ANCIENT LAPIDARY
A Study using Scanning Electron Microscopy and Functional Analysis

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In the chronology of the development of ancient stone tools, drills and drilling were late additions to paleolithic technology. They had been preceded by other shaped liths and other uses such as scrapers and burins for hundreds of thousands of years. Subsequently, all ancient peoples learned the craft of drilling. Changes and improvements, however, took place slowly. Unfortunately, since the variety of drill tips excavated is scarce, the evidence for how drilling was done and when changes occurred, was frequently not as hard as the objects drilled! There is much that is unknown.

For example, how were the tiny holes this size o, less than a millimeter, made on the beads from the neolithic period? No one has been able to duplicate them and the many other examples of ancient lapidary virtuosity. To make the case more outstanding and impressive, this manufacture first took place before the use of metal tools, on stones such as quartz, whose Mohs hardness is 7 (copper is 3, bronze is 4, iron is 5-6, diamond is 10). Other examples of remarkable lapidary
artifact are the bannertones of the North American Indians; the anterior teeth of ancient Meso and South Americans, drilled and inlaid with tiny cabochons of jade and flat disks of hematite; the rock crystal and obsidian cylinder seals of the Jomart, Naxchivan, and 3000 B.C., in Mesopotamia. Indeed, the small tools needed for this kind of drilling are thus far undiscovered.

One purpose of this paper is to describe a theoretical framework and methodology to investigate ancient drilling, which stems from an assumed idea that it is possible to tell the tool from the tool mark. The earliest written expression of this idea was made in 1754 by a skillful lapidary named Lorenzo Natter in A Treatise on the Ancients' Methods of Engraving, dedicated to King George III.

By "ancient" he meant ancient Greek. He wrote, "I copied with great exactness the works of the ancient engravers... I observed that the first strokes of my tools made it greatly resemble a bad antique engraving... Hence I perceived with some surprise that the ancient engraver... used the same tools as I did (and) convinced me of the reality of what has hitherto been regarded only as a supposition... namely, that their Method was precisely the same as ours."

A contemporary variant of this idea is the hypothesis described by Semenov in Prehistoric Technology (1964), which he called "functional analysis." It is stated that by duplicating the microscopic markings found on ancient laths through use, in the manner and function suggested by the shape of the lath, a strong inference could be made about the function of the tool.

Our hypothetical reformulation is as follows: It is possible to identify the tool from the tool mark, providing (1) "standards" of ancient tool marks are developed and (2) these tool marks or patterns can be duplicated experimentally.

Indeed, both formulations are like contemporary ballistics applied to ancient artifacts. For Semenov, the focus is on the tool (bullet) and for us, since the tool is in question, on the artifact (bullet hole). In either case, it is deceptively complicated. For example, a range of possibilities exists for the tools, i.e., bones, stones, woods, metals, etc. The pattern that each leaves may vary. The range of stones or stone-like material on which these tools were used is also wide. These may be wear of the tool used in their manufacture and unknown to the maker; (3) although the sample was limited, notable differences were observed between natural and fake marks.

MATERIALS AND METHOD

In this report another experimental method is being introduced in order to facilitate comparisons between the "standards" developed from ancient artifacts and the duplication of these patterns. The choice for this method, which we call "sequential drilling and replication," is based on our previous finding that the wear form in the cross section view. In reality this latter form is an elevation in the stone.

1. Model showing sequential drilling of a compound (both) and sandstone. The wood drill (open arrow) and the stone (closed arrow) are shown at ten different intervals.

2. Diagrammatic reconstruction of the changes in a wooden drill stick (both) and state with time. Note the change in overall pattern from a flat base to a tapered form due to wear of the wood. The wear pattern can be described as "tapering." Within this pattern there is an easy elevation in the center of the stone drilling (Stage #2) and similar to Knoblock's drilling shown in Fig. 4 (see arrow). However, this changes to a new stage (Stage #3) and a related shape in Stage #5, the leading edge of the drill stick has worn until it is almost flat and a new elevation similar to Stage #3 in reappearing. Stage #4 bears a likeness to Stage #5 with a depression in the stone and a related change in the wood. The detailed changes in the wood showing minor depressions in Stages 2, 3, and 5 were due to the embedding of sand in the tool's leading edge. In all cases procedures would be similar to "charging."
of the tool during usage leaves different patterns after different intervals of time.

The experimental mode of "sequential drilling" differs from previous experimental drilling in the following way: in the latter, drilling was done for various lengths of time at different sites and then silicone impressions were made at each drilling site and compared. In "sequential drilling" the drilling is done in the same site.

However, at various intervals, e.g., every one to two minutes, a silicone impression and an epoxy resin model were made of both the drill and the substrate, therefore the name "sequential replication." The results show very dramatically in Fig. 7. Almost in animation, the continuing and related changes (Fig. 8 A & B) on the tool and on the substrate. The recorded experiment can then be compared to the "normal" or the "standard" using replication and SEM.

Another purpose of this report is to describe the abrasion patterns on another group of seals and to describe a few preliminary experiments at their duplication. The artifacts used in this study consisted of twenty-eight ancient Near Eastern stamp seal cylinder seals from the Metropolitan Museum and the Göteborg Collection. The seals were divided into two groups. In the first were twenty-four made of cryptocrystalline quartz, i.e., chalcedony, jasper, and agate. The periods ranged as follows: Early Dynastic II (ca. 2700 B.C.), Akkadian (ca. 2350 B.C.), Old Babylonian (ca. 1700 B.C.), Kassite (ca. 1500 B.C.), Assyrian (ca. 1400 B.C.), Mittan- nian (ca. 1400 B.C.), Middle Assyrian (ca. 1300 B.C.), Neo-Assyrian (ca. 700 B.C.), Neo-Babylonian (ca. 700 B.C.), Achaemenid (ca. 600 B.C.), and Sassanian (ca. A.D. 600).

The second group of four consisted of seals made from other stones and some other periods such as steatite (Menard Nasr, ca. 3000 B.C.); obsidian (Proto-Elamite, ca. 3000 B.C.); rock crystal (Old Babylonian, ca. 1700 B.C.); and hematite (Mittanian, ca. 1400 B.C.).

Silicone impressions were made of the central boxes and of the engraved surfaces as previously described. These were examined in the SEM, and photo micrographs and composite photo reconstructions were made.

FINDINGS AND DISCUSSION

Bore Characteristics

With some interesting variations, the findings on the bore were consistent and similar to those found in the previous study (Expedition, Winter 1979). These were: (1) in each instance the drilling was begun from both ends; (2) the shape of the bore varied from tapered to nearly straight and parallel; the opening of the bore was usually flared; and (3) in all instances, the bore contained concentric abrasion rings irregular in depth and distance with smooth areas in between—characteristic of drilling with an abrasive. The smooth intervals may be explained by the polishing effect that takes place as the abrasive and substrate break down into fines and finer particles. No differences in the concentric ring pattern were found related to the period of seal manufacture. However, in some instances they are much flatter and more regular than in others. A possible explanation for the fine and regular concentric lines is that the abrasive has become charged or embedded in the tool and produces a configuration similar to a contemporary ceramic-bonded abrasive stone.

The variety of bore shapes may be explained:

1. A variation in the shape and wear of the tool, i.e., a wooden tool wears rapidly and therefore tapers more than a stone or metal tool.
2. The amount of wobble in the spindle in experimental drilling will also affect the shape of the core. This is commonly experienced in experimental drilling. It is likely that the biconical shape so frequently found in ancient drilling is due not only to drilling from either end but also to the coincidental occurrence of wear and wobble of the tool. This is evident in the experimental drilling of Byron Knobil and our own sequential drilling (Fig. 8 A & B). The ancient methods of securing the stone and maintaining a straight line require further investigation.

3. While a tubular drill seems to produce less wobble, the inner core invariably tapers toward the top (Fig. 1). This has been shown in Petrie's text in Tools and Weapons.
The seals on which the pattern of the leading edge of the drill was clear are as follows:

Neo-Assyrian Seal (Fig. 12). The extreme axial misalignment of the bore when drilled from either end provided a clear picture of the effects of the leading edge of the drill bit. We have used the term “terracing” to describe the shape produced. This pattern is similar to that seen in our experimental “sequential drilling” using a wooden drill with fine sand on slate and slateite (Fig. 7). The sequence shows the continuing wear pattern on the wooden drill bit to produce the terraced appearance and also an elevation and a depression at the base of the wood depending on the stage of the sequence. This observation was useful when globe forms were examined and will be elaborated further (see Fig. 20). Although these are patterns consistent with the shape of the tool, it does not necessarily mean that it was the only tool used—rather, it was the last one used. Further proof in this instance would require experimental drilling on quartz.

Neo-Babylonian Seal (Gorlich Collection Cat. 8-44). Because the drilling from either end was very crooked and almost did not meet, the silicone impression provided a clear picture of the effects of the leading edge of the drill tip. This was manifest as a rounded edge with an elevation in the base of the stone. Translated to the tool, this would appear as a depression. The shape bears a close resemblance to stone microoliths used for bone manufacture excavated by Tosi at Shahr-i-Sokhta, Iran in 1968-69 and reported in East and West: Pigorino, reviewing these microoliths (South Asian Archaeology, 1973) described their shape as due to wear patterns. Proof of this would require further experimental drilling with similar stones, substrates and abrasives.

Achaemenid Stamp Seal (Fig. 16). This seal had a typical bore as well as one that was incompletely drilled alongside. The reason for this is unknown; it may indeed have been a craftsman’s error. The shape at the dead end, however, had an interesting configuration. The major portion of the floor showed what appeared to be fracture planes manifest as several facets. If a solid core of quartz, produced by a tubular drill, were fractured, it would leave a conchoidal fracture pattern such as this one. Proof of this conjecture would require experimental drilling with various tubular drills and abrasives.
Collar Shapes

On ten of the 24 boxes of the quartz seals but on none of the other stones an unusual shape was discovered on the side walls. In the impression it can be described as a “collar” (Fig. 18), in the bore as a “furrow” that is completely circular. The shapes are symmetrically rounded like a partial globe and occur at various distances into the bore—usually seen one-fourth of the way down, then nearly half way down (see Fig. 10). They are found at either end and vary in depth. They were found only on the following crystalline quartz seals: Early Dynastic, Akkad, Old Babylonian (rock crystal), Kassite (2), Mitannian, Middle Assyrian, Neo-Assyrian, Neo-Babylonian, Neo-Babylonian (stamp).

Two hypothetical explanations are offered for the collar shape which was very likely accidental and unknown to the seal maker. Firstly, if abrasive and substrate debris is not removed from the drilling site it becomes packed at the cutting interface. Continued pressure from, and rotary action of, the drill on this material eventually lead to abrasion of the wall immediately adjacent to the floor of the hole. Circular underruts will form and continue to deepen as long as packing persists. The rate at which the hole deepens will slow and become evident to the seal maker who will clean out the debris, allowing progressive drilling.

Another explanation for the furrow is that it was created by a metal tool with a ball or oval shape. This could occur if one postulates a spindle being rotated from a horizontal drill instead of from a vertical position (Fig. 19). Inside the barrel drill was being held with both hands in front of the rotating drill bit and moved slightly, perhaps impatiently, from side to side, a furrow shape could be created. Perhaps this was done to widen the bore, or if resistance was encountered, prior to vertical drilling. The SEM reveals that the furrow invariably has a rough surface compared with the adjacent surfaces which seem to be smoother and somewhat polished. This could occur when the furrow, as an undercut region, was bypassed as further drilling took place. Therefore, the usual breakdown of the abrasive into finer particles to produce a polish would not happen. We were able to duplicate the furrow shape experimentally using a motorized lathe and a ball-shaped grinding stone. The presence of furrows in nearly half the sample of stones with a Mohs hardness of 7 (i.e., 10 of 24) and in none of the other stones suggests the possible use of different tools and/or techniques. However, this requires further investigation and a larger sample to verify.

The furrows seen may not be of the original size. As the bore was widened the original tool or tool bits flew, the furrow would become shallower and shallower. As stated, furrows of different depths are seen. File marks are also seen on several of the seals indicating frequent reversal (Fig. 10).

If the second hypothesis on the use of a horizontal spindle is correct, then it would suggest relating previous speculations as to its inception from the Kassite period, since the furrows are found in seals of the Early Dynastic period, almost a thousand years earlier. Indeed, it seems to have been used from then on. However, this is speculation and requires further experimental investigation using functional analysis on a larger sample to verify the shape.

History of Horizontal Spindle

The earliest depiction of a horizontal spindle, sometimes called a “bow lathe” was found on the stele of the grave of a Roman gem carver. According to Neuberger in The Technical Arts and Sciences of the Ancients, it was mentioned by Pliny in VII, 198.

This type of spindle may very well have been the antecedent to the traditional lathe used for turnery shown on the thrones of Assyrian kings. Strictly speaking, the term “lathe” is used when the work is turned and a tool is held against it. A variety of terms are used for the horizontal spindle, but the work is held and brought to the rotating tool, whether it be a drill, tube or disc. The term “bone in terminology may indeed be a reflection of the under- spindle on an engraved plate in his previously mentioned book. Hansford describes it in discussing ancient Chinese jade manufacture, and Wilfl has photographs of primitive versions still used by Iranian craftsmen. The specifics of the lathes shown by Wilfl and the permissible materials used may account for their not having been found in archaeological excavations.

Scholars of the history of ancient technology describe the twisting discontinuous motion of a hand, holding a pointed lathe, as the precursor of the bow-drill. It is interesting to speculate that another ethnographic parallel may be the origin of the horizontal spindle. Some gain for the drill may be found in the following observation made in 1774 by John Lawson in his History of Carolina describing his own observations of Indians drilling shells to make wampum. “Drilling is the most difficult to the Englishman, which the Indians manage with a nail stuck in a cane or reed.

Thus they roll it continually on their thighs with their right hand, holding the bit of shell with their left so in time they drill a hole quite through it, which is a very tedious work.”

The Engraved Surface

While there has been speculation about the invention of the horizontal spindle prior to the Kassite period, the evidence has been absent. As early as 1894 McGuire suggested that the “straight lines show the longitudinal stria as a small wheel would wear them”... and this occurred “prior to 3000 B.C.” in the ancient Near East. (Singer said that he believed that the lathe was used in the Bronze Age but could not prove it.) Recently, Nissen has offered a similar conjecture regarding seals of the Late Uruk and Jemdet Nasr periods.
There is a consensus that an ancient rotating disk can be used only on a horizontal spindle. Therefore, the proof of the invention of the horizontal spindle could be made by demonstrating the markings of a disk and clearly distinguishing it from a hand-engraved straight line. We offer preliminary evidence for this from a Proto-Elamite seal of obsidian and a Middle Near Eastern seal of marble, both ca. 3000 B.C. By contrast, note the difference in a hand-engraved line from a hematite seal of the Old Babylonian period.

The scanning electron microscope reveals that disks commonly leave parallel striations in the direction of the furrow cut by the disk. This was true with the diamond and copper disks which we used experimentally. The size, shape and termination of the furrow depend upon the shape of the tool, i.e., flat, round or knife-edged, and also on the nature of the tool, i.e., metal, shell or embedded with an abrasive. A grinding stone abraded to shape, etc., in contrast, hand-engraved furrows show irregular striations and irregularities along the sides and direction of the furrow. Further proof along the lines of our original hypothesis is needed, therefore, to identify other distinguishing features. The continuing problem of a differential diagnosis on the engraved surface will always exist if it has been thoroughly polished.
and replication. Ball-shaped drills are shown by Nutter and Hunsford and indeed have always been used in dentistry to start and enlarge the site of drilling.

Several globe forms on seals of the Jemdet Nasr period were examined. The stones were all much softer than the quartz seals previously described, having a Mohs hardness of 1-3. The pattern shown consisted of "terracing." The terracing phenomenon is also found in the cavities drilled in teeth of the Ancient Maya. Our "sequential drilling and replication" (see Fig. 7) suggests that a wooden drill tip was used to create these forms. While the use of wood as a drill has been conjectured, our finding based on functional analysis is the firmer evidence to date. The size of the drill tip and its perishable nature make the lack of archaeological evidence understandable. The use of a wooden drill tip was observed in present-day Iran by Prof. Toni and in Iraq by Prof. Gibson (personal communication).

In the ancient Near East the choice of stones for seals seems to follow a trend that is related to their hardness. This was determined by cataloging 2200 seals according to their Mohs hardness. These were taken from the catalogues of the following collections: Morgan, Ashmolean, Moor British Museum, and others. The stones used were steatite, marble, limestone, alabaster. In the pre-Obis period, there were no seals with a Mohs hardness of 4 through 7. These were found subsequently, but remained a minority until the Old Babylonian and Kassite periods (ca. 2000-1550) when a Mohs hardness of 4 through 7 predominated. Stones of hematite, lapiz, and obsidian were used during this period.

From the Middle Assyrian period (ca. 1350 B.C.) through the Sassanian period (A.D. 642), stones with a Mohs hardness of 7 predominated. These included quartz and cryptocrystalline quartz material. During the Sassanian
period seals with a Mohs hardness of 1-3 were virtually absent (see Fig. 29). In the Asean there was a similar trend. Early Helladic and early Minoan seals were of softer stones, late Helladic and late Minoan of harder stones. A repetition of this trend occurred after the Dark Ages—soft stones being used in the Geometric period and hard stones subsequently.

In each period the tool was not much harder and indeed, many have not been as hard as the stone, for example, bronze, Mohs 4, used on hematite, Mohs 6. Therefore, the constant use of an abrasive would be essential. An exception might be flint on stone—which, from our own and Kashub's experimental drilling, does not require an abrasive.

Indeed, if the tool is often not as hard as the stone, why change? Three hypothetical explanations are that, first, the change from wood and stone to metal may have had to do with the amount of breakage that occurred both in making and in using the tools—particularly with microliths. This has been observed by several investigators. Correlated with that is the excessive amount of wear with wood and/or reed.

Second, metal permitted tools with a finer point and cutting edge for finer engraving—such as the fine disc and narrow tubular drill. Metal was easier to sharpen and could be reused.

And third, the finding that iron could be used as efficiently on harder quartz stones as was bronze on softer hematite or serpentine.

Given the constant use of an abrasive, how much difference is there in the drilling efficiency with various kinds of tools, stones, and abrasives?

This has been repeated by various scholars in a variety of fields over the years. A summary is interesting.

A most carefully measured study was reported by B. W. Knoblock. He used a bow-drill which rotated the spindle at 800 R.P.M. A full stroke of the bow developed eleven revolutions forward and eleven backward. Using dry, fine, quartz sand as an abrasive on the same hawled slate pebble (Fig. 4), he compared three different drill sticks, namely, hickory, hallow cane (Arundinaria gigantea) and flint. He drilled on six different sites, i.e., for 5, 15 and 90 minutes with hickory, for 30 minutes with cane and for 1 minute and 90/2 minutes with flint. He reported that flint was the most efficient. In 90/2 minutes, a drill hole a half inch in depth was created, that required 17,000 revolutions of the spindle. Interpolating the data, an equivalent depth would have taken 50 minutes using the hickory spindle and 120 minutes using cane. In his study, hickory drilled four times faster than cane and flint three times faster than hickory. Other studies are compared in Fig. 30.

In the same report the drilling time by cane of a ferruginous quartz pebble was also recorded. It took thirty hours of actual drilling time to effect a depth of one-half inch, fifteen times longer than on slate. About 3,200,000 revolutions were required and twenty-seven inches of cane would have worn away.

The relative advantage of copper tubing over cane, for drilling on quartz, can be derived from the experiment of McGuire. He used a pump-drill with a tubular spindle hammered from a native nugget of copper. Finery and quartz sand were used as an abrasive. It took three hours to drill a half inch, ten times faster than the cane used by Knoblock.

McGuire also compared the drilling time in quartz using a solid copper point versus a wooden toothpick. He reported that the copper tool was five times faster.

By way of comparison to contemporary motorized drilling, Sperisen reported that he drilled quartz to a depth of 29/20 inches in ten minutes using a tubular steel drill at 2,500 R.P.M with a diamond abrasive in oil. Spinel and corundum took twenty minutes and jadeite one hour. When he reduced the R.P.M. to 750 and changed the abrasive to silicon carbide, 220 grit, drilling on Jasper (Mohs 7), it took twenty minutes.

It is evident from these experiments why the earliest seals were generally made from stones with the Mohs hardness of 1-3 (Slates 4-5). Although it was possible to drill hard stones such as quartz (Mohs hardness 7) with wood, the amount of time and worn drill tips would explain why quartz seals are relatively few in number during the pre-copper tool period. Indeed, they may have been reserved for special members of the establishment, as Nissen suggests. Dr. Thomas Vuletic, a lapidary, fabricated a marble seal one inch by one-half inch experimentally, using modern lapidary methods, in one hour.

Future experimentation into the length of time to drill or indeed fabricate a seal completely by ancient methods, may eventually provide information as to the cost of seals, the weight of the seal maker and his relative position in his society. Larsen describes texts from the Old Assyrian trading colony, ca. 1800 B.C., about two seals of lapis. They weighed 13/4 shekels (12.5 grams—45 ounces). Given those weights, the seal could have been one inch in height and one-half inch in depth. It cost 10 1/2 shekels of silver.

Recently, Larsen has indicated that 10 1/2 shekels would also buy five sacks of barley, or an ox, or four or five sheep, or one or two textiles. A slave girl or a donkey would cost a little more, about 20 shekels.

Let us assume that it took one day to make. This would provide some parameter to the cost of production, the wages involved, and the relative position of the seal maker in his society. For example, according to Talbott, an average workman in Achaemenid times received one quarter of flour, whereas the chief official of the economic administration received two to three quarters plus extras. Where did the seal maker fit into this spectrum?
SUMMARY AND CONCLUSION

An investigation into the methods of drilling ancient Near Eastern stamp and cylinder seals was undertaken using "functional analysis," "sequential drilling and replication" and scanning electron microscopy. Twenty-eight seals were examined. Evidence was obtained as to some of the drill tips used, such as wood, flint and a tubular drill. Proof that a wooden drill tip was used with an abrasive on the globe forms of early steatite seals ca. 3000 B.C. was found. Initial evidence for the ingenious adaptation of the bow-drill to form a horizontal spindle for use with a cutting disc was found. This occurred on seals dated much earlier than was previously conjectured for the use of the horizontal spindle and cutting disc.

The pattern of concentric rings produced by an abrasive as part of drilling was a consistent finding similar to that previously reported.

File marks and exaggerated circular furrows not previously seen were evident in a significant number of seals.

A flare or bevel was evident at the open ends of several of the bores. Rather than being due to the cord by which the seal was usually worn, it was more likely the result of the lapidary technique to commence drilling. Evidence for this can be seen in unfinished bannerstones which also exhibit a bevel (Fig. 1).

Our hypothetical formulation was supported as follows: It is possible to identify the tool from the tool mark, providing (1) "standards" of ancient tool marks are developed, and (2) these tool marks or patterns can be duplicated experimentally. This warrants a broader investigation into all the methods of that skillful craftsman, the ancient lapidary, so that his role in his society may be better understood.

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