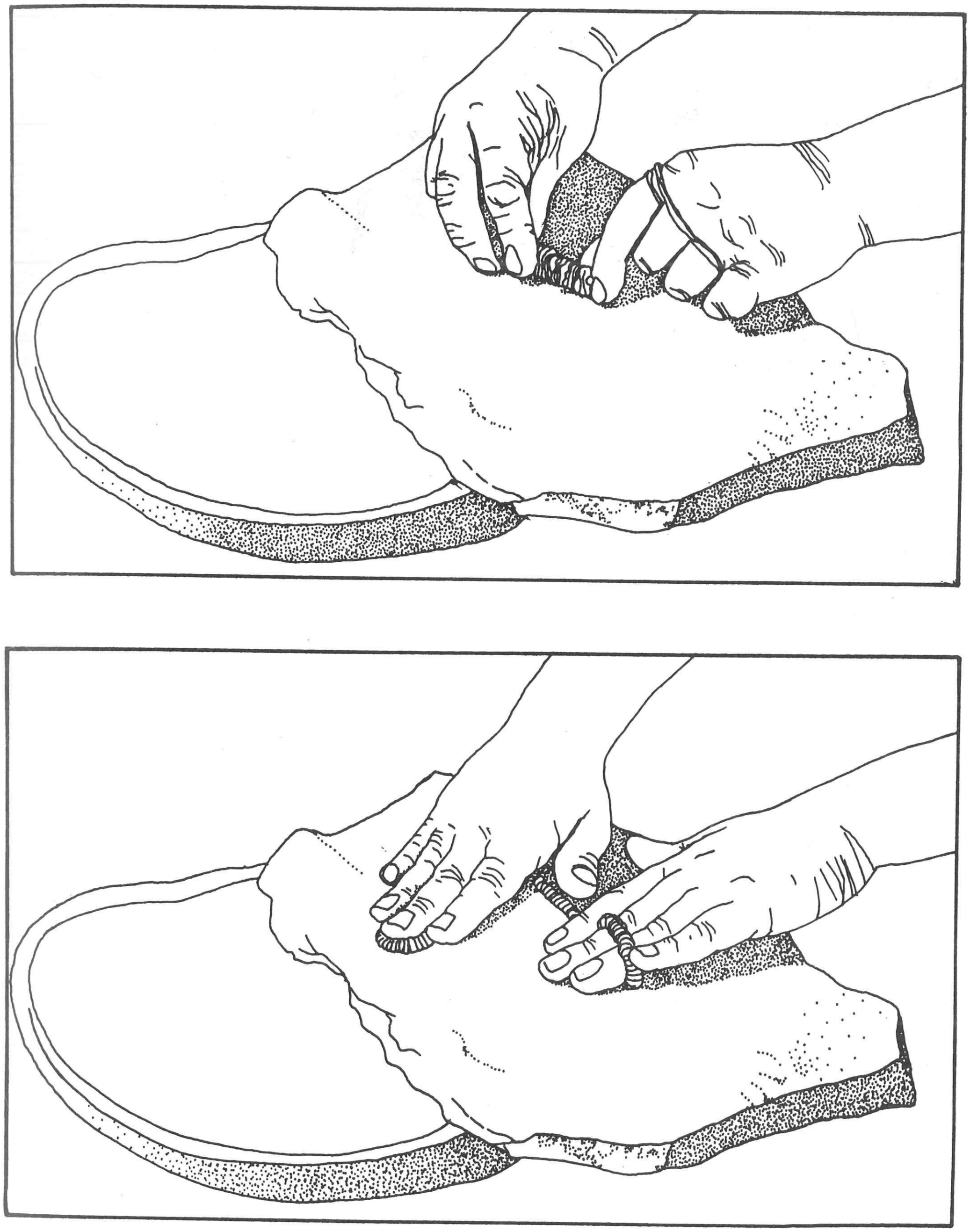
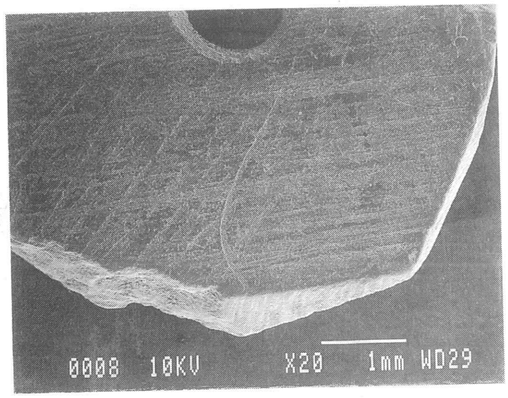


Fig. 27 - A traditional technique for rounding disk beads used by Pueblo native Americans (redrafted after Foreman 1987).



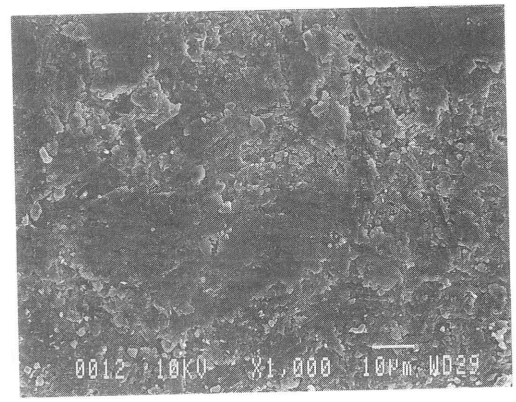


Fig. 28 - SEM image with detail of the surface of a perforated polygon, showing a pattern of coarse grooves probably due to grinding (× 20).

Fig. 29 - SEM image of one of the ridges between the grinding grooves in the blank of Fig. 28 (see Figs. 28 and 29). In the dark areas, the stone particles have been flattened and partially soldered together (× 1000).

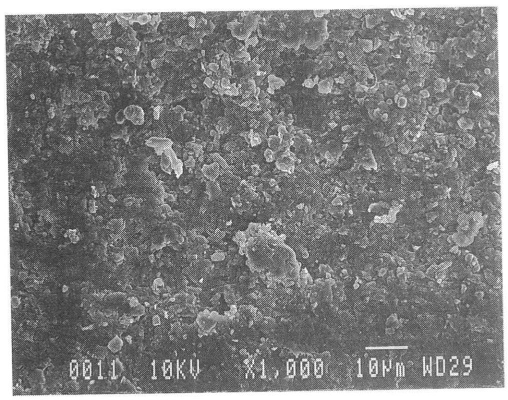
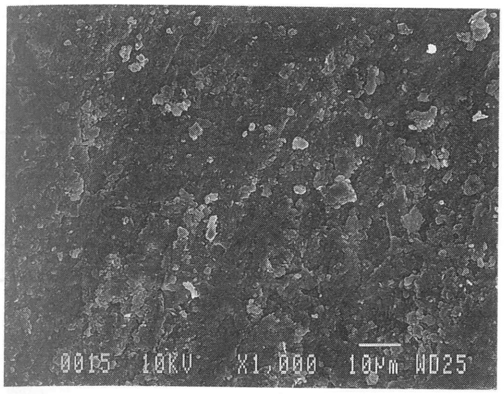


Fig. 30 - SEM image of the surface of the same blank, with a detail of the bottom of one of the coarse grinding groove. The stone particles show a chaotic setting (× 1000). The thickness of this groove is about 70-80 μ.

10 cm of rod blank. As it becomes difficult to saw properly short rod segments, this operation had a rather high percentage of waste (on average, I was unable to use more than 1/5 of the original octagonal rod blank). In a minute I was able to cut about 5 blanks.

My blanks were often irregular (honestly, they were really bad). They were too thick, with uneven thickness, and they often needed a substantial grinding before the following manufacturing stages. After this, the blanks were faceted at the edge. The blanks were hold and ground with an oblique direction on the grinding stone. The grinding phase was a combination of rotation and repositioning movements. On average, it took me 38 sec. to facet the edge of one blank. The blanks so obtained were observed with SEM. The similarity of the experimental replicas with the archaeological blanks may be evaluated comparing the images of Figs. 19 and 36.



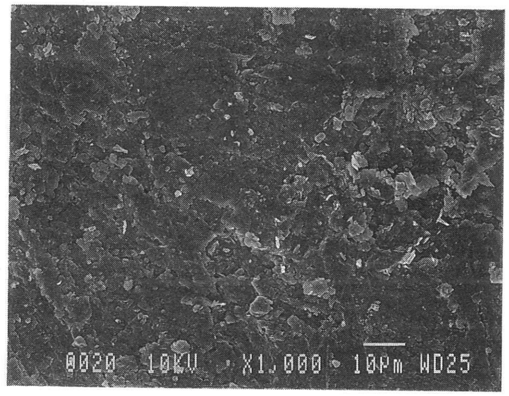


Fig. 31 - SEM image showing a detail of the ground or rough polished surface of a sub-rounded element (× 1000). The grooves have a single orientation and are 10 to 30 μ wide.

Fig. 32 - SEM image of a detail of a fine polished bead (× 1000). It is possible to observe a chaotic cross pattern of thin polishing grooves, 2-4 μ wide.

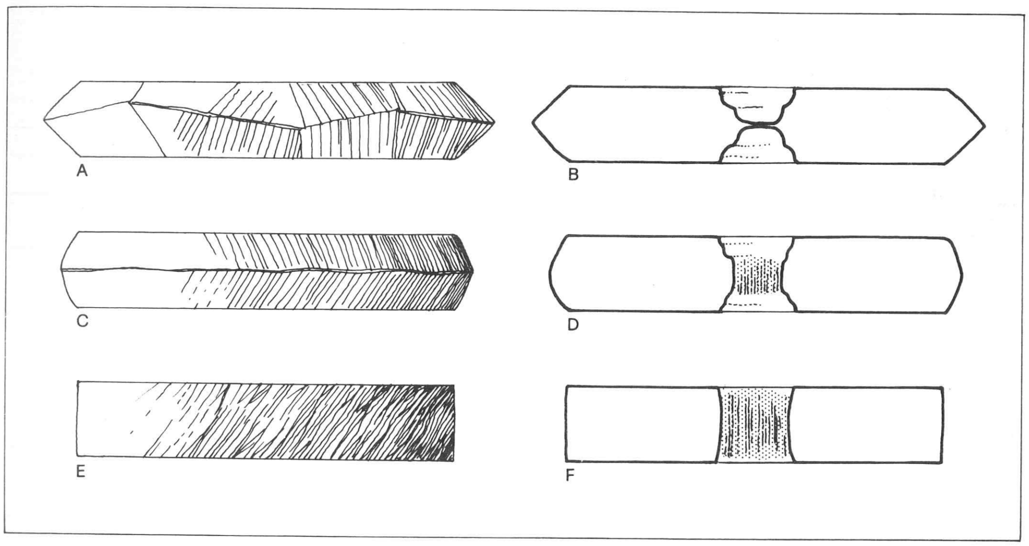
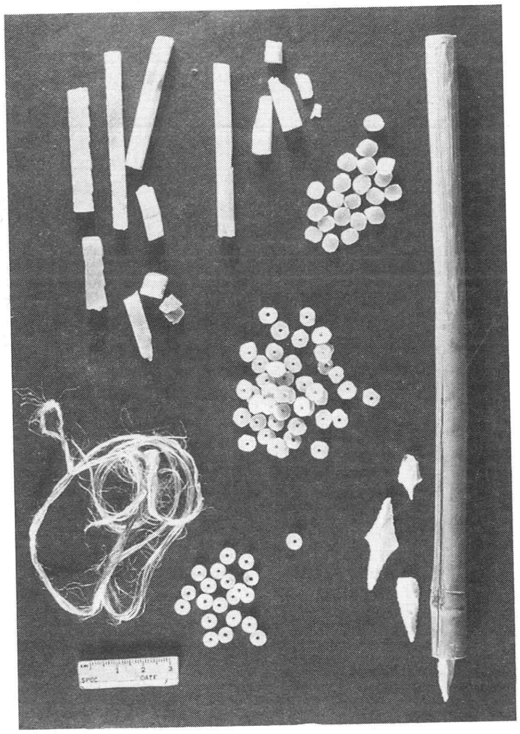


Fig. 33 - Ideal reconstruction of the correlation between the progressive rounding of the edge and the formation of an inner wear in the drill holes, based on archaeological evidence.

Drilling was carried out with a hand drill. A chert blade was modified into a drill point and inserted in a wooden stick. The stick was simply rolled within both palms, the hands sliding back and forth (see Foreman 1978). The weight and pressure of the arms was enough to perforate easily the soft talc blanks. The disks were partially perforated from one side, reversed and bipolarity drilled from the opposite face. One



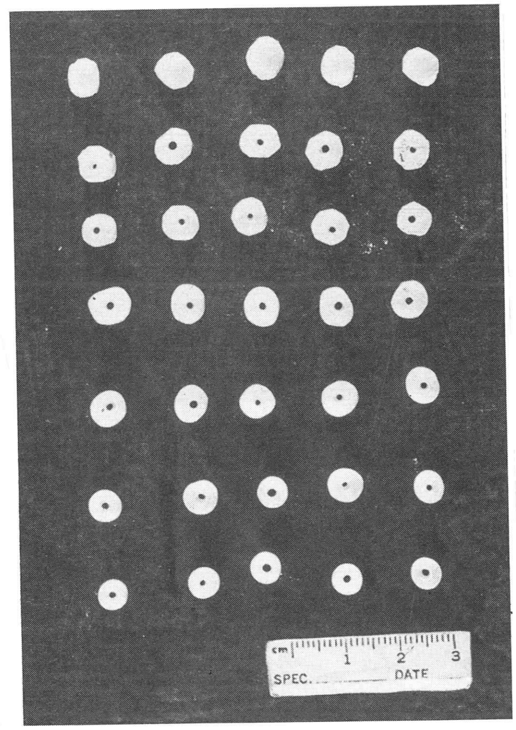


Fig. 34 - Materials and tools used in the experimental simulations, including talc drawing sticks, blanks, and beads, hand drill with chert points and rough hemp fiber.

Fig. 35 - Progressive stages of transformation in the experimental manufacturing sequence. Starting from the upper row: polygonal blanks; drilled blanks; drilled and faceted blanks; after 5 min. of rounding; after 10 min. of rounding; after 20 min. of rounding; after 27 min. rounding.

soon learns to control the depth of drilling by the sound as well as by the amount of powder gathering around the drill bit. When the two holes meet, the bead starts revolving around itself, as the chert bit encounters the asymmetrical form of the opposite hole. Any irregular feature of the drill holes may be easily corrected holding the bead with one hand and revolving the stick of the drill with the other. It never took more than 20 sec. to perforate a blank. I had very little drilling failures.

The stepped profile of the chert drill holes may be positively compared with the profile of the drill holes in the archaeological blanks (Figs. 26 and 41).

One of the main purposes of the experimental simulations was to replicate the rounding process and to establish if the limited friction underwent by the beads could explain the wear trace found on the archaeological samples.

About 50 beads were strung on a rough hemp fiber from Pakistan, and ground on the grinding stone following the procedures above described. Stringing took about

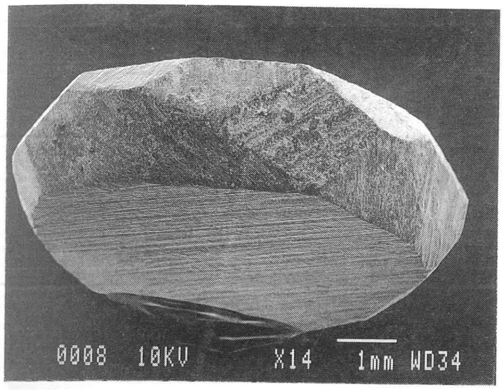


Fig. 36 - SEM image of an experimental blank faceted at the edge (compare with Fig. 19) (× 14).

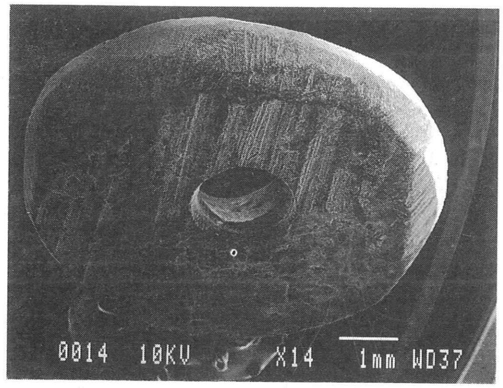


Fig. 37 - SEM image of an experimental bead after 5 min. of rounding (× 14).

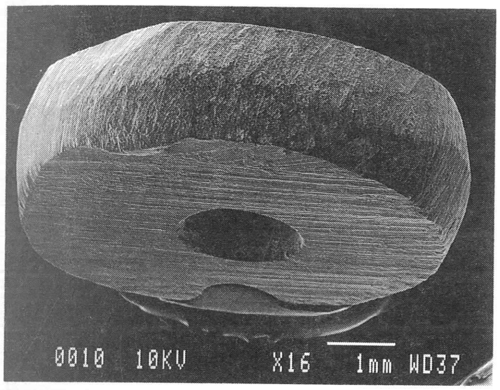


Fig. 38 - SEM image of an experimental bead after 10 min. of rounding (× 16).

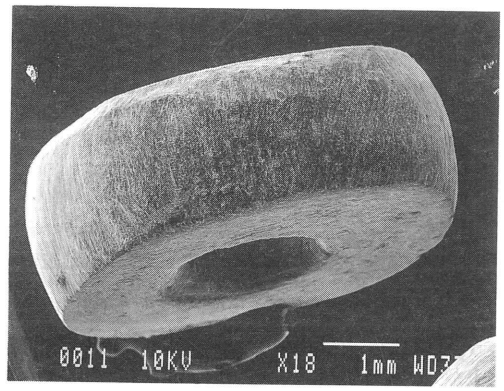


Fig. 39 - SEM image of an experimental bead after 20 min. of rounding (× 18).

10 min. The beads became rounded after about 30 min. of grinding. Bead samples were removed from the string at intervals of time to document the progressive transformation of the beads' shape (Fig. 35). Figs. 36-40 show 4 stages of this process. Fig. 36 shows a polygonal blank faceted at the edge. Fig. 37 shows a similar bead after 5 min. of rounding. The faceted edge is still visible, but most of the corners are smoothed and partially rounded. After 10 min. (Fig. 38), the facets of the edge appear transformed

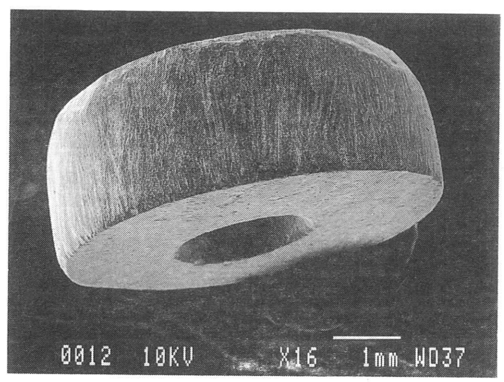
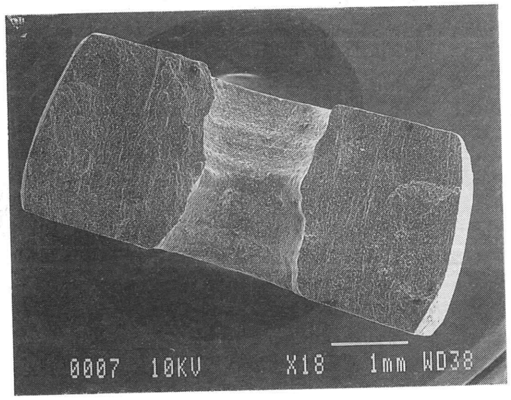


Fig. 40 - SEM image of an experimental bead after 27 min. of rounding (× 16).



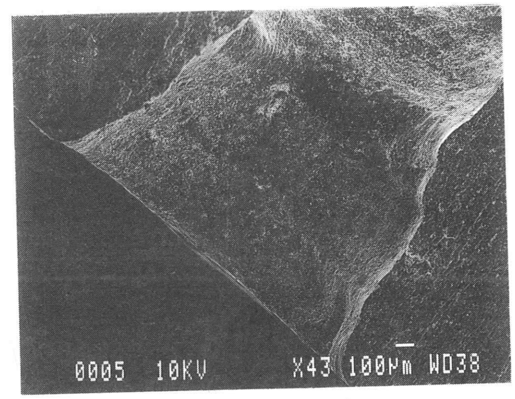


Fig. 41 - SEM image of an experimental bead with bipolar, biconical, symmetrical drill hole and central wear (compare with Fig. 24, D and Fig. 26) (× 18).

Fig. 42 - SEM image of the worn surface in the bead of Fig. 41 (× 43).

into a continuous, slightly wavy ridge. The section of the edge is still pointed, but the angle is blunt. After 20 min. of grinding (Fig. 39), the bead is almost rounded, but the edge retains a slightly rounded section. The first beads attained a good round shape after about 25-27 min. (Fig. 40). In these specimens, the edge is definetely flat, and on the surface of the edge appears a double pattern of slightly diverging grooves comparable to that observed on the archaeological rounded beads. According to the simulations, the beads of Group SSP could have been broken after 10-15 min. of rounding, and those of Group RSP after about 20 min.

Five beads were randomly selected and removed from the string after 20 min. of rounding and broken in half, to see if the drill holes did develop the inner wear found in the Mehrgarh unfinished beads (mainly SSP and RSP). All of the 5 specimens actually showed traces of inner wear developing in the narrowest sections of the drill holes (Figs. 41, 42).

Conclusions

On the whole, the experimental simulations of the manufacturing sequence supports the reconstruction proposed on the base of the study of the archaeological objects. Obviously, this does not rule out the possibility that very similar material effects could have been the result of techniques different from those I took into account. The experiments only make the reconstruction more probable.

Two points seem important to me. The first involves the 'style' of this bead-making technology. The careful faceting of the edge of the blanks requires an investement of attention and labour in shaping the blanks, i.e. in an intermediate stage of the manufacturing sequence. This option may be contrasted with the steatite (talc) bead-making sequence reconstructed in the DK-A workshop found on the surface of Mohenjo-Daro (Vidale 1989), where rod blanks and blanks were simply sawn out of stone blocklets and then perforated.

Secondly, even in a small sample like this one there is evidence of a certain range of technological variation (faceting of the edge or not, monopolar versus bipolar drilling). This relative variability could be explained in different ways:

a) assuming that a single craftsman used different techniques;

b) assuming that more craftsmen were active in the site;

c) assuming that the refuse was discarded by a group of craftsmen including personnel at various levels of skill.

These hypotheses are very difficult to test. b) and c) do not exclude each other, and I would suggest that a) is the least probable.

The experimental simulations were successful in providing first-hand experience of some of the most evident constraints of the manufacturing sequence, as well as in testing a set of specific material implications of the archaeological reconstruction. What simulations cannot provide (at least in this stage of research) is an analogical ground for simple and straightforward deductions on the efficiency of the techniques, the failure rates, or the times of production. The main practical problems, in this case, were (in order of importance) my lack of experience as a beadmaker and the difference between the two types of raw material. Various factors could also affect each other: for example, my blanks were much thicker than the Mehrgarh ones, and this could have had important consequences for the rounding process.

Conceptual or ideological approach to production might have been another important factor. For example, according to Foreman (1978: 17), Pueblo native American disk bead-making in New Mexico is conceived more in terms of a teaching and learning relationship than as a production event. Therefore

> [...] time of the western linear or 'flowing' type does not exist. In place of 'time' there is a sort of dynamic set of still-print comprising events. This allows a 'timeless' approach to beadmaking that eliminates the vexing problems the westerner sees in the time consumed by the traditional method.

In spite of these possible problems of interpretation, Appendix A reports an estimate of the time involved in the production of a necklace of steatite disk beads according to the experimental simulations. I was also surprised of the very low rate of failures of the experiments. This gave me the impression that the activity area of Mehrgarh 2 might actually include the leftovers of the production of huge amounts of steatite disk beads.

APPENDIX A

Timing of Experimental Manufacturing Sequence

Being a westerner and vexed by the problems of linear time, I include the timing per blank and bead of my own manufacturing sequence.

	Time in sec.
Shaping the octagonal rod blank	10
Cutting the rod blank	12
Faceting the edge	38
Stringing	12
Rounding	36
Tot. time (in sec.)	128

This estimate refers only to the part of the manufacturing sequence I was able to replicate, and obviously excludes the time and labour needed for mining, transporting and cutting the stone and the polishing process. It also excludes the time needed to shift from one stage to the following one. As the average thickness of my blanks was 2.45 mm, to produce a necklace having a length of 70 cm I should have worked without interruptions for more than 10 hours.

[32]

APPENDIX B

The sample of Blanks and Beads (Tables 1-6)

Table 1

Type	UUP	FUP	PEP	PME	PDB	SPP	SPC	SSP	PRE	RSP	Tot. no.
No.	8	6	21	4	1	155	2	39	9	62	307
%	2.6	1.9	6.8	1.3	0.3	50.5	0.6	12.7	2.9	20.2	(99.8%)

Mehrgarh, steatite activity area. Overall composition of the studied sample, classified in paleotechnological groups. UUP: Unbroken Unperforated Polygons; FUP: Fragmentary Unperforated Polygons; PEP: Perforated Polygons (from unbroken to slightly damaged); PME: Polygons with Missing Edges; PDB: Polygons with Defective Bi-polar Perforation; SPP: Split Perforated Polygons; SPC: Split Perforated polygons with Cutting marks; SSP: Sub-rounded Split Perforated elements; PRE: Perforated Rounded Elements (undamaged); RSP: Rounded Split Perforated elemens.

Table 2

	1	2	3	4	5	
No.	1	22	7	2	8	Tot. 40
%	2.5	55	17.5	5	20	(100%)

Mehrgarh, steatite activity area. Basic shapes of polygonal (i.e. non rounded) elements (UUP, FUP, PEP, PME, PDB).

	1	2	3	4	5	
No.	2	70	6	3	76	Tot. 157
%	1.3	44.6	3.8	1.9	48.4	(100%)

Mehrgarh, steatite activity area. Basic shapes of polygonal elements, some of which possibly modified by preliminary rounding operations (SPP, SPC). 1: irregular ellipsis; 2: irregular polygons; 3: regular polygon; 4: composite shape (e.g. partially rounded and partially not); 5: non determinable.

Table 3

Type	1	%	2	%	3	%	4	%	ND	%
UUP	1	12.5	4	50	3	37.5				
FUP			2	19	1	16.7			3	50
PEP	10	47.6	4	19	5	23.8			2	9.5
PME	1	25	2	50					1	25
PDB			1							
SPP (*)	37	23.6	91	59.2	15	9.5			12	7.64
SPC			2							
SSP	22	56.4	12	30.8	1	2.6	3	7.7	1	2.6
PRE	8	88.9			1	11.1				
RSP	53	85.5	2	3.2			7	11.3		

(*) SPP and SPC counted together.

Mehrgarh, steatite activity area. Distribution of various types of edge sections in the debitage. 1: flat; 2: pointed (diamond-faceted); 3: partially falt and partially pointed, i.e. faceted; 4: rounded.

Table 4

	1	2	3	4	5	ND
UUP	2	5	1			
FUP		3				3
PEP	7	9	3			2
PME		3				1
PDB		1				
SPP	41	79	14			21
SPC	1	1				
SSP	4	3		30	1	1
PRE				9		
RSP	1	1		60		

Mehrgarh, steatite activity area. Distribution of various types of manufacturing traces on the edges of blanks and beads. 1: Parallel grooves running orthogonally to the main axis of ground facets; 2: Parallel grooves running obliquely to the main axis of an abrasion facet; 3: An abrasion pattern resulting from the superimposition of 2 and 3; 4: Discontinuous wavy parallel grooves, from orthogonal to oblique along the beads edge; 5: Highly worn or polished edge.

Table 5

Type	1	%	2	%	3	%	4	%	5	%	A	%	B	%	C	%	D	%	E	%	ND	%
UUP																						
FUP																						
PEP	7	33.3	3	14.3	2	9.5															9	42.8
PME	2	50	1	25																	1	25
PDB					1																	
SPP (*)	41	27.4	29	18.5	9	5.7	50	31.8	3	1.9	4	2.5	1	0.6	3	1.9	6	3.8			9	5.7
SPC	2																					
SSP	3	7.7	2	5.1			2	5.1			16	41	5	12.8	7	17.9	2	5.1	1	2.6	1	2.6
PRE																					8	
RSP	2	3.2	3	4.8							33	53.2	5	8.1	13		5	8.1			1	1.6

(*) SPP and SPC counted together.

Mehrgarh, steatite activity area. Distribution of various types of technological features of perforation holes in the assemblage (see also Fig. 23, 1-5, and 24, A-E). 1: Bipolar, biconical, symmetrical perforation; 2: Bipolar, biconical, asymmetrical perforation; 3: Unipolar, conical perforation; 4: Unipolar perforation ending in breakage; 5: Defective bipolar perforation; A: Uniformily worn, cylindrical perforation; B: Asymmetrical or unipolar, conical perforation with extensive wear; C: Asymmetrical bipolar perforation with incipient wear; D: Symmetrical bipolar perforation with incipient wear; E: Irregular unipolar perforation with extensive wear on the fracture.

Table 6

	Max. Diam.	Max. Thick.	Min. Thick.
Polygons (UUP, FUP)	7.88	1.35	1.12
Perforated polygons (PEP, PME, PDB, SPP, SPC)	7.35	1.3	1.10
Sub-rounded blanks (SSP)	7.1	1.2	1.01
Finished beads (PRE, RSP)	7.35	1.04	0.9

Mehrgarh, steatite activity area. Average values of maximum diameter, maximum thickness and minimum thickness of blanks and beads, showing the extent of the reduction process.

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