ARCHAEOLOGICAL CHEMISTRY: PAST, PRESENT, FUTURE

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Abstract

The ACS Division of the History of Chemistry (HIST) is the sponsor of possibly the largest and most comprehensive collection of volumes specifically on the topic of Archaeological Chemistry (AC) in the world. While it might be difficult to measure this content against other collections, the oeuvre consists of nine volumes published between 1974 and 2020. This paper will detail the past, consisting of the contents of the first seven volumes published between 1974 and 2007; the present, consisting of the contents of the last two volumes published in the second decade of the 21st century; and the future, consisting of projections and consultations with currently practicing archaeological chemists.

Introduction

"Archaeological chemistry is a topic which, when mentioned in a general public gathering, makes heads turn, eyes brighten, smiles burst forth and questions emerge" (1). This, the opening sentence of the most recently published HIST volume on archaeological chemistry, has held true for the entire 47-year history of this series.

The symposia, followed by volume publication, and held on average about every six years since 1973, have been co-sponsored by HIST's Subdivision of Archaeological Chemistry since 1974, although four other symposia (2) preceded those which are now contained in the nine published volumes attributed to HIST's direct sponsorship. Many of the subdivision's members are associate members, which means that they are not ACS members due to ineligibility, international status, or practice of a related discipline. But they come out in droves for this long-awaited event, lending a visibility and camaraderie to both HIST and to the ACS that can only be described as enviable. As a collection, the nine volumes have traced the development of archaeological chemistry from an emphasis on excavations, instrumental methods, and interdisciplinary coverage to an emphasis on cultural context, combined analytical techniques and statistics to interpret results and discoveries.

A Little Bit of History

"In the beginning" archaeological chemistry could be defined as the application of chemistry to archaeological materials. According to Oxford archaeological chemist A. Mark Pollard, the first published chemical analyses of archaeological bronzes in 1777 by Johann Christian Wiegleb (1732-1800) marks archaeological chemistry as one of the first disciplines to make use of gravimetric chemistry (3). This established relationship between archaeology and the analytical sciences continued with the work of Martin Heinrich Klaproth (1743-1817) who applied analytical techniques to the composition of some Greek and Roman coins. Other eminent scientists

Table 1. Summaries of the Prefaces of Volumes I through VII of the Archaeological Chemistry Series (1974-2007)

Volume	**Preface Summary**
AC I: 1974 C. Beck, Ed. (6)	AC is becoming a discipline in its own right. Data developed reveals patterns useful for determining context and meaning of archaeological data. It defines artifact analysis as the particular province of chemists.
AC II: 1978 G. Carter, Ed. (7)	AC is a maturing field showing signs of vigorous growth. Its avowed purpose is to "deduce history from the analysis and investigation of artifacts." It defines data reporting procedures, sample handling procedures, and standards definitions as areas to be addressed.
AC III: 1984 J. B. Lambert, Ed. (8)	This volume emphasizes how analytical instrumentation provides mainstream contributions to our understanding of archaeological artifacts and how advanced methods have made possible entirely new applications in archaeology, for example, to date objects as well as analyze them.
AC IV: 1989 R. O. Allen, Ed. (9)	This volume expands the field of AC to encompass not only a better understanding of the past, but also an ability to project a future. It also views AC as inherently multidisciplinary.
AC V: 1995 M. V. Orna, Ed. (10)	This volume emphasizes how coupling some instrumental methods in tandem allows for expanding the scope of the kinds of materials that can be examined as well as their increased sensitivity to ultratrace levels.
AC VI: 2002 K. A. Jakes, Ed. (11)	Emphasis in this volume is on nondestructive methods, ability to infer human behavior through analysis and new developments in age dating.
AC VII: 2007 M. D. Glascock, R. J. Speakman and R. S. Popelka-Filcoff, Eds. (12)	This volume continues the themes of the past six volumes, again putting emphasis on the broad interdisciplinarity of the field.

dedicated to the scientific examination of antiquities over the course of the 18th and 19th centuries were Humphry Davy (1778-1829), Jöns Jakob Berzelius (1779-1848) and Marcelin Berthelot (1827-1907) (4).

Shedding light on the past by means of scientific examination received great impetus when major museums began to establish laboratories for that purpose on their premises in the early 20th century. For example, the work of Alexander Scott (1853-1947) gave rise to the world-renowned laboratories of the British Museum. While museums were mainly concerned with examination of their own holdings, many university laboratories in departments of archaeology, anthropology and chemistry found ample work by examination of materials from excavations worldwide. The modern field of archaeological chemistry arose during the first 30 years following World War II as a result of the development of instrumental methods of inorganic analysis which made it possible to cultivate new areas in archaeological chemistry. However, the task of the archaeological chemist has become more complex than ever over the past half-century. Gone are the days of trying to answer the simple questions of "what?," "when?" and "where?" At one time, archaeological chemistry may have been considered the domain of analytical chemists turned "amateur archaeologists." However, effective work in this area demands being attuned to the increasingly multidisciplinary nature of the field along with the necessity of advanced instrumentation, ability to handle and interpret large databases of information and meaningful collaboration among many different kinds of workers (5). In the final section of this paper, we will hear directly from eminent practicing archaeological chemists as to how they perceive the future of this developing discipline. But first we must take a peek at the past and the present as discerned from the contents of the HIST AC collection.

Archaeological Chemistry Past

Admittedly, each of these volumes was a snapshot of what was going on in an emerging field at a particular moment in time. As such, we are dealing with a very small

Table 2. Subject Matter by Chapter Addressed by All Nine AC Volumes (1974-2020)

Subject Matter	**I 1974**	**II 1978**	**III 1984**	**IV 1989**	**V 1995**	**VI 2002**	**VII 2007**	**VIII 2013**	**IX 2020**
Number of Chapters	13	20	22	27	31	15	28	23	18
Number of Pages	254	389	487	508	459	259	571	472	509
Perspectives, General, Techniques	2	5			4	4	6	7	1
Role of Chemists in AC				1					
History of AC								1	
Educational Applications									3
Building Materials, Minerals, Materials Science							3	3	6
Ceramics, Glass, Pottery	4	4	4	4	2	5	7		
Colorants, Inks	1		3		3	1	1	4	6
Diet Analysis						1			
Fibers				5	7				
Isotope Analysis, Dating								3	
Lithic Materials, Soils, Residues, Bone, Shell	1		6	3	10		3	5	
Metals	5	5	3	7	3	1	5		
Nucleic Acids Analysis					2				
Organic Materials		6	6	7		3	3		2

slice of a very large pie and therefore, any conclusions drawn must necessarily be taken with a grain of salt. The topics addressed reflect the specific interests of the participants. Taken together, they may not represent the entire body of archaeological chemists.

One way of getting a taste of each volume is to read the preface which gives an overview of the discipline and at the same time summarizes the work in the individual chapters. Table 1 presents précis of the first seven of the volumes which, altogether, describe "Archaeological Chemistry Past."

From the content of these prefaces, it is possible to discern an evolution from an emerging to a mature discipline with a clear direction regarding subject matter, interpretation, methodology, and interdisciplinary nature. What becomes apparent from the preface of volume VII is that the growth in self-knowledge of the discipline has become asymptotic—tapering off to repeat the themes of the past.

By analyzing the chapter content of all nine volumes, as given in Table 2, although again with the caveat that this is a very small sample size, we can come to some more tentative conclusions.

Archaeological Chemistry Present

From Table 2, it is possible to discern a nearly clean break between the first seven volumes in the series and the last two volumes. There is an ongoing interest in artifacts comprised of ceramics, glass, pottery, metals and organic materials that falls sharply to zero after 2007. On the other hand, the final two volumes in the series expand into materials science, place greater emphasis on colorants and inks, and for the first time we see isotope analysis and dating the subject of three full chapters in volume VIII (although this was an ongoing subject in the previous volumes, but only peripherally). Thus, we might say that the 2013 and 2020 volumes represent Archaeological Chemistry as harbingers of the Present. Within the "present," we also see the history of archaeological chemistry and educational applications

Table 3. Subject Matter by Grouped Topics Addressed by Two International Symposia on Archaeometry (ISA) in 2016 and 2018 (inclusive of oral and poster papers)

Symposium	**41st: 2016 (13)**		**42nd: 2018 (14)**	
Subject Matter	**Number of papers**	**% (n=447)**	**Number of papers**	**% (n=268)**
Stone, Plaster and Pigments	102	21.8	68	25.9
Ceramics, Glazes, Glass and Vitreous Materials	127	27.4	63	22.9
Metals and Metallurgical Ceramics	102	22.2	59	21.9
Archaeochronometry	36	7.6	22	8.1
Human-Environment Interactions	53	13.2	42	15.5
Remote Sensing, Geophysical Prospection and Field Archaeology	21	5.1	14	5.7
From Bronze Age to Iron Age	6	2.7		–

addressed for the first time. At the same time, we recognize that the perceived break between Volumes VII and VIII represents a shift in the interests of the symposium participants and possibly an artifact of small sample size, but not necessarily a decline in interest in the traditional artifact groupings by the more universal archaeological community. Indeed, if we examine the subject matter addressed in Table 3 for two recent international symposia on archaeometry for which complete data were available, we get a more complete picture.

From Table 3, we can see that interest in all areas was quite similar with a slight rise in stone, plaster and pigments and a slight dip in ceramics. Almost all of them reflect the interests shown for the first seven of the HIST volumes with the exception of field archaeology and Bronze Age to Iron Age transition. This is to be expected given that archaeological chemistry and archaeometry are not exactly identical: archaeological chemistry is the subset of archaeometry in which chemical analytical methods are applied to the study of archaeological artifacts, not necessarily the entire battery of scientific measurement techniques. The important point is that the HIST volumes are not outliers in the general topics covered in these recent international symposia.

By breaking out the specific analytical techniques used in all nine volumes, we can come to an even greater insight regarding the perceived break noted in Table 2 moving into the 2010-2020 decade. Although 58 instrumental techniques were used in the nine volumes, those enumerated in Table 4 (n = 17) are those that were used more than twice.

It is easy to see that MS, FTIR, XRD and XRF continue to be the workhorses right up to 2020, whereas NAA, one of the principal methods used up until 2010, fell away. At the same time, methods not necessarily used, but very much discussed for the first time in the Armitage/Burton (2013) and Orna/Rasmussen (2020) volumes, are: counter immunoelectrophoresis (CIEP), enzyme-linked immunosorbant assay (ELISA), fiber optic reflectance spectroscopy (FORS), forensic photography, hyperspectral imaging spectroscopy (HIS), polymerase chain reaction (PCR), portable hand-held devices, radioimmunoassay (RIA), Raman spectroscopy, surface enhanced Raman spectroscopy (SERS), and short-wavelength infrared spectroscopy (SWIR). There are numerous other methods not even touched upon, but these seem to be the ones that may carry AC forward. However, our best insight into the present state of AC can be gleaned from the prefaces of the final two volumes, as given in Table 5.

Note that these two statements, the present state of affairs, have shifted the emphasis on instrumentation and artifacts to different considerations that had not been possible previously: *in situ* and non-destructive analyses using the appropriate equipment, new kinds of questions regarding space, chronology, materials and culture, and how to handle growing amounts of data in these areas. We would be remiss if we did not include the questions raised by the 12 papers in the special issue of *Accounts of Chemical Research*, 2002 (17): artifact methods of manufacture, material sources, degradation and conservation, and extraneous information to be derived from buried remains. The situation will shift again and, indeed, we can almost sense the seismic activity already underway among practicing archaeological chemists. The next section will query some of them with respect to what they see is the future of archaeological chemistry in

Table 4. Number of Times (>2) Specific Analytical Techniques Were Used in the 9 Volumes

Specific Analytical Techniques	**I: 1974**	**II: 1978**	**III: 1984**	**IV: 1989**	**V: 1995**	**VI: 2002**	**VII: 2007**	**VIII: 2013**	**IX: 2020**
Atomic absorption spectrometry (AAS)		2	5	1					1
C-14 dating		1	1	2	5	1			
Electron microprobe analysis (EMA)					2	2	2	1	1
Electron spin resonance (ESR)				1	2	1	1	1	
Elemental analysis (wet)		1	2		4				1
Fourier transform infrared (FTIR)			1	2	2	2	1	3	2
Mass spectroscopy (MS) and Gas chromatography mass spectroscopy (GC-MS)			1	2	5	2	1	7	3
Inductively coupled plasma-MS (ICP-MS)					2	1	8	1	1
Neutron activation analysis (NAA)	5	4	7	7	4	1	5		
Nuclear magnetic resonance (NMR)				1		1			1
Polarized light microscopy (PLM)			3		1	1	1	3	
Scanning electron microscopy (SEM-EDS)			2	3	1	1	2	5	
Stable isotope analysis	1	2		2	2	2	2	4	
Ultraviolet-Visible (UV-Vis) spectroscopy		1			1			1	1
X-ray diffraction (XRD)			2	1	2		2	3	6
X-ray fluorescence (XRF)		1	3	3	1	2	6	12	6

terms of methodology, treatment of archaeological sites, examination of archaeological artifacts, interdisciplinary interests, perspectives, evolutionary trends and cultural implications, to name a few (18).

As part of the present situation, Pollard observes that

> increasingly into the mid-20th century, we have been given a large set of legacy data, of varying quality archaeologically and chemically. This is something that current and future archaeological chemists need to come to terms with including the following options: (a) Ignore and use only "modern" data—this discards a large number of data, and is unlikely to be possible on any meaningful scale or (b) Adjust the nature of the question to the quality of the available data. I actually believe that some of the "legacy" datasets are the best quality analyses that we have, but obviously only for major and minor elements since the technology to measure trace elements came later. The large samples taken (inconceivable now) means that heterogeneity issues are minimized (unlike laser ablation techniques), and the self-checking of the analytical total is absolutely priceless—again, often not independently provided now.

Robert Tykot adds:

> There will always be limitations on the actual context of the artifacts analyzed (and many may not even have a context, but from surface or other finds), AND limitations on elemental analysis due to which elements were analyzed/reported and how the results are calibrated (and whether [they] can be directly compared with other studies).

Whither Archaeological Chemistry?

In 1996, and again in 2008, **A. Mark Pollard** and **Carl Heron** asked the question that is the title of this section (19). Where, indeed, did they see the science of archaeological chemistry going? First, in 1996, they

Table 5. Summaries of the Prefaces of Volumes VIII and IX of the Archaeological Chemistry Series (2013 and 2020)

Volume	Preface Summary
AC VIII: 2013 R. A. Armitage and J. H. Burton, Eds. (15)	AC "today is more than the usual studies of trace elements in pottery and lithics, which continue to contribute to our understanding of human behavior in the past. New areas of research include more focus on portability to analyze pigments *in situ* and artifacts in museums, nascent developments in non- and minimally destructive chemical characterization, new applications of isotopic analyses, and an increasing interest in archaeological biomolecules."
AC IX: 2020 M. V. Orna and S. C. Rasmussen, Eds. (16)	AC's "traditional fields of interest—matter, time, and place—have been transformed due to different kinds of questions about the past that modern methods of scientific examination are in a position to shed some light on. Enhanced capabilities, for the most part multidisciplinary in nature, have revealed the limitations of confining archaeological investigations to chronological, spatial, and material areas without also considering the cultural context, the power of combined analytical techniques, and the ability of chemometrics to handle large databases to help interpret results."

named a present reality: the availability of good quality, albeit expensive, analytical facilities. But laboratories are not the whole answer to the future of AC since they noted that emphasis would fall into the world of ideas, not practical matters. Good ideas come from good and relevant questions, from intelligent interpretation of results within a sound theoretical framework, leading, hopefully, to the better integration of archaeological chemical data. They also said that chemistry will have a very important role to play in materials conservation since it will be the chemists who will be best situated to understand the mechanisms of corrosion and strategies to mitigate its effects. Another future consideration would be the changing policies of the relevant local authorities with respect to handling the preservation of archaeological sites and artifacts, and the legal ramifications arising from such policies. For example, many countries have substituted policies of "preservation by burial" as opposed to excavation of archaeological sites.

In 2008, Pollard and Heron (20) continued their analysis by naming the three areas that have had the greatest impact on the archaeological sciences in the past 100 years: dating techniques, provenance studies, and studies in human diet, nutrition, status and mobility. They feel that these applications will steer the future direction of archaeological thinking. In addition, understanding material culture, but harmonized with other studies of social and cultural context of archaeological problems, promises to be a very useful area of investigation for the archaeological chemist. They frame the real restrictions to good AC in terms of the quality of thinking rather than practicalities, requiring careful construction of relevant archaeological questions and intelligent interpretation of results within a sound theoretical framework. Finally, as excavation sites are increasingly threatened by development, archaeological chemists will need to concentrate on studying deterioration mechanisms of archaeological materials and understanding of contextual variations leading to strategies for their control—a potentially political as well as scientific issue. They finish on a hopeful note: "the archaeological demand for qualified archaeological chemists or archaeologists with considerable chemical knowledge has never been greater."

Figure 1. *Bust of Queen Nefertiti excavated from Amarna. Treated as an archaeological object, the iconic headdress was found to have been painted with Egyptian Blue, calcium copper tetrasilicate. Public domain.*

Williams College archaeological chemist, **Anne Skinner**, asks a further relevant question regarding sites and burials: what about the existing controversy on whether to leave a portion of any site unexcavated, so that subsequent investigators can determine things not accessible now? Of course, she observes, this does not apply to the multitude of sites being excavated in advance of destruction, although there, perhaps, some samples could be archived.

Another important area of concern is the contemporary effort to broaden the number of people working in the field. Involvement of the local population and local archaeologists has been varied depending upon the perceived importance of archaeology to non-archaeologically attuned scientists in a given country. Skinner says that currently archaeologists (and many others), are being encouraged to involve people from the countries being studied, not just as laborers in the field but also as professional colleagues who lead projects. Many countries often do not have state-of-the-art facilities but the work being done is worth a hearing. She pointed out two *New York Times* articles that addressed these issues. One refers to efforts to "decolonize" archaeological field efforts by involving the local population from the beginning in terms of consultation, jobs, decision-making regarding the fate of artifacts and respect for the local culture (21). "Decolonization" also varies from country to country; presently, about half a dozen South American countries are carrying out their own scholarly work in excavations and artifact analyses, and many countries limit the removal of artifacts from their territories. The other *NYT* article addresses a similar question but delves more deeply into problems like squabbling over turf, overstretching conclusions from minimal data points, and the danger of "imperializing" archaeology. Specifically, the issue is the continuing improvement in instrumentation and methodology to allow more precise analyses, perhaps on smaller samples and new materials. This very fact will continue a move towards centralization of labs since these new instruments are not cheap, either to purchase or to run, leading to significant fees for users. In some cases, they require great skill in order to obtain optimum results. However, these centralized labs then may end up controlling what work is done. Only those who can afford the charges and whose work interests the operators will have access. More seriously, those who cannot use these high-quality labs may find that they are unable to publish their work (except, of course, in predatory journals), because reviewers will ask to see the "better" data. An example of the perfect being an enemy of the good, as they say (22).

Another issue regarding "decolonization" was the established pattern beginning in the 18th century for European scientists to transport their colonies' natural treasures to deposit them in museums in their home countries. An example is shown in Figure 1. In 1912, the exquisitely painted limestone bust of Nefertiti was excavated at Tell el-Amarna and promptly packed off to the Staatliche Museen zu Berlin. "Legal" or not, Nefertiti became the focus of a growing national outrage at what was perceived as foreign exploitation and appropriation of Egyptian heritage (23). There are many equally famous examples of what many now regard as plunder permanently ensconced in museums far from their origin. The Rosetta stone and the Parthenon sculptures come immediately to mind—with all of the legal ramifications attached thereto. What if the home countries demanded restitution of these artifacts and how would the possessors respond? We already know some of these answers. There may be many more issues to address in the future.

I have direct experience of an event that took place in Israel that addressed this problem front and center. Following the June 1967 so-called six-day war between Israel and its three adversaries, Jordan, Syria and Egypt, Israel's archaeologists moved into its vast newly occupied territory in the Sinai and began a major excavation program that ended in 1982 when the Sinai was returned to Egypt. They investigated over 1300 hitherto untouched archaeological sites that lay beneath the sands and unearthed thousands of artifacts including pottery sherds, jewelry and tombstones. Cataloguing, dating and analyzing this trove took decades and was still not complete by December 28, 1994, which is where I come into the picture. I spent a Fulbright year in Israel (1994-1995) and was invited to the December event, a reception at the Rockefeller Archaeological Museum in Jerusalem, to honor the Egyptian archaeologists who had come to receive back their artifacts as a condition of the peace treaty between Israel and Egypt.(24, 25). Although it took two more years to effect the transfer, under the terms of the treaty, it took quite a few more years for the artifacts to find disparate homes in Egypt. One of these sites was at Al-Arish, about 30 miles west of the Egypt-Israel border where a national museum was built in 2008 to, admittedly, simply "warehouse" the artifacts (26). The second is the Museum of Taba City on Pharaoh's Island where over 700 of the Sinai artifacts are on display and are touted as a major tourist destination (27, 28).

University of South Florida archaeological scientist **Robert H. Tykot** weighs in on the major technological advances and changes in the practice of archaeological material studies that have taken place in this millennium.

> Separate from advances in the study of ancient DNA, stable isotope analysis, proteomics, and drones used for 3D mapping, light detection and ranging (LiDAR), NIR, and other remote sensing, I see the ability to conduct non-destructive elemental analysis using hand-held portable X-ray fluorescence spectrometers (pXRF) as having the greatest archaeological chemistry impact on archaeology. It has specifically enabled analysis of objects within museums and storage facilities around the world, saving destructive sampling, transport, and international permission, while providing rapid and low-cost yet quantitative analysis of major and trace elements. Starting in 2007, I personally have used this on more than 10,000 obsidian artifacts from 300 sites throughout Italy, allowing statistical comparisons between sites and time periods (29). I have also used pXRF on objects that could never be destructively sampled, including museum display metal artifacts (e.g. copper alloys, silver/gold alloys), ceramics, cave paintings (in situ!), and other cases (30). The "educated user" can properly calibrate the results, and deal with surface analysis interpretations, just as with regular XRF and SEM-EDS users have done in the past. While even the latest pXRF models (I have the Bruker 5g) are not a substitute for regular XRF, or ICP-MS or INAA instruments (all producing results for more elements), which either require powder samples or a small object to fit in the machine, the ability to take samples for analysis outside of museums and especially from foreign countries has decreased significantly. This is a result of political and institutionalized management of museum and other past collections, the increased importance of conservation on museum collections (see the unfortunate event of the major national museum fire in Brazil in 2018 (31)), and the scientific limitations of non-destructive pXRF poorly understood by non-scientist museum officials. Nevertheless, I expect the development and use of pXRF and other non-destructive analytical instruments to increase even more in the future.

Another area of study that has expanded considerably in the past several decades is stable isotope analysis of human remains as a means of studying ancient diets, explains Tykot. In his recently published encyclopedia article (32), he outlines the principles, methodology, data that can be obtained, and future directions for this approach. Some of the chief issues currently being addressed are early hominin dietary practices, Mesolithic-Neolithic dietary changes, migration and mobility, dietary practices based on gender or on social status, and the importance of staple foodstuffs like maize and millet in different populations. Future directions will include expanding the number of elements used to study diet and methods to decrease even further the sample size necessary for analysis.

Following up on Rob Tykot's analysis, Professor **Ian C. Freestone** of University College London Institute of Archaeology makes four important points:

- "Synchrotron techniques need to be used more constructively to address real problems. For example, we have used X-ray absorption spectroscopy (XAS) to determine oxidation states of Fe, Mn and so on but the results should be calibrated against replica compositions run in gas-mixing furnaces to determine… conditions of firing" and ultimately, quantitative phase compositions of ceramic bodies and glazes.
- "The identification of small production groups or production events can enable an understanding of production organisation (e.g., The work of Martinón-Torres on the weapons of the Terracotta Army (33)) and the recognition of sets and consignments so we can understand how artefacts were procured (e.g., work we have done on glass)."
- "While we are aware that metals and glass were recycled it is challenging to determine the relative intensity of the recycling process…[so it might be] possible to come up with some qualitative indicators… [of] assemblages and societies." (34)
- "On the instrumentation front, we need development of portable laser micro-sampling of artefacts as a routine approach so it can be used in the field and samples taken back to the lab for isotopic and elemental analysis."

Zvi Koren, Director of the Edelstein Center for the Analysis of Ancient Textiles and Related Artifacts at Shenkar College, Israel, muses on the role of color in AC, among other things:

> What I would like to see in the future of archaeological science and conservation are approaches that would be truly interdisciplinary. Of course there are the "regular" ideas such as developing and improving non-destructive testing (NDT) of various pigments, dyes, and other non-colorant residues (food, drinks, cosmetics, etc.) What truly fascinated me about 15 years ago when I first saw it in the Istanbul Archaeological Museum was a colorful recreation of a tall statue of a Greek or Roman woman… This was a colored image of what the statue may have looked like when it was first created according to the artist that rendered this image.

(Author's Note: The statue was the Peplos Kore as Artemis reproduction of an original from the Athens Acropolis that is part of a traveling exhibit called "Gods in Color" from the Munich Glyptothek. Figure 2.)

***Figure 2**. Peplos Kore as Artemis (ca. 530 BCE) Polychrome Restoration. Wikimedia Commons (https://commons.wikimedia.org/wiki/File:NAMABG-Peplos_Kore_as_Artemis.JPG).*

> The big picture is this: For quite a while now, archaeologists, museum curators, conservators, and scientists realize that many of the Greek and Roman and much older statues that today have a practically white and colorless appearance when quickly looking at them, were originally colored/painted. A close inspection of some of these statues, even with the naked eye, one could still see residual pigments. Obviously with some magnification more colors may become apparent. Hence, the scientists would scan the object with a non-destructive technique, such as XRF, in order to identify these pigments, and also, if needed, micro-sampled in a minimal invasive method, then the pigments would be identifiable. Now the conservation artist can take over and propose an image of how the statue first appeared. This image (of course not needed to be the full size of the statue) would be placed next to the statue to get a "wow" moment of the grandeur of that artistic work.
>
> In my museum visits I often go right up to the object, if allowed, and visually look for these "nearly invisible" colorations and have seen them on various pieces, including Assyrian sandals on the long stone reliefs in the British Museum. These are not quite 3,000 years old and amazing to see. I would love it if these would be studied, and offer an artistic rendition of what they looked like. Many other such cases exist.
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> But not only statues, of course, but structures, buildings too. For example, during a family hike, we came to an ancient synagogue (possibly about the 5th century CE) in *Ein Keshatot* ("Spring of Arches") in the Golan. There was an earthquake in this area so that all the stones of the synagogue came tumbling down and since there were no major villages nearby, practically all the synagogue's stones were still present at this site (and not carried away for secondary usage). This synagogue was excavated and reconstructed with advanced technological methods by scanning each brick and digitally putting the stones together as one giant 3D puzzle. (That is another interesting method for future archaeological conservation and preservation.) But my main point is when I inspected the reconstructed Holy Ark, on its columns you could still see residual blue rings at the top and bottom that decorated the 2 columns. I haven't seen that reported on and like many other sites, it would be wonderful to analyze that and the rest of the Ark's structure.

Scientific Director of the Biomolecular Archaeology Project at the Penn Museum, **Patrick McGovern**, summarizes much of what has already been said with a global spin on a science that has evolved in mini-steps with its eyes literally on the ground (and underneath it) to capture and then analyze artifacts:

> Archaeological Chemistry or Biomolecular Archaeology is the "wave of the future" in archaeology. By rigorously applying ever more precise chemical and archaeological techniques, this nascent, highly multidisciplinary field, blending together the humanities and sciences, holds out the prospect of uncovering much more of what it means to be human biologically, medically, and culturally over the past 4 million years and more. Optimistically, we might envision a "new history of humankind" eventually being written. This prospect was adumbrated in this writer's 1995 "Science in Archaeology" piece (35) and, most recently, in the updated Afterword to his *Ancient Wine: The Search for the Origins of Viniculture* (36). Ancient viniculture exemplifies how Archaeological Chemistry can be integrated into a holistic investigation of a truly remarkable plant and its product intertwining itself with human culture and technology around the world."

Joseph B. Lambert, archaeological chemist at Trinity University in San Antonio, is concerned for the professional future of AC in the United States. He says that here,

> future directions for archaeological chemistry largely will follow the money. The field is well funded and active in Europe, especially England, and Asia, but there is no stable, major, external funding in the United States. Consequently, the field tends to be an avocation for individuals at major universities or a focus for individuals at liberal arts colleges and other places where outside funding is not the driving force. The most successful models in the United States are museum laboratories and archaeology programs. Both venues have long invested in archaeological technology (dating, prospection, and elemental/molecular analysis). The Getty and the Smithsonian have excellent programs, and other museums also are very productive. Noreen Tuross is Landon T. Clay Professor of Scientific Archaeology at Harvard, and Nikolaas van der Merwe preceded her in a similar position there. Douglas Price, now retired, established the Laboratory for Archaeological Chemistry at the University of Wisconsin Madison and was elected to the National Academy of Sciences for his archaeology and archaeological chemistry in 2018. They attracted strong funding for archaeological chemistry and carried out significant research in the field over a long period of time. All three are primarily archaeologists rather than chemists and represent the model that will be most successful in the future for making broad contributions to the field.

Similarly, Heather Lechtman at MIT has been a major influence in the development of archaeology and archaeological chemistry for over half a century. The Center for Materials Research in Archaeology and Ethnology, established by Lechtman in the late 1970s, has produced a large cadre of science-oriented archaeology faculty.

Mark Pollard, having raised the question of "whither," gets the penultimate word:

> [L]ooking forward, some things are obvious. The big change over my career is that when we started we often had to build the equipment ourselves—I started at York and Oxford by building an XRF system, and writing a computer programme (in Fortran!) to carry out the necessary primary and secondary absorption corrections. We are now, for better or worse, largely in the hands of the instrument manufacturers—very few innovations are made specifically for archaeological/cultural heritage purposes—perhaps the last was the combined XRF/XRD for pigment analysis on paintings and manuscripts.
>
> This is good and bad. It is good because we have available an amazing range of analytical and isotopic tools—many are too expensive for archaeological labs to purchase, but usually access can be arranged. The downside is that they have become black boxes—not just pXRF, but, for most instruments now, it is very difficult to find out what the processing software is actually doing. This is not necessarily a problem providing that great care is taken with primary and secondary standards, but this is rarely done, and even more rarely reported. The explosion of pXRF is a particular issue—it has "democritised" analysis, but can produce unhelpful results. The key question for me is what is the analysis done for—is it to answer a specific question (e.g., is this coin gold or electrum, etc.), or is it intended to produce an analysis of record, which can be used by others? pXRF is probably best suited to the former in most cases.
>
> There are now methods of analysis available archaeologically which were undreamt of in the 1970s. Examples especially are in the field of organics—compound specific isotopic methods, proteomics, etc. These open up new fields of research—I am particularly interested in the potential for copper corrosion products to retain organic evidence from vessel use—which requires some knowledge about organometallic chemistry.
>
> Another good thing is that archaeology now has a good number of trained chemists working within it. When I started, the model for "archaeometry," at least as expressed by Martin Aitken (1922-2017) (37), was to get a "trained scientist" and a "trained archaeologist" to work together. This distinction has largely gone in archaeology, with some trained scientists working *within archaeology*—I think this is important, because, with the best will in the world, we have seen too many specialisms arise in science departments as a result of individual enthusiasm, only to disappear on retirement. There is always a place for specialised collaboration, but I think mainstreaming chemistry into archaeology, at least to the level of "informed consumer" has been a good achievement—albeit with the potential for people stepping outside their competences occasionally!
>
> I have a bit of a bee in my bonnet about the distinction between archaeological science and heritage science. Both focus on the examination of artefacts (ranging from trace deposits to landscapes), but the intentions are quite different. At least in my definition, archaeology is about people—the analysis of objects is a stepping stone to understanding the activities and intentions of people in the past. Heritage science is about objects—it includes manufacturing techniques, but also includes conservation, restoration, presentation, etc.
>
> For me, the measure of success in archaeological chemistry is the extent to which the work changes the archaeological narrative—a good example would be the earlier appearance of milk in the archaeological

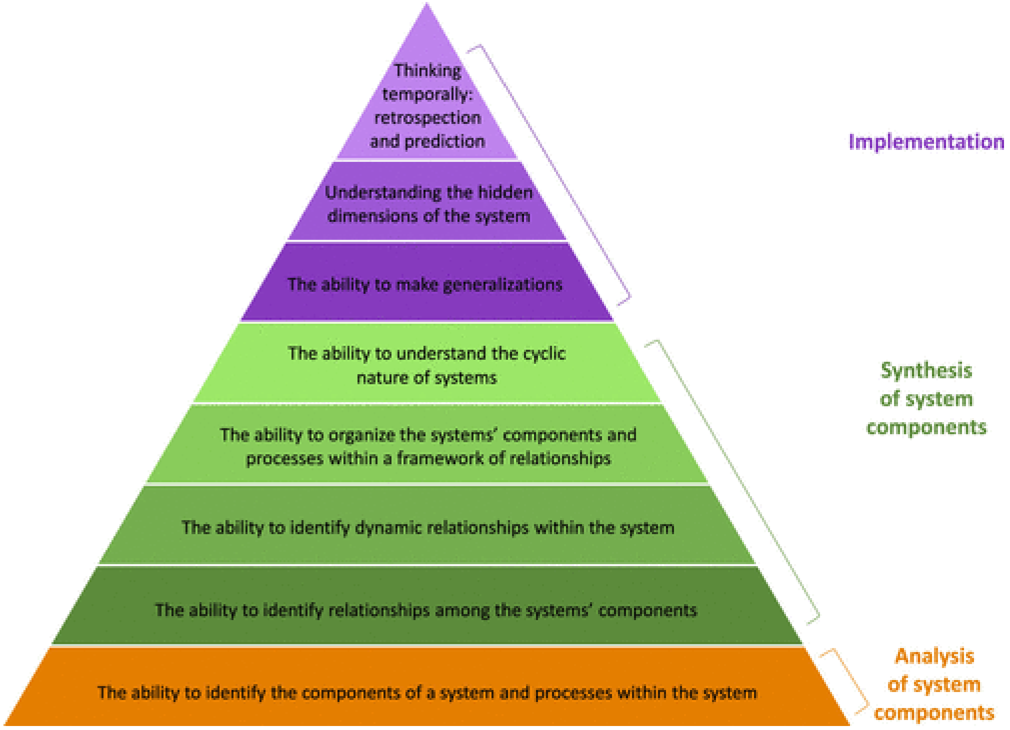

Figure 3. *Systems Thinking Hierarchical Model Pyramid from Ref. 40, https://pubs.acs.org/doi/10.1021/acs.jchemed.9b00169. Used with permission. Copyright 2019, American Chemical Society. Further permission related to the material excerpted should be directed to the ACS.*

> record than had otherwise been expected, but there are many others. I think I am more interested in the quality of the question than the sophistication of the chemistry applied, although it is clear that novel chemistry can allow old questions to be revisited, or new questions to be addressed.

Conclusion

As the author of this essay, I reserve for myself the last word. Throughout the speculative and hope-filled contributions of the distinguished archaeological scientists whom I queried, our eyes were lifted to the heavens to visualize a future that transcends material objects in order to include meaning, culture and context. This future is, in fact, inevitable given the greater complexity of techniques that drives the formerly simple questions of "what," "when," and "where" into areas like human modes of operation, environmental conditions, and other concerns. These factors have shifted chronological, spatial and material limitations to another level. For example, in addressing the question of time, the archaeologist turned novelist Karin Altenberg remarks, "The exploration of the past is an exercise in empathy, a way of becoming conscious of what it is to be human in another time and place" (38). There was a time when archaeology was all about finds, i.e., artifacts that had shouldered their way into the present. Now it is all about the absence that emerges from our examination of the artifact: what are the blanks that have to be filled in? Is the instrumental arsenal at hand enough, or do we need additional tools and information? Pollard hinted at how the existence of some of this information in the form of legacy databases could help. Are we finding ways and means of writing a new history of humankind, as conjectured by Pat McGovern? What happens to our science when we begin to be all-inclusive, as examined by Anne Skinner? Does broadening out lead to dilution or to enrichment? Any archaeological object is like a two-sided coin: a part that has passed and a part that remains. The part that remains can be queried about its role in the past. The part that has passed remains shrouded in mystery unless, bit by bit, the context for its fabrication and use can be pieced together from external evidence (39).

All of these questions cry out for a paradigm shift in our practice of the discipline. We are being called to reverse our gaze, to zoom out from the discipline-bound outlook of the past to embrace a more holistic view of archaeological chemistry and its intimate connection with a network of societal systems. The entire issue of the

Journal of Chemical Education for December 2019 was devoted to examining this possible U-turn (view-turn) with respect to chemical education. Such thinking invites us (a) to visualize the interconnections and relationships among the parts of a system, (b) to examine how behaviors and attitudes change over time and (c) to examine how systems-level phenomena emerge from interactions among the systems' parts (40). Acknowledging that archaeological chemistry is inherently multidisciplinary has not helped much in moving us completely out of our individual silos. A helpful graphic representing an analysis, synthesis and implementation of system components that are common to virtually every discipline (Figure 3) might enable us to discern where we are on the pyramid.

Making us aware of and appreciating the continuous presence of the past in our lives is a work-in-progress of the archaeological chemistry community. Becoming more aware of the global nature of that presence may be a way forward toward realizing that more complete and inclusive new history of humankind that we all desire.

Acknowledgments

The author is indebted to all of her interlocutors for sharing their insights and expertise in the realization of this paper, and particularly to the two referees and the co-editor, Carmen Giunta, for their invaluable help and advice. Special thanks go to Rob Tykot for providing some hard to get references and for his suggestions that rounded out the material presented.

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