INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 14, Issue 4, October-December 2023: 1327-1342 www.ijcs.ro

DOI: 10.36868/IJCS.2023.04.04

# ANALYSIS AND RESTORATION OF GRECO-ROMAN POTTERY IN EGYPT

Walid Kamel ELGHAREB[1,*]

[1] Zagazig University, Faculty of Archaeology, Conservation Department, University Street, 44519, Zagazig, Egypt.

***Abstract***

*The research aims to identify features of the industry and assess the pottery damage through various examinations and analyses, such as examination by polarised microscope (PLM), examination by Scanning Electron Microscope with Energy Dispersive X-ray unit "SEM-EDX", analysis by X-ray diffraction powder XRD, and thermal analysis TGA. Archaeometric features of archaeological pottery were identified. The used clay is Nile Clay; the additives are sand, limestone powder, pottery powder (grog), and straw. The moulding technique is the hand and potter wheel technique. The surface treatment is a red wash and slip layer. The burning atmosphere is oxidising for the first and second pottery pieces and reducing for the third and fourth pottery pieces. The burning temperature is about 816°C for the first sample, 887°C for the second sample, 706°C for the third sample, and 651°C for the fourth sample. The texture is medium to coarse fabric for the first sample; the second sample fabric is fine; and the third and fourth samples have a coarse texture. The research proved that the pottery objects suffer from some different damage aspects such as fracture, loss of some parts, lack of strength, weakness, cracking, soil sediments, soot spots and black core, and salt crystallisation (chloride, sulphate, carbonate, and phosphate salts). The research proved the use of a mixture of distilled water, acetone, and ethyl alcohol at a ratio of 1:1:1, respectively, for removing clay soil deposits. EDTA is used to remove lime deposits. Nano-silica at a concentration of 0.5% is used to strengthen archaeological pottery by spraying. Paralloid B 82 dissolved in trichloroethylene at a concentration of 50% in assembling the pottery sherds; it is preferable to display it in the museum at a temperature of 20°C and a relative humidity of 55:60%.*

***Keywords**: Pottery; Slip layer; Burning; Damage; Examinations; Restoration.*

## Introduction

Tell Daphna is about 12km west of the city of Qantra in Port Said Governorate [1]. It is one of the important archaeological sites dating back to the Greco-Roman period [2]. It is considered one of the commercial centres of the 26th Dynasty in the east of the Delta [3]. The discoveries at this site were the ruins of fortifications protecting the borders of the eastern delta. The excavations had revealed many different pottery objects [4]. Tell Daphna is one of the five archaeological sites that were chosen (the eastern entrance) for its development within the panorama project of Egypt’s military history and the development of archaeological sites in the Suez Canal, which are Tell Habwa, Tell Abu Saifi, Tell Farma, and Tell Maskhota [5].

Examination and analysis of the important processes that precede the process of treatment and maintenance. Restoration, treatment, and maintenance benefited from scientific progress in the fields of diagnostic examinations, microanalyses, and spectroscopic analyses. In the past two decades, it has shown its scientific accuracy and great potential in our archaeological knowledge

* Corresponding author: walidelghareb@yahoo.com

about archaeometric materials [6]. Microscopic examination, micro, and spectroscopic analysis methods have diversified during the last two decades [7, 8]. The examination and analysis process gives information about archaeometric features, especially manufacturing, additives, and texture [9]. It also plays an important role in clarifying the nature of the pottery matrix, causes of deterioration, manifestations of various types of pottery damage, and evaluating the treatment. Risk assessment is a critical step in identifying and choosing suitable treatment processes according to deterioration aspects [10]. It is not possible to identify and evaluate damage without various examination and analysis methods [11]. Laboratory analysis is important to assess the current damage, weathering, and deterioration [12].

Examinations and analyses play an important role in determining different damage manifestations such as cracking, soiling, crystallisation of salts, various stains, and organic damage [13]. The pottery in Tell Daphna suffers from various damage aspects, which necessitated conducting various diagnostic examinations and analyses to identify damage forms and assess the condition, risks, and deterioration manifestations. Based on the results of the examinations and analyses, a scientific treatment plan was prepared for restoration, treatment, maintenance, and museum display of our pottery. No previous studies have been conducted on this archaeological site. Therefore, this study is considered one of the first studies at this archaeological site.

## Materials and Methods

### *Materials*

Four pottery samples were selected from the archaeological site, as well as a soil sample. These samples were used in the examinations and analyses that were conducted in the research.

### *Methods*

*Visual Examination* is one of the important methods that show the archaeometric features of pottery and damage manifestations, whether with the naked eye or by using different lenses whose magnification ranges between "4× and 6× " or by using a USB digital microscope [14].

*Examination by Polarising Microscope* is used to study the petrographic structure and nature of burning, additions (tempers), textures, and damage to archaeological pottery [15]. A thin section of pottery samples was prepared for petrographic examination using a polarising microscope (Olympus BX51 TF Japan attached to a digital camera) with a magnification of 4× up to 40×. It was done at the faculty of science at the University of Zagazig.

*Examination by Scanning Electron Microscope (SEM-EDX)* describes surface morphology and the determination of damage forms [16]. The pottery samples were examined using an environmental scanning electron microscope JEOL JSM-840 and SEM Quanta 200 FEG, XTE 325/D8395. The operating conditions were 20kV and $1\times10^{-9}$A. This examination was carried out using an environmental scanning electron microscope equipped with an EDX unit at the faculty of science at the University of Zagazig.

*Analysis by X-ray Diffraction Method* is one of the important methods that determine the mineral composition of pottery, which helps identify archaeometric features and damage manifestations [17]. The device used is a Philips wave separation unit (‘X’Pert Graphics’ and 'Identify', by Philips). The diffraction pattern used is between 4–70 2θ. The operating conditions were carried out using Cu-K α radiation at 45kV and 40mA. This analysis was carried out at the X-ray diffraction centre at the Faculty of Nanotechnology, Cairo University.

*Thermal analysis* plays an important role in determining the firing temperature of pottery and the deterioration of a substance matrix [18–21]. TGA analyses were performed using Shimadzu-simultaneous thermal analysis type TGA-50. This thermal analysis was carried out at the thermal analysis centre at the Faculty of Nanotechnology, Cairo University.

## Results

*Visual Examination*

The preliminary examination of the excavated archaeological pottery group at Tell Daphna in Port Said Governorate showed various damage manifestations such as stains, soil sediments, crystallisation of salts, fractures, soot, black core, and cracks, as shown in figure 1.


**Fig. 1**. The pottery pieces: A - amphora, B - plate, C - bowl, D - terracotta

*Polarizing Microscope*

Four samples of pottery pieces extracted from Tell Daphna in Port Said, in the east of the delta, were examined by a polarising microscope. Figure 2a of the first sample shows the presence of sub-round grains, acute-angular quartz grains, calcite, biotite, pottery powder, burnt straw, and iron (10X-CN). Figure 2b shows the presence of semi-circular quartz grains, angular quartz grains, calcite, grog, muscovite, plagioclase, some cracks, lime deposits, and iron oxide (10X-CN). Figure 2c for another part of the same sample also shows the presence of quartz grains, calcite, grog, plagioclase, biotite, muscovite, fossils, calcareous deposits, and iron (20X-CN).

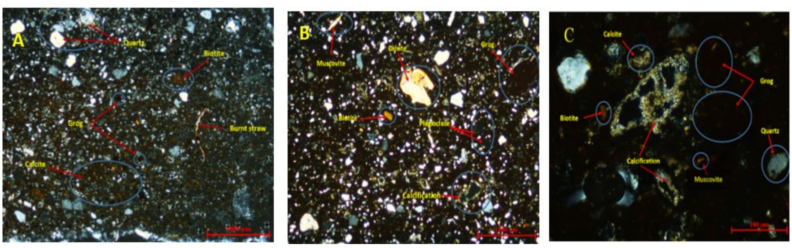


**Fig. 2.** PLM examination of the first pottery sample shows quartz, calcite, biotite, grog, and burnt straw (A), also, the same pottery sample shows quartz, calcite, grog, biotite, muscovite, and plagioclase (B); and respectively, another part of the same sample shows quartz grains, calcite, grog, plagioclase, biotite, muscovite, fossil, calcareous deposit, and iron (C)

Figure 3a shows the presence of different grains of quartz, calcite, grog, rutile, and iron oxide (10X-CN). Figure 3b for the same sample shows the presence of angular quartz grains, grog, calcite, biotite, pyroxene, and iron oxide (10X-CN). Figure 3c for another part of the same sample also shows the presence of sharp-angled quartz grains, plagioclase, orthoclase, grog, and iron oxide (20X-CN).

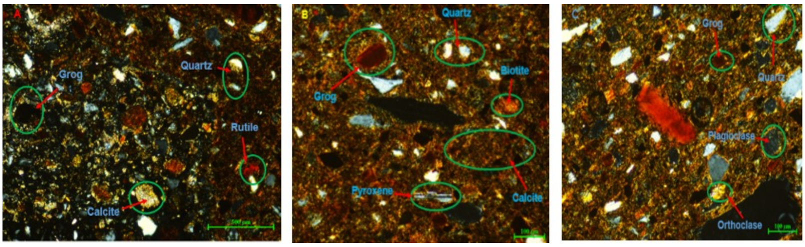


**Fig. 3.** PLM examination of the second pottery sample shows quartz, calcite, grog, rutile, and iron oxide (A), also, the same pottery sample shows quartz grains, grog, calcite, biotite, pyroxene, and iron (B), and another part of the second sample shows sharp-angled quartz grains, plagioclase, orthoclase, and grog (C)

Figure 4a shows the presence of different quartz grains between round grains, sub-round grains, acute-angled quartz grains, limestone powder "calcite," pottery powder "grog," plagioclase, and iron oxide (10X-CN). Figure 4b shows the presence of angular quartz grains, calcite, muscovite, plagioclase, and iron oxide in the pottery sample (10X-CN). Figure 4c of another part shows the presence of quartz, plagioclase, microcline, muscovite, calcite, iron oxide, and cracking (10X-CN).

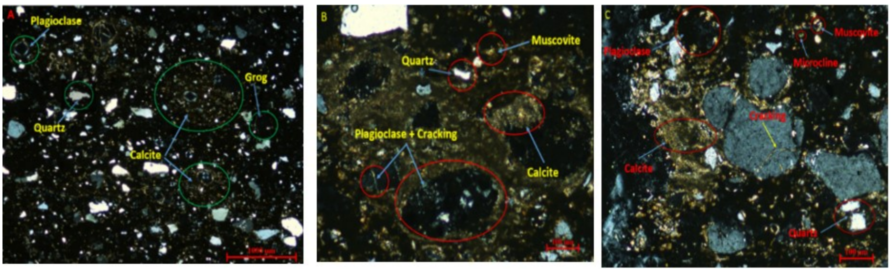


**Fig. 4.** PLM examination of the third pottery sample shows quartz, calcite, grog, and plagioclase (A), also, the same pottery sample shows quartz, calcite, muscovite, plagioclase, and fissure (B), and respectively, another part of the third sample shows quartz, plagioclase, microcline, muscovite, calcite, iron oxide, and cracking (C)

Figure 5a shows the presence of quartz grains, fine texture, calcite, plagioclase, rutile, and iron oxide (10X-CN). Figure 5b shows the presence of sharp-angled quartz grains, grog, calcite, orthoclase, plagioclase, and iron oxide (10X-CN). Figure 5c of another part of the sample shows the presence of sharp-angled quartz grains, grog, pyroxene, microcline, burnt straw, biotite, and iron oxide (10X-CN).

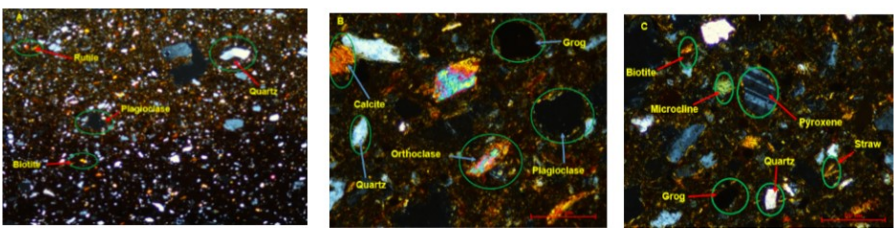


**Fig. 5.** PLM examination of the fourth pottery sample shows quartz, fine texture, calcite, plagioclase, rutile, and iron oxide (A); it also shows quartz, grog, calcite, orthoclase, plagioclase, and iron oxide (B), and another part of the same sample shows sharp-angled quartz, grog, pyroxene, microcline, burnt straw, biotite, and iron oxide (C)

*Examination by Scanning Electron Microscope*

SEM examined the first pottery sample; it shows the presence of fractures, cracks, gaps, peeling of the slip layer, and salts (200×), as shown in figure 6a. SEM examination also shows the phenomenon of crystallisation of salts, gaps, cracks, and coarse quartz grains (1600×), as shown in figure 6b.

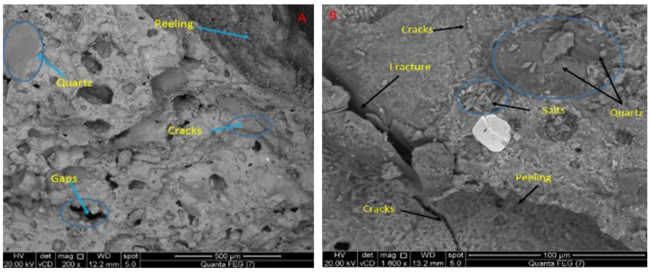


**Fig. 6.** SEM photomicrograph of the first pottery sample shows cracks, gaps, and peeling quartz (A) and also shows crystallisation of salts, gaps, cracks, and coarse quartz grains, peeling, and fracture (B)

Figure 7a shows the scanning electron microscope of the second sample for the surface, proving the presence of flaking, crystallisation of salts, and quartz grains (900×). Figure 7b shows the examination of the same sample for the core area, proving the presence of separation, spread of quartz grains, many gaps, and crystallisation of salts (1000×).

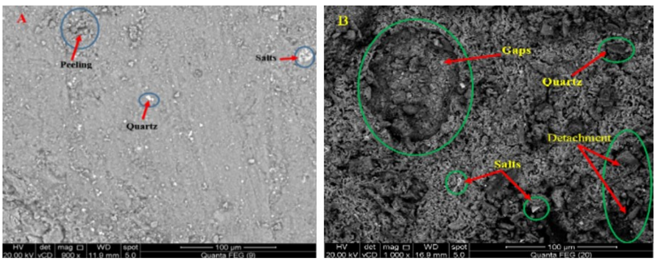


**Fig. 7.** SEM photomicrograph of the second pottery sample shows exfoliation and crystallisation of salts (A) and also shows gaps, separation, and crystallisation of salts (B)

Figure 8a represents the scanning electron microscope of the third pottery sample of the surface area, showing the phenomenon of fracture, separation of grains, soot spots, and crystallisation of salts (2000×). Figure 8b shows the examination of the same sample for the surface area, proving the phenomenon of spots, soot, surface peeling, fracture, and crystallisation of salts (2500×).

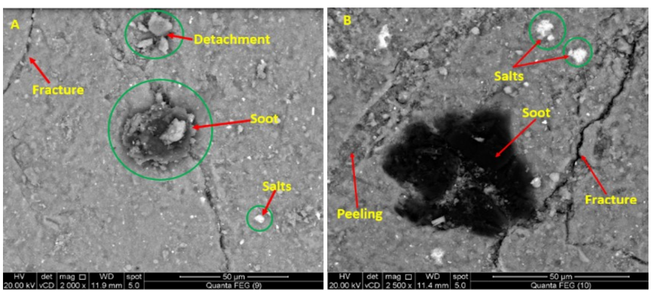


**Fig. 8.** SEM photomicrograph of the third pottery sample shows the phenomenon of fracture, separation of grains, soot spots, and crystallisation of salts (A), as well as soot, surface peeling, fracture, and crystallisation of salts (B)

Figure 9a shows the scanning electron microscope of the fourth pottery sample for the surface area, proving the presence of the phenomenon of cracking, gaps, crystallisation of salts, and flaking (200×). Figure 9b represents an examination of the same sample of the core, showing the phenomenon of salt crystallisation and the spread of gaps (4000×).

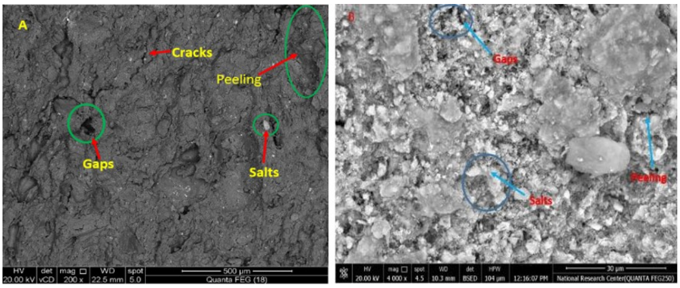


**Fig. 9.** SEM photomicrograph of the fourth pottery sample shows cracking, gaps, crystallisation of salts and peeling (A), as well as the phenomenon of salt crystallisation and the spread of gaps (B)

*The EDX Analysis*

The results of the EDX analysis of four pottery samples, as shown in figures 10a–d, clarified the presence of carbon, oxygen, sodium, magnesium, aluminium, silica, phosphor, sulphur, chlorine, potassium, calcium, titanium, and iron. These EDX analytical results for four sample results are shown in Table 1.

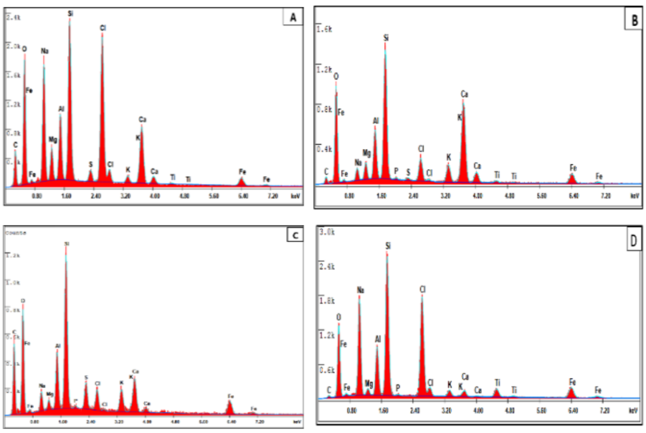


**Fig. 10.** EDX analysis patterns of pottery samples, Tell Daphana, Port Said: A - the first sample (amphora), B - the second sample (plate), C - the third sample (Vessel), D - the fourth sample (terracotta)

**Table 1**. EDX analytical results of investigated pottery samples

| Elemental Weight % | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| C | 2.48 | 5.50 | 27.92 | 5.98 |
| O | 29.79 | 26.82 | 20.08 | 15.74 |
| Na | 1.38 | 1.96 | 1.16 | 14.34 |
| Mg | 1.69 | 2.16 | 0.91 | 0.92 |
| Al | 8.09 | 6.26 | 5.35 | 6.75 |
| Si | 19.26 | 16.91 | 14.95 | 18.81 |

| Elemental Weight % | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| P | 2.07 | 1.33 | 1.31 | 1.26 |
| S | 3.61 | 1.43 | 4.26 | - |
| Cl | 6.26 | 6.12 | 4.90 | 19.49 |
| K | 1.54 | 2.02 | 4.05 | 1.62 |
| Ca | 18.43 | 21.01 | 6.73 | 5.68 |
| Ti | 0.75 | 0.88 | - | 1.58 |
| Fe | 9.88 | 7.60 | 8.37 | 7.83 |

*X-Ray Diffraction Analysis*

Four pottery samples from Tell Daphna in Port Said Governorate and a soil sample were analysed by X-ray diffraction, which revealed the presence of quartz, diopside, rutile, illite, calcite, graphite, and schafarzikite, as shown in figure 11 and table 2.

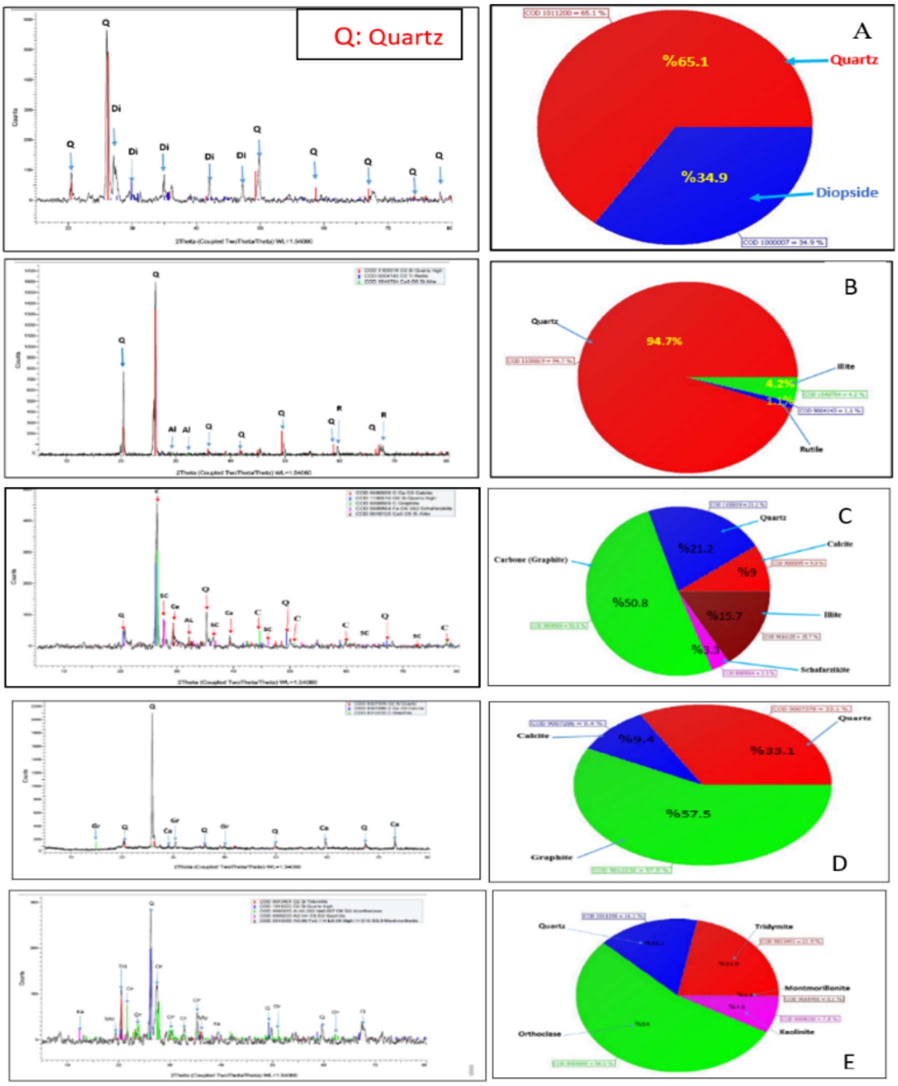


**Fig. 11.** X-ray diffraction: A - the first sample, B - the second sample, C - the third sample, D - the fourth sample, E - the soil sample

**Table 2**. XRD analytical results of pottery samples

| Mineralogical Compositions | | Pottery | samples | | | |
|---|---|---|---|---|---|---|
| Minerals | Chemical composition | a | b | c | d | f soil |
| quartz | $SiO_2$ | 65.1 | 94.7 | 21.2 | 33.1 | 16.1 |
| diopside | $CaMgSi_2O_6$ | 34.9 | - | - | - | - |
| calcite | $CaCO_3$ | - | - | 9 | 9.4 | - |
| rutile | $TiO_2$ | - | 1.1 | - | - | - |
| orthoclase | $KAlSi_3O_8$ | - | - | - | - | 54 |
| tridymite | $SiO_2$ | - | - | - | - | 21.9 |
| graphite | C | - | - | 50.8 | 57.5 | - |
| schafarzikite | $Fe(Sb)_2O_4$ | - | - | 3.3 | - | - |
| illite | $K_xAl_4SiO_{10}(OH)_4$ | - | 4.2 | 15.7 | - | - |
| kaolinite | $Al_2Si_2O_5(OH)_4$ | - | - | - | - | 7.8 |
| montmorillonite | $(Mg,Fe)_4Si_2O_{10})(OH)_8$ | - | - | - | - | 1.1 |

*Thermal analysis*

The thermal analysis TGA shows the weight loss of the first pottery sample due to firing temperature. The weight loss of the sample was 0.195 milligrammes at a firing temperature of 28.60 to 246.88°C. The weight loss of the pottery sample decreased to 0.146mg from 249.21 to 490.63°C; the weight loss of the sample increased to 0.328mg from 490.63 to 813.22°C; the weight loss decreased to 0.102mg at firing temperature from 816.06 to 995.31°C, as shown in figure 12.

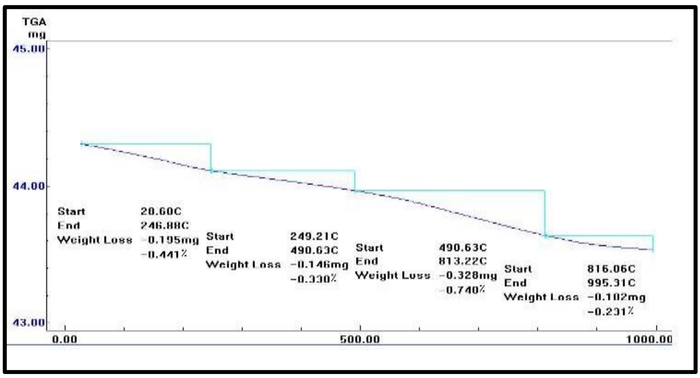


**Fig. 12.** TGA pattern of the first pottery sample

The thermal analysis TGA shows the weight loss of the second pottery sample due to firing temperature. The result of weight loss was 0.788 milligrammes at a firing temperature of 25 to 31.30°C. The weight loss increased to 1.071mg from 316.13 to 648.44°C, the weight loss decreased to 1.065mg from 648.44 to 807.77°C, and the weight loss increased to 4.362mg at firing temperature from 887.81 to 995.31°C, as shown in figure 13.

TGA also shows the weight loss of the third pottery sample due to firing temperature. The weight loss of the sample was 1.414 milligrammes at a firing temperature of 30.03 to 222.47°C. The weight loss decreased to 0.801 milligrammes from 225.38 to 411.39°C, the weight loss increased to 1.839mg from 414.35 to 705.24°C, and the weight loss decreased to 0.778mg at firing temperature from 706.25 to 995.31°C, as shown in figure 14.

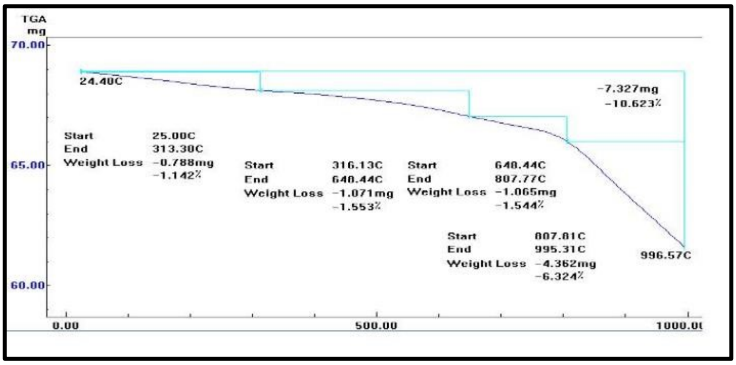


**Fig. 13.** TGA pattern of the second pottery sample

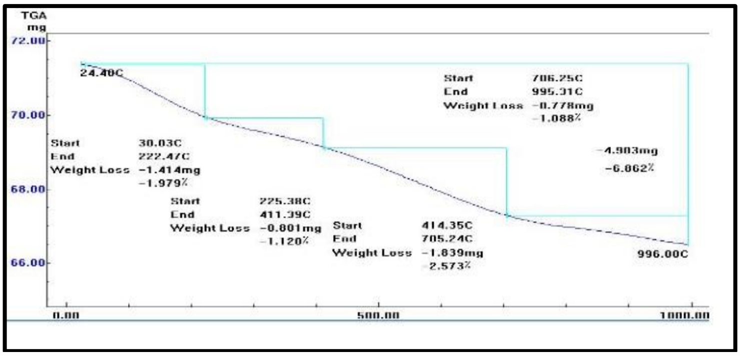


**Fig. 14.** TGA pattern of the third pottery sample

The result of weight loss was 0.343 milligrammes at a firing temperature of 29 to 287.19°C. The weight loss increased to 404mg from 287.50 to 650.51°C. The weight loss was increased to 0.559mg from 651.56 to 705.97°C, as shown in figure 15.

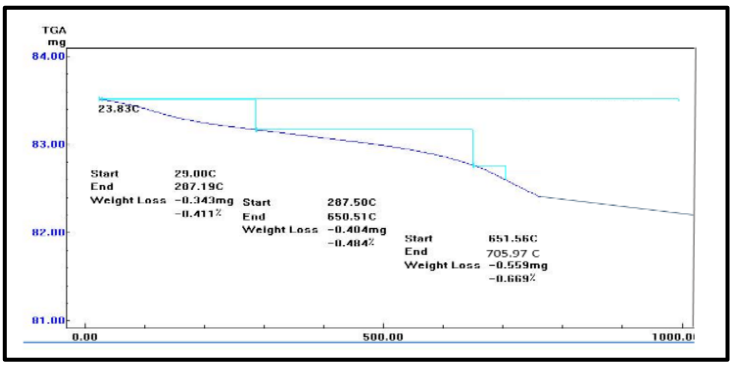


**Fig. 15.** TGA pattern of the fourth pottery sample

## Discussions

Diagnostic examinations and analyses of the components of archaeological pottery extracted from Tell Daphna give a description and identification of archaeometric features, especially raw materials, manufacturing, and fillers, whether organic or inorganic additives, in addition to the identification of surface treatments such as slip layer, degree of burning, and the identification of mineral components and glass phases resulting from burning. As well as various manifestations of damage.

The visual examination proved the manufacturing technology, such as hand or potter wheel shaping techniques, slip layer treatment, and the damage manifestations such as spotting, surface deformation, crystallisation of salts, and fracture due to mechanical damage of the soil [22–24]. The damage is due to the heterogeneity of its mineral components [25] or to burial in the soil [26]. The exposure environment increases the severity of damage, especially temperature and relative humidity [27].

Polarized microscope proved that the clay used in the manufacturing of pottery at Tell Daphna is Nile Clay because of the presence of some minerals such as biotite, muscovite, pyroxene, and plagioclase [28], as shown in figures 2-5. In addition, examination with a polarised microscope demonstrated the presence of some additives to clay in the manufacturing of pottery at this site, such as sand, limestone powder, grog powder, and straw. These organic or inorganic additives are common materials in ancient Egyptian pottery [29], as shown in figures 2-5.

The polarised microscope examination also confirmed the presence of the surface treatment by applying the red wash and slip layer. These surface treatments were common in ancient Egypt. The red wash is a mixture of hematite and water. The slip layer is a mixture of fine grains of clay and water [30]. The examination with a polarised microscope proved the presence of textures ranging from fine to coarse. The first sample has a fine texture, as shown in figure 2a-c; the second sample fabric is from fine to coarse, as shown in figure 3a-c; and the third sample fabric is from medium to coarse, as shown in figure 4a-c. The fourth sample is coarse fabric, as shown in figures 5a-c. The texture appears to be determined by the shape and relationship of the grains to each other [31]. The texture varies according to the type of clay, shaping technique, surface treatment, and burning [32].

Examination with a scanning electron microscope showed that there are some semblances of damage; the first sample suffered from cracks, gaps, and fractures, as shown in figures 6a-b. The second sample suffered from separation, gaps, crusting, and cracks, as shown in figures 7a-b. The third sample suffered from separation, cracking, fracture, spotting, crusting, and crystallisation of salts, as shown in figures 8a-b. The fourth sample suffered from peeling, gaps, cracks, and crystallisation of salts, as shown in figures 9a-b. It is known that the scanning electron microscope plays an important role in identifying and evaluating damage and risks [33]. Cracks may result from the swelling of the clay or the shrinkage of irregular drying [34]. Some cracks in pottery are due to the internal pressures resulting from crystallization of salts [35]. Examination and analysis with a scanning electron microscope equipped with an X-ray energy dispersion unit (EDX) confirmed the burning quality of the first piece of pottery, where the percentage of carbon is 2.48% and the second is 5.50%, and the poor quality of burning for the third sample, where the percentage of carbon is 27.92% and the fourth is 5.98%. The burning atmosphere inside the kiln is oxidising the first and second pieces. It was a reduced atmosphere for the third and fourth samples, as shown in Table 1. The percentage of carbon in the samples indicates a burning atmosphere; it is oxidising in cases of a low percentage of carbon. It is reduced if the percentage of carbon is high [36].

Examination and analysis by scanning electron microscopy (SEM equipped with an X-ray energy dispersion unit) confirmed the presence of chloride, sulphate, and phosphate salts, where the percentage of chlorine in the samples ranged from 4.90 to 19.49%, as shown in Table 1. It turns out that the fourth sample is the toughest and most crystallised, "halite salt." The percentage of chlorine is 19.49% because it is a poor-burning sample-retaining mineral clay core that has a hygroscopic characteristic [37].

The presence of calcium in pottery samples was proven by EDX; the percentage of calcium reached 5.68 to 21.01%, as shown in Table 1. The presence of calcium in the pottery is due to the addition of calcite powder as an additive to the clay to improve its properties [38].

The presence of calcite may be due to the crystallisation of salts due to burial in the soil [39]. The percentage of sulphur in pottery samples ranged from 1.43 to 4.26%, as shown in Table 1. The presence of sulphate salts is due to their burial in the soil. It is one of the insoluble salts in water [40]. EDX also proved the presence of phosphorous in pottery samples, ranging from 1.31 to 2.07%, as shown in Table 1. The salts of chlorides and phosphates are hygroscopic and soluble in water [41]. The crystallization of salts is one of the most important manifestations of damage to the pottery buried in the soil, because pottery is a hygroscopic material that absorbs saline water from the soil [42].

The analysis by X-ray diffraction method proved the presence of quartz and diopside, which indicates that the sample has good burning due to the presence of diopside, which is one of the glass phases that appears above 850°C [43]. As shown in figure 11a, quartz, rutile, and illite were clear from the results of the second sample, as shown in figure 11b. It is clear from the results of the third sample that it burns poorly due to the presence of illite, quartz, and calcite, as shown in figure 11c. It is clear from the results of the fourth sample that the sample had poor burning due to the presence of quartz, graphite, and calcite, as shown in figure 11d and Table 2. It is known that the presence of calcite and the absence of glass phases indicate a low burning temperature [44]. The analysis proved the presence of calcite, which indicates carbonate salts or additives [45], as shown in figure 11. presence of carbonate salts due to burial in the soil [46]. The XRD analysis revealed the presence of quartz, kaolinite, and montmorillonite in the soil of the archaeological site, which confirms that the soil is sandy clay soil.

Thermal analysis of pottery samples proved that the burning temperature of the first sample is about 816.06°C, as shown in figure 12, the second sample is about 887.81°C, as shown in figure 13, the third sample is about 706.25°C, as shown in figure 14, and the fourth sample is 651.56°C, as shown in figure 15. These results indicate that the first and second samples have good burning, the third sample has medium burning, and the fourth sample has poor burning, as shown in figures 12-15. It is known that thermal analysis refers to the determination of the burning heat of pottery [47].

## Restoration

Various examinations and analyses, such as petrographic examination (PLM) with a scanning electron microscope with EDX, X-ray diffraction, and thermal study of pottery at Tell Daphna in Port Said, have proven the presence of soil deposits, in addition to the crystallisation of chloride, sulphate, and phosphate salts and various stains. The research proved the phenomenon of cracking and fracture because of the mechanical action of the soil. Based on these results, the restoration and maintenance of four pottery pieces were restored according to the nature of their damage and scientific studies in the field of restoration, treatment, and maintenance of pottery, where the restoration process included the following:

The pottery at Tell Daphana in Port Said was photographed and documented using examination and analysis techniques. The mechanical cleaning was done according to scientific restoration and treatment strategies, using soft hairbrushes to clean all soil deposits. It played an important role in cleaning fragile soil sediments. The hardened soil sediments adhered to the pottery body were cleaned using metal brushes and scalpels. The cleaning process was carried out under a lens. The mechanical cleaning process continued until the cleaning process became futile. Then chemical cleaning is carried out according to scientific restoration and treatment strategies. Clay soil sediments were cleaned using a mixture of distilled water, acetone, and ethyl alcohol at a ratio of 1:1:1, respectively. Chemical cleaning is carried out locally. Soot spots were also cleaned using a mixture of distilled water and ammonia topically. Lime deposits were cleaned using an EDTA poultice. Crystallised salts were cleaned according to a scientific strategy. Mechanical cleaning was the first, using various brushes and scalpels. The crystallised salts were cleaned under lenses with "6×" magnification so as not to injure the pottery surface. Soluble salts are cleaned by distilled water, especially halite and phosphate salts; insoluble salts are cleaned by Mora poultice, especially calcite and gypsum [48].

The pottery objects were strengthened using nanosilica at a concentration of 0.5%. The consolidation process was applied using the spray method. The initial assembly process started to find out the locations of the pottery fragments. In order to avoid any errors in the final assembly process, the pottery sherds were assembled using paralloid B-82 dissolved in trichloroethylene at a concentration of 50% [49]. The restoration processes are illustrated in Figure 16.


**Fig. 16.** The restoration processes are: A and B—before and after restoration of the first pottery piece; C and D—before and after restoration of the second pottery piece; E and F—before and after restoration of the third pottery piece; and G and H—before and after restoration of the fourth pottery piece

## Conclusion

The research was conducted through diagnostic examinations to identify archaeometric aspects of pottery manufacture at this archaeological site, "Tell Daphna." The clay used in its manufacture is Nile clay. As for the tempers, it was found that they are sand, limestone powder, pottery powder, and straw. The shaping technique is the hand and potter wheel method. The surface treatment is a red wash and slip layer. The burning atmosphere is oxidising for the first and second samples and reducing for the third and fourth samples. The texture ranges from fine to coarse. The burning temperature is about 816°C for the first sample, 887°C for the second sample, 706°C for the third sample, and 651°C for the fourth sample. The research also proved that the samples suffer from different damage aspects such as surface deformation by dirt, spotting with soot, crystallisation of salts, gaps, crusting, separation of grains, various cracks, black spots, fractures, peeling, and some missing parts. It also proved the presence of chloride, sulphate, carbonate, and phosphate salts, as well as the phenomenon of the weakness and lack of durability of pottery pieces at this archaeological site.

The research proved the use of a mixture of distilled water, acetone, and ethyl alcohol at a ratio of 1:1:1, respectively, for removing clay soil deposits. EDTA is used to remove lime deposits. Nano-silica at a concentration of 0.5% is used to strengthen archaeological pottery by the spraying method. Paralloid B 82 dissolved in trichloroethylene at a concentration of 50% in assembling the pottery sherds; it is preferable to display it in the museum at a temperature of 20°C and a relative humidity of 55–60%.

**Acknowledgments**

I extend my sincere thanks and appreciation to Dr. Mohamed Abd Elmaqsod, supervisor of excavation at the archaeological site, and I extend my thanks and gratitude to the restoration specialists and antiquities inspectors in Ismailia in the East of Delta.

**References**

[1] A. Nour El-Din, **Sites of Ancient Egyptian Antiquities**, Part 1, Dar Al-Aqsa Printing and Publishing, Cairo, 2016, p. 361.

[2] I. Kamel, **East Delta Region**, Cairo, 1981.

[3] W. M. Petrie, **History of Egypt**, Vol. 3, Scribner's Sons, 1905, p. 330.

[4] L. François, J. Spencer, **Tell Dafana Reconsidered: the Archaeology of an Egyptian Frontier Town,** British Museum, London, 2014.

[5] M. Abdul-Maqsoud, **Tell Daphna Excavations Reports**, Supreme Council of Antiquities, 2015.

[6] T. Li, *Investigating pre-1949 Chinese paper-based materials by Raman spectroscopy: short review (2000-2017*), **International Journal of Conservation Science, 10**(1), 2019, pp. 15-24.

[7] O. Abdel-ziz, M. Mahmoud, Y. Abo-elfath, M. Samir, A. Ali, *Evaluation of conventional treatments for mirrored silver gelatin prints: experimental and applied study*, **International Journal of Conservation Science, 10**(1), 2019, pp. 81-96.

[8] M. Janpourtahe, *Scientific approach of preservation treatment and restoration procedures on historical royal Songket Sarong*, **International Journal of Conservation Science, 10**(1), 2019, pp. 69-80.

[9] W. Elghareb, *Analytical study of some unfinished obelisk quarry pottery vessels in Aswan, Egypt, Case Study*, **American International Journal of Contemporary Research, 7**(4), 2017, pp. 74-85

[10] A.R. Ramalhinho, M.F. Macedo, *Cultural Heritage risk analysis models: an overview,* **International Journal of Conservation Science, 10**(1), 2019, pp. 39-58.

[11] L. Rampazzi, C. Cort, *Are Commercial pigments reliable references for the analysis of painting?* **International Journal of Conservation Science, 10(**2), 2019, pp. 207-220.

[12] N.A. Bader, *Experimental tests used for treatment of disintegrated granite in valley temple of Khafre – Egypt,* **International Journal of Conservation Science, 10**(2), 2019, pp. 221-232.

[13] M. Ali, S. Omar, *Analytical investigation of deterioration aspects in mihrab of madrasa Gawhariyya of Al-Azhar mosque, Egypt*, **Egyptian Journal of Archaeological and Restoration Studies, 11**(1),2021, pp. 9-17.

[14] G. Montana, A. M. Polito, E. Kistler, M. Mohr, F. Spatafora, *The indigenous settlement of Monte Iato (western Sicily):an ethnoarchaeometric approach for outlining local Archaic*

*ceramic productions*, **Archaeological and Anthropological Sciences, 13**, 2021, Article Number: 142. DOI: 10.1007/s12520-021-01380-7.

[15] W. Elghareb, *Deterioration and consolidation of some pottery vessels in Tel Ajrud, Suez, Egypt*, **International Journal of Conservation Science, 10**(3), 2019, p. 415-428.

[16] H. Barakat, E. Ciliberto, S. Darwish, O. Saqr, *Analytical and experimental study of blemishes formation and preventive conservation of Cellulose acetate microfilms,* **International Journal of Conservation Science, 10**(2), 2019, pp. 279-290.

[17] C. Lucian, *Conservation, maintenance and repair of the old boma historic building in Bagamoyo, Tanzania,* **International Journal of Conservation Science, 10**(3), 2019, pp. 429-440.

[18] G. Deak, F.D. Dumitru, M.A. Moncea, A.M. Panait, A.G. Baraitaru, M.V. Olteanu, M.G. Boboc, S. Stanciu, *Synthesis of ZnO nanoparticles for water treatment applications*, **International Journal of Conservation Science, 10**(2), 2019, pp. 343-350.

[19] I. Sandu, G. Deak, Y. Ding, Y. Ivashko, A.V. Sandu, A. Moncea, I.G. Sandu, *Materials for Finishing of Ancient Monuments and Process of Obtaining and Applying,* **International Journal of Conservation Science, 12**(4), 2021, pp. 1249-1258.

[20] G. Deak, M.A. Moncea, I. Sandu, M. Boboc, F.D. Dumitru, G. Ghita, I.G. Sandu, *Synthesis and characterization of an eco-friendly material for stone monuments prezervation starting from the eggshells,* **International Journal of Conservation Science, 12**(4), 2021, pp. 1289-1296.

[21] I. Sandu, *Modern Aspects Regarding the Conservation of Cultural Heritage Artifacts,* **International Journal of Conservation Science, 13**(4), 2022, pp. 1187-1208.

[22] M. Orlenko, Y. Ivashko, P. Chang, Y. Ding, M. Krupa, K. Kusnierz, I.G. Sandu, *The Specificity of the Restoration and Monument Protective Measures for the Preservation of Historical Chinese Gardens,* **International Journal of Conservation Science, 12**(3), 2021, pp. 1003-1026.

[23] I. Sandu, *New Materials and Advanced Procedures of Conservation Ancient Artifacts,* **Applied Sciences-Basel, 13**(14), 2023, Article Number: 8387, https://doi.org/10.3390/app13148387.

[24] I. Sandu, *Obtaining, Characterization and Applications of Advanced Materials,* **Applied Sciences, 13**(15), 2023, Article Number: 8698, https://doi.org/10.3390/app13148698,

[25] M. Hamdan, M. Garcia, M. Nogues, F. Hassan, A. Flower, M. Aly, A.Senussi, E. Ibrahim, *Ancient Egyptian pottery from the subsurface flood plain of the Saqqara–Memphis area: its mineralogical and geochemical implications*, **Archaeometry, 56**(6), 2014, pp. 987-1008.

[26] S. Buys, V. Oakley, **The Conservation and Restoration of Ceramics,** first edition, Butterworth, Oxford, 1993, pp. 193-194.

[27] J. Cronyn, **The Elements of Archaeological Conservation,** first edition, Routledge, London, 1996, pp. 205-210.

[28] W. Elghareb, *Archaeometry Study and Deterioration of Some Pottery Objects of Suhail Island in South Western Aswan, Egypt: Case Study*, **Current Science International, 7**(2), 2018, pp. 176-190.

[29] S. Panda, G. Jena, D. Garnayak, *Characterization of representative ancient potteries: Chemical, Mineralogical and Morphological Studies,* **International Journal of Conservation Science, 10**(2), 2019, pp. 317-326

[30] L. Damjanović, B. Vesna, Š. Kristina, E. Suzana, H.A. Ivanka, *Characterization of the early Byzantine pottery from Caričin Grad (South Serbia) in terms of composition and firing temperature,* **Journal of Archaeological Science, 46**, 2014, pp. 156-172.

[31] L. Damjanović, I. H. Antunović, B. Ubavka Mioč, V. Bikić, D. Milovanović, R.E. Ivana, *Archaeometric study of medieval pottery excavated at Stari (Old) Ras, Serbia,* **Journal of Archaeological Science, 38**(4), 2011, pp. 818-828.

[32] J. Riederer, **Thin Section Microscopy Applied to the Study of Archaeological Ceramics,** Academic Publishers, Netherlands, Hyperfine Interaction 154, 2004, pp. 143–158.

[33] R. Ravisankar, A. Naseerutheen , G.R. Annamalai, A. Chandrasekaran, A. Rajalakshmi, K. V. Kanagasabapathy, M.V.R. Prasad, K.K. Satpathy, *The analytical investigations of ancient pottery from Kaveripakkam, Vellore dist, Tamilnadu by spectroscopic techniques,* **Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 121,** 2014, pp. 457-463.

[34] P. Rice, **Pottery Analysis**, University of Chicago Press, Ltd., 1996, pp. 354 – 357

[35] M. El-Gohary, W. El-Ghareb, M. Saad, *Damage quantification of archaeological pottery in Sheikh Hamad "Athribis" Sohag- Egypt,* **Ceramics International Journal, 45**(14), 2019, pp.17611-17619.

[36] A. Iordanidis, J.G. Guinea, G. K. Mentessidi, *Analytical study of ancient pottery from the archaeological site of Aiani, northern Greece,* **Materials Characterization, 60**(4), 2009, pp. 292-302.

[37] A. El-Badry, *Deterioration mechanisms affecting the bricks used in the building of water wells at karnak temples, Luxor, Egypt*, **Egyptian Journal of Archaeological and Restoration Studies, 9**(1), 2019, pp. 13-25.

[38] L. Schleicher, V. Miller, K. S. Watkins, L. Naughton, M. Ramsing, *Non-destructive chemical characterization of Ceramic shards from Shipwreck 31CR314 and Brunswick Town, North Carolina,* **Journal of Archaeological Science, 35**(10), 2008, pp.2824-2838

[39] A. Paterakis, M. Steiger, *Salt efflorescence on pottery in the Athenian Agora: a closer look,* **Studies in Conservation, 60**(3), 2015, pp.172–184.

[40] S. Hemeda, K. Walid, *Evaluating the rate of stone art deterioration in Wadi Maghara and Wadi Mukattab, Sinai, Egypt*, **International Journal of Conservation Science, 3**(2), 2012, pp. 79-86.

[41] S. Laura, *Comparison of indoor climate features following different climate guidelines in conservation examples of selected churches in Albania*, **International Journal of Conservation Science, 10**(4), 2019, pp. 623-630.

[42] M.M. Ibrahim, W.S. Mohamed, H.M. Mohamed, *Evaluation of the efficacy of traditional and nano paralloid B 72 for pottery consolidation*, **International Journal of Conservation Science, 13**(1), 2022, pp. 15-30.

[43] M.S. Tite, *Ceramic production, provenance and use—a review,* **Archaeometry, 50**(2), 2008, pp. 216-231.

[44] G. Montana, l. Randazzo, C.B. Fantauzzi, *Archaeometric characterization of late archaic ceramic from Erice (Sicily) aimed to provenance determination,* **Journal of Archaeological Science, 10**(4), 2014, pp. 605-622.

[45] I. Sandu, V. Cotiuga, A.V. Sandu, A.C. Ciocan, G.I. Olteanu, V. Vasilache, *New Archaeometric Characteristics for Ancient Pottery Identification,* **International Journal of Conservation Science, 1**(2), 2010, pp. 75-82.

[46] W. Elghareb, *Archaeometric Investigation of Two Corroded Glass Wares in Tel El-kharoba, North Sinai, Egypt: Case Study*, **American International Journal of Research in Formal, Applied & Natural Sciences, 24**(1), 2018, pp. 22-31.

[47] G. Velraj, A.M. Musthafa, K. Janaki, K. Deenadayalan, N. Basavaiah, *Estimation of firing temperature and ancient geomagnetic field intensity of archaeological potteries recently excavated from Tamilnadu, India,* **Applied Clay Science, 50**(1), 2010, pp. 148-153.
[48] W. Elghareb, *Analysis and restoration of pottery artifacts from tell El-hir, North Sinai, Egypt: A Case study,* **International Journal of Conservation Science, 12**(4), 2021, pp. 1327-1342.
[49] M.M. Ibrahim, S.O. Mohamed, Y.K. Hefni, A.I. Ahmed, *Nano materials for Consolidation and Protection of Egyptian Faience form Matteria, Egypt*, **Journal of Nano Research**, **56**, 2018, pp. 39-48.

---

*Received: August 05, 2022*
*Accepted: September 10, 2023*