HINDSIGHT

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1999 OHS meeting and presentation by Jay Enoch:

OHS president Walter Chase reported the following about the annual OHS meeting held in Seattle on Friday, December 10, 1999, in conjunction with the annual meeting of the American Academy of Optometry: The meeting was in the Cedar Room of the Sheraton Seattle Hotel and Towers. Light refreshments were served, and the attendees were treated to an excellent two-projector presentation by Dr. Jay Enoch, Ph.D., D. Sc., Professor of the Graduate School and Dean Emeritus at the School of optometry, University of California at Berkeley. The title of his presentation was: "New Finding on Ancient Egyptian Lenses Dating from 4600 Years ago, Including a Demonstration of the 'Eye Following Illusion' Model."

Enoch's paper was published in *Cogan Ophthalmic History Society,* Volume 1, June 18-20, 1999 under the title "First Known Lenses Originating in Egypt about 4600 Years Ago!" with the subtitle "Incredible/Unique Optical Properties of these Lenses and Time Line" (pages 57-71). The text of the article is reprinted here with permission:

Abstract

The first known lenses (ca. Vth Dynasties of the Old Kingdom of Egypt. These lenses are found in The Louvre Museum in Paris and The Egyptian Museum in Cairo. They were components of extraordinary eye constructs in statues which had unique qualities. Namely, the "eyes" appear to follow the viewer as he/she rotates about these statues in any direction. This effect can be photographed and reproduced 2620-2400 B.C., 4620-4400 Before Present=B.P.) appeared mainly during the IVth and optically. This effect has been modeled here. The lenses were ground from high quality (!) rock crystal (a form of quartz, n ~ 1.46). Each had a convex and highly polished front "corneal" surface. Thus, in a sense, these were multifocal lenses. The iris aperture may or may not have been open to a substantial posterior "vitreous" cavity formed largely by curved copper plates which extended forward to create the lid structures of these eyes. Were these a form of schematic eyes? Could such fine quality and complex (sophisticated) lenses be the first lenses? Clearly, the observer was intended to look at these eyes and follow their apparent movements. The total structure of these eyes indicated an advanced understanding of ocular anatomy and a surprising knowledge of optics. There are many questions.

Introduction

The first known lenses, which were fabricated primarily between ca. 2620-2400 B.C., first appeared at the very end of the Egyptian Early Kingdom Period (Dynasty III) and mainly during the beginning of the Old Kingdom Period (during Dynasties IV and V).[1-7] Add 2000 years to 2600 B.C. and this is 4600 years ago or B.P. (Before the present time). All existing examples of these lenses are found in The Louvre Museum in Paris and The Egyptian Museum in Cairo.[1,2,4-7] These lenses were components of eye constructs in elegant statues and had unique qualities. In particular, the "eyes" appear to follow the viewer as he/she rotates about the statues in any direction. Clearly, this was an intended perceptual effect which can be readily photographed (and duplicated and understood optically).

The early lenses considered here were ground from very high quality (!) rock crystal (a form of quartz). These lenses had a convex and highly polished front surface. On the approximately flat or "plano" rear lens surface an "iris" was painted. Centered in the dark-appearing pupil zone was a small approximately hemispheric negative ground, high power, concave lens surface. Thus, these earliest known lenses were multifocals with two different optical areas (iris area and pupil area) and, in part, dual optical surfaces in the pupillary zone! It is this dual optical zone which results in the apparent observer following action by the eyes of these statues. For added detailed information about these statues, please consult references 1,2,4; see also references 5-7.

The pupil aperture may or may not have been open to a sizable posterior cavity in these "eyes" created largely by curved copper plates.[1-7] These plates extended forward from the rear of the eye to form the lid structures of these eye structures. Figure B is modified from a small drawing which appeared in Bouquillon and Quéré.[5] While Fig. B may not be quite correct, an attempt has been made to correct some observed apparent errors in the referenced published drawing.[5] That is, the location of the sclera-equivalent component relative to the lens, the aperture treatment, the attachment of the lens unit to a substrate are not correct as shown in their diagram. The sclera is visible on both top and bottom of the lens unit on these statues, the edge of the lens is readily seen, some of the apertures are open or partially so,[1,4] and the lens is supported structurally. The optical unit was apparently attached to the "sclera-equivalent" by a resinous substance. The pupillary aperture was open in some eyes, partly occluded by resin in others, and occluded by resin in some - but the hollow of the concave lens element on the rear of the lens elements had to be open in order to achieve the optical apparent movement of effects associated with these statues.

In some statues, the scleral portions were made of white marble which had fine red-veined impurities which simulated conjunctival capillaries, and were over-painted with added delicate vessels.[5] Were these entire units designed as schematic eyes?[5-7] The total structure of these "eyes" indicates at a minimum (for that time) a very advanced understanding of ocular anatomy.[6,7]

How and from whence did the necessary technologies emerge? Could such fine and complex optical elements be the first lenses? How did it happen that they disappeared in the VIth Egyptian Dynasty, then re-appear briefly in the XIIIth Dynasty (ca. 1700 B.C. or 3700 B.P.), then disappeared again permanently?[2,7]

A fine lens then appeared at the Little Palace of Knossos in Crete during the Minoan period, but the design was different (ca. 1550-1500 B.C. or 3550-3500 B.P.), and this lens and its significance are also of special interest (for shape of the Minoan lens, see Fig. A).[8-14]

Egypt: A Brief Pertinent Time Line

To better understand the sequence of events, it is necessary to place key aspects of these arguments in time-line sequence.[3] There are several books addressing time-line comparisons and these need to be cross-referenced.

Pre-dynastic Egypt: Intermittent trade was established between Egypt and Mesopotamia, Turkey, Syria and the Levant, Palestine, Lebanon, and possibly other locations. This trade originated prior to recorded history. For example, hard stones (obsidian and flint for weapons and scrapers), jewelry, etc., were traded.

Writing and cylinder seals came into use in Sumer (ca. 3500-3000 B.C., or 5500-5000 B.P.) which is located in modern Iraq.[3,15,16]

Na'armer united upper and lower (Nile Delta area) Egypt. Mining of hard stones was begun in the desert of eastern Egypt.

Working of hard stones is significant, because development of lenses, which occurred at a later time, depended upon utilization of related technologies. Trade and wars enhanced technological interactions between populations. Question: Did later lens developments have origin in Egypt, *per se,* or was this an important art/science which built upon local skills learned in fabrication of hard stone materials?[17]

Early dynastic period: Dynasties I-III (ca. 2920-2575 B.C.): Technologies for mining, grinding, and fabricating hard stone objects (not statues) were developed to an advanced state during Dynasties I and II. However, work with rock crystal (a form of quartz later used for lenses, #7 on the Mohs hardness scale) was limited (e.g., see reference 18; for mid-eastern locations other than Egypt, see Collon[15]).

A. COMPARING EGYPTIAN AND MINOAN LENS STYLES

Figure A. Here are compared the designs of lenses found in Egypt (and associated with the unique statues and eye structures described) and those found in Crete (Minoan civilization). The Minoan design (convex-plano) was used over long time periods in Greece and later in many Roman and other lenses.

"Ka" statues were developed as funerary substitutes for the deceased (Dynasty III onward). They served rather like representations of the individual's soul or "essence." They were intended to be long-lasting, and some technology associated with working hard stone materials was associated with ka statue development.[19]

King Djoser (Dynasty III) built the distinctive Step-Pyramid at Saqqara or Sakkara. A number of statues containing the special lens/eye constructs (Fig. B) were located in mastaba burial chambers at Saqqara (these were constructed later), and some of the lens/eye constructs were ka statues.[19,20]

B. SCHEMATIC: EGYPTIAN LENS/EYE STRUCTURE

Figure B. This is an assumed schematic cut through the lens/eye structures found in the Egyptian statues. These eye structures were manufactured by teams of artisans and were inserted *en bloc* in the statues, many of which were approximately the same size. The author has no information about the extent of the copper plates at the rear of the eye structures, nor the details of the "scleral" support structure for the lens, i.e., one only sees the exposed scleral surface. The resin "tag" in the pupillary aperture is symbolic of the material seen in some statues. The author assumes that the volume posterior to the pupillary aperture simulates the vitreous and retina of the eye. Eye physicians were then already using couching techniques for cataract displacement.[27]

The King Djoser statue, now at the Egyptian Museum (a copy is at Saqqara), has peg holes for eye inserts,[20] and evidence of copper rimming of the lids. However, the eye sockets were too small for the later elegant lens/eye units. There is another IIIrd Dynasty statue (one of three women in a group) at the Egyptian Museum with copper eye rims.[21]

Old Kingdom, Dynasties IV-VIII (2575-2134 B.C.): Between roughly 2620-2400 B.C., the lens/eye constructs now displayed at the Egyptian Museum and The Louvre were created. Statues of Ra.hotep and Nofert are dated ca. 2620 B.C.[2] Were these the first statues containing the unique eye and lens structures? Apparently peak production of lens/eye units occurred ca. 2475 B.C. (Deduced from dates listed with each statue at the two museums). During Dynasty V (ca. 2453-2325 B.C.), the statue of The Funerary Priest Kaemked was created (ca. 2400 B.C.?). This statue had the eye structures, but not the rock crystal lenses. Obsidian, a black and opaque volcanic glass, had been substituted.[2] Thus, the first period of lens use in the Egyptian special eye structures was in decline. By the time of the reign of King Pepi I (ca. 2281-2241 B.C.) During Dynasty VI, a different eye structure was being employed in statues. Limestone and obsidian were used.[2]

Middle Kingdom: Dynasties XI-XIII (ca. 2040-1640 B.C.): This time-line is resumed during Dynasty XII (ca. 1991-1783 B.C.). Then, an odd set of occurrences were recorded. The Lady Khnumet was buried in ca. 1895 B.C. at Dahshur in the Nile Delta; she was called "the Lady from Crete".[17,18] On a pendant of one of her necklaces a figure of a bull is found (this item was not on display in The Jewelry Room at the Egyptian Museum during Enoch's visit, 1998). The design of this piece of jewelry was covered with rock crystal.[18] Was this rock crystal component a convex-plano lens? Such lens formats were found later in Crete and Greece (Fig. A).[9-12,22] Included in this jewelry were fine gold granulations which had already been in use in Mesopotamia for ca. 500 years.[18]

Khnumet may not have been from Crete; the appellation, Lady from Crete, was given to her, because the bull pattern was religious symbol in the Minoan civilization in Crete.[17,21] However, Khnumet did come from the Greek islands. Is it possible that lenses were reintroduced into Egypt through items brought there by her or others?

During Dynasty XIII one encounters the remarkable Ka-statue of King Auib-rê Hor (ca. 1700 B.C.).[2] In this ka figure, there was reappearance of lens/eye structures seen in the IV/Vth Egyptian Dynasties.

How did the reappearance of the earlier Egyptian design lens/eye construct occur after more than a half-millennium of apparent non-use (i.e., from ca. 2400-1700 B.C.)? In King Hor's ka figure, the eye was rimmed with bronze (not copper), the lenses were of rock crystal and the sclera-equivalent utilized white quartz.[1] The eye following effect was readily observed in this statue by one correspondent[19] and by direct observation by Enoch, 1998.

In the collections at The Louvre in Paris and The Egyptian Museum in Cairo, there are located a separate complete or near-complete lens/eye unit construct (not part of a statue).[1] Thus, a model for the eyes may have been present in the artisans' work areas.

Again the Egyptian lens design was different in design from the Minoan lens (Fig. A).

After the appearance of the King Hor statue, there is no evidence of comparable lens/eye structures in Egypt, nor, to the author's knowledge, other lenses prior to a discovery made at Tanis in the Nile Delta by the distinguished British archeologist Flinders Petrie[23] of two large convex-plano Minoan or Greek style lenses (Fig. A). These probable magnifying lenses (greenish rock crystal, imperfect) were found in the home of an artist. These magnifiers had origin in about 50 A.D., and are now located in The British Museum.[24]

Separately, an elegant Hellenistic/Roman-style bronze of a head (ca. 27 B.C.-14 A.D.), fabricated in Alexandria, Egypt, was found in Meroe, The Sudan. The eyes in this bronze head incorporate Greek-style lenses (Fig. A) covering a brightly painted iris and dark pupil;[25] this item is located at The British Museum.

The Minoan Civilization in Crete: A Brief Time Line

Pre-Palace Period (2600-2000 B.C.): Bronze-working, art objects, pottery, stone carving, other metalwork, gold-work, and fine seal engraving were developed. Fine work with rock crystal was found in jewelry. There was an enhancement of society and culture in general.[12]

Old Palace Period (2000-1700 B.C.): The earliest Minoan Palace was built at Knossos, Crete, possibly by King Minos. Extensive trade was developed with Egypt, the Levant, Lebanon, the Cyclades, and Israel/Palestine.

The Golden Age of Crete. The New Palace Period (1700-1450 B.C.): The Bull's Head Rhyton was created between 1550-1500 B.C., or ca. 3550-3500 B.P. It was found at the Little Palace of Knossos by Arthur Evans. This libation vessel had a right eye with a rock crystal lens. It was convex-plano and was painted with a (white or cream color) human face in silhouette on the plano side. This was backed with a blood red "pupil" surrounded by a black "iris". The left eye is a replica.

Minoan palaces were destroyed by the eruption of the volcano at Thera (Santorini), ca. 1450 B.C.

About 400 B.C: Magnifying lenses appeared in Greece, later Rome. They were used in jewelry and in decorative settings. Also, lenses were placed in a number of eyes of statues (from 400 B.C. onward). These lenses had convex-plano design (Fig. A)[22] (also see statues in The Archaeological Museum in Athens, Delos, etc.).

The author has discussed the Minoan lens in the Bull's Head Rhyton and its unique properties in detail elsewhere, and refers the interested reader to those sources[8-14] and to an additional paper by Enoch in press. This is an equally fascinating matter.

The Egyptian Lenses

The main optical features of the Egyptian lenses and the "eye following action" of these lenses have been modeled by the author. To achieve this, a metal washer was placed on a sheet of white paper to simulate the iris/pupil plane. Note: in the model, no distinction was made between the iris and pupillary zones of the construct. A strong negative or concave lens (a -20 Diopter Spherical trial case lens) was used as the rear lens element, and a moderate plus or convex lens was used for the front lens element (simulating the corneal front surface of the Egyptian lens). As in the statues, the plus lens had a less positive power than the negative lens had minus power. About a +8 Diopter Spherical lens was used. The higher power minus lens was separated from the washer by a hollow plastic tube, and the positive lens was further separated from the washer and the negative lens. Essentially the two lenses and washer, separated, were formed into a concentric stack. The primary focal plane of the negative lens lay behind the washer plane, and the secondary focal point of the plus was also located behind the plane of the washer. The image of the washer was seen as magnified through the whole construct. As one rotated about the construct in any direction, the image of the washer clearly followed (moved with) the observer.

Adjusting the height of the plus or minus lenses a bit (or their curvatures or powers), varies the speed of the apparent rate of movement of the "pupil" with observer rotation in the model. The author has observed in the magnificent Egyptian statue "Le Scribe Accroupi" (the seated scribe), found at Saqqara (near Memphis) and now at the Louvre in Paris) that the pupil translations are not quite equal as one rotates in front of the statue. This is probably due to modest differences in the powers of the lens elements. In the Egyptian originals, differences are probably greatest in depth of grind and curvature of the rear or negative power lens elements, because they are the more optically powerful of the two lens surfaces. If this argument is true, one surmises this lens surface would be the one most difficult to control during fabrication. Also, in order to optimize this combined lens structure, one assumes that more than one model had to be fabricated (at least initially). This argument suggests that the lenses used in the eye constructs in these statues were not the first/initial lenses constructed.

This is a complex multiple lens structure with truly unique optical properties! Even the quality of the rock crystal chosen for the lenses, and fine polish of the product speak against these being first lens constructs. And the apparent perceived movement of the pupillary aperture was a desired or intended effect created by the artisans fabricating the lenses. The artisan designer or designers were certainly brilliant individuals!

One can only infer the significance of the design of the lens and eye structures. These constructs were incredibly advanced for their time. These are remarkable achievements taken individually or as a group.

As asked above, did the Egyptian lenses build upon the hard rock technology of the Early Kingdom, or was the design and technology imported from abroad through trade or war - or was there a bit of both? What was used to grind and polish the lenses? P. Hunt at Stanford[26] describes early Carborundum mines in Naxos in the Greek Cyclades. Was this connection made? Clearly, there are many unanswered questions. One can only express awe at this level of sophistication 4600 years ago! The writer knows of no modern lens design which utilizes this unique and ancient apparent following movement feature.

Acknowledgments

This paper was written in cooperation with very able ophthalmological historians in France [Robert Heitz, Jean Royer], a number of distinguished archaeologists and Egyptologists in Egypt and the United States [Patrick Hunt (Stanford U.), Carol Redmount (U.C. Berkeley), Kathleen Keller (U.C. Berkeley), Mohammed Saleh (Egyptian Museum), My Trad and her associate Hanná (Egyptian Museum), R. Parkinson (British Museum)], and individuals associated with either Enoch's lab [Elisabetta Strada (U. Bologna), Stacey Choi (U. Auckland), Vasudevan Lakshminarayanan (UMSL)] or the Ophthalmological Research Institute of Giza [Zenab Osman, Tareq Youssef]. The author expresses his very considerable appreciation to all of these individuals as well as others.

Comments

This paper overlaps to some degree with a paper presented as the H. Leibowitz Festschrift held in State College, PA, in June, 1999. That paper will appear in a special Festschrift volume published by and for the American Psychological Association/Springer-Verlag. In that paper, the more perceptual aspects (Egyptian statue eye following/movement illusion) of this discussion were emphasized. Leibowitz is well known for his distinguished work on a number of vision-related topics, including ocular illusions. Another, but much briefer (two page abstract) version of this work will appear in the Proceedings of the International Commission on Optics Meeting XVIII, San Francisco, CA, August, 1999. The latter will be published by the SPIE. In that presentation, the more optical aspects of the issues at hand will be emphasized. These are quite different audiences.

References

In order to conserve space, this list is limited and annotated. Some references, identified with an *, have extensive literature citations. The reader is referred to two museum catalogues.[1,2]

1. Saleh M, Surouzian H. Official catalogue of the Egyptian Museum Cairo. Cairo: Organization of Egyptian Antiquities; and Mainz, Germany: Verlag Philipp von Zabern, 1987.*
2. Ziegler C. Catalogue Louvre: Les statues Égyptiennes de l'ancien empire (in French). Paris: Éditions de la Réunion des Musées Nationaux, 1997.

To place developments in proper sequence, the reader should reference "time-line" books pertinent to these ancient time periods and regions. An example is given in reference 3:

3. Richman R, ed. The age of the God-kings: Time-frame 3000-1500 B.C. Alexandria, VA: Time-Life Books, 1987.
4. Lucas A, Harris JR. Ancient Egyptian materials and industries, 4th ed. London: Edward Arnold, 1962.* (There are several meaningful and relevant chapters in this book. They deal with inlaid eyes, resins, glazes, glass, precious and semi-precious stones, etc.)
5. Bouquillon A, Quéré G. Le regard du scribe (in French). Pour Le Science Feb 1997; (232):27.
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20. Keller K. Personal communications, 1998.
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26. Hunt P. Personal communication, December, 1998.
27. Osman Z. Personal communication, October, 1998.

ILAMO to be a priority for planned giving:

An article in the February 14, 2000 issue of the American Optometric Association News states that the International Library, Archives and Museum of Optometry (ILAMO), housed at the American Optometric Association headquarters in St. Louis, will be a priority of planned giving to the American Optometric Association. The article notes that ILAMO is home to many historically significant items. Some of the examples mentioned are Wichterle's original prototype for spin-cast manufacture of the first flexible contact lenses and a scleral contact lens fitting set designed by William Feinbloom. Funds for the planned giving campaign will be targeted toward storage space for ILAMO. Information on the American Optometric Association planned giving program can be obtained from Renee Brauns at 800-365-2219, ext. 133.

D.A.G.

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Two figures were inadvertently omitted from page 12 of the April, 2000 (volume 31) issue of Hindsight. Enclosed please find pages 31/11 and 31/12 to replace those in the copy of the April issue that you previously received. We apologize for any inconvenience.

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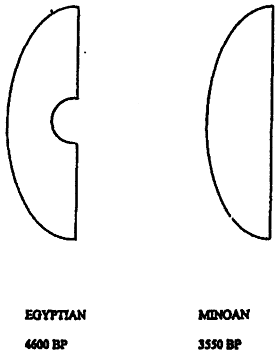

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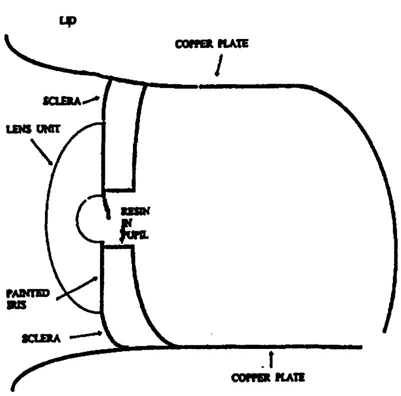

Figure B. This is an assumed schematic cut through the lens/eye structures found in the Egyptian statues. These eye structures were manufactured by teams of artisans and were inserted *en bloc* in the statues, many of which were approximately the same size. The author has no information about the extent of the copper plates at the rear of the eye structures, nor the details of the "scleral" support structure for the lens, i.e., one only sees the exposed scleral surface. The resin "tag" in the pupillary aperture is symbolic of the material seen in some statues. The author assumes that the volume posterior to the pupillary aperture simulates the vitreous and retina of the eye. Eye physicians were then already using couching techniques for cataract displacement.[27]