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Partial Conservation treatment and Reconstruction of Pottery Artifacts Excavated from Terrestrial and Marine Environments, Leptis, Libya

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Abstract: Pottery is the most excavated material; it was manufactured in varied shapes, sizes, and colours; to appropriate their occupations. Studied objects were unearthed as sherds; an initial repair was a requirement till complete the excavation. Determination of the deterioration rates of the pottery objects was significant to take the correct decision for conservation treatment. This work aims to characterize the chemical structure of pottery objects and determine the deterioration aspects and their caused factors in the original environment using functional analyses. Mechanical cleaning was the first and safe step of conservation procedures. Then, desalination treatment was used for the long-term stabilization of the excavated pottery; internal stresses was decreased. Immersion in distilled water was efficient for decreasing water-soluble salts as halite. Insoluble water-salts were removed mechanically and chemically using dilute hydrochloric acid. Colour and thickness of the pott-sherds were the clues for the classification of the assembled sherds. Reconstruction of the excavated sherds was the main goal for understanding the occupation of the objects.
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Keywords: Archaeological Pottery, Deterioration Mechanism, Re-construction, Desalination treatment, Conservation treatment.

Introduction

Excavation is the generation of archaeological materials. Pottery was known since the Neolithic age[1]. Pottery finds are one of the most excavated artifacts from the marine and terrestrial environments[2]; they endure the surrounding conditions. It represents a senior important and special type of archaeology science; it is a physical clue of the daily activity in ancient life, and it had an intrinsic role.

In ancient ages, Libya was famous for commercial and industrial activities. Salfium and olive oil were exported to many neighboring regions, which required pottery vessels to save it for the long-term. Some historians mention that Libyan pottery had been imported the pottery, but this view cannot be taken; because there is much evidence to prove that pottery is mainly locally produced. Many pottery artifacts were found as well as the remains of pottery kilns such as those found in the archaeological museum of Leptis. There is crockery containing seals, which are confirmed that they are made in Libya[3].

Pottery contains many basic minerals such as kaolin, montamorelite, and elite (weathered silicates). Quartz, feldspar, mica, olefin, pyroxene, and some other minerals such as hematite and rutile, calcite, anhydrite, albite ($NaAlSi_3O_8$) and apatite ($Ca_5(PO_4)_3.[F,OH,Cl]$) were identified as either course temper added to the pottery or secondary minerals formed by the firing of the clay matrix[4]. Kaolin–serpentine series clay minerals are comprised of one tetrahedral layer linked to one octahedral layer with no interlayer cations and are termed 1:1 layer structures connected by O–H–O bonds. The chemical formula of kaolin is $Al_2Si_2O_5(OH)_4$, whereas the Mg end-member serpentine has the formula $Mg_3Si_2O_5(OH)_4$,[5,6].

It is the covalent structure of primary building units. Specifically, in an effort to construct metal halide analogs of zeolites and clays, Cu^+, Zn^{2+}, and Al^{3+} halides have been selected as tetrahedral building blocks, and Zr^{4+} as an octahedral building block[7,8].

Chemical structure induces the colour of pottery as gray, yellowish, and orange. The chemical composition of the clay is not a significant criterion in determining and distinguishing the classification of the pottery type. Clay for manufacturing pots should be properly prepared. The raw material contains inclusions that can damage the pot wall during shaping or later firing by cracking. The raw clay is levigated before mixing with water and then kneaded until the mass is smooth[9,10]. A green wave was used to cover the surface to be smooth. The burning temperature depends on the strength of interconnects of the child's molecules,[11,12] the chemical composition of the clay, the additives, and the temperature of combustion often determine the physical properties of the pottery. Fagan stated that the ancient manufacturer added many additives such as organic matter and some salts [13] shown in figure (1).

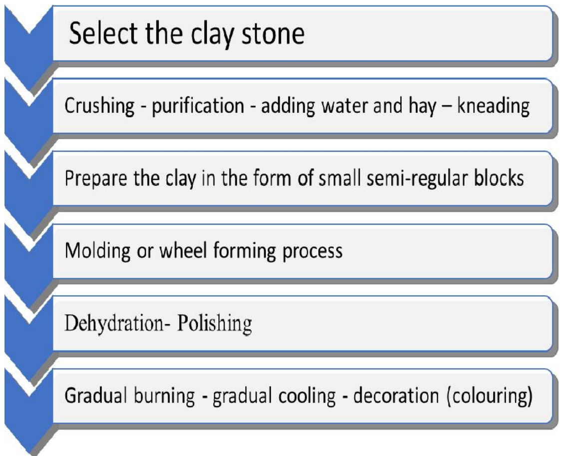

Fig.1. process of pottery technology[14]

Decorative techniques involve slip, painting, incision, excision, and scraping. Some pottery tempered with crushed ashes of a tree bark is found[15]. The chemical structure of clay, stages of manufacturing techniques such as drying, the effect of water-dissolved elements and gases, and the biological activity of microorganisms, the burial environment are the main deterioration of the pottery.

Pottery pieces undergo from staining phenomenon, because of firing conditions, the chemical structure of clay and additives, and iron deposits in the soil of archaeological site[16]. Both the burial periods in soil and soaking in seawater affected the physical and mechanical properties of the pottery. But, the impact of the marine environment is significant in increasing rates of manifestations of damage such as calcite and sulfides salts, clear vertical cracks, and erosion in some parts. Soil is an aggregate of organic and inorganic materials, water, and gases. Some soil parts play a positive role in the burials. Pottery is a fairly material easy to break because it is characterized by earthenware structure vulnerable.

Pottery is a porous inorganic-material, absorbing saline water through capillary properties making internal stresses. Salt efflorescence is related to the porosity, chemical structure, and the surrounding conditions. Through the burial condition in the marine environment or salty soil, the adsorbed salt appeared after dehydration[17,18]. Salts are a hygroscopic material that attack porous surfaces. The increasing accumulation of salt affects the drying rate by lowering the vapour pressure of the saline solution, hence reducing the rate of moisture loss[19]. Initial pressure induced from the crystallization of salts and the movement of saline solutions. Fragments of broken objects may require some treatment works to prevent loss from continued fragmentation or abrasion of edges[20]. If the pottery objects are left untreated, the crystallization of salts inside the pores will affect the occurrence of physical damage represented by porous and cracks interior the body; risks deteriorating faster when brought in contact with air[21]. Also, these crystals exert immense pressure and may cause the surface layer to spall off[22]. To decrease the effect of salts, it is preferable to treat pottery, as soon as they are recovered.

Pott-sherds should be labeled on the interior side. Plain sherds should generally be labeled on the interior surface unless the vessel form is a plate or shallow dish, in which case the reverse applies.

There was no a conservation lab. of archaeological pottery in Libya (2013); the conservation facilities were poor. Mechanical cleaning is reliant in the initial state of objects' damage, the necessity of conservation treatment, acceptable level of skill and individual performance of conservators, accuracy, and precision[23]. For instance, if mechanical cleaning techniques were used inexpertly or carelessly, there is a danger of scratching, abrading, removing some of the object surface or physically damaging the fabric of pottery[24].

Dynamic water as tap water, immersion in distilled water and poultices are used to extract water-soluble salts from the pores of the pottery. Through the porous surfaces, paper poultice prepared with tissue paper and the chosen solvent can be used for the desalination treatment. To slow the evaporation of the solvent, cover the poultice layer with plastic film.

Fired material fracture needs fast restoration of the original shape before destruction. Chemical treatment is the convenient for removing insoluble-water salts. Sodium hexametaphosphate (calgon) is used to suffice and remove calcareous deposits[25].

Many materials were used in assembling pottery such as bitumen or lead clamps[26]. Also, based adhesives used to assemble the sheds of broken pottery like clay, black cement animal glue, araldite, UHU, cellulose nitrate (CN), poly vinyl acetate (PVAc) and acrylic such as Paraloid B-72. UHU is composed of poly vinyl acetate (PVAc) and some cellulose nitrate (CN) to be relatively stable [27]. Gap filling is not essential to complete the conservation procedures; when pottery have not problem in the mechanical balance.

This study presents the chemical characterization of the soil and seabed, and pottery objects. Also, strategy of conservation treatment of some broken and deteriorated pottery excavated from the terrestrial and marine environment was studied.

Materials and Methods

Investigation and analyses were used to characterize the chemical structure of pottery and adhering burial sediments to understand the deterioration mechanism. Separated solid samples from the excavation sites and archaeological pottery objects were analyzed by the device XRF. Powder samples were analyzed by XRD.

Thermal Test of Reassembling the pottery fragments

An experiment was conducted to assist the resistance of UHU to withstand the high temperature. Modern pottery object was assembled by UHU in regular reciprocal drops. Then it was placed in the oven at 100°C for a period of 30 minutes followed by the exposure the sudden cooling.

Optical microscope

It is considered one of the most important methods of examination, through which it can quantify texture of pottery, the layers, and the alien vehicles attached to the surfaces of fired clay pots before burning [28].

X-Ray radiography

X-ray imaging was used in order to identify the case of pottery objects in terms of the presence of fine or large cracks or decorations under soil calcification. Sirona X-Ray radiography was used to examine the sherds before the conservation treatment shown in figure (2).

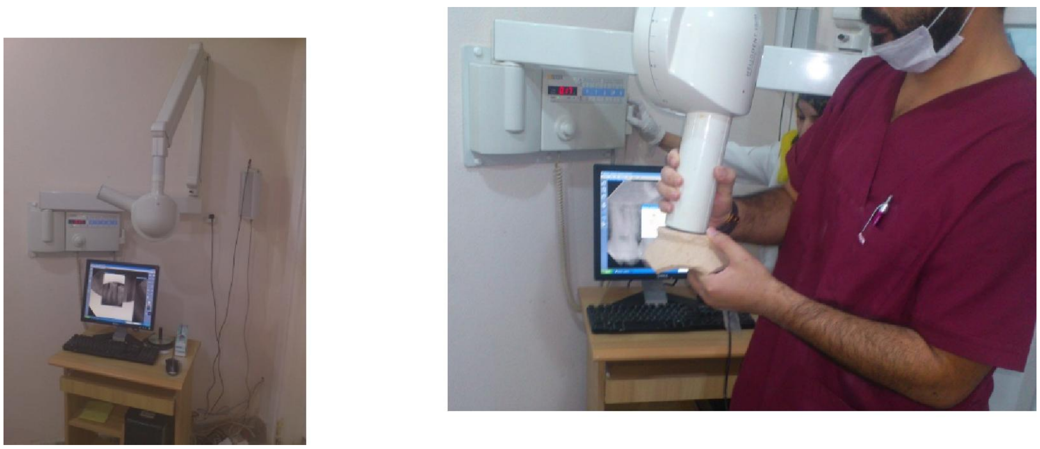

Fig.2 . X-Ray radiography of pottery objects

X-Ray diffraction

XRD diffraction analysis permitted the identification the chemical structure of pottery pots and diagnosing the archaeological pottery damage. PHLIPS, PW1800 X-ray powder diffractometer was used for characterization the chemical structure of pottery. The beginning of the analysis of the 2θ angle at 2, the end at 80, the temperature at 20.2°C, the relative humidity at 42%, and the use of copper as a positive electrode for the analysis tube, the sample was prepared by a well-injected and placed in the designated area[29]. Samples from pottery objects, burial soil and seabed were analyzed by XRD. Specimens of pottery have been ground in agate mortar[30].

X-ray fluorescence

This procedure used to estimate the missing values for the other element in the data set was to replace any missing value by the minimum detection limits (MDL) determined by XRF[31]. It is a non-destructive method, where the device was used without taking a sample, and without transferring the artifact to not being damaged.

TDS device

This device is suited to measure the proportion of salts, especially sodium chloride in water or liquid solutions unit (part of a million). It is divided into two parts: the lower part is intended for water sample placement and the other is intended of screen.

Case study

Freshly excavation was undertaken by Archeology and Tourism faculty at Mergib University from 2012 to 2015. The archaeological site of excavation is located in Leptis city, north-west of Tripolis (coastal area) as shown in figure (3). It represented a Roman seaport, and it is the most important archaeological site in Libya, it is the largest ancient Greek City[32]. There was no in situ conservation, the objects were preserved at the storage for one year.

Most excavated objects of Leptis City are inorganic. There is inflow of such finds in this area ranging from ruins of temple, glass, pottery and metals. Among the set of the finds, two objects were selected showing different aspects of damage, which differ in typology, occupation and deterioration rates. They date back to the Byzantine period, in comparison to the form and decoration.

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Fig.4. The beaker during the excavation

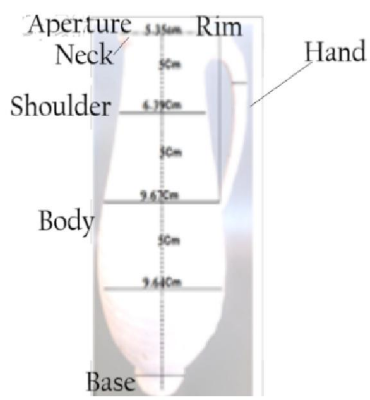

Fig. 5. Measures of the beaker

As shown in figure (6,7), small scale of oil lamp was made of red pottery resulting from well fired. It consists of two parts, upper opening from the top: the first one in the middle to the exit of the wick, and the other opening found at the edge to enter the oil. It was decorated by two different circles in the diameter; the outer one represents the perimeter of the oil lamp. Between of them, there are many orbit points; the distance between them is about 0.4cm. Details of oil lamp decorated with impressions made with a dentate spatula. Mass handle is parallel with the edge opening. There is a missing part in the middle, the most weakening of the object.

Fig.6. The discovered oil lamp

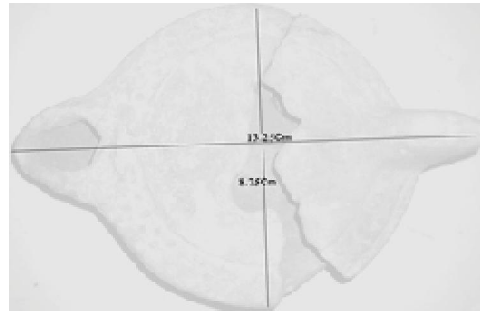

Fig. 7. Measures of the oil lamp

As shown in figures (8 and 9), the third object emphasized decorative form, it is a candlestick which consists of the body, the nozzle and vertical mass handles. Marine candlestick is free of painted decorations. Marine weathering of the object surface and edge was seen. White and grey stains were seen on the surface.

Fig. 8.Candlestick excavated from the saline environment

Fig. 9. Measures of the candlestick

Unknown big sherds which were investigated by X-Ray radiography (A and B), and the other (C) illustrates salt-laden sherd. When the humid evaporates, the salt efflorescence is seen.

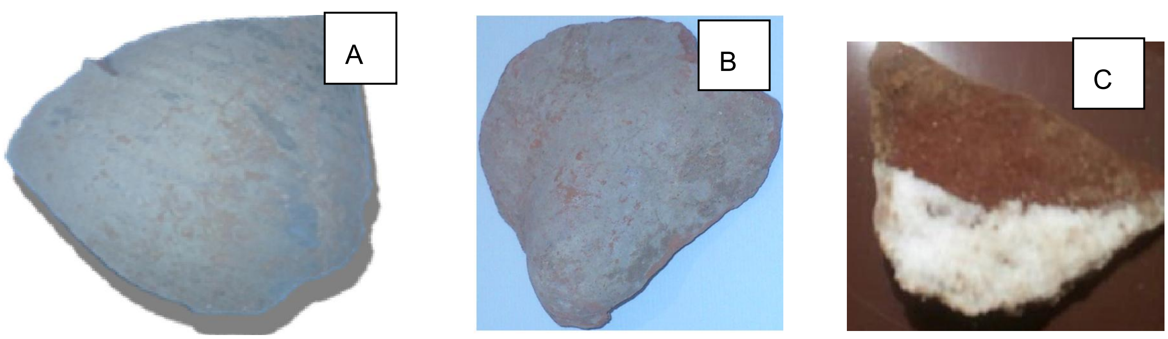

Fig. 10. Unknown sherds excavated from the Leptis City

Results

Optical microscope

From the visual examination of the excavation site, soil is a sandy soil with a percentage of lime, clay minerals and halite. Seabed was indeed composed of white sand with high percentage of salts.

Images taken by optical microscope show that irregularly structure inside the pottery objects. Fig. 8a illustrates that fired clay and iron oxides appears with red colour and silica with yellow. Fig. 8b shows the irregularly structure in the pores.

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Fig.12. X-ray imaging shows checking broken parts from the excavated collection, A and B show the examination of unknown sherds (photo and X-ray radiography). C and D show the examination of the unknown sherds (photo and X-ray radiography)

X-Ray diffraction

Quartz and calcite were the major minerals in the both seabed and soil burial environments by fresco ruins in the excavation site, in addition to microcline, albite, dolomite and halite [33]. Moreover, $ZrSiO_4$ and ZrO_2 resulted from the natural zircon sand in the seabed; they differentiate this environment. Both seabed and coastal environments are similar in the same chemical structure, but they differentiate in the identification of titanite, rutile and polyhalite based on the geographic area. At the same time, halite (2.45%.) was detected in the seabed sample; it is an essential component of seawater with 3.5%. X-ray diffraction was study to identify the chemical structure of the pottery objects as shown in the following table 1.

Table (1), XRD semiquantative result of samples extracted from the original environment of the pottery (seabed and soil)

Mineral	Chemical structure	Concentration %		
		Seabed	Soil	
Quartz	SiO_2	55.21	50.02	39.8
Calcite	$CaCO_3$	19.63	29.47	39.8
Microcline	$KalSi_3O_8$	----------	9.90	9.95
Albite	$NaAlSi_3O_8$	----------	8.04	4.98
Zircon silicate	$ZrSiO_4$	9.82	--------	-------
Zircon Oxide	ZrO_2	6.13	-------	--------
Titanite	$TiCaSiO_5$	---------	8.94	--------
Polyhalite	$K_2CaMg(SO_4)_{42}$	----------	6.00	---------
Rutile	TiO_2	1.23	3.00	---------
Dolomite	$CaMg\ (CO_3)_2$	1.84	2.73	3.98
Halite	NaCl	2.45	1.49	1.49
Hematite	Fe_2O_3	3.68	-------	--------

As shown in the following table (2), the analysis by X-ray diffraction showed that the clay used in making pottery contain many primary minerals such as quartz and some other minerals. Quartz and albite are the major mineral in the chemical structure. Besides, calcite and microcline were detected in the beaker minerals. Orthoclase and hematite were detected in the chemical structure of the oil lamp.

Table (2), XRD semiquantative result of powder samples of beaker and oil lamp

Mineral	Chemical structure	Concentration %	
		Beaker	Oil lamp
Quartz	SiO_2	61.35	44.08
Hematite	Fe_2O_3	--------	10.62
Albite	$NaAlSi_3O_8$	14.72	31.98
Orthoclase	$KAlSi_3O_5$	--------	13.32
Calcite	$CaCO_3$	14.11	--------
Microcline	$KalSi_3O_8$	9.82	--------

Albite, quartz and calcite are the major minerals in the chemical structure of the candlestick's body. White stains are composed of aragonite and dolomite, calcite and quartz. Iron oxides are grown on the surface composed of lepidocrocite, geothite and albite associated to calcite as illustrated in table (3).

Table (3), XRD semiquantative result of powder samples of marine candlestick

Mineral	Chemical structure	Concentration %		
		body	White stains	Brown stains
Quartz	SiO_2	35.30	3.91	-------
Dolomite	$(Ca,Mg)CO_3$	------	22.35	7.25
Calcite	$CaCO_3$	25.24	8.94	---------
Aragonite	CaCO3	-------	64.80	---------
Lepidocrocite	FeO(OH)	-------	--------	57.97
Goethite	FeO(OH)	---- ---	--------	15.39
Albite	$NaAlSi_3O_8$	39.46	---------	19.39

Chemical constituents of the extracted pottery are categorized as present in major (quartz, calcite and clay deposits), the same composition of the find site as illustrated in figure (13).

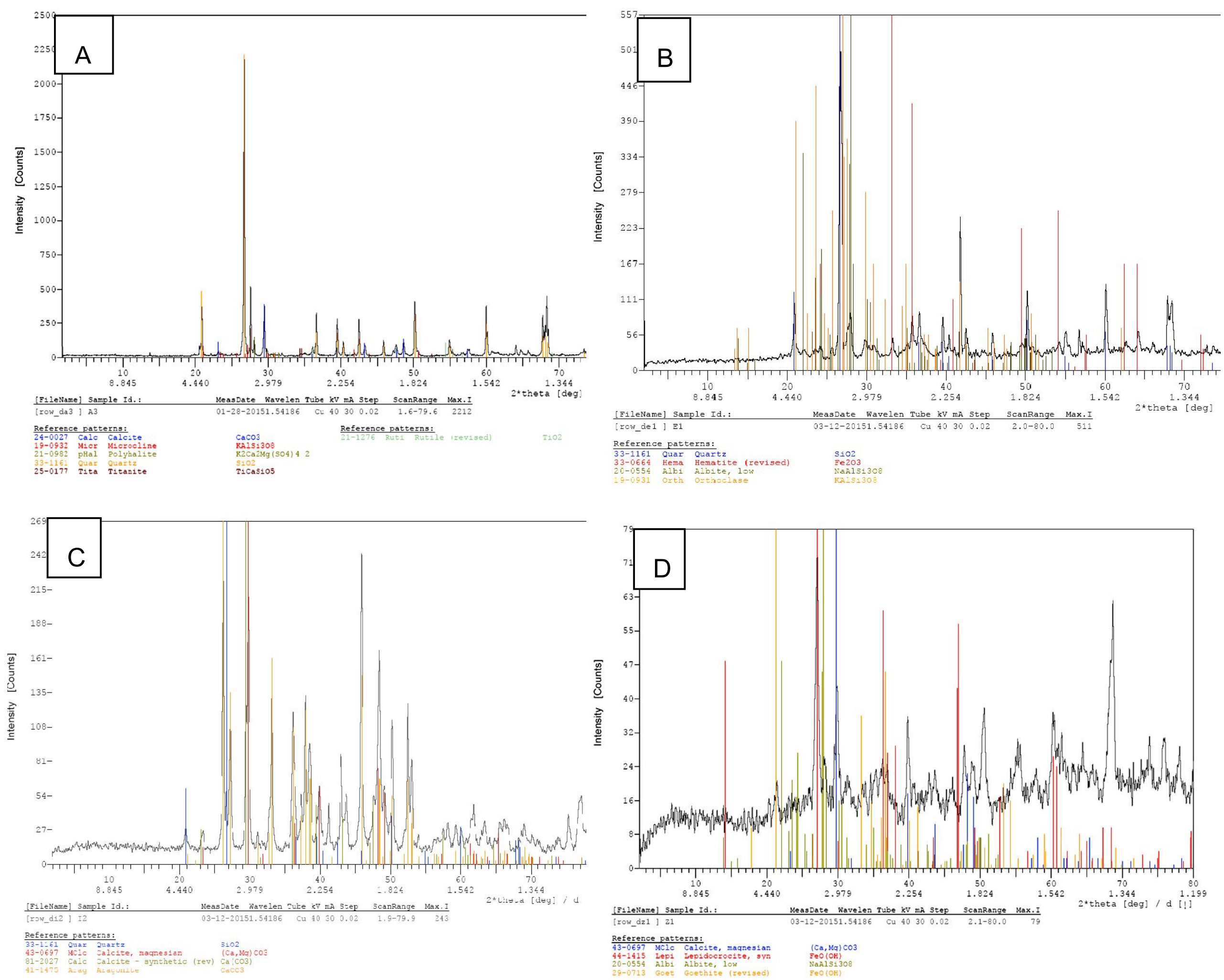

Fig.(13) XRD patterns of soil (A), beaker (B), white stain (C), and red stain (D) respectively

As shown in table (4), elemental concentration analyses were performed by X-ray fluorescence, the results obtained confirm XRD results. Chemical structure of pottery objects is different. The presence gold with amalgam proves that the beaker was likely used in the extraction of gold. In addition to As, Co, Th, Rb and Nb were detected, they likely were associated to gold ores.

Table (4). Results of X-ray florescence for samples from the archaeological pottery objects

Elements	Beaker, ppm	Oil lamp, ppm	Candlestick, ppm
Mn	384	-------	-------
Zr	372	28.6	48
Sr	153	17.5	39
Al	96.05	------	-----
Zn	93	54	87
Si	127	170	151
Pb	-----	28	-----
As	63	------	-----
Co	51	------	-------
Au	48	-------	-------
Th	42.43	-------	------
Rb	35	26	30
Nb	10	12	-------
Hg	21	------	-------
Mo	------	4	------
Fe	3.57	2.93	3.44
Ti	0.3	0.28	------

Conservation treatment of the pottery

Removing the interior soil encrustations

Conservation treatment was not performed after excavation in situ. Since there were calcifications of encrustation in the exterior and interior of pottery. Mechanical treatment was the first aid of conservation. Hand tools have been used such as scalpels, fiberglass and tooth brushes to remove calcifications of the soil and salts from the inner of the beaker and oil lamp as shown in figure (14).

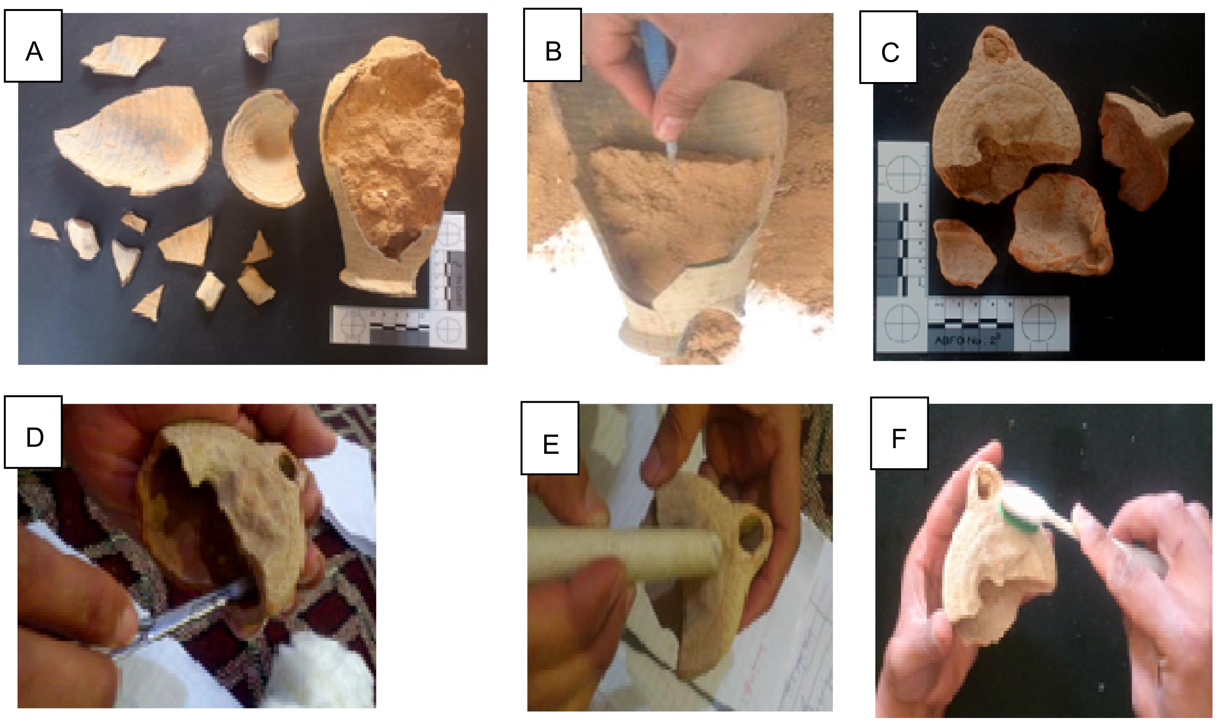

Fig .14. The stages of mechanical cleaning of pottery objects, A and B: integral state; clay encrustations inside the beaker, C: integral state of oil lamp, D, E and F: Removal of unwanted soil encrustations inside the oil lamp respectively

Also, 3% hydrogen peroxide and soap were convenient to remove the inside encrustations completely. Soot and burnt surface was treated using 2% acetone.

Desalination treatment by immersion in distilled water

Pottery is a porosity material lead to good penetration. Objects extracted from the burial environment were saturated with dissolved salts, when pottery was exposed to the air environment, the danger of salts appeared to be recrystallization above the surface and inside the pores. The most important salts that dissolve in water (chlorides, nitrates, and phosphates). Water-soluble salts were removed by immersion in distilled water. Then, distilled water was changed to renew the activation of salt removal as illustrated in figure (15).

Fig.15. Desalination procedures of the beaker, oil lamp, and candlestick

Monitoring the desalination progress was undertaken by TDS. Firstly, the salts ratio was lower, but it was increased over time. The distribution of salts remaining after treatment is seen as shown in table (5).

Table (5). The proportion of the salinity through desalination treatment in distilled water

Duration	Ratio of salt (PPM)		
	Beaker	Oil lamp	Candlestick
At the beginning immersion	83	93	177
24 hrs	177	257	629
48 hrs	75	136	472
72hrs	46	94	123
96hrs	23	26	36

Removal of unwanted encrustations of insoluble salts was performed by chemical treatment. Tap water was not used in the desalination treatment; the ratio of salinity was higher (164 ppm).

Removing soot and water-insoluble salts

Firstly, organic solvents as xylene and acetone were used to degrease the appearance by removing the soot and earthen accumulations from the beaker surface. After extracting the marine object from distilled water, the insoluble-water salts as calcium carbonate were not completely removed. They were mechanically cleaned; then chemical treatment was undertaken by dilute hydrochloric acid (2%). After that, the sherds were immersed in distilled water to remove the chemical residues.

Desalination treatment of marine candlestick

The desalination treatment of the marine candlestick is different comparison to the terrestrial pottery. Salts dissolved in water move to the porous pottery due to the capillary property and then crystallize in the pores during the drying[34].

The desalination treatment is The object was immersed in 50:50 seawater/distilled water for three days. Then, it was transferred to pure distilled water with adding biocide to the solution until salts were decreased[35]. Extracting the insoluble salts such as calcium carbonate and iron stains was done by dilute hydrochloric acid. After extracting the pottery from distilled water, solvents and warm air stream were used to dry pott-sherds shown in Fig. (17).

Fig.17. Warm air stream through dehydration of the beaker

Reconstruction of the archaeological pottery

Reconstruction of the beaker and oil lamp were carefully performed by spot treated. To ensure that the adhesive material is suitable for use in a bonding pottery fractures; popular polymer as paraloid B-72 was not found (2014). The use of UHU depended on

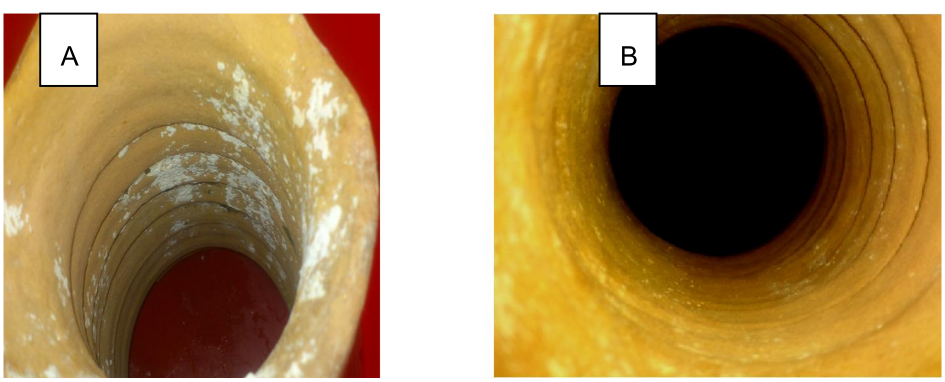

Fig.16. Calcification of salts inside the candlestick (A). The object after treatment using dilute hydrochloric acid (B)

the thickness of the wall sherds are not thick. Some parts are missing, conservation treatment will complete after finishing the excavation.

They were joined using UHU, then hiding the assembly points. Oil lamp was broken into three parts, two parts from the base were joined to build the upper part. There is still a missing part that extends from the base to the top.

Firstly, edges of pott-sherds were cleaned with acetone and water to prepare them to joining. The adhesive was placed with mutual points on the two edges after cleaning, and combine the two parts well to be affixed, and after the adhesive was hardened, and removed the excess from the adhesive using scalpel or cotton dampened with an alcohol solution.

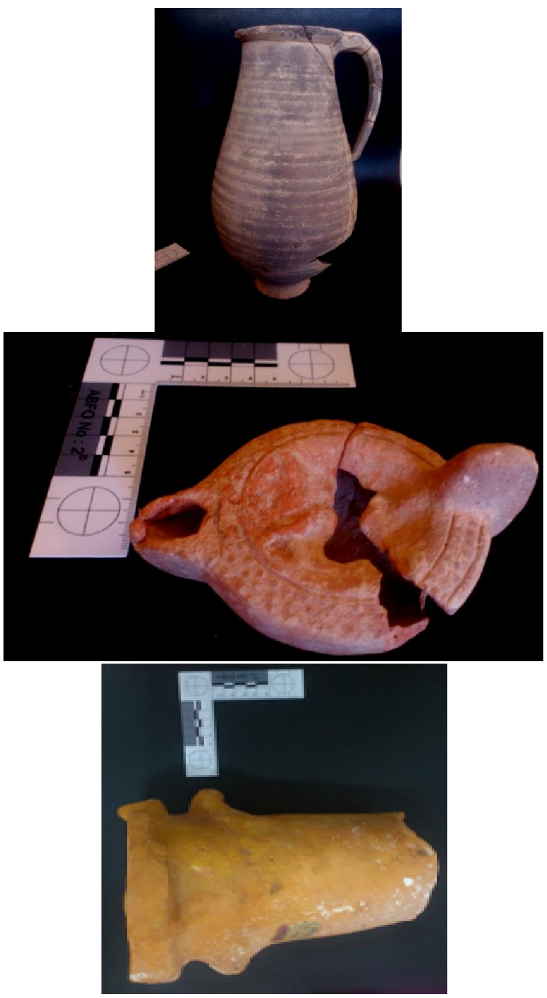

Fig.18. Pottery objects after finishing the conservation treatment

A preliminary conservation was done without gap filling; pottery stabilizes over time; they display dynamically; to preserve the archaeological and aesthetic values, and the missing parts is small and does not affect their conditions. White and blackish stains were not removed completely; it was difficult and needs the use of concenter chemicals.

Long-term Preservation of treated objects

The future conservation of pottery artifacts found in terrestrial and marine archaeological sites appears to be a straightforward material science problem, involving elucidation of the structure to develop conservation procedures that prevent the deterioration, it is constrained by ethics, aesthetics, and cultural contexts that may complicate, constrain, and ultimately direct preservation strategies[36].

For avoiding unnecessary handling, painted iron stands were prepared. The height of the stand of the beaker is 15 Cm, and the height of the stand of the lamp is 10 Cm. Iron stands were painted with a suitable coating of black paint to protect the pottery from the effect of iron
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tery objects[37]. The chemical composition of clay is not a reliable standard in identifying and distinguishing the type of clay after firing. Clay with similar chemical composition differs in some of its physiochemical properties as surface colour according to its preparation and the additives. The excavation site at Leptis City revealed a group of pottery artifacts leached from the marine and coastal environments.

Pottery objects were exposed to different factors and aspects of deterioration that affect the internal structure and physiochemical properties [38]. Of the pottery collection preserved at the storage of Faculty of Tourism and Archaeology, Mergib University, two objects were selected for this study.

The occupation of the oil lamp, beaker and candlestick were the reason to be easier for cracking or/and breakage. The pH in seawater ranges from 4.5 to 8.5, but it is mostly acidic. The ratio of carbon dioxide, oxygen, and organic materials affects the pH value [39, 40]. As the pieces of the pottery look to be disturbed, the mutilation was undertaken before the burial; there was missing parts.

After investigation with the naked eyes, magnifying lenses, optical microscope, X-ray radiography and analyses techniques concluded that the archaeological pottery in their original environments exposed to various deterioration factors. Crystallization of insoluble salts on the surfaces of candlestick in the form of calcifications was the most difficult to remove. When self-drying the pottery immediately after extraction from the marine or coastal environment without treatment, salts crystallize inside the porous increasing the initial pressure cracks; these phenomena caused by the lack of immediate treatment contributed to increase the damage rates.

The marine pottery was leached as one piece, on the contrary, the pottery was excavated from the terrestrial environment as small pieces resulting from the pressure of soil layers. Sand in the soil is more preservative condition than in the seawater; the continues changes in seawater is the main deterioration factor. Seabed of the marine environment contains a high content of quartz, calcite and halite; deterioration rate in the marine environment was heavier than burial environment. Therefore, marine pottery needed special care in removing salts to remove water-soluble salts such as chlorides, it was easily soluble and removed by washing and immersion in distilled water[41].

X-ray fluorescence results demonstrate that gold and mercury were detected inside the beaker, at the same time, beaker's surface was covered with soot, these estimates assume that it was likely used in the cupellation of gold.

XRD results revealed that halite identified in the seabed at (2.45%), this ratio is lower the known percentage in seawater (3.5%). Most excavated pottery from the terrestrial and marine environment was saturated with salts as sodium chlorides and calcium carbonate[42]. Despite the proximity of the excavation site to the sea, objects were extracted from dry environment, and their condition is coherent. Salt crystallization was seen on some unknown pott-sherds lead to the physio-chemical properties loosening.

Mechanical treatment was used to remove the accumulation of earthen sediments to reveal the pottery surface. Brushing the surface by tooth and fiberglass brushes was undertaken to remove the adhering foreign materials. Chemical treatment was undertaken using hydrogen peroxide (3%) for removing the calcification; it is an oxidizing agent. Calcium carbonate adhered with the surfaces was the most popular salts that did not dissolve in water and. It was preferable to remove insoluble salts using mechanical cleaning, then chemical treatment by dilute hydrochloric acid (2%) was efficient. After that, they were immersed in distilled water to remove the residual acid[43].

After visual inspection, experimented pott-sherds which were assembled using UHU resisting thermal aging; to ensure that the adhesive material is suitable for use in a bonding pottery fractures when popular polymer as paraloid B-72 is not found. Surface colour and the wall thickness were the guide for reconstruction the sherds. For good joining, pott-sherds were cleaned carefully before reconstruction. Also, stains on the surface after joining the broken parts by UHU adhesive were not seen. There was no disintegration of the assembled parts. Further excavation in Leptis city will be conducted to complete the missing parts of the treated objects.

Conclusion

Some pottery artifacts came from the excavation at Leptis City, the geographical location was suitable for preservation the objects for the long-term. The study demonstrates that both of the burial period in soil and seawater affected the physical and mechanical properties of the pottery, and the impact of the marine environment is significant in increasing rates of manifestations of damage. The main deterioration factors upon excavation were the pressure of soil layers led to break the pottery objects. Sandy soil was dry and the objects were buried in greater depth far from the effect of the ground water, humidity and rains. XRD results revealed that the chemical construction of the deposits inside the pots matched with the chemical structure of the surrounding environment.

Mechanical treatment and repeated immersion in distilled water were efficiency for removal the soluble-water salts, and earthen encrustations.

Comparative analysis provides indication of the chemical structure of the pottery and the original environments (burial and seabed). X-ray fluorescence results demonstrate that silicon, zircon and zinc are the main elements in the chemical structure of the pottery objects. Zircon increases the pottery resistance of the surrounding environment. Form, surface colour and chemical structure of the objects confirm that the clay likely made of the vessels was not taken from the same source. It also showed that the clay contains a high percentage of sand, as well as calcite. Calcium carbonate and iron stains were the most calcified salts found in the marine candlestick.

Results demonstrate that marine environment was more deteriorate than sandy soil; continues changes of the surrounding conditions induced by kinetic of waves, such as chemical structure of the seabed, temperature, and the effect of insoluble-water salt as calcium carbonate and sulfides. The saturation of the marine pottery with salts resulted in the change of the surface color of the pottery from inside and outside, and increasing the specific weight. Partial treatment of the pottery; gaps were not filled to dictate finding the missing parts till finishing the excavation. UHU was used in assembling the sherds; it's ease of use and resisting the surrounding conditions.

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