

# MAKING RED GOLD: AN EVALUATION OF ANCIENT SHELL BEAD PERFORATION TECHNIQUES

Alison Barton, Andrew Bogdan, Elizabeth Day, Emily Fee, Samantha Giugliano, Phillip Holzsaeger, Sandra Korn, Joseph Massaglia, Laura Polding, Laura Poole, Colleen Reynolds

Advisor: Dr. Benjamin Carter  
Assistant: Katie Seither

## ABSTRACT

The Manteño Indians of South America greatly valued small beads made from *Spondylus* shell—the beads have even been called “red gold” in reference to the shell’s coloring. Before 1200 AD, the Manteño and their predecessors produced shell beads using a procedure that included perforation by lithic (chert) microdrills; however, evidence for microdrills after 1200 AD is sparse. Additionally, bead characteristics changed in this era, suggesting a modification in methods of shell bead manufacture. Using a bow drill along with combinations of primary materials (chert, oak, teak, copper, and shell), and auxiliary materials (water, sand, and ground pumice stone) we tested possible perforation techniques. We were thus able to determine combinations of materials the Manteño might have employed to perforate *Spondylus* shell.

## INTRODUCTION

For thousands of years, cultures across the world have imbued beads with artistic, religious, and economic significance. One such people were the Manteño, who produced and traded tiny beads made of *Spondylus* shell (Fig. 1) from about 700 to 1532 AD.

Widespread production of *Spondylus* shell beads in South America began around 200 AD. The Manteno and their predecessors used lithic microdrills to perforate the shells, and archaeologists have found about as many of these drills as actual beads. In contrast, very few corresponding stone drills have been found from after 1200 AD. Beads fashioned before 1200 AD share certain characteristics, including small size and even finishes, and are called Chaîne I beads; those produced after 1200 AD are larger and less finished, and are referred to as Chaîne II beads. Researchers do not know how the Manteño perforated Chaîne II beads, and have conducted only limited investigation on alternative methods of *Spondylus* perforation. Until now, most research has been focused on lithic microdrills [1]. By reproducing possible alternative methods of shell drilling, we were able to determine feasible explanations for the later-era perforations and to dismiss unlikely processes.



Figure 1: A selection of Chaîne II beads excavated from archaeological sites in Ecuador.

Understanding the process by which people can turn shells into beads holds great importance as it indicates a society's level of technological development [2]. A comprehension of the methods used to produce shell beads also helps researchers "understand the role of shell working as a craft activity within the local socio-economic system" [3]. Thus, by narrowing down the possible explanations for ancient means of shell perforation, we can contribute to an understanding of the Manteño society.

## BACKGROUND

### The Manteño

Between 700 and 900 A.D., as the Guangala culture of South America began to decline, the Manteño society emerged. Based on the characteristic ceramics of both societies, archaeologists believe that the Manteño developed from what was left of the Guangala. The Manteño, also known as the Huancavilca, occupied the coastal region of Ecuador (Fig. 2) until the arrival of Spanish conquistadors in the early 1500s. However, no definite dates or boundaries are known for the Manteño culture [1].

While some of the Manteño people lived in large inland settlements, the majority of communities were located on or near beaches with water management systems to provide freshwater for human consumption and agriculture. The Manteño depended heavily upon the ocean for food, raw materials, transportation, and trade. In order to take advantage of marine resources, they constructed rafts of balsa, a lightweight and buoyant wood ideal for use in large sailing vessels. Fish, mollusks, and seabirds provided an important source of protein in the Manteño diet. In addition, the Manteño ate animals, such as guinea pigs, Muscovy ducks, dogs, and deer. They also grew squash, beans, maize, peppers, sweet potatoes, and tomatoes [4].

In addition to trading with nearby littoral communities, the Manteño exchanged goods with groups in Peru. While they mostly traded raw goods, Spanish explorers report that the Manteño also bartered ceramic goods, silver and gold items, textiles, religious items, Spondylus shells for obsidian, metal, copper, and wood. There is some evidence that the Spondylus shells were used as a "standard of value" in these regions [4]. The Manteño imported pumice stones



Figure 2: This map shows the current boundaries of Ecuador. The Manteño occupied regions of its western coast.

from the highland regions. They grounded the pumice stone and mixed it in with ceramics as a temper [5].

The Manteño made use of a number of materials for tools and containers. Ceramics were used for ritualistic vessels, cooking, casting metal, urns for the dead, and as musical instruments. The Manteño utilized flakes of stone for cutting; stone also served as parts of weights, hammers, axes, saws, and clubs. Although no wooden tools have survived, archaeologists believe that the Manteño used wood for digging, bows and arrows, and other purposes. In addition, the Manteño used arsenical bronze (an alloy of arsenic and copper) as digging stick tips, needles, tweezers, axes, and possibly money [4].

Little is known about Manteño societal structure, but some form of social hierarchy certainly existed. While families and communities appear to have produced goods as a unit, there seems to have been some specialization in labor. Although each home would manufacture its own products, a high degree of standardization did exist, especially in the production of Spondylus beads [4].

The Manteño honored their ancestors, believed in spirits, and worshiped idols. The religion was highly ritualized and included sacrifice of birds and war captives, as well as offerings of textiles and jewelry, especially of Spondylus shell beads. The dead were buried with goods including ceramics, shell beads, and tools for making beads [4].

While Spondylus shell beads held great importance for the Manteño, they were not the first, nor the last, culture to manufacture them. The Manteño inherited both production techniques and their high regard for shell beads from their predecessors and neighbors.



Figure 3: A Spondylus shell, the material from which the Manteño crafted their beads.

### Shell Bead Products

The Manteño produced beads out of Spondylus shell (Fig. 3). Of the three species of Spondylus, the Manteño used *S. calcifer* and *S. princeps*, each of which have hard shells that vary in color between orange, red, and purple. Spondylus are only found in Ecuador and extreme northwestern Peru. Numerous cultures, including the Manteño, Sican, Moche, and Chimú, traded with the Manteño for Spondylus beads, which were used in religious and cultural rituals. [1].

Prior to 200 AD, production of Spondylus beads was localized and small-scale, and the beads created were large and irregular. As time went on and whole communities began manufacturing beads, the beads became smaller and more regular; these are known as *chaquira* or Chaîne I beads [1]. The beads' development into a major trade good was expedited by the invention of balsa rafts [1]. After 1200 AD, the shape and style of the beads themselves changed; beads produced after this period were termed Chaîne II beads. While “Chaîne I beads are produced from whole shells or large chunks of shell...Chaîne II beads

appear to be made mainly, though not exclusively, from *conchilla*, small water worn shell fragments found along the beach” [1]. Rather than small and finished, as the Chaîne I were, Chaîne II beads became larger and more irregular. Information on bead production following the arrival of the Spanish in 1532 remains scarce.

Spondylus beads held great cultural significance to the Manteño. The shell beads represented war and peace, power and wealth, connections with deities, and internments of the dead, and may have been used as “a standard of value” [4]. Beads have been found at the corners of fields, in wells, and burial tombs. They were used in dedications, and strung together in intricate pectorals that were worn by powerful figures [1]. Each family generally produced their own beads, which were made from Spondylus shell harvested from the nearby ocean.

### *Production of Chaîne I*

The production method for *chaquiras*, or Chaîne I beads, has been fairly well documented. First, Spondylus shells were acquired by Manteño divers, and then reduced to small fragments by percussion on hard rocks. Bead shapes were roughed out by grinding the shell fragments against sandstone, and then the edges were faceted, also with sandstone. Then, the beads were perforated with lithic microdrills chipped out from chert. For every shell bead found, archaeologists have found approximately one drill tip, suggesting that they were frequently replaced. Most likely, the Manteño would sit with a shell bead blank held between their feet or toes, insert the microdrill



into a shaft made of wood, and rotate it between their palms or with a bow drill or pump drill. Lastly, the beads were rotationally ground by stringing dozens of beads on a string and rolling them against sandstone to provide an even, circular finish [1].

Figure 4: The production process of a Chaîne I bead: (a) a rough chip of shell, (b) bead shape, (c and d) partially perforated beads, (e) fully perforated and ground bead, (f) cross-section of bead

### *Production of Chaîne II*

Whereas most intact Chaîne I beads found are finished and fully perforated, Chaîne II beads are larger and more irregular in perforation. Some Chaîne II beads are in different stages of the production process; beads may be rounded but with rough faces, have smooth faces but rough edges, be partially perforated or fully perforated. Thus, the production techniques for Chaîne II beads are not yet fully understood. Archaeologists do not know if beads were perforated before or after being faceted, although they do know that rotational grinding was usually the final step in production. Most importantly, very few lithic microdrills have been found from this era—about one microdrill for every 500 beads, as compared to a one-to-one ratio for Chaîne I beads—suggesting that the later-era Manteño employed a different method of perforation. As most of the Chaîne II bead production process requires “very little effort,” it seems likely that the drilling technique was also efficient [1].

## EXPERIMENTAL DESIGN

### Primary and Secondary Materials

Experimental testing centered upon combinations of primary and secondary materials. The drill bits themselves (Fig. 6) were comprised of primary materials, and were used in combination with one or more secondary materials to perforate pieces of shell (Fig. 5).

Chert, the material comprising lithic microdrills, served as a control. We utilized realistic replicas of these chert drills made by Jack Cresson, a professional flintnapper, including those classified JC-95-01 through JC-95-05 [1]. These served as a point of comparison for other techniques in terms of effectiveness and efficiency.

While choosing materials to test, we considered what materials would have been available to the Manteño prior to European contact. The Manteño had access to much wood of varying hardness [1]. According to J.D. McGuire, previous studies in methods of drilling

determined that “care must be taken not to select a wood too hard, and to choose wood which is too soft is equally unfortunate” [6]. Tests were performed with two common types of wood that differ greatly in hardness on the Janka scale: Brazilian Teak and Red Oak. The Janka scale is a method used to measure the hardness of a wood by measuring the amount of force required to push a 0.444 inch steel ball into the wood to a distance of half its diameter. The Brazilian Teak requires 3540 pounds-force, while Oak requires 1290 pounds-force [7].

In addition to wood, the Manteño had access to arsenic bronze, an alloy of arsenic and copper, through trade.



Figure 5: A Spondylus shell demonstrating multiple test perforations



Figure 6: From left to right, chert microdrill, teak, copper, and red oak drill shafts

The last primary material tested was shell sharpened to a point. Spondylus itself is an exceptionally hard shell, and although it was somewhat inconvenient for the Manteno to procure, it might prove an effective drilling material.

In addition to these primary materials, three auxiliary materials were used in combination with the primary drill bit materials. Both sand and pumice were used as abrasive materials. Figure 7 demonstrates the difference in the surfaces of sand and pumice as captured in an SEM image: ground pumice has sharper and small fragments, in contrast to sand's rounded grains.

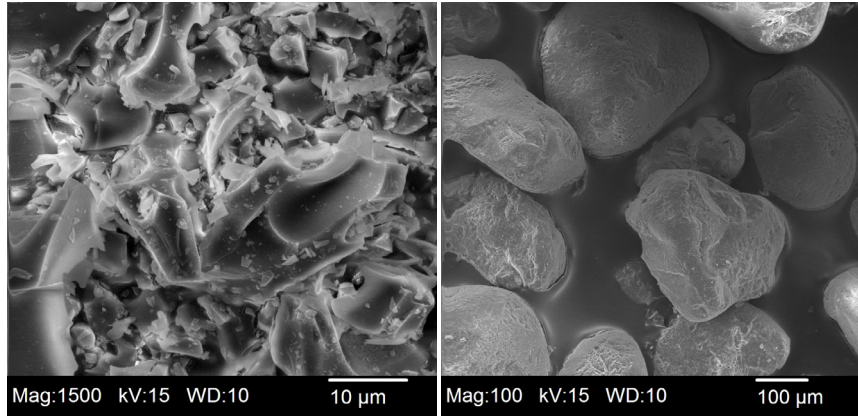


Figure 7: These pumice (left) and sand (right) particles were tested as abrasives. Note that the sand grains are more than ten times larger than the pumice

### Drilling Techniques

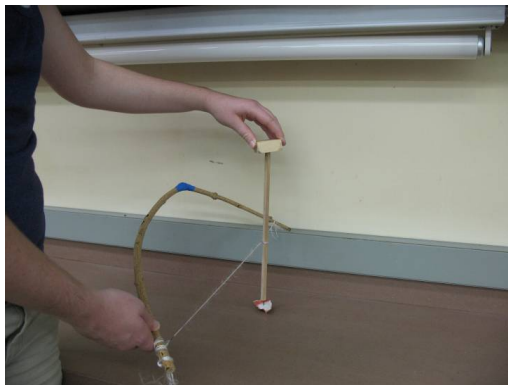


Figure 8: Operation of a bow drill, the primary method used in drill testing.

A more efficient technique was the bow drill method (Fig. 8). In this method, a string is tied to the ends of a supple stick, forming a bow. The shaft of the drill is then round around the string, and the bow is pulled back and forth to twirl the shaft rapidly. The shaft is held in place by applying downward pressure to a wooden block on top of the shaft [6]. This method was used by all groups in testing drill methods, although every hole was “started” either with a hand-held chert tip or with a power drill with a steel drill bit.

Lastly, the pump drill is a more advanced and efficient method for drilling; however, its relative complexity made it impractical for use as a testing tool.

The abrasive secondary materials—sand, ground pumice, and water were added in small amounts at the beginning and often halfway through the drilling process, in 0.02g increments. Water was added a drop at a time during the beginning and sometimes halfway through the drilling process. In testing the two woods, effort was made to embed the abrasive in the wooden shaft, so the tip was pressed into the sand or pumice particles. These abrasives were used to increase the rigidity of the drill point and provide a sharp cutting edge in the place of the smooth surface of the wooden and copper drill bits.

The number of revolutions of the drill tip was counted by measuring the circumference of a shaft and marking out a section of string on the bow corresponding to ten times that distance, then counting the number of passes of the bow per hole. A nylon string was used to prevent stretching. Details such as this were given so much attention for the purpose of measuring the efficiency of each drill method and material. Counting revolutions and preventing stretching of the string allowed each group to follow more similar methods to each other, and therefore have more compatible data with each other at the end of the experiment. Revolution counts provided a broad basis by which to determine relative efficiency of different materials.

### Testing Process

In order to test each combination of primary and secondary materials, the team split into three groups, 1, 2, and 3; each drill tip was tested by two groups, and tested alone, with each of the two abrasives, and with each abrasive plus water. The group test assignments are as follows:

**Table 1: Material Testing Assignments**

	<b>Alone</b>	<b>Water</b>	<b>Sand</b>	<b>Sand and Water</b>	<b>Pumice</b>	<b>Pumice and Water</b>
<b>Chert (Stone)</b>	1, 2, 3	1, 2, 3	1, 2	1, 2	2	2
<b>Oak</b>	2, 3	2, 3	2, 3	2, 3	2, 3	2, 3
<b>Brazilian Teak</b>	1, 2	1, 2	1, 2	1, 2	1, 2	1, 2
<b>Copper</b>	1, 3	1, 3	1, 3	1, 3	1, 3	1, 3
<b>Shell</b>	2, 3	2, 3	2, 3	2, 3	2, 3	2, 3

### Examination under the SEM

Once each group completed their assigned holes, the perforations had to be prepared for examination under the Scanning Electron Microscope (SEM). Because the actual shell was too large of a sample to examine, we first had to take impressions of each hole using Examix NDS, a hydrophilic vinyl polysiloxane, the same substance used to make dental impressions [8]. The hardening mix was carefully inserted into each of the drilled holes using a low pressure gun, being careful not to allow air bubbles to form and subsequently ruin the impression. After two

minutes, the solid impression material could be removed, cut down to a small enough size to fit into the SEM, and labeled depending on which material it was made from. Each impression was then cut in half so that its profile could later be viewed under the SEM. Finally, the half impressions were put onto metal SEM stubs using double sided tape.

Before each stub could be viewed under the SEM however, it had to be gold sputter coated. The SEM, a microscope which uses a concentrated beam of electrons to produce an image, works best when the specimens are electrically conductive, allowing the electrons to bounce off, thus creating a clearer image. Sputter coating is a process in which a gold-palladium target inside a chamber is struck with argon gas particles. Metal ions are then ejected from the target and hit the specimen. A cloud of metal ions allows the specimen to be evenly coated throughout a four minute period [9].

Coated specimens were imaged in the Scanning Electron Microscope. In a Scanning Electron Microscope, a beam of electrons is emitted from an electron gun fitted with a tungsten filament cathode. A series of lenses within the electron column condense the emitted electrons into a thin, tight, coherent beam. The surface of the specimen—in this case, an impression of a perforation—is scanned by the electron beam in a grid like raster pattern; the process is repeated until the entire surface has been scanned. Signals including backscattered and secondary electrons are emitted from the surface of the specimen. After detecting the electrons, a cathode ray tube translates the electrons into differences of brightness. An image is produced from the variations of brightness with adjustable magnification, contrast, focus, and brightness. A computer may then reproduce the image [9].

## EXPERIMENTAL RESULTS

### Lithic Microdrills (Chert)

The chert drill bits effectively perforated the Spondylus shell in every trial (Table 2). Alone, the chert succeeded in drilling a deep hole in the surface of the shell in 3000 rotations. However, when sand was added as an abrasive, this method was less productive, and drilled a medium hole in 3,500 rotations—possibly wore away at the drill during the process.

Conversely, water allowed the chert to drill more efficiently by removing shell dust from the hole. With both sand and water, the chert drilled still more efficiently, producing a deep hole in only 2,600 rotations; the

**Table 3: Chert Drill Results**

<b>Primary Material</b>	<b>Auxiliary Material</b>	<b>Result</b>	<b>Rotations</b>
Chert	None	Medium hole	3000
Chert	Sand	Medium hole	3500
Chert	Sand and water	Medium hole	2600
Chert	Water	Deep hole	
Chert	Pumice	Medium hole	
Chert	Pumice and water	Medium hole	



water circulated the abrasive sand and removed the shell dust. Powdered pumice and water proved to be less effective than chert alone.

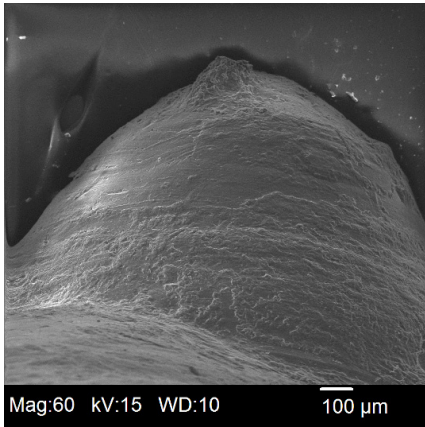


Figure 9: SEM image of perforation from the chert microdrill alone

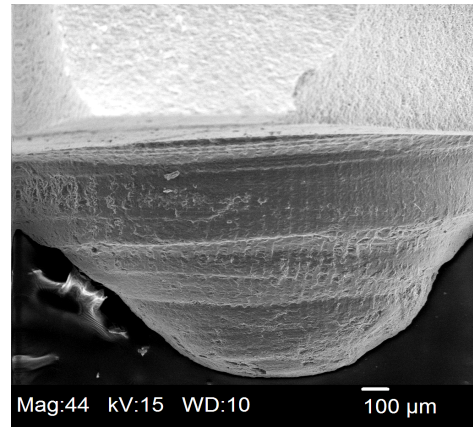


Figure 10: SEM image of perforation from the chert microdrill and water

From SEM images, we observed distinct characteristics on the perforation walls with each combination of abrasive and water. Without any auxiliary materials, the chert drills produced a hole with an uneven chipped surface due to the drill's irregular edges (Figure 9). The perforations made with the chert drill and water had distinctive striations (Figure 10) while the chert and sand produced a fairly smooth hole with faint, even, horizontal striations. The perforations made with pumice and chert appeared much smoother. The vertical lines appearing in Figure 9 do not represent a characteristic of the perforation itself, but simply the "grain" of the shell. All perforations made with the chert microdrill tips had a characteristic funnel-like shape.

**Table 3: Red Oak Drill Results**

Primary Material	Auxiliary Material	Results	Rotation
Red Oak	None	No hole	8,000
Red Oak	Water	No hole	8,000
Red Oak	Sand	No hole	8,000
Red Oak	Sand and Water	No hole	8,000
Red Oak	Pumice	No hole	8,000
Red Oak	Pumice and Water	Wide shallow hole	8,000

Red Oak as a Drill

After experimentation, groups discovered that red oak does not make effective drill material (Table 3). The oak drills failed to produce perforations when employed alone, with water, sand, sand and water, or pumice. During experimentation, the soft oak drill points

would constantly become dull; after every few thousand drill rotations, the blunt tips would

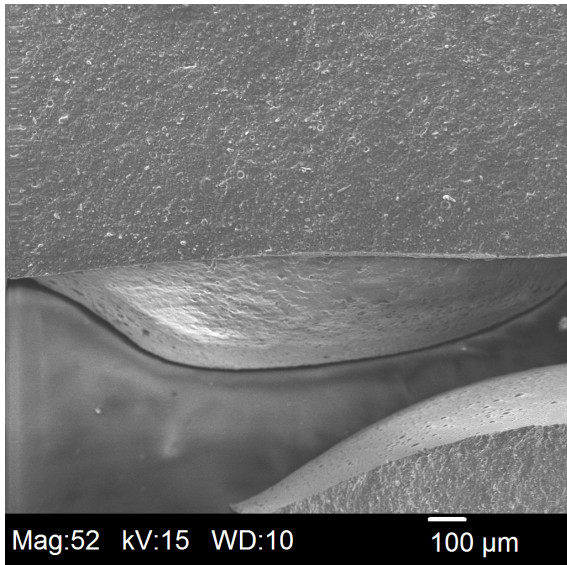


Figure 11: SEM image of perforation created by a red oak drill with pumice and water.

require sharpening. The water hindered the production of a perforation with the oak as it softened the wood, and weakened the tip. Each group also encountered several problems when testing the oak drills with sand. Although sand is commonly used as an abrasive, the team discovered that the spherical shape of the sand grains actually served as a lubricant. The oak drill only produced one perforation when combined with pumice and water. After 8,000 drill rotations, this combination created a shallow hole. However, this result could not be replicated.

As observed from the SEM image, this single oak drill perforation created a very shallow hole with a flat bottom (Figure 11). Unlike the other holes, the oak drill perforation lacks distinct markings. The surface is relatively smooth with very faint horizontal lines and small chip marks.

Copper as a Drill

The copper drills produced very small and shallow holes. Using a smooth copper drill tip, a very small perforation was created with 8,000 drill rotations. After the team discovered that the holes could be produced more quickly by roughening the copper tip with a stone hammer, a small hole was produced with 5,000 drill rotations. Subsequently, groups used roughened copper drill tips to create more small perforations in the shell. After about 8,000 drill rotations, small indentations were produced by the copper drills alone, with water, with pumice, and with pumice and water.

**Table 4: Copper Drill Results**

Primary Material	Auxiliary Material	Results	Rotation
Copper	None	Very Small hole	8,000
			5,000
Copper	Water	Very Shallow hole	8,000
Copper	Sand	Very Shallow hole	5,000
Copper	Sand and Water	No hole	n/a
Copper	Pumice	Almost nothing	1,500
		Very Shallow hole	8,000
Copper	Pumice and Water	Very Shallow hole	8,000
		Almost Nothing	1,500 8,000

When using pumice and water as an abrasive (Figure 12), more water than pumice was required to avoid creating a paste on the surface of the shell. Using the copper drills with sand was also unsuccessful due to the smooth, spherical grains of sand.

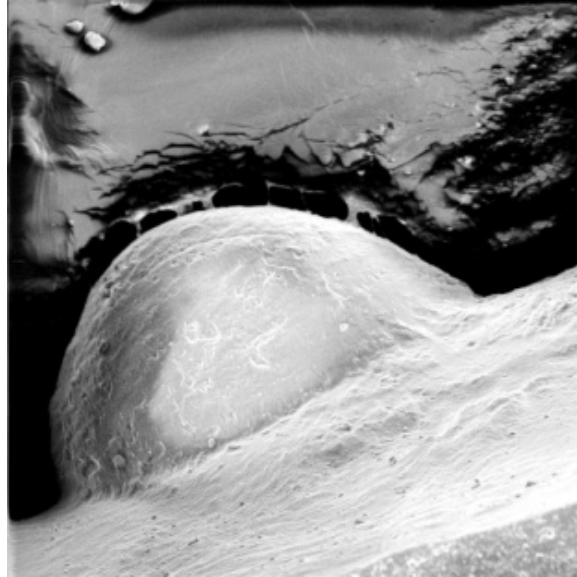


Figure 12: Copper drill tip with water and pumice

Upon visual inspection, the holes produced by copper drill tips were visibly metallic and shiny, and appeared more narrow than other holes of similar depth. SEM micrographs showed that the holes created from copper alone were narrow, with rounded bottoms. These holes have uneven surfaces with rough chip marks and faint horizontal striations. The hole produced using copper and pumice had a smoother surface than that made with copper alone, and had more visible striations. Similarly, the hole created using copper and water had a relatively even surface with horizontal striations. When copper was used with pumice and water, the holes produced had uneven surfaces with many bumps and few lines.

### Spondylus Shell as a Drill

When drilling with the Spondylus shell drill tip several successful perforations were produced (Table 5).

**Table 5: Spondylus Shell Drill Results**

<b>Primary Material</b>	<b>Auxiliary Material</b>	<b>Results</b>	<b>Rotations</b>
Spondylus Shell	None	Shallow	21,000
Spondylus Shell	Water	Wide and shallow	16,800
Spondylus Shell	Sand	Very shallow hole	N/A
Spondylus Shell	Sand and water	Very shallow hole	N/A
Spondylus Shell	Pumice	Wide very shallow hole	12,600
Spondylus Shell	Pumice and water	Hole	10,500

Shell alone created a wide and shallow hole after 21,000 rotations. When aided by pumice as an abrasive and water, a wide shallow hole was also produced in only 10,500 rotations. When the shell drill tip was aided only by water, a hole of medium depth was formed after 16,800 rotations.

The hole produced by the shell drill tip with only the pumice abrasive was very shallow and wide after 12,600 rotations.

Meanwhile, when sand or sand and water in combination were used, wide and fairly shallow holes were made.

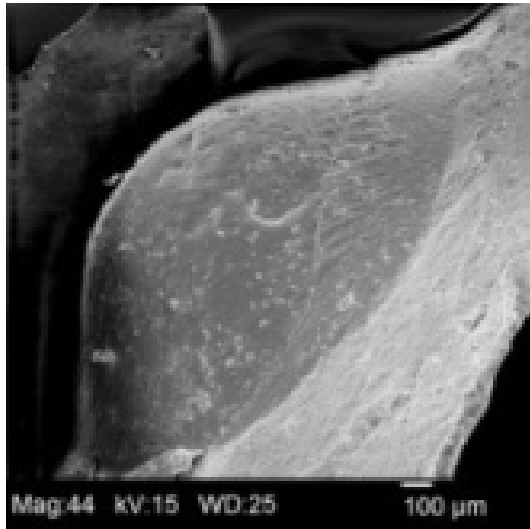


Figure 13: Spondylus shell drill with water

SEM images depicted thin rings on the perforation walls, especially in the perforations made by shell with water (Figure 13).

#### Brazilian Teak as a Drill

The Brazilian teak drill tip was only able to produce a few successful perforations (Table 6). Pumice and pumice in combination with water both led to slow progress. The teak drill with pumice and water produce a very small perforation in 10,500 rotations, as did the teak with pumice in 6,300 rotations. However, combinations of the teak drill with water and sand, with sand, and alone were unable to produce a hole after 2100, 3120, and 4000 rotations respectively. In all trials the drill was observed to dull after a few thousand revolutions, especially when weakened with water, thus requiring

the driller either to sharpen the drill or continue drilling with a less efficient drill tip.

From the SEM images it appeared that the teak drill with water and pumice produced a hole with smooth walls; the teak alone simply smoothed out the walls of the perforation but did little to make the hole much deeper

**Table 6: Brazilian Teak Drill Results**

Primary Material	Auxiliary Material	Results	Rotations
Brazilian Teak	None	No hole	4,000
Brazilian Teak	Sand	No hole	2,000 3,120
Brazilian Teak	Sand and water	No hole	2,100
Brazilian Teak	Pumice	No hole	6,300
Brazilian Teak	Pumice and water	Very shallow hole	5,000 5,000
		Medium hole	10,500

Primary Results Summary

Out of the five primary materials tested, the chert microdrills were clearly both the most effective and the most efficient perforators, especially when used with auxiliary materials. The woods, both Brazilian teak and Red Oak, served as rather ineffective drills. Copper was also an inefficient method of drilling, producing very small holes. The most successful of our experimental materials were Spondylus shell drills, which were most effective when used with water.

Auxiliary Materials: Sand, Ground Pumice, and Water

While originally only sand was included as an abrasive, the round grains often behaved more as a lubricant and simply smoothed the hole. Ground pumice, with much smaller and sharper granules, was also tested as an abrasive.

The three auxiliary materials, sand, water and pumice, had drastic effects on the different drill materials. The sand and the pumice when used in conjunction with chert seemed to hamper the drill's efficiency; however, when used with water or water and either sand or pumice, the chert drilled more effectively. Most likely, the abrasives, when caught in grooves in the drill material, ground away at the walls of the hole, leaving characteristic horizontal striations and smoothing out the shell. On the other hand, the water kept both the debris and the abrasives circulating which both minimized the wear on the drill and prevented the hole from clogging.

With the wood drills, the sand, water, and both sand and water each had adverse effects on the effectiveness of the drills. The water weakened the tip causing it to quickly dull from the pressure of drilling and the sand grains were too smooth to dig. However, the pumice was finer and rougher and aided the wood drills by scraping away at the shell. When both pumice and water were used with a wooden drill, the pumice stuck to the wood better and was able to scrape away at the shell while the debris was circulated preventing clogging.

Copper seemed to work best with water but without any abrasive. This tip's smooth surface was unable to grip the abrasive and scrape the edges of the perforation while the pumice and water combination formed a cement-like paste, which clogged the hole. When these factors were present, the copper was better able to perforate the shell.

The Spondylus shell drill tip was successful by itself, with water, and with both water and pumice. The water seemed especially effective in cleaning out the hole with this drill; however, the shell with both water and sand was not as successful because the sand was too smooth to effect the shell. The pumice was so fine that in addition to the shell fragments worn away from both the perforation and drill clogged the hole, hampering the drill's effectiveness.

## **INTERPRETATION**

### Conclusions from Drilling Results

Various drilling materials were used to replicate the perforations made during the creation of shell beads, including copper, teak, oak, and shell, with water, sand, and ground pumice. However, none of these materials created perforations as effectively as the chert in our trials. Archaeologists such as J. D. McGuire believe that ancient cultures often employed wood in drills; however, the results suggest that it is ineffective for hard materials like shell [6]. Both woods created shallow perforations, and did so inefficiently: oak and teak required an average of 8000 and 5000 revolutions, respectively, while chert tips drilled larger holes with 3000 revolutions. Even copper drills created only small and shallow perforations with approximately 6000 revolutions per hole, and shell required more than 10,000 rotations. Therefore, the Manteño would presumably not forego their original stone drills for any of the tested materials.

The lack of lithic microdrills found in conjunction with Chaîne II beads implies that the Manteño used some other means of perforation [1]. However, the results clearly indicated that out of the materials tested, chert made the most efficient drill bit. Therefore, these results do not suggest any definitive conclusion about methods of perforation after 1200 AD. Perhaps the Manteño used lithic microdrills after 1200 AD, and archaeologists have simply not discovered them yet. Most likely, some other material not included in this experiment perforated Spondylus shell more efficiently than any tested substance. Additionally, the Manteño possibly used one of the materials tested, but in some more efficient manner.

### Sources of Experimental Error

The small sample size made the greatest contribution to error in this experiment. Variability due to a number of factors could have been eliminated with a larger sample size.

First, hole-making methodology may have varied across the three groups. While each group utilized a bow drill and nylon string, the physical orientation of the drill, tension of the string, and pressure applied on the shaft varied between the groups, contributing to holes of different widths and depths. Additional divergences in method include dissimilar applications of the auxiliary drilling material. The three groups should have standardized the quantity and frequency of auxiliary material application in drilling.

Additionally, a particular number of revolutions in one group may have been much more effective than the same number of revolutions in another group because of the differences in the physical shape of the drill tips. The differences in sharpness or roughness of drill bits account for discrepancies in data such as the greater success Group 3 had in drilling with a copper drill bit than Group 1. Even within a single group, repeated trials can easily dull a drill tip, making it less effective. If this experiment were to be repeated, methods for preparing and sharpening each drill tip should also be standardized to yield results that are more consistent.

In sum, the small sample of data collected led to large variability in results, which accounted for most of the error experienced. A thorough experiment would allow for several replications for each drill material combination to eliminate trial-by-trial variability and control for mistakes in drilling, and would therefore generate more reliable results to indicate if a material was or was not utilized by the Manteño.

#### Recommendations for Future Analysis

Due to time constraints, this experiment was not as complete nor as controlled as would be ideal. Given more time, several changes and additions could produce more detailed and concrete conclusions about the Manteño drilling methods. Hopefully, future studies of this ancient culture will use these findings and suggestions as a basis to learn more about the intricate and culturally important shell production of this Ecuadorian culture.

Due to time constraints, the number of primary and auxiliary test materials was limited to those thought to be most feasible and likely. Future projects could test a broader range of drilling materials in the hopes of identifying a more effective combination. For example, wood of moderate hardness, like tiger wood, might drill more efficiently than either red oak or Brazilian Teak; conversely, a wood even harder than teak might meet with greater success. Alternate metals, like bronze, or stones, like quartz, should also be examined. In addition, proximity to the ocean provided with Manteño with hard materials like fish bones and sea urchin spines. Bones and teeth from other hunted animals would have been readily available, as well as plants like reed and cactus spines. Furthermore, auxiliary materials such as shattered quartz, salt water, and acids derived from plant and animal sources should be tested in combination with different primary drilling materials.

All of our trials were conducted with bow drills, which give greater rotational speed and consistency than shaft drills at the expense of manipulability. However, it is possible that the Manteño made perforations using shaft drills or pump drills for the majority or even entire process. In fact, the Manteño may well have used pump drills to perforate beads, as they are easily operated by a single person (6). Perhaps differences in drill type may explain the inefficiencies we experienced when drilling with materials besides chert. Varying angles and

pressures on the shell could also result from different kinds of drills, which would affect resulting perforations.

SEM images allowed a visualization of the distinct patterns created by each material; thus, images of the experimental holes can be compared to SEM images of perforations in the beads made by the Manteño to determine which patterns most closely match those of the true drill material. Future researchers can thus draw more definitive conclusions about Manteño drilling techniques based off visual evidence. As well as comparing visual patterns, efficiency should be evaluated: the volume of material removed can be calculated by analysis of the SEM images, and by comparing this information to a revolution count, the volume-removed-per-revolution can be calculated. This will allow a more exact analysis of effective drilling techniques and lend greater support to hypotheses about which materials the Manteño actually employed.

This experiment provided a sound basis upon which further investigation into Manteño shell perforation techniques may rest. Although results were inconclusive due to time constraints, the same procedures may be followed by future researchers in order to examine other procedures and materials, and thus learn more about the Manteño culture.

## **CONCLUSION**

For almost a thousand years, South American cultures such as the Guangala and the Manteño made small shell beads out of *Spondylus* efficiently and neatly by perforating them with lithic microdrills. After 1200 AD, archaeological evidence for these microdrills all but disappeared. The beads changed in shape and size, and were clearly perforated by a different process. By replicating procedures the Manteño might have employed to perforate *Spondylus* shells, we discovered several possible effective techniques: for example, drills made of teak used with both pumice and water and shell drills used with pumice and water. However, none of these techniques matched the efficiency and effectiveness of the lithic microdrills employed in the earlier era. Although we cannot conclusively determine the exact methods used by the Manteño to perforate *Spondylus* shells after 1200 A.D., we can deduce that they utilized some form of some natural substance such as copper, shell, or wood as well as an abrasive to facilitate perforation. Surely the Manteño had some efficient way of producing the massive numbers of shell beads that archaeologists have unearthed in regions of South America. Understanding the methodologies used by the Manteño facilitates a comprehension of their technological innovation, thus providing us with key insights into their cultural development. The replication of drilling techniques in the lab “can help identify processes used in the past and identify the level at which these processes were employed.” [2]. These experiments provide a baseline of information upon which further research may be carried out. However, much is still yet to be found and further archaeological research is needed to understand the role of shell beads in Manteño culture.

## **WORKS CITED**

(1) Carter BP. *Technology, Society and Change; Shell artifact production among the Manteño (A.D. 800-1532) of Coastal Ecuador* [dissertation]. 2008. [St. Louis (MO)]: Washington University in St. Louis.



- (2) Francis PD. The manufacture of beads from shell. In: Proceedings of the 1986 Shell Bead Conferences: Selected Papers; 1986. Rochester (NY): Rochester Museum and Science Center.
- (3) Masucci MA. 1995. Marine shell production and the role of domestic craft activities in the economy of the Guangala Phase, southwest Ecuador. *Latin American Antiquity* 6(1):70-84.
- (4) Stothert KE. Manteño. In: Enber M, Peregrine P, editors. *Encyclopedia of Prehistory*, Vol. 5: Middle America. (NY): Kluwer. 2001. p.303-309.
- (5) Macfarlane A, Masucci MA. 1997. An application of the geological survey and ceramic petrography to provenance studies of Guangala Phase ceramics of ancient Ecuador. *Geoarchaeology: An International Journal* 12(7):765-793.
- (6) McGuire JD. A study of the primitive methods of drilling. Washington (D.C.): Smithsonian Institution. p. 657-673.
- (7) Forest Products Laboratory. *Wood Handbook: Wood as an Engineering Material*. Madison (WI): U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1999. General Technical Report No. FPL–GTR–113.
- (8) Examix NDS Vinyl Polysiloxane Impression Material. [Internet]. Alsip (IL): GC America; [cited 2009 Jul 27]. Available from: <http://www.gcamerica.com/gcxmixnd.html>.
- (9) Leary JJ, Skoog D. *Principles of Instrumental Analysis*. 4<sup>th</sup> ed. (NY): Harcourt Brace. 1992.