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A BRIEF HISTORY OF DRILLS AND DRILLING

A. John Gwinnett and Leonard Gorelick[1]

A microscopic examination of silicone impressions of the perforations of beads, sealstones, and amulets has produced a data base of characteristics that help to define what type of drill was used to make them. This article outlines the various types of drills that have been used from the Palaeolithic period to the present day, and notes what microscopic features characterize each one. Scanning electron micrographs illustrate the minute details that are revealed by the silicone impressions.

INTRODUCTION

Among the first objects to be perforated by ancient humans were shells and teeth (Braidwood 1967). By perforating them, the hunters and gatherers of the Upper Palaeolithic period (ca. 25,000-12,000 B.C.E.) could string and wear these objects which served as amulets. These objects were perforated by means of hand-held lithic borers which preceded clockwise/counterclockwise rotational drilling. Generally made of flint, the borers were pressed against the object to be perforated and then twisted back and forth at low speed and relatively high torque. The method was very effective on soft stone (Mohs' scale 1-3) but ineffective on harder stones.

While it is reasonable to speculate that drilling technology had its roots in the Upper Palaeolithic, it is a matter of record that our knowledge of the early history and development of drills and drilling is woefully incomplete. Other than flint artifacts, tools of wood and metal, particularly drills, have rarely been found in a lapidary context. Consequently, we must seek other sources of information.

In an effort to overcome the relative lack of drills and their components from archaeological contexts, we devised a method for determining the type of drill (i.e., metal, stone, or wood) that had been used to perforate an object by analyzing the drill marks (Gorelick and Gwinnett 1978). The process is an

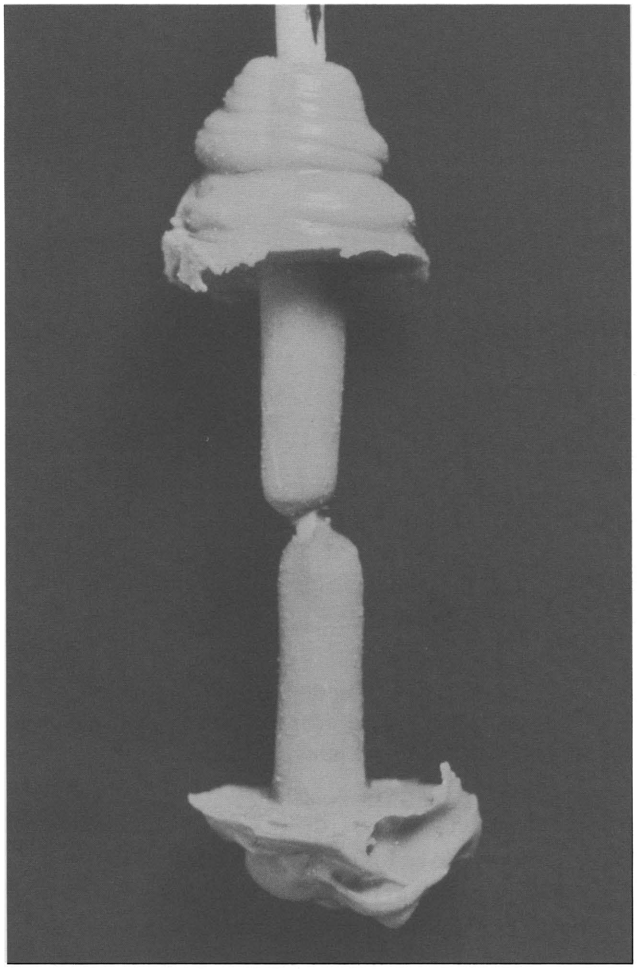

Figure 1. Silicone impression of the parallel-sided perforation of a cylinder seal which was drilled from either end. Consequently, the two segments do not align perfectly. The central constriction necessitated the removal of the impression in two pieces which were then reassembled (all photographs by the authors).

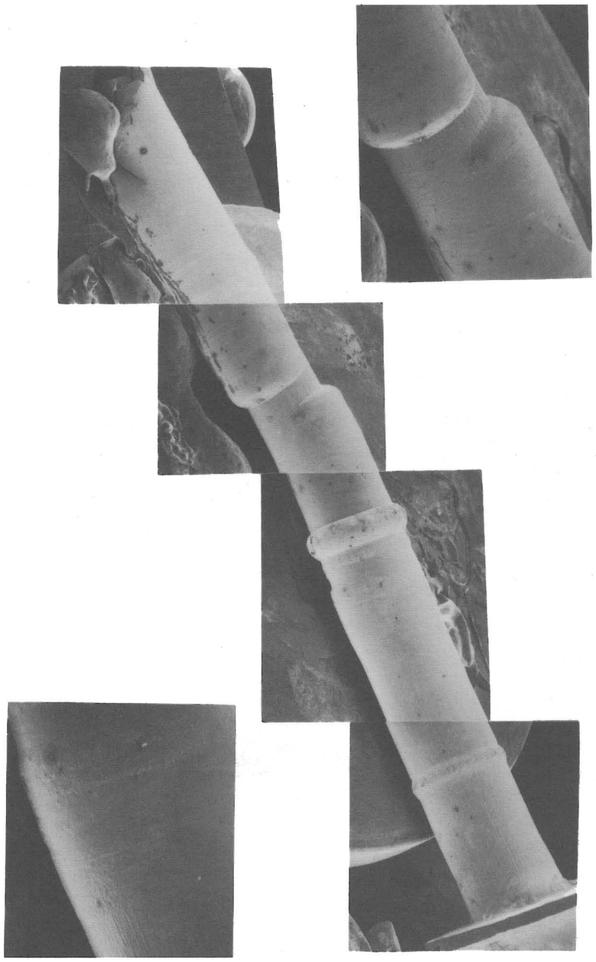

Figure 2. A composite scanning electron micrograph of an impression taken from a cylinder seal reveals a number of features of a drill hole, including its shape.

Figure 3. Scanning electron micrograph of an impression showing the sidewall characteristics of a drill hole. Note the concentric grooves of various sizes and depths.

extension of a method first described by Semenov (1976) and referred to as functional analysis. Semenov studied the wear patterns on ancient tools, reconstructed similar tools and used them in a variety of ways. Whenever a match in the wear pattern occurred, he was able to deduce the use to which the ancient tool had been put.

In our method, we start by making an impression of the drill hole (Fig. 1) using vinyl polysiloxane, a substance sold under the trade name of Reprosil which is produced by Dentsply Caulk of Milford, Delaware. When this material hardens, its surface records every microscopic mark of the perforation and, being pliable, is easily removed from the hole. The casting is then examined using light optical stereomicroscopy and scanning electron microscopy to determine the nature of the drill marks. This is followed by experimental duplication of the observed drill marks (abrasions and cutting anomalies) using a variety of drills, abrasives, and lubricants. Three attributes are central to the proper identification of the type of drill that was used: 1) the shape of the drill hole; e.g., tapered or parallel-sided (Fig. 2); 2) the side-wall pattern; e.g., concentric grooves (Fig. 3); and 3) the marks, if any, left at the leading edge of drilling; e.g., a raised central elevation or a pattern of conchoidal fractures (Figs. 4-5).

A CHRONOLOGY OF DRILL USE

The Epipalaeolithic Period

Our research began with objects from the Mesolithic Period, which began approximately 12,000 B.C.E. in western and southern Asia. In the early part

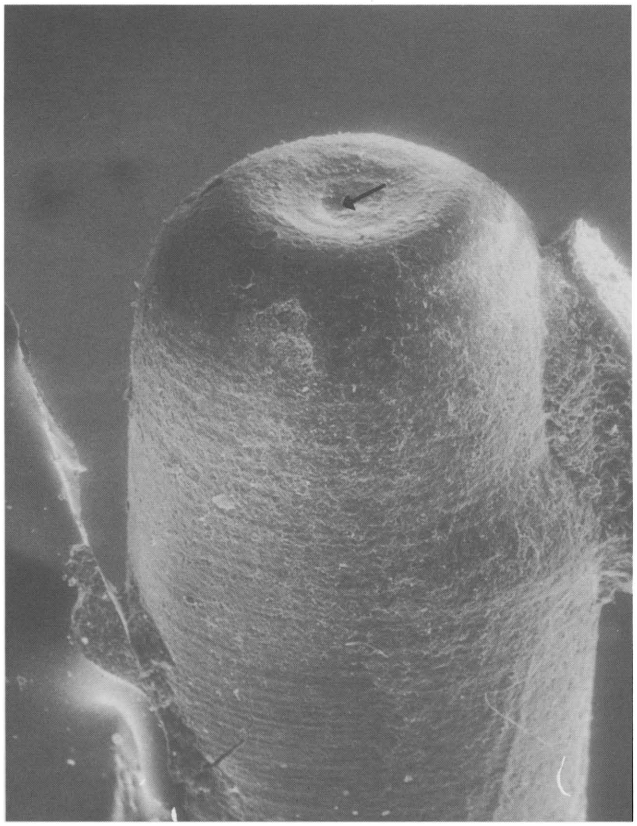

Figure 4. Micrograph of the impression of the leading edge of a severely misaligned drill hole. The depression (arrow) was created by a slight elevation in the substrate and represents the region of greatest wear in the end of a solid rod-shaped drill (i.e., the shape of the leading edge of drilling frequently reflects the shape of the drill itself).

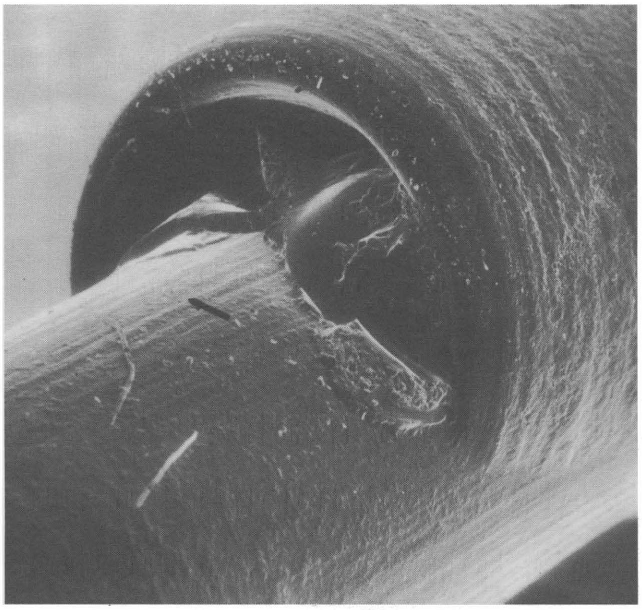

Figure 5. Micrograph of the leading edge of a drill hole made using a tubular drill. The semi-lunar shape shows a rounded, relatively smooth periphery representing the thin wall of the drill. To the inside of this can be seen the typical conchoidal fracture pattern that results in rock crystal following the fracture and removal of the "core" that occupied the interior of the tubular drill. Some longitudinal file marks (arrow) are in contrast to the circumferential grooves created by the drill and abrasive.

of this broad period, flint perforators were common. Compared to the Palaeolithic era, the drills were smaller (microliths) and probably hafted in bone or wooden handles. Held by hand, these tools were less cumbersome and more efficient than their Palaeolithic predecessors. The drills became more rhombohedral, thereby increasing the number and angle of the drilling edges (Fig. 6). This modification foreshadowed the raking angle of contemporary burs.

The application of the palm-driven wooden fire stick to the microdrill significantly increased rotation speed. Drilling technology underwent another ingenious and momentous change with the adoption of the bow drill (Fig. 7). Rapidly moving the bow back and forth rotated the drill at approximately 850 revolutions per minute (Knobloch 1939). The bow drill requires that a palm rest be placed on the upper end of the drill shaft to exert downward pressure. Such drills are still in use among various groups worldwide–for example, the bead drillers of Cambay in India (Possehl 1981).

The microdrill–whether flint or obsidian–was breakable, could not be easily reused, and was confined to drilling relatively soft substances. The shape, sidewall pattern, and leading edge characteristics of microdrills are easy to recognize (Fig. 8), though variations are common based on the shape and wear of the drill.

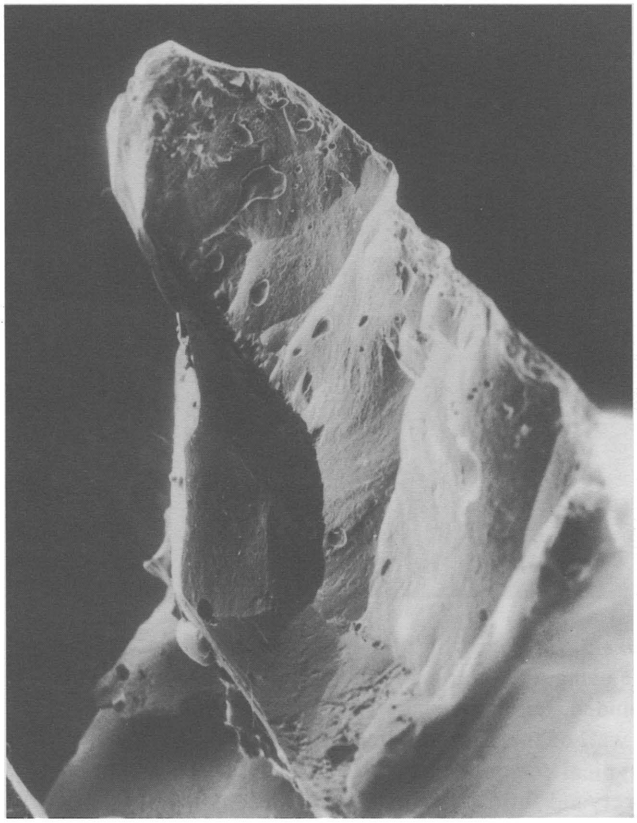

Figure 6. Micrograph of a flaked-flint microlith. The object is arrowhead-shaped, polyhedral with distinctive cutting edges.

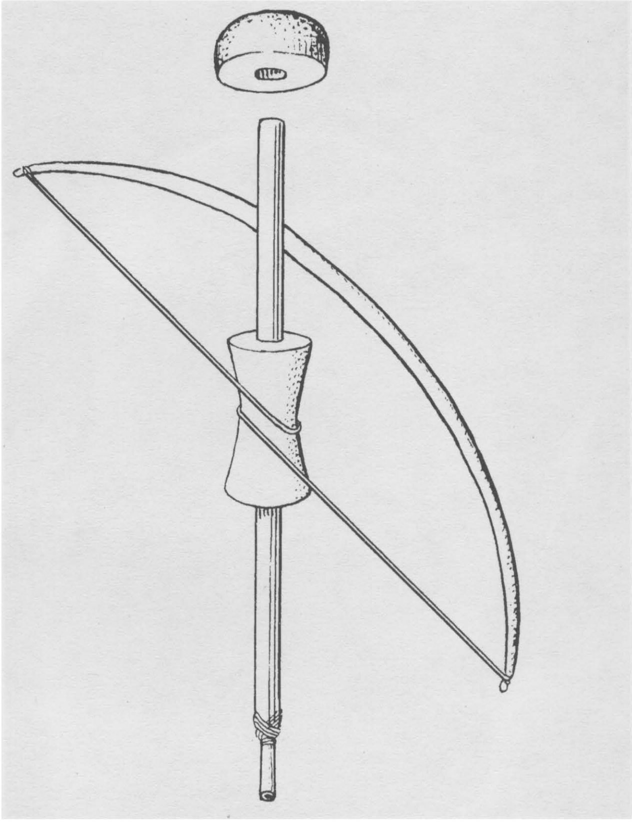

Figure 7. A typical bow drill. The palm rest is used to apply pressure to the drill during reciprocal rotation.

The Neolithic Period

The limitations of microdrills were eventually overcome by developments in the Neolithic period (ca. 8,000-4,000 B.C.E.), also known as the New Stone Age or "ground stone age." A change from hunting and gathering to agriculture required the clearing of fields, the cutting of trees, and the building of shelters. New types of tools were needed to meet the changing demands of evolving societies. Thus, chipped flint tools gave way to those shaped by pecking and grinding. Neolithic craftsmen learned about different types of loose abrasives and developed shaped-stone drills to work the abrasives against a substrate. The experience gained reflected itself in new lapidary techniques which permitted hardstones such as quartz to be formed into elaborate and decorative beads.

Drill holes produced by stone drills and loose abrasives vary in profile from tapered to parallel-sided. The side-wall pattern, when present, is comprised of concentric grooves of various depths,

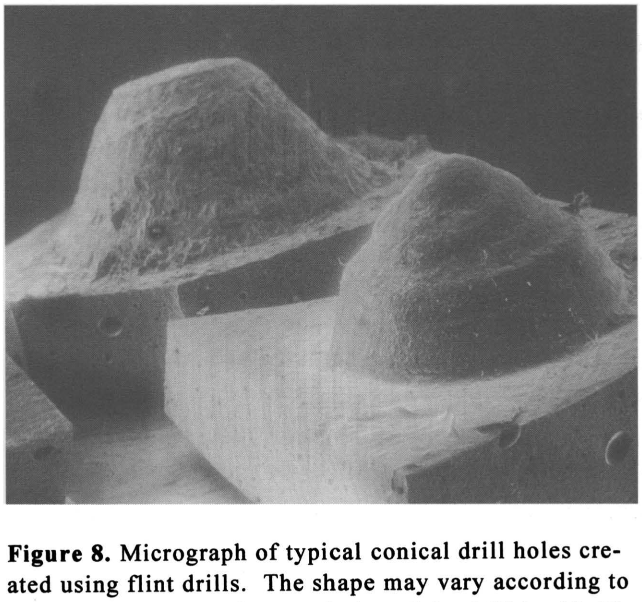

Figure 8. Micrograph of typical conical drill holes created using flint drills. The shape may vary according to the shape and wear characteristics of the drill itself. The terraced appearance represents the various cutting facets on the flint.

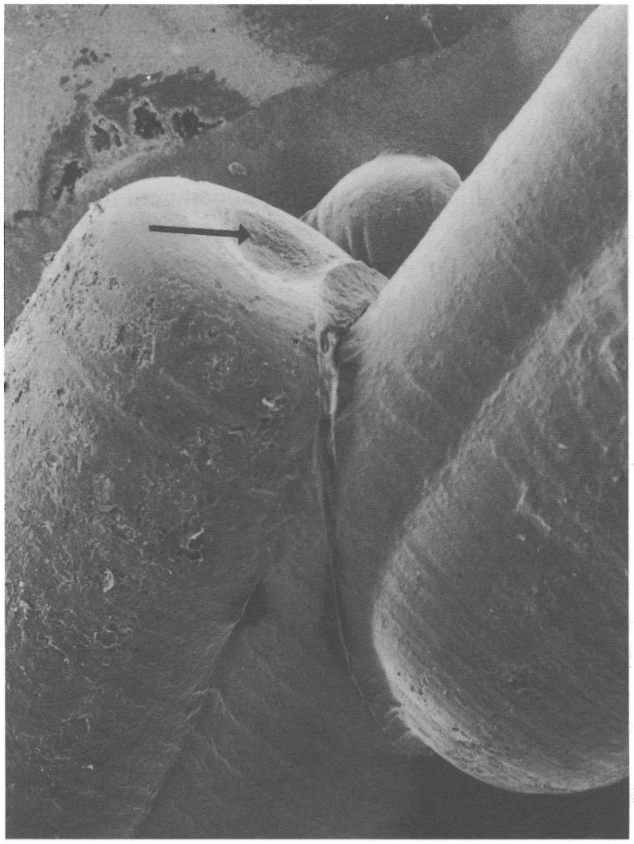

Figure 9. The leading edge of a drill hole which was probably made with a rod. The central depression (arrow) represents a slight elevation in the stone caused by a depression in the end of the drill. Shallow concentric grooves in the side wall can be attributed to abrasive which would have been used with a rod-shaped drill.

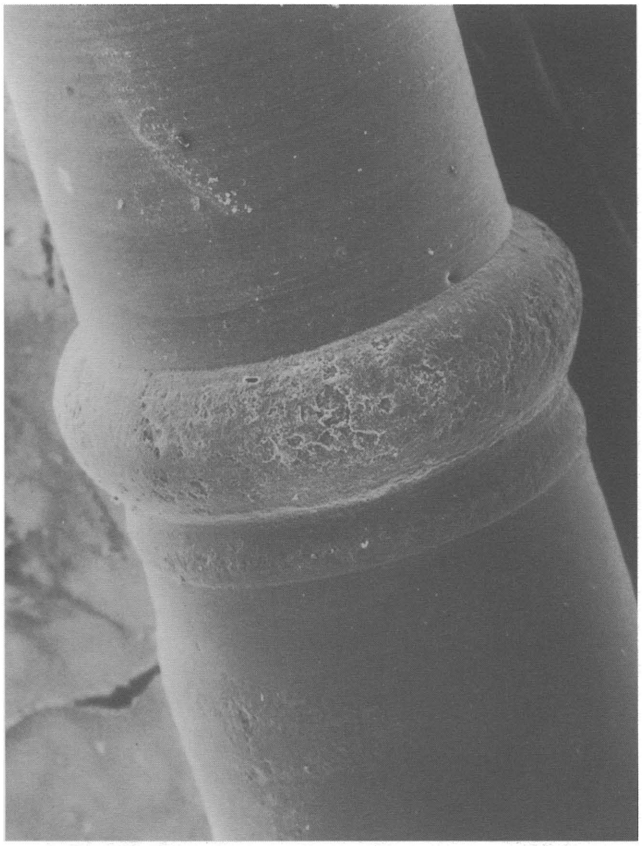

Figure 10. Micrograph showing the "collar" phenomenon characteristic of a copper drill.

and the leading edge commonly shows a small central elevation in the drill hole (Fig. 9) due to localized wear in the drill itself.

The Chalcolithic Period

Further changes to drilling technology occurred during the Chalcolithic period approximately 4,000 B.C.E. and reached their zenith in the Bronze Age. A major innovation centers on the apparent realization that a chipped-stone drill was not an efficient carrier of abrasives. This led to the introduction of a flat rod of soft metal which allowed the abrasive to be temporarily embedded or charged. Copper was ideal for this purpose because it was not easily broken, could be reused and was soft enough to permit the embedding of an abrasive. Another important consideration was that the rods could be mass produced. We have been able to demonstrate and document the change from stone to copper drills (Gorelick and Gwinnett 1987).

Archaeological excavations have not yet produced copper or bronze drills in a lapidary context. We have been able, however, to provide evidence for the use of copper drills through several serendipitous findings. The first occurred during an examination of quartz cylinder seals whose drill-hole impressions disclosed a peculiar anomaly on the sidewall (Fig. 10). We produced this same phenomenon, which we called a collar (Gorelick and Gwinnett 1989), quite accidentally while drilling on glass using a copper rod, quartz abrasive, and water (Fig. 11). We hypothesized that this occurred through plastic deformation of the copper rod's leading edge as a result of frictional heat and downward pressure on the rod. The ancient craftsman created the collars unwittingly during the course of

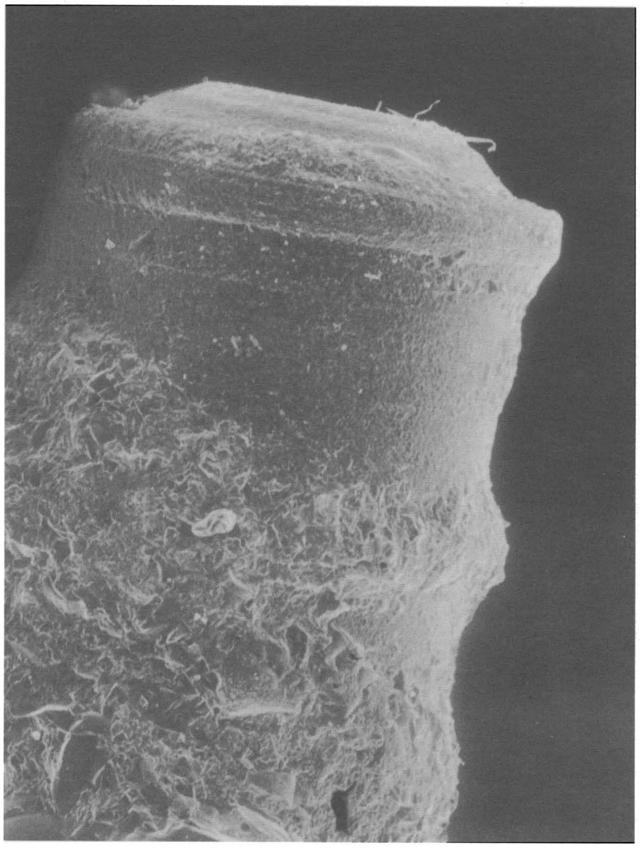

Figure 11. Micrograph of an impression taken from an experimental drill hole in which a copper rod and abrasive were used on a glass slab. The recreation of the "collar" phenomenon is evident.

drilling. If he added loose abrasive and lubricant in inadequate quantity, the drilling advanced slowly. Aware of this, he may have consequently applied greater pressure on the palm rest, thus distorting the drill. As he continued to add abrasive, the flare on the drill disappeared, but not before it produced a characteristic groove in the sidewall of the drill hole (Fig. 10). This phenomenon is unique to copper and the presence of a collar in the perforation of a bead is evidence of the use of a copper drill.

While bronze, a mixture of copper and tin, was used by craftsmen, it is speculated that it was rarely used in early metal-drill technology. The cost and scarcity of tin (Moorey 1982) would probably have precluded its use. Our unpublished experimental studies on drilling efficiency show no significant advantage of bronze over copper.

An increase in drilling efficiency occurred in the Bronze Age, however, because of another important discovery, namely emery. With a Mohs' hardness of 9, this material afforded a major increase in abrasiveness and was particularly effective on quartz (Mohs' hardness of 7). We have been able to document its use during the Middle Bronze Age, ca. 2,000 B.C.E. (Gorelick and Gwinnett 1986), and suggest that the increased use of hardstones for beads, seals, and amulets stemmed from the awareness, availability, and use of emery as a loose abrasive.

The Iron Age

The ancient use of iron for drilling has been poorly documented. One notable find–an arrow-shaped drill–was made by Flinders Petrie (1917). We have found by experimentation that other shapes could have been used as well. The use of the arrow-shaped iron drill is a derivation of the chipped-stone drill, both of which are effective on softstones. Iron, however, is more durable and could easily be reshaped and reused. For stones harder than 4 on the Mohs' hardness scale, an iron rod in combination with loose abrasive would be very efficient.

Other Developments

The eventual invention of the drill brace provided a method for unidirectional rotation of a drill. While more efficient than bow or pump drills, the drill brace did not entirely replace them. Further developments which would lead to the development of contemporary drills had to await the innovations of the Industrial Revolution and steel technology. Major changes in the use of loose abrasives required the development of ceramic and electroplating technology to create bonded abrasives. Abrasives changed from quartz and emery to silicon carbide and diamond.

DISCUSSION AND CONCLUSION

While this hypothetical reconstruction of a history of drills and drilling has evolved from evidence derived predominantly from the Aegean and ancient Near East, it generally applies to other cultures as well. Drilling variations that are encountered in other

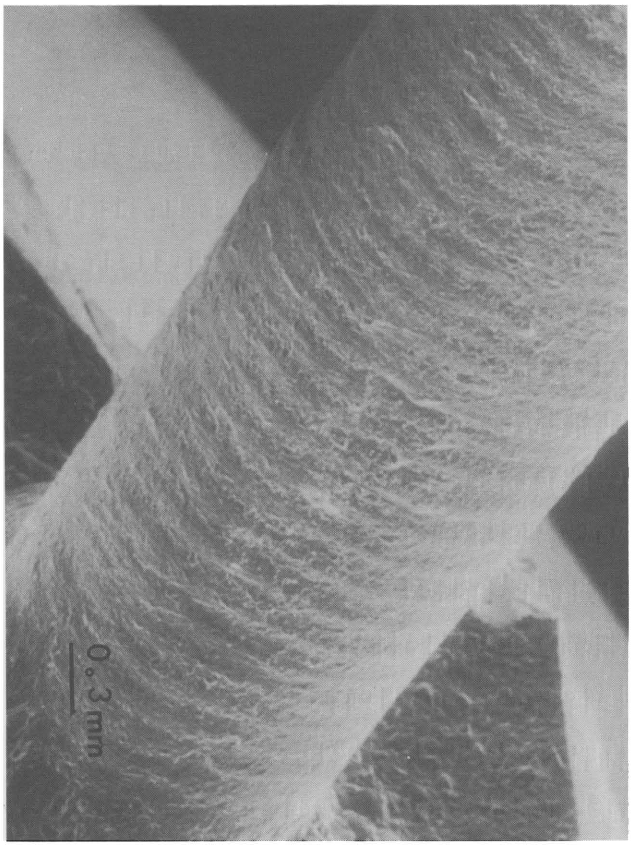

Figure 12. The sidewall of a drill hole in a rock-crystal bead showing the pattern characteristic of a twin-splinter diamond drill. Regular, concentric, and uniformly spaced grooves are characteristic of this type of drill.

cultures relate to their particular history and cultural development, as well as the methods of technology transfer and trade. The ancient Maya, for example, did not have metal tools, but they developed specialized techniques for drilling nonetheless (Fastlich 1976; Gwinnett and Gorelick 1979).

More recently, we have uncovered preliminary evidence for the use of a drill utilizing diamond splinters as cutting points (Gwinnett and Gorelick 1986). These were used in ancient South Arabia, Iran, and Sri Lanka. It is known that diamonds were abundant in ancient India and that craftsmen learned to haft and use them for drilling. Indeed, the practice is still carried on in Cambay, India. The regular, concentrically grooved sidewall pattern of the parallel-sided perforation (Fig. 12) and a small, central conchoidal-fracture pattern at the leading edge of drilling (Fig. 13) are characteristic of this type of drill.

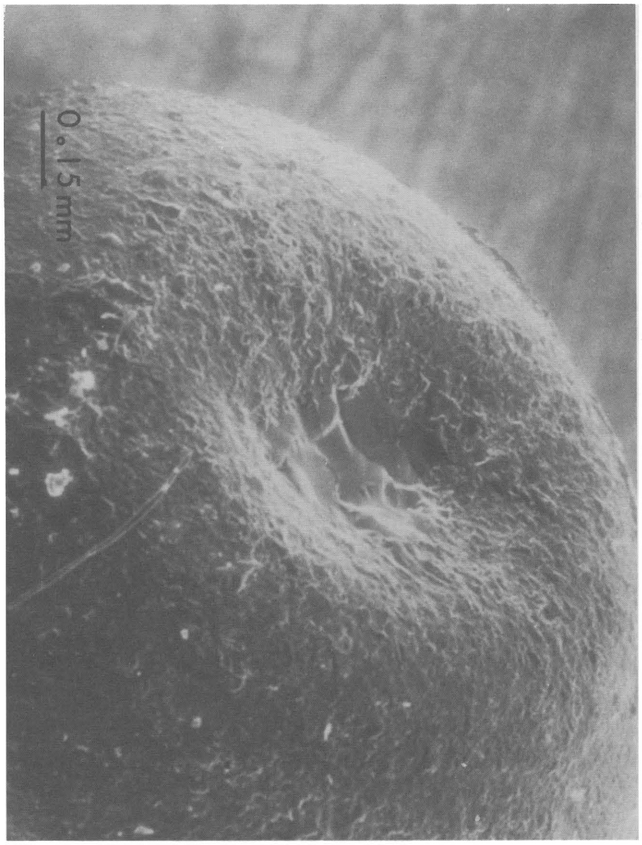

Figure 13. The leading edge of a drill hole created with a twin-splinter diamond drill. In the center is a small depression showing a conchoidal fracture pattern. This is characteristic of diamond drilling and contrasts with the size and smoothness of those created by a rod and abrasive (*see* Fig. 9).

In conclusion, functional analysis is a simple means of gaining insight into the evolution of drills and drilling, as well as engraving. The method we espouse is non-destructive and permits the capture of telltale drilling characteristics from an artifact which, when compared with a data base of standard drilling shapes and sidewall and leading-edge patterns, help to identify the type of drill that was utilized.

ENDNOTE

1. This paper was originally presented during the Stone Bead Symposium at Bead Expo '96 in Austin, Texas. It is sad to note that both authors have since passed away.

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