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A Pilot Study Comparing the Penetration Properties of Bilobed and Trilobed Bronze Arrowhead Points Modeled from Neo-Assyrian Finds from Ziyaret Tepe, Turkey

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A Pilot Study Comparing the Penetration Properties of Bilobed and Trilobed Bronze Arrowhead Points Modeled from Neo-Assyrian Finds from Ziyaret Tepe, Turkey

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Abstract

The aim of this project is to help understand how and why cultures implement technology. This paper specifically focuses on testing and analyzing how morphological variation in arrowhead shape affects performance attributes. As a model of variation, we have chosen to concentrate on two different types of bronze arrowhead based on Neo-Assyrian finds, bilobed and trilobed, to see if they, by virtue of morphology only, have differing penetration capabilities.

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Archaeology is the study of data clustered into archaeological entities based on socio-political groups of the past; often described as cultures and defined in their temporal context through the use of archaeological data and models (Clarke 1978:11–12). These models are generated through the isolation of essential factors and interrelationships to help simplify, partially represent, and predict complex human behavior (Clarke 1972:1–2). Models to conceptualize the processes that catalyze innovation, stimulate its acceptance, and lead to its dissemination to other entities are of crucial importance to archeology as they help us understand how ideas, knowledge, and technology are transported through space and time (Stockhammer and Maran 2017:1) Why the transmission of ideas is so imperative to archaeology is because, according to some scholars, culture *is* information; defined by (Mesoudi 2011:2–3) as: “information that is acquired from other individuals via social transmission mechanisms such as imitation, teaching, or language.” Without models to describe the diffusion of ideas, we cannot understand how culture developed and evolved throughout our past.

The use of the bow and arrow by *Homo sapiens* reaches back long before written records existed. Archaeological evidence shows that they date to at least as far back as the advent of agriculture some 10,000 years ago (Baker 1994:43), with newer finds suggesting dates as early as 64,000 years ago (Lombard and Phillipson 2010:645–646). Regardless, while the depth of their reach into the past may be uncertain, it is certain that by the time written records existed, the bow and arrow had already been used long enough for humans to have attained a reasonably advanced understanding of the materials and technology required to create efficient weapons for both hunting and warfare.

Since that time, the bow and arrow have not only seen ongoing use but have also progressed as materials, technology, and our understanding of physics has improved. It is gaining insight into this evolution of technology and materials that form the basis of this project.

To help facilitate this understanding, this study focuses on the ancient Near East, where several complementary data sources exist that can be employed as a case study. Written cuneiform texts describing the processes and materials used to craft bows and arrows, wall reliefs displaying the styles and forms they took, and archaeological artifacts that have physically survived have been compiled and studied, permitting archaeologists to replicate and infer how they were both crafted and employed in ancient times. Finds from one particular site in present-day Turkey, Ziyaret Tepe, suggest that the Neo-Assyrian soldier used multiple arrowheads in their arsenal. Arrowheads with not only differing morphological attributes but also composed of varying materials, specifically iron and bronze, were all found in association with each other in Iron Age contexts (Matney et al. 2017:186–189). It is the goal of this study to understand the motivations of the Neo-Assyrians in using these different arrowhead forms at the same time. And while this question is too complex to fully answer in this project, the process has been initiated with a pilot study. This pilot study is a comparative ballistics test on one element of arrow variation: morphology; specifically focusing on the bronze, socketed, bilobed (also bilobate or leaf) arrowheads and the bronze, socketed, trilobed (also trilobate or trefoil) arrowheads, concentrating on one dimension of performance: penetration.

This reasons behind choosing to model the points in the study on the Ziyaret Tepe artifacts and conduct ballistic tests are based on two key factors. First, the two arrowhead types were modeled after finds found in the same assemblage from the archaeological, Neo-Assyrian site of Ziyaret Tepe. The site of Ziyaret Tepe is dated to span from the end of the Late Bronze Age through the early Iron Age in two separate periods of settlement (Matney et al. 2017:29–30). This is important because it provides insight into the transition between the two ages through the perspective of one socio-political tradition. The finds at Ziyaret Tepe also display the continued use of bronze arrowheads even after the advent of iron arrowheads during the Early Iron Age. As an advisor to the author and director of the Ziyaret Tepe expedition, Dr. Matney could provide accurate models of the different arrowheads types to be used for replication. Second, the proximity to Kent State University's archaeology lab facilitated the firing of the two different types of arrowhead in a controlled environment.

Experimental Archaeology

The purpose of Experimental Archaeology is to "furnish a foundation for explaining technological variation and change" (Schiffer et al. 1994:198), creating strong theoretical principles that can be applied to test archeological hypotheses while rigorously following the scientific process (Marsh and Ferguson 2010:2). To achieve this, all archaeological experiments should begin with controlled tests to create statistically valid results for analysis.

However, after these results and analysis are applied to facilitate the development of hypotheses, they should then be further tested against the archaeological record by attempting to replicate the conditions, technology, materials, and other variables that existed in the context of the processes being studied.

To answer the questions that instigated this project, the results of this and other tests (see below) must be compiled, analyzed, and synthesized into workable hypotheses that are then tested under parameters that replicate the technology, materials, culture, and other variables studied. To achieve this, future studies should include:

- Arrows hafted with materials and technology available to the people and fired from bows replicating those used by the subjects at the correct draw weights.
- Points created with metallic compositions mimicking those available to them and under the same pyrotechnological limitations.
- Targets mimicking and including carcasses or synthesis of human and/or animal bodies.
    - This should include both bare-skinned and with various levels of protective garments or body armors available at the time.

The Ancient Near East

The ancient Near East refers to the area that roughly encompasses modern-day Turkey in the north through the Persian Gulf and the Sinai Desert in the south, and from the coast of the Mediterranean in the west into the Iranian Plateau in present-day Iran in the east. Often referred to as the Cradle of Civilization, it is usually looked upon by modern Western societies as the origin of their shared cultural heritage. It saw the rise and fall of the Natufians, Babylonians, Akkadians, and many other cultures throughout the Neolithic, Chalcolithic and Bronze Ages while technological innovations including agriculture, writing, metallurgy, irrigation, city and state political boundaries, as well as the foundations of many of today's religions, were developed.

The Bow, the Arrow, and the Scythian Arrowhead

Ancient bow and arrow technology can be difficult to study as both the bows themselves as well as the arrow shafts are often made from organic materials like wood, sinew, and bone; all of which decompose readily and are often lost to the archaeological record. As such, it is often only the arrowheads that are available as artifactual evidence.

Nevertheless, arrowheads, when used in conjunction with available pictorial and textual records, can facilitate an understanding of the technologies and methods employed by ancient craftsmen of the past. The bow and arrow have been used by humans for a very long time; so much so that the forms in which the arrow points take can be a significant indication of the culture who produced the object. However, as is the case with pottery, one arrow type is not a direct indication of a cultural group. In the past, scholars of the ancient Near East once thought that bronze, socketed, trilobed points were the products of invasion or influence from a group of Iranian-speaking, Eurasian, steppe-dwelling nomads often referred to as Scythians (Manco 2015:140; Hellmuth 2014:1–4; Szudy 2015:358), and thus once designated all arrowheads of this type as Scythian points. However, new research indicates that the points likely originated in the ancient Near East in present-day Iran (Szudy 2015:168; Wright 2008:29) and, as such, I will refer the points by their more descriptive name: trilobate or trefoil points.

The Advent of Bronze

Bronze, much like most technological innovations and transitions, did not suddenly appear in the standardized 88-89% copper to 8-12% tin Tin-Bronze that exists today (National Bronze 2019). Finds indicating the earliest admixing of copper with other metals in the ancient Near East date to roughly the fifth millennium B.C. in sites across the region, including Nahal Mishmar, Tepe Gawra, Ur, Amuq, and Abu Matar (Figure 1) (Tylecote 2002:12); with some more recent evidence indicating that it may stretch back even further by as much as a millennium (Garfinkel et al. 2014:5). These bronzes, however, contained a variety of different alloying metals including arsenic, tin, nickel, antimony, lead, and others; often in varying amounts, compositions, and mixtures; to create a metal that is easier to melt and cast than raw copper and usually harder and more resilient to oxidation. However, while archeologists can determine the compositions of the objects created in antiquity, they do not understand how much knowledge of the different materials and combinations nor the level of intentionality employed by ancient smiths when they crafted the items. Furthermore, because some of the mixtures would be too dangerous to create with the tools and facilities available to us in this project, a standard, current, composition of 90/10% copper to tin was used.

The Advent of Iron

Much like bronze, the adoption of iron was not an event, but rather a process. Archaeological finds of iron in the form of worked meteoric and telluric iron date back as far as the third and fourth millennium B.C. (Erb-Satullo 2019:6; Tylecote 2002:3), while smelted and worked iron finds have yet to be reliably dated to before 1000 B.C. (Erb-Satullo 2019:8). Nevertheless, the Iron Age in the ancient Near East is considered to have begun after the widespread socio-economic and cultural collapse[1] of the Bronze Age around 1200 B.C., with clear signs of wide-ranging adoption of iron and iron-working by 800 - 600 B.C. (Tylecote 2002:47; Erb-Satullo 2019:10–14; Curtis et al. 1979:369). However, iron technology in the ancient Near East was confined to the forging of bloom iron[2] as, unlike bronze, the

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[1] The end of the Bronze Age is referred by some as a Dark Age across the Mediterranean because of the widespread collapse of several regional socio-political states around the Mediterranean, Africa, and Near East. Cultures like the Mycenaeans, Hittites, and Cannanites disappear from the record as distinct groups while others like the Egyptians and Assyrians begin a period of weakening. The so-called Dark Age is contiguous with the Early Iron Age in the Mediterranean and is often said to have ended around 800 B.C. with the emergence of several new political states and a resurgence of written records.

[2] Bloom iron is iron that has been smelted and purified. Unlike ingots, which are melted and cast, bloom iron must be forged. (Muhly et al. 1985:68)

pyrotechonology[3] and metallurgical understanding required to melt and cast iron was not achieved in the region for many centuries (David Killick and Thomas Fenn 2012:564–565; Muhly et al. 1985:68), presumably ensuring the relevance of bronze even after iron's widespread adoption; a limitation encountered on this study as well.

The Rise of Assyria

The Assyrians are recognized by archaeologists as a distinct socio-political entity that originated around 2000 B.C. in the city-state of Assur (Harper et al. 1995:13, 15; Van De Meiroop 2016:100–104). Their influence in the region is often broken into three distinct periods or stages. The first takes place from about the 20th through 18th centuries B.C. and is notable as a period of prolific international trade through the city of Assur and a network of trading colonies (Harper et al. 1995:21–24; Van De Meiroop 2016:100–104; Postgate 1992:247). The second stage, known as the Middle Assyrian period, began in the 14th century B.C. and lasted until the 11th century. This period saw the rise of the Assyrian military and the first major expansion of its territories that lasted until the end of the Late Bronze Age, when, along with many other regional polities (see footnote 1 above), they declined (Kuhurt 1995:473; Van De Meiroop 2016:141–181; Matney et al. 2017:18; Postgate 1992:248). However, the people of Assur did not disappear and, after a period of over 300 years, new texts began to surface describing a new Assyrian (i.e. Neo-Assyrian) kingdom.

The Neo-Assyrian empire is often divided into two time periods. The first, from the mid-tenth century to the mid-eighth, was encompassed by a series of seasonal campaigns, divinely commanded by the god Assur and conducted and orchestrated by the king. These campaigns

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[3] Pyrotechnology is defined by (McDonnell 2008:493) as a "deliberate processes utilizing the control and manipulation of fire."

brought about some expansion of the Assyrian territories, restoring it back to its former territorial holdings. However, though they traveled into other lands and campaigned against other groups, their general policy was to assert Assyrian military dominance over conquered groups and force them to pay an annual tribute. Some conquered states maintained more or less political independence, while others were made into vassal states. However, towards the end of the period, starting in the mid-ninth century, the empire began to suffer from internal and successional conflicts, resulting in its slow decline over the next century. (Kuhurt 1995:478–489; Van De Meiroop 2016:255–261; Postgate 1992:249–256).

Nevertheless, by the mid-eighth century, a second phase of the Assyrian expansion begins. This time, Neo-Assyrians not only retake lands lost to them from their decline and re-establish control of former vassal states, but also conquer new territories. This period of imperial conquest and domination lasted until the end of the seventh century, when, after several years of internal conflict, rebellion, and external threats, the city of Nineveh was sacked. (Kuhurt 1995:493–501; Van De Meiroop 2016:265–288; Matney et al. 2017:18–19).

The Neo-Assyrian Army

The key to the Neo-Assyrian empire’s expansion was their army, which was not only the most impressive and dominant military force in the region at the time but possibly also the first professional army (Szudy 2015:76; Van De Meiroop 2016:266; Dezsö 2012a:13–21). It was composed of infantry from conquered peoples with a core of cavalry and chariot riders from the homeland (Dezsö 2012a:23–24; Dezsö 2016:10; Van De Meiroop 2016:266; Kuhurt 1995:533; Szudy 2015:76). What is known about the Neo-Assyrian army is primarily learned through palace reliefs and a vast archive of written cuneiform texts, the latter of which documented military campaigns and tactics, economic impacts, and the social importance of warfare in

Assyrian. The full army encompassed of infantry (Figures 2 and 3), chariots (Figure 4), archers (Figure 5), and cavalry (Figure 6); all of whom carried bows and arrows or were supported by troops who carried them into combat (Dezsö 2012a:21).

The Neo-Assyrian Archer

As noted above, nearly all Assyrian soldiers carried the bow and arrow into combat, although not all were dedicated users. Among the infantry, there were light, regular, and heavy archers (Dezsö 2012a:21, 25, 82, 100–107), while the cavalry had both regular and heavy archers (Dezsö 2012b:13–32), and the bodyguard of the king encompassed archers protected by shield-bearers (Dezsö 2012a:115). The infantry and cavalry both were led by officers who were often equipped with a mace and bow as well (Dezsö 2012a:144; Dezsö 2012b:39–55).

The standard Neo-Assyrian chariot carried a driver and an archer. They were sent to the front of the army to soften enemy troops by riding in and showering them with arrows, typically fleeing before the enemy could react. After battles, they would pursue routed enemies as they fled the battlefield (Dezsö 2012b:56–58).

The importance of the bow and arrow to the Neo-Assyrian army was not only clear in its disbursement among its troops but also elucidated by depictions of the great god, Assur, wielding a bow on the side of a chariot (Figure 7) found among the carvings at the palace of Sargon II (Dezsö 2012b:66–67). Even the king, when shown engaging in battle against enemies, is depicted with a bow (Dezsö 2012b:65).

The Neo-Assyrian Bow

As with the army, what is known about the Neo-Assyrian bow comes to us primarily from reliefs and texts, though some examples have survived the archaeological record, most notably from the tomb of the Egyptian pharaoh, Tutankhamun[4] (Loades 2016:12). These surviving records and the artefactual evidence found has provided sufficient evidence for modern bowyers to create replicas that give us an idea of their shape, how they worked, and the power of their pull.

The Neo-Assyrians used single-stave self-bows made with a single piece of wood as well as a variety of composite[5] and composite recurve bows[6] made of wood, bark, sinew, and horn or bone; with the recurve most often depicted during the reign of Assurnasirpal II (Loades 2016:12; Szudy 2015:106–109). Replica bows, created by modern bowyers who specialize in making bows from traditional techniques and with materials that mimic the original have shown that Neo-Assyrian composite recurve bows had a draw-weight of roughly 75lbs, yet remained light and easy to maneuver (Loades 2016:12).

Arrows used by the archers were carried in leather, wood, or bronze quivers or bow cases (Szudy 2015:110–119). The shafts were composed of unknown materials, though textual records indicate that reed fortified with a hardwood foreshaft was likely used in the ancient Near East, as it was in Egypt (Loades 2016:68; Szudy 2015:119–120). Arrowheads came in a variety of shapes and sizes and were sometimes made of stone or bone, though more commonly with bronze or

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[4] While Tutankhamun was an Egyptian pharaoh, it is thought that the style of bow found in his tomb was similar in form, materials, and construction as the bows used by the Neo-Assyrians.

[5] Composite bows are bows made of more than one material, held together by binding agents.

[6] There is some discrepancy in the desriptions of the bows that likely attests to descriptive preferences.

While (Loades 2016:6) states that:

> “There are two esselential elements to a composite bow – the geometry and the materials. To begin with, the geometry: bow limbs that bend away from the archer are known as reflex and those that bend towards the archer are known as deflex. A combination of reflex and deflex is called a recurve. Composite bows appear in a variety of forms but they are all, to a greater or lesser extent, recurve bows.”

(Szudy 2015:107) instead lists several different types of compound bows, including: “convex, triangular, recurved and B-shaped”.

iron. Iron, though more naturally abundant and relatively easy to form into simple arrowheads, was however not preferred over bronze due to its ability to be molded and cast, thus allowing it to be formed into more complex and socketed forms (Szudy 2015:135–141).

The Experiment

Different arrow forms and materials found at the same site in the same context from the same period illicit multiple questions. Why different arrow morphologies? Why different materials? What properties did these arrowheads possess that motivated the Neo-Assyrians to carry such a variety of them into battle? We know that different arrowhead forms today are used for different purposes and we can reasonably expect the likelihood that the arrowheads used by the Neo-Assyrians also had different purposes. So, what were their purposes?

The first step of understanding what purpose the arrowheads served in this project was to determine if the morphological differences between bilobed and trilobed point types would affect the penetration ability of the arrow. It has been suggested by scholars, specialists, enthusiasts alike that the weight of a projectile is the primary (or only) determinant of its penetration potential (Szudy 2015:158–159). Therefore, any two arrowheads, regardless of differences in size, morphology, surface area, or any other variables, should have no variation in their penetration capabilities. While certainly possible, it seemed also conceivable that the friction caused by trilobate arrowheads greater surface area upon entering the target could slow it down more than the lesser friction caused by the bilobate arrows. To test this, two different styles of arrowheads based on dimensions from artifactual finds from Ziyaret Tepe were constructed: bilobate and trilobate. Mass was added to the lighter bilobed points to ensure all of the points of equal weight. They were then fired into the same material at controlled velocities to see if the typology of the arrows significantly impacted the ability of the projectile to penetrate the target.

Materials and Creation of Arrowheads and Arrow Shafts

University of Akron metalsmithing student Alex Morrison crafted four bronze arrowheads, two bilobed, two trilobed, using a modern version of a lost-wax casting technique that was used by Neo-Assyrian craftsman. The bronze that was used to create the arrowheads was derived from previously smelted and cast materials of nearly pure (>99%) tin and copper purchased from a commercial source, RotoMetals of San Leandro, California. The alloy created at the University of Akron in the Mary Schiller Myers School of Art metalsmithing lab had a final composition of 10% tin to 90% copper by weight. Once the arrowheads were completed, they were cleaned and sharpened. Because the sockets of the arrowheads were inconsistent between the samples, they were sent to Michael R. Fisch Ph.D. of the College of Aeronautics and Engineering at Kent State to clean, align and bore.

Arrow shafts were created by the author using 1/4in dowel rods made of birch, selected by hand for best consistency in both diameter and straightness. The sections of the rods that would be fitted into the sockets were then filed down and affixed to the dowels using Ferr-L-Tite Glue, a modern arrow adhesive. SummerHouse High-Density Lead tape was applied to each bilobed-tipped arrow, directly behind the socket, to add weight and make them consistent with their trilobed counterparts. The arrows were then cut to the same length and knocks were cut into the rear of the shafts. Fake sinew was then added at a consistent thickness along the socket onto the shaft of the dowel, over the weighted sections to help stabilize the union of the arrowhead at the socket and to cover the lead tape.

Methodology

The arrows were fired at The Kent State University Experimental Archaeology Laboratory at Kent State University, using a 29lb draw Microburner MX model compound bow produced by PSE (Precision Shooting Equipment), Inc. mounted to a Spot-Hogg “Hooter Shooter”, designed for calibration of compound bows; but here used to control the consistency of the pull weight. The device fired each arrow a distance of 2.75m at a fixed pull force into blocks of moist terracotta; texturally consistent earthenware clay containing crystalline silica, which has been used as a substitute for meat and tissue in other studies conducted at the university (Bebber and Eren 2018:39; Werner et al. 2018:8–9). The clay was in its manufactured state of both consistency and moisture and still left in its original plastic wrapper. As the arrows were fired, the velocity was measured using a Gamma Master Model Shooting Chrony chronometer as they travel towards the block of clay. Penetration was then determined by tape, measuring the depth in which the shaft infiltrated into the block of clay by marking the point on the shaft where the arrow stopped, pulling the shaft out of the clay, and measuring from the tip of the arrowhead to the mark on the shaft. Each arrow was then to be fired 15 times, totaling 30 shots with each arrowhead type, thus allowing for statistical analysis.

Discussion

The project in its original inception faced several challenges and setbacks that forced the overall scope to be modified. Below is a general description of the challenges that were encountered, how they were addressed, the outcomes, and other notes that are important to understand the experiment and how the project was conducted and unfolded.

Challenges and Setbacks, Solutions and Compromises

The original intention of the project was to not only test the differences between the two types of bronze arrowhead and then compare those two types not only against each other, but also against iron arrowheads; and to do so along multiple measures of performance. The hypothesis was that if the performance characteristics of the arrowheads could be delineated, they would explain why the different arrowheads were used in conjunction with each other. Which would, in turn, facilitate an understanding of one aspect of the transition between the bronze and iron ages.

However, as the project began and challenges arose, the scope had to be adjusted in order to complete it in a timely and realistic manner while still producing results. Therefore, while the overall question and experimental goals have not changed, the scope originally strove for in this project would require resources and time that are simply unavailable under the circumstances and confines of this project. Nevertheless, tests were conducted, data was collected, and results were secured.

The first issue to be addressed was setbacks, delays, and complications in the production of the bronze and iron points originally proposed. These pushed the hafting and testing phases of the project back several months and resulted in a reduced sample of bronze points to test; while the timeframe and complications in producing the iron points required them to be discarded from this phase of the project entirely.

Once the construction of the points was completed, they were polished and sharpened. However, during this process, it was discovered that cavities existed from the casting process. Most of the cavities were very small (Figures 8, 9, and 10) and only impacted the consistency of the weights between the similar morphological examples with the exception of one of the bilobed points, which was lacking internal consistency in the density of material at the tip (Figure 11). However, because the cavity was still filled a compacted, chalk-like powder, presumably a residue from the casting process, likely plaster, it was determined that the void would not interfere with the overall test results beyond requiring more weight to be added to make it consistent with the rest of the arrowheads. Another issue resulting from the initial casting was small inconsistencies in the sockets; particularly in the location of the socket in one of the trilobed points, which was slightly off-center. However, because the shafts had to be shaved in order to be socketed anyway and the joint between the shaft and arrowhead would be stabilized by the addition of the fake sinew, it was decided that the offsetting of the socket would not affect the test results. The shaft for that particular arrowhead was shaved off-center to match the socket, ensuring that the arrow was consistent at the joint between the two.

Initially, the points were mounted upon modern arrow shafts with fletching. In order to compensate for the heavier weights of the trilobed points, leather was wrapped around the shafts (Figure 12). After a misfire caused the bilobed arrowhead with the cavity to break from the shaft and slightly damage the tip (Figure 11), it was noted that the leather was hitting the bow as it was being fired and causing the arrow to fly erratically, eventually ending in one arrow missing the clay entirely and hitting the wood backdrop. It was decided to switch the arrowheads to longer, non-fletched, dowel shafts that were closer in circumference to the arrow sockets and to find a form of weight to add to them that would not protrude as far as the leather had, therefore avoiding more misfires. After fixing the arrowhead through cold-hammering and researching other methods to add weight to the arrows, it was decided that lead tape could provide a reasonably heavy, yet non-intrusive option.

After the new arrows were crafted, test-firing commenced. The arrows were shot in order from A through D, taking one shot from each, then moving onto the second with all four, then the third and so on. After shot number 3, *Arrow A* began to wobble – indicating that the glue holding the arrow to the dowel had failed and the point was being held in place by only the fake-sinew. Testing commenced for three more rounds of shots until it was determined that the wobble was affecting the penetration ability of the arrow. Testing was stopped in order to re-haft the arrowhead and after a quick repair using Gorilla brand super glue to re-affix the head to the shaft, testing commenced; first retaking shots affected by the wobble and then continuing in the pattern before.

During shot number 11, the arrowhead of *Arrow D* broke completely. The arrow was set aside and one more round of shots were taken with the other arrows following the same protocol, but skipping *Arrow D*. However, nearing the end of the day and after the second round of shots without *Arrow D*, it was decided that the experiment should not commence until *Arrow D* was re-hafted and the firing order was rectified. Because it would be a few days before the experiment could continue and the issues with the arrowheads breaking free from the mounts, it was determined that the lull in time would allow for some research into new adhesives that would better bind the metal heads to the wooden shafts and that all of the arrowheads would be remounted using the new adhesive technique.

The arrows were all removed from the shafts and re-hafted; this time using a combination of high-strength Gorilla brand epoxy and Gorilla brand super glue. After waiting several days for the new mounts to thoroughly cure, testing commenced again. *Arrow D* was the first to be shot, as it was two shots behind the rotation of the group. However, during the second shot, *Arrow D* again broke where the dowel rod inserted into the socket. It was then concluded that the dowel wood was too soft and had to be shaved too thin at the point of entry into the sockets to withstand the forces being exerted upon them. Therefore, a whole new approach would need to be applied in order to test further.

With time quickly running out before the project deadline, it was decided that enough data had been collected with the shots that had succeeded to run statistical tests and determine if the morphology of the arrowheads had affected their ability to penetrate the clay. (See Table 1 for arrow measurements, Table 2 for *Arrow A* performance, Table 3 for *Arrow B* performance, Table 4 for *Arrow C* performance, and Table 5 for *Arrow D* performance. Figure 13 displays a scatterplot of combined results and Figure 14 shows a histogram grouped by morphological type.)

Results

Mass and velocity were both controlled in the experiment to isolate morphology as the only possible cause of variation in penetration. Each arrow was fired 12 times, excepting Arrow D, which achieved 11 successful shots. The results were then grouped by the arrowhead morphology, with a total of 23 bilobate shots and 24 trilobate shots. The data was analyzed using IBM SPSS v. 23. An independent sample t-test was deemed appropriate for this analysis given the following criteria: 1) this is a two group problem, 2) the groups are independent from one another, 3) the sample sizes were small (below 30 for each group), and 4) the data was normally distributed, and thus appropriate for a t-test. The goal of the statistical analysis was to determine if there are significant differences in penetration depth between the means of the two groups bilobate (n= 23) versus trilobite (n = 24). Results of the test show no significant difference (t = .669, p = .507) in the scores for bilobate (M= 18.50, SD = .69) and those of the trilobite (M= 18.67, SD = .95). (Tables 6 lists the SPSS T-test statistics and 7 show SPSS T-test results.)

Conclusion

The tests conducted in this study have found that there is no significant difference in penetration depth caused by the variations in morphology between the two arrowhead types when the weights and materials are the same. This indicates that the morphology of the point type was not selected based on its ability to penetrate human flesh and, therefore, further testing of other aerodynamic properties of the arrowheads against other materials must be conducted to understand the purpose behind both types occurring simultaneously in one context.

This project is a pilot study with limited results. Only one small portion of a much larger question has been answered. However, it still yielded results and has allowed us to move our research further towards a greater understanding of technological innovation, acceptance, and spread among groups.

Future Work

As is often the case in science, the track to answers often leads to many more questions. Because of the issues faced, observations made during the process, and the narrow results of the testing, several other questions have arisen that require further pursuit; while still proceeding towards answering the original questions proposed.

This study helps us understand the challenges and parameters that must be overcome during larger testing of not only bronze points and their aerodynamic properties, but also iron points, and testing their abilities in real-world scenarios against flesh, bone, and even armor. All of this to help us understand the evolution of the role of weapon typologies against defensive armaments as well as materials. While it did, ultimately, provide results relating to one part of the question, it also provided very important information and perspective on moving forward with the testing. Below are some notes and observations to consider as the project continues in the future.

- While attempts were made to make sure the arrows weighed the same between them, it was decided that, because the short range of the tests (2.75m), adjusting the balance of the arrows or adding fletching would not affect the penetration potential between the different morphological types. However, this resulted in the much heavier front portions of the arrows dipping down slightly during flight. As they hit the clay, they did so at a slight angle. As the arrowhead entered the matrix and straightened out, the shaft would whip against the clay, presumably causing a large amount of force upon the shaft at the point where it enters into the arrowhead and likely causing the failures experienced at this union. While it cannot be verified that this is what was occurring, it was considered the most likely cause of the shaft failures in conjunction with the general softness of the wood itself. Future testing should include properly balanced and fletched arrow shafts with appropriate spine[7] strength to withstand the forces being exerted to avoid any potential issues that may have come from improper balance and construction.

- Though not measured, it was noted that the trilobate arrows appeared to leave noticeably larger and likely more destructive cavities in the clay matrix. In future studies, measurements to qualify the wound patterns and severity left by each arrowhead type will be conducted. While not originally considered during the planning of this project, it was decided that this aspect may be an important performance characteristic variation between the point typologies and therefore should also be collected.
- Under normal circumstances, the trilobed arrowheads would naturally weigh more than the bilobed arrowheads and, at similar velocities, be expected to penetrate further. Tests of each type conducted at natural weights should be conducted at the same velocities (requiring different pull weights) and at similar pull weights (resulting in different

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[7] The spine of the arrow is its rigidity and stiffness as measured by its flex at a given weight. If the spine of the arrow is not appropriate for the force being exerted upon it, problems can occur during the firing or flight process. Spine requirements are determined using a formula based on the weight of the arrowhead and pull weight of the bow (Cosgrove 1994:227–229).

velocities) to understand the variations in penetration specifically resulting from point morphology.

- In following the previous note, tests with varying physical characteristics beyond weight (size, other morphologies, etc.) should be conducted to understand how they affect various performance characteristics.
- Shortly before initial testing began, it was learned that Kent State University has a foundry that was both capable and willing to craft arrowheads on both a larger scale and level of precision than the points used for this study. With more points and more precision molding, many of the issues faced during this study may be overcome; or, in contrast, shown to be caused by other sources.
- Tests of other aerodynamic and performance properties of the different arrowhead styles and materials should be conducted. (Wright 2008:27–28) suggests that the position of the lobes on the trefoil points granted them greater precision in flight than the bilobed points. This assertion should also be tested.
- As experiments that are controlled using modern materials yield results about morphology and material performance, future testing should commence attempting to replicate the technologies and materials (bitumen adhesives, bronzes with varying compositions, etc.) available to ancient peoples to better replicate the conditions and context in which they were chosen and adopted.

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Tables

Table 1

Arrow Measurements

Arrow	Weight (grams)	Length (cm)	Re-haft Weight
A	82	84.2	84.2
B	82	84.2	N/A
C	81	84.1	N/A
D	82	84.2	84.95

Note: The re-haft weight for Arrow D was slightly higher due to a change in the hafting process that increased the weight of all of the arrows to similar levels. However, after re-hafting and reshooting one shot with the arrow, it broke again and the experiment was stopped.

Table 2

Arrow A Firing Results

Date	Shot #	Depth (cm)	Velocity (m/sec)	Notes
6/12/2019	1	18.5	Err 1	
6/12/2019	2	17.3	26.6	
6/12/2019	3	18.3	29.96	
6/12/2019	4	17.5	28.86	Refire
6/12/2019	5	17.3	24.54	Refire
6/12/2019	6	17.5	28.74	Refire
6/12/2019	7	19.3	28.79	Refire
6/12/2019	8	19.2	24.53	
6/12/2019	9	19.4	Err 2	
6/12/2019	10	18.3	28.55	
6/12/2019	11	19	28.78	
6/12/2019	12	18.9	28.71	

Note: Shots 4 – 7 were refired after the arrowhead was re-hafted with Gorilla brand superglue following its separation from the shaft and subsequent wobble.

Table 3

Arrow B Firing Results

Date	Shot #	Depth (cm)	Velocity (m/sec)	Notes
6/12/2019	1	20	Err 1	
6/12/2019	2	20.4	30.02	
6/12/2019	3	18.7	29.65	
6/12/2019	4	17.7	29.23	
6/12/2019	5	18	29.49	
6/12/2019	6	18	29.22	
6/12/2019	7	18.1	29.2	
6/12/2019	8	20.2	29.36	
6/12/2019	9	18.6	29.16	
6/12/2019	10	19	28.93	
6/12/2019	11	20.4	29.26	
6/12/2019	12	18.4	29.16	

Table 4

Arrow C Firing Results

Date	Shot #	Depth (cm)	Velocity (m/sec)	Notes
6/12/2019	1	18.7	29.79	
6/12/2019	2	18.8	29.86	
6/12/2019	3	17.7	29.57	
6/12/2019	4	18.3	29.28	
6/12/2019	5	19.3	29.44	
6/12/2019	6	18.2	29.27	
6/12/2019	7	18.4	29.49	
6/12/2019	8	19.1	29.32	
6/12/2019	9	17.3	25.05	
6/12/2019	10	19.3	29.31	
6/12/2019	11	18.1	29.38	
6/12/2019	12	17.6	29.12	

Table 5

Arrow D Firing Results

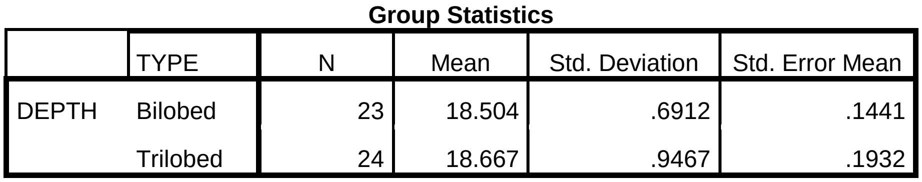
Date	Shot #	Depth (cm)	Velocity (m/sec)	Notes
6/12/2019	1	18.3	29.52	
6/12/2019	2	19.9	29.74	Shot hit very high on clay

Date	Shot #	Depth (cm)	Velocity (m/sec)	Notes
6/12/2019	3	17.5	28.97	
6/12/2019	4	18.4	29.28	
6/12/2019	5	17.9	34.97	
6/12/2019	6	19.1	28.99	
6/12/2019	7	19.3	28.96	
6/12/2019	8	19.5	28.71	
6/12/2019	9	18.2	Err 2	
6/12/2019	10	18.2	29	
6/17/2019	11	18.5	28.75	Refire
6/17/2019	12	N/A	24.71	Arrow broke

Note: Shot 2 hit the clay high but does not seem to have affected the results. After shot 10, the arrowhead began to wobble and it was removed from the rotation to be re-hafted. After re-hafting, it was fired again, but broke during the second shot.

Table 6

T-test Statistics

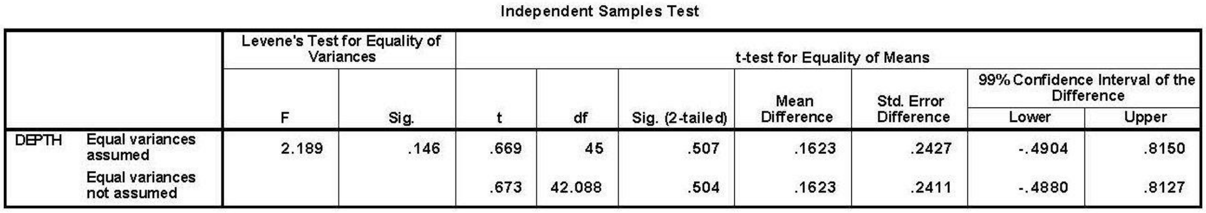


Group Statistics

	TYPE	N	Mean	Std. Deviation	Std. Error Mean
DEPTH	Bilobed	23	18.504	.6912	.1441
	Trilobed	24	18.667	.9467	.1932

Table 7

T-test Results



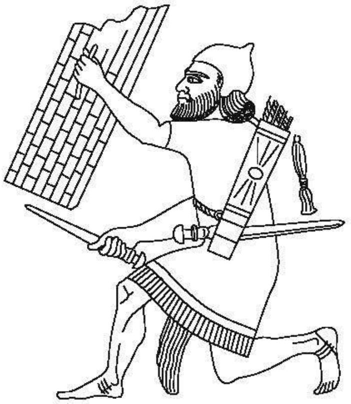
Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
									Lower	Upper
DEPTH	Equal variances assumed	2.189	.146	.669	45	.507	.1623	.2427	-.4904	.8150
	Equal variances not assumed			.673	42.088	.504	.1623	.2411	-.4880	.8127

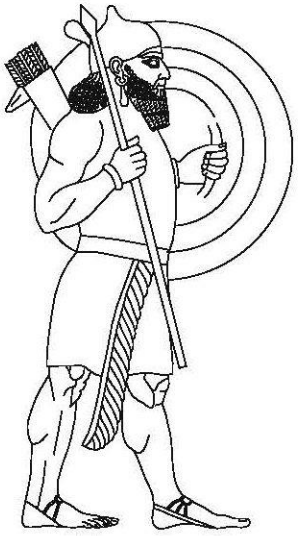
Figures

Sources: Esri, USGS, NOAA, Sources: Esri, Garmin, USGS, NPS

Figure 1. Map of the Near East showing the locations of Nahal Mishmar, Tepe Gawra, Amuz, and Abu Matar (Mullen 2019).

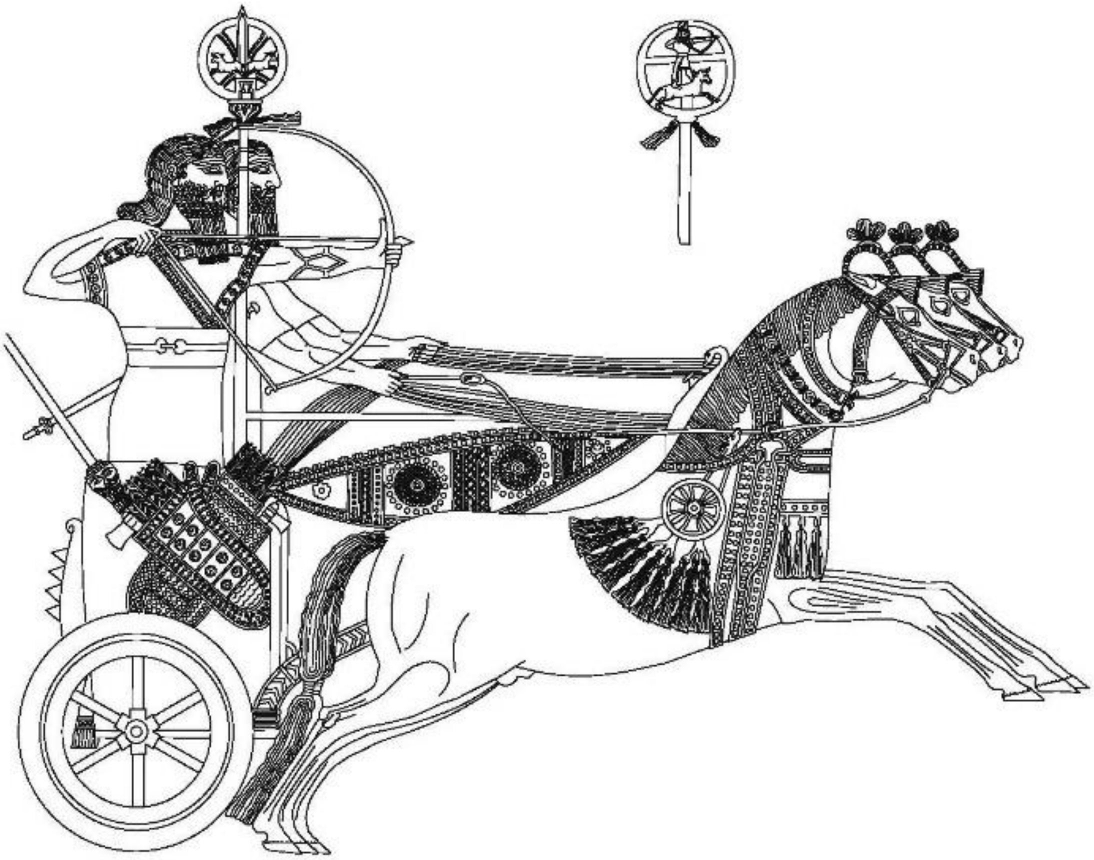


78. Botta - Flandin 1849, I, 68



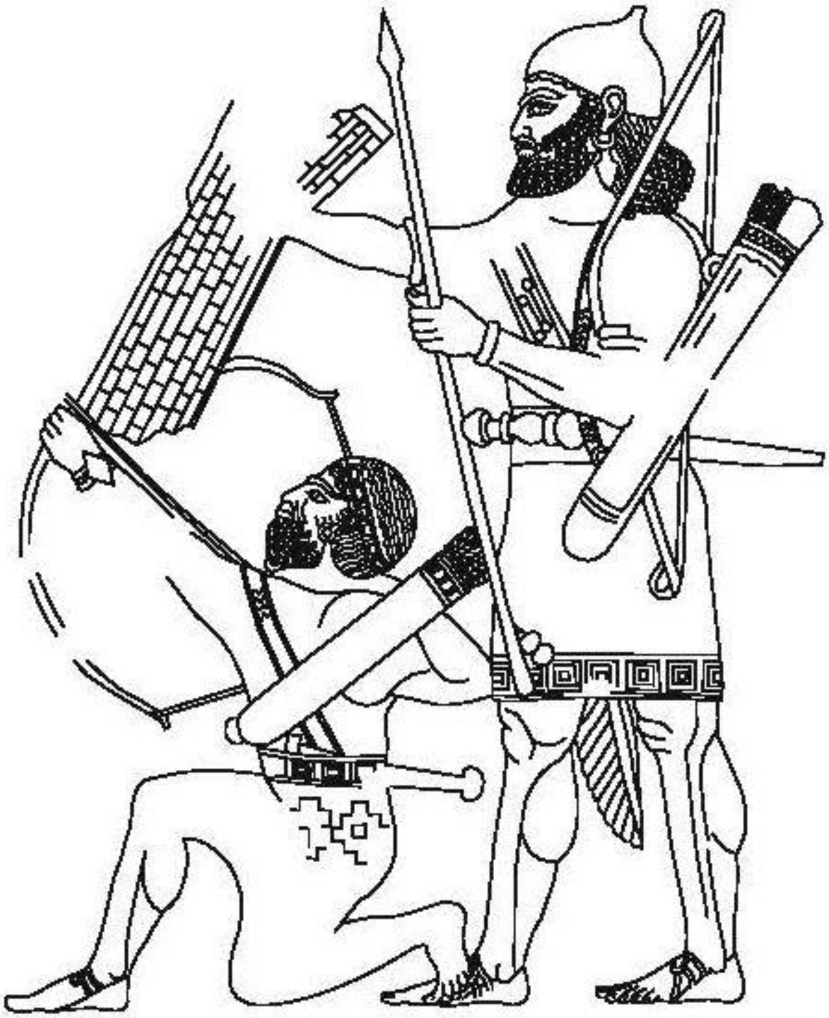
80. Botta - Flandin 1849, I, 63

Figures 2 and 3. Sketches of wall reliefs showing Neo-Assyrian infantry troops, both equipped with bows and arrows. (Dezsö 2012a:309)



24. Layard 1853A, 14

Figure 4. Sketch of a wall relief showing a Neo-Assyrian chariot. (Dezsö 2012b:266)



79. Botta - Flandin 1849, I, 62

Figure 5. Sketch of a wall relief showing a Neo-Assyrian archer along with a shield-bearer who is also equipped with a bow and arrow. (Dezsö 2012a:309)

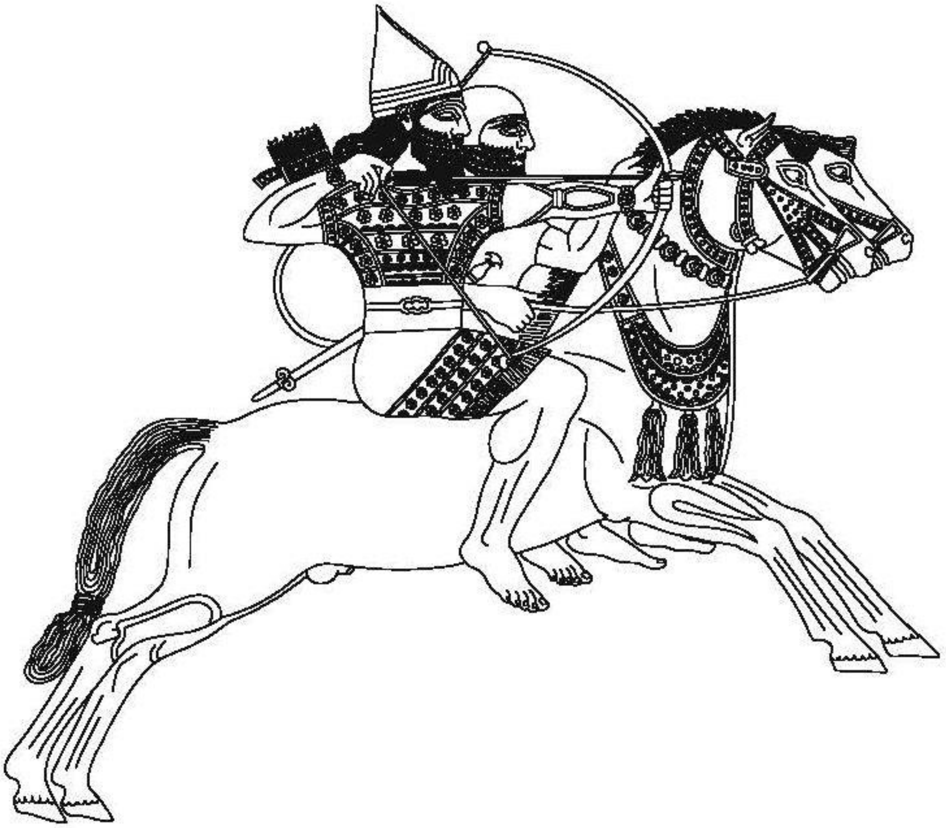
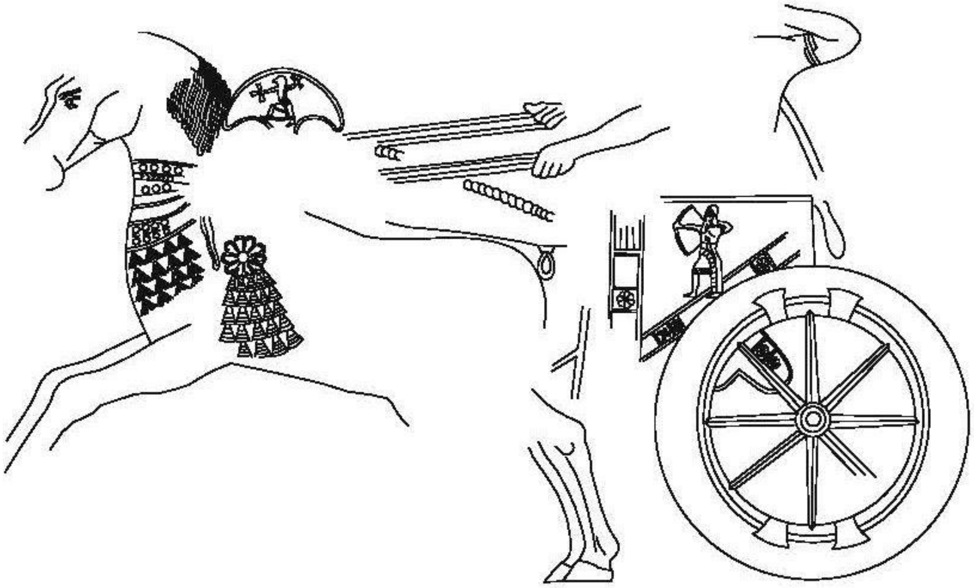


Figure 6. Sketch of a wall relief showing Neo-Assyrian cavalry riders, one equipped with a bow and arrow. (Dezsö 2012b:255)



30. Botta - Flandin 1849, 56

Figure 7. A depiction of the god Assur wielding a bow on the side of a chariot from a sketch of a palace relief (Dezsö 2012b:270).

Figures 8 and 9. Photos of an unpolished trilobate point after casting. The red circles indicate the small voids left by the casting process. (Images have been adjusted for clarity.)

Figure 10. Larger photo of an unpolished trilobate point after casting with another red circle to indicate the small voids left by the casting process. Also visible in this image are the sprues from the casting process. (Image has been adjusted for clarity.)

Figure 11. Photo of the bilobate point after being damaged from a misfire and repaired through cold-hammering. The image also shows the extent of the void in the point. While the size of the void was clearly larger than the other arrowheads initially, the full extent of it was not apparent until after it was damaged. (Image has been adjusted for clarity.)

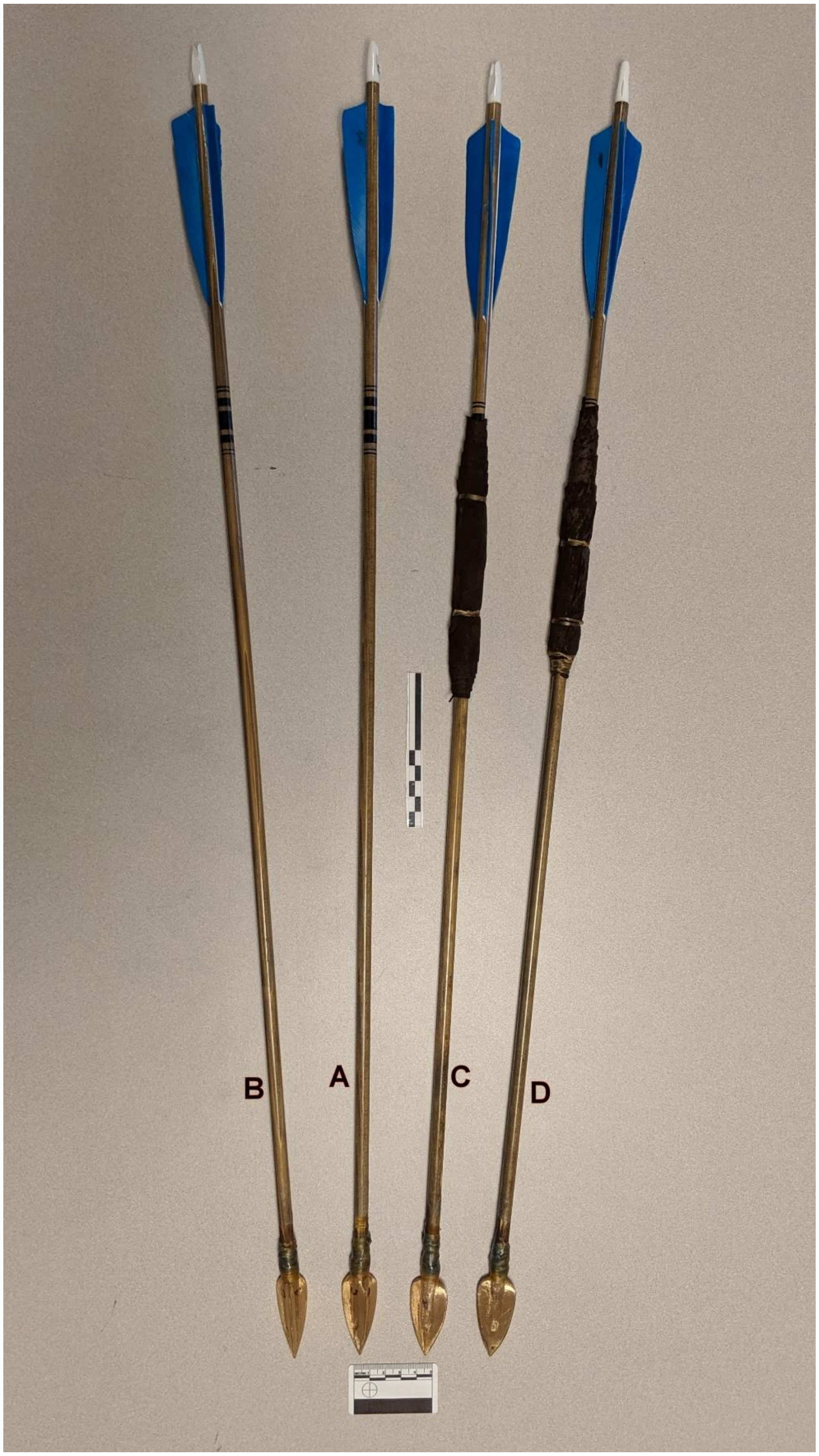


Figure 12. Photo of the first arrows that were crafted using leather wraps to adjust the weights of the bilobate points.

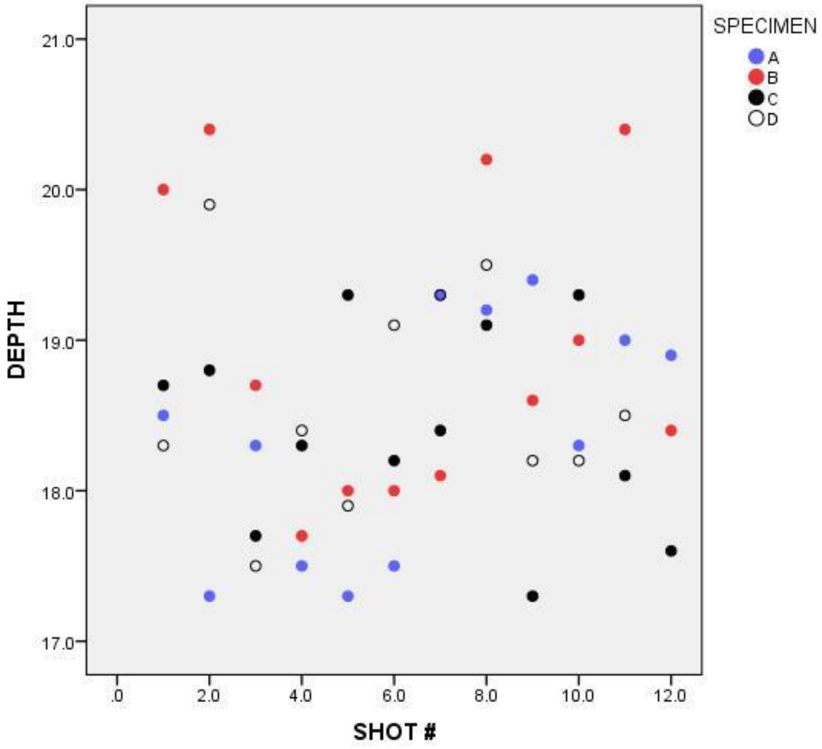


Figure 13. Scatter plot of penetration depth values for each shot taken by each arrowhead.

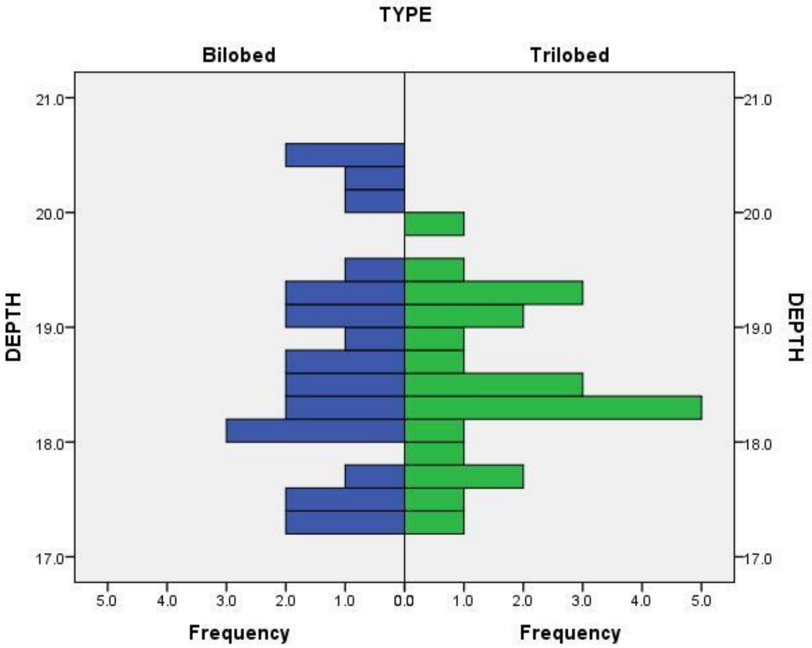


Figure 14. Histogram of penetration depth by morphometric type of arrowhead.