Ge-conservación
Conservação | Conservation

Conservation of archaeological copper alloy artifacts from Al Ain National Museum collection: the role of desalination

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Abstract: Al Ain National Museum is in the city of Al Ain, within the Emirate of Abu Dhabi, United Arab Emirates. This museum preserves an excellent collection of copper alloy archeological objects from different archeological sites around Al Ain all dated from the Neolithic era. We have observed a high concentration of chloride salts in most objects, which favors their corrosion. We conjecture that this may be the case for most sites located in arid zones near the coast.

This paper aims to highlight the desalination treatments used during the conservation project of these artifacts. Desalination was the central treatment to achieve their stabilization and to promote their preservation for as long as possible. While the B70 desalination system has proven to be quite effective; salts still remain on the objects. Therefore, relative humidity and temperature monitoring are required to avoid variations that could reactivate sealed chlorides inside the objects.

Keyword: Copper alloy, stabilization, chloride, passive layer, minimal treatment

Conservación-restauración de las colecciones arqueológicas de aleación base cobre del Museo Nacional de Al Ain: la importancia de la desalación

Resumen: El Museo Nacional de Al Ain se halla en la ciudad de Al Ain en el Emirato de Abu Dhabi (Emiratos Árabes Unidos). Este Museo preserva una importante colección de objetos neolíticos de aleación base cobre procedentes de diferentes yacimientos localizados en las cercanías de la misma ciudad. Durante el proceso de conservación-restauración de las piezas, se notificó la presencia acusada de iones cloro en la mayoría de los objetos procedentes de los ecosistemas áridos cercanos a la costa donde se encontraron.

Este artículo hace hincapié en los procedimientos de desalación realizados durante el proyecto por ser fundamentales para alcanzar la estabilización de los objetos garantizando su preservación por el mayor tiempo posible. El proceso conocido como B70 ha resultado ser efectivo a pesar de no eliminar todas las sales de los objetos, lo que exige un control de los parámetros ambientales para asegurar la salvaguarda de las colecciones.

Palabras clave: Aleación base-cobre, estabilización, cloruro, capa de pasivación, mínima intervención

Conservação-restauração das coleções arqueológicas em liga de cobre do Museu Nacional de Al Ain: a importância da dessalinização

Resumo: O Museu Nacional de Al Ain localiza-se na cidade de Al Ain, nos Emiratos Árabes Unidos. Este museu preserva uma importante coleção de objetos arqueológicos neolíticos em liga de cobre provenientes de jazidas localizadas na periferia da mesma cidade. Durante o processo de conservação e restauro das peças foi detetada a presença de iões cloreto na maioria dos objetos oriundos de ecossistemas áridos da zona costeira onde foram encontrados.

Este artigo reforça a importância dos procedimentos de dessalinização realizados durante o projeto por se revelarem fundamentais para se alcançar a estabilização dos objetose assim uma preservação mais duradoura dos mesmos. O processo conhecido por B70 foi eficaz apesar de não eliminar a totalidade dos sais dos objetos, o que exige um controlo dos parâmetros ambientais para se assegurar a salvaguarda das coleções.

Palavras-chave: Liga de cobre, estabilização, cloretos, camada passivante, intervenção mínima

Introduction

Restoration and conservation works are not novelty in United Arab Emirates. In fact, Al Ain National Museum holds reports dating back to the 1970s about conservation applied during that decade by French and German cultural conservators –restorers at this Museum. However, no conservation reports from this institution have been published, despite the great historical value and technical quality of the treated artifacts.

Al Ain Oasis displays remnants dating back to Late Stone Age and settlements from the Neolithic until present, though not in the Late pre-Islamic or Late Antique periods, which is relatively rare in the Arabian Peninsula and may reflect its favorable location at the foothills of the Hajar Mountains, with available water and copper sources (Yildirim and El Masri, 2010; Powers, 2015). The relevance of these settlements has prompted an active conservation policy (Muhamad and Chabbi 2013).

Copper objects are particularly important for the reconstruction of the pre-history of Arabian Peninsula (Magee, 1998) as well as elsewhere (Paterakis, 1999). Accordingly, a conservation project was conceived concerning copper alloy objects at Al Ain National Museum, with the primary goal of stabilizing the artifacts and later protecting them for display or storage. Mineralized organic materials were also present in the objects, especially in daggers and knives handles.

Copper alloy objects are particularly sensitive to corrosion, because marine aerosol provides a rich source of chloride, which is abundant in the Al Ain soil. Therefore, desalination was an essential process for the metal conservation and its preservation over time (Logan 2007).

Contrary to widespread belief, copper chlorides do not participate directly in the corrosion process, which is electrochemically driven (Tait, 2012), but they precipitate as highly soluble salts, which are highly hygroscopic. The presence of these salts favors the condensation of water at relative humidity levels well below saturation. Condensation of water leads to brine films, whose high ionic strength favors the dissolution of Cu and other metals and electrochemical redox processes. This has been long understood by the archeologists and archeological conservators (Scott, 1990, 2002). The problem is particularly severe at coastal areas such as those in the Arabian Peninsula where there are high marine aerosol loads combined with a moderate relative humidity during the day, which can increase (higher than the deliquescence humidity of chloride salts) during the night. These conditions favor copper corrosion (Lin and Frankel 2013).

The archaeological science literature is rich regarding metallic objects treatment (Dillmann 2014). Cleaning, inhibition, consolidation, adhesion, reintegration or protections are common procedures in the field of metal conservation. Treatments include laser (Diaz and Garcia 2015), cryogenic cleanings, electrolytic reductions with potentiostats, gaseous plasma, bioprotection (Joseph, 2012) or nanotechnology (Faraldi, 2017) to get punctual and less aggressive cleanings over the metal surface.

However, dechlorinating is poorly addressed in publications related to the metal conservation field and data about this topic is quite scarce. Some of the published works highlight the cleaning of the objects and the metal finishing, inhibition or protection directly without previous desalinations (Pasíes 2005).

Specifically, salinity stabilization methods such as the B70 system (also known as Thouvenin method) (Bertholon and Relier 1990) or the Organ method (Organ, 1977) are the standard, but their effectiveness and limitations are rarely discussed. Chlorides vaporization by the use of laser through the artifact surface is also a common process. Sometimes this procedure is adopted for copper alloys along with 2-amino-5-mercapto-1,3,4-tiadiazol (AMT) (Ganorkar 1988), because this product can be used both as an inhibitor and a dechlorinator. Desalination is also frequently performed by immersion in deionized water where electrical conductivity is measured in order to calculate chloride concentration.

We think that the lack of literature favors the absence of adequate treatment protocols for the desalination phase. Nevertheless, this treatment is the longest and the most important when it comes to the conservation of archaeological metals. In fact, previous treatments performed on few objects have hindered the effectiveness of the treatment, probably due to lack of knowledge about active corrosion.

This paper aims to highlight the achievements within the conservation process of the archaeological artifacts from Al Ain National Museum collection, with emphasis on desalinization procedures. We think that this can be an adequate solution for the more critical problem of coastal areas in arid countries such as the Arabian Peninsula, than in other environments.

Materials and methods

—The artifacts and the local conditions

This conservation project concerns copper alloy objects displayed inside the showcases 140, 141, 148, 151 and 152 in the Archaeological Room at Al Ain National Museum. These objects come from Qattara dated in 1800 B.C.; Hili North and Garn Bint Saud dated in 900-600 B.C; and Rumailah dated in 1000-500 B.C. In addition, a number of relevant objects located in the Archaeological warehouse inside the Museum were also included in the project.

These artifacts come from Qattara dated in 1800 B.C. and Hili garden, dated in 2400-2000 B.C.

Al Ain environmental conditions are characterized by a moderate relative humidity (average 60%) and high temperature (27ºC) throughout the year. While these average conditions appear to be good for metal preservation, daily temperature fluctuations cause significant increases in relative humidity. Thus, even though the climate is generally dry during the day, relative humidity is generally above 75% (at which point water condensates on NaCl crystals) during the night. Furthermore, the soil where the objects were once buried is rich in mineral salts, especially iron salts and chlorides, mostly coming from marine aerosol and groundwater evaporation at the oasis. As mentioned in the introduction, chloride salts are known to favor corrosion, albeit indirectly, and are thus an undesirable for metal preservation.

During this conservation project [1] 95 copper alloy archaeological objects were restored, 38 during the first phase, 24 during the second phase and 33 during the third phase [table 1].

Artifacts were generally in fair condition; most of them were complete and still contain a high percent of metal core. The objects' surfaces were usually covered by dust, inorganic deposits, and concretions belonging to the burial environment where the objects were excavated. Artifacts showed physical damage such as scratches, fissures and fractures due to their utility in life and/or their burial environment. Bumps are also common due to the chlorides presence. A few of them were fragmented as well.

Corrosion products deformed the artifact's surface. The most common precipitates in corrosion layers were copper oxides formed by cuprite (Cu2O) visible as red-brown and, less frequent, tenorite (CuO) typified by black. A large range of carbonates was also frequent. As possible compounds that can be found, we emphasize malachite $Cu_2CO_3(OH)_2$ green, and azurite $(Cu_3(CO_3)2(OH)_2)$ blue among the most common. Oxides and carbonates form a passivation layer or "patina", a natural protective cover that protects the metal core against deterioration agents. Unfortunately, chloride salts were quite frequent. Several different types of chlorides were found, such as nantochite (CuCl), which is waxy and grey and paraatachamite $((Cu^{2+})_3(Cu\ Zn)(OH)_6Cl_2)$, a green-blue powdery deposit that causes pitting corrosion.

In addition, few artifacts exhibited old conservation treatments, such as over cleanings, adhesions and protective layers made by thermoplastic or thermostable resins painted in order to imitate metal colors. Volumetric reintegrations made with colored epoxy resins and acrylic paint coatings covering the surface were also frequent. Paradoxically, over cleaning may have been predominately responsible for active corrosion on the objects. Weapons

Table 1.- Copper alloy artifacts restored during three campaigns.

ARCHAEOLOGICAL SITE	MUSEUM LOCATION	OBJECTS
1st conservation phase		
Qattara tomb 1800 B.C.	Showcase 141	17 Swords
		6 Daggers and knives
		9 Spearheads
Hili North 2200-2000 B.C.	Showcase 140	6 Spearheads
2nd conservation phase		
Qattara tomb 1800 B.C.	Archaeological Storage	2 swords
		1 knife
		1 Dagger
		1 spearhead
		7 bracelets
		2 rings
Hili 8 2200-2000 B.C.	Showcase 151	1 Axe
Garn Bint Saud 900-600 B.C.	Showcase 151 and 152	2 Spearheads
		4 Swords
		3 Bowls
3rd conservation phase		
Rumailah 1000-500 B.C.	Showcase 148	4 anklets
		1000-500 B.C.
		2 farm tools
		1 needle
		2 dagger
		1 chisel
Garn Bint Saud 1000-500 B.C.	Showcase 148	6 arrowheads
Qattara tomb 1800 B.C.	Archaeological Storage	3 rings
		2 bracelets
		3 arrowheads
		3 swords
		1 spearhead
		2 rods
Hili garden 2400-2000 B.C.	Archaeological Storage	1 razor

from Garn Bint Saud or anklets from Rumailah settlement are a good example of this undesirable condition. In these cases, old cleaning processes removed passivation metal layers exposing artifacts' metal cores to the deteriorating agents for long time (Diaz and Garcia 2011).

—The conservation process

The present treatment consisted of the following steps:

1) In the absence of a database, a conservation report datasheet was created for each object to document all the information regarding the conservation treatment. This report contains relevant information to identify each artifact inside the Museum, as well as the object condition (type of surface deposits and corrosion, corrosion products identification, old treatments and physical damages) and treatments proposal (conservation procedures and products).

2) Once the artifact condition was known and treatment had been decided, each object was photographed; this documentation register involved the production of general and details photos before and during all the conservation phases until the end of the procedure.

3) Prior to cleaning, a number objects were pre consolidated with acrylic resins because of the fragility of some areas. Traces of mineralized wood or probably bone or horn badly adhered to the surface and fragile borders, which could not support a mechanical cleaning, were also consolidated in order to avoid their loss.

4) Furthermore, qualitative chemical analyses were performed whenever any doubt came up about the nature of corrosion products. Accordingly, samples were often taken and put it in contact with acid drops to identify the corrosion products throughout spot tests before the cleaning procedure.

5) The cleaning consisted in removing dust, inorganic and organic concretions from the object's surface. The process started with dry mechanical systems: scalpels, brushes and micro drills helped by wet mechanical methods. Whenever more attention was required, the process was done under microscope to avoid scratching or removing important areas such as wood remains. Samples of organic components, sand or corrosion products were saved often in polyethylene bags for possible future analysis.

Objects showing old treatments like adhesions and protective coatings were treated by the total or near-total removal of the old glue and acrylic resin layers. Mechanical procedures were supported with heat specifically to remove these treatments.

6) Once the cleaning was finished, the objects were desalinated. This is probably the most important step to reach the metal stabilization and guarantee their future protection.

The stabilization of chloride salts is essential to achieve this goal. Details are explained below.

B70 system consists in the application of two baths; the first one (90% methanol + 6.8% deionized water + 3.2% ammonia), removes chlorides [figure 7a] and the second (90% methanol + 10% hydrogen peroxide), forms an oxide layer on crops holes [figure 7b]. The procedure is repeated several times before testing its effectiveness in the humidity chamber.

The process known as the Organ Method consists in mechanical removal of the chlorides (paratachamite) and introducing silver oxide mixed with ethanol into the outcrop holes. Then, objects are placed in a humidity chamber for 24 hours in order to form silver chloride, a stable component.

Almost half of the objects presented active corrosion inside the fissures and under bumps on their surface. The process began with several baths following the B70 system when the chloride concentration was very high. However, if the concentration of these ions was low, silver oxide was applied in the outcrops

The desalination success was determined by inspecting them under a microscope after removing the objects from the humidity chamber to verify the presence of active chlorides (paraatachamite). When new outcrops appeared, the desalination process was repeated until stabilization.

7) Once the artifacts were stabilized, the inhibition process was performed. Inhibitors are substances that help to preserve metals stability by inhibiting and delaying the formation of corrosion products (Cano and Lafuente 2013). Inhibition was done in a dynamic warm bath (60ºC) of benzotriazole in ethanol.

8) After inhibition, metals were protected with an acrylic warm resin bath (40º C) diluted in an aromatic hydrocarbon.

9) When the objects were fragmented, fragments were bonded. Adhesion involved the application of an acrylic resin with an organic solvent. When a structural adhesion was necessary, a thermoplastic resin was used and a previous protection of the fragments borders with an acrylic resin was made.

10) Volumetric reintegration was considered in just one case (3877/402) because structural adhesion to support a fragile and fragmented area was needed. The volume reintegration was carried out with color putty composed by a thermoplastic resin and natural pigments and, once again, the artifact borders had been previously protected with an acrylic resin.

11) Finally, a warm coating of microcrystalline wax diluted in an aliphatic hydrocarbon was applied in order to ensure that the metal surface became water-repellent and to remove the brightness caused by previous treatment.

12) Once the conservation process was finished, objects were placed inside of museum showcases with silica gel and vapor-phase corrosion inhibitors for an appropriate preservation. Artifacts that could not be displayed at the moment were conveniently stored in the Museum's archaeological storage. These objects were wrapped in polyester sheets and placed in high-density polyethylene foam with the objects shape. Additionally, this foam is filled in polyethylene hermetic containers with silica gel for an optimal metal conservation.

For optimal preservation, metals were stored in an environment where temperature is around 20 ± 2ºC and relative humidity parameters no higher than 35-40%. Additionally,the protective coating system may require lower light levels, between 150-200 lux with a radiation component of less than 75 m W / lumen and restricted display periods (Diaz and Garcia 2015).

— Desalination

As mentioned, copper alloy object desalination is an essential process for its proper preservation; however, it can be long and tedious. The main reason is the high chlorine ions concentration on the objects, which requires countless repetitions of procedures, particularly in case of the artifacts that were previously over cleaned.

The desalination protocol evolved two desalination systems: the Organ method and the B70 system.

The Organ method was used occasionally on objects that showed very specific outcrops. Its use was limited because it leaves silver compounds remains (Martinez 2016) and black coloration on the artifact surface, despite of its usefulness.

On the other hand, the B70 system was most commonly used on objects that maintained a high concentration of chlorine ions, and showed good results. The treatment was repeated several times according to the active corrosion evidences on the artifacts before testing its effectiveness in the humidity chamber.

During the third conservation phase, stainless-steel containers were used to improve the effectiveness of B70 system. These containers allowed to make warm dynamic baths in an atmosphere without oxygen, increasing the effectiveness of the treatment. Moreover, most of the baths were individual for each object and each B70 bath was measured with the conductivity meter at the end of the procedure.

In those circumstances where stabilization was more complicated to achieve, the B70 system and the silver oxide method were combined. Firstly, the B70 system was performed several times as usual, and later silver oxide was added in those most vulnerable areas before testing the treatment effectiveness in the humidity chamber.

— Results and discussion

The main goal of this paper is to highlight and to evaluate dechlorinating treatments carried out during three conservation phases. Simultaneously, the effectiveness and the harmlessness of desalination systems have been evaluated and improved as well as the damage these processes could cause on these artifacts.

Throughout the first phase [figure 1], artifacts stabilization was more complicated than initially expected because of high salts concentration. The Organ Method previously used, was inappropriate since its recurrent use could produce silver chloride visible as dark spots on the artifacts surface. Consequently, the B70 system began to be used with good results. Once the treatment was finished, its effectiveness was tested in the humidity chamber.

During the second phase [figure 2], the same B70 bath system was applied with good results except for those objects over-cleaned before that required more immersions. In those cases whenever stabilization became quite difficult (more than 25 baths) to achieve, B70 system was complemented by Organ Method but with a smaller number of applications than in the first phase.

During of these two phases, an post validation of the stability thought the humidity chamber test was performed. Therefore, those artifacts treated under the B70 system procedure were grouped in plastic containers, where the treatment was repeated intuitively before testing its effectiveness in the humidity chamber test. Despite the successful stabilization of metals this chloride removal procedure was not very precise. Furthermore, it required the submission of artifacts to the humidity test without a proper knowledge of chloride concentration of the baths. This test presents a high risk for these kind of metal objects due to their vulnerability to such high relative humidity ranges.

Regarding to the third phase, we aimed to solve the problem of introducing objects into the humidity chamber without proper knowledge of the chlorides concentration. Besides, we already knew those objects over-cleaned before were more difficult to stabilize, so we also tried to improve dechlorinating effectiveness as well. So that, individual baths were carried out, mostly for the objects in the hermetic stainless-steel containers. The duration between each bath was 30 minutes with an initial transparent coloration. As immersions were repeated, the first bath (90% methanol + 6.8% deionized water + 3.2% ammonia) color turned increasingly blue because of its saturation. Therefore, a new solution was necessary to keep the baths effectiveness, particularly with those objects that were recently treated. These objects needed a change of the solution more regularly than those that had not been restored previously since their stabilization was more problematic. Moreover, after each bath, the conductivity was measured. All baths carried out were recorded in a data table indicating their conductivity as well whenever a change of solution was made according to the bath saturation. The results obtained during the third phase are shown in figures 3 and 4. These graphics include measurements of each B70 bath. The compilation of these data was useful for determining the optimal time to test the objects in the humidity chamber avoiding unnecessary damage.

Those objects that did not contain chlorides after finishing of the cleaning process were additionally tested in the humidity chamber as a preventive measure, mainly because similar objects from the same archaeological sites presented chlorine ions on their surface before or during the conservation procedures.

— *Statistic study of desalination treatments during 1st phase*

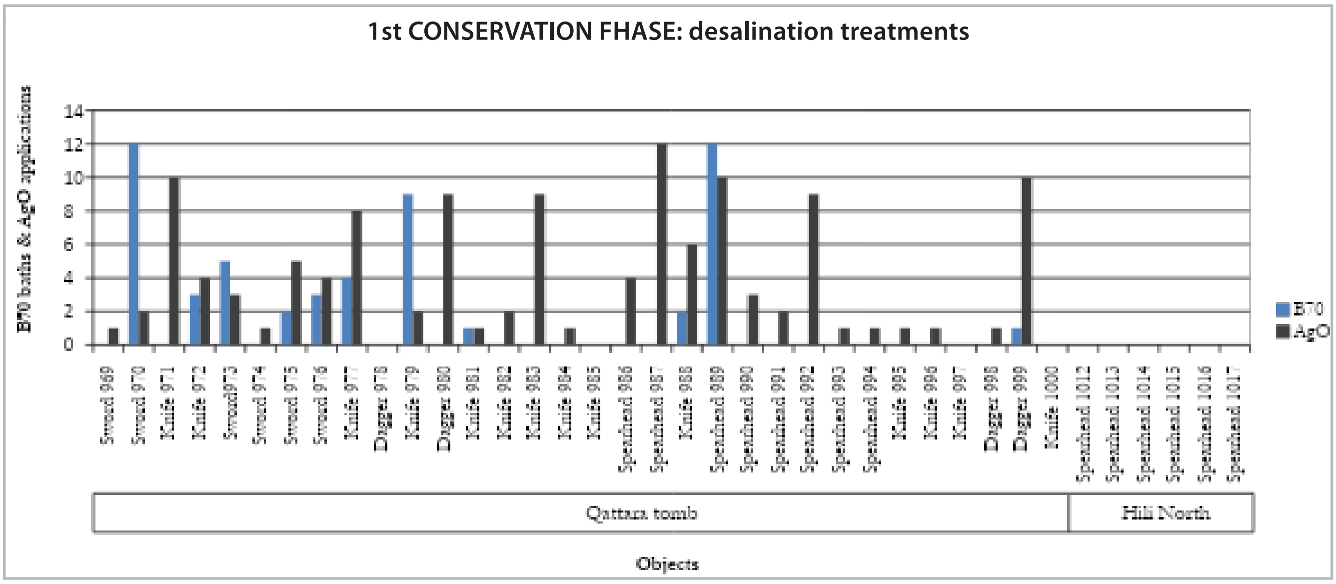


Figure 1.- Desalination progress of some artifacts from Qattara tomb and some over cleaned artifacts before from Hili North.

— *Statistic study of desalination treatments during 2st phase*

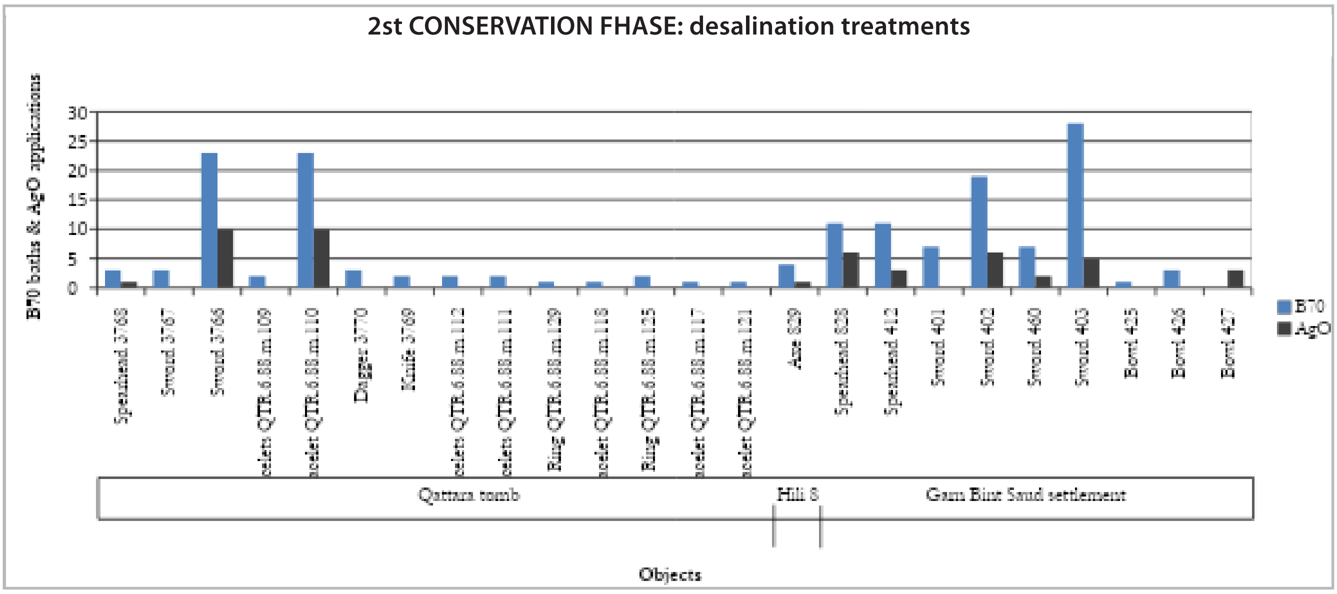
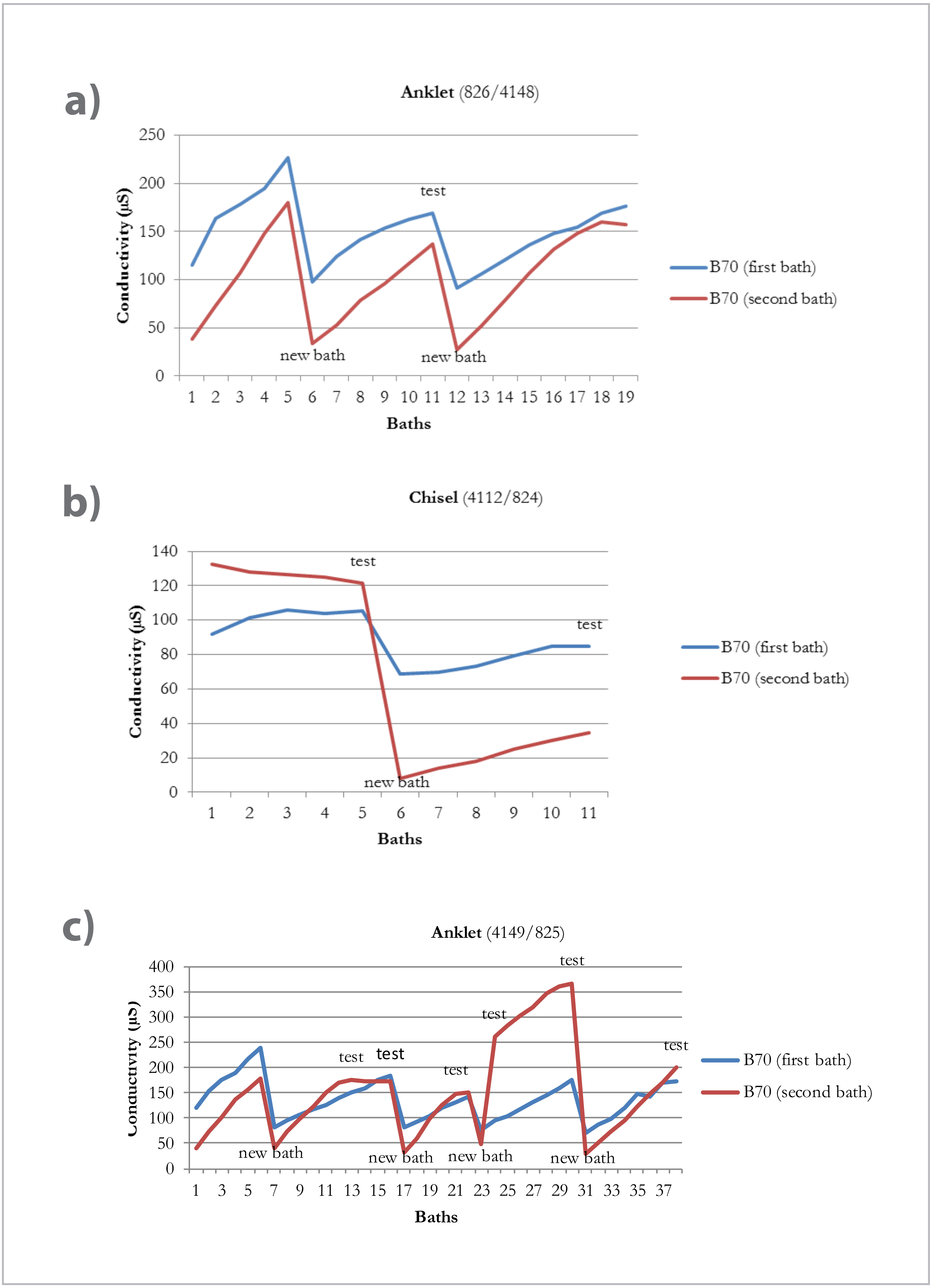


Figure 2.- Desalination progress of some artifacts from Qattara tomb and some over cleaned artifacts before from Hili North and Garn Bint Saud settlement.

— *Statistic study of desalination treatments during 3rd phase* [2]



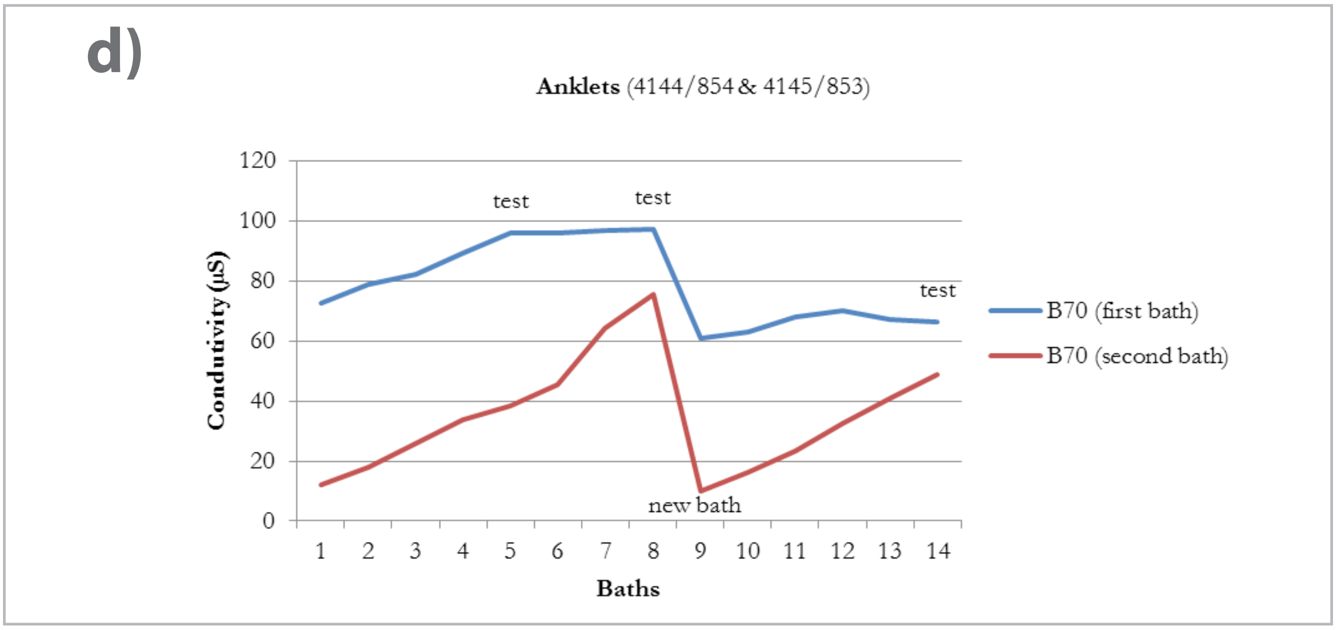
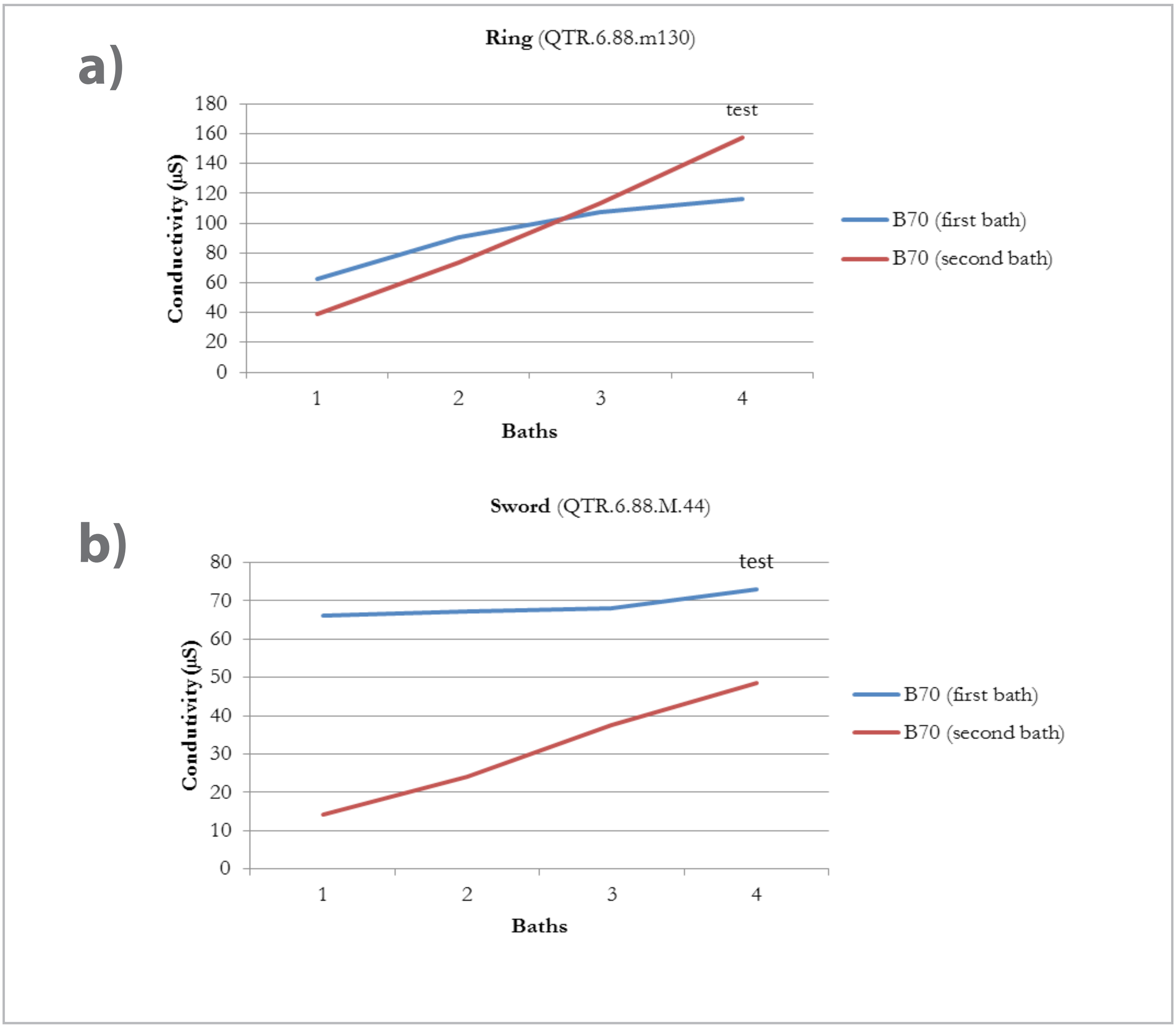


Figure 3.- Desalination progress of some over cleaned artifacts before from Rumailah settlement. a) Anklet (826/4148); b) Chisel (4112/824); c) Anklet (4149/825); d) Anklets (4144/854 & 4145/853).



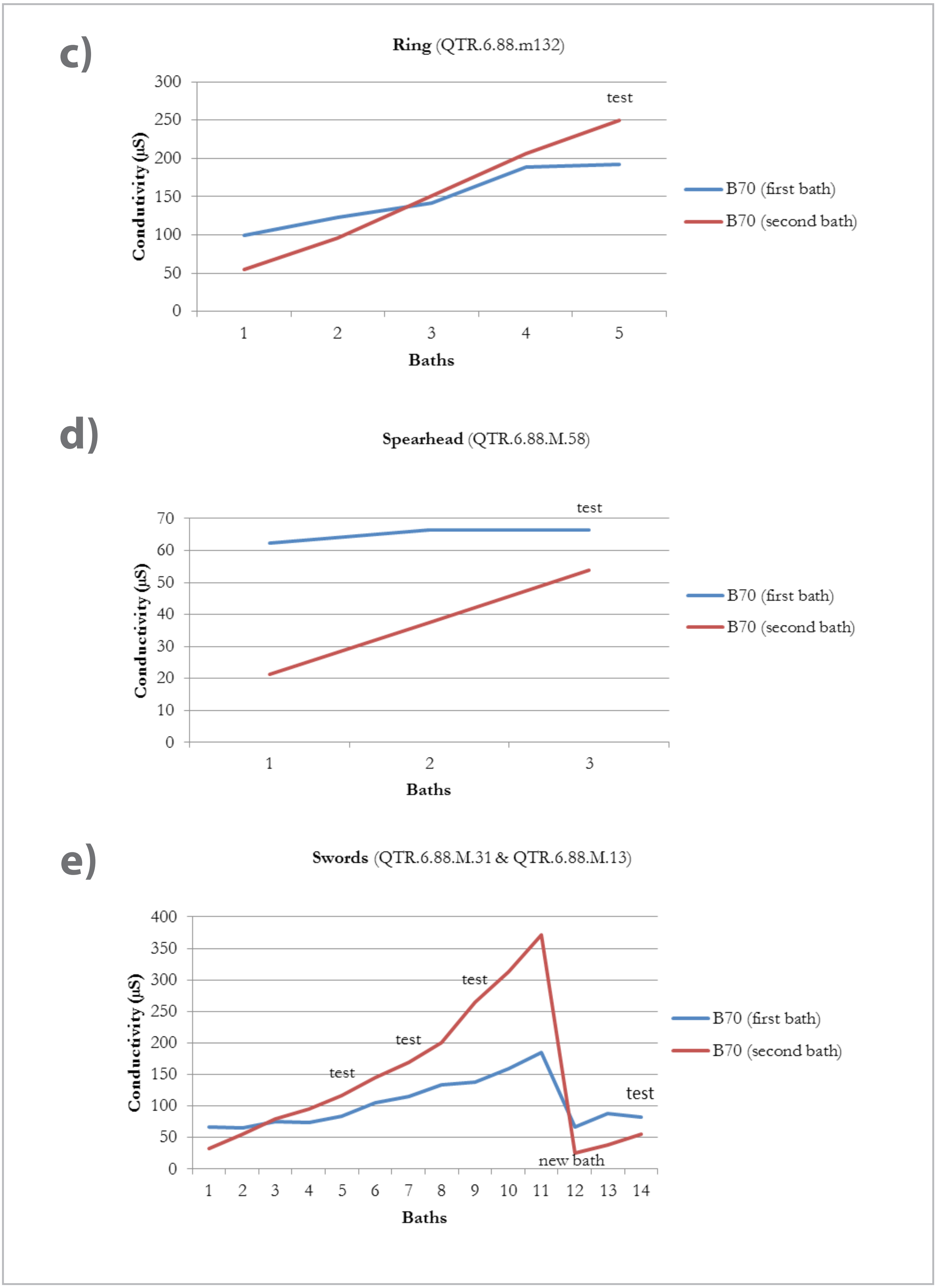


Figure 4.- Desalination progress of some artifacts from Qattara tomb. a) Ring (QTR.6.88.m130); b) Sword (QTR.6.88.M.44); c) Ring (QTR.6.88.m132); d) Spearhead (QTR.6.88.M.58); e) Swords (QTR.6.88.M.31 & QTR.6.88.M.13).

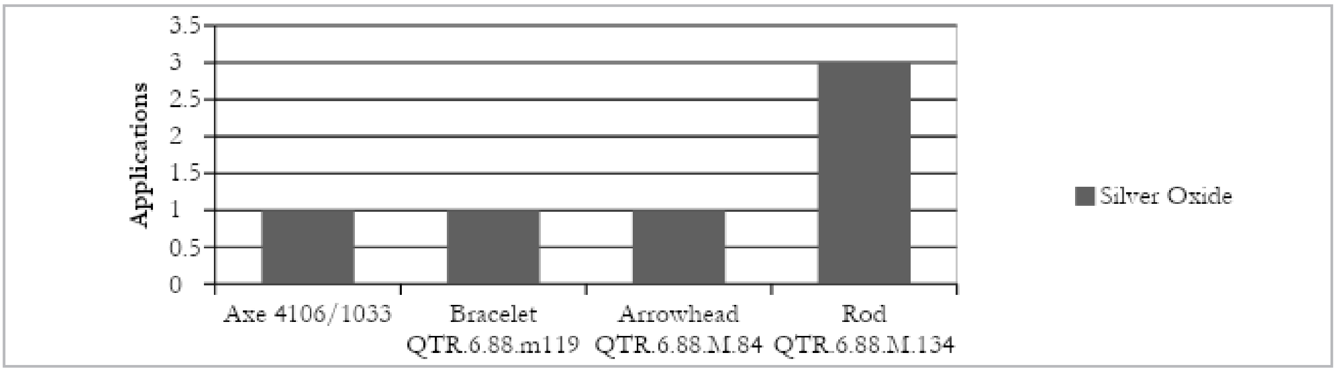


Figure 5.- Metal stabilization with silver oxide procedure carried on the artifacts from Rumailah (axe) and Qattara tomb (bracelet, arrowhead and rod)

— *Desalination treatments results of each phase*

1st conservation phase			
Objects from Qattara tomb			
Desalination system	**Applications ner**	**Objects ner**	**Average**
B70 system	54	11	4.9
AgO	122	27	4.51

2nd conservation phase				
Objects from Qattara tomb, Hili 8 and Garn Bint Saud settlement				
Desalination system		**Applications ner**	**Objects ner**	**Average**
B70 system	All the objects	159	24	6.6
	Objects not restored before from Qattara tomb	81	15	5.4
	Over-cleaned objects from Garn Bint Saud and Hili 8	78	9	8.6
AgO		47	10	4.7

3rd conservation phase				
Objects from Qattara tomb and Rumailah settlement				
Desalination system		**Applications ner**	**Objects ner**	**Average**
B70 system	All the objects	112	11	10.18
	Objects not restored before from Qattara tomb	30	6	5
	Over-cleaned objects from Rumailah settlement	82	5	16.4
AgO		6	4	1.5

TOTAL				
Desalination system		**Applications ner**	**Objects ner**	**Average**
B70 system	All the objects	325	46	7.06
	Objects not restored before	165	32	5.15
	Over-cleaned objects	160	14	11.42
AgO		175	31	5.64

Figure 6.- Desalination treatment results achieved during three restoration phases. a) First restoration phase; b) Second restoration phase; c) Third restoration phase; d) Total results from three restoration phases.

According to the final results [figure 6] obtained from the desalination processes [figures 1, 2, 3, 4 and 5], we can conclude that during the three conservation phases, those objects which have not been treated before needed an average of 5 baths each to stabilize them. However, those objects that have been restored previously needed more baths, around 11 baths. Objects from Garn Bint Saud [figure 14 and 18b] required 8.6 average baths while artifacts from Rumailah [figures 2 and 6b] reached a much higher average with 16.4 baths. As an example, one anklet (4149/825) from Rumailah [figues 3c] received the biggest number of B70 baths, specifically 38 baths to reach its stabilization.

Such a large number of baths was required because of a deeper penetration of corrosion. Despite the high presence of chlorides in Al Ain soil because of marine aerosol, we think that this deeper corrosion may have been also caused by previous treatments, which removed the passivation layer that protects the weapon naturally, thus exposing the metal core to deterioration agents.

B70 treatment was quite effective on objects with higher salt concentration, particularly those not treated before and those that had lost the passivation layer during old treatments as well. Moreover, a soft cleaning is essential to guarantee the stabilization of the objects throughout the conservation procedure.

The Thouvenin method, also known as the B70 method has recently become a subject of criticism (Schmutzler *et al*., 2017) because ammonium generates highly alkaline conditions that may favor the formation of copper hydroxides, which may turn to copper oxide under heating.

Although, the high number of baths we did not notice color changes in objects not restored before. In fact, comparing two recently treated objects where one received desalination treatment [figue 7a and figure 7c] and another that did not [figure 7b and figure 7d], both show a similar visual result. Furthermore, there are no color changes when comparing objects that were recently treated with those that had been treated during the first phase two years ago. All the artifacts preserved the same natural green patina typical of the copper carbonate. Indeed, the formation of copper hydroxides can be discarded and the objects remain stable, without copper chlorides in their surface.

However, in case of the anklet (4149-825) from Rumailah, which was over-cleaned before and received 38 baths to attain its stabilization, we noticed a color change of the metal core to green-blue, probably because of the high number of baths. New case studies and characterization analysis would be suitable to confirm this hypothesis in order to know if this copper hydroxides formations could be a limitation of this treatment. Nevertheless, this was the only exception in 46 desalted objects with this system during three conservation campaigns.

Figure 7.- Two restored artifacts from Qattara tomb: a) Sword before treatment; b) Knife before treatment; c) Sword treated during third phase with the B70 system which does not show color changes after desalting process; b) Knife restored during first phase which was not desalted during restoration treatment..

On the other hand, system of sealing chlorides with silver oxide was barely used after the first phase because of the silver remains on the surface and on the dark spots that were typically found after its use. We started using this procedure during the first phase, when we were unaware of the spreading of active corrosion. Once we understood that chlorides concentration was very high on most objects and the treatment had to be repeated regularly to reach their stabilization, we decided to change to the B70 desalination system.

Both desalination systems were considered due to the limited resources of the laboratory in that moment, and mainly because the short duration of each project didn't allow to execute longer treatments. Once the cleaning procedure was performed, stabilization was often necessary since this process activated the corrosion due of the high concentration of salts inside the artifacts and lack the environmental control in the laboratory.

Although the desalination procedure was successful, according to these results, preventive conservation is crucial to guarantee the objects long-term stabilization. Dechlorinating is not a definitive treatment; relative humidity and temperature control inside the museum and adequate storage are essential to avoid the chlorides reactivation on the objects. Moreover, these desalination treatments require monitoring of its effectiveness as well as possible side effects these procedures could cause on these collections in the long -term

Even when the intervention was completed with success, there were some processes that could have been carried out in a different way in order to improve the results of the restoration. A localized B70 method application (Martinez 2016) when the chlorides presence is not too evident could be considered. This may prevent desalination by immersion, which could chemically or visually modify the object. Additionally, this procedure could replace silver oxide treatment.

On the other hand, measurement systems such as a titrator (Raskova 2007) or a colorimeter would be interesting because it can provide more accurate results to identify and measure the chlorides concentration in a solution.

It is well known that lasers would help to increase the quality of work without any risk of damaging the object surface. However, in some occasions, they also can provide a good result against salts (Atanassova 2019) when laser beam fall upon and vaporize them.

The search for an adequate system that guarantees correct preservation of these collections with our scarce resources was our concern and priority and the results are offered here.

Conclusions

Despite such a large number of baths, we can confirm that the desalination procedure was successful. All of the objects were successfully stabilized, even those that were previously over-cleaned.

In conclusion, baths measurement was a remarkable improvement, which allowed to significantly improve the B70 desalination system by increasing the effectiveness of the treatment and with better achievements, making it possible to eliminate unnecessary damages for the objects during humidity tests. These results can be verified by examining the small number of desalination baths received by those objects restored during third conservation phase from Qattara tomb. In addition, no treatment side effects have been detected typified by color changes in the form of hydroxides. B70 system was carried out on 78 objects with active corrosion during the three conservation phases and all of them were stabilized, including those that had been over cleaned previously. Furthermore, at the end of each conservation phase, aesthetic results obtained over all the objects have been always the correct one.

However, despite of the treatment's effectiveness on objects without previous interventions, and even considering the different archaeological sites of their provenance, we would like to highlight the role that the loss of patina caused by old cleanings might have had in the stabilization procedures. In fact, these objects required a large number of baths to reach stabilization, and this increased number of baths can cause color changes on its surface as occurred with one object from Rumailah. On the other hand, due to the lack of specific bibliography about the use of this method, it is difficult to compare the results obtained in our study with those obtained by other authors.

Despite their stabilization, there are some objects that still are vulnerable to the humidity. To face this problem, preventive conservation is essential to ensure the collection's preservation with special emphasis on the relative humidity and temperature control to avoid sudden variations that could reactivate sealed chlorides inside the copper alloy objects.

Monitoring of collections condition is essential in order to evaluate the dechlorinating effectiveness as well as side effects these processes may have on the objects. Techniques such as neutron and X-ray tomography –still under study- (Jacot-Guillarmod 2019) can be used for this purpose.

Metal desalinization is rarely considered but was an essential phase for the correct metal preservation in this case due to the high chlorine ion concentration inside the objects. We think that this could be a frequent problem in most extremely arid conditions, especially in coastal areas or near oases. In these environmental conditions, chloride salts in the soil either from evaporation of groundwater discharge or by deposition of marine aerosol. Moreover, moderate humidity may favor water condensation on hygroscopic salts during the night, when temperature falls causing relative humidity to increase. Condensation and the ensuing brine formation enable metal corrosion. Therefore, conservation projects in these types of environments should emphasize desalination.

Notes

[1] This conservation project was divided in three campaigns due to the other commitment of the team with the general survey of Al Ain National Museum collections and to the need of setting priorities within the artifacts condition during our visa stay.

[2] As mentioned above, two immersions are involved in the B70 system, the first one removes chlorides (blue color) and the second forms an oxide layer on crops holes (red color). Each bath (indicated on the X axis) is made up of these two immersions to complete the desalination procedure. This process was repeated until the conductivity was low enough in order to pass the humidity chamber test. However, a few objects previously restored needed to continue with the desalination process but the duration of our project disallowed to extend the treatment. Therefore the humidity chamber test was carried out sooner than recommended.

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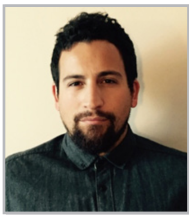

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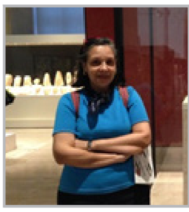

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