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# EFFECTS OF CLEANING AND REGARD FOR CLEANING GOALS: ELEVEN YEARS LATER

Niccolo Caldararo


## Abstract

This paper revisits the 1993 article in *North American Archaeologist* 14:289-303, "Some effects of the use of ultrasonic devices in conservation and the question of standards for cleaning objects", and includes a summary of recent research and advances by the author and in the field, including the effects of cleaning on ancient DNA. The paper discusses how both attitudes and needs in the conservation field have changed since 1993 and will reexamine earlier work, especially with regard to ultrasound. The paper includes an assessment of how conservation has responded to the challenge of both technology and changing fashion, focusing on the idea of information lost versus idealized appearance. A number of philosophical and ethical questions are posed.


## 1. Introduction

The author has a long standing interest in the effects of cleaning on artifacts and the evaluation of conservation treatments historically employed. Beginning in the early eighties, the author has questioned accepted treatments. For instance, the author began correspondence with H. Brinch Madsen about the long-term effects of BTA treatment on bronzes (Madsen 1983) and with Joan Gardner at the Carnegie Museum about some techniques she had used on the Spiro artifacts (Gardner 1980) in order to learn of the current condition of the artifacts and whether Gardner had adapted the treatments previously used by Forest Clements (1936) or Douglas (1931); see also Bennie Keel, 1963, on Leechman).[1]

Gardner replied that she had read the Clements article several years beforehand, but was not sure if her treatments had in fact been the same as Clements (Clements 1936). She thought he described a “too stringent” approach and felt it was unwise to cite his paper as it would “call attention to it.” “Too many people, “ she pointed out, “blindly follow instructions without considering the condition of the specimens involved and without considering all the cautionary notes associated with a treatment method.” Certainly this is true, but it is also true that we can only make progress through an evaluation of the deficiencies of prior methods and materials.

As a result of this correspondence, the author decided to undertake a study of the durability of specific treatments and the decision-making process that led to treatment selection. Other conservators also have evaluated current conservation methodology. For instance, in 1975 Judith Weston and Meryl Johnson reported on the conservation of Benin Bronzes at the Detroit Institute of Arts. The focus of their paper was the use of protective coatings, including waxes and resins which were applied by collectors, restorers and conservators to enhance the aesthetic qualities of the objects. These coatings also covered previously treated areas, as well as untreated ones, which later became active sites of bronze disease and caused substantial damage and loss. The authors pointed out the need for attention to forms of compensation that mask potential areas of future damage. Also essential to an assessment of treatment goals was an understanding of what was viewed as the original surface.

Research has shown that even a ‘gentle’ cleaning treatment such as wiping a saliva dampened swab across a paint surface can have a perceptible effect. Figures 1 and 2 show a comparison of cleaning with saliva on a painted surface by Alan Phenix and Aviva Burnstock (1990). Certainly the surface is cleaned of dirt and other debris but there are also visible diagonal lines on the cleaned surface from the swabbing process; apparently the result of the physical action of the swab against the paint and/or the process of leaching water-soluble components in the varnish film**.** Figures 3 and 4 illustrate another example of the use of a cotton wool swab on varnish producing unmistakable lines in the varnish (Phenix and Burnstock 1990). There has been considerable debate concerning the process of leaching and solvents. Ken Sutherland has provided more information on the effects of cleaning on painting materials with his measurements of both cleaning and the leaching of soluble components during varnishing (Sutherland 2004). The question is not whether change occurs, but how much change is acceptable.

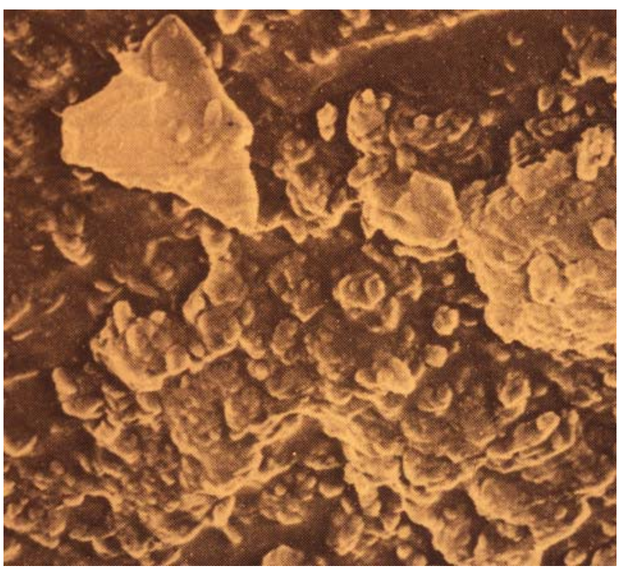

Figure 1. Painted surface, before cleaning with saliva.

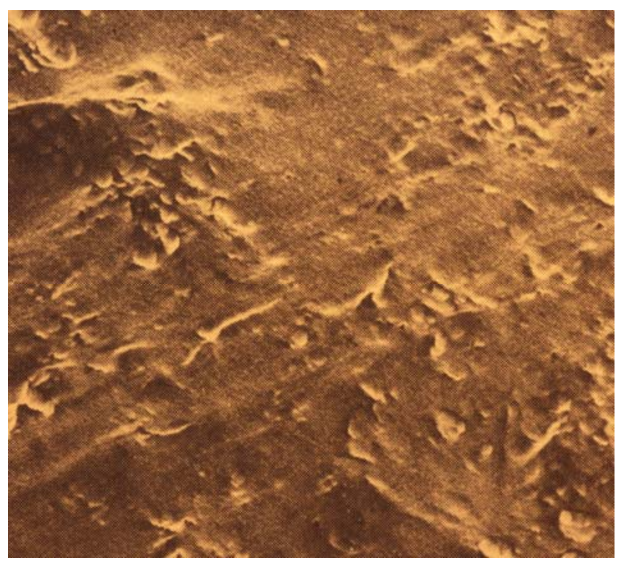

Figure 2. Painted surface, after cleaning with saliva.

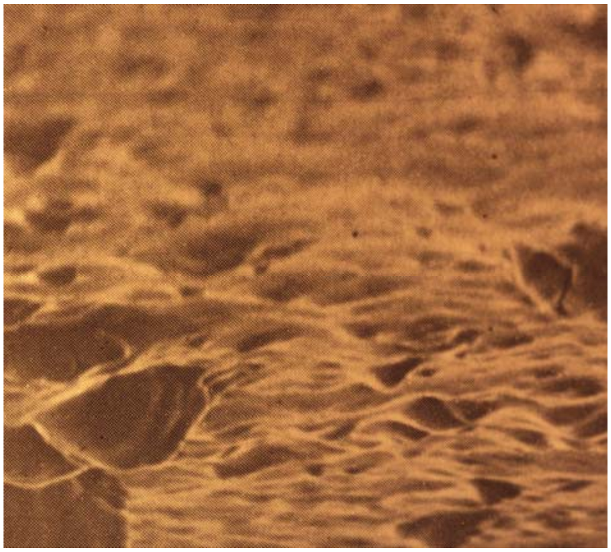

Figure 3. Varnish, before cleaning with swab.

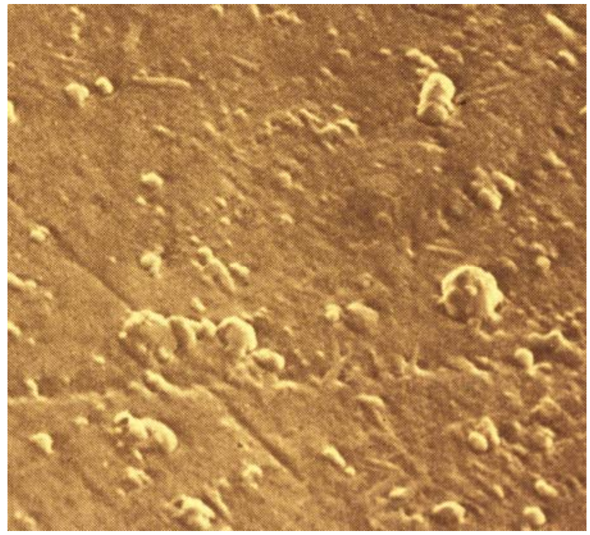

Figure 4. Varnish, after cleaning with swab.

The earlier comparison using SEM images (Phenix and Burnstock 1990) shows a discernible change from the cleaning process. On the other hand, photography of a horn artifact before cleaning (Figure 5, overall and Figure 6, detail at 40x) compared with subsequent treatment photography after cleaning using ultrasound with a detergent (Figure 7) does not produce such a dramatic effect when compared by the eye. Of course, some change must have taken place but

Figure 5. Horn artifact before cleaning.

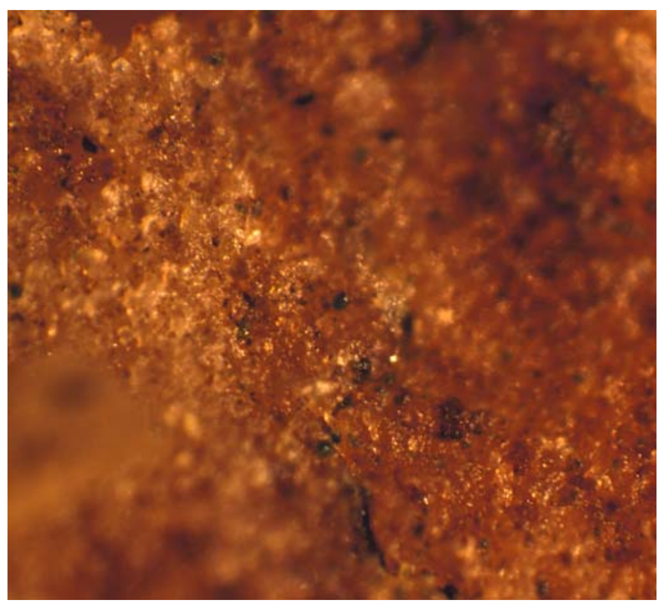

Figure 6. Horn artifact before cleaning, detail.

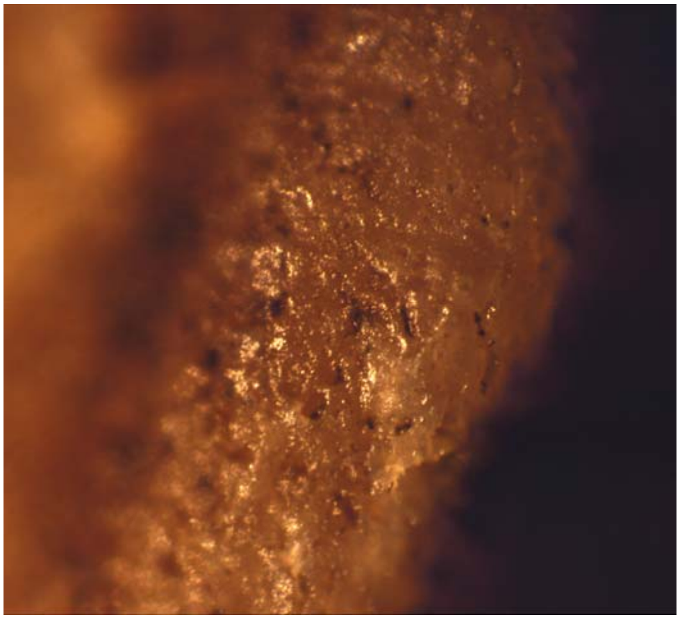

Figure 7. Horn artifact, after cleaning, detail.

within the viewing context none is apparent. In another example, when before treatment photographs of a political pin shown full size in Figure 8 and in detail at 40x in Figure 9 are compared with subsequent treatment photograph (Figure 10) after cleaning with ultrasound and a detergent, a visible change is perceived. Something has happened.

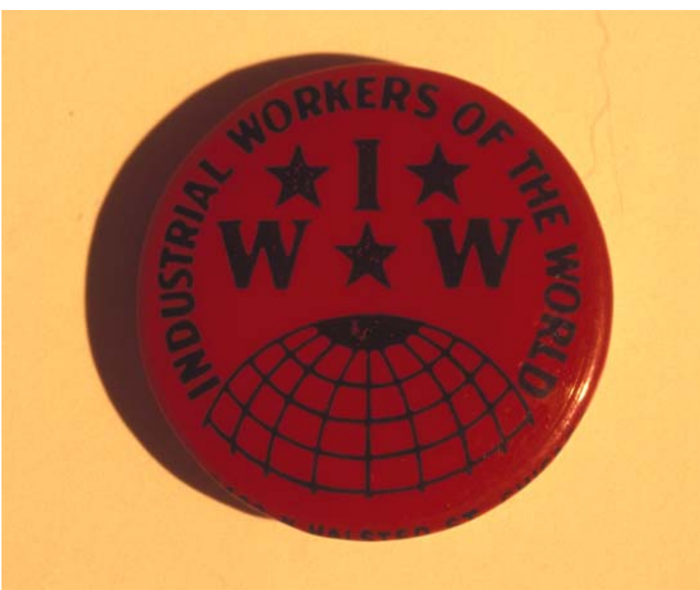


Figure 8. Political pin, before treatment.

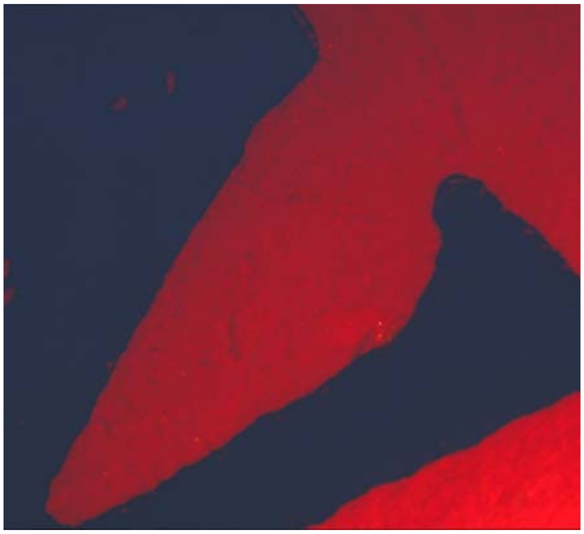

Figure 9. Political pin, detail before treatment.

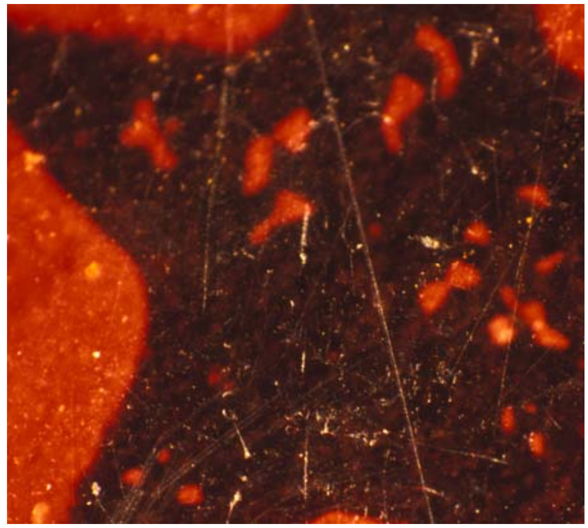

Figure 10. Political pin, detail after treatment.

**2. Treatment, Retreatment or No Treatment**

How do conservators determine whether a treatment is acceptable? (See Calderaro 1993). Are controlled long term studies required, similar to those required by the FDA for drugs, or is it acceptable to simply use the treatment for a while and see what happens?

Treatment, retreatment and no treatment in combination with preventive conservation have become common themes in conservation discussions in the past 20 years. For example, in search of data to understand the durability of treatments, Julie Dawson (1988), restudied bronzes treated at the Fitzwilliam Museum. She notes that one of the most difficult problems conservators face in attempting assessments of past treatments is the lack of documentation as well as the expense of re-examination. A study of the long-term durability of the treatment of painting on glass and ceramics (Calderaro 1997) found that these problems were magnified by the difficulty of gaining the cooperation of the owners of objects, especially museums. This study used a list of conservators who had responded to a previous request for information from conservators who treated reverse glass paintings (Aiken 1990). Aiken felt that the response was disappointing and her comments on the results of efforts to elicit information were prophetic. With few exceptions conservators did not share information about the durability of their treatments. This was not entirely unexpected, given the time required to contact an owner, compare their documentation with the present condition and then write an assessment. Thomas G. Stone also reported that a 1994 survey of objects in Canadian collections was hampered by both the lack of documentation and by the variable nature of the documentary information (Stone 1996).
It was obvious that cleaning, and the goals of cleaning, were of concern to many people. Sheldon Keck's illuminating and thoughtful article (Keck, S. 1984) described many of the issues that have

been restated with less clarity over the past 20 years, and Eric Hulmer's book (Hulmer 1955) is a stimulating and careful analysis with excellent illustrations of how the conservator and the curator/collector relate to the problem of cleaning and the changed surface. Contrary to Beck's view expressed at the 2004 AIC conference (Beck 2004), there has been a considerable history of criticism in conservation, one need look no farther than Caroline Keck's criticism (1973) of Kelly's book, *Art Restoration* (Kelly 1972). It is true that the debates and concerns of conservators have not become well known to the public, and perhaps this is a good thing. Acrimonious debate is detrimental to a constructive and positive public image, and detracts from the confidence conservators wish to earn in the public eye. On the other hand, science advances by study and re-study, debate and disagreement. Science is self-corrective and the process of this progress is public criticism. The history and nature of criticism in conservation would make an excellent topic for a dissertation.

In the 1980s the author was working with archaeologists whose main reason for cleaning was to make objects available for analysis. Using Thomas Loy's research (1983) on the identification of blood proteins on lithics, it was possible to convince the archaeologists that cleaning could destroy significant information. Current procedures for artifact cleaning were potentially destroying information about diet as well as the possible use of the lithics as weapons.

Test cleaning strategies suggested by CAS suggested the possibility of cleaning only portions of objects, but this approach was unacceptable to the archaeologists. At the 1982 IIC conference in Washington, during a discussion of cleaning archaeological artifacts, Caldararo engaged in a discussion with Garry Thomson on this dilemma. The conclusion was that mass collections of shards, lithics and other material could be sampled by randomly selecting objects to be treated for analysis, and that rare objects should be able to be partially cleaned. As rational and logical as this seems now, it was not an easily workable solution at the time. The concern was that since the archaeological record is already a sample produced by the processes of degradation and accident, cleaning only a random sample of artifacts might not produce an accurate picture of the material that was recovered. Still, this was only an assumption, and given that resources for collection maintenance and conservation have always been tiny, in retrospect these feelings seem today rather absurd.

In 1981 and 1982 the author sent out a survey to conservators and archaeologists to determine current practice, attitudes towards cleaning, who was doing the work and how they had been trained. The questionnaire asked what methods were used to treat artifacts, what books, articles and other information sources were used as reference material and what training they had taken to produce the skills necessary to carry out conservation treatments in their laboratories. Over 200 requests were sent out; there were fewer than 50 responses. Some were written and some were only phone conversations based on a randomly selected group who had not responded by mail. The results of this study were published as part of a more comprehensive study of the preservation approach and methods used in anthropology and archaeology (Calderaro 1987). One of the most interesting results of the survey was the great variety of methods and techniques that were picked up by archaeologists through conferences and publications generally, without reference to the conservation literature. In fact, many of the most important artifacts, especially fossils, were being treated in field or university labs by archaeologists who had learned their skills from other archaeologists.

The dominant attitude was that the information that was being sought by the scientist was available only to his or her eye based on their knowledge of the unique nature of the specimen or the techniques of manufacture of the object. The idea that a technician trained in conservation could do better or preserve the object with greater skill was often dismissed as naïve. An example often referred to was the notorious case of a cast described by Marsh (1876) of the endocranial cavity of Coryphodon, a large ungulate that lived about 55 million years ago. In the specimen in question, the entire auditory bullae were removed when the skull was readied for the cast by a preparator. Marsh then mistook the excavated region of the auditory bullae for a cerebellum. The error was not realized until noticed by Ediger and Tilney more than 50 years later (Jerison, 1973).

Cleaning can reveal information otherwise not visible as well as remove original materials and information. It stands to reason that that experience and knowledge will lead to the recovery of more information. The renowned archaeologist Sir Leonard Woolley was also famous for his restoration skills. Yelena Rakic (1998) describes his efforts to salvage the sculpture, "Ram Caught in a Thicket" from the Royal Cemetery of Ur. No conservation records exist, but Woolley's notes, and later retreatment efforts, have uncovered the process he used. Virginia Greene's recent article (2003) describing the use of excavation reports and conservation examination methods to discover the original form of an object goes far towards defining that element of professionalism which identifies the essential role conservation can play as a necessary part of archaeological science. Such examples also address the difficulties in defining the original state as Caple (1999) has so aptly described it**.**

Some times the anthropologist's expertise is not employed, as in the case of the Thunder Pipe of the Blackfoot; long one of the most renowned objects on display at the American Museum of Natural History. Stanley Freed (1981) described how he discovered the pipe was a pastiche produced by a museum worker who created a bowl for the pipe. This bowl did not exist when the pipe was collected and was not mentioned by Clark Wissler, the collector. It is assumed that Wissler must have permitted the addition of the bowl as the pipe was on display for so long during his lifetime.

Any conservation treatment can cause a visible change in an artifact, as illustrated by the design of a hanging method for painted skins of Kiowa origin (Figure 11). The Native Americans involved in the show ("Plains Indian Painting", DeYoung Museum, San Francisco, Downtown Center, 1980) wanted the skins exhibited in the manner of Western art, and the skins were framed. The attachment of Japanese tissue hinges to the reverse with wheat starch paste was considered the least damaging intervention (Figure 12). The process of removing the hinges resulted in the removal of some of a yellow coating from the back of two skins (Figure 13).

Figure 11. Kiowa painted skin.

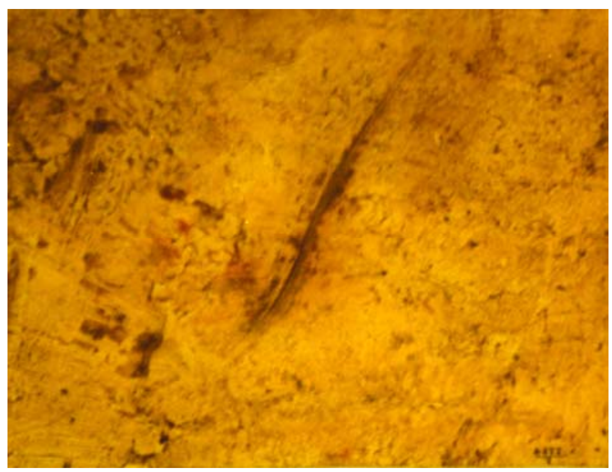

Figure 12. Attachment of hinges to the reverse of the painted skin.

Figure 13. Reverse of skin, after removal of hinge.

The coating was identified as an arsenic compound applied with a brush, and the removal of a minute quantity was not considered significant as no change was visible. No transfer was noted on the removed hinges, but there was a texture change on the object, even though the paste was entirely removed. The coating was later analyzed to confirm that it did not contain pigment of Native American origin (Calderaro 1991). Nevertheless, the conservation process had changed the object.

This brings up another topic, mistakes. All conservators make mistakes, but they are seldom described in print (Calderaro 1993). This failure contributed to the problem noted by Reedy & Ready (1988) in their survey of conservation science research, that there were no studies prior to 1988 which tried to validate previously published conservation research techniques. Certainly we have seen a considerable change from this situation in the last 16 years, especially the volume edited by Vincent Daniels in 1988 and volume 42, no. 2 of the *Journal of the American Institute for Conservation* in 2003, both of which focused on treatment reviews and evaluations. Still, without a discussion of mistakes, both in the choice of materials (even allowing for what was available at the time) and in judgment or execution, we cannot understand the process of our work - and cannot train students adequately. Barbara Applebaum is currently writing a book on decision making in conservation which should make a valuable contribution.

### 3. The Nature of Cleaning

In a paper given at the 1987 AIC meeting, Richard D. Smith maintained that reversibility did not exist (Smith 1987). Surfaces are cleaned and materials removed, consolidants are added, and it would be impossible to remove every molecule should one attempt to reverse the treatment.

Barbara Appelbaum took this idea further in her attempt to address the limits of treatment within the framework of an object's context and original appearance, acknowledging that treatment can change or remove information. However, her argument that "cleaning does not necessarily destroy information" and that the goal of conservation should be "retreatability" is problematic (Appelbaum 1987:67). She did acknowledge that cleaning was irreversible and that exact materials could never be replaced; and that conservators should adjust their thinking about changes introduced by cleaning. In her mind, the important goal of treatment was to achieve a state where the "...capability of reversing the visual effect [is] important" (Appelbaum 1987:67). Also she makes the point that an informed conservation plan could determine the nature of the information affected by cleaning and that based on this knowledge a determination could be made to limit loss or to preserve certain aspects of this information. While all types of cleaning destroy some information, perhaps conservators must accept the idea that there are both acceptable levels of loss and of degrees of reversibility. This idea was also encompassed in a talk by Arno Schniewind which focused on the problem of communication between conservators and owners/curators (Schniewind 1987). Changes do occur, as both Schniewind and Smith note, and the conservator has an essential role to play in the process of discussing both practical results of treatment (including the possibility of critical losses) and the client's goals.

The author's response to this discussion (Calderaro 1988, 1990) addressed the issue of "no effect" and "no change". By reference to a number of studies it attempted to demonstrate that most treatments, and specifically in this case, no paper conservation treatment could be said to result in either "no change" or have "no effect" on the object. Treatments from erasure to deacidification all induced change and have effects on both the paper support and the media. Significantly, conservators were edging toward despair because new analytical techniques could detect and measure change and its effects where nothing had previously been perceptible. It was found that deacidification changed some colorants chemically and both water and solvent treatments resulted in paper fiber repositioning (Cook & Mansell 1981). As Schnienwind reflects, this knowledge certainly makes the job of the conservator harder, but it also heightens the challenge. Learning to communicate that any treatment will effect change to curator and client alike should enhance regard for conservation and not be a source of disillusion.

For example, in the 1990s the author began to work with Steve Gabow (Anthropology Dept., San Francisco State University) and Dr. Joe Romeo (Molecular Biology Dept., San Francisco State University) on a project to develop a teaching module for molecular biology designed to address aDNA analysis and phylogenetic studies in human evolution. The research also covered the possible effect of conservation treatments on ancient DNA. A number of studies were conducted (Calderaro and Gabow 2000). The research focused on the nature of DNA degradation and how conservation activities might impinge on this process. This followed research on the effects of conservation treatments on dating methods (Caldararo, 1994; Kahle & Caldararo, 1986). Cleaning methods have been shown to further degrade samples, making them difficult to analyze (Lassen 1996, see Fig. 14)) or skewing data (Caldararo and Gabow 2000, see Fig. 15; Pusch and Bachmann 2004, see Fig. 16).

TABLE I Summary of the results of Lassen *et al.* (1996), showing relatively poor amplification of amelogenin sequences from bones treated with preservatives

| *Burial site* | *Number of PCRs* | *Number of successful PCRs* | *Number giving 106-bp product* | *Percent success rate* |
|---|---|---|---|---|
| Ofnet[a] | 8 | 2 | 0 | 25 |
| Wremen | 21 | 8 | 5 | 38 |
| Lubeck | 4 | 3 | 2 | 75 |
| Aegerten | 106 | 72 | 2 | 68 |

a. Bones treated with preservative.

Figure 14. Chart from Lassen 1996, showing evidence of degradation of bone treated with preservative.

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| *Substitution* | *Modern H. sapiens sapiens* | | *Neandertal* | | *Ancient H. sapiens sapiens* | |
|---|---|---|---|---|---|---|
| | *Number* | *%* | *Number* | *%* | *Number* | *%* |
| T→A | 4 | 1 | 0 | 0 | 4 | 3 |
| C→G | 2 | 0.5 | 1 | 1 | 0 | 0 |
| G→C | 2 | 0.5 | 0 | 0 | 0 | 0 |
| G→T | 0 | 0 | 2 | 3 | 4 | 3 |
| C→T + T→C | 261 | 68 | 41 | 57 | 59 | 49 |
| Totals | 383 | | 72 | | 119 | |

Data refer to nucleotide positions 16020–16409.

Figure 15. Chart from Caldararo and Gabow 2000, with evidence of skewed data.

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**Table 3**
**Frequency of Mutations Listed in Table 2 Among Cloned PCR Products of a 148-bp Stretch of Mitochondrial HVRI (16147–16294) of Spiked Contemporary Human DNA**

| mtDNA Position | Observed Mutation | Number of Clones Affected | Percentage of Clones Affected | mtDNA Position | Observed Mutation | Number of Clones Affected | Percentage of Clones Affected |
|---|---|---|---|---|---|---|---|
| 16172[a] | T→C | 3 | 0.6% | 16223[a] | C→T | 317 | 57.9% |
| 16182[a,b] | A→C | 2 | 0.4% | 16224 | C→T | 15 | 2.7% |
| 16183[a,c] | A→C | 340 | 62.1% | 16230[a,c] | A→G | 225 | 41.1% |
| 16188 | C→T | 131 | 23.9% | 16234[a,c] | C→T | 225 | 41.1% |
| 16189[a,c] | T→C | 373 | 68.2% | 16236 | C→T | 3 | 0.5% |
| 16191 | C→gap | 5 | 0.9% | 16244[c] | G→A | 233 | 42.6% |
| 16192[a] | C→gap | 13 | 2.4% | 16244 | G→C | 3 | 0.5% |
| 16192[a] | C→T | 6 | 1.1% | 16245 | C→T | 103 | 19.8% |
| 16193 | C→gap | 59 | 10.8% | 16247 | A→G | 114 | 21.9% |
| 16193.1 | gap→C | 142 | 25.9% | 16253 | A→G | 94 | 18.1% |
| 16196 | G→C | 4 | 0.7% | 16255 | G→A | 85 | 16.3% |
| 16211 | C→T | 17 | 3.1% | 16256[c] | C→A | 4 | 0.8% |
| 16213 | G→A | 302 | 55.2% | 16258[d] | A→G | 254 | 48.8% |
| 16216 | A→T | 302 | 55.2% | 16260 | C→T | 3 | 0.6% |
| 16216 | A→G | 4 | 0.7% | 16261 | C→T | 3 | 0.6% |
| 16217 | T→C | 302 | 55.2% | 16261 | C→gap | 8 | 1.5% |
| 16221 | C→T | 3 | 0.5% | 16262[c] | C→T | 12 | 2.3% |
| 16222 | C→T | 30 | 5.5% | 16263.1[c] | gap→A | 12 | 2.3% |
| 16222.1[c] | gap→C | 281 | 51.4% | 16269 | A→G | 4 | 0.8% |

[a] Mutation hotspots according to Gilbert *et al.* (2003b).
[b] Mutation also found in Neandertal sequences AF254446, AF282971, AY149291.
[c] Mutation also found in Neandertal sequences AF011222, AF254446, AF282971, AY149291.
[d] Mutation also found in Neandertal sequences AF011222, AF282971.

Figure 16. Chart from Pusch and Bachman 2004, with evidence of skewed data.

To advance, the field must produce critical reviews of treatment and methodology. Such reviews must be based not only on the changes in condition that may be found to be detrimental to appearance or to have destroyed information (see Gardner 1980). Conservators must also evaluate the effect of treatment materials on the durability of the work, as well as the question of how much variability of outcome is due to variations between conservators. How reliable are treatment methodologies in producing desired outcomes? (See Calderaro 1987). As Giorgio Torraca has pointed out, we need more time and research directed to the needs of conservators:

> Conservation today is a production line....It no longer proceeds at the leisurely pace of the still-recent past, when conservation was such a quiet and pleasant profession. Problems must be solved within deadlines that do not allow sufficient time for experimentation and analysis. (Torraca 1999:9)

The Getty is undertaking such research, especially in the area of the effects of different conservator's styles of working and skill level in carrying out the same tasks (Anon. 1999). Torraca also asks if conservation science is really a science or if we are "gambling" with explanations of complex problems in a science which has not yet established a thorough characterization of its goals (Torraca 1999). These questions have been asked for 300 years with little progress in the development of goals and the understanding of outcomes (Koller 2000) and the discussion needs to be continued in an open forum, not just behind closed doors

## 4.0 Ultrasound and Conservation

### 4.1 Introduction

Research into the use of conservation and restoration techniques in anthropology revealed that a large number of people have been using ultrasound - a powerful tool that is still not well understood. With the waning interest in manual methods of cleaning and approaches like air abrasion techniques due to the increasing dissatisfaction over procedure and aggressive results, one could expect the introduction of new cleaning methods (Caldararo, 1987). There are two approaches to the use of ultrasound. Batching-- immersing objects in an ultrasonic bath and misting of a surface using a nebulizer, humidifier or steamer. Robert Organ introduced ultrasound to the field of conservation in 1959 and had always warned people of the potential consequences of the energy directed against fragile surfaces. Few people, however, seemed to understand or take heed of his concerns (Organ, 1992). However, when ultrasound was first used for cleaning the consensus was that little damage could be done, and the results were quite striking.

As research on ultrasound continued, however, it became clear how much energy was involved, even for short exposure. The phenomenon of energy delivery in ultrasound is caused by the application of oscillatory electrical energy on two metal plates, creating an electric field in which a crystal vibrates generating waves in a medium. If concentrated, this energy can result in such effects as the abrasion of small glass fragments off the walls of test tubes filled with distilled water (Abdulla 1988). Bursting bubbles in the ultrasound process collapse and an imploding shock wave results along with high temperature and light emission. Katz and Man (1978) have noted that ultrasound results in significant diagenic change in shell. Research has demonstrated that temperatures of up to 7,000 degK can be created by ultrasonic devices, and that collapsing bubbles produced in ultrasonic tanks can create holes in metal (Crum and Suslick 1995; Flint and Suslick 1991). Ultrasound can produce a specific chemical reaction known as aqueous sonochemistry (Suslick and Doktycz 1990), and can also induce unique chemical changes in non-aqueous solutions (Abdulla 1988). Ultrasound drives interparticle collisions, especially of metal particles at high enough velocities to induce melting on collision (Doktycz and Suslick 1990).

Ultrasound is deflected by low concentrations of fluid (Lin, Chou and Chang 2004) and this deflection may be the agency by which ultrasound effects the uniform distribution of moisture in a humidifier and of consolidant in a nebulizer. It has been found that ultrasonic nebulizers produce a drop size that differs significantly from other kinds of spray formation, like air sprayers (Shoh 1979) and airless sprayers (Fair 1984). Two influences seem to be involved with droplet formation, one is described by cavitation phenomena and the other, simplified wave theory**.** But explanations of the process are still subject to controversy. Nevertheless, it is apparent from experimental results that ejection velocity from the transducer depends on cavitation as droplet velocity increases with voltage and droplet size varies as well along an air/liquid interface of a wave front (Barreras, Amaveda & Lozano 2002) .

Bubbles identified as resulting from cavitation are seen in photographs of the process (Barreras, Amaveda & Lozano 2002: 407-409, Figs. 3-9). The atmosphere contains water molecules and a steamer produces a directed flow of moisture toward a target object. The application of ultrasound then has no boundary to prevent its passage. This is true of the degradation of propellers during cavitation produced by pressure and thrust (Anon. 2003), other bubble production and degradation effects as in film damage (Debregeas, de Gennes & Brochard-Wyart 1998) or of the use of ultrasonic scalers which act under the same principle (Drisko, et al. 2000). It has been demonstrated that microcracks appear under ultrasonic radiation as well as other damage to the tooth, dental work and gum tissue (Drisko et al. 2000).

### 4.2 Conservation Applications of Ultrasound

There has been a lot of conservation research into ultrasound both to investigate its potential for use in humidification, consolidation and cleaning, and to improve upon the working properties of the technique.

Still, evidence for the effects of misting via ultrasound is contradictory. On the one hand, Stephan Michalski (1998) argues that there will be no effect since there is no continuous film to carry the ultrasonic energy. Michalski quotes from a review by K.S. Suslick in the Encyclopedia of Chemical Technology (Suslik 1998) to support his interpretation. His references, however, do not cover the entire subject of energy-induced changes of ultrasound as reviewed here, but only some aspects of sonochemistry. This is a misinterpretation of how ultrasound works, but also a problem of emphasis. For example, Michalski states that ultrasound cannot be transmitted in air, and that air forms a barrier, an air/liquid one. However, neither of these assertions is true: ultrasound does travel in air (Petculescu & Sabatier 2004) and there is always some moisture in "air".

In response to Michalski's argument, it is worth asking what effect ultrasonic nebulizers and steamers have if there is no ultrasonic radiation. Is there any reason to use the more expensive device rather than one without ultrasound? Does the ultrasonic device add a quality that might be described as the "spooky action at a distance" discussed by Bell's Theorem (Herbert 1985). Is it magic? Michalski (Michalski, Dignard, Handel and Arnold 1994) discusses a number of applications for consolidants delivered by ultrasound, but the action of ultrasound is never explained. Michalski (1998) recommends that even if ultrasonic energy is involved, the mister transducer be a considerable distance (one meter) from any surface that is being treated. However, in the same article the authors state that a distance of only "a few millimeters from the surface" is required for the effects desired for the handpiece (Michalski, Dignard, Handel & Arnold 1994: 500). There is, therefore, a continuous ejection stream from transducer to handpiece and object, and the separation of this stream occurs at the mouth of the handpiece. The area in which Barreras, et al. (2002) observed bubbles is within 5 mm from ejection sprays. Since their experiments were limited to areas close to transducers it is not known at present if bubbles exist all along the stream. The design of the LDPE bottle with the consolidant (Michalski, Dignard, van Handel & Arnold, 1998:500) shows the bottle above the ultrasonic oscillator, so that the ultrasound must move through the plastic bottle to cause effects [2]. If a liquid contact is necessary, as Michalski maintains, how does the ultrasonic energy reach the consolidant and produce the mist effects? The use of ultrasonic nebulizers has found acceptance in medical contexts due to some delivery problems noted with pneumatic nebulizers (Hess 2000). However, their expense and more frequent breakdown (Hess 2000) and the possibility of drug inactivation (Gale 1985) make them less attractive. As heat is generated over conversion of ultrasonic energy to mechanical energy the transducer produces heat. Water couplant chambers are provided for most nebulizers (Hess 2000) to disperse this heat and one imagines that Michalski's water bath in which the bottle of consolidant sits (Michalski et al. 1998) has a similar function.

Some discrepancy exists between the comparison of effects in the use of ultrasonic humidifiers and nebulizers as reported by Arnold (1996). This may be due to the differences in apparatus and not in the droplet delivery potential of the two systems. Weidner (1993) has recommended a modified delivery method that provides the positive effects of ultrasound but avoids the possible exposure to elevated levels of ultrasonic energy. Nevertheless, the use of ultrasound in humidification and consolidation of powdery pigment produces very effective and desirable result. There is no doubt that the research and development of methods and materials by Michalski and his colleagues has greatly benefited the field, advancing the use of ultrasound greatly since the technique was first introduced by Organ; see for instance their research testing consolidants (Michalski & Dignard, 1997; Dignard, et al., 1997). However, the effects of use still need characterization. It is clear that the newer means of application allows for a substantial increase in control in the delivery of moisture and consolidant (Michalski, Dignard, Handel and Arnold 2002). Michalski and his colleagues have provided the bench worker with a substantial amount of direction in the use of ultrasound. Their apparatus is well designed and their cautions regarding overspray and health effects timely. The handpiece not only produces a variable spray that can be tailored to use, but attached to a vacuum it sucks back the mist that is not discharged directly to the object surface.

The experiments of Marilyn Kemp Weidener leading to the development of the suction and ultrasonic misting table (Weidner 1993) have been of great importance to the field of paper conservation. This achievement has advanced the treatment of fragile works on paper and paper-like supports. An additional benefit of her work is the complete reporting of her working method, which at times included problems in treatment design or the decision not to treat. Weidener also reports on a number of treatments using ultrasound that have been reexamined after several years and found to exhibit no reversal of staining, changes in coloration or physical conditions.

The ways in which sonochemistry and the physical aspects of the radiation affect paper, fabrics and cellulose in general are yet to be discovered and characterized. Timothy Barrett conducted a number of experiments in 1989 to describe and measured the ways in which papers were affected by exposure to ultrasound. A number of measurable changes in behavior were found. For example, when sized after irradiation, in chainline direction grain, higher in-plane and out-of-plane values, and again, associated with gelatin concentration. Zero span values were changed, though not greatly in all cases.

Bonnie Rose Curtin (1988), in experiments with ultrasound as a deacidification method, found variations regarding gelatin-sized papers in the pH achieved in washed and unwashed papers exposed to ultrasonic alkaline humidification. Also, the distribution of pH and alkaline reserve tended to vary slightly across a sheet of paper buffered with their ultrasonic method.

Barton & Wiek's experiments (1986) with feathers fibers showed that exposure to ultrasound in water had little effect on fiber condition or cleaning, but the use of solvents or additives produced drastic breakage in feathers, but less damage than that observed using a soft artist's brush and detergent. Cooke's experiments (1989) with textiles using a variety of additives and solvents, especially Industrialized Methylated Spirits (IMS) and Carbon Tetrachloride, demonstrated superior cleaning with little damage to the fabric (3.5% change in weight Use of water and detergents produced the release of soiling, but also size of the fibers and 22% of the original fiber mass became detached.

It is worth noting that this research has focused on studying the application of technique, rather than long-term effects of the treatment. For instance, in testing the changes different consolidants impart to powdery pigment, Michalski and his colleagues have essentially reproduced Debra Daly's 1978 experiments (Michalski & Dignard, 1997; Dignard, et al., 1997). Their findings that gelatin produces a durable adhesive bond, and is the best consolidant producing the least change, support her results. However, Michalski and his colleagues did not investigate Daly's (1978) conclusion that gelatin does not age well, and darkens considerably, which are problems in considering gelatin as a consolidant for many objects.

Understanding the inherent properties of original materials in an object brings up another aspect of long-term effects. Michalski et al. (1998) mention that individual pigments have different bonding requirements. They note that particles of green earth, red ochre and raw umber formed cohesive layers even though no binder was present and suggest that no consolidation may be necessary. They cite Grisson's analysis of one kind of green earth pigment . Mayer (1970) notes a number of variations of green earth pigment including a burnt green earth, a native clay colored by small amounts of iron and manganese, though there are a legion of varieties of burnt green earth. Michalski et al. report that other pigments such as calcium carbonate, chrome yellow, ivory black and ultramarine (the specific ultramarine is not given) "were found to be much more powdery". While "powdery" is a difficult term to quantify in scientific terms, a variety of physical and chemical characteristics can be used to group these pigments and their tendencies to adhere with and without binders. Ian Cook and Heather Mansell (1981) have characterized many of these pigments, and described their behavior in a number of solvents as well as consolidants. However, as Grubenmann (1993) has noted, there are a number of reasons why uniform responses to exposure to solvents cannot be expected. Nevertheless, while the immediate benefits and improvements to consolidation of fragile objects are obvious and well documented (Michalski and Dignard 1997, Michalski et al. 1998), the long-term effects are uncertain. It is not clear if color changes occur or if there is a long term benefit in adhesion.

Maheux and McWilliams (1995) note that in the use of the mister to consolidate flaking gouache paint, the size of some flakes reduced the effectiveness of the delivered consolidant and traditional methods were required to adequately adhere these flakes. It would be helpful to know the limitations of the misting process, and how large a flake can be successfully treated. Arnold

(1996, 2004) believes that the size of flake determines the success of consolidation with the mister approach. The use of a nebulizer to deliver more consolidant and reduce the wet/dry cycle, as well as the speed of application, simplicity and cost is appealing. This is especially true given the problem of over-spray error (due to both sprayer manufacture and operator error) that seems difficult to avoid

One aspect of the research of Michalski and Dignard is the use of the ultrasonic mister as a means of removing adhesives from fragile surfaces. Dignard et al.(1997) describe this method in detail on a work of art on paper with a suction table. But Michalski and Dignard (1997) note potential uses on other objects where tidelines and stains have developed. Dignard et al. (1997) have also suggested its use for reforming small areas of bloomed varnish and to allow for consolidation and correction of deformed surfaces. The ability to apply consolidant, humidity or solvents in localized and minute areas and structures gives the ultrasonic methodologies of Michalski and Dignard great utility over earlier methods such as tenting objects in enclosed areas.

## 5. Experiments with Ultrasound

Ultrasound cleans by the delivery of mechanical waves produced by the piezoelectric effect through a gas or a liquid to the surface of an object. Therefore, it was determined that both immersion and humidification were both valid techniques to investigate. It had become popular to humidify paper using an ultrasonic humidifier and to use such a device to deliver small amounts of pigment or consolidant. As Grattan has pointed out (Grattan 1989) thermally applied energy in one form (vibrational, translational or rotational) is redistributed to the others. This leads to a number of questions: What effects would ultrasound have on objects? Could these effects be quantified? Is it possible to observe such effects before damage was done? How much of the damage, if any, could be seen by an observer?

If objects are exposed to ultrasound through a medium like air or moisture, would the effects be visible? This would be more indicative of the power of the energy delivered instead of objects sitting directly in a solution exposed to ultrasound, as more power means more chemical action. Concentrated delivery of water in the form of steam involves the action of at least three kinds of energy: ultrasound, heat from the steam and the mechanical entrance of the water molecules into the substrate, this is a force and there is also the factor of a pressure created by the bubbles created by the ultrasound (McNamara, Didenko and Suslick 2003Published research suggesting that ultrasound can be destructive to all types of surfaces. This realization led the author to organize and carry out a number of experiments with ultrasound.

Experiments were conducted to determine some specific effects that might occur when ultrasound was used for humidification and mist delivery of consolidant. Both immersion and steaming were included (Caldararo, 1992). The results can be seen in Figures 17- 21. Samples of paper were prepared by typing text onto Strathmore 20% cotton fiber typewriter paper using a Brother Ax-22 electronic typewriter. Sample “A” (Figure 17) was the control with no treatment. Sample “B” (Figure 18) was soaked in de-ionized water for 10 minutes. Sample “C” (Figure 19) was exposed to steam from an Osrow Model SB hand fabric steamer for 3 to 5 minutes, enough time to saturate the paper with moisture. The steamer mouth was kept at least 3 to 5 inches from the sample to minimize heating. Sample “D” (Figure 20) was exposed to moisture delivered by an ultrasonic humidifier (Biotech BT-200) for 5 minutes. Sample “E” (Figure 21) was exposed to an ultrasonic bath in de-ionized water for 5 minutes using a Sonicor Model SC-105T, 50/60Hz cycles, at 1.5 amps.

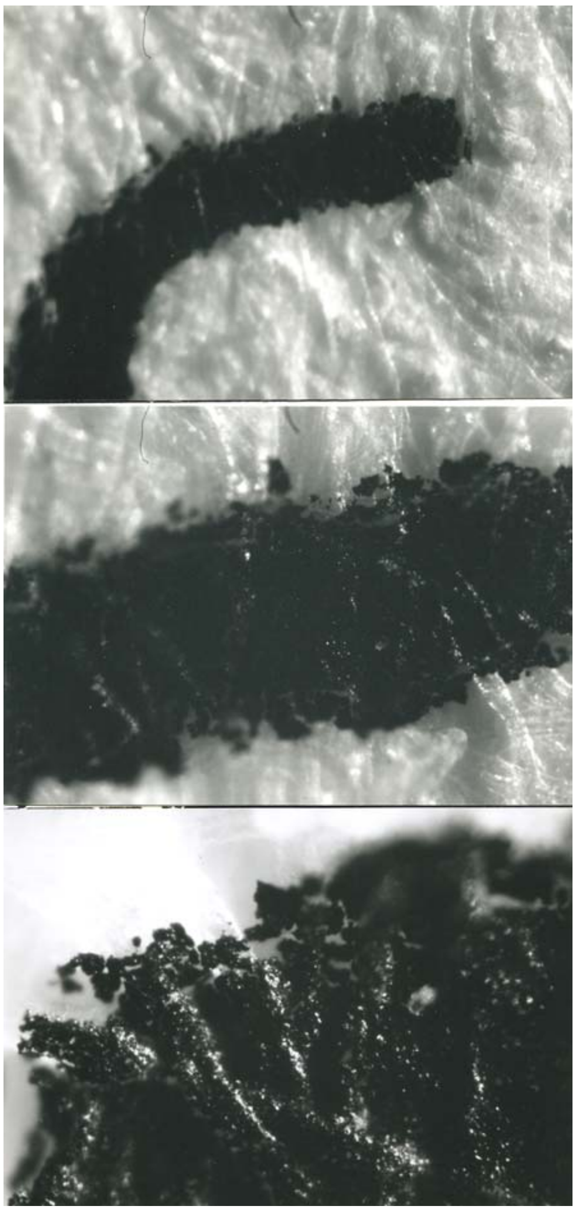

Figure 17. Paper sample ‘A’: control, no treatment. Top to bottom: 40x, 100x, 200x.

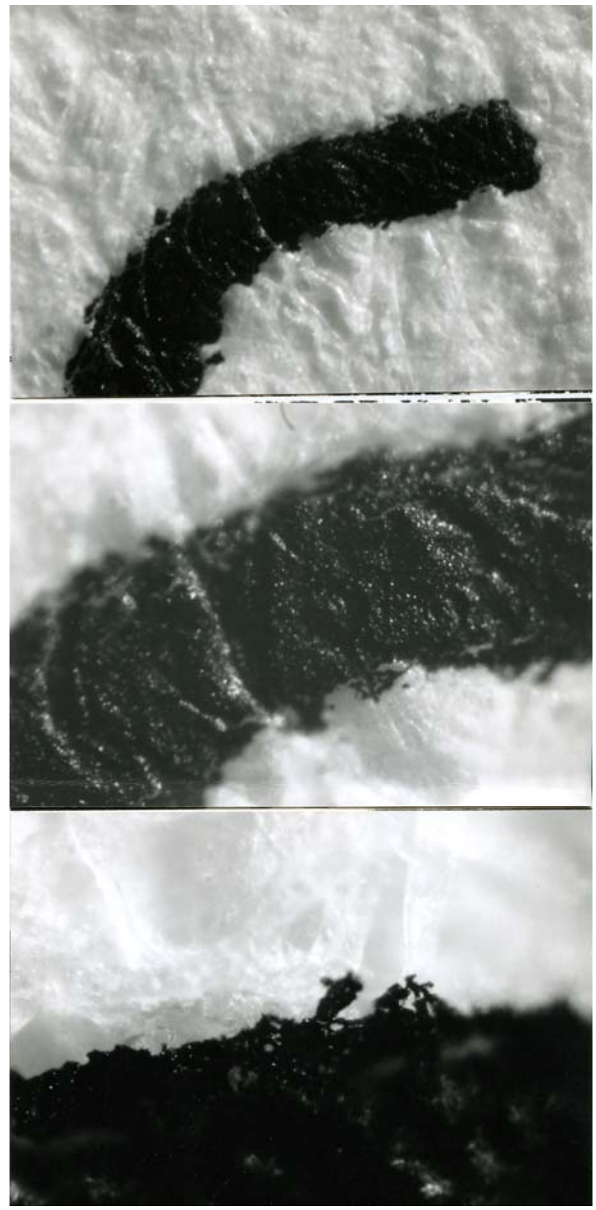

Figure 18. Paper sample ‘B’: soaked in deionized water, 10 min. Top to bottom: 40x, 100x, 200x.

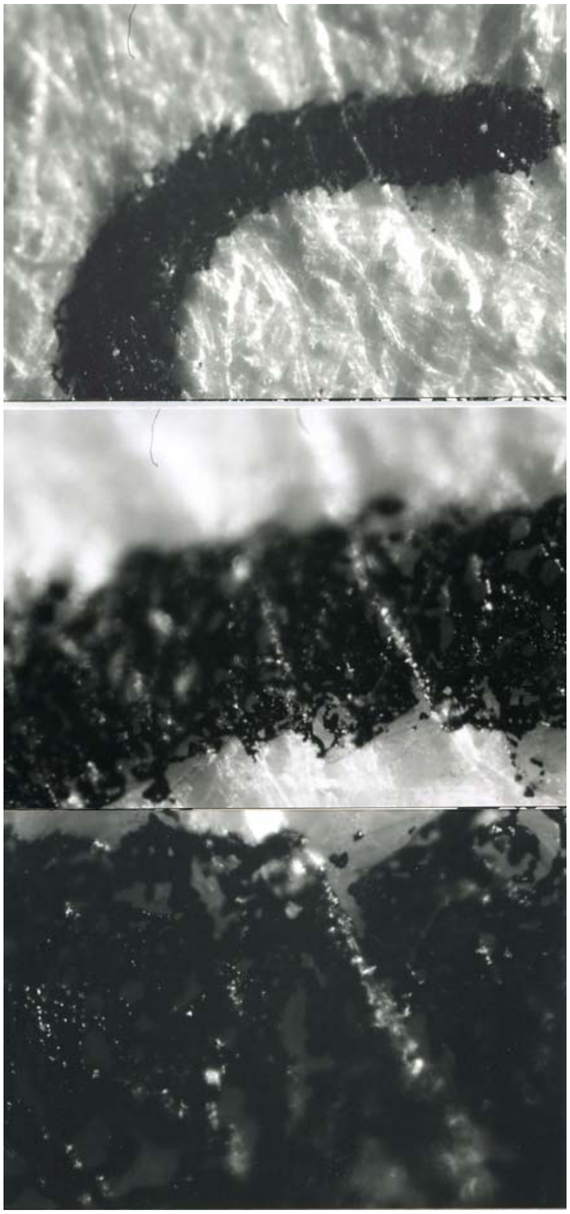

Figure 19. Paper sample ‘C’: exposed to steam. Top to bottom: 40x, 100x, 200x.

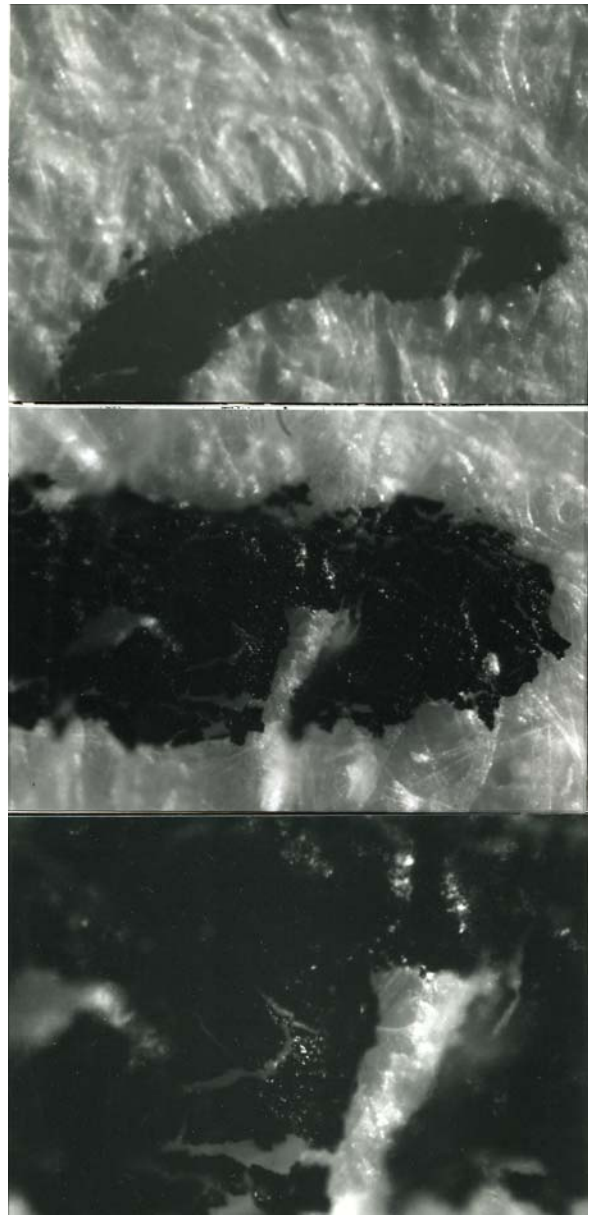

Figure 20. Paper sample ‘D’: Humidified by ultrasound. Top to bottom, 40x, 100x, 200x.

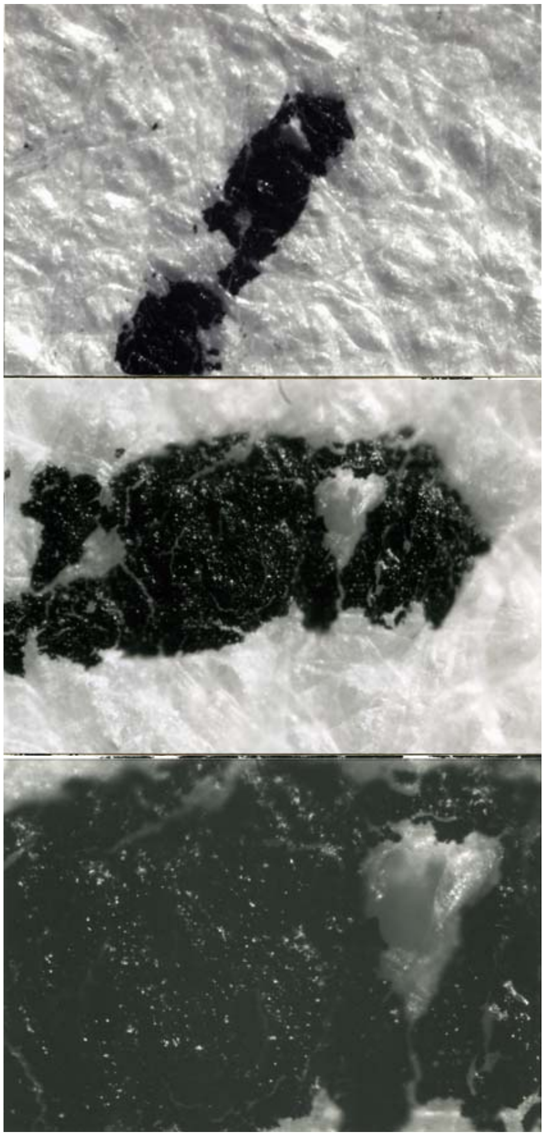

Figure 21. Paper sample ‘E’: placed in ultrasonic bath. Top to bottom: 40x, 100x, 200x.

Comparison of the results with the control showed that the letter matrix fragmented and fissured in the ultrasonic bath and less so under the direction of moisture delivered by the ultrasonic humidifier. Fiber movement is evident in all the samples compared with the control. The sample exposed to the steam humidifier demonstrated the kind of degradation seen when the type matrix is exposed to heat or solvent. Soaking samples in hot water did not have the same effect.

The fact that these procedures induce changes is not a surprise. To use the method with understanding it is necessary to know the magnitude of the changes, and whether they are appropriate and acceptable.

Many individuals use sonicators to clean fragile shells (Katz and Mann 1978). It is known that diagenic changes are induced by such exposure. The question is then whether they can be cleaned by any other means with less damage or change. If there is no other more satisfactory treatment, then should these objects be treated at all?

Can these results be applied to other objects and other contexts? Certainly when an object is immersed in a fluid it is subject to a greater degree of energy produced by the ultrasound, especially with regard to sonochemistry and other induced chemical changes and interactions.

## 6. Cleaning Goals: Surprises and Conflicts

Conservators in museums and in private practice must deal with the expectations of the owner or guardian of an object. Sometimes the goal of cleaning can change during treatment based on unexpected discoveries. In one case in the author's experience, the owner of a Maya sculpture requested analysis of a coating to determine if it should be removed. The object in question was similar in some regards to the one illustrated by Shimbunsha (1974: page, figure or plate number) but differed in surface texture and finish (Figure 22). As can be seen in Figure 23 the sculpture has a broken base that has been repaired. There is no published information or unpublished notes on this restoration or when it occurred. The figure was covered with what appeared to be original dirt from burial. Tests demonstrated that it was soil embedded in a resin-like adhesive, and a small area was cleaned to show the client. This cleaned area can be seen in the “lap” or bench area and was partly cleaned with saliva and turpentine (Figure 23; see Calderaro 2000 for complete results of examination and testing). The owner opted for a general reduction of the coating but not its complete removal (Figure 24). The coating hid a greenish toned stone which also had what appeared to be a crack that was filled with a paste. Throughout this process the owner continued to consult with dealers, museum curators and archaeologists in an attempt to find what should be the “restored” image.

Questions concerning the object revolved about several aspects of both the one treated by the author and the one illustrated in Shimbunsha (1974). What was the significance of the crack in both objects? Was the crack in the object treated by the author purposely introduced to mimic the image published in the catalogue, and if so, why was the crack subsequently concealed? While the discoveries from the examination proved disturbing to the owner, they can provide scholars with new information about objects and art history. The influence of catalogues and other publications on fakers has been discussed by the author in an article which compared the recently-treated object with that illustrated by Shimbunsha, as well as 52 other published images, some with archaeological provenance and many without (Caldararo, 2000).

Figure 22. Figurine illustrated by Shimbunsha, for comparison.

Figure 23. Figurine conserved by author.

Figure 24. Figurine treated by author, after cleaning.

## 7. Conclusion

One of the most obvious conclusions is that the development of new instrumentation over the past 30 years has allowed conservators to perceive the nature of interventions with greater clarity. The difference in what can be seen in terms of the effects of treatment is on a scale of magnitude comparable to the visual perception of the naked eye and SEM. But this really does not do justice to the changed situation. During the 1980 AIC meetings in San Francisco Caroline Keck came into the Conservation Laboratory at the California Palace of the Legion of Honor. She sat down and one of the first things she said was, "What's that thing here for?", as she gestured towards a new Nikon microscope on the lab table. "Trying to impress clients with science? That's the only reason most people have them!" The same comment appears in an important article on the future of conservation, published in 1980 (Keck, C. 1980). In many ways she was right, and yet the routine use of the microscope in conservation practice has increased dramatically in the past 30 years. Certainly there were microscopes available to many conservators 30 years ago and SEM was also being applied to conservation treatments, especially to evaluate treatments in paper conservation (Cook and Mansell 1987). But conservators have become much more sensitive to the micro level and more knowledgeable in how and why changes take place.

When Talley described the pressuring role of the Art Historian in conservation at the AIC Conference in Portland this year (Talley 2004), it struck a cord for many bench conservators. He pointed out that it is not so much that conservators have driven treatments, but that curators and owners have, and that our role has become nearly impossible by owing to two contradictory improvements: one in our perceptions of the effects of treatments and the other in new techniques to control and to limit those effects. We are more able to make changes and to make them imperceptible and yet know more precisely how significant they are than ever before. Like Sisyphus the nature of our work is impossible, we aspire to perfection and yet we are trained to see every imperfection.

## Acknowledgements

I would like to thank all the students who have worked in my laboratory while the projects mentioned in this paper were undertaken. I would also like to thank all the conservators and scientists who I have tormented with questions over the years. The kindness and goodfellowship which characterizes our field is a constant source of inspiration.

## Endnotes

1. Keel's (1963) pamphlet is valuable for a number of reasons, one of which is that it tells us what was recommended for use on objects for those museum and park service employees, local museum staff and university preparators in the 1960s and 1970s. For example, Keel (1963:17) recommends spraying Krylon on glass which has lost it luster. For other sources used by such workers during this period see Caldararo (1981).

2. Maheux and McWilliams (1995) note that the bottom of bottles in his position often become blistered and bubbled with prolonged use. They also mention that the use of solvents with the mister assembly can deliver solubilized components of the hoses and other parts of the apparatus. This should be quantified and verified by testing.

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