

Fig. 1. The Olmec region. Courtesy David Shelton.

# Archaeometry Applied to Olmec Iron-Ore Beads

*Modern research tools reveal the curious  
workmanship used in the ancient drilling of small  
beads found at archaeological digs in Mesoamerica.*

Steven E. Jones, Samuel T. Jones, and David E. Jones

Archaeometry is the use of advanced physical methods in the study of archaeology. The tools of applied physics allow us to search for clues contained in ancient objects themselves. Here we report what we have learned regarding iron-ore beads discovered in the Olmec region. We refer to these artifacts as “beads” since they are thumb-sized and multiply pierced, although their use by the Olmec remains a mystery. These beautiful objects were carved out of stone, shaped, drilled, and polished approximately three thousand years ago. This process required considerable workmanship in view of the hardness of the iron-titanium ore from which the beads were manufactured. Although iron and titanium are common today and rather inexpensive, their rarity three thousand years ago evidently lent to these metals a high value that led to their being hidden away and preserved.<sup>1</sup> Using photomicroscopy, x-ray fluorescence spectroscopy, electron microprobe analysis, and magnetometer analysis, we have learned more about the origin, manufacture, and possible function of the beads.

## **The Olmec Civilization**

“The most ancient Mexican civilisation is that called the ‘Olmec.’”<sup>2</sup> The Olmec civilization arose in southern Mexico around 2500 B.C. By 1200 B.C., the Olmec had built a center at present-day San Lorenzo in Veracruz.<sup>3</sup> The area dominated by the Olmec is shown on the map in figure 1. Trade and other influences of the

remarkably advanced Olmec civilization extended over a much greater area, including Oaxaca and Chiapas.<sup>4</sup> By 400 B.C., the civilization had come to an abrupt halt:

Then La Venta [a major Olmec city] comes to an end. The cause and nature of its fate is lost in mystery, a mystery that we shall also see at the great Olmec center of San Lorenzo. All construction comes to a halt, no more tombs are built and stocked, no more offerings are made beneath its multi-colored floors. Its ruler and people are gone. . . . Olmec civilization had died.<sup>5</sup>

The reasons for the demise of the civilization still elude researchers.

It is interesting to note that the Olmec civilization coincides in time (and possibly in location) with the Jaredite civilization described in the book of Ether in the Book of Mormon. In particular, the Jaredite civilization came to a curiously abrupt end between 600 and 300 B.C., just as the Olmec civilization did. We read of the Jaredite civilization:

They were exceedingly industrious, and they did buy and sell and traffic one with another, that they might get gain. And they did work in all manner of ore, . . . [including] iron. . . . And they did work all manner of fine work. . . . And they did make all manner of tools. . . . And they did work all manner of work of exceedingly curious workmanship. (Ether 10:22-27)

If the Olmec civilization coincides with the Jaredites, these iron-ore beads may be an example of the Jaredites' "exceedingly curious workmanship."

### **Discovery of the Beads**

In 1967, Michael Coe of Yale University supervised the excavation of a large basalt head in San Lorenzo, in the Tehuantepec region of Mexico. While unearthing this Olmec monument, he discovered large amounts of pottery and a cache of heavy beads.<sup>6</sup> The head monument and beads are dated to the Early Formative period of the Olmec civilization (about 1100 B.C.).<sup>7</sup> Since then, other large caches of these beads have been found in the San Lorenzo area<sup>8</sup> and in the nearby Tuxtla Mountains.<sup>9</sup> In addition, in the 1970s Pierre Agrinier discovered several more of these objects, along with a quantity of unworked ore, in the Chiapas region.<sup>10</sup> Dr. John



Clark of the Department of Anthropology at BYU obtained several of these beads on the surface at San Lorenzo along with some raw ore samples from Plumajillo in the Chiapas region. With the permission of the Instituto de Anthropologia y Historia, Dr. Clark brought them out of Mexico for analysis.

Here we have a tantalizing mystery. What is the source of these objects, and how and why were they made? We look for clues in the physical parameters of the beads.

### **Description of the Beads**

Our sample consists of five whole artifacts, some broken fragments, and a quantity of unworked ore. A striking feature is that the surfaces of the objects are smoothed and polished. Some surfaces remain quite shiny, even though three millennia have elapsed since their manufacture. The worked beads are rough parallelepipeds<sup>11</sup> about 2 cm x 2 cm x 3 cm. Each has a large primary hole and two smaller holes drilled perpendicular to the primary hole. The corners and surfaces are smoothed and polished and generally have a metallic luster. The broken fragments reveal the boreholes, aiding our study (fig. 2).



Fig. 2. An Olmec bead. The rectangular shape and polished sides are typical of these three-thousand-year-old stone beads. Over time, the holes drilled through the bead have filled with sand. Courtesy Scott Daniel.

### **Physical Properties**

With David Tingey of the BYU Geology Department, we performed scratch tests with the objects. We discovered that the material easily scratches obsidian but scratches glass with difficulty. It cannot be scratched by glass. The material is also scratched by quartz but will not scratch quartz. These tests established that the hardness is slightly more than 5.5 (see fig. 6).



Next we probed the surface of the artifacts with a sensitive Hall magnetometer to look for any residual magnetic fields. We found magnetic fields up to about 8 gauss on some of the beads, but the orientations of these fields were not correlated with the alignments of the holes. The weak magnetic fields indicated the presence of iron or nickel in the ore.

### **Microscopic Examination of Bead Surfaces**

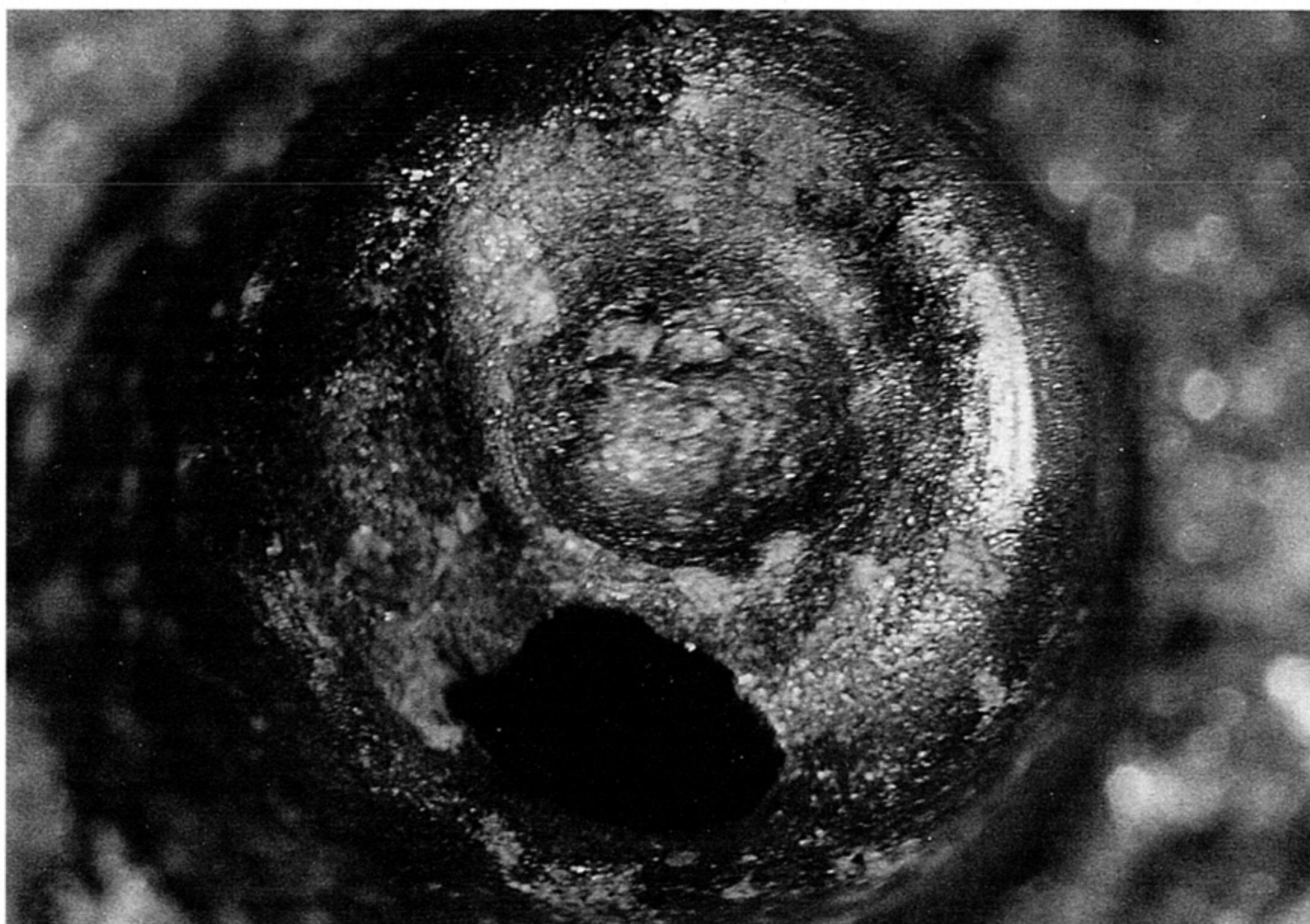
Subjecting artifacts to a microscopic examination provides evidence on how the objects may have been manufactured. Using a dissecting microscope, we obtained photomicrographs that show several interesting features (figs. 3, 4).

Scratch markings in the boreholes clearly demonstrate circular patterns. The observed circular patterns show that the holes were almost certainly drilled by a tool operated in a rotating manner, implying considerable sophistication when one considers the hardness of the material. One observes also a prominent raised point in the center of an incomplete borehole (fig. 4). This suggests



Fig. 3. Ilmenite ore and broken bead. The broken bead, on the right, reveals the circular pattern made by a drilling tool. Courtesy Scott Daniel.





**Fig. 4.** Looking into an incomplete borehole in a bead. The out-of-focus area around the edge is the top of the bead; the dark area is a broken section of the borehole. The shine of the drilled hole demonstrates how mirrorlike the stone becomes when polished. The bottom of the borehole is raised, showing that the point of the boring tool was worn away. Courtesy Scott Daniel.

that the tip of the boring tool was softer or less efficient at cutting than the outer rotating perimeter of the tool.

We also photographed microscopic cross-sections of both unworked ore and the drilled beads to compare them for similarities. Our photographs show pyrrhotite blebs of similar sizes in both materials. According to Dr. Jeffrey Keith, this indicates that the ore and beads came from the same geological formation.<sup>12</sup> Also seen are inclusions of amphibole, chlorite, and feldspar. These structures also strongly link the ore and the bead material. Similar observations have been seen in the ore deposits in the Oaxaca mountains.<sup>13</sup>

### **Composition Analysis**

Molecular composition determines the minerals present and also bears a signature of the ore's original location. Analyzing the



composition of the artifacts can therefore yield important information about where the resources for these artifacts originated and what they could have been used for.

We engaged the help of Professor David Tingey to apply x-ray fluorescence spectroscopy analysis on a powdered sample of the mineral from one of the Olmec beads. The analysis showed an abundance of both iron and titanium (see fig. 5), suggesting that the material is ilmenite, an ore comprised of iron and titanium oxides.

To expand on these results, we used a Cameca SX-40 electron microprobe at the Department of Geology and Geophysics at the University of Utah to determine the mass percentage of the major oxides contained in both the beads and the unworked ore. The microprobe operates by directing a tightly focused electron beam on a sample. The electrons excite the material, which then emits x-rays. The energy of the emitted x-rays provides a signature of the elements present. In this way, a precise elemental analysis of a small sample may be obtained.

We used two samples for this analysis: a thin section from the unworked ore and a thin section from the smallest of the artifacts.<sup>14</sup> We had more artifacts from the same find but considered it unjustifiable to cut sections from more of them.

From the x-ray spectroscopy results, it was clear that the metallic ore was titaniferous. Dr. Jeffrey Keith suggested that the following elements might be expected in titaniferous deposits such as ilmenite: titanium, silicon, aluminum, chromium, iron, manganese, magnesium, calcium, and zinc.<sup>15</sup>

On February 16, 1996, we used the Cameca SX-40 electron microprobe with the assistance of Ray Lambert of the University of Utah department of Geology and Geophysics. An x-ray fluorescence scan of the samples was first conducted to search for any elements present other than those listed above. The scan revealed a small amount of potassium in addition to the expected minerals.

We then proceeded to calibrate the microprobe to measure occurrences of the nine metals previously stated and also potassium. Once calibrated, we scanned the surface of the ore sample. The material was mostly composed of ilmenite, with occasional traces of other minerals. We analyzed various points on the sample, trying to target the ilmenite crystals and several of the inclusions. The

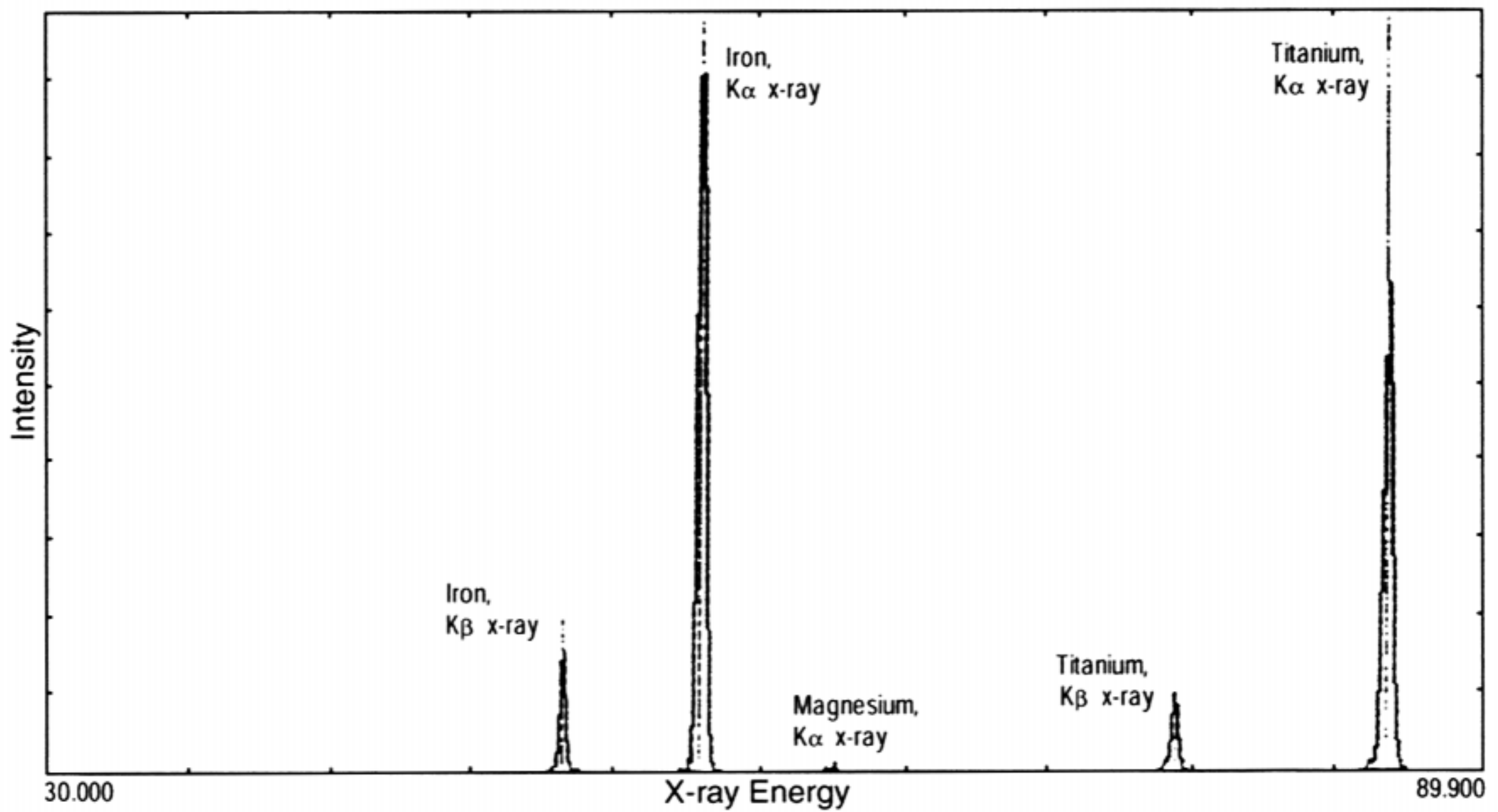


Fig. 5. X-ray fluorescence spectrograph of bead. Courtesy David Tingey.

results of the microprobe analysis on the ore sample are shown in table 1. We proceeded in a similar manner with the thin section from the Olmec bead and obtained the results displayed in table 2.

There are two expected sources of difference between the composition of the ore and artifact: measurement error and natural variation between ore samples. To estimate expected errors, we compared results with those of another researcher using the same microprobe under similar conditions on similar materials.<sup>16</sup> We found that for large percentages (around 30%), one should expect about 0.3% error, and for small trace occurrences (around 0.1%), one should expect errors of about 0.02%.

The iron oxide content in the ore and in the artifact is found to be  $55.43\% \pm 0.31\%$ , which shows agreement within experimental error. The next most prevalent metal in the bead was titanium; the  $\text{TiO}_2$  content in the unworked ore and in the finished bead was  $42.43\% \pm 0.27\%$ , which again shows consistency within measurement error. A comparison of two ilmenite crystals within the *same* bead sample shows comparable small differences. Note also the similarity in the iron oxide content of the magnetite inclusions in the ore and the artifact,  $93.85\% \pm 0.72\%$ . Magnetite will provide ferromagnetic properties to the beads such as those measured with the magnetometer.



The small variations we found in the elemental compositions in inclusions in the samples should be viewed as the expected variations that occur in igneous formations such as ilmenite. This is expected in magmatic formations such as ilmenite ore. It is also expected that the compositions of inclusions in the ilmenite vary somewhat between different regions of the same formation. Silicates such as amphiboles, chlorites, and pyroxenes and the aluminum-rich spinel inclusions are not unusual in such a magmatic ore.<sup>17</sup>

We conclude that the unworked ore and the bead samples almost certainly originated from the same source. It is evident that the material used to make the beads was an ilmenite ore from a natural igneous deposit. The physical properties of the beads such as hardness are also consistent with those of ilmenite ore.

### **Other Analyses**

Previous researchers have used Mössbauer spectroscopy to analyze the composition of Olmec artifacts from San Lorenzo and Chiapas.<sup>18</sup> The conclusion of this analysis was that some San Lorenzo and Chiapas artifacts were composed of ilmenite from a common but unknown source. Ilmenite is a relatively rare ore that exists in few parts of the world and is not natural to the San Lorenzo area where the drilled beads were found. There is a small ilmenite deposit in the Chiapas region, and the ore is abundant in the Oaxaca mountains about 140 miles (220 km) to the southwest. Some San Lorenzo artifacts are similar in composition to formations reported by E. Paulson from the Pluma Hidalgo part of the Oaxaca region.<sup>19</sup>

The logical continuation of this research would be to use modern physical methods to compare the compositions of ilmenite deposits in Mesoamerica and of ilmenite artifacts found at various Olmec and Maya sites, including those recently discovered in the Tuxtla Mountains. Microprobe (or, alternatively, proton-induced x-ray emission) analyses of these samples should show which ilmenite ore body corresponds to a given artifact.

### **Bead Manufacture**

How were these iron-ore beads drilled? Owing to the hardness of the ilmenite ore, the grinding abrasive used was probably harder than six on the Mohs scale<sup>20</sup> (fig. 6). This excludes obsidian,

which was also in use among the Olmec.<sup>21</sup> Some possible grinding minerals available to the Olmec are quartz sand, topaz, and corundum. The consistent circular pattern in the holes shows that the holes were formed or at least finished by drilling. The raised point at the center of some of the smaller bore holes indicates that a hollow or soft-centered tool was used to drill these holes. It seems likely that a rotating wooden rod was used with wet quartz sand as grit for the drilling tool. The process would have required hours of careful labor for each bead. Wet quartz sand could also have been used to polish the surface of the beads to a smooth finish.

We also note the presence of round indentations common on the large Olmec head monuments.<sup>22</sup> We hypothesize that a drilling process may have been used to make these markings, since the beads provide clear evidence that drilling was used by the Olmec. Drilling into rock to a certain depth provides a means of fracturing

INDEX MINERALS		COMMON OBJECTS
Talc	1	
Gypsum	2	Fingernail
Calcite	3	Copper penny
Fluorite	4	
Apatite	5	Glass      Obsidian
Orthoclase	6	Steel file      Ilmenite
Quartz	7	
Topaz	8	
Corundum	9	
Diamond	10	

Fig. 6. The Mohs Scale, with common objects and ilmenite and obsidian.



rock at that depth so as to remove large pieces as the sculpting of the face is begun.<sup>23</sup>

### **Speculations on Ancient Use of the Beads**

A puzzle of considerable interest is how these drilled beads were used by the Olmec people. Because the Olmec carved, polished, drilled, and cached away these beads, one is led to surmise that the beads were valuable and were used either as money or as ornamental jewelry. Indeed, the possibility of ornamental use was suggested by Michael Coe when he first discovered the artifacts.<sup>24</sup> Using the bored holes, the beads could easily have been strung together on a cord for carrying or wearing.

On the other hand, the possibility that the artifacts had a functional utility is suggested by the nature of the perpendicular holes. A small hammer could be made by inserting a shaft through the main hole and pinning it through the smaller holes. Such hammers could be used to chip obsidian, which is softer, into blades, or to shape other ilmenite beads.

Another possibility promoted by Ann Cyphers Guillen is that the bead could have been used as a capstone to guide a stick as it was used in a bow drill to drill other stone or wood.<sup>25</sup> However, the fact that the large holes penetrate all the way through the beads argues against their use as capstones for bow drills, since this penetration would leave the holding-hand unprotected. The material is too hard to be cut by a wooden drill alone (without abrasive). Furthermore, the beads are too small to be used effectively with bow drills and have multiple holes, not just one. These observations argue against the bow drill-capstone hypothesis.

The surface, when polished, becomes quite mirrorlike. Thus, these beads may once have served as mirrors that one could carry on a cord or as mirror pendants such as those seen later among the neighboring Maya.

Protective armor could be another use of the beads. The multiple holes would allow the metallic beads to be cross-tied together to form a hard yet flexible shield, a type of mail. Such mail could be worn on the head of a warrior as a protective helmet<sup>26</sup> or over his chest. Such armor would have an awe-inspiring appearance, especially when polished (see 3 Ne. 4:7).

## **Conclusion**

We have applied several advanced tools of physics to probe three-thousand-year-old objects made by the Olmec in Mesoamerica. The results show that the artifacts are primarily composed of ilmenite, which is harder than obsidian. The beads have multiple penetrating holes which have evidently been drilled using a rotating tool, not chipped out. Circular scratches along the walls of the boreholes clearly demonstrate that the cutting tool was rotating. Because the material is ilmenite, the artifacts were probably drilled by something harder than obsidian, possibly using wet quartz sand as an abrasive on the tip of a wooden tool.

The ore and the beads that we scrutinized are very similar in physical composition. We have also found that the bead ore is similar in composition to ilmenite from Oaxaca, 140 miles from the cache where the drilled beads were first found. If we can determine for certain the source of the ilmenite for these artifacts, we may learn more about trade between San Lorenzo, Chiapas, and Oaxaca around 1000 B.C., during the Jaredite period.

Finally, we note that the workmanship of these beads is consistent with the description given in the Book of Mormon regarding the Jaredite civilization that worked ore using “exceedingly curious workmanship” (Ether 10:27). The high value of iron anciently is suggested by these beautifully worked iron-ore beads.

## **Acknowledgments**

We particularly acknowledge the assistance of Professor John Clark of the BYU Anthropology Department. We also thank Jeffrey Keith and David Tingey of the BYU Geology Department and Ray Lambert of the University of Utah Department of Geology and Geophysics for their assistance. This project was funded by the BYU Physics Department, the BYU Honors Program, and the BYU Office of Research and Creative Activities.

Steven E. Jones is Professor of Physics at Brigham Young University. Samuel T. Jones is a graduate of Brigham Young University in physics. David E. Jones is a graduate of Brigham Young University in computer science.



**Table 1: Microprobe Analysis of Samples of Ore (Oxide % by Weight)**

	SAMPLE 1	SAMPLE 2	INCLUSION 1	INCLUSION 2	INCLUSION 3
TiO <sub>2</sub>	42.15	42.24	0.35	0.34	1.37
SiO <sub>2</sub>	0.00 *	0.00 *	0.03	51.29	40.94
Al <sub>2</sub> O <sub>3</sub>	0.03	0.04	0.25	4.18	14.46
Cr <sub>2</sub> O <sub>3</sub>	0.10	0.11	0.45	0.11	0.05
FeO	55.74	55.38	94.57	8.81	14.28
MnO	0.45	0.31	0.00 *	0.09	0.07
MgO	1.47	1.46	0.00 *	20.63	13.84
CaO	0.00 *	0.00 *	0.03	12.25	11.38
ZnO	0.11	0.00 *	0.11	0.11	0.15
K <sub>2</sub> O	0.00 *	0.00 *	0.03	0.10	0.86
Mineral:	Ilmenite	Ilmenite	Magnetite	Clino- pyroxene	Amphibole

**Table 2: Microprobe Analysis of Samples of Artifact (Oxide % by Weight)**

	SAMPLE 1	SAMPLE 2	INCLUSION 1	INCLUSION 2	INCLUSION 3
TiO <sub>2</sub>	42.70	41.74	1.96	6.61	0.06
SiO <sub>2</sub>	0.00 *	0.01	0.02	0.01	27.79
Al <sub>2</sub> O <sub>3</sub>	0.06	0.06	0.17	65.27	25.52
Cr <sub>2</sub> O <sub>3</sub>	0.17	0.18	1.12	0.61	0.01
FeO	55.13	55.51	93.14	20.11	7.28
MnO	0.38	0.31	0.00 *	0.08	0.00
MgO	1.83	1.71	0.03	8.37	31.23
CaO	0.01	0.00 *	0.00 *	0.00 *	0.03
ZnO	0.06	0.00 *	0.00 *	4.71	0.08
K <sub>2</sub> O	0.00 *	0.00 *	0.00 *	0.01	0.02
Mineral:	Ilmenite	Ilmenite	Magnetite	Spinel	Chlorite

\* Less than 0.01%

## NOTES

<sup>1</sup>For comments on the scarcity of iron, see "Decorative Iron in Early Israel," in *Reexploring the Book of Mormon*, ed. John W. Welch (Salt Lake City: Deseret Book, 1992), 133-34.

<sup>2</sup>Michael D. Coe, *Mexico, Ancient Peoples and Places*, no. 29 (New York: Frederick A. Praeger, 1962), 83.

<sup>3</sup>George E. Stuart and Gene S. Stuart, *The Mysterious Maya* (Washington, D.C.: National Geographic Society, 1977), 24-25.

<sup>4</sup>John E. Clark, *Los Olmecas en Mesoamérica* (Mexico: El Equilibrista/Turner Books, 1994), 61.

<sup>5</sup>Michael D. Coe, *America's First Civilization* (New York: American Heritage, 1968), 67, quoted in David A. Palmer, *In Search of Cumorah: New Evidences for the Book of Mormon from Ancient Mexico* (Bountiful, Utah: Horizon, 1981), 142-43.

<sup>6</sup>Michael D. Coe and Richard A. Diehl, *In the Land of the Olmec* (Austin: University of Texas Press, 1980), 324.

<sup>7</sup>Coe and Diehl, *Land of the Olmec*, 23, 324.

<sup>8</sup>Clark, *Los Olmecas en Mesoamérica*, 61.

<sup>9</sup>Philip J. Arnold III, "Ethnicity, Pottery, and the Gulf Olmec of Ancient Veracruz, Mexico," *Biblical Archaeologist* 58 (December 1995): 195.

<sup>10</sup>Pierre Agrinier, *The Early Olmec Horizon at Mirador, Chiapas, Mexico*, Papers of the New World Archaeological Foundation, no. 48, ed. Susanna M. Ekholm (Provo, Utah: New World Archaeological Foundation, 1984), 4-5, 75-81.

<sup>11</sup>Parallelepipeds are objects whose six sides are all parallelograms.

<sup>12</sup>Jeffrey Keith, telephone conversation with Samuel T. Jones, summer 1995.

<sup>13</sup>Edwin G. Paulson, "Mineralogy and Origin of the Titaniferous Deposit at Pluma Hidalgo, Oaxaca, Mexico," *Economic Geology* 59 (1964): 758-59.

<sup>14</sup>We should note that an external beam of protons from the BYU Van de Graaf accelerator will soon make it possible to do proton-induced x-ray emission (PIXE) analysis without destructive cutting of specimens.

<sup>15</sup>Keith, telephone conversation.

<sup>16</sup>Donald H. Lindsley, in *Oxide Minerals*, Reviews in Mineralogy, vol. 3, ed. Douglas Rumble III (Blacksburg, Va.: Southern Printing, 1976; reprint, Chelsea, Mich.: Bookcrafters, 1981), L-40.

<sup>17</sup>Keith, telephone conversation.

<sup>18</sup>Jane W. Pires-Ferreira, *Formative Mesoamerican Exchange Networks with Special Reference to the Valley of Oaxaca*, Memoirs of the Museum of Anthropology, University of Michigan, no. 7: Prehistory and Human Ecology of the Valley of Oaxaca, vol. 3, ed. Kent V. Flannery (Ann Arbor: University of Michigan, 1975), 51, 56-57; Jane W. Pires-Ferreira, "Shell and Iron-Ore Mirror Exchange in Formative Mesoamerica, with Comments on Other Commodities," in *The Early Mesoamerican Village*, ed. Kent V. Flannery (New York: Academic Press, 1976), 317-23.

<sup>19</sup>Paulson, "Mineralogy," 758-59.

<sup>20</sup>W. K. Hamblin and J. D. Howard, *Exercises in Physical Geology* (Edina, Minn.: Burgess, 1986), 10.



<sup>21</sup>Clark, *Los Olmecas en Mesoamérica*, 61.

<sup>22</sup>See Clark, *Los Olmecas en Mesoamérica*, 61.

<sup>23</sup>Douglas Chabries, conversation with Steven E. Jones, May 1996.

<sup>24</sup>Coe and Diehl, *Land of the Olmec*, 242.

<sup>25</sup>John Clark, telephone conversation with Steven E. Jones, June 1997; see also Clark, *Los Olmecas en Mesoamérica*, 61.

<sup>26</sup>John Sorenson, telephone conversation with Steven E. Jones, May 1997.