Ancient Peruvian optics
with emphasis on Chavin and Moche cultures

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SUMMARY. – On the occasion of the meeting of the Peruvian Optical Society, Lima, Peru, October 5-6, 2006, we considered aspects of the early optics of Peru. Prof. M.L. Calvo has taken the lead in addressing mirror optics, with emphasis on anthracite mirrors employed by the Chavín de Huántar peoples. A rather unique Moche copper-mirror frame was also considered. Prof. Enoch emphasized the rise of technologies providing capability for development of lens optics by the Chavin and Moche peoples. Prof. Enoch considered the development of grinding and polishing technologies, formation of lens-like surfaces in necklace beads, magnification associated with development of these objects, and possible lenses at the Larco Museum in Lima and those located at the Art Institute of Chicago, USA.

Key words: Optics in antiquity; Perú; Chavín de Huántar; Moche cultures; mirrors, ancient; anthracite mirrors; lenses, ancient; necklaces made of crystal, rock-crystal; lens-like objects at the Art Institute of Chicago, necklaces shown by A.J. de Lavalle and W. Lang, and those found at the Larco Museum, Lima, Perú; ancient anthracite mirrors at the Larco Museum in Lima, Perú, and at the Anthropological and Archaeological Museum, Lima, Perú; etc.

1. Introduction

The oldest known mirrors date from ca 6000 BCE (Before the Common Era) or 8000 BP (Before the Present) in Çatalhöyük – spelled variously, an early large and remarkable city located in ancient Anatolia. That community was located in the Konya Plane in South – Central modern-day Turkey.

The oldest lenses known, but not the earliest lenses (they were of fine quality, and just too complex to be the first lenses) can be dated to the “Old Kingdom” of Egypt early in Dynasty IV (ca 2575-2551 BCE) (1). When we
consider Pre-Columbian optics in the Americas, New World history is not as well developed as Egyptian or Mesopotamian histories and records. So saying, early-on Peruvian peoples were dominant participants. As in the case of the “Old World”, “New World” mirrors pre-dated subsequent lens development. Lunazzi (2) calls attention to early mirrors found at the coastal cities of Huaca de los Reyes and Gramalote, and in the Andes at Shillacoto and Kotosh. Somewhat later, mirrors appeared among the Chavín de Huántar peoples; this civilization was approximately contemporary with that of the Olmecs of Mexico (3). Most early South and Central American mirrors were made from stone/crystalline substances of varying reflectance (21% reflectance for Magnetite, 28% for Hematite, and 55% for iron Pyrite). In addition, Lunazzi (3) noted that grinding compounds used were emery (aluminum oxide), hematite powder, ochre (hematite jeweler’s rouge, very fine), or sand(s). The same author noted that, later, polished copper and copper-alloy (bronze) mirrors were employed by the Incas. The authors of the present study have also found samples of iron pyrite mirrors dated during the Moche culture, as well as copper mirror frames (Metropolitan Museum of Art, New York City). In general, early optical discoveries on the American continent occurred remarkably early but these are not exhaustively documented.

Chronologically, mirrors appeared (by 4000 BP) before lenses did in the American Continent. The earliest discoveries of mirrors on the American continent have been located in Perú, in Brazil, and in Central America (4-7).

A number of interesting findings in the history of lenses and mirrors on the American Continent appeared to be linked to the post-Columbian civilization and the Colonies of the New World (8).

In a previous paper (9), the authors reported anthracite mirrors located in various museums in the United States of America and in Perú. They were dated during the so-called Chavín-horizon time period (ca. 2900 BP - 2200 BP [a second source gives the same time period as 2800-2300 BP]). The Chavín culture spanned the time period, ca. 1300-300/200 BC. Note: the Moche “Early Intermediate Period” spanned the time period, ca: 300 BC- 600 AD.

In our earlier paper, lack of direct access to such mirrors prevented our considering their optical quality. In a visit to the Larco Museum and to the Anthropological and Archaeological Museum in Lima, the authors were able to observe and to inspect directly anthracite mirrors having origin during the Chavín-horizon period.

In Section II, we present a number of photographs taken by one of the authors (JME) on the occasion of our visit to the above mentioned museums. It is important to note the high quality of the inspected mirror surfaces. This indicates both the advanced-level skills learned and the care taken by the Chavín artisans in their construction of these mirrors.

In Section III we present some results determined when assessing reflection properties of anthracite mirrors based upon samples obtained in the laboratory of one of the authors (MLC). These results clearly document the
ancient Peruvian optics with emphasis on the development of techniques for grinding and polishing mirror surfaces during the Chavín period and the enduring quality of those surfaces.

2. Report on some anthracite mirrors located in two Peruvian museums

The authors first visited the Larco Museum in the city of Lima (Peru). The Larco Museum was founded by Rafael Larco Hoyle, a Peruvian engineer who discovered ancient Peruvian graves of Native American inhabitants situated on his family property located at the Valle de Chicama (located north of Lima). His interest in Archaeology was enhanced through the influence of his father. The family private collection was dramatically increased by detailed excavations. Today, this Museum has one of the most compendiums of Pre-Columbian artistic and technological achievements. In particular, there are outstanding collections of Chavín and Moche objects made of ceramics, some of which are combined with metals. And there are unique samples of anthracite mirrors. At present, clear explanations of applications of these mirrors are not provided. So saying, since these objects were found in the graves of individuals, one can speculate that they were used for personal decorative purposes and/or for personal observation. Also, they may have been used by shaman(s) and high priests for religious and/or for ceremonial purposes. Apparently, they were also used to symbolize the high cast of certain individuals. Since the authors are not historians, we do not want to enter further into consideration of anthropological data; rather, here we will concentrate on the study of the optical quality of these remarkable objects.

In Fig. 1 are displayed three objects (first row) made of anthracite. The two objects to the right are circular mirrors. It is notable that the design included a rear-side anthracite hand support also made from the same block of anthracite. In this figure one can appreciate the reflective quality of the surfaces.

A similar mirror can be found at the Chilean Museum of Pre-Columbian Art (Fig. 2), although the authors have not observed this mirror. Notice that the size of this mirror is much smaller than the two items shown in Fig. 1.

In Fig. 3 there are shown two additional anthracite mirrors at the Larco Museum. We were able to handle and to inspect these items. Note, rather small decorative mirrors were found on a number of items at the Museum and these served artistic or symbolic purposes.

At the Anthropological and Archaeological Museum located also in Lima, the authors had direct access to a number of additional Chavín anthracite mirrors (dated during the Chavín-horizon period) having various geometries and sizes (Figs. 4-6). These had origin at either lowland sites or at higher altitudes. Most were either circular or approximately rectangular. These were placed in a storage area and were not on public display. Note: Prof. Lunazzi stated to us that there were added mirrors to be seen at the Gold Museum in Lima. An example of one of the collections observed at the Archaeological
FIG. 1
A showcase at the Larco Museum (Lima, Peru) in which one can find three objects in anthracite (first row). The two objects at the very right are circular anthracite mirrors.

Fig. 2
Anthracite circular mirror located at the Chilean Museum of Pre-Columbian Art (Santiago de Chile). Diameter: 78 mm. In this case, the handle was broken.

Museum is shown in Fig. 4. The authors were able to analyze the quality of surface polish by direct visual inspection. The degree of reflectivity of the surfaces is remarkable. Please appreciate here that we are looking at mirrors manufactured over 2000 years ago! We observe reflectance from a broad white-light lantern source. These reflections are rather homogeneous throughout the whole mirror surface. This finding can be appreciated in Figs. 5 and 6.
FIG. 3

Two samples of anthracite mirrors located at the Rafael Larco Museum (Lima, Perú). One can readily appreciate the diverse geometries of these mirror designs. Most had either convex or near flat surfaces.

FIG. 4

A collection of various anthracite mirrors located at the Anthropological Museum of Lima (Perú).
Inspection of the reflectivity of a circular anthracite mirror by illuminating the surface with a white light.

A similar observation was made in Fig. 6 as was done in Fig. 5. In this case a rectangular anthracite mirror was employed.

After considering the interesting properties and quality of the inspected mirrors the authors wanted to obtain objective scientific results on the optical properties of a polishing anthracite surface. The results are presented in Section III.
3. Optical properties of anthracite polished surfaces

After considering the interesting properties and quality of these mirrors, the authors sought to obtain objective scientific data pertaining to the optical properties of a polished anthracite surface. This material is a form of bituminous organic coal, a metamorphic rock, having a black color. It has high luster. The hardness of samples on the Mohs scale varies between 2.5-4.0. The refractive index values are: 1.64-1.68 (for wavelength 589 nm), and it has high reflective properties. This material does not exhibit pleochroism. It can be crystalline or stone—often having massive size. When rubbed, these materials can be electrically charged.

Perú has some of the World’s largest charcoal mines. Such resources have been exploited from the very early days of pre-Columbian civilizations. They are located all along the Andes Mountains with very important mining locations to be found at Chacamarca (10) (this area is not far from the early settlements of the Chavin civilization).

We have obtained two samples of anthracite coal from Northern Spanish charcoal mines (see Fig. 7). The two blocks were cut in two different planes, namely, one which is parallel to, and one which is perpendicular to the plane of exfoliation. These planes define layers with easy mechanical cleavage. After obtaining these samples, a standard polishing procedure was applied (with water and fabric on a metallic surface).

An optical set-up was designed to obtain and to assess the reflected images (see Fig. 8).

A laser source (a solid-state laser emitting in the green range of the visible spectrum: 552 nm) was used to illuminate the surfaces. The beam was spatially filtered and collimated. The collimated beam impinged upon the surface at with an inclination of 45 degrees. A CCD camera (Hitachi) captured the light reflected from the surfaces (see Figs. 9a, 9b). These images were treated digitally (11). The corresponding line profile of the images provides information on the efficiency of these reflections. Figs. 9c-9d show the corresponding line profiles.

In order to achieve more accurate data we have applied a Fast Fourier Transformation (FFT) to the images (Figs. 9e-9f). This provides the two spectra associated with the reflected light from the two surfaces, respectively, and these are presented in 3-D. One can then state that the resultant reflectivity depends on the technical procedures employed in the preparation of the sample. The reflectance perpendicular to the plane of exfoliation shows higher efficiency. This is related to the presence of micro layers, which are highly reflective, as can be seen when they are observed directly by eye. Note, this may also be due to the degree of partial polarization of the reflected light.

As a first estimate, the use of direct exfoliation planes could have allowed the Chavin artisans to obtain highly reflective surfaces. Probably, a simple
Two anthracite mirrors obtained in the author’s laboratory (MLC). The right one was cut parallel to the exfoliation planes of the crystal-like coal block, and the left one was cut perpendicular to the same planes. Note the reflection of the nearby goggles.

Two anthracite mirrors obtained in the author’s laboratory (MLC). The right one was cut parallel to the exfoliation planes of the crystal-like coal block, and the left one was cut perpendicular to the same planes. Note the reflection of the nearby goggles.
form of polishing was applied to those surfaces. So saying, based upon direct observation of light reflected by the ancient Chavín mirrors (described above), we cannot yet assess quality of these particular surfaces, nor can we draw conclusions as to how (and if) polishing techniques were applied. These aspects are now being studied by the authors.

4. Conclusions

Based upon observations and direct inspection of ancient anthracite mirrors and upon additional technical data obtained from two samples of Spanish anthracite mirror surfaces, [performed by the authors], one may conclude that anthracite-based mirror-technologies were present in a number of Peruvian and related cultures. Included was the Chavín civilization, which was a precursor of the later Incan civilization, as well as the Moche culture that expanded with the demise of the Chavín culture. All necessary skills and tools needed to create mirrors were mastered by available artisans and technicians working within these two societies/cultures over extended periods of time. The appropriate materials were available and employed, adequate skill at grinding, shaping and polishing (convex) hard surfaces developed, items manufactured exhibited properties of optical reflectivity. We state that these pre-Columbian civilizations were clearly capable of developing optical technologies, however we cannot prove conclusively that they employed the designed optical devices for generally accepted optical purposes (e.g., for burning purposes, reflected-image formation, etc.) within these cultures.

The searching of logical connections is always a difficult task. Nevertheless, the authors are now pursuing additional studies.

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The results of Section III were obtained with the technical and scientific assistance of Oscar Martínez Matos and José A. Rodrigo of the Interdiscipli-
The anthracite polished samples were provided to us by Ana Manzanares, and these were obtained from GreenLight Solutions, Madrid, Spain.

Fig. 9

Image of reflected light from anthracite surface cut perpendicular to the planes of exfoliation. b) Image of reflected light from anthracite surface cut parallel to the planes of exfoliation. c) and d) the respective line profiles obtained. e) and f) the respective Fourier spectra represented in 3-D.
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