RECORDING THREE LEEUWENHOEK MICROSCOPES

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Centuries after being lost, new Leeuwenhoek microscopes are appearing. The author has identified two new examples in the space of a year. During a prolific lifetime between 1632 and 1723 the pioneering Dutch investigator Antony van Leeuwenhoek is believed to have constructed at least 500 single-lens microscopes. He did not commence his microscopical researches until he was 40, yet went on to devote half a century to developing our science of microscopy.

Leeuwenhoek was clearly influenced by Robert Hooke. The preface to Hooke's book *Micrographia* describes how to make a microscope of the design that Leeuwenhoek manufactured, and the first specimens Leeuwenhoek sent to London were those described in his book by Hooke, and listed in the same order.[1] When Leeuwenhoek died, most of his diminutive microscopes were lost.[2] There are 'eel-viewer' microscopes (Aalkijker) though these are of a different design, possibly made by others. Standard reference sources list nine surviving microscopes of the standard Leeuwenhoek design, though I am regularly approached with new examples that invariably turn out to be replicas. However, that number can be superseded by recent discoveries: a paper published in 2002 increased the total to ten, and within the space of a year it has now increased to twelve. This paper will briefly describe each of the new arrivals, and discuss the significance of the damaged lens that was found in the final example. The contour of the original lens, and its optical parameters, can be recreated using computer technology to envisage the original geometry. These microscopes (and one that was recently sold) tell a fascinating story that, in each case, is distinct and unprecedented: one new microscope was locked away and ignored; another was found in a drawer of toys and privately sold for a fraction of its real

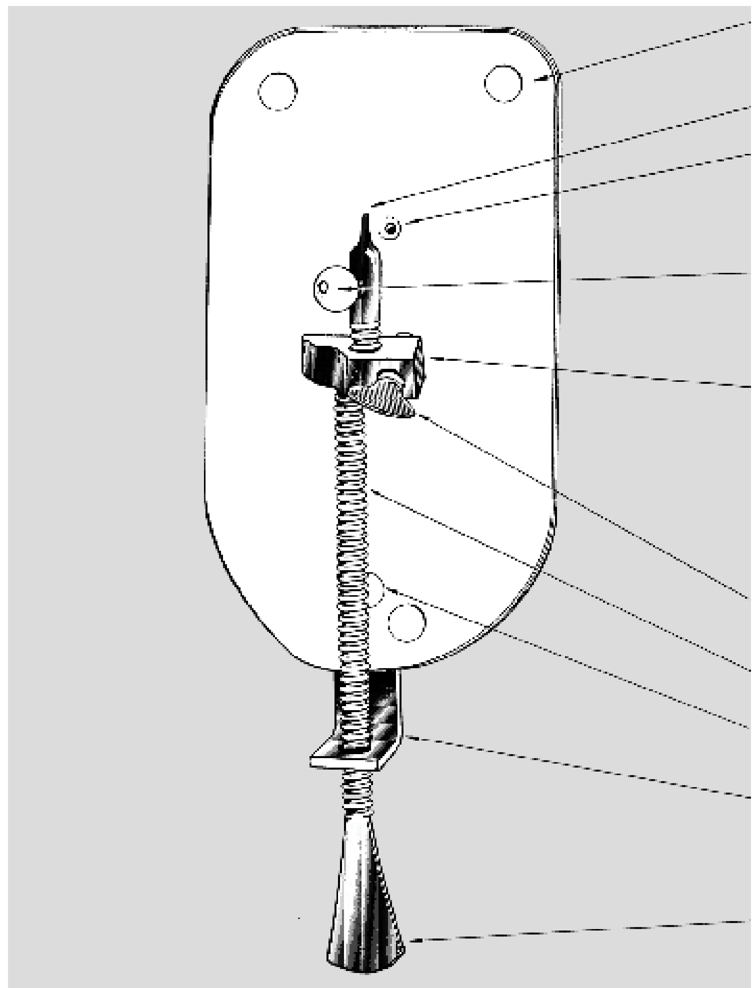

Figure 1: *This diagram is of the most familiar of Leeuwenhoek's microscopes, a brass instrument preserved at the Museum for the History of Science at Ultrecht University, Netherlands. The body plates measure 24 x 46 mm and are secured by rivets. Usually there are four, equidistant from the lens. This example magnifies 266x.*

Figure 2: *After the public interest in the Leeuwenhoek specimens in 1981, this silver microscope was brought into the Boerhaave Museum in Leiden, Netherlands. This is the tenth microscope to be attributed to Leeuwenhoek. Although its owner had recognised its importance, its existence was not published until 2002. The lens magnifies 68x.*

value, while the third was excavated from a landfill site and advertised on eBay.

The microscope in a box

Each of the standard Leeuwenhoek microscopes has a small rectangular body the size of a postage stamp. They have little intrinsic value, and their importance as items of commercial significance was realised only when one was put on public sale in 2009. This microscope had been purchased in a box of oddments by Han Willemse for ten guilders (£3) in 1978. He kept it a secret, though Willemse was an anatomist at the Erasmus University in Rotterdam and he purchased the little box when the laboratory was being reorganised. He knew that the box contained a Leeuwenhoek-type microscope, and insists that he thought it was merely a replica. However, he had no receipt, and nothing happened to the microscope until 2008[3]. It happens that thirty years is the period of limitation for prosecutions of art theft in the Netherlands. If an object is possessed by an individual for that length of time, the object becomes their property. When the time had elapsed, Willemse cautiously announced that he might have a genuine Leeuwenhoek microscope in his possession. He brought it to Christie's auction house in London and, six months later, it became the highlight of a sale of antiquities[4].

On 8 April 2009 the estimate placed on this lot 88 was £70,000 - £100,000 ($103,040 - $147,200). After a sale punctuated by long pauses while overseas bidders considered their next offer, it eventually cost the purchaser £313,237 ($491,766), three times the estimated hammer price. This tiny instrument had raised almost half a million dollars[5].

The purchaser's agent was Mr Rick Watson, proprietor of W P Watson Antiquarian Books in London. Watson said that the buyer wished to remain anonymous, and eventually revealed that the microscope had been acquired by "a biotech organisation in an EC country" and "may ultimately go to a medical library/institution[6]."

Figure 3: *Hidden among doll's house toys, this silver microscope lay for years in a drawer. Occasionally it was polished. The owner brought it into a London auction house, where I was asked if it might be authentic. There is no reason to doubts its genuine nature. This is the eleventh in the Leeuwenhoek list and it encouraged me to develop objective means of establishing authenticity.*

Watson and I have remained in contact; however his client remains obdurate and this crucially important object of our scientific heritage remains lost to the public and to scholarship. Its whereabouts are unknown.

The microscope in a cupboard

There was considerable interest in my discovery of the specimens of van Leeuwenhoek in 1981. The specimens consisted of botanical and bovine material prepared between 1674 and 1686 and were subjected to light and scanning electron microscopy. The correlated results gave us much new insight into Leeuwenhoek's techniques and his methods of working. Following the publication of the original

Figure 4: *The twelfth microscope was excavated from mud that had been dredged from the canals of Delft and was advertised on eBay. The vendor believed it to be a "weird kind of drawing instrument" and for a time he told the purchaser that it had been lost. The brass plates measure 17 x 40 mm though the lens has been severely abraded. This was the first to be examined by SEM.*

Figure 5: *This SEM macrograph was assembled from 70 frames taken with the Hitachi S-3400N variable-pressure microscope at the Cavendish Laboratory, Cambridge. It correlates with the digital camera image from the Olympus E-500 camera with Zuiko Digital 35mm macro lens and assembled from 40 frames (fig 4). These images measure 27,000 pixels (218 cm) long.*

paper by the Royal Society[7] reports also appeared in *Nature*[8] and *New Scientist*[9].

There were many international press reports and the Boerhaave Museum in Leiden decided to mount an exhibition on the specimens I had unearthed. Leeuwenhoek microscopes were also put on show. As a result of the publicity, a resident of the Netherlands realised that they owned a silver microscope that fitted the description, and it was taken to the Museum a year later. This was an astonishing revelation yet the microscope was locked away in a cupboard. Nothing more was heard about it by scholars and it remained a 'secret discovery'. The Boerhaave Museum waited until 2002 and, finding no challenge to their ownership, published a short account in an obscure Dutch journal[10]. There was no reaction. Nothing was reported, and the article was not cited. Even now, over a decade later, the paper has not previously been cited in a paper even though it reveals a discovery of immense significance to historians of science and (as the price paid for the Willemse microscope substantiates) of considerable value.

The two microscopes confirmed two crucial realities: (a) that a Leeuwenhoek microscope was the most valuable of all early scientific instruments and (b) new examples could still come to light. It was suddenly apparent that there were not nine of these Leeuwenhoek microscopes, but ten.

The microscope in a drawer

On 6 March 2014 I received an email from James Hyslop, the science instrument specialist at Christie's auction house in London. It transpired that a client had brought in a Leeuwenhoek microscope with a view to having it authenticated and possibly auctioned. Close-up inspection showed that the microscope was of silver (and had been vigorously polished) and it had all the signs of being a genuine example. Additionally, it was hallmarked with a stamp used between 1814 and 1831 as are other surviving silver examples. As in the case of each microscope so far considered, there was no documentary connection with Leeuwenhoek and provenance for them all was non-existent. We relied upon familiarity with other microscopes of confirmed origin, and I became increasingly uncertain about recourse to such essentially subjective criteria. I was beginning to form the view that objective analytical procedures should be identified.

The hallmarks were inclusive. They can be forged. Hallmarked silver (from a Georgian teapot, for example) could be re-used to create an artefact of authentic appearance. I envisaged carrying out energy dispersive X-ray microanalysis (EDX) at the scanning electron microscopy unit at the Cavendish Laboratory, University of Cambridge, but was advised of its limitations by Professor Sir Alan Fersh FRS (master of Gonville and Caius College, where I am based at Cambridge). His extensive investigation of antique timepieces had revealed the extent to which forged components can be fabricated from contemporaneous alloys in order to give an impression of authenticity. I am familiar with the details of a Leeuwenhoek microscope, and the way the screw threads and rivets were disposed, so it became clear that a close inspection alone would provide evidence of manufacturing methods. Conventional close-up photography was insufficient; I therefore resolved to use scanning

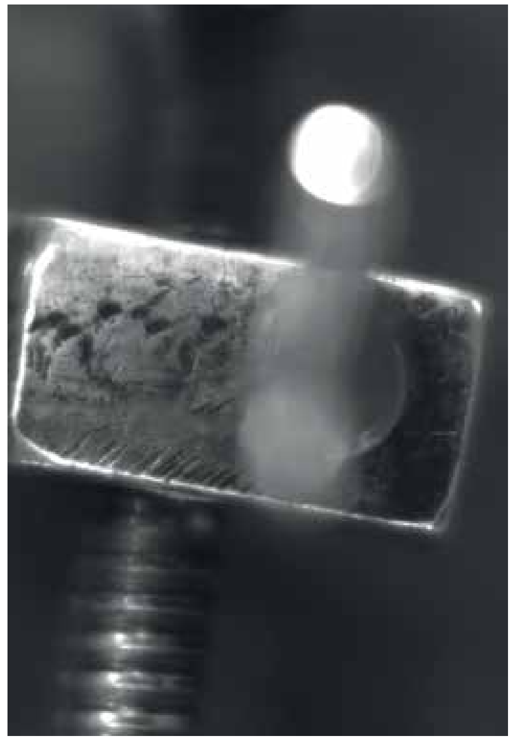

Figure 6: *During its scientific examination, the stage block of the eleventh microscope was conventionally photographed in Leiden to reveal details of the surface configuration. The main screw thread can be made out, though the focussing screw is not focussed. This instrument, made of silver, is typical of those Leeuwenhoek made during a fifty-year career.*

Figure 7: *Care was taken to capture close-up images of the twelfth microscope with the Zuiko macro lens, and specific components (like the focussing adjustment, right) were separately photographed for superimposition. By optimising exposure and illumination levels we can maximise the detail visible. Note the canal detritus in the threads of the main screw (lower left).*

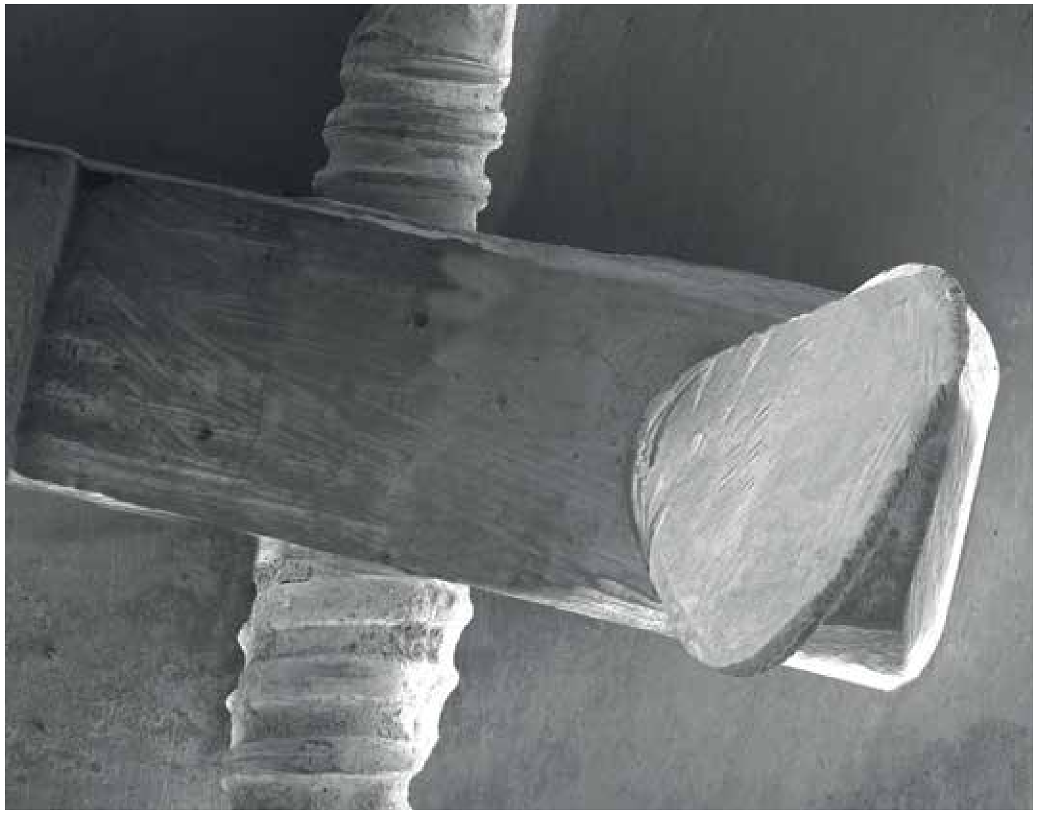

Figure 8: *SEM macrography provides evidence of the hand-working of the brass, and diagnostic details of the screw threads. The apical groove along the crest of the thread and its greater diameter than the brass pin above, shows that it has been rolled. The screw threads of typical replicas are cut with a die. This approach provides far more insight than conventional photography.*

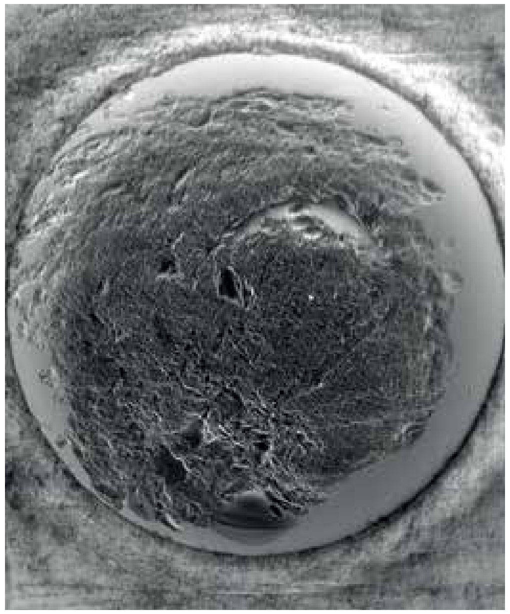

Figure 9a: *The specimen side of the lens in the SEM at a magnification of 40x and accelerating voltage 8kV shows abrasion and conchoidal fractures. The surface has been ground away, though peripheral zones retain an indication of the original configuration. Further deliberate damage to the lens would have been limited by the proximity of the stage assembly. Lens diameter 1.6 mm.*

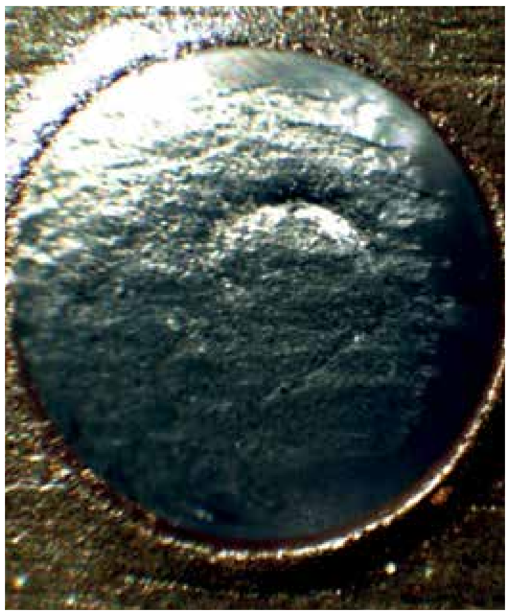

Figure 9b: *The specimen side of the lens under the BM-51-2 microscope shows conchoidal fracturing and abrasion. There are grinding marks visible on the brass body plates. Such macrographic images are traditionally used to report on antique scientific instruments. Lens diameter 1.6mm. The SEM images offer such greater resolution that they should be used in future.*

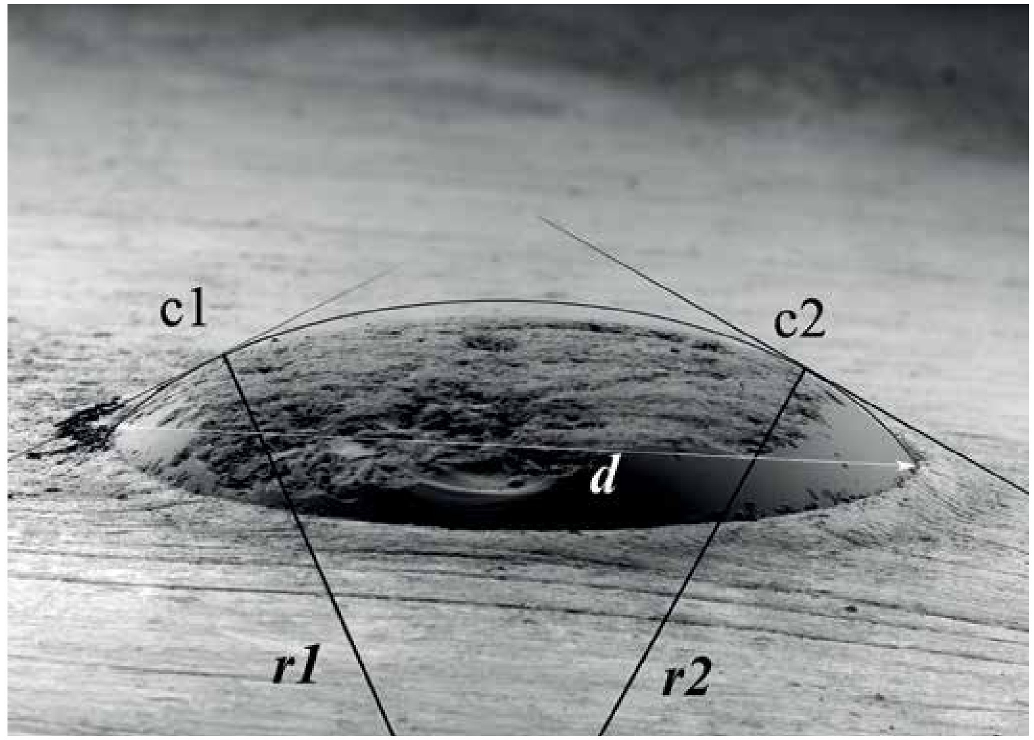

Figure 10: *Adobe Photoshop allows us to re-envisage the original lens contour. The diameter (d) is 1.6 mm, and the radius (r1, r2) 1.2 mm. If we assume the length to be axially symmetrical, this indicates a magnification of 118x. Note the slight protuberance holding the lens in place; only a biconvex lens can be thus secured.*

electron microscopy at relatively low magnification. In research using the scanning electron microscope (SEM) the trend is always to increased resolution and higher magnification. For these investigations I resolved to use low magnifications to inspect entire instruments at unprecedentedly high resolution. Scanning electron macrography would provide the insight we needed.

Hyslop subsequently informed me that the vendors were not interested in pursuing these further investigations. Rather than putting it on public sale in a forthcoming auction, Christie's contacted a property developer and collector in the Netherlands whom they knew to be interested in acquiring antique scientific instruments, and he agreed to purchase it privately for a modest five-figure sum. Examination by the Boerhaave Museum using X-ray fluorescence (XRF) analysis showed that the alloy was approximately 90 per cent silver and almost 10 per cent copper. This is harder than pure silver, and is similar to the composition of contemporaneous coinage. Up to 1 percent proved to be elemental chromium, which at the time was not known to science. However, similar amounts of chromium are found on the surface of other silver objects of early date and are residues from the recent use of polishes that contain high proportions of chromium oxide. The microscope itself had traces of the paste-like cleaner embedded around the periphery of the lens, though this has apparently not been analysed by way of confirmation. Close visual inspection of this new microscope in London suggested to me that is was probably genuine, a conclusion that was subsequently agreed by Tiemen Cocquyt at the Boerhaave Museum in Leiden[11]. Although several macrographs were taken of the microscope at the Museum they were only conventional close-up studies and revealed little. Cocquyt at the Museum was intrigued by the concept of SEM examination, however the new owner was indifferent to the proposal. He was simply satisfied to own this prize possession of his collection. Thus the total number of these similar microscopes attributed to Leeuwenhoek had now risen from ten to eleven.

The microscope in mud

In December 2014 a curious lot was advertised for sale on the eBay on-line auction site which consisted of objects retrieved using metal detectors from a landfill site where mud, excavated from canals in Delft, had been deposited. The objects in this auction lot comprised a few small antique medical items (including a specimen jar, forceps and a scalpel) and what the vendor identified as "a weird kind of drawing instrument". That object caught the eye of microscopist collectors who belonged to the Facebook group for the History of the Microscope and also the Field Microscopes group. Several people asked my opinion and I expressed the view that the object, though twisted out of shape, had much in common with a Leeuwenhoek microscope. Using the fragmentary photographs on the eBay web site it proved possible to recreate the appearance of the original microscope. Meanwhile the bidding on eBay stood at $99 whereupon the item was peremptorily withdrawn from sale.

Several years ago Dr Tomás Camacho had contacted me about early microscopes. Camacho is medical director of the Laboratorio Lema & Bandín in Vigo, Spain and a Fellow of the American College of Medical Toxicology. For some decades he has amassed a collection of early microscopes which have been restored and polished. Now he was again in touch, this time with the information that he had privately purchased the microscope advertised on eBay and, after several problems in retrieving it from the vendor, he was sending it to Cambridge by courier. It was in my hands the next day. Not only did examination substantiate my view that it was an original Leeuwenhoek microscope, but it proved to be remarkably similar to an example in the collections of the Boerhaave Museum which is of undoubted provenance[12]. As an academic, Camacho was persuaded of my view that SEM macrography would be useful, and he placed no time constraints upon the period over which the investigations could last.

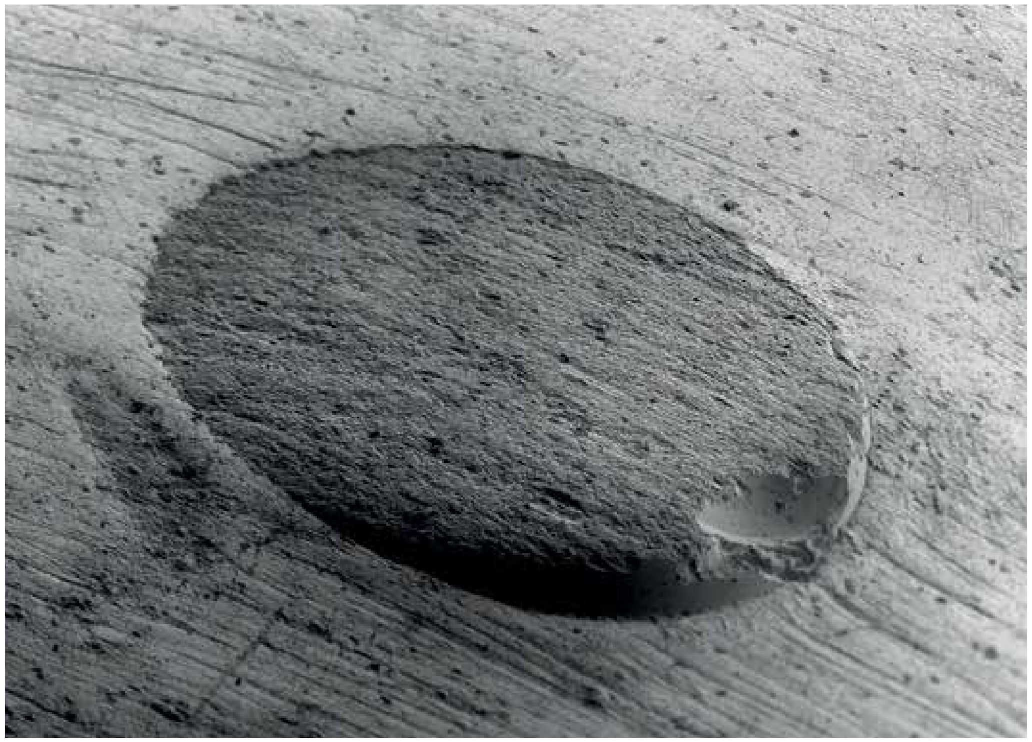

Figure 11: *Severe abrasion characterises the side of the lens facing towards the observer. This surface has been ground flat and conchoidal fracture is also evident. Leeuwenhoek was known to insist on the highest standards for his lenses and the only reasonable explanation for this remarkable result is that it was deliberately destroyed by its maker.*

The microscope on arrival was discoloured and bore traces of mud in the screw thread and between the plates. None surrounded the lenses, for it had been washed away, and on close visual inspection the lens surfaces exhibited a scratched, matte surface. Otherwise this curious artefact had all the features of a genuine Leeuwenhoek microscope. In manufacturing these diminutive instruments, Leeuwenhoek aimed to produce a serviceable microscope though gave little thought to such superfluities as a fine finish. The discolouration led Camacho and his restorer to conclude that the microscope was constructed from silver, but this example (like its near-twin in Leiden) proved to be made of brass. The rough working and scratched surface are typical of those that Leeuwenhoek produced. However, even if the finish was relatively crude, his method of construction was precise; when he secured the plates with rivets, they were correctly sited and perfectly proportioned, their surfaces being flush with the surrounding plates. In a standard Leeuwenhoek microscope the body plates are secured with four rivets and the lens aperture lies at the intersection of an imaginary line that would be drawn between opposite rivets. Some of the forgeries can be immediately assumed to be of more recent production because care was not taken to ensure that the lens was in that precise position.

In a standard Leeuwenhoek microscope, the specimen is held on a pin that is screw-mounted into a stage block. Arthropods, like small arachnids and insects, were sometimes simply impaled on the pin. Others, including plant material, were doubtless secured as Hooke mentioned (for example in his Observ. XXVII in *Micrographia*) "with a very small touch of hard Wax, or Glew, which is better." Living aquatic specimens were examined in capillary tube which can easily be produced with flat sides. The stage block, in these brass microscopes, was a portion cut from a rectangular bar with a profiled cross-section. Details of the profiling may disclose unique features that could be compared with the other surviving instruments of confirmed provenance. The surface marks are themselves of relevance here, and they are clearly visible only using the high resolution of the SEM. Similarly, the screw threads are themselves characteristic and close inspection shows that this microscope has a visual appearance very like that of other genuine examples yet significantly distinct from the threads on replica microscopes. Visual inspection provides the essential clues on which authentication is conventionally based. Museums customarily supplement this with close-up photography of the relevant details. This is the approach that it is time to change: the current research shows that the trained eye, even when supplemented by photomicrography, can be supplanted by the high-resolution images obtained with the scanning electron microscope thus giving us a new resource: the SEM macrograph.

Macrography with the SEM

Most scanning electron microscopes have a relatively small chamber and specimens customarily have dimensions of <10mm since high magnification is the aim. In this case we were seeking to study at low magnification an object measuring 70 mm overall, the body plates alone being 40 mm in length. The facility recommended by Professor Richard Langford and Mr Jon Rickard, my colleagues at the Cavendish Laboratory in Cambridge, was the Hitachi S-3400N variable-pressure microscope and an accelerating voltage typically of 10kV was used to generate a secondary electron image. Typical initial magnifications of 8x to 20x were found to be appropriate: this facilitated detailed surface study and unequalled depth of field. In this way we can see details including the file marks on the body plates, the finishing of the stage block, the precise configuration of the tripartite perforations that characterise the positioning screw handle, and the details of the abrasions that gave the lens is unusual appearance.

Two sets of macrographs were taken. The first covered the microscope and the stage assembly in an orientation normal to the electron detector and covered the entire microscope in 27 separate frames at a representative magnification of 13x. A second set of 7 frames imaged the microscope at an angle of approximately 25 degrees and an initial magnification of 5x to give an oblique view. From the initial images, almost 70 entire frames or portions thereof were selected to compile a composite view of the entire microscope. Stitching software was not utilised, dimensional and tonal matching being carried out manually, utilising the transform and image adjustment parameters in Adobe Photoshop CS since it was felt this gave more precise control over the final image. Approximately 40 close-up digital photographs were similarly taken using the Olympus E-500 camera with Zuiko Digital 35mm macro lens. The resulting compilations gave us correlated images of the Leeuwenhoek microscope in conventional photographic and high-resolution SEM macrograph modalities. These are large final images: the vertical dimensions of the images of the initial compilation are 27,000 pixels (equivalent to an image 2185 mm in length, over seven feet long). Subsequent comparable studies were made of replica microscopes. The replica made for the author by Mr Hansen van Walle of Antwerp is based on the instrument in the Museum for the History of Science at Utrecht University and eight images were taken to cover the entire microscope. Another replica, this time of an authentic Leeuwenhoek brass microscope at the Boerhaave Museum in Leiden, was made by Mr. Arie de Vink of Leiden and this was similarly imaged by the Hitachi S-3400N variable-pressure microscope. This presented a particularly interesting comparison since it is a design of remarkable similarity to the Camacho microscope excavated from the landfill mud. Overall 960 files were amassed during the five months of research and they offer an unprecedented insight into the manufacture and constructional details of these unique artefacts. Thus we could examine the concentric machining that indicates the use of a lathe to make the specimen pin of the replica microscopes, comparing it with the faceted hand-worked profile of the Camacho microscope which was wrought by hand. Similarly, we could identify the rolled screw threads on the Camacho instrument and compare those with the more modern die-cut threads that feature in the replicas. Most important were the studies of the lens both with light microscopes and utilising the SEM macrographs, for these revealed an unexpected finding: the lens surfaces had been deliberately abraded. We first imagined that the matte surface was consequent upon being embedding in canal mud for several centuries but the only reasonable conclusion is that the lens had been defaced.

Reconstructing the lens

Under a low-power BM-51-2 microscope at 8.75x the abraded lens surfaces present a remarkable spectacle: one surface has been ground flat and the other, while extensively abraded, shows conchoidal fracturing. This surface retains some of the original profile at the periphery, and were this the case on both surfaces it might have been possible to strike an image through the fragmentary remains. Examination using Bi WF 10x eyepieces with the Plan 4x and the Plan 10x objectives on the Olympus BH trinocular microscope reveals the details of the abraded and undamaged regions of the lens and its mount while the Plan 40x objective gave insights into the fine structure of the damage and the perforation in which the lens is mounted. The lens has a diameter that is only about 0.05 mm greater than the body plate aperture, so it is held in place by approximately 0.025 mm of its periphery. It was extreme diligence of construction that allowed Leeuwenhoek to undertake this and the design of replica microscopes is usually less refined. Numerous digital images were obtained throughout these manoeuvres.

These were carried out with the lens dry, though the refractive index and elemental composition of the glass were also of importance. Mr Es Reid of Cambridge used his expertise to test the lens with minute droplets of refractive index (R.I.) reference liquids. Reid was bequeathed a series of R.I. standards by our late mutual friend, Mr Horace Dall of Luton, and we were able to show that the lens was composed of conventional soda-glass and not of any higher refractive mineral. Later experiments used Cargille oil of R.I. 1.5150 ±0.0002 which was close to that of the lens. Bracketed trials have not been progressed; this is a delicate artefact and the lens mount is marginal so any unnecessary stress should be avoided in case the lens is displaced. Some of the close-up photographs and photomicrographs were taken with a decentred condenser in order to reveal surface discrepancies. The results present a comprehensive survey of the damage and there can be no mistake: this is a lens that was deliberately damaged. It is not the result of chemical or microbial degradation through the centuries buried in mud.

Faced with a damaged lens we realised that computer reconstruction of the original profile would allow an estimate to be made of its optical parameters. At the Cavendish Laboratory, Rickard recommended taking oblique angled macrographs with the Hitachi SEM that would provide a lateral view of the damaged lens profile. Images were obtained from an angle of approximately 5 degrees at an accelerating voltage of 8kV with an initial magnification of 50x. The SEM macrograph confirmed that the lens setting is remarkably skilful; there is only a minor indentation of the brass body plate, the lens being set ingeniously in position with as much meticulous precision as if it had been an item of jewellery. The replicas are typically characterised by a relatively crude protrusion that more easily accommodates the lens and few could approach Leeuwenhoek's precision.

The extent of the damage to the lens contour was striking: on one side the lens had been ground down almost flush with the surface, whereas the opposite lens surface, even though it has been largely ground away, still shows small portions of the periphery intact. This was sufficient for an attempt to be made at continuing the profile and constructing the likely lens contour of the original. Because there was little remaining on the opposite side of the lens the same technique could not be applied, though we could assume that the lens was approximately symmetrical. The diameter of the lens aperture d=1.5 mm with a very small peripheral region of the lens held within the recess of the brass body plate, from which we can deduce that the lens diameter must be approximately 1.6 mm. The reconstructed lens profile allows one to infer that the radius of curvature of the lens surface ($r1$, $r2$) is approximately 1.2 mm. If the lens is considered symmetrical in cross-section the thickness would have been approximately 0.7 mm. This data allows us to calculate that the original magnification would have been approximately 120x. The magnification of the similar microscope at Leiden was calculated by van Zuylen to be 118x, so we may have conclude that the two instruments were made around the same time.

This microscope bore a biconvex lens, not a glass bead. One of the most pervasive rumours about Leeuwenhoek's microscopes is that he used 'beads of glass' and the term has even been used to describe his instruments, but this is erroneous. Leeuwenhoek's lenses were biconvex. It is recorded by Zacharias Conrad von Uffenbach that Leeuwenhoek decried the use of melted beads of glass: when he visited Leeuwenhoek on 4 December 1710 he wrote that Leeuwenhoek displayed "great contempt" for the idea. No sphere of glass could be held between metal plates in the way we see here; the mounting depends upon the lens having a peripheral zone that can be gripped by the body plates. Uffenbach noted: "[Leeuwenhoek] pointed out to us how thin his microscopes were, compared with others, and how close together the plates were between which the lens lay, so that no spherical glass could be thus mounted, all his lenses being ground, contrariwise, convex on both sides[13]." The scanning electron microscope reveals the truth of his assertion: the brass plates of a Leeuwenhoek microscope are indeed thin, they are certainly placed in close apposition, though the meticulous refinement of design stands in contrast to the relatively crude finish of the metal surfaces.

Rationalising the damage

The microscope had been subject to cleansing since it was removed from the mud, and some screw threads were bright indicating that it had been disassembled prior to its arrival in England. As would be anticipated, we could detect mud in the root of the threads, and it was also evident between the body plates. However, it was the lens that was of particular interest for it clearly tells something of the history of the microscope. One side had been ground virtually flat, whereas the other has been abraded so that only parts of the periphery remain. The way the lens was originally oriented cannot be assumed to be unaltered, since the microscope has been taken apart (presumably for cleaning) and the body may have been reversed in the process. However, we can perhaps infer the original orientation. The lens has not been eroded by microbial or chemical interaction during its centuries buried in mud, for the marks of abrasion are unmistakable and the composition of the glass remains unaltered. Leeuwenhoek was a man of high standards, and rejected facilities that he found to be lacking: if a lens proved to be of poor performance he would reject it. The lens has clearly been placed against a grindstone to damage its profile. If the lens was destroyed by Leeuwenhoek because it proved to be inferior or unsatisfactory, this will have been after the microscope was assembled and thus the extent and position of the damage may be related to the design of the microscope. The specimen side of the microscope has the stage block and pin adjacent to the lens, which would limit the extent to which the lens could be damaged on a grindstone; conversely the observer's side has no such encumbrances and would facilitate the lens being ground flat. In this way we can reach an educated conclusion on the original orientation: the fully abraded aspect faces the observer while we can conclude that the surface that still stands proud faced the specimen.

To analyse the glass, we used energy dispersive X-ray microanalysis data from the Hitachi S-3400N SEM. Sample *a* revealed 34.95% Si, 31.47% O, and 3.19% Cu; sample *b* 40.06% Si, 34.57% O, and 12.73% Cu; sample *c* 40.06% Si, 34.67% O, and 3.19% Cu. The Cu was certainly due to the detection of the brass from which the microscope was constructed, and Zn was also detected (≈1%). Sodium was present as a trace (≈ 0.6%) and, remarkably, Ca was absent. Dr Gary Laughlin at the McCrone Research Institute in Chicago has reviewed our data and advises that: "CaO would be expected in such glass, since it aids workability." Glass in the recent era has contained significant levels of CaO and the absence of this compound substantiates the genuineness of this as an antique artefact.

We assume this was a symmetrical biconvex lens and the geometric reconstruction provides these data:

Diameter of lens = 1.6 mm

Radius of curvature (both sides) 1.2 mm

RI of glass = 1.52

Lens thickness (approx) = 0.6 mm

Our optical specialist, Mr Reid, calculates that this provides f = 1.12 with a magnification of 118x. This is precisely coincident with the lens parameters of the remarkably similar brass microscope in Leiden. One can only deduce that they were constructed at the same time. Indeed, if it is the case that this lens was rejected and deliberately destroyed by Leeuwenhoek, it could be possible that the Leiden microscope was the second attempt to create an instrument with these particular specifications. Although it is tempting to assume that an inferior lens could easily be replaced, the design of a microscope with riveted plates would make it impossible to replace the lens. Furthermore, it is not until the lens is securely mounted in position that it could be assessed, and this is when any optical inadequacies would first be revealed. We can imagine Leeuwenhoek finishing work on the microscope, finding it unusable, and then grinding away the lens in frustration before throwing the rejected instrument into the canal. This is conjecture, of course, but it is consonant with the facts. Not only have we the unexpected situation of recognising two unknown Leeuwenhoek microscopes with the space of a year, but one of them is not simply an instrument of magnification, but has features that may tell something of events at the time it was made. This has been an exhaustive enquiry, with almost 1,000 microscopical images being acquired in the course of the research. Our investigations at the Cavendish have revealed that there are unique features to this microscope, for which one possible rationale has been advanced. Should there be alternative explanations of this unique little instrument, we would review them with interest.

References

[1] Brian J Ford., *Leeuwenhoek Legacy*, Bristol: Biopress, London: Farrand Press, New York: Lubrecht & Cramer, 1991.

[2] Brian J Ford., What were the missing Leeuwenhoek microscopes really like? *Proceedings of the Royal Microscopical Society* **18** (2): 118-124. 1982.

[3] Hendrik Spiering, Uit een laatje met troep, *NRC Wetenschapsbijlage,* 11 April 2009

[4] Christie's sale catalogue No 5808 *Travel, Science and Natural History,* London: South Kensington, March 2009.

[5] Gary Laughlin, Rare Leeuwenhoek bids for history, *The Microscope* **57** (1): ii, June 2009.

[6] Rick Watson, e-mail communication to the author, 14 September 2009.

[7] Brian J Ford, The van Leeuwenhoek Specimens, *Notes & Records of the Royal Society*, **36** (1): 37-59, 1981.

[8] Brian J Ford, Leeuwenhoek's Specimens discovered after 307 years, *Nature,* **292:** 407, 30 July 1981.

[9] Brian J Ford, Found - van Leeuwenhoek's Original Specimens, *New Scientist,* **91:** 301, 30 July 1981.

[10] Marian Fournier, De doos van Pandora, een Microscoop van Antoni van Leeuwenhoek, *Gewina* **25:** 70-74, 2002.

[11] Tiemen Cocquyt, *Evaluation of a silver microscope after van Leeuwenhoek*, 8pp, Leiden: Museum Boerhaave, December 2014.

[12] Brian J Ford, 2015, Deepening mystery of the disappearing microscope, *Laboratory News*: 10 February 2015.

[13] Zacharias Conrad von Uffenbach, M*erkwürdige Reisen durch Niedersachsen Holland und Engelland*, Frankfurt: Johann Georg Schelhorn, 1753, v III pp 349-360.

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