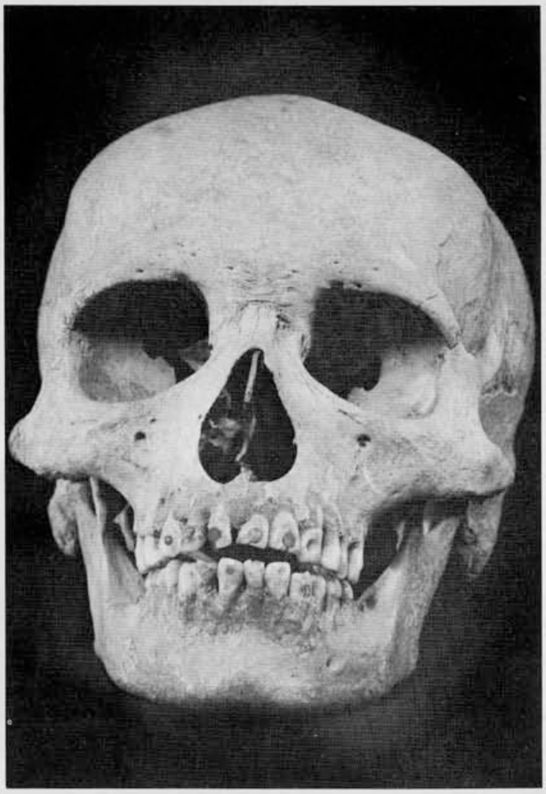
ANCIENT LAPIDARY

A Study using Scanning Electron Microscopy and Functional Analysis

A. JOHN GWINNETT
LEONARD GORELICK



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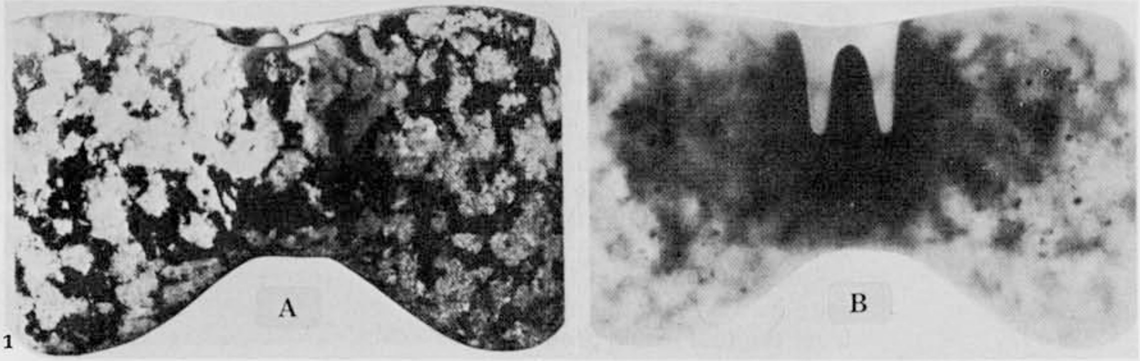
Ancient Maya skull showing teeth inlaid with jade and hematite. (Courtesy American Museum of Natural History).

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 ○, 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



1A, B
Bannerstone of the North American Indian with central bore shown by x-ray (B). Note the results of wear and wobble on the shape of the inner bore. Typically, the bore tapers toward the bottom while the solid core narrows toward the top. (Copied from Knoblock 1939)

artifact are the bannerstones 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 Jemdet Nasr period, ca. 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 the borrowed 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 lapidarist named Lorenzo Natter in *A Treatise on the Ancient 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 much pleasure 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." In it he stated that by duplicating the microscopic markings found on ancient liths through use, in the manner and function suggested by the shape of the lith, 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 affected differently by different tools and abrasives. Tools wear leaving altered patterns. In addition, tool marks, particularly shallow ones, were often polished away. However, since the deeply drilled central bores of most ancient artifacts would have had no reason to be polished, we realized that this would be a useful place to start. Also, if drilling on the surface of the artifact were deep enough, it might have escaped a polish, providing another site to examine.

Indeed, such a preliminary investigation was made and reported in *Expedition* (Winter, 1978). In that report, a method of making silicone impressions of the central bore and engraved surface of four ancient Near Eastern stamp and cylinder seals was described. These were examined in the scanning electron microscope (SEM). Some of our findings were (1) the continued application of an abrasive, such as sand, was a primary method of abrasion in ancient times as shown by the concentric abrasion rings found on the bores of seals that ranged from 3000 B.C. to A.D. 600; (2) the microscopic differences in the globe forms on the engraved surface depicting the Pleiades were very likely due to the

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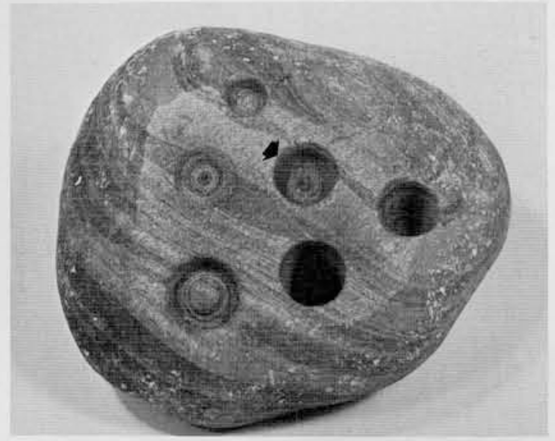
Obsidian cylinder seal of the Proto-Elamite period ca. 3000 B.C. in the Ancient Near East. (Gorelick Collection).

wear of the tool used in their manufacture and unknown to the maker; (3) although the sample was limited, notable differences were observed between the abrasion characteristics of genuine and forged seals.

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



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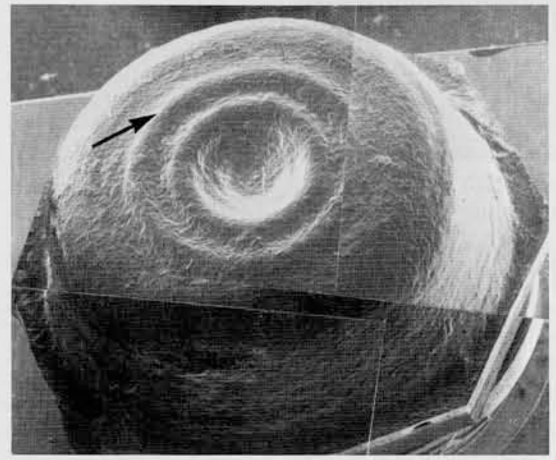
Slate pebble drilled using solid wood, hollow cane and flint with a bow drill on six different sites for different intervals of time. (Copied from Knoblock 1939). (For meaning of arrow, see Fig. 5 caption).



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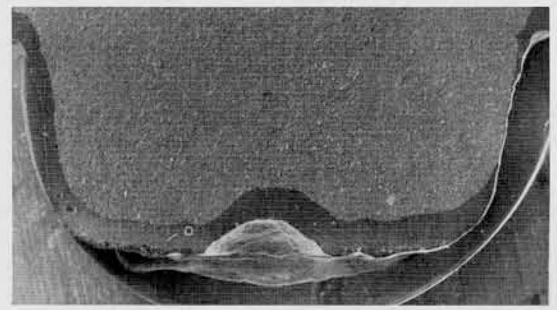
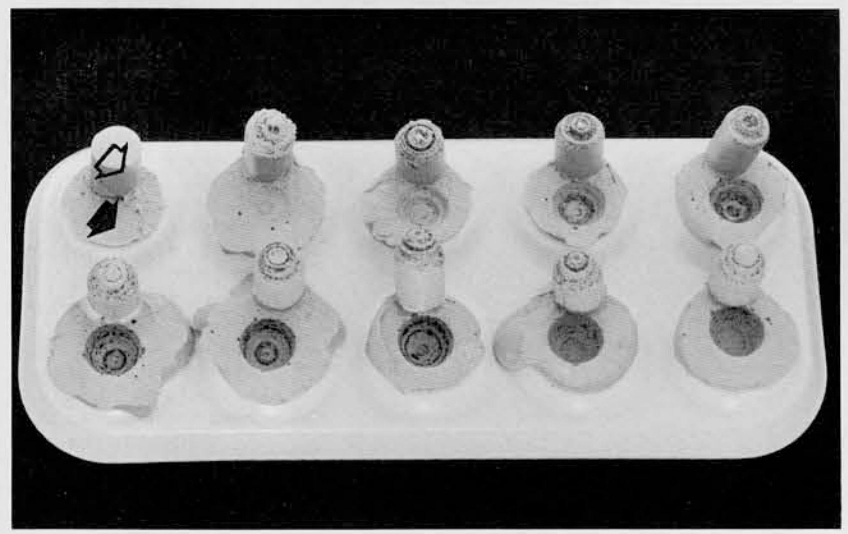


5b

5A, B
Scanning photomicrographic composite of an impression of the drilling site identified by an arrow in Fig. 4 in which solid wood and sand were used. Note the terracing (arrow) and central depressed form in the cross sectional view. In reality this latter form is an elevation in the stone.



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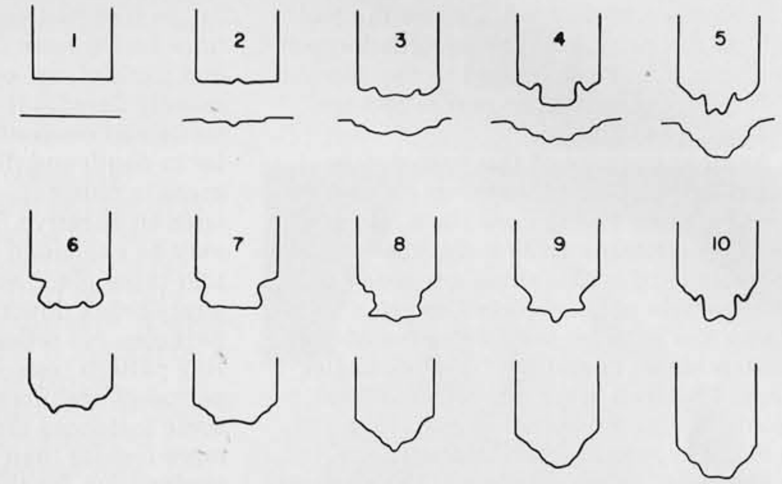
Model showing sequential drilling using wood (birch) and sand on slate. The wood drill (open arrow) and the slate (closed arrow) are shown at ten different intervals.



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Diagrammatic reconstruction of the changes in a wooden drill stick (birch) and slate 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 "terracing." Within this pattern there is an early elevation in the center of the slate drilling (Stage #3) and similar to Knoblock's drilling shown in Fig. 4 (see arrow). However, this changes to a marked depression, (Stage #5) and a related shape in the wood. At the 7th stage the leading edge of the drill stick has worn until it is almost flat again and a new elevation similar to Stage #3 is reappearing. Stage #8 bears a resemblance 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 lapidary procedures this 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. 8A & 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 attempts at their duplication. The artifacts used in this study consisted of twenty-eight ancient Near Eastern stamp and cylinder seals from the Metropolitan Museum and the Gorelick Collections. The seals were divided into two groups. In the first were twenty-four made of crypto-crystalline quartz, i.e., chalcedony, jasper and agate. The periods ranged as follows: Early Dynastic II (ca. 2700 B.C.), Akkad (ca. 2350 B.C.), Old Babylonian (ca. 1700 B.C.), Kassite (ca. 1500 B.C.), Syrian (ca. 1400 B.C.), Mitannian (ca. 1400 B.C.), Middle Assyrian (ca. 1300 B.C.), Neo-Assyrian (ca. 700 B.C.), Neo-Babylonian (ca. 700 B.C.), Achaemenid (ca. 400 B.C.), and Sassanian (ca. A.D. 400).

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

Silicone impressions were made of the central bores 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 in the bores were consistent and similar to those found in the previous study (*Expedition*, Winter 1978). 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; (3) in all examples, 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 finer 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 finer 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 ceramically bonded abrading stone.

The variety of bore shapes may be explained by:

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 Knoblock and our own sequential drilling (Fig. 8A & 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*.

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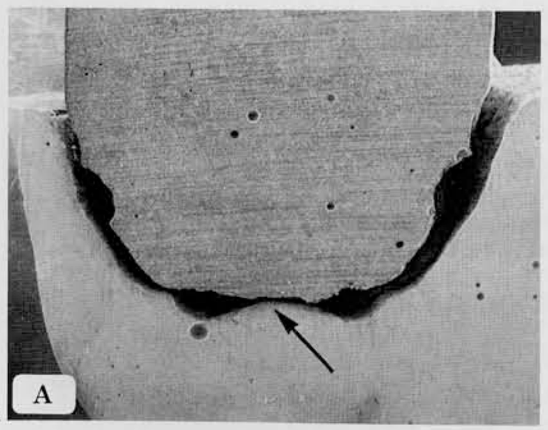
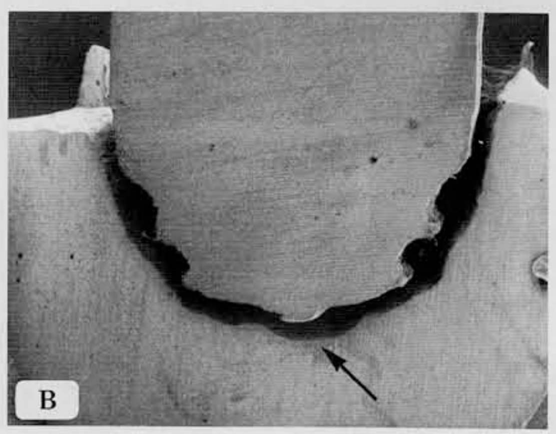
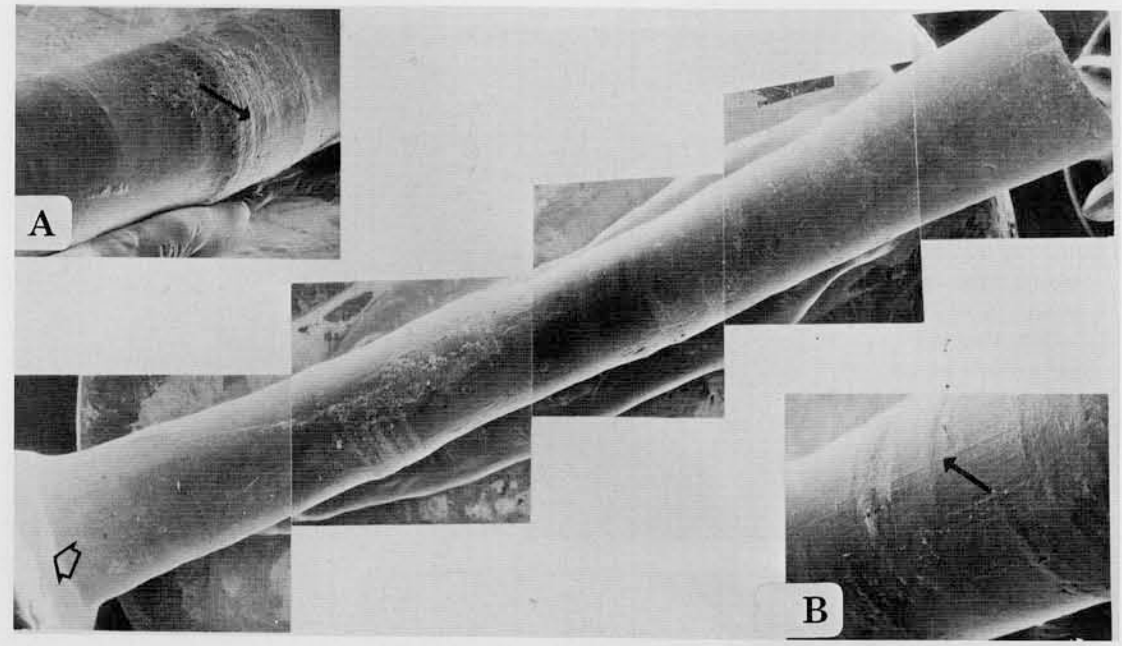




8A, B
Scanning micrographs of a section through a wooden drill *in situ* in slate identical to Stages #3 and #8 in which the drill has become tapered and the leading edge shows a terraced pattern with A) an elevation (arrow) in the slate and B) a depression (arrow) in the slate at different stages. The larger diameter of the cavity compared to that of the tool is due to wobble and peripheral abrasive action. Indeed, the biconical shape frequently reported for ancient drilling is related undoubtedly to both wear and wobble in addition to the shape of the tool at commencement of drilling.



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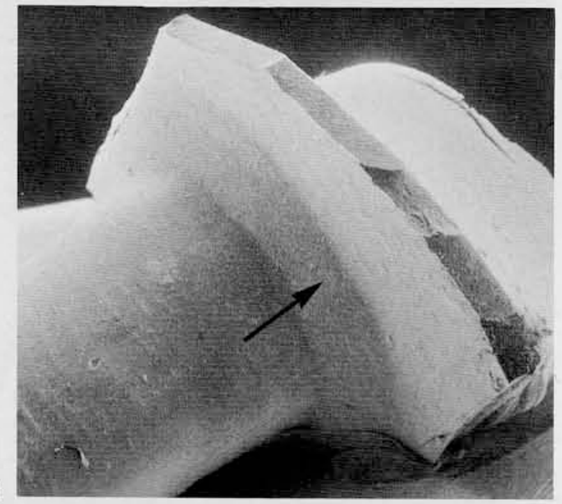
Scanning micrograph of an impression of the bore of an Old Babylonian crypto-crystalline seal. Note the narrowing toward the center indicating drilling from either end. Concentric abrasion rings are seen (inset A arrow) with longitudinal marks (inset B arrow) undoubtedly created by a file. Note the flare (open arrow).



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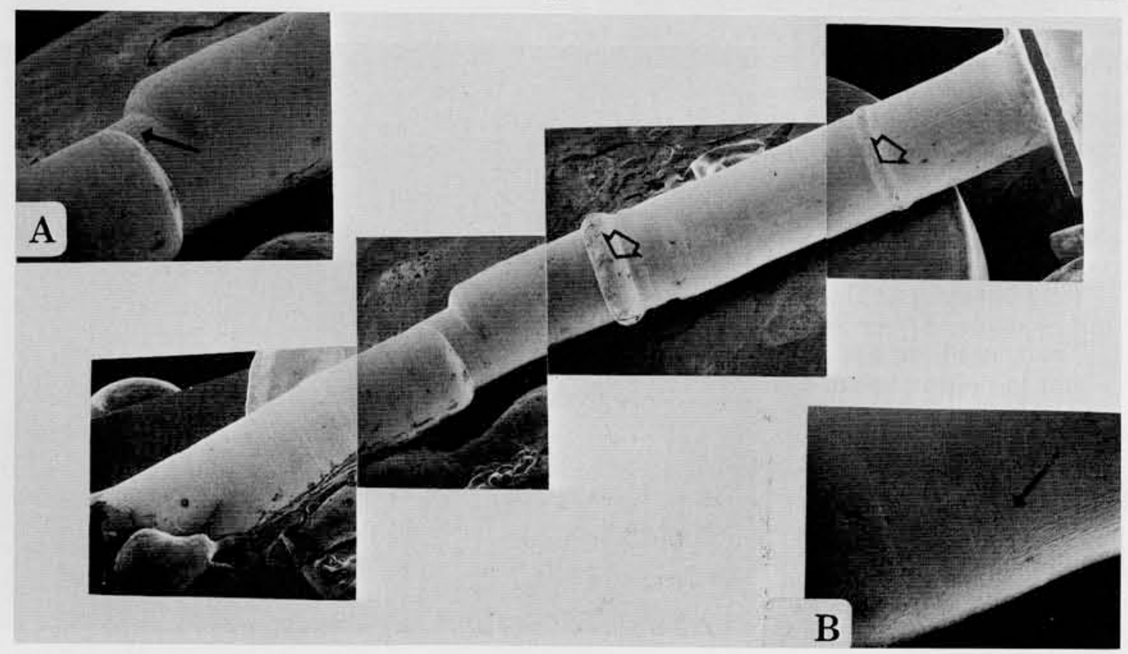
It is interesting that the greatest width of the bore occurs as a flare (arrow), as distinguished from wobble, at the bore opening. This is very likely due to the method used to start the bore opening and not to the manner in which the seal was worn. A similar flare can be seen on other drillings such as teeth and bannerstones which were not worn. A similar feature can be seen on Knoblock's experimental drilling in Fig. 5 and the unused bannerstone shown in Fig. 1.



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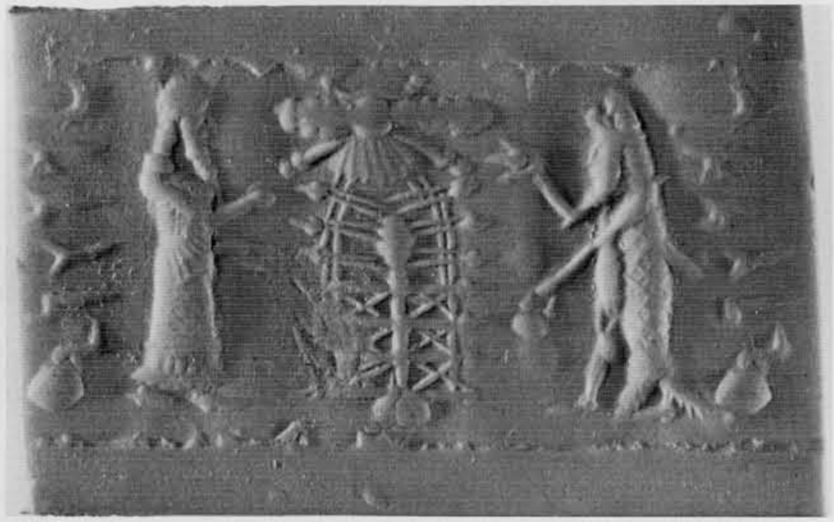
Scanning micrograph of an impression of the bore of a Middle Assyrian crypto-crystalline seal. Note that although the walls are remarkably parallel, the drill holes from each end did not meet. The file marks (inset A arrow) were very likely an attempt to break through and widen the bore. Concentric abrasion marks (inset B arrow) are also evident. The collar shapes (open arrows) will be discussed later.



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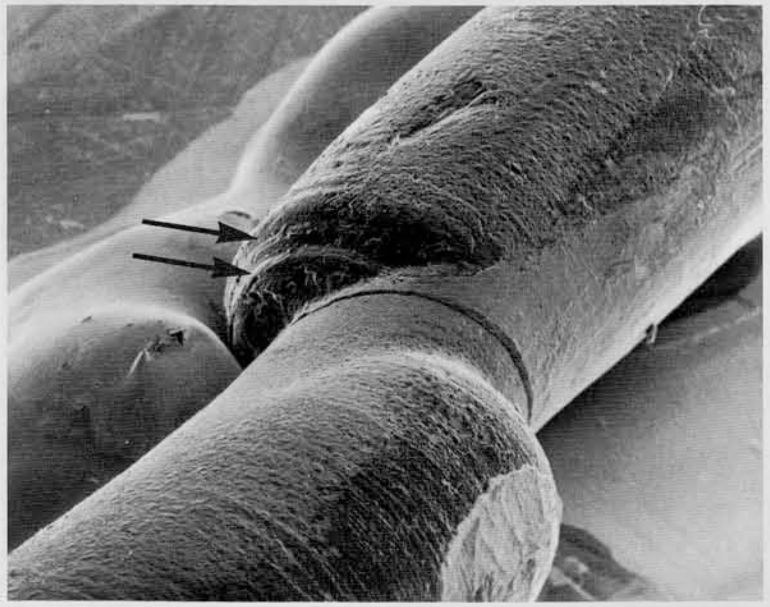
Neo-Assyrian seal showing a priest in the garb of a fish standing before a sacred tree above which is a winged sun disk.



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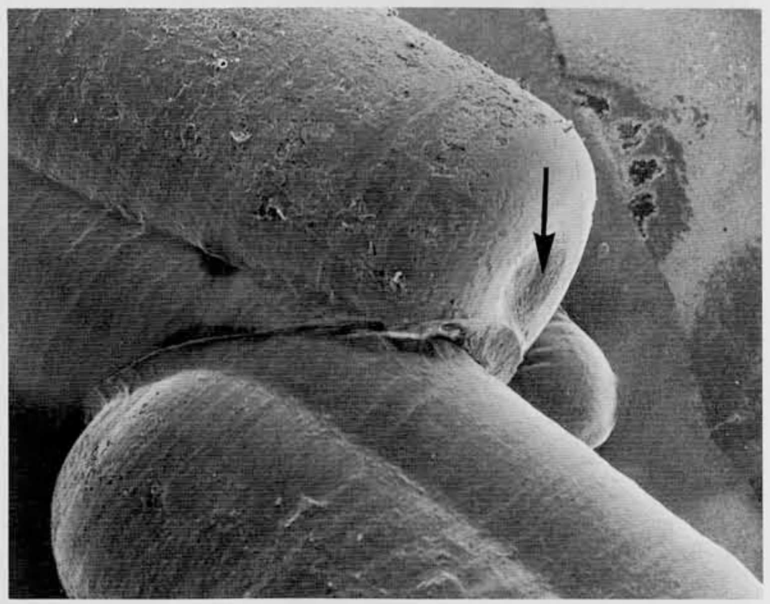
Scanning micrograph of the Neo-Assyrian seal in Fig. 12, in which the leading edge shows a terracing effect (arrows). Even though the central portion was not visible, the terracing appears similar to Stage #4 in our experimental drilling shown in Fig. 7.



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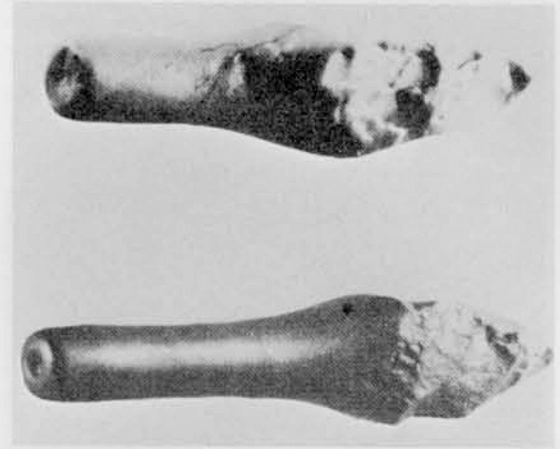
Scanning micrograph of a Neo-Babylonian seal in which the leading edge was an elevated base in the stone, seen here as a depression (arrow) in the impression.



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Microliths excavated by Tosi at Shahr-i-Sokta. Note the similarity of the depression and rounding to Fig. 14.

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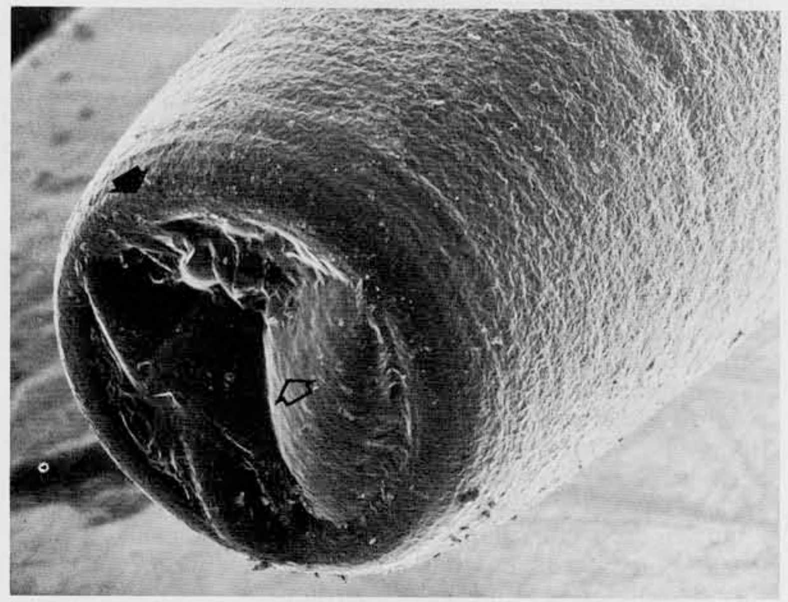
Achaemenid stamp seal showing a king attacking a lion.



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Scanning micrograph of the bore of an agate seal of the Achaemenid period. Drilling with a tubular drill produces a solid core similar to that shown in Fig. 1. Measurements suggest a drill with an outside diameter of 1.5 mm. and an inside diameter of 1.2 mm., possibly of metal 0.15 mm. thick. The fracture pattern (open arrow) produced at the base is conchoidal and consistent with removal of a solid core. The gently rounded angle between the floor and the walls (solid arrow) is typical of tubular drilling.

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 tip. 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 steatite (Fig. 7). The sequence shows the continuing wear pattern on the wooden drill tip 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. 26). 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: (Gorelick Collection Cat. #44). Because the drilling from either end was very crooked and almost did not meet, the silicone impression provided a very 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 some stone microliths used for bead manufacture excavated by Tosi at Shahr-i-Sokta, Iran in 1968-69 and reported in *East and West*. Piperno, reviewing these microliths (*South Asian Archaeology, 1973*) described their shape as due to a wear pattern. Proof of this would require further experimental drilling with similar stones, substrates and abrasives.

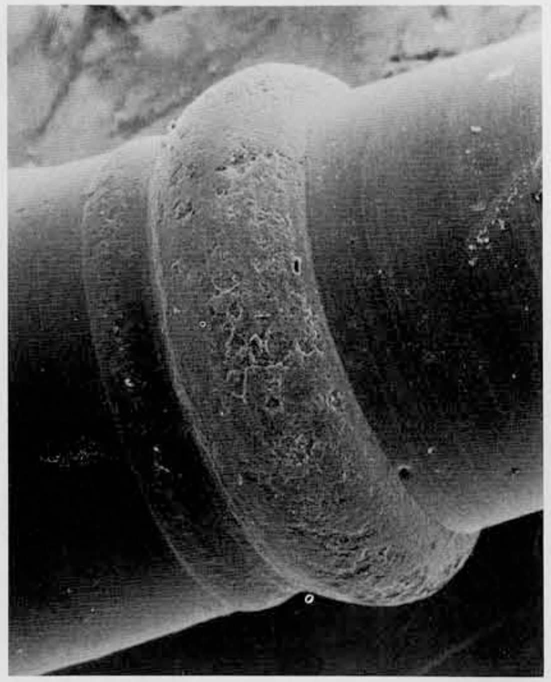
Achaemenid Stamp Seal (Fig. 16). This seal had a typical bore as well as one that was incompletely drilled alongside. The reason for this is unknown. It may indeed have been a craftsman's error. The shape at the dead end, however, had an interesting configuration. The major portion of the floor showed 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 bores 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 form 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 crypto-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 undercuts 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* instead of a vertical position (Fig. 19). If the partly drilled seal were being held with two 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.



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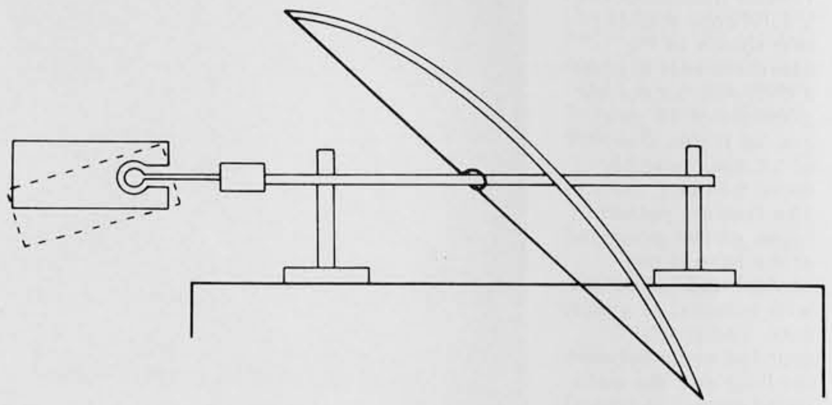
Scanning micrograph showing a characteristic collar shape. The surface was invariably rougher than the adjacent regions containing few, if any, concentric abrasion marks prominent to either side of the collar.



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Drawing demonstrating how, in theory, a collar shape can be produced with a ball-shaped metal tool on a horizontal spindle while gently moving the seal.

The furrows seen may not be of the original size. As the bore was widened with the original tool or with files, 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 use (see Figs. 9 and 10).

If the second hypothesis on the use of a horizontal spindle is correct, then it would suggest redating 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 stelae 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.

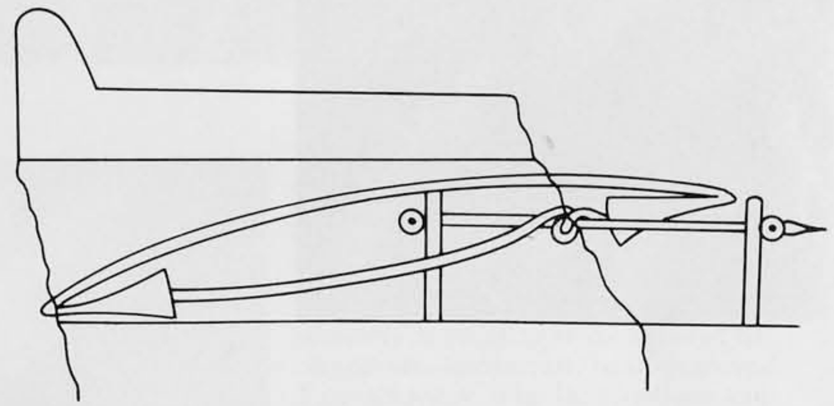
This type of spindle may very well have been the antecedent to the traditional lathe used for turnery seen on the thrones of Assyrian kings. Strictly speaking, the term "lathe" is used when the work is turned and a tool is held against it. A variety of terms are used for the horizontal spindle in which the work is held and brought to the rotating tool, whether it be a drill, tube or disc.

The looseness in terminology may indeed be a reflection of the underemphasis and lack of appreciation of the importance and utility of the horizontal spindle in ancient lapidary procedures. By freeing both hands, it allows the work to be more carefully and rapidly manipulated to produce desired shapes. The technological creativity in turning the vertical bow-drill on its side and supporting the spindle on either end almost has the ingenuity and simplicity of the invention of the wheel. Indeed, it has been used continuously ever since.

Wülff mentions a lathe used by a Moslem scientist to make a parabolic mirror ca. A.D. 1000. An engraved plate in Klemm's *History of Western Technology* shows a craftsman in A.D. 1390 using a "bowstring operated (*horizontal*) boring machine for preparing pearls for necklaces."

Natter shows a foot-powered horizontal spindle on an engraved plate in his previously mentioned book. Hansford describes it in discussing ancient Chinese jade manufacture, and Wülff has photographs of primitive versions still used by Iranian craftsmen. The makeshift nature of the lathes shown by Wülff and the perishable 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 lith, 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 grist for the drill may be found in the following observation made in 1714 by John Lawson in his *History of Carolina* in 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."



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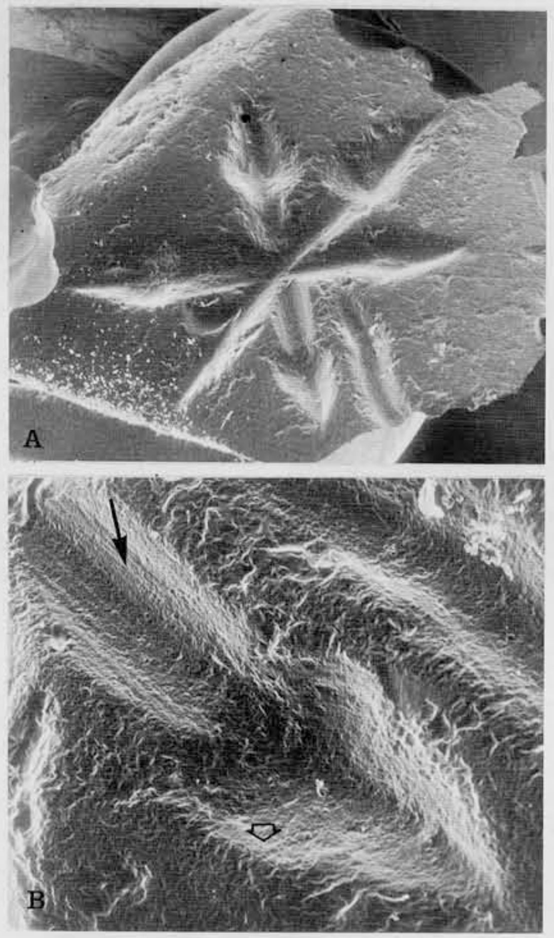
Drawing of a "bow lathe" found on the stela of a grave of a Roman gem carver.

The Engraved Surface

While there has been speculation about the inception of the horizontal spindle prior to the Kassite period, clear-cut 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 inception 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 Jemdet Nasr 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



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21A, B
Scanning micrograph of an obsidian Proto-Elamite seal demonstrating (A) configuration and markings consistent with those produced partly by a disk which are characterized at higher magnification (B) by numerous regular, parallel lines (arrow) in the direction of the furrow. The triangular form below was hand engraved. This seal is shown in Fig. 3 and suggests evidence for a horizontal spindle much earlier than previously shown.

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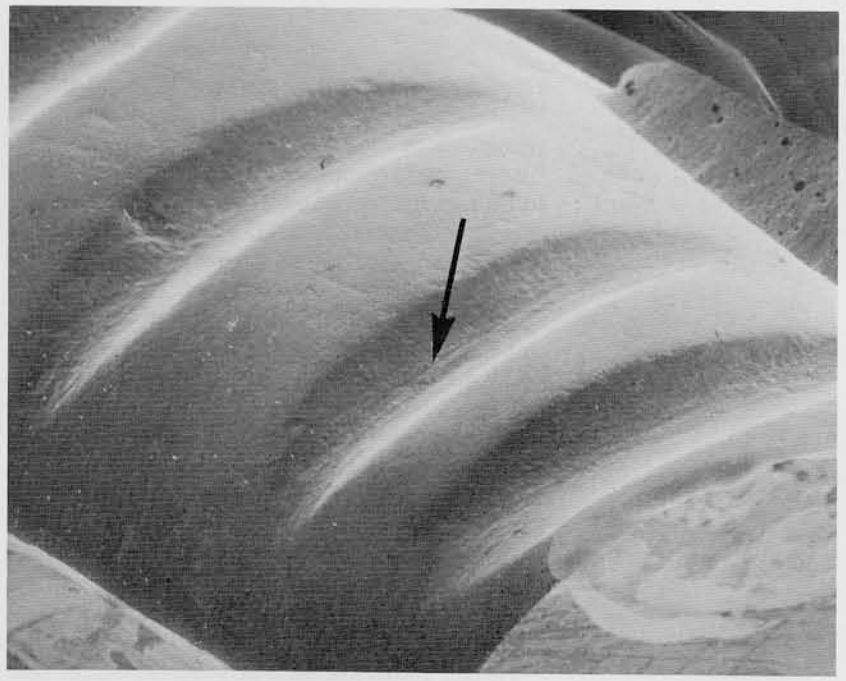
Scanning micrograph of a white marble seal from the Jemdet Nasr period. Note a pattern of parallel lines (arrow) similar to those seen in Fig. 21.



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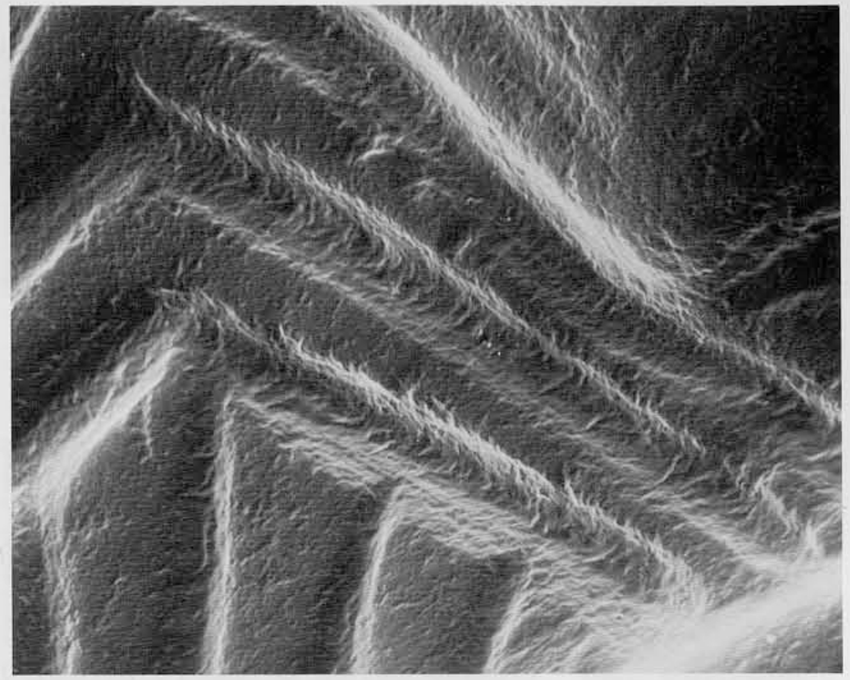

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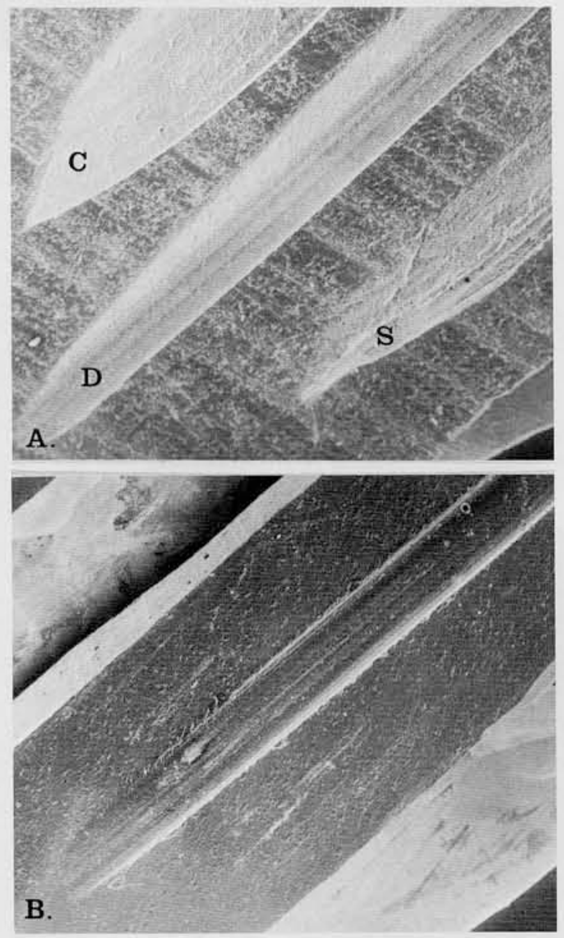
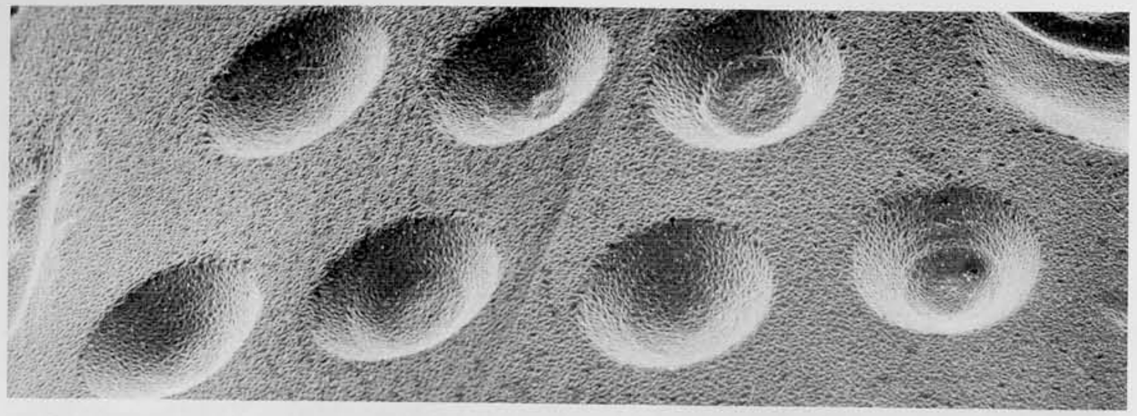
23
Scanning micrograph of a hematite seal of the Old Babylonian period showing a hand-engraved line. Note the irregular furrow outline and the absence of fine lines in the furrow.

24A, B
Scanning micrograph of experimental disking on steatite (A) using a knife-edged copper disk (C), a diamond disk (D) and a hand steel engraved furrow (S). Both disk shapes have regular margins, distinctive geometric outlines and narrow, regular parallel lines in contrast to general irregularities in the hand-engraved furrow. While not shown in the micrograph, the cutting entry and exit shapes left by disks are symmetrical. Note that the effect of a diamond disk on obsidian (B) compares closely with that seen in Fig. 21.



24

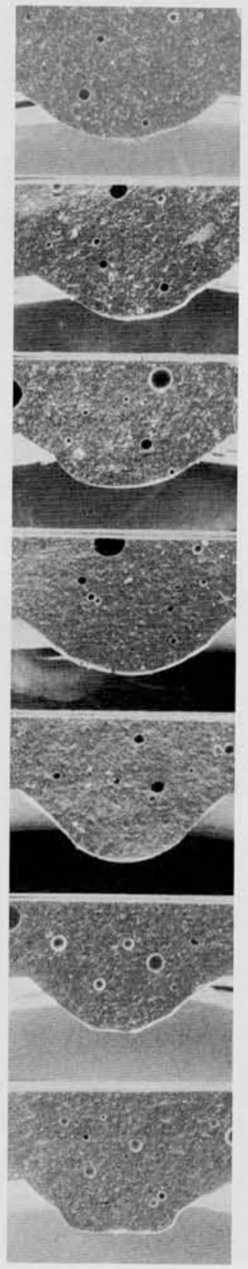
diamond and copper disks which we used experimentally. The size, shape and termination of the furrow depend upon the shape of the tool, i.e., flat, rounded or knife-edged, and also on the nature of the tool, i.e., metal, shellac embedded with an abrasive, a grinding stone abraded to shape, etc. In contrast, 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.



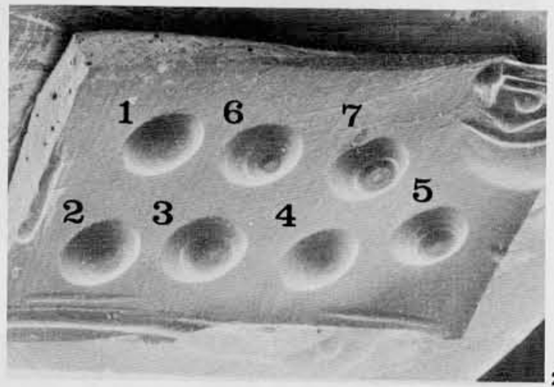
25

25
Scanning micrograph showing seven globe forms of the Pleiades in which the base is either rounded, slightly elevated or flattened.

26A, B
Scanning micrographs showing the central profiles of the globe forms in Fig. 25. They have been ordered according to a prediction of tool wear dictating shape. It is assumed that one tool was used. Measurements of width, slope, depth and configuration of the globes suggest a single tool. The drilling sequence of the Pleiades is predicted in the accompanying micrograph.



26a



26b

Globe Forms

The twenty-four crypto-crystalline quartz seals were examined for the presence of globe forms. Fifteen seals had such forms, which ranged from a low of one globe per seal to well over twenty globes per seal.

The vast majority of globe forms were smooth, rounded, hemispherical configurations. Where globe forms existed side by side as in the depiction of the Pleiades, certain changes in shape were evident. Four seals showed such a feature. The most common configuration was smooth and rounded (13), followed by elevated base (7), flat floor (6) and depressed base (2). Figure 25 shows the globe forms of the Pleiades in which the rounded and flattened floors dominate.

As in our previous report, we consider the changes in the globe forms to be a reflection of the wear pattern of the tool. The fineness of the shape suggests the use of a rounded metal tool; however, more research is needed using sequential drilling and replication. Ball-shaped drills are shown by Natter and Hansford and indeed have always been used in dentistry to start and enlarge the site of drilling.

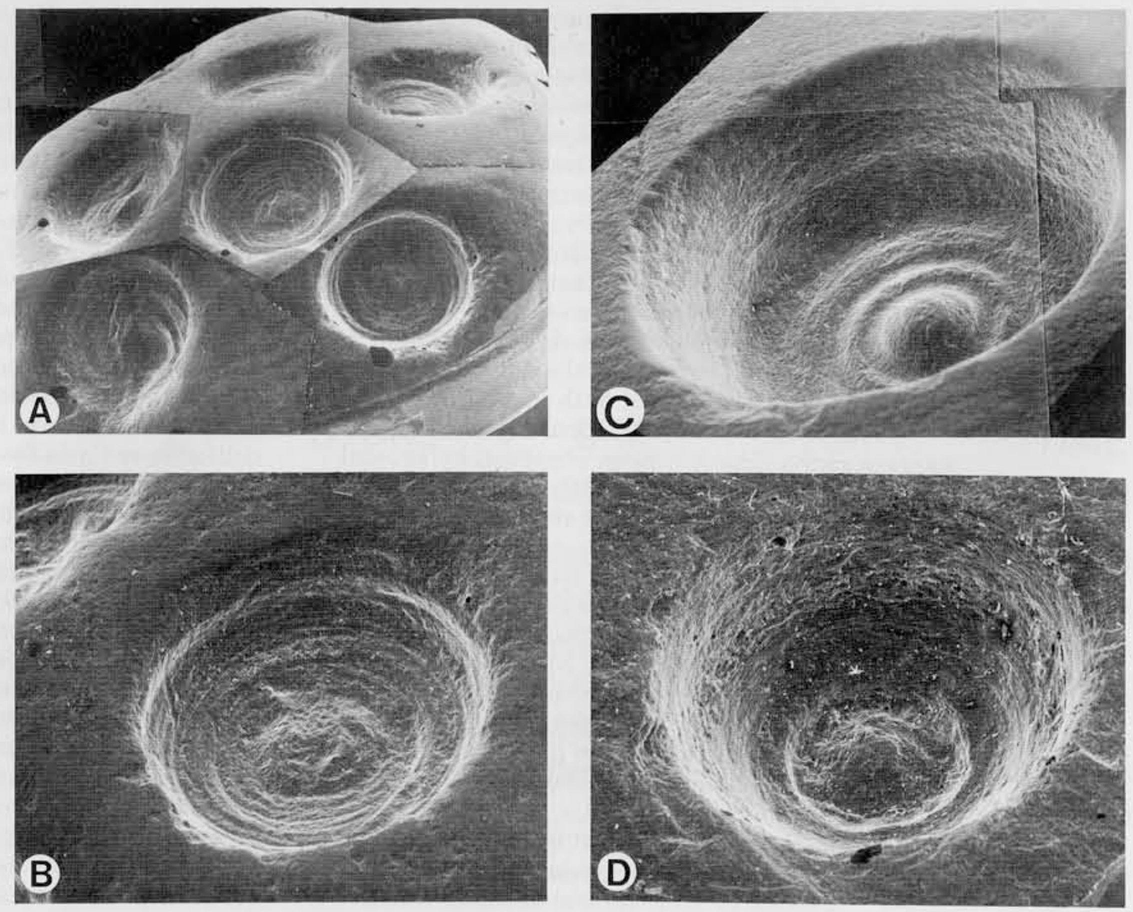
Several globe forms on seals of the Jemdet Nasr period were examined. The stones were all much softer than the quartz seals previously described, having a Mohs hardness of 1-3. The pattern shown consisted of "terracing." The terracing phenomenon is also found in the cavities drilled in teeth of the Ancient 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 firmest 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. Tosi 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 collating 2200 seals according to their Mohs hardness. These were taken from the catalogues of the following collections: Morgan, Ashmolean, Moore, British Museum Stamp Seals (BIVAR), Les cachets mesopotamiens (Homès-Fredericq).

It was found that seals with a Mohs hardness of 1-3 predominated from the Obeid period (3800 B.C.) through Ur III (ca. 2300 B.C.). The stones often used were steatite, marble, limestone, alabaster. In the pre-Obeid 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. 2000-1150) when a Mohs hardness of 4 through 6 predominated. Stones of hematite, lapis, 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 crypto-crystalline quartz material. During the Sassanian

27A, B, C, D
Photograph (A) and scaning micrograph (B) showing a globe form from a steatite stamp seal of the late 4th millennium B.C. Note the "terracing" which may be keyed to Stage #5 in Fig. 7 and the similarity to Knoblock's experimental drilling (C) and our own (D), both on slate. All were done with a wooden drill.



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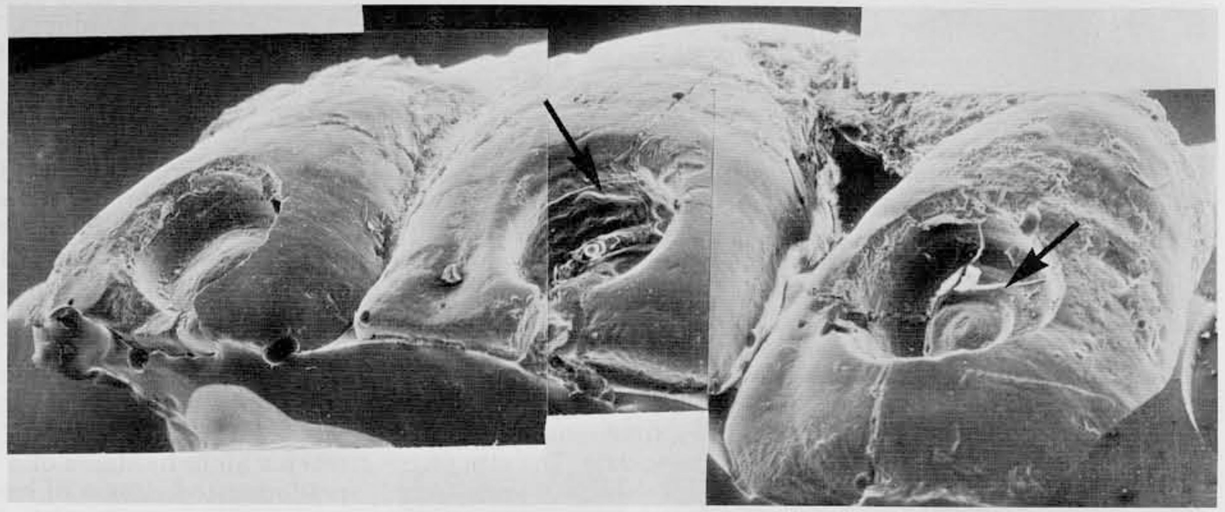


28
Scanning micrograph of cavities in the teeth of an Ancient Maya, showing "terracing" (arrows) consistent with our evidence using functional analysis for the use of wood as a drill.

period seals with a Mohs hardness of 1-3 were virtually absent (see Fig. 29).

In the Aegean 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, may not have 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 steatite—which, from our own and Knoblock's experimental drilling, does not require an abrasive.

Indeed, if the tool is often not as hard as the stone, why the changes? 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 tool—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?

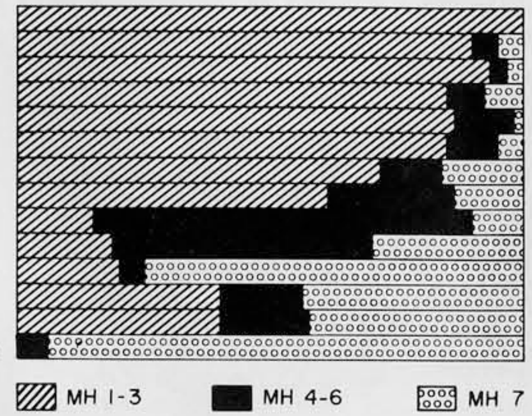
This has been studied by various scholars in a variety of fields over the years. A summary is interesting.

A most carefully measured study was reported by B. W. Knoblock. He used a bow-drill which rotated the spindle at 856 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 banded slate pebble (Fig. 4), he compared three different drill sticks, namely, hickory, hollow cane (Arundinarea 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 9½ minutes with flint. He reported that flint was the most efficient. In 9½ minutes, a drill hole a half inch in depth was created, that required 17,888 revolutions of the spindle. Interpolating the data, an equivalent depth would have taken 30 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 3,250,000 revolutions were required and twenty-seven inches of cane would have been worn away!

The relative advantage of copper tubing over cane, for drilling on quartz, can be derived from the experimentation of McGuire. He used a pump drill with a tubular spindle hammered from a native nugget of copper. Emery 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.

DATE	PERIOD	% MOHS HARDNESS 1-3	4-6	7
4500 - 3800	PRE-OBEID	100	0	0
3800 - 3400	OBEID	92	2	2
3400 - 3200	URUK	96	2	2
3200 - 2900	JEMDET NASR	86	7	7
2900 - 2370	EARLY DYNASTIC	88	11	1
2370 - 2154	AKKAD	85	9	6
2154 - 2112	POST AKKAD	71	13	16
2112 - 2004	UR III	62	24	12
1894 - 1750	OLD BABYLONIAN	14	76	10
1590 - 1150	KASSITE	18	50	32
1350 - 1000	MIDDLE ASSYRIAN	20	4	76
1000 - 627	NEO-BAB.---NEO-ASSYR.	40	16	44
539 - 331	ACHAEMENID	40	17	43
244 A.D.- 642 A.D.	SASANIAN	0	7	93



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 .28 of an inch in ten minutes using a tubular steel drill at 2,500 R.P.M. with #3 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. (Slate is 3.) 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. Thomashow, a lapidarist, 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 wages 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 1½ shekels (12.6 grams—.45 ounces). Given these weights, the seal could have been one inch in height and one-half inch in depth. It cost 16½ shekels of silver. Recently, Larsen has indicated that 16½ 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 Hallock, an average workman in Achaemenid times received one quart of flour, whereas the chief official of the economic administration received 180 quarts plus extras. Where did the seal maker fit into this spectrum?

29
Table showing the relationship of period of seal manufacture to Mohs hardness of stones used.

30
Table showing drilling time to achieve one-half inch depth using sand and various drills.

STONE	DRILL TIP	ROTARY MECHANISM	TIME
Slate*	Wood (hickory)	Bow Drill	30 min.
Slate*	Cane	" "	120 min.
Slate*	Flint	" "	10 min.
Quartz*	Cane	" "	30 hrs.
Quartz**	Copper Tube	Pump Drill	3 hrs.
Quartz***	Steel Tube	Motorized Drill	35 min.
Quartz***	" "	" "	15 min.

* KNOBLOCK and ** McGUIRE USED SAND. *** SPERISON USED SILICONE CARBIDE and DIAMOND POWDER RESPECTIVELY.

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 lapidarist, so that his role in his society may be better understood.

Acknowledgments
We acknowledge and express appreciation for the cooperation and encouragement of Vaughn Crawford, Prudence O. Harper, Pieter Meyers and Holly Pittman of the Metropolitan Museum of Art and for the Grant from the Adelaide de Groot Fund. We also acknowledge useful consultations with Ed. Wiener, master jeweler, and Dr. Milton Thomashow on lapidary; with Drs. Dan Kaplan and Ron Wyatt, Curators of Anthropology at the Garvies Point Museum, and Dr. Gordon Ekholm, Curator Emeritus at the American Museum of Natural History. Finally, we express appreciation to Byron Knoblock for the generous loan of his experimental drill material, and to Dr. Mogens Trolle Larsen, Professor of Assyriology, University of Copenhagen for his advice on ancient measuring standards.

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Dr. John Gwinnett (top) is an Associate Professor of Oral Biology and Pathology at the Health Sciences Center, S.U.N.Y. at Stony Brook, New York. **Dr. Leonard Gorelick** is an Assistant Professor of Children's Dentistry at Stony Brook Dental School, Long Island, and a staff orthodontist at Long Island Jewish-Hillside Medical Center. Their mutual interest in the use of the scanning electron microscope in the study of changes in the surface morphology of materials led to their extension of this use to the study of ancient artifacts. Its use in the study of the bore of seals was reported in *Expedition* 20, 2. Here they have gone further in the use of modern science in an effort to learn more about ancient lapidary techniques and the tools used.