

Damage quantification of archaeological pottery in Sheikh Hamad “Athribis” Sohag-Egypt

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ABSTRACT

Many archaeological potteries in Sheikh Hamad (Athribis) Sohag, Egypt suffer from different processes, which led to many deterioration forms. Samples collected from Athribis were submitted to qualitative and quantitative measurements through using different techniques to evaluate their durability states. Significant information derived from these techniques prove that our materials are composed of Si, Al, Fe, Mg, K, Ca, Na and Cl as the main elements of Quartz Albite, Microcline, Calcite and Hemetite (main components of Nile clays) and Halite (main salt characterizes Egyptian land). In addition, SEM reveals that the samples are characterized by cohesion of the granules, non homogeneous texture and different size pores in addition to degradation, dissolution features and cracks. Finally, it can be concluded that most of these artifacts are affected by two main aggressive mechanisms: their burial environment (before excavation) and aired environment (after excavation). These process that finally led to some aggressive deterioration forms.

1. Introduction

1.1. The area under the study

Sheikh Hamad or Athribis (Hut-heryib) area, [fig. \(1-a\)](#) is located on the western bank of the Nile, close to and extending into the rocky slopes on the neighboring desert edge of a farmland at latitude 26°-28° north and longitude 31°-39° east [1,2]. In ancient times, it was situated in the ninth Upper Egyptian Nome, called Mn,w “Min”. During the Greco-Roman times, this nome extended from a point to the south of modern Tahta in the north to some point to the north of modern al-Hagarisa (i.e. ancient Sn-Hr) and al-Munsah, the ancient city of Ptolemais Hermiou in the south. Additionally, the Ptolemaic temple of Athribis is located near the modern city of Sohag, about 200 km to the north of Luxor [3,4]. Through field observations, the area lies in the middle of a flat and open deserted environment. Consequently, there was a great decay of its remains including the various antiquities through different factors, e.g. the natural, religious and human ones. Additionally, the effects of topographical, geomorphological, geological and geo-archaeological effects dominated the site, as well as the effects of the surrounding (burying-external) environments. Morphologically, the underlying soil in the study area is determined by the slope of the limestone rock of the Libyan desert range, against which the mound is

leaning in the west and north-west, [fig. \(1-b\)](#). Geomorphologically, the study area is located in the southwestern part of Sohag governorate, and it is divided into three main geomorphological areas. It reaches its maximum height in the west and includes the following main areas: Floodplain, Wadi mains and Surface of the Eocene limestone plateau. Geologically, it is noted that the prevailing rocks in the region fall into six sediment rock levels that have been deposited through different times and in different levels in the evolution of the Nile valley in Egypt [5–8]. They are recognized from the latest (Modern era) to the oldest one (Eocene time) as follow: 1) Deposits of the wadi, 2) Dandra formation, 3) Qena sand formation, 4) Paleonile sediments, 5) Drunka formation, 6) Thebes formation.

1.2. Pottery's types in Sheikh Hamad

Pottery is the most abundant finding among the archaeological artifacts, where it is certainly a key element in the field of cultural heritage [9]. The study of pottery is useful in defining societal roles and can be used to determine social rankings and relationships to other societies [10]. According to Birch [11] Egyptian pottery has been described as being unglazed, and consequently, being only used for common and domestic purposes, did not require any high degree of skill from potters. Different types and shapes of potteries in the study area were found

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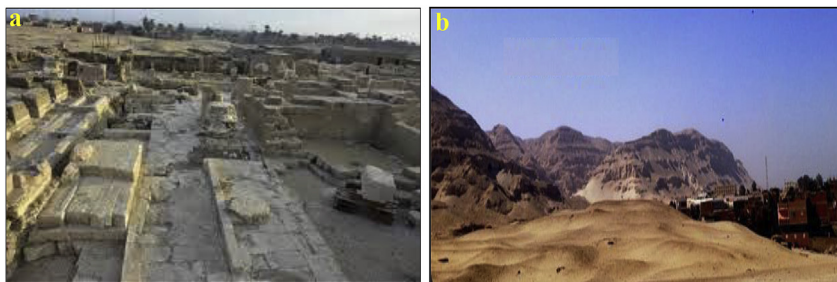


Fig. 1. a. Location of Sheikh Hamad or Athribis (Hut-heryib) area on the western bank of the Nile, b. Morphological features of the area.

such as amphorae, lamp stands, ovens, vessels, plates. In the late 4th and early 5th centuries, the study area underwent various changes, where it was inhabited by the Copts. A layer of plaster was put on the surfaces of some pottery and this layer was decorated with writings and paintings representing the features of the Coptic art. Additionally, there were other belongings including pottery oven, as well as the remains of pottery that preserved the scenes of birds, animals, and human. In addition to geometric and floral paintings in various colors on a light-colored underlay that probably date back to the 13th–18th centuries [12]. In the study area; the styles of pottery varied regarding shape, size, component, color, manufacture method, purpose and history. It was mostly made of Nile silt mixed with silica particles in molds resulting in different degrees of brown. Its decorations were sprig and tangle branches of grapes that dominated in the Coptic art [13].

1.3. Deterioration processes affecting archaeological pottery in Sheikh Hamad

Most of pottery artifacts in the study area suffer from severe deterioration processes both before and after excavation, specially those resulting from aggressive burial environment [14]. On the one hand, its materials are broken down through physical, chemical, and/or biological processes [15]. These effects that result essentially from absence of light, frequent presence of salts in groundwater which in contact with the complex corrosive soils [16,17]. Moreover, an extremely stable temperature, relative humidity and finally limited access of air (particularly, oxygen) [18]. Physically, in this environment pottery can be modified by being broken through soil loads (*Overburden*), freezing/thawing cycles, abrasion, and crystallizing/hydration cycles [19–22]. In addition to the physical effects caused by plant roots penetrations, especially large ones [23]. Chemically, groundwater and soluble salts are the main factors of chemical deterioration of pottery artifacts. In the study area, there are various sources of water, e.g. drinking water, sanitation networks, rain, and canals but the most dangerous of which are sanitation and agricultural networks because of salts and organic materials they contain [24]. Both of them play important roles in deterioration cycles through dissolving of the metal components [25], this process may generate internal pressures sufficient to reduce the entire pottery to dust [17]. Furthermore, these factors cause deterioration and friability to the components of pottery pots due to high proportion of dissolved salts (*salt erosion*) [26] such as sodium chloride, calcium sulfate, calcium and sodium carbonate. Biologically, soils are populated with plant roots, small animals, and many kinds of microbes, e.g. protozoa, algae, fungi, and bacteria. These factors are important to the soil, but most of the biomass and biological activity is provided by plant roots, fungi, and bacteria [27,28]. Regarding plant roots in the soil when pottery becomes softer after being buried in wet conditions, they may penetrate through the body causing complete damage. This may happen, particularly, in the case of cremation urns interred in acid soils as plant roots grow towards the nutrient-rich materials inside the urns. However, this may not be the end of the matter because when pottery is stained in this manner it finds its way into a deposit containing decaying vegetation, there is a danger of generating tannic acids when

plants react with the iron compounds to produce iron tannates. These cause blue-black stains, and are chemically very similar to old-fashioned iron gall ink [29]. On the other hand, all of the previous deterioration mechanisms are boosted after excavation due to the presences of some effective extrinsic factors. According to many searchers [30–34]. These factors include temperature, relative humidity, air pollution, light, and wrong storage. In this regard, the object undergoes a transformation that can affect its color, weight, composition and size, which leads to total deterioration. This can be quite traumatic for the object, starting processes which can result in its complete disappearance, sometimes within a few hours. Finally, all of these factors and its related mechanisms leading to deterioration forms are shown in Fig. 2.

2. Materials and methods

2.1. Materials used

Six shards of archaeological pottery were collected from *Sheikh Hamad* in order to describe, analyze, and correlate the collected data, in addition to qualify the pottery deterioration features.

2.2. Methods used

According to some specialists [35–38] PM model *Nikon, Eclipse Lvioopol* was used for studying our samples using different magnifications to describe the fabric, size, mineralogical components. Added to that, identifying granules form, determining the intra-relations of granules and studying some deterioration products. SEM-EDS model *Quanta FEG250 SEM unit* at ENRC was adapted to characterize and defines the provenances of pottery shards through comparing its elemental components to reference groups [39]. Furthermore, studying the raw materials used, surface decoration and information of firing procedures [40]. XRD device model *Philips Analytical X-Ray B.V. was used* to identify different mineral phases in the samples [41], as well as identifying manufacture techniques, firing conditions, atmosphere and, firing techniques employed by the potters [42]. According to Tite [43,44]. TG-DTA analyses were performed using *Shimadzu-simultaneous thermal analysis type DTA-50* to determine the firing temperature of our samples and evaluate their function of temperature and materials characterization. Also, to explain how individual minerals or substances change during a gradual increase in temperature after heating the sample in approximately 1000 °C [45]. In addition to obtaining some additional information about the properties such as degree of crystallinity, particle size, state of hydration, decomposition and transformation [46]. Production technology, original burning temperature, gaseous weather, type of clay used, and added minerals as well [47].

3. Results

3.1. PLM investigation results

The studied shards were examined by a polarized microscope,

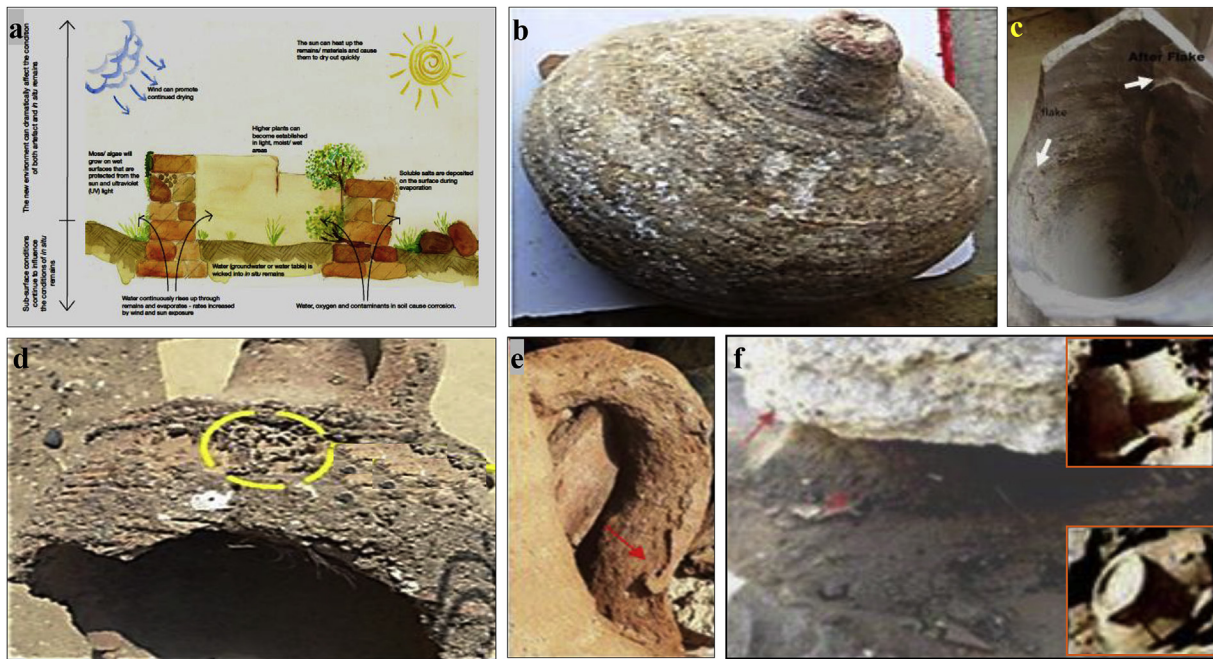


Fig. 2. a. Factors affecting the deterioration of archaeological remains after (Acton & Holt, 2012), b. Some flake zones, c. Crystallized salts, d. Soiling and crusting, e. Heat effect, f. Crushing empty pots into small fractions.

Table 1
Visual appearances of investigated pottery shards.

Investigated shards			
1		4	
2		5	
3		6	

Table 1 illustrates the spread of fine quartz grains, angular quartz granules, calcite and grog (added materials), in addition to limestone fauna (microfossils of calcium carbonate). Another sample contains quartz granules; mostly sharp edged and partly of mica and rutile, in

the middle, pyroxene, twinning plagioclase, rutile and ferric oxides. Thus, it could be concluded that the samples composed have Nile clays origin, all of these features are shown fig. (3).

3.2. SEM observations and SEM-EDS analytical results

The core of the investigated shards examined by SEM illustrating the tininess of granules' size forming the pottery and complete cohesion. It includes many gaps and cracks of different sizes and forms. It also shows that the sample's textures are mostly non-homogeneous and affected by degradation processes, in addition to the presence of some salts and impurities in the pores and gaps especially chlorides. Moreover, the existence of magnesium oxides, aluminum, silicon, potassium and iron is observed as shown in fig. (4). EDS analytical results of the same area attested that there are some minor differences between the investigated samples as listed in Table 2. They are mostly composed of silicon, aluminum, iron, magnesium, and potassium oxides as the main elements, in addition to some minor elements as sodium, chlorine, phosphor, titanium, and sulphur.

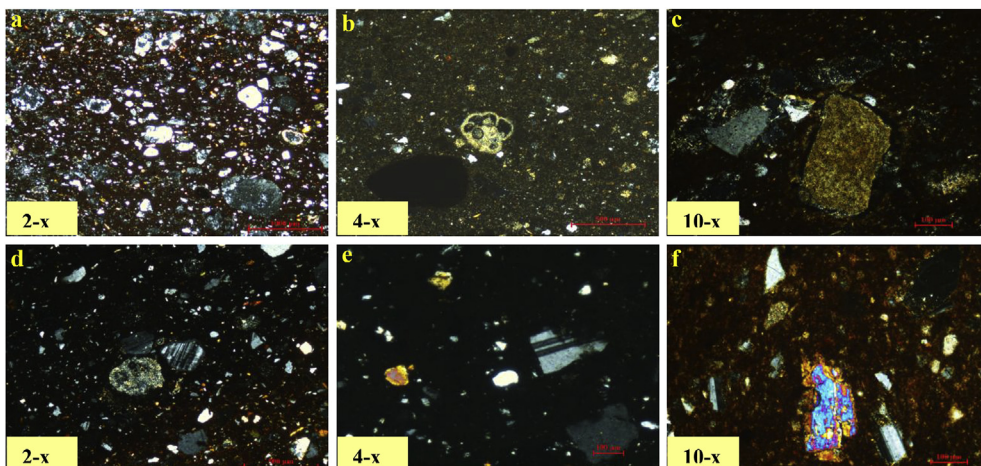


Fig. 3. PM examination of some pottery shards show a. Quartz “fine to medium fabric” and iron oxide, b. A fossil of calcium carbonate on a surface rich in ferric oxides, c. Calcite and quartz grains, d. Mica minerals, e.g. biotite and rutile heavily exist on a fabric rich in ferric oxides, e. Plagioclase, pyroxene, quartz and rutile, f. Rutile, plagioclase and pyroxene.

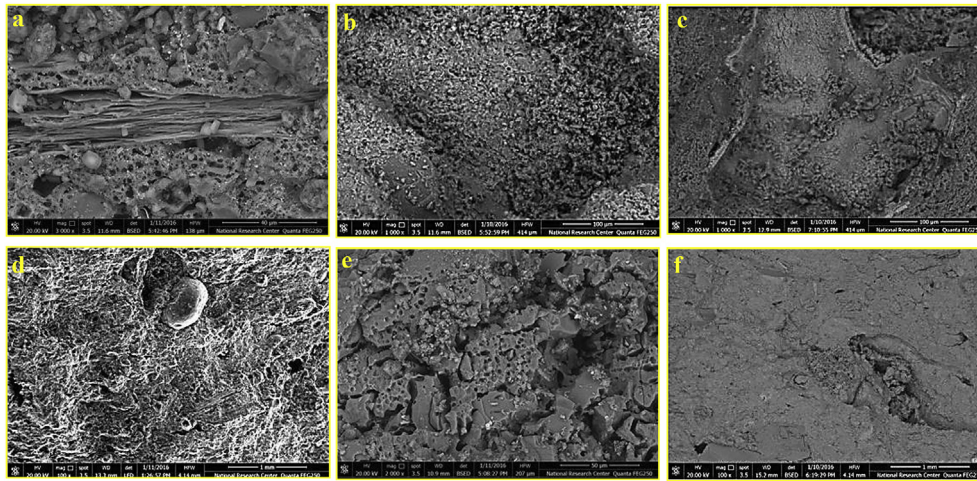


Fig. 4. SEM photomicrograph of some pottery shards show a. Fine size (1000-x), b. Cohesion of the granules (100-x), c. A non homogeneous texture and different size pores (100-x), d. Some degradation and dissolution features (100-x), e. White crystals, spread thin gaps and cracks (2000-x), f. Non-homogenous tissue (3000-x).

Table 2

EDS analytical results of investigated pottery shards.

Elemental Weight %	Samples					
	1	2	3	4	5	6
C	–	2.72	–	–	–	–
O	42.75	50.71	40.07	47.47	49.36	50.04
Na	2.92	–	9.94	2.34	4.04	1.97
Mg	2.18	2.69	2.79	2.51	–	1.76
Al	7.80	7.23	5.27	9.62	10.42	7.23
Si	23.13	18.6	11.12	24.0	20.52	22.22
P	–	0.47	–	–	–	–
S	–	0.59	2.47	–	–	–
Cl	1.88	0.82	6.98	0.85	0.62	0.55
Ca	3.93	–	6.95	3.37	5.00	8.26
K	2.99	1.93	1.78	1.48	3.22	1.89
Fe	12.41	1.39	13.67	8.35	2.12	5.5

3.3. XRD analytical results

X-ray diffraction analysis illustrates that the samples contains many and different mineral phases in three main categories (*major, minor and trace one*). The major minerals contain quartz, calcite, albite, and microcline. The minor ones include halit and hemetite, in addition to traces one; it is magnetite. All these results are listed in Table 3 and its phases are shown in fig. (5).

3.4. Thermogravimetric-differential thermal analysis (TG-DTA)

The thermal analysis of the investigated shards (TG-DTA) proves the next five points: 1) endothermic peak is around (100 °C) in 1, 3 and 4 shards and it dues to moisture content. The same peak in shards 2, 5,

Table 3

XRD analytical results (Semi quantitative %) of investigated pottery shards.

Mineralogical Compositions		Samples					
Minerals	Chemical composition	1	2	3	4	5	6
Quartz (Q)	SiO ₂	43.5	40.3	16	50.9	48.7	53.7
Calcite (Ca)	CaCO ₃	–	33.7	–	–	–	21
Albite (A)	NaAlSi ₃ O ₈	34.1	26	26.4	37.4	29.9	29.1
Microcline (MI)	KAlSi ₃ O ₈	17.0	–	57.6	–	21.4	–
Halit (Ha)	NaCl	–	–	–	–	–	5.4
Hemetite (H)	Fe ₂ O ₃	–	–	–	11.7	–	–
Magnetite (M)	Fe ₃ O ₄	5.3	–	–	–	–	–

and 6 appearing at about (292 °C) it is attributed to “bound” water, or to “hydrated” interlayer cations (as in swelling clay minerals). 2) The endothermic effect from room temperature (100 °C) which was identified in 1, 3 and 4 shards is due to the release of hygroscopic water. 3) Weight loss in all shards from room temperature to (> 100 °C), changing between 0.212% – 10.409% and it is attributed to the removal of hygroscopic water. 4) Weight loss in all shards at (400–600 °C) changing between 0.974% and 4.093% was assigned to the decomposition of hydroxyls (organic materials) and it is attributed to the presence of organic molecule in all investigated shards. 5) Weight loss in shards 1, 2 and 4 varies between 0.472% – 0.989% at (700 °C–800 °C) and it was assigned to the decomposition of calcite. While there is no calcite decomposition in 3, 5, 6 shards in the same rang, which is proven by XRD results. These results are listed in Table 4 and shown in Fig. 6.

4. Discussion

All deterioration symptoms that affected pottery artifacts in our case study are essentially related, on the one hand, to invisible factors or buried environment (*before excavation*), which act their negative role beneath the surface [48]. On other hand, they are related to visible factors (*after excavation*) that plays their role through extrinsic deterioration processes [49]. Regarding crystallized salts and flake zones, fig. (4-b & c) it is well known that they are linked parameters in the deterioration process of archaeological pottery. Where pottery can't be generally found intact, this allows the infiltration of aqueous borne contaminants, e.g. dissolved salts, into their body (*before excavation*). These salts can infiltrate pottery bodies and crystallize when they become dry (*after excavation*) [50]. Furthermore, crystallization process can also happen on pottery surfaces, which lead to *body flake* pieces with the salt crystals expanding [51]. Furthermore, different types of soil salts may play a great role in the deterioration of buried pottery, especially with high rates of moisture depending on the location and other surrounding conditions [24,52]. In addition to many other issues, such as: *salt type, rate of ventilation, solubility, existence of ions* that help deposition, *pores' dirt and moisture* [53,54]. Through our presented results, it could be claimed that soluble salts commonly associated with deterioration of potteries is sodium chlorides (NaCl) particularly when it re-crystallizing [29]. In addition to some other washable salts as nitrates and phosphates, while, nitrates are generally originate from decaying organic materials, phosphates are found in considerable concentrations in kiln sites owing to the presence of flay ash [55,56]. Moreover, carbonates are often referred to as insoluble salts although they are in fact slowly soluble and may be associated with pottery damage [57].

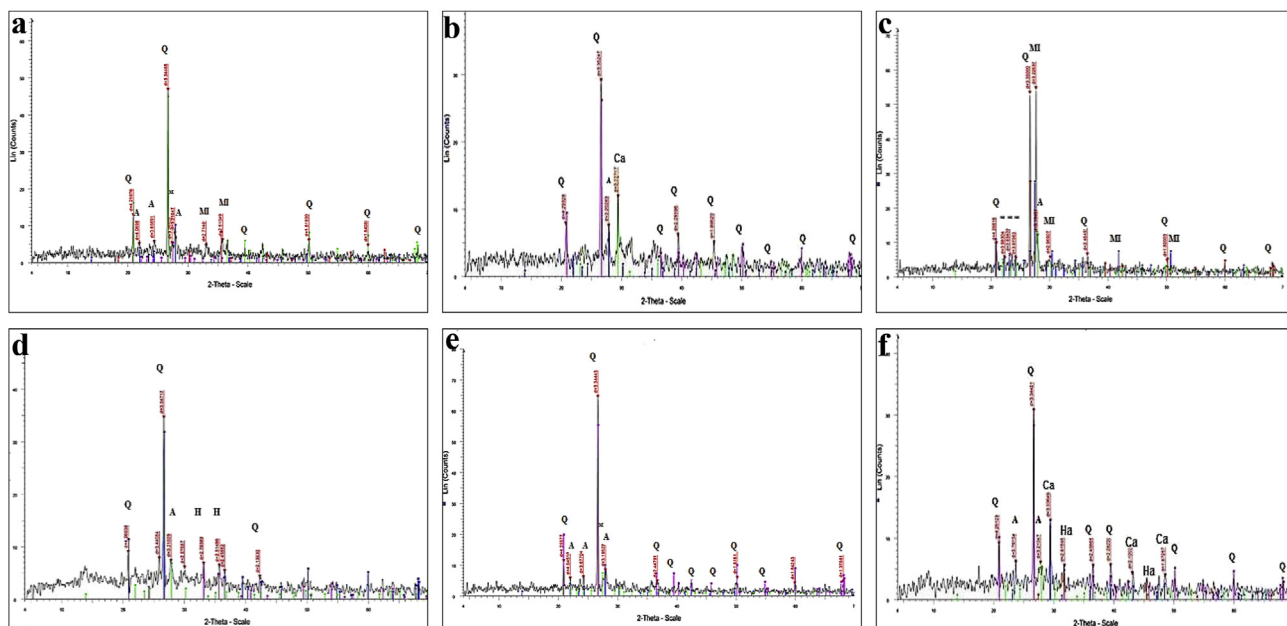


Fig. 5. XRD charts show mineralogical composition of 2 of pottery shards samples (due to the similarity of XRD patterns).

Heat effects (*thermal shock & Fading feature*) may come from natural sources, e.g. sun, or artificial ones, e.g. heating, light, fuel burning or fire [38]. According to Jin & Mai [58] temperature plays an important role in the deterioration of archaeological pottery, whether because of its role individually or for being with the other factors in addition to its impact on other climate elements. In our case study, the differences in temperature rates lead to variation in the shrinkage and expansion indexes, then changing the mineralogical components of pottery that are transformed over time into separate components [59]. Furthermore, violent changes of temperature known by thermal shock cause stresses on our artifacts that may result in aggressive damage features as argued by Kuhn [60]. Extremes of temperature especially those associated with rapid fluctuations over short periods of time can also cause damages by thermal shock or by weakening existing faults [29]. In this regard, there are two main deterioration mechanisms that could have happened due to differences in temperature degrees both in the exposure and the burial environments as reported previously in Sadek [57]. The first one is expansion and contraction mechanism that causes internal stresses, deformities and cracks [61], in addition to structural damages, warping, splitting, and breaking forms [62]. The second one is the rapid evaporation of salty solutions caused by high temperature which make

different salts become fluorescent on the outer or lower surface of pottery, causing a deformation of the surface and eliminating its decorations through flaking off [63]. Within the same context, loose cohesion, fig. (4-d & e) is also attributed to the effects of different rates of temperature. These difference that play an important role in changing the crystalline forms of salts dissolved in water to take several forms particularly with alternative cycles of wetting and drying [49].

Soiling and crusting; are two major forms of deterioration that are essentially attributed to the aggressive effects of air pollutants and some anthropogenic activities [64]. In our case, soiling present as dirt deposits that created through particles, droppings or anthropogenic influences as attested by Pavia Santamaria [65] in her case study. Crusting both dark and light color are firmly adhesive deposits [66] and it is mostly attributed to burial and/or anthropogenic influences in certain areas. These deposits are mainly composed of (Ca, Si, C, Al, Fe, and Mg & K), in addition some salty components (Na & Cl) as could be seen in EDX patterns, fig (7-a, b). Crushing affecting empty pots into small fractions, fig. (4-f) is the main deterioration form resulting from burial environment in general, and it is the main symptom that affected our pottery. According to Saad [14] this form is mostly due to soil loads or overburden by nature, dynamic and burial or displacement of

Table 4
TG-DTA analytical results of investigated pottery shards.

Samples	Thermal Characteristics								
	DTA (%) Up to		TG (°C)						
	Endo.	Exo.	100	400	500	700	800	900	1000
1	130.72 700.27	0	1.753	1.824	–	3.436	0.939	1.103	–
2	0	344.83 437.01 878.95 974.98	2.988	–	–	4.093	0.502	0.118	–
3	133- 174.27	663.11	0.627	–	0.749	–	–	0.171	–
4	139.68	450.35 892.92	0.212	0.674	–	0.587	–	–	–
5	0	148.86 796.19	0.258	–	0.869	–	–	0.388	–
6	–	281.99	10.409	1.945	3.692	–	–	–	–

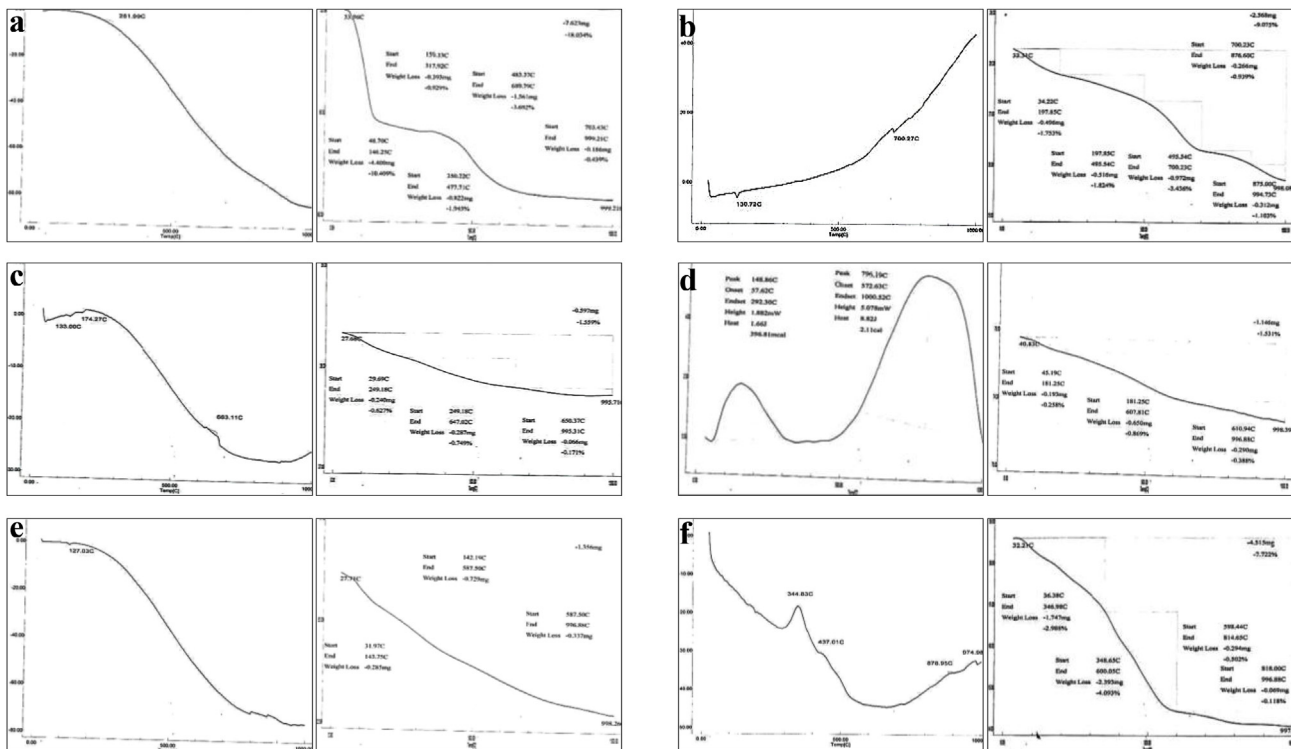


Fig. 6. TG-DTA analytical results of 2 of pottery shards samples (due to the similarity of TG-DTA analytical results).

artifacts or due to “normal” syn-depositional and post-depositional biomechanical endogenic processes. Where, soft pottery may be permanently deformed as a results of mechanical loads and pressure (*outside to inside*) buried in the soil [20,21]. All of the previous deterioration processes and its resulted forms are associated with many manufacturing faults related to the life-cycle of pottery (*intrinsic deterioration processes*). These faults that could be concluded as faults of: 1) collecting and preparing, 2) blending and kneading, 3) shaping, 4) drying and 5) firing.

Upon investigation, fig. (3) it can be concluded that the presence of quartz “*fine to medium fabric*”, in addition to mica, biotite, rutile and grog, indicates that the pottery raw material has Nile origin. It is called “*Nile alluvium or Nile silt*” and it is composed of particles carried by Nile waters that usually consist of large amounts of silica [67]. Quartz is the most important and versatile ceramic component that is widely available in raw materials in the earth's surface, and it is a fundamental constituent of a wide range of ceramic products [68]. Iron oxide is considered one of the main components of Egyptian clays basically composed of hydrous aluminum, iron and magnesium silicates which can play an important role in the characteristics of the final product of pottery [69]. Limestone fauna originates from a type of limestone made mostly of calcium carbonate (CaCO_3) with an abundance of fossils or fossil traces, especially *nummulites sp* [70,71]. It may be also attributed to some fossils activities particularly *foraminifera sp* [72]. Calcite appears as primary and regular grains due to the burning degree which is less than 800°C or above [73]. Or it could be added as a flux to the clay dough to improve its characteristics during kneading and formation or reduction of the burning temperature [55]. Mica and rutile heavily exist on fabrics rich in ferric oxides, where, mica belongs to the isomorphous clay minerals family [74]. These minerals are naturally added materials within clays, and they function as tempers in ceramic mixture, which lead to good workability, good drying characteristics, toughness and strength after firing [75,76]. Plagioclase is feldspar minerals composed of silicates containing considerable amounts of sodium and calcium [17]. They play as tempers in ceramic mixture similar to micas [77]. Pyroxene and rutile spread in most of the shards indicating that they are

well-burned which suggests that the used clay was brought from the Nile. Pyroxene is a natural raw material constituent present in various ceramic families [78]; it is responsible for the pale red or pale yellow color of the investigated samples as argued by Brich [79]. Rutile occurs as a primary deposit tends to be low in iron-bearing impurity [80], and it is responsible for yellow color present in some study shards as attested previously by Gustavo de Castro et al. [69].

Through evaluation using SEM micrographs, fig. (4), it can be claimed that most of our samples are deteriorated because of different surrounding environmental factors. Where the cohesion of the granules resulted essentially due to the effects of brittleness and less perfect connection of the lattices along the grain boundaries [81], in addition to the effects of leaching conditions which can evidence the loss of cohesion among particles attributed to the increase of the water absorption [69]. Non-homogeneous texture and different size of pores are mostly attributed to the aggressive effects of wet and dry abrasive processes that lead to breakdown of pottery materials [26]. Moreover, the geometry of the pore spaces (*pore-size distribution, pore tortuosity, and the connectivity among pores*) are also affected which becomes much more complicated because of the changing of soil structure during its wetting and leaching processes [82,83]. Degradation and dissolution features; can occur especially in low-fired potteries (*around 600°C*), particularly with the presence of some mineral particles that are soluble in water, such as CaCO_3 or $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ as presented previously by Buys & Oakley [29]. This process that can be created through entering the salts within the clay bodies, these salts which are varied between the types buried underground for decades, or that are already naturally occurring in the components of the materials used [84]. In our case study this process lead to alternative cycles of hydration and crystallization, then crumble the physical component of the object body overtime until it is completely destroyed [85]. White crystals spread thin gaps and cracks caused by salt contamination that may occur in unwashed objects recovered from buried or underwater sites. These crystals result from soluble salts that are mostly composed of chlorides and sulfates. They mostly affect pottery deterioration through witting (*dissolving*) and drying (*re-crystallizing*) processes [29] leading finally to

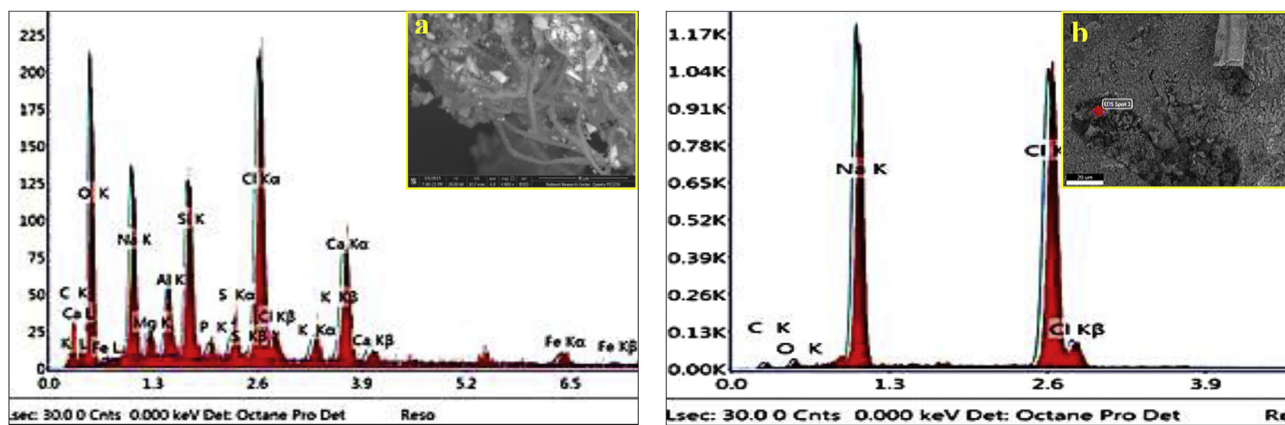


Fig. 7. EDS-SEM analytical results of soiling and crusting accumulated on pottery shards on 2 of pottery shards (due to the similarity of EDS analytical results).

expand and break up the ceramic as argued before by Gilroy & Godfrey [86]. Gaps and cracks are mostly resulted by some manufacturers' defects that attributed to the phases of drying and burning, where, large granules are formed on the surface and the body becomes full of gaps or pits [87,88]. Also, some types of cracks are caused by the effects of internal stresses created by the effects of temperature fluctuations (heating & cooling cycles) as reported by Sadek [57] in his master study.

Within the same context, the quantitative elemental data, Table 2, Fig. 7 prove that our pottery is a well-burned type because carbon does not accurately exist in the most investigated samples but they contain some chlorides. However, the existence of the above mentioned elements suggest that the clay used is brought from the Nile because these elements characterize any pottery made of Nile clay [89]. Regarding the presence of C, in sample (2) it mainly generates in two major forms (CO and/or CO₂) and it is due to firing of clays in conventional furnaces using fuels such as wood, charcoal, etc... as reported previously by Faria et al. [90]. The existence of Na and Cl in the most of the samples is related to salt contamination through effects of (NaCl) characterized groundwater dominated in Egyptian land [91,92]. Furthermore, the presence of sulphur (S) and phosphorous (P) with lower ratios prove the existence of their salts being buried in the soil and the presence of fly ash [14]. Through these results, we can classify the clay used in our case as kaolinite-based clay with higher values of SiO₂ and Al₂O₃, in addition to considerable amounts of Fe₂O₃, MgO, CaO and K₂O. Where, the presence of Iron (phase hematite) indicates that the firing atmosphere in the kiln was oxidized [93]. Also, its present as fondant agent points to the prone for the red color achieved after firing as reported previously by Gustavo de Castro et al. [69]. Regarding magnesium, calcium and potassium oxides; they lead to lower clay refractory properties. In addition to that, calcium may result from dissolution of CaCO₃ because of post-deposition of pottery due to the low pH environment of the soil [94].

The estimated minerals by X-ray diffraction given in Table 3 & fig (5) are confirmed by the findings of the main results of PM where, quartz, calcite, albite and microcline are the major components of the investigated materials. These minerals that are essentially composed of Nile alluvium or Nile silt [95]. On the other hand, the presence of halite as a minor component that amounts to 5.4% in samples (6) is attributed to the deposition and burial processes by layers of sediments. In addition to some changes brought about by the effects of the elevated temperatures and pressures within the soil as attested by Haas et al. [96]. Regarding hematite and magnetite; they are present as unique components dominated in buried soil. According to Refs. [97–99] the high amount of hematite (Fe₂O₃) in some samples (11.7% in sample 4) is due to the crystallization process between 800 °C and 1200 °C after the processing of clay minerals. It also indicates on one hand, the prone for the red color achieved after firing. On the other hand, it indicates the presence goethite mineral (FeO·OH) in clays of pottery as reported

by Gustavo de Castro [69] in his case study. Through explaining TG-DTA data, Fig. 6 it could be concluded that the endothermic effects of room temperature in investigated sample (1) up to 130 °C is attributed to the release of hygroscopic water. The DTA curve exhibits a small endothermic peak at about 700 °C. It results from calcium carbonate formed from calcium in the solution and CO₂ dissolved from air, while exothermic is not showed of this shard [46,100]. The TG curves present the gradual weight loss in shard one due to the dehydration of water molecules at a temperature range of 34.22–197.85 °C (1.753%). Weight loss of shard one is caused by the decomposition of hydroxyls (organic materials) 3.436% at (495.54–700.23 °C). The decomposition reaction of carbonates that appeared at a range of (700.23–876.6 °C) was identified with weight losses changing between (3.436 and 0.939%). Furthermore, the existence of calcite-Albite was previously revealed by XRD. Moreover, the exothermic effect of room temperature in sample (2) up to 344 °C and it is attributed to the recrystallization of amorphous or ill-crystallized Fe-oxy hydroxides. The exothermic peaks in the range of 437 °C were caused by the combustion of the organic constituent, while the peaks observed in the range of (878–974 °C). In this regard, the exothermic effects identified within these temperatures were attributed to the combustion of DE carbonation reactions of calcite and albite mainly. However, the endothermic is not showed of this shard. The TG curves present the gradual weight loss in shard two due to the dehydration of water molecules at a temperature range of 36.38–346.98 °C (2.988%). Weight loss of shard two is caused by the decomposition of hydroxyls (organic materials) 4.093% at (346–600 °C). The decomposition reaction of carbonates that appeared at a range of (600–814 °C) was identified with the weight losses changing between (4.093 and 0.502%).

5. Conclusion

This study aims to quantify the deterioration forms affected of archaeological pottery in Sheikh Hamad "Athribis" Sohag-Egypt. It illustrates how long-term deterioration affected these artifacts, and how similar are they to other mechanisms of damaging factors. Such factors are mainly due to the environments of burial and excavation, in addition to some intrinsic factors like firing temperatures and conditions. To better understand such factors, a number of examinations were carried out for quantifying the different deterioration mechanisms and forms. PM examinations prove that the studied materials are composed of Nile clay, and indicate the presence of added quartz, calcite, and limestone fauna. XRD investigation illustrates that the samples contain three mineral phases (major, minor, and trace) such as albite, microcline, halite, hematite, and magnetite. SEM-EDS investigation proves that the samples have non-homogeneous textures and they include many gaps and cracks of different sizes and forms filled with some salts, in addition to impurities that composed of aluminum, silicon, magnesium,

potassium and iron. Finally, TG-DTA resulted data endothermic peak is around in (100 °C) in samples 1, 3 and 4 due to moisture content and about (292 °C) 2, 5, and 6 due to “bound” water, or to “hydrated” interlayer cations. Weight loss in all shards in different temperature degrees varies due to different factors as follow: removal of hygroscopic water, decomposition of hydroxyls (organic materials), presence of organic molecule, and decomposition of calcite. Finally, it can be said that our objects suffer from aggressive deterioration factors, and need a plan for restoration and conservation including procedures of intervention, particularly cleaning and consolidating processes.

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