The Change from Stone Drills to Copper Drills in Mesopotamia

An Experimental Perspective

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An important craft in ancient Mesopotamia was that of the lapidary—the maker of stone beads, amulets, figurines, small vessels and cylinder seals. One of the primary tools of the lapidary is the drill, used to shape, pierce, and decorate the surface of such artifacts. The earliest drills that have been recovered archaeologically are made of flint. These were eventually replaced or supplemented by copper or bronze drills, but little is known about the development of such metal tools. It is the origin of copper/bronze drilling technology that we wish to investigate in this article. We have focused on the manufacture of cylinder seals, since such artifacts often preserve drill marks that have been removed by subsequent polishing on beads or vessels.

Archaeological evidence for copper/bronze drills and the abrasives used with them in ancient Mesopotamia is extremely limited (see below). Cuneiform texts dating before 2000 B.C. supply the ancient word for "seal cutter" (***bur-gul*** in Sumerian and ***purkullu*** in the Akkadian language), but have thus far yielded little information on materials or technology (see Porada in Gibson and Biggs 1977). We have therefore chosen a different approach in order to make up for deficiencies in the archaeological and historical records. This approach relies on the examination of the marks left by ancient drills on stone cylinder seals, and the experimental duplication of such marks under controlled laboratory conditions.

Archaeological Evidence

Flint drills and workshops for the production of beads made from rocks and minerals have been discovered at sites such as Neolithic Cayönü in Turkey (ca. 7000 B.C.), and Bronze Age Shahr-i Sokhta and Tepe Hissar in Iran (ca. 2800-2200 B.C.; see Tosi and Piperno 1973). By contrast, copper drills are very seldom found, as a result of both ancient and modern factors.

First, ancient copper drills may be rare because they were seldom thrown out as trash, and are simply not present in the deposits investigated by archaeologists. When a stone drill suffers a major break, it is beyond repair—useless and cheaply replaced. But when a copper tool breaks, it still has value as scrap metal that can eventually be remelted and formed into another implement or ornament. Second, thin metal rods are subject to corrosion and are therefore much more perishable than chipped flint drills. Finally, even if copper drills were deposited as part of a site and recovered by the archaeologist they might not be recognized, since the wear marks that are critical in identifying copper rods as drills would have disappeared under a layer of corrosion.

Within Mesopotamia, only one copper tool has been tentatively identified as a lapidary's drill. This came from Tell Asmar in the Diyala region of Mesopotamia and dates to the Dynasty of Sargon of Akkad ca. 2350 B.C. At Tell Asmar, a series of hoards packed into small pots was found buried beneath the ground. One such hoard seems to have been "the working capital of a seal cutter" (Frankfort 1933:47; 1939:5). It included several finished cylinder seals made of stone, some undecorated stone beads that may be "blanks" or unfinished seals, several copper tools, and a whetstone. Most of the copper tools had pointed working ends and were probably used as chisels or engravers. Of more interest to us, however, was an implement with a spatula-shaped cutting edge and a square-sectioned tang that has been interpreted as a drill bit or borer (Frankfort 1939:5). The tang of this copper tool was presumably set into a wooden shaft, so that the bit could be rotated with a bow (see Fig. 2).

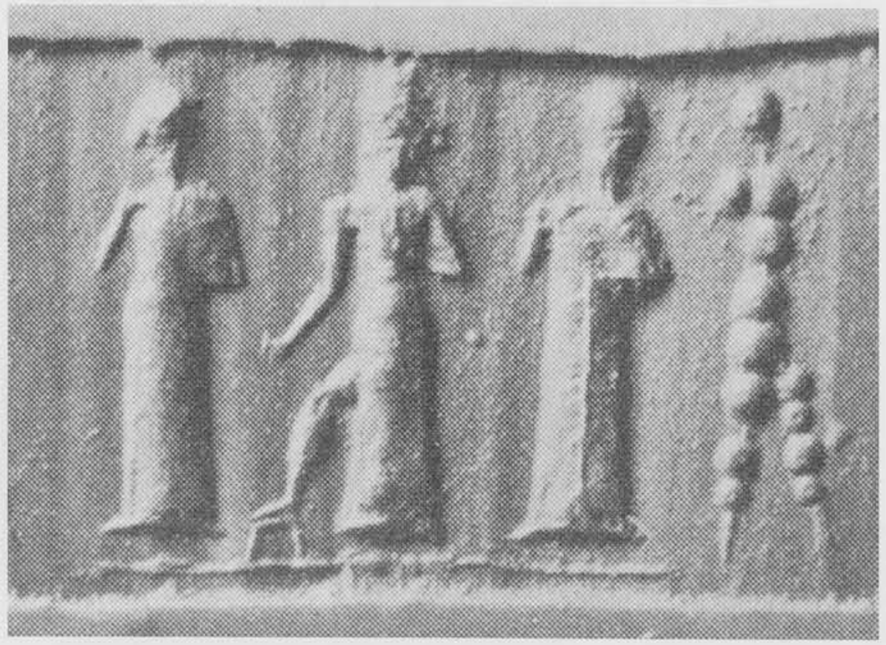
Henri Frankfort, director of the excavations in the Diyala and an authority on ancient Near Eastern art, was particularly interested in cylinder seals (Fig. 1). This artifact type was first made in Mesopotamia around 3700 B.C. Based on the hoard from Asmar and his observations of modern drilling technology in the Middle East, he made the following generalization: "Until Assyrian times, when iron came into use, *all* cylinder seals were cut, drilled through and decorated by means of copper tools, which in the case of hard stones were probably fed with emery powder" (Frankfort 1939:5; our emphasis). Nothing further has been published either corroborating or contradicting Frankfort's conclusions, and these have remained as conventional wisdom (see, for example, Nissen in Gibson and Biggs 1977).

A New Approach to the Study of Ancient Cylinder Seals

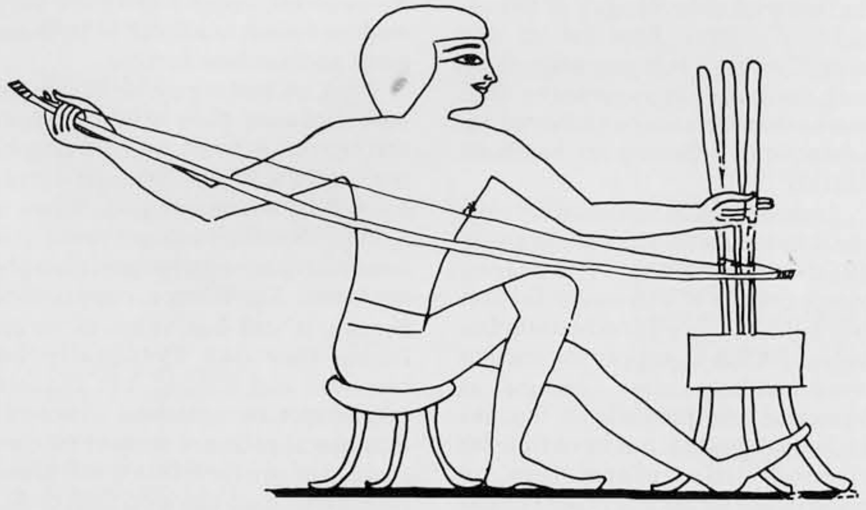
Our earlier experimental research on techniques of stone working suggested that some of Frankfort's conclusions were incorrect. Specifically, it was our guess that early cylinder seals in Mesopotamia were made with chipped stone drills, and that copper/bronze ones were not introduced until later on, perhaps coinciding with a preference for seals made of very hard rock such as hematite after 2000 B.C.

The purpose of our research, therefore, was to test the following set of related hypotheses:

1. Mesopotamian cylinder seals fabricated in ca. 3000 B.C. were made using chipped stone drills, and not necessarily copper ones.
2. Cylinder seals made of hematite ca. 2000 B.C. were most likely manufactured by using copper/bronze drills.
3. Chipped stone drills were not used on hematite seals after 2000 B.C.
4. The abrasive used with copper/bronze tools to make seals could have been crushed quartz (sand) or emery.
5. The abrasive was not used dry, but with a lubricant such as water or oil.
6. Chipped stone drills used on soft stones such as marble did not require an abrasive.



1
Impression of Old Babylonian seal from Ischali. The scene carved on the seal shows the sun god (with horned headdress) between two standing figures. A fourth, unfinished figure suggests that all of the figures on the seal were first outlined with a series of drill holes and then fleshed out by means of an engraving tool. Hematite seal. H. 2.2 cm, Dia. 1 cm. (From Frankfort 1955, Pl. 89, No. 950. Reproduced by permission of the Oriental Institute, University of Chicago)



2
This Egyptian craftsman uses a bow drill to bore holes in stone beads, a process requiring a good deal of manual dexterity. (Scene from the tomb of Rekh-mi-rē‘ at Thebes. After Davies 1943: Pl. 54)

Experimental Materials and Methods

Twenty-four stone cylinder seals were studied. A majority (13) came from documented archaeological contexts, recovered through excavation at four sites in the Diyala region of Mesopotamia; they are now in the collection of the Oriental Institute of the University of Chicago. The rest were purchased from antiquities dealers, or found on the surface of sites, and now reside in the collections of the Metropolitan Museum of Art, the Brooklyn Museum, and the Oriental Institute.

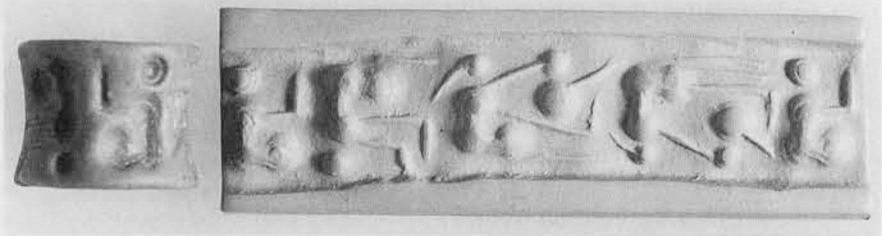
These seals were divided into two groups based on raw material. Because of changing preferences for specific rocks and minerals through time, they also fall into two stylistic and chronological groups. Group 1, with 12 examples, consists of seals made of marble and calcite (limestone or shell), the most common raw materials used for seals in this period. All of these rocks are soft, with a hardness of 3 on the Mohs scale. With one exception, the Group 1 seals are dated to the Uruk and Jemdat Nasr periods, ca. 3100 to 2900 B.C. (Fig. 3). Group 2 consists of 12 seals made of hematite (11) and limonite (1), with a Mohs hardness of 5-6 (Fig. 4). All are dated to the Isin-Larsa and Old Babylonian periods, from 2000 to 1600 B.C.

Our research is essentially a variation on the type of functional analysis originated by Semenov, a Russian scientist whose research on the use of early stone tools began in the 1930s. The methods that we used to determine the type of drill used in the manufacture of these seals have been described in detail in our previous publications (see bibliography). Briefly, they include: (1) making silicone impressions of drill holes on the engraved surface and the central bore of each of the cylinder seals (Fig. 5a); (2) an examination of these impressions for tool marks, using the scanning electron microscope (Fig. 5b); (3) an attempt to duplicate such tool marks experimentally on a stone similar to that of the seal being studied, using a variety of possible drills and abrasives.

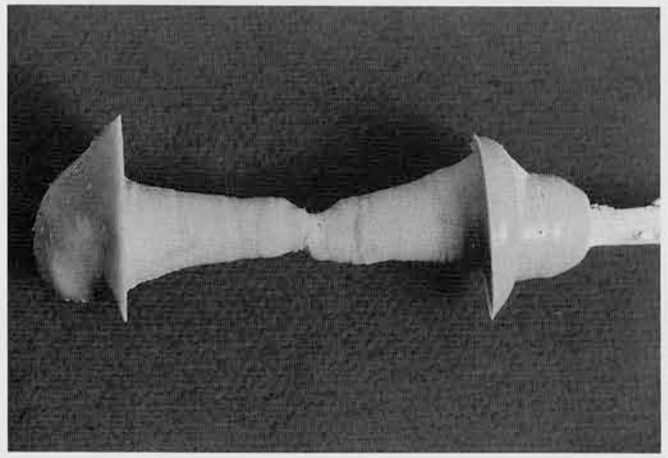
This last step often requires an additional process which we have called sequential drilling and replication. It entails drilling in the same hole and stopping at prescribed intervals in order to take impressions of both the drill and the drill hole. As drilling proceeds, the drill bit shows wear, and the hole not only becomes deeper but also shows a changing form. Thus a given sequence of impressions documents the relationship of the wear pattern of the drill to that of the drill hole.

Our type of functional analysis is analogous to the study of ballistics in which information about the bullet can be obtained from the bullet hole

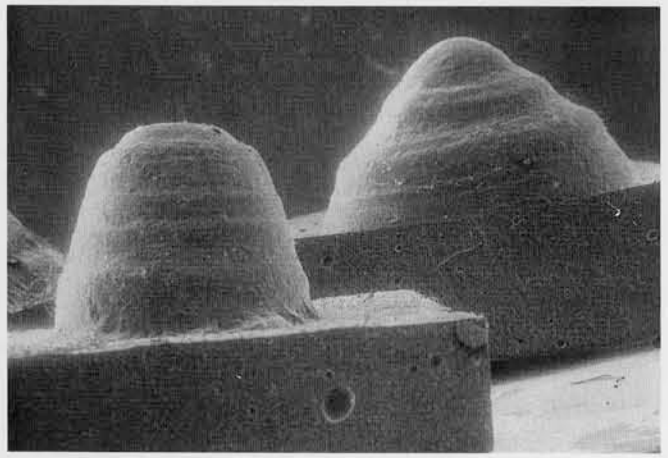
3
A Group 1 seal from the Jemdet Nasr/Uruk period, 3000-2000 B.C. Marble. H. 1.60 cm, Dia. 2.05 cm. (From Noveck 1975:11)



4
A Group 2 seal dated to the Old Babylonian period, ca. 1700 B.C. Hematite. H. 2.30 cm, Dia. 1.26 cm. (From Noveck 1975:23)



5a
Microphotograph of a silicone impression of the central drill hole typical of Group 1 seals. The hole has been drilled from both ends of the seal.



5b
A scanning electron micrograph of drill holes on the engraved surface of a seal. Like the central drill hole, they show a characteristic taper.

and vice versa. Our methodology provides confirmation about the missing drill (bullet) from the drill hole (gun barrel) when a match can be made between the pattern exhibited by the drill hole in the artifact and that produced experimentally on a similar raw material.

Findings

The findings for Group 1, Group 2, and the experimental duplicates can be described in terms of the following characteristics (Table 1):

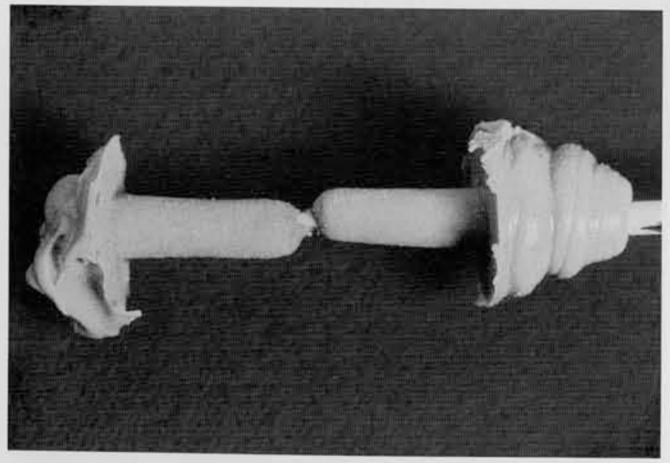
1. the overall shape of the central drill (bore) hole and any holes drilled on the engraved surface (Figs. 6a, 6b, 8c);
2. the pattern on the side walls of the drill holes (Fig. 7a,b);
3. the pattern produced by the leading edge of the drill (Fig. 8a). This was sometimes visible in the central bore, when the drilling was severely misaligned or incompletely drilled (Fig. 8b). It appeared on the engraved surface when the drill hole was part of the design and/or had not been obliterated by an engraving tool.

Both macroscopically and at the high magnification obtained with a scanning electron microscope, it was evident that a different pattern existed for the two seal groups (Fig. 9).

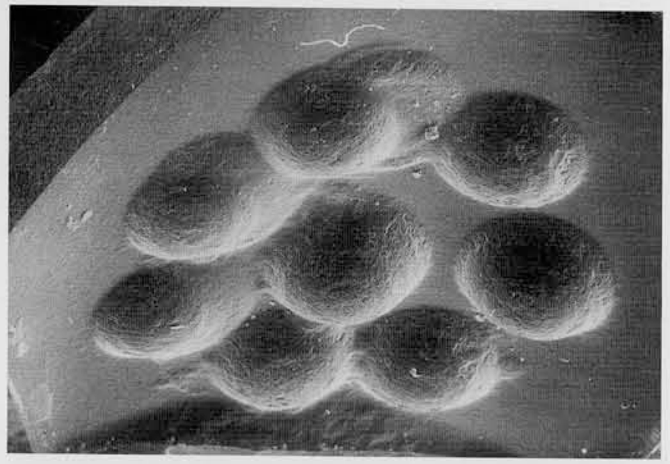
Table 1

Analysis of Drill Marks on the Seals

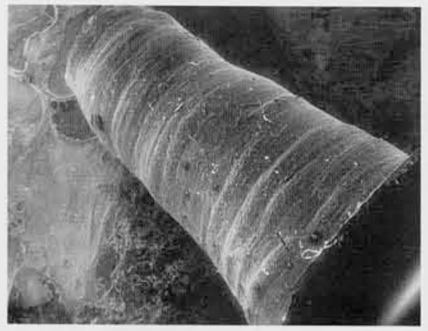
		Shape of the Drill Holes
Group 1	(a)	Central Bore: tapered and biconical in shape because all were drilled from each end (Fig. 5a). The *degree of taper was severe*, varying from 4:1 to 2:1. The degree of taper probably depends on the shape of the drill.
	(b)	Engraved Surface: a similar degree of taper was found on most drill holes on the engraved surface (Fig. 5b).
Group 2	(a)	Central Bore: all were tapered and biconical (drilled from either end). *Degree of taper was very slight,* and in some instances nearly parallel (Fig. 6a).
	(b)	Engraved Surface: drilling generally very shallow and rounded (Fig. 6b).
		Pattern on the Side Wall
Group 1	(a,b)	Central Bore and Engraved Surface: all seals exhibited a series of *concentric grooves on the side walls of all drill holes* (Fig. 7a).
Group 2	(a)	Central Bore: *most of the seals exhibited concentric lines* (Fig. 7b). In several instances these lines were interrupted by areas of smoothness.
	(b)	Engraved Surface: varied from rough to smooth; some holes with concentric lines.
		Pattern Produced by the Leading Edge of the Drill
Group 1	(a)	Central Bore: no leading edge pattern observed, since there were no examples of misalignment.
	(b)	Engraved Surface: pattern varied from angular to flattened to rounded (Figs. 5b and 8a).
Group 2	(a)	Central Bore: roundness at the periphery and a central elevation in the stone observed on the only instance where misalignment occurred (Fig. 8b).
	(b)	Engraved Surface: rounded, flattened or occasionally elevated (Fig. 8c).



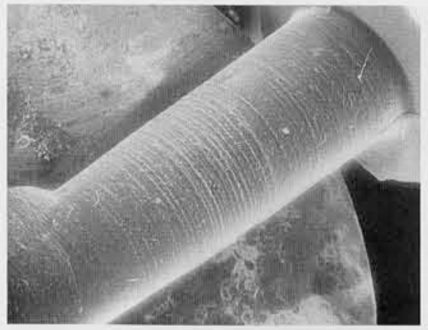
6a
Macrophotograph of a silicone impression of the central drill hole typical of Group 2 seals. Contrast the nearly parallel sides with the taper of Group 1 seals (Fig. 5a).



6b
A scanning electron micrograph of drill holes from the engraved surface of a Group 2 seal shows a typical roundness, in contrast to the taper shown in Group 1 seals (Fig. 5b).



7a
A scanning electron micrograph shows the pattern of concentric grooves (arrows) found typically on the side walls of the holes in the Group 1 seals.



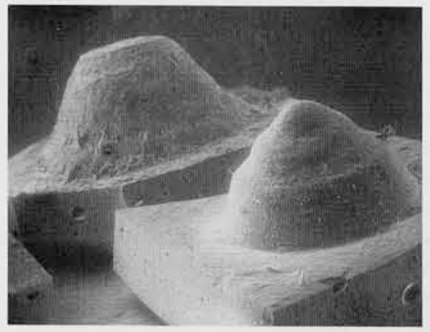
7b
Micrograph of the side walls of a Group 2 seal, showing the characteristic concentric lines.

Glossary

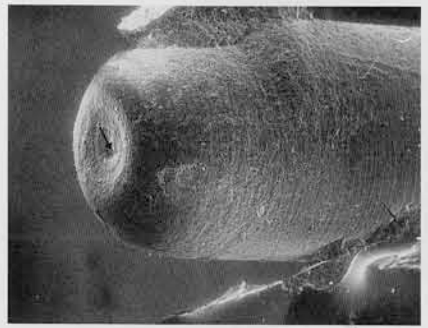
Hematite: iron oxide, Fe_2O_3. The specular hematite used for seals is a lustrous grayish black mineral.

Limonite: hydrated iron oxide, FeO(OH). The crystalline hydrated iron used for seals is called goethite.

Mohs Hardness Scale: an arbitrary scale based on the hardness of ten common minerals, with talc as the softest at 1, and diamond the hardest at 10.

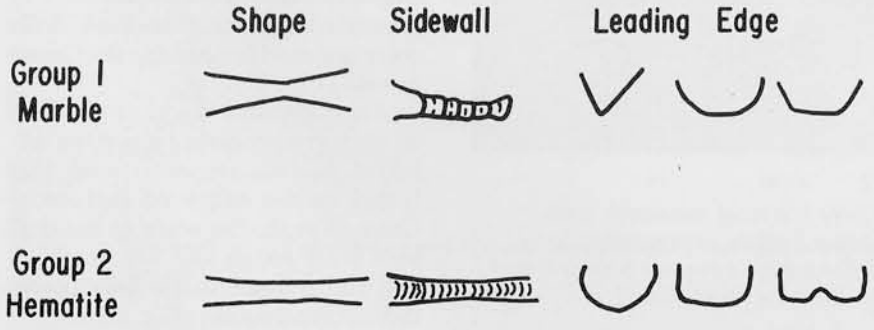


8a
The leading edge of a drill hole shows a most revealing shape and clue to the type of drill used. This may vary from flat to somewhat rounded and occasionally angular. The scanning micrograph was made from drill holes on the engraved surface of a Group 1 seal.



8b
Misaligned drillings from either end of the central bore of a Group 2 seal reveal a shape that is totally different from the pattern on Group 1 seals. Note the rounded periphery and central depression (arrow). On the seal itself, the depression is actually an elevation in the stone due to the localized wear of the drill.

8c
Drill hole on the engraved surface of a Group 2 seal. The shape is similar to that in the central bore, but in most instances the hole was either round or flat.

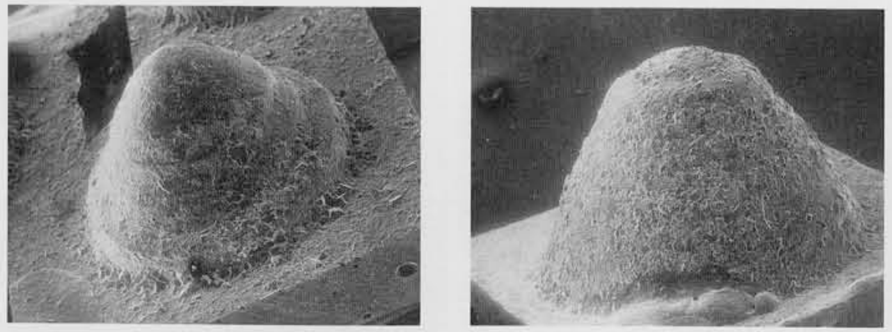


9
The three characteristics that demonstrate the difference between Group 1 and Group 2 seals are shown diagrammatically. They consist of (1) the shape of the drill hole (tapered walls versus nearly parallel walls); (2) pattern on the side walls (concentric grooves versus concentric lines); and (3) leading edge (flat or somewhat rounded versus perfectly round or somewhat flattened, occasionally with a central elevation).

Group 1 seals generally had a strongly tapered biconical central bore hole with concentric grooves on the side walls of this hole. Group 2 seals, on the other hand, had only a slight biconical taper in their central bore hole, and concentric lines on the sides of this hole. Differences were also observed in the range of variation in the shape of drill marks on the outer engraved surface created by the leading edge of the drill. Verification that these differences were caused by the use of chipped stone drills in the manufacture of Group 1 seals, and copper/bronze drills on Group 2 seals required the next step, experimental duplication.

Experimental Duplication

In order to exercise control, the following conditions prevailed



10a,b
Tapered, grooved drill holes with a flat or rounded leading edge created experimentally on marble with a flint drill. Note their close resemblance to Group 1 seals (Figs. 5a,b, 9).

10c
Holes made by a copper rod with an abrasive on marble. These do not match Group 1 seals.

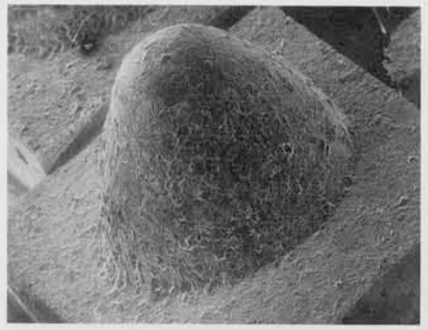
during the experimental duplications:

1. The stones that were experimentally drilled were similar to that of the seals: marble and hematite.
2. A chipped flint drill, a rod-shaped copper drill, an arrow-shaped copper drill (similar to that found at Tell Asmar), and a copper ball drill were used on each experimental stone. Each was 1/4 inch in diameter. They were used separately and/or sequentially as previously described.
3. Each of the drills was used with and without an abrasive. The abrasives were sand, crushed quartz, and emery; they were used dry, with water, and with olive oil.
4. Drilling with the flint drill bit was accomplished using a hand-held brace that was rotated back and forth in a manner similar to a bow drill. (We had previously established that the pattern produced by a bow drill was not altered when either a brace or a motorized drill press was used.)
5. Drilling with the copper drill bits was accomplished using a motorized drill press running at 1,000 RPM at a relatively constant pressure.

Experimental Findings

Marble

A *chipped flint drill* used with or without an abrasive on marble produced a pattern that was identical to that found on all the Group 1 seals. This pattern consisted of a conical shape with a severe taper, concentric grooves on the side walls and an angular to rounded leading edge (Fig. 10a, b). Rounding seems to be due to wear on the drill point rather than fracture. Use of an abrasive did not result in any increase in the speed of drilling. The findings, therefore, provide strong evidence for the use of a flint drill in the manufacture of the Group 1 seals (Table 2).



11
The result of experimental drilling with the arrow-shaped copper drill. While the tapered shape is similar to that on Group 1 seals, there is no grooved pattern on the side walls (see Fig. 7a) nor any matching characteristics on the leading edge (see Fig. 8a).

12
There is a total mismatch with Group 1 when experimentally drilling with a copper ball drill and an abrasive on marble.

A *flat-bottomed, cylindrical copper rod* without an abrasive would not drill. As the bit was rotated on a marble surface, it became slightly rough, and copper plated onto it. When abrasives such as sand, crushed quartz, or emery were used with water or olive oil the pattern was completely different from that found in Group 1. The drill hole was nearly cylindrical, with roughened side walls and a slightly rounded leading edge (Fig. 10c). These results strongly suggest that a copper rod was not used to drill Group 1 seals.

An *arrow-shaped copper drill* was used with and without an abrasive. The bore hole was tapered and conical, but no concentric grooves were produced. The leading edge was slightly rounded. The absence of grooves suggests that such drills were not used to produce the Group 1 seals (Fig. 11).

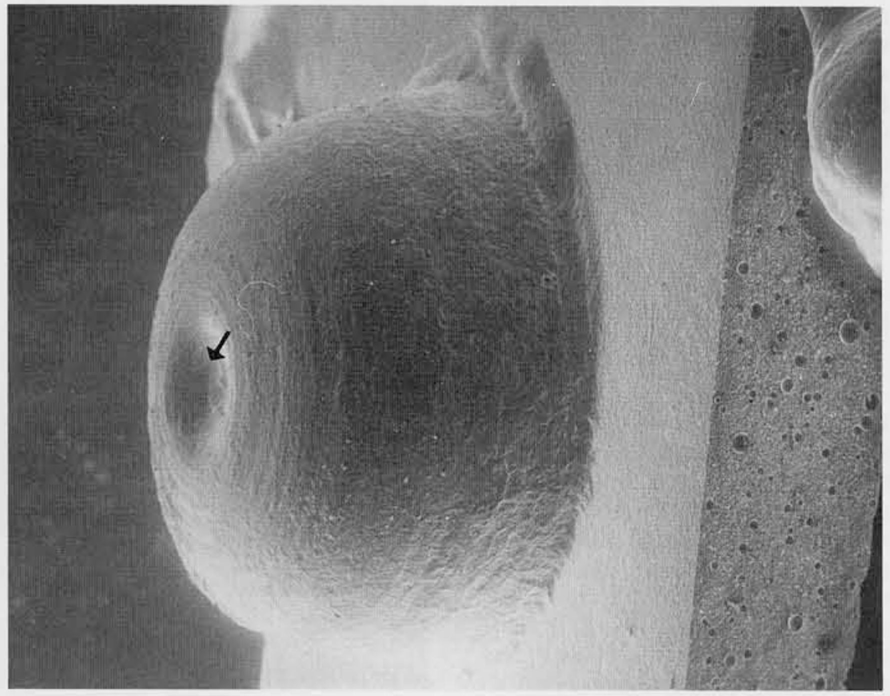
A *copper ball drill* with and without an abrasive produced a pattern different in two respects from that found on the engraved surface of Group 1 seals: the walls of the drill hole were rough and not grooved, and the overall shape was round rather than angular (Fig. 12).

Hematite

We were unable to drill into hematite using a *chipped flint drill*. This was true whether or not an abrasive was used. A *copper rod* applied to hematite without an abrasive produced the same negative result. When an abrasive was used, however, the rod produced drill holes that were almost identical to those described for Group 2 seals: the drill hole had nearly parallel sides, and the walls exhibited concentric lines. The leading edge had a central elevation in the hematite (Fig. 13), a pattern not seen in marble.

An *arrow-shaped copper drill* without an abrasive was ineffective on hematite. Used with an abrasive, it produced a tapered conical shape and concentric lines. Since this tapered shape was not found on any of the Group 2 seals (all of which had nearly parallel sides), the arrow-shaped drill can be ruled out as having been used on hematite seals in antiquity. Contrary to what one might expect, this pointed tool (with an abrasive) also seemed to drill much more slowly than a copper rod (with an abrasive).

A *copper ball* would not drill without an abrasive. A copper ball drill with an abrasive produced a



13
The rounded periphery and central depression (arrow) created with a copper rod and an abrasive on hematite is a perfect match to that found in the central bore and occasionally on the engraved surface of the Group 2 seals (Fig. 8b).

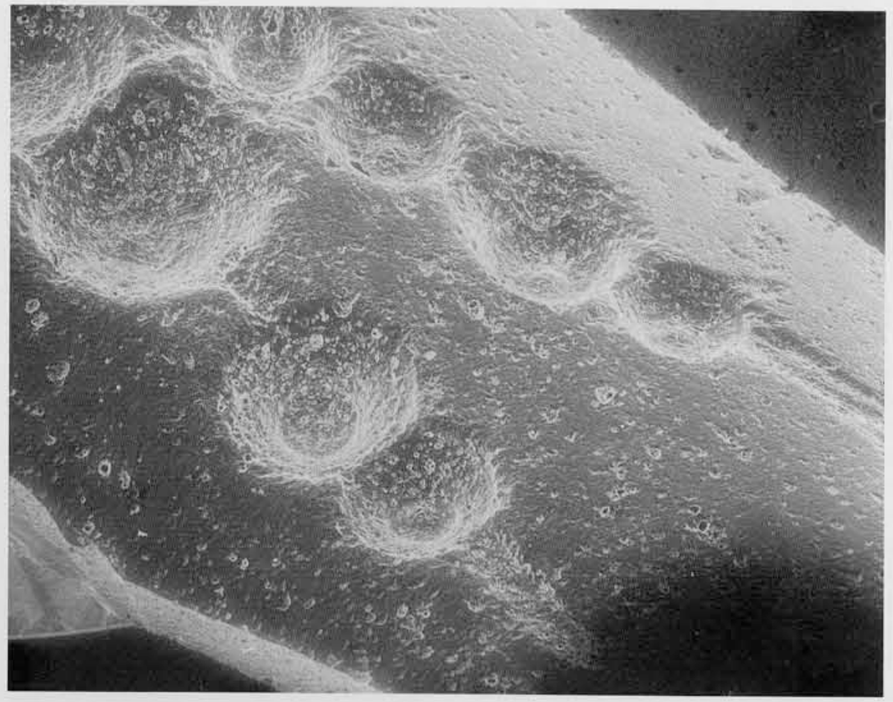
Table 2

Experimental Drilling on Marble (M) and Hematite (H) Using Various Drills with Abrasives

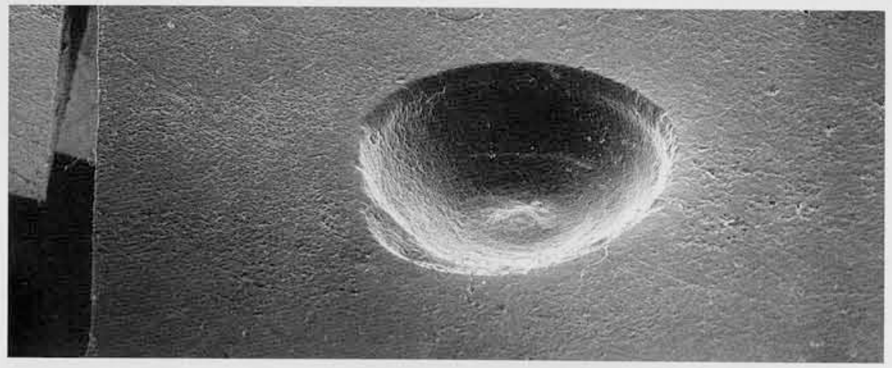
Drill	Shape		Side Wall		Leading Edge	
	M	H	M	H	M	H
Flint	Tapered conical	Didn't drill	Concentric grooves	Didn't drill	Angular, flat, rounded	Didn't drill
Copper Rod	Nearly parallel	Nearly parallel	Rough	Concentric lines	Round	Round and/or central elevation
Copper Ball	Round	Round	Rough	Rough or concentric lines	Round	Round and/or central elevation
Copper Arrow	Tapered and conical	Tapered and conical	Rough	Concentric lines	Slightly round	Round and/or central elevation

The three characteristics of the central bores and engraved surfaces of Group 1 seals were *duplicated only* by the flint drill, as shown by the boxed sections on the table under the **M** headings. The three characteristics of the central bores and engraved surfaces of Group 2 seals were *duplicated only* by a copper rod and ball and an abrasive, also shown by boxed sections under the **H** headings. The remainder are mismatches.

round pattern similar to that found on the engraved surface of Group 2 seals and totally unlike the pattern found on Group 1 seals. In the sequential drilling procedure, a pattern of wear was found similar to that shown on one of the Group 2 seals (Fig. 14a, b; see also Table 2).



14a
A series of drill holes outlines the incompletely engraved figure on a Group 2 seal from the Diyala. Examination of the drill holes reveals shapes that are either round or round with a central elevation.



14b
Results of experimental drilling on hematite using a copper ball drill and a water slurry of emery.

Abrasives and Lubricants

As previously stated, the abrasives used in this study consisted of crushed quartz (sand) and emery. In order to determine more precisely the characteristics of these abrasives when drilling hematite, conditions were varied while using a copper rod as drill bit: two sizes of grit (60-90 and 120-250) were employed, and each size was used dry, with water, and with olive oil. The results are summarized in Table 3.

None of the abrasives could drill hematite when used dry. Sand or crushed quartz did penetrate the rock, but did not produce the characteristic pattern of concentric lines on the side walls, regardless of the lubricant used (Fig. 15a). With emery and a lubricant, however, such lines were produced (Fig. 15b), their depth varying with grit size and type of lubricant. In general, the finer the grit, the finer the lines were. The lines produced with water were more faint than those produced with oil.

Thus it is highly probable that emery was used to drill the central bores of the hematite seals in our sample. The lubricant for the emery may have been either water or some type of oil; while we used olive oil, another vegetable oil, or even animal fat could have been used in antiquity.

Rate of Drilling

Our original research was done with a copper drill. Bronze, an alloy of copper and tin, is harder than copper and holds an edge better. We have therefore begun a new series of experiments to determine the relative efficiency of these two materials in the drilling process. Specifically, was the rate of drilling different when a copper or a bronze drill was used?

The tests are presently limited to drilling on hematite using crushed quartz with a 60-90 grit size. Preliminary findings indicate that the rate (speed) of drilling was the same, whether the rod-shaped drill was of copper or of bronze. Since bronze drills offered little or no advantage, it is probable that copper drills were preferred, at least during the early 2nd millennium B.C. when tin was both scarce and expensive (Moorey 1982).

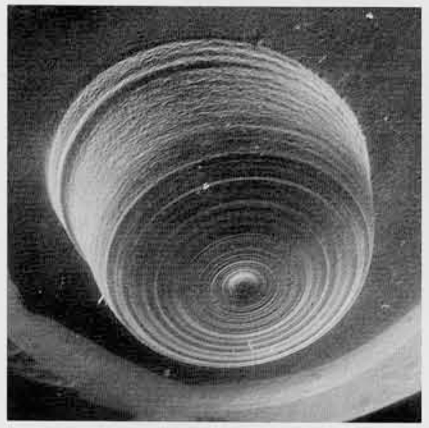
The drilling rate with a copper/bronze drill is, on the other hand, greatly affected by the type of abrasive and the type of vehicle used. We found that crushed quartz 60-90 grit in combination with olive oil drilled twice as fast as the same grit in combination with water. Emery 60-90 grit in combination with olive oil also drilled twice as fast as the same grit with water, and four times as fast as quartz with water.

Initially, our examination of ancient seals and experimental procedures established that in the 2nd millennium B.C. hematite was probably drilled using a copper or bronze rod, emery as an abrasive, and water or oil as a lubricant. We have now been able to show that this combination of materials is highly efficient, and that the most advantageous process would employ oil rather than water.

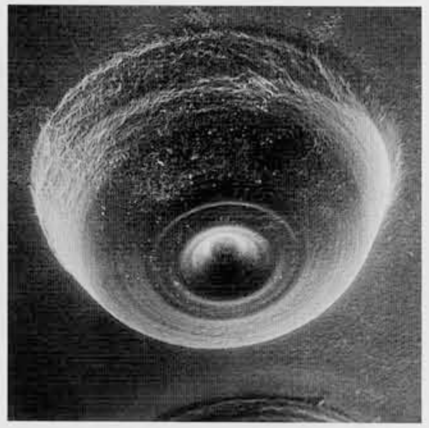
Table 3

Results of Drilling On Hematite with a Copper Rod, Abrasive, and Lubricant

	Grit Size	Lubricant	Results
EMERY	60-90	Water	Lines and grooves
	60-90	Oil	Lines and grooves
	60-90	None	—
	120-250	Water	Fine lines
	120-250	Oil	Fine lines
	120-250	None	—
QUARTZ	60-90	Water	Rough
	60-90	Oil	Rough
	60-90	None	No lines
	120-250	Water	Rough
	120-250	Oil	Rough
	120-250	None	No lines



15a
Crushed quartz with oil produced only roughness on hematite, and never concentric lines.



15b
Emery in combination with olive oil as a lubricant resulted in grooves or concentric lines on the side walls of the drill hole in hematite.

Discussion

It seems evident from our experiments that the Group 1 seals made of soft stones were not manufactured using copper drills, as originally suggested by Frankfort and accepted by others, but were made using chipped flint microdrills. Eleven of these marble or limestone seals have been dated to ca. 3000 B.C., but one is securely dated by both style and stratigraphy after 2000 B.C. The Group 2 or hematite seals, on the other hand, could not be drilled with chipped flint; they were instead made using copper or bronze drills, establishing the development of such metal tools by ca. 2000 B.C. After this time, the type of drill employed by Mesopotamian lapidaries may have depended on the kind of raw material to be worked.

The technology developed to work very hard stones involved not only copper drills, but also an abrasive and a lubricant. Our experiments have shown that the abrasive used with copper drills on hematite was almost certainly emery, and not sand or crushed quartz. This abrasive required the use of a lubricant such as water or olive oil, since the copper drill was ineffective when the abrasive was used dry.

The “discovery” that copper and an abrasive in a liquid vehicle could effectively drill hard stones can be broken down into a series of empirical observations made by the ancient stone workers. They are: (1) that copper drills broke less easily than stone drills; (2) that an abrasive was essential with a copper drill and was able to increase the speed of drilling; (3) that a lubricant was necessary when using an abrasive; and (4) that a flat-bottomed copper rod which could apply pressure on the abrasive was more effective than a pointed (arrow-shaped) copper drill.

No evidence has been found for the use of an abrasive with chipped stone drills. This is hardly surprising, given the mechanics of drilling with a chipped flint drill: an abrasive offered little advantage, since this type of tool is in a sense self-sharpening. As the tool wears and the sharp cutting edges of the tip break, other equally sharp edges appears due to the fracture pattern intrinsic to microcrystalline minerals such as flint. We judged that the speed of drilling on marble with a chipped stone drill was the same with and without an abrasive.

Our experimentation with the arrow-shaped copper drill, analogous to the copper drill recovered archaeologically from Tell Asmar, was interesting and we would like to propose a hypothetical explanation for this rare and unusual find. While our arrow-shaped copper drill was able to drill marble, it was slower than flint and therefore offered no advantage for soft stones. Given that the technique for making stone microdrills was well known and probably relatively inexpensive, and that copper technology was probably more complicated and costly, it is unlikely that the copper arrow drill was intended for use on soft stones.

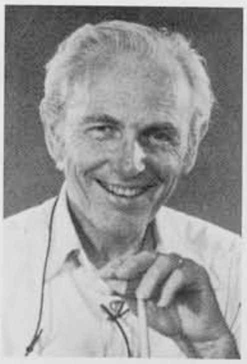
Assuming that the identification of the Diyala copper tool as a drill is correct, why is the tip arrow-shaped instead of a flat rod or a ball? It is our guess that the arrow shape was copied from the earlier flint microdrills, and might represent an interim stage in drilling technology. New methods and new materials often copy from the past. Is it possible, then, that at some time after the Akkadian period the arrow-shaped drill was altered to a rod shape because the latter was more efficient?

Conclusion

In attempting to reconstruct the history of ancient lapidary technology, functional analysis as described has again been found to be a useful and necessary complement to archaeological excavations. Using this method we have presented strong evidence that contrary to conventional opinion, chipped stone microdrills were still being used to fabricate seals in ancient Mesopotamia ca. 3000 B.C. By ca. 2000 B.C., copper (and not bronze) drills were being used with abrasives, at least for hard stones such as hematite. The advantages of using the abrasive emery in combination with a vehicle such as olive oil seems also to have been learned.

Using the experimental methods described, our future research is aimed at providing information concerning the following questions:

1. When did the change from stone drills to metal drills take place?
2. How were hard stones drilled during the Neolithic? (e.g., carnelian from Jarmo, ca. 7000 B.C. and obsidian beads from Çatal Hüyük, ca. 6000 B.C.).
3. Were seals made of stones harder than marble but softer than hematite drilled with chipped stone or copper? If copper, what type of abrasive and vehicle were used?
4. Did seals softer than hematite continue to be made with flint drills after 2000 B.C.?
5. What is the relationship between the change in tools from flint to copper, and the style of engraving on seals?
6. What other changes occurred in tools and technology in later periods, and what was their effect on style?



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Acknowledgment
The authors are grateful to the curators at The Oriental Institute, Univ. of Chicago, and to the Ancient Near Eastern Dept. of The Metropolitan Museum of Art for permitting us to work on the seals. We thank Prudence Harper, Holly Pittman, and Oscar White Muscarella of the Metropolitan for their guidance and suggestions.

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