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**Investigation of the Corrosion of Islamic Lead-Glazed Pottery  
from Jordan and its Deterioration**

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**Gender, Race, and Male Privilege in Post- Modern Society**

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**Abstract**

In antiquity, two types of glaze were known: alkaline and lead glazes. The former seemed to be first known in Ancient Egypt a few thousand years ago. In this study, examination deals with a biochemical and physical alteration of a lead-glazed pottery. A multi-analytical approach was used to investigate Islamic lead-glazed pottery artefacts from the archaeological site Tal al alhusun, Jordan. The chemical, structural, and micro-morphological characterizations were performed using a combination of ICP–AES, to identify the clay materials and the glaze, optical and scanning electron microscopy (SEM) and analyzed semi-quantitatively using an energy dispersive spectrometer. Sample under microscope showed some brilliant particles of a gray-black compound contained within most of the cracks and bubbles, Semi-quantitative chemical analyses, using EDS, were carried out in gray-black zones (cracks, bubbles, etc.). On the other hand, EDX analysis showed glaze contained lead sulfide or galena (PbS) as well as lead aluminum silicate:  $\text{Pb}_6\text{Al}_2\text{Si}_6\text{O}_{21}$ . Degradation phenomena such as the partial devitrification of the glaze, i.e. the slow structural reorganization towards stable crystalline phases, and the leaching by mineral dissolution in the soil, were determined. It is understood, however, that the chemical composition of the glaze, especially its lead content and its preparation and firing conditions (which develop the physical aspect: cracks, bubbles, thickness, etc.) are the parameters that control the intensity of this degradation process and consequently the observed phenomenon.

**Keywords:** Lead-glazed, Islamic pottery, corrosion, SEM -EDS, XRD.

**Acknowledgements:** The author wish to thank Prof. Zeidoun Al-Muheisen and prof. Abde alrahman serojy from Yarmouk University for providing suitable samples from well dated archaeological contexts.

## Introduction

A glaze is a thin coating of glass (enamel) applied on the surface of a ceramic vessel. It is usually applied in a second stage firing, after a first firing of the vessel. However, simultaneous glazing is also common particularly in salt glazing where the ceramist throws alkaline salts in the kiln once the high temperature is achieved. The glaze is expected to have one or both of two functions: esthetic, by displaying and supporting colorful decoration, and technical by rendering the ceramic vessel impermeable to liquids.

In antiquity, two types of glaze were known: alkaline and lead glazes. The former seemed to be first known in Ancient Egypt a few thousand years ago. The latter, however, was first observed in ceramics from Ancient Greece. Both glazes were discovered and have been in use before the glass itself (Kleinmann, 1986). Glazing remained a minor component of the ceramic industry throughout the Antiquity and the Classical period, despite a continuous evolution especially in the Roman period. It only started to prosper during the Middle Ages in both China and the Islamic empire. During this period, advanced ceramic and glazing technologies started to spread out from the Middle East to Western Europe through Italian city-states and the direct Islamic presence in Spain (Abd-Allah, 2010).

Glasses and glazes are materials vulnerable to alteration due to their unstable structure and composition. The alteration is commonly manifested by ion exchange (dissolution) and devitrification, leading to destruction of the glass structure. Meanwhile, corrosion of lead glaze or at least the release of its lead component continued to be an important health issue. The observation of the characteristic corrosion products on buried glass goes back at least as far as Brewster (1863) who reported the characteristic flakiness and surface iridescence. The scientific interpretation of these phenomena appear that when glass is in contact with moisture or, when a glass reacts with water or with an aqueous solution, chemical changes occur at the surface and may then spread to the whole of the glass body, depending on which type of surface has been produced. Lead had not been deliberately added to glass and glass maker did not have the knowledge that lead could be used as a main fluxing ingredient. So, lead was probably including a long with other constituents as an impurity. The earliest known glass with a significant amount of lead is a lapis blue fragment from Nipper, Mesopotamia dating back to 1400BC (Charleston, 1960).

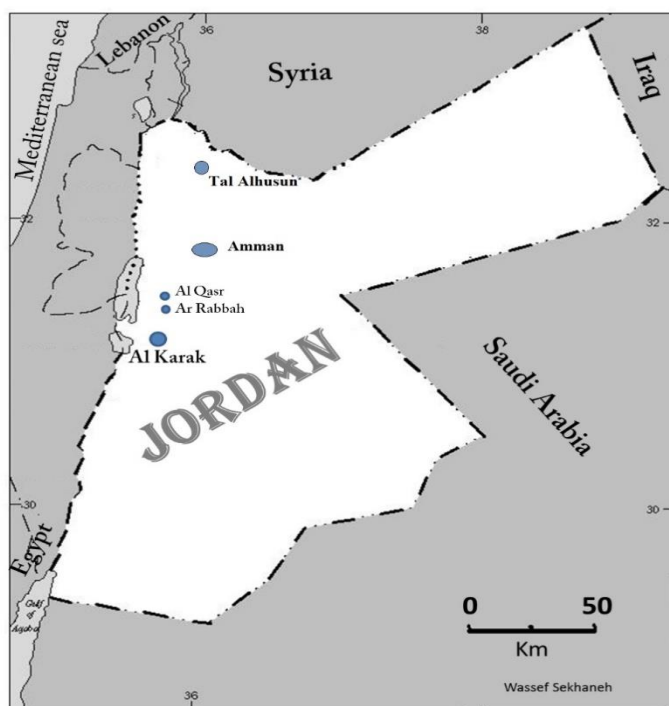
Lead glass is dense, soft, brilliant, and suitable for facet cutting (Newton and Davison, 1989). Lead oxide seems to have been added to glass as far as Second Millennium BC in Mesopotamia (Turner 1956a). Being free from seed and highly fluid, Lead glass desirable properties enable glassmakers to counterfeit precious stones and high quality glassware (Al-Ahmed and AL-Muheisen, 1995). However, problem related to lead glass arises during the purification process. Two types of lead glass are accounted for the ancient world: low lead glass and high lead glass. Low lead glass is composed of 22% lead oxide along with lime (4.51%), soda (10.72%), and potash (1.26%). The second type is composed of a much higher lead oxide content (**17.5-44<sup>3</sup>/<sub>4</sub>**), a lesser lime, soda, and potash composition (Al• Ahmed and AL-Muheisen, 1995).

However, the corrosion/alteration of lead glaze may have some archaeological implications. On one hand, understanding the mechanism and corrosion products of the process can reveal invaluable information on the technology of that ceramic production, and on the other hand, it should be a helpful tool to archaeologists in classification of these ceramics. Previous studies of Islamic lead-glazed pottery have focused on determining the provenance of the ceramics based on the composition of their body.

In this case study, investigation deals with a biochemical and physical alteration of Islamic lead-glazed ceramic product. The studied samples were excavated from Tell al Husun Archaeological site, Jordan (see Figure 1). The ceramic sherds and pottery sample were stored at Yarmouk University storage area. The ceramic sherds present a green to yellow glaze with brown – black coloration, which characterizes lead glazes applied on a light paste, some of these sherds belong to the same vessel (Figure2).

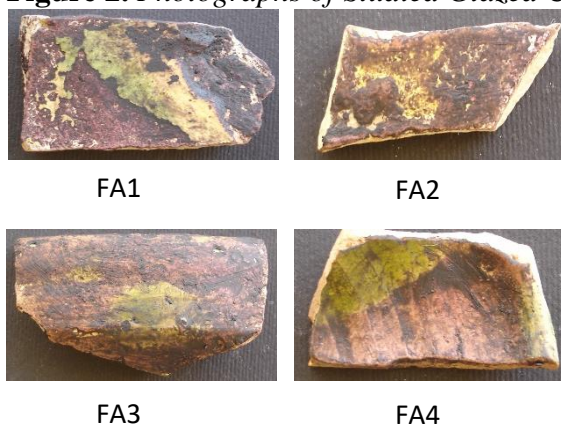
The objectives of this study are therefore to study the deterioration features of the glazed ceramic and pottery samples (Figure 3). Also to determine the mechanism of corrosion products and its formation. First of all, morphological evaluation and compositional analyses were carried out by using Scanning Electron Microscopy coupled with the Energy Dispersive X-ray microanalysis (SEM-EDX) ICP–AES, to identify the clay materials and the glaze component and optical microscope. SEM-EDX is the most suitable technique in the study of archaeological pottery in order to simultaneously perform a morphological study and to obtain information on the elemental composition both on surface layers and on bodies (Froh, 2004; Gulmini *et al.* 2006; Mirti *et al.* 2004; Pace *et al.* 2008).

**Figure 1.** Location Map of the Study Area



Source: Alawneh 2017

**Figure 2.** *Photographs of Studied Glazed Ceramic Samples*



Source: Alawneh 2017

**Figure 3.** *Photographs of the Studied Islamic Pottery*



Source: Alawneh 2017

## Literature Review

There are many studies that entailed the chemical composition, manufacturing technology and provenance of glazed pottery using numerous scientific techniques. Most of these studies investigated the glazing layer only and few others incorporated the body.

As stated by Rice (1987), the application of the scientific techniques to investigate archaeological artifacts can be traced to the late eighteenth century by M. H. Klaproth who is usually cited (Caley, 1949; Meschel, 1978; Bishop et al. 1989) as the pioneer for his work on the investigation of the chemical composition of colorant in the ancient Italian glass tesserae. Chemical analysis of pottery goes back to the mid-nineteenth century, when Layard (1853) analyzed the composition of the pottery from Nineveh, in the same year, Faraday found lead in the Roman

pottery glazes from Nineveh. Forty years later, Richards (1985) studied the chemical composition of some Iranian pottery to determine its origin, laying the basis for the provenance studies. Such studies spread widely with different approaches especially in the 1950s and upward. Issues of specialized books began to appear such as "Ceramics for the Archaeologist" (Shepard 1976), "Pots and Potters" (Rice 1984), and "Pottery Analysis: A source book" (Rice 1987). The scientific studies in the 1990 examined different aspects of glazed pottery. For example, many researchers studied the chemistry of glazes. Tite et al. (1998) demonstrated that the principal advantages of transparent high lead glazes, as compared to alkaline glazes, are ease of preparation and application of the glaze suspension, low susceptibility to glaze crazing and crawling and high optical brilliance. Molera and Vendrell-Saz (2001) found that all the Islamic Spanish opaque glazes from Eastern Spain are lead glazes with a PbO concentration that ranges from 37-56% and pacifiers with tin oxide in the range of 4-15%. Benedetto et al. (2004) stated that Canosa pottery differ from the other Roman lead-glazed pottery in using a non-calcareous clay body in association with a lead-silica glazing mixture rather than using lead itself. Hill et al. (2004) stated that Sasanian and Early Islamic alkaline glazed ceramics that were excavated from Deh Luran plain in Southwestern Iran have paste compositions that are distinct from contemporary and later ceramics decorated with alkaline-low-lead and lead glazes. Numerous studies entitled the manufacturing technology of glazes as well as corrosion of glazed pottery and these sources include text books by Eitel (1965), Hamer and Hamer (1997), Kingery et al. (1974), Kingery and Vandiver (1986), Lawrence and West (1982), Nordyke (1984), Parmelee (1948) and Singer and German (1960).

In 1971, Plenderleith and Werner pointed out that since the weathering crusts on glass are often iridescent, opaque or black, and hence the original color and transparency cannot be seen, removal of crusts has often been advocated on aesthetic grounds.

Archaeometric studies of ancient ceramics from Jordan are very scarce. They consist mostly of disconnected case studies that mainly focused on individual sites, such as Al Saad et al. (1999) who studied the Petrographic and Thermal Analysis of a Collection of Islamic Painted Pottery. Ata (1998) determined the provenance and technology of the Umayyad pottery from Hayyan Al-Mushref based on mineralogical and thermal analyses. Shraim (1999) determined provenance and technology of painted Nabataean pottery from Khirbe Edh-Dharh depending on mineralogical, physical and thermal analysis. Haddad (1999) work on Roman pottery using thermal techniques. Abu-Jaber and Al Saad (2000) studied provenance and technology of a collection of middle Islamic pottery from Khirbet Faris based on petrography. Abu-Jaber et al. (2000) use chemical, mineralogical and geological approach in their study on early Bronze Age pottery from Jebel Abu Thawwab. Al-Shereideh and Hatamleh (2003) estimated the initial firing temperature while study Umayyad pottery.

Some researchers combined between scientific and typological approaches in studying ancient pottery that were excavated from Jordan such as the study of Al-Kousheh (1999) who obtained comprehensive results regarding the technology

and provenance of the Roman and Byzantine pottery from Yasileh. Al-Rashdan (2001) determined provenance and technology of Ayyubid Mamluk pottery from EL-Bediyeh. Bataina (2003) explored the nature, provenance and firing temperatures of the Ayyubid-Mamluk pottery from Hayyan Al-Mushref. Batayneh (2005) studied the provenance and technology of the Ayyubid Mamluk pottery from EL-Bediyeh. However, few scientific studies were performed on glazed

However, few scientific studies were performed on glazed pottery in Jordan. For example, the combination of stylistic, typology scientific approaches allowed Tawalbeh (1996) to obtain information about manufacturing technology and provenance of the painted and glazed Ayyubid-Mamluk pottery from Dohaleh/ North Jordan. Azzam (1998) classified the 10th century AD Islamic glazed pottery from Ayla using the chemical analysis of these glazes. Al-Saad (2002) studied the chemical composition and manufacturing technology of a collection of various types of Islamic glazes that were excavated from Dohaleh/Jordan based on chemical analysis.

Therefore, a multi-technique approach is required (Bertolino and Fabra 2003). The SEM examination of the fresh fractures of the fragments allowed the evaluation of the micro-morphology and of the degree of vitrification of the ceramic paste, as well as the study of the glaze layer and the determination of the corrosion products mechanism (Belfiore *et al.* 2007; Maniatis and Tite 1982).

## Methodology

Four corroded glazed ceramic sherds of different typologies and colors were collected. These objects represent a special case; they appear to be the most decayed and completely corroded objects. Whereas the Fifth object which represent an Islamic glazed pottery stored in the storage area at Yarmouk university.

The studied samples as well as the black coloration were observed using optical and scanning electron microscopy (SEM) and analyzed semi-quantitatively using an energy dispersive spectrometer.

The chemical compositions of the ceramic bodies were determined by a Perkin Elmer Optima 3300RL ICP–AES at the Department of natural authority Amman, Jordan.

For the microstructural examination of the glazes, samples were examined in polished section by backscatter electron imaging using a Cameca SU30 SEM at the department of industrial engineering, Hashemite University. The chemical compositions of the glazes were determined using wavelength-dispersive spectrometers (WDS) attached either to the RLAHA's Cameca SU30 or to a Jeol JXA-8800 super probe in the Department of Industrial engineering, Hashemite University, Jordan. Both instruments were routinely run at 10-30 kV and 5 nA, with spot sizes between 17 mm.



## Results

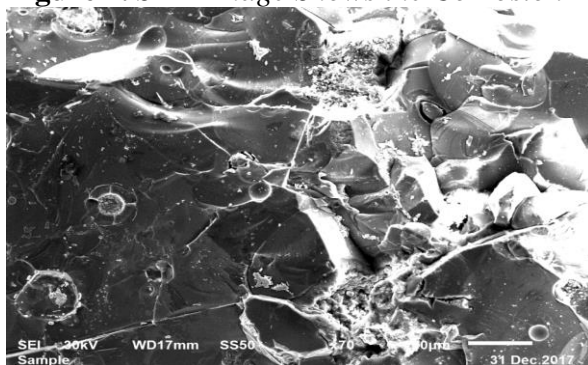
The preliminary examination done by naked eye and a magnifying hand lens (x 10) indicates that these ceramic sherds varied in their decay rate and corrosion nature. It seems likely that the weathering crusts found on sample FA1, 2, 3 and 4 are an extreme form and cover the entire sample. Whereas the surfaces of these objects are covered by a thick blackened enamel-like weathering surface, which in some areas has flaked away to reveal an iridescent layer beneath (a variegated coloration of the glass surface). The corroded surfaces had become very soft, powdery and easy to destroy.

Some of the invaluable corroded glass fragment and corrosion crusts, flaked a way or separated from the ceramic surface.

SEM has been used to study the surfaces and microstructures of ancient and historic glasses: SEM has been used to detect flaked weathering surfaces, pacifiers and colorants in glass.

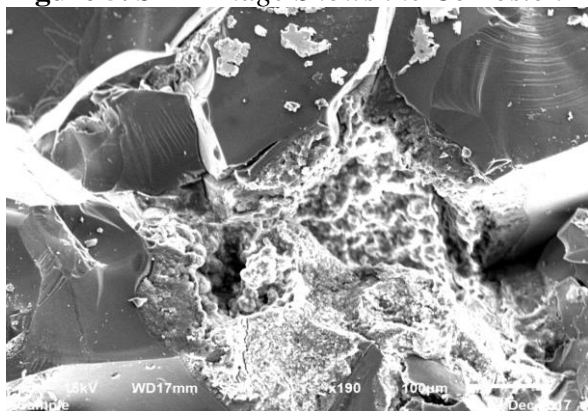
According to SEM of the corroded ceramic samples, it can be seen that all glass surfaces seems to be inhomogeneous pitted, surface planar and highly fractured forms Figure 4. Large areas of the withering crust were destroyed and rich in dissolution voids and micro cracks. In addition, other aspects of sugar-like surface and flaking also observed (see Figure 5).

**Figure 4. SEM Image Shows the Corrosion Features**



Source: Alawneh 2017

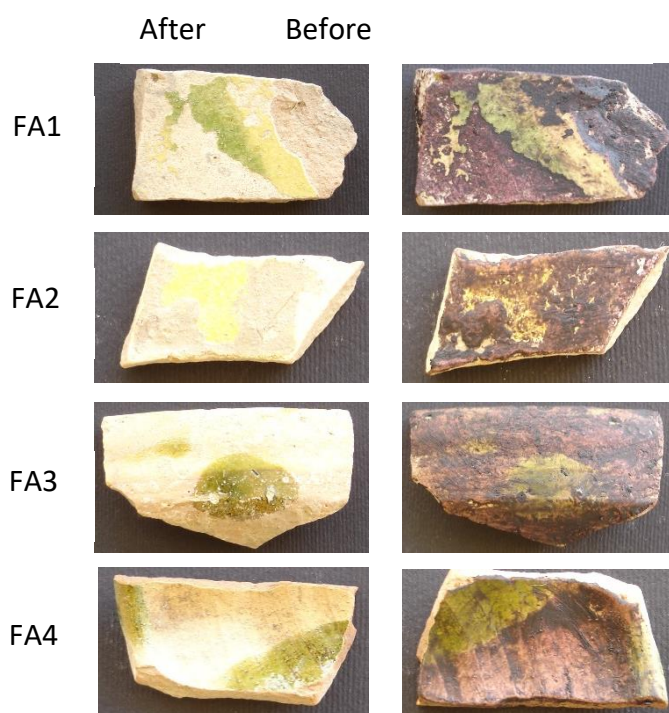
**Figure 5. SEM Image Shows the Corrosion Products**



Source: Alawneh 2017

Examination of glazed ceramic sherds under microscope showed brown-black coloration compound contained within most of the cracks and bubbles. These particles are not seen in the pottery sample. The black coloration was vanishing upon treatment with hydrogen peroxide ( $H_2O_2$ ) or dilute acids and produces a yellow and green color which is thought to be the original one (Figure6).

**Figure 6.** Photographs Shows Ceramic Sherd Before and after Treated with Hydrogen Peroxide ( $H_2O_2$ ).



Source: Alawneh 2017

The result of Chemical analysis using ICP–AES of altered and unaltered glazes confirmed the presence of sulfur in the former (1.6 wt.% S which corresponds approximately to 12 wt.% PbS), and it's almost complete absence in the latter see table 1, 2 and 3. Semi-quantitative chemical analyses mapping , using EDS, were carried out (Figure. 7) on: (a) an altered sample in gray-black zones (cracks, bubbles, etc.), (b) light zones of the same sample, and (c) on an unaltered sample. Despite the superposition of principal lines of lead and sulfur, it was noted that the proportion of lead, compared to of silicon and aluminum, is higher in the altered zones than in the unaltered zones. So, it is thought that there is some diffusion and concentration of lead towards the cracks, bubbles and surface of the glaze.

**Table 1.** *Chemical Analysis of The Ceramic Clay Paste*

<i>Sample no.</i>	<i>SiO<sub>2</sub></i>	<i>Al<sub>2</sub>O<sub>3</sub></i>	<i>Na<sub>2</sub>O</i>	<i>K<sub>2</sub>O</i>	<i>MgO</i>	<i>CaO</i>	<i>Fe<sub>2</sub>O<sub>3</sub></i>	<i>TiO<sub>2</sub></i>
<b>FA1</b>	<b>64.25</b>	<b>20.37</b>	<b>0.75</b>	<b>2.82</b>	<b>1.25</b>	<b>2.45</b>	<b>2.31</b>	<b>0.25</b>
<b>FA2</b>	<b>71.30</b>	<b>21.34</b>	<b>0.68</b>	<b>3.21</b>	<b>1.68</b>	<b>2.62</b>	<b>3.68</b>	<b>0.75</b>
<b>FA3</b>	<b>67.28</b>	<b>24.33</b>	<b>0.67</b>	<b>1.87</b>	<b>1.36</b>	<b>3.17</b>	<b>2.17</b>	<b>0.63</b>
<b>FA4</b>	<b>70.14</b>	<b>20.74</b>	<b>0.58</b>	<b>2.67</b>	<b>1.64</b>	<b>2.22</b>	<b>3.22</b>	<b>0.88</b>
<b>Pottery</b>	<b>71.23</b>	<b>21.10</b>	<b>0.71</b>	<b>3.21</b>	<b>2.14</b>	<b>3.74</b>	<b>4.23</b>	<b>0.96</b>

**Table 2.** *Chemical Analysis of the Glazed Composition for Unaltered Ceramic Samples*

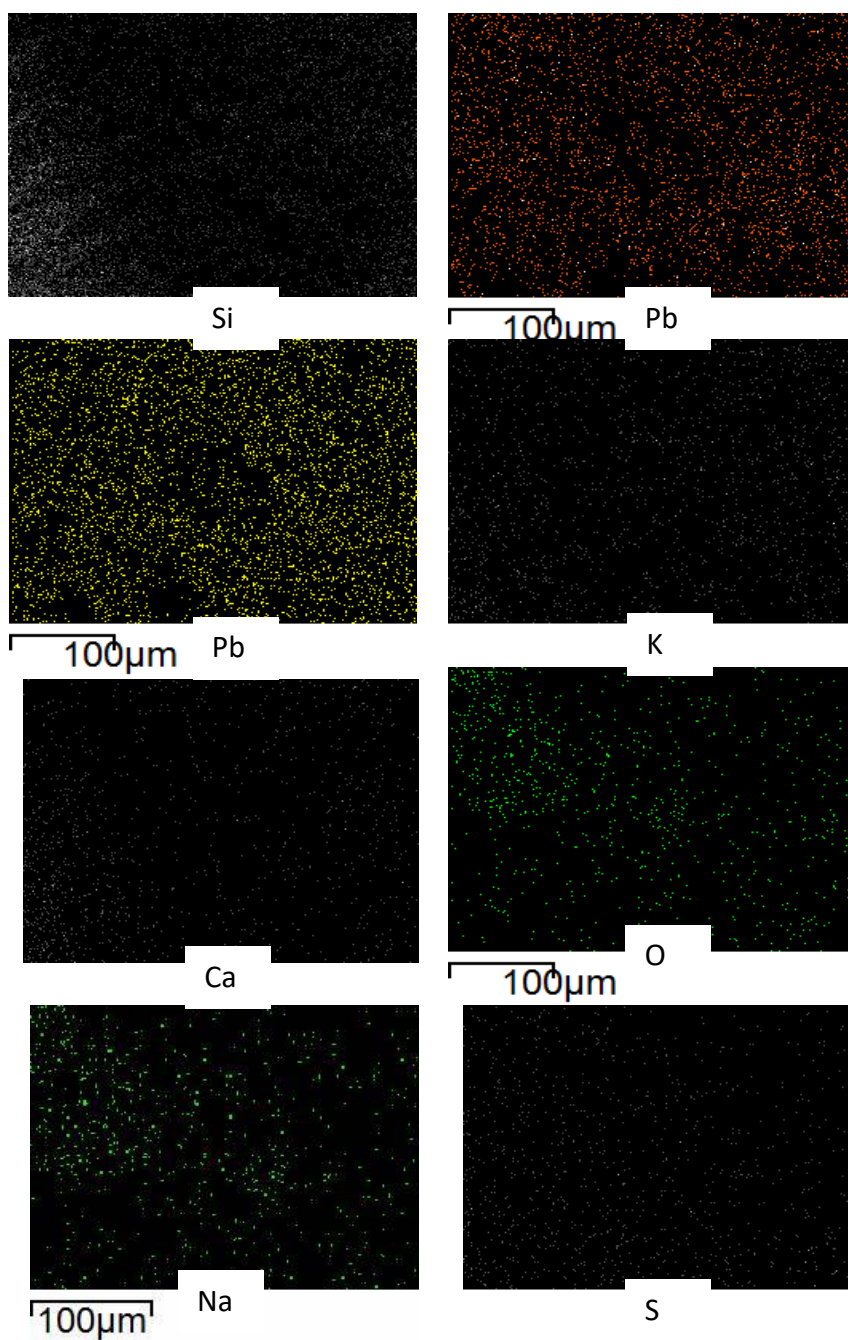
<i>Sample no.</i>	<i>Na<sub>2</sub>O</i>	<i>MgO</i>	<i>Al<sub>2</sub>O<sub>3</sub></i>	<i>SiO<sub>2</sub></i>	<i>PbO</i>	<i>K<sub>2</sub>O</i>	<i>CaO</i>	<i>FeO</i>	<i>TiO<sub>2</sub></i>	<i>CuO</i>
<b>FA1</b>	0.07	0.33	9.23	18.3422	68.53	0.78	0.37	0.83	0.35	0.24
<b>FA2</b>	0.15	0.25	8.57	17.55	70.36	0.57	0.32	1.74	0.39	0.08
<b>FA3</b>	0.19	0.30	8.42	18.67	71.47	0.52	0.36	0.70	0.32	0.25
<b>FA4</b>	0.07	0.35	8.21	21.30	68.08	0.47	0.27	0.77	0.37	0.18
<b>Pottery</b>	0.11	0.36	9.78	16.66	69.77	0.81	0.42	0.67	0.33	0.56

**Tale 3.** *Chemical Analysis of altered glazed Composition with Black Layers*

<i>Sample no.</i>	<i>Na<sub>2</sub>O</i>	<i>MgO</i>	<i>Al<sub>2</sub>O<sub>3</sub></i>	<i>SiO<sub>2</sub></i>	<i>PbO</i>	<i>K<sub>2</sub>O</i>	<i>CaO</i>	<i>FeO</i>	<i>TiO<sub>2</sub></i>	<i>S</i>
<b>FA1</b>	0.47	0.63	3.32	8.21	92.25	0.85	0.18	0.24	0.22	1.32
<b>FA2</b>	0.25	0.95	2.58	6.54	94.16	0.67	0.16	0.97	0.19	1.29
<b>FA3</b>	0.40	0.87	3.17	7.55	95.85	0.77	0.82	0.57	0.36	1.36
<b>FA4</b>	0.63	0.64	4.12	5.84	96.33	0.99	0.61	0.35	0.42	1.35

The degradation of a glass surface due to interaction with the atmosphere referred to as weathering. Depending on the amount of condensed water involved, this process can be dominated by acidic or by alkaline attack. If a water droplet remains on the surface, dealkalization of the glass occurs with a simultaneous increase of the pH of the water. Depending on the external conditions these droplets may run off naturally, carrying away the reaction products. If evaporation of moisture occurs before droplets are formed, the

**Figure 7.** *Elemental Maps for the Altered Sample Shows the Elemental Distribution of Glazed Components and Corrosion Products*



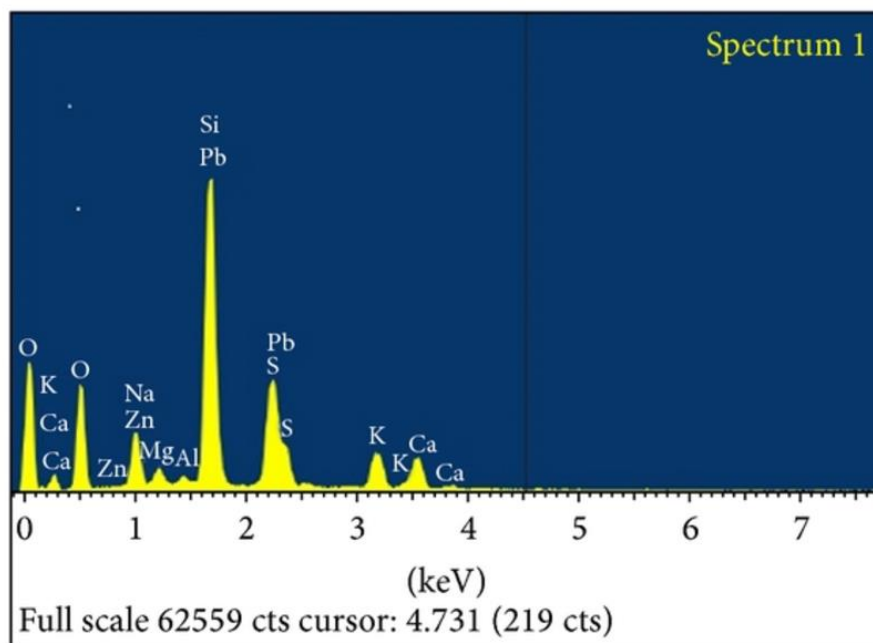
Source: Alawneh 2017

Reaction products remain on the glass surface, ready to react with acid gases such as CO<sub>2</sub> or SO<sub>2</sub> to form their respective salts. (Tennent, 1999).

EDS analysis of the unaltered glaze showed the absence of spectral lines (excluding some lines which are attributed to non-dissolved quartz or to sample contamination from the ceramic support during sampling). On the other hand, the

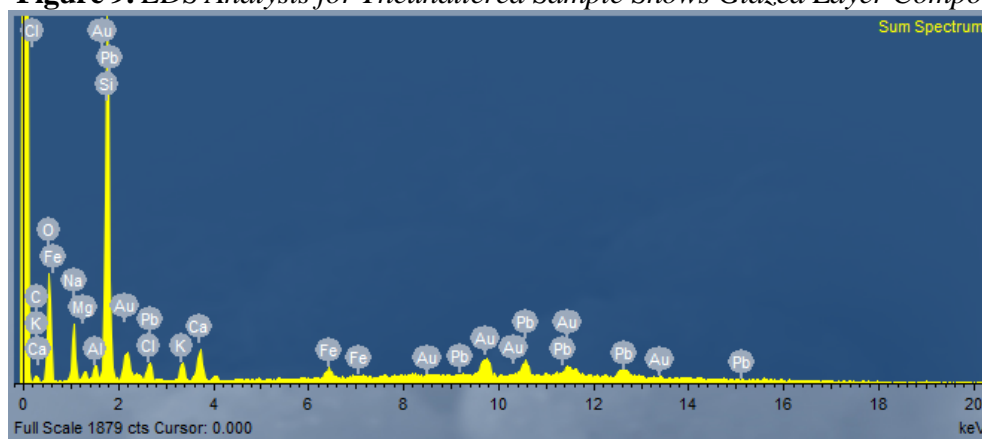
altered glaze contained lead sulfide or galena (PbS) as well as lead aluminum silicate:  $\text{Pb}_6\text{Al}_2\text{Si}_6\text{O}_{21}$  Figure 8 and 9.

**Figure 8.** EDS Analysis for the Altered Sample Shows Corrosion Product Pbs



Source: Alawneh 2017

**Figure 9.** EDS Analysis for Theunaltered Sample Shows Glazed Layer Composition



Source: Alawneh 2017

## Discussion

At the early stages of glass corrosion, isolated pits appear; those further grow and connect with each other forming craters, which increasingly become deeper and more abundant. In turns, the craters grow and become interconnected in such

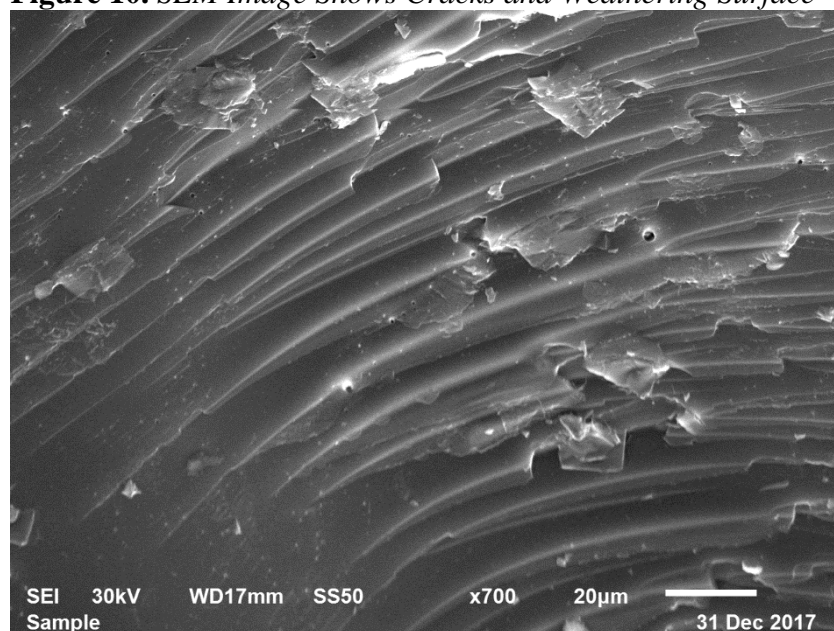
a way that they form a continuous altered, opaque corrosion crust (Bettembourg, 1976). Spontaneous cracking of glass occurs as the result of deterioration processes.

The formation of a thick hydrated surface layer undergoes dehydration with extensive loss of silica and thus a decrease in volume. The resulting strain on the surface is relieved by the formation of fractures. The process is likely to be the cause of a surface being covered with a network of tiny cracks. The cracks may be confined to the surface layers, or penetrate deeper, allowing ingress of attacking solutions, and may eventually lead to the total collapse of the glass. In such cases moisture within the cracks and layers of decomposed glass may be all that holds the object together so that it disintegrates on drying (Newton and Davison, 1989).

(i) The outer layers of hydrated silica are not different from silica gel. Being hygroscopic they behave in the same manner in response to changes in atmospheric water (relative humidity) or liquid water. The layers absorb and desorb water (vapor) at the same time expand and contract, which leads to the formation of microscopic surface cracks. These allow agents of destruction to penetrate deeper into the glass Figure 10.

Excavated glass may have an opaque blackened layer on the surface, Figure 11 the darkening or blackening may due to oxidation of iron and manganese ions, the action of Sulphur reducing bacteria actively producing hydrogen sulfide in anaerobic conditions or due to the formation of lead sulfide (Abd-Allah, 2002).

**Figure 10.** SEM Image Shows Cracks and Weathering Surface



Source: Alawneh 2017



**Figure 11.** *Photograph Shows Darkening or Blackening May Due to Oxidation.*

Source: Alawneh 2017.

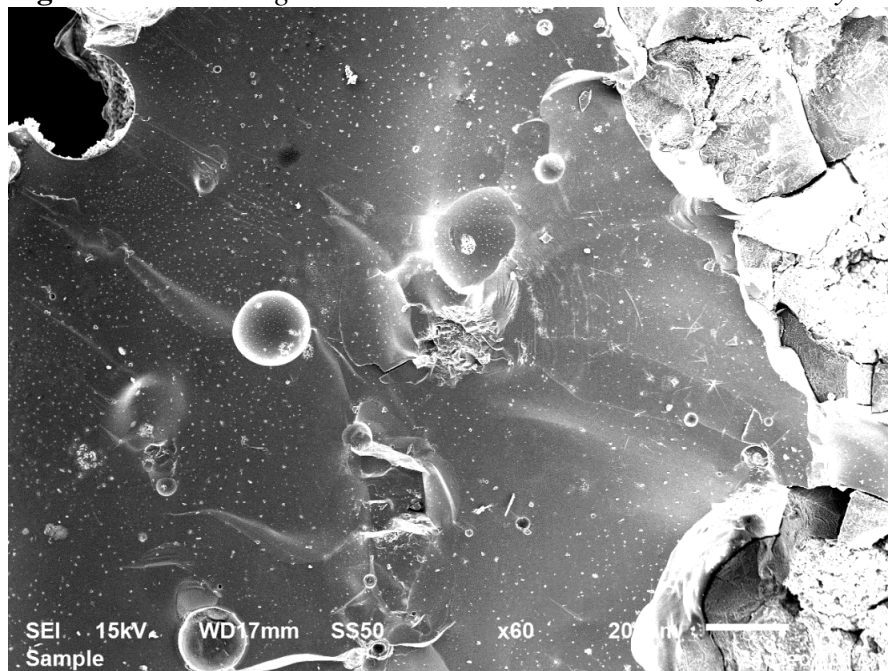
This is an obvious change in the composition of the outer weathering crusts in comparison with interior glaze cores underlying them, where sodium and potassium content decreases and silica content increase see Table 2, 3 and Figure 12. This only occurs in glass with high lead content, buried in anaerobic conditions where sulfate reducing bacteria are actively producing hydrogen sulfide.

The oxidation process is most rapid in the high alkaline conditions at leached layer. This can be seen in Figure 2 where brownish-black layer deposit on the glass surface followed the line of cracks. Organic growths may be associated with glass deterioration. Micro-organisms such as bacteria do not attack clean glass. While they do not require any nutrients since they obtain food by photosynthesis, they require dirt, grease or pitting as a substrate to provide a foothold on the glass. Lichenous growths probably do not attack glass directly but promote corrosion by trapping moisture next to the glass and thus help to accelerate decomposition. The brownish color of the altered glaze, in fact a mixture of yellow and gray-black, is due to the presence of PbS. It appears only in the cracks, the bubbles and some surface areas. This phenomenon resulted from the attack of the glaze by H<sub>2</sub>S present in its soil environment. (Miller, 1956). This gas is liberated in the soil solution as a metabolic product of sulfate-reducing bacteria, which obtain the required energy for their cellular activities by reducing sulfate ions. The H<sub>2</sub>S production by certain sulfate-reducing bacteria can attain 3.1 g/l. H<sub>2</sub>S behaves in aqueous solution as an acid. (Ivarson, 1976). The cation "M", called a modifier, can be monovalent (like K<sup>+</sup> or Na<sup>+</sup>) or bivalent (such as Pb<sup>2+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>). When liberated in solution, lead cations (Pb<sup>2+</sup>) combine with sulfide ions (S<sup>2-</sup>) to give PbS, which precipitates.

The corrosion of glass by acid solution with the liberation of modifiers (K<sup>+</sup>, Na<sup>+</sup>, Pb<sup>2+</sup>, etc.) is a common phenomenon showed that liberation of the (Miller, 1956; Ivarson, 1976) cations depends on the number of neighboring "non-bridging" oxygen atoms (Sphere of Influence Theory). This number can be calculated for each cation from its concentration in the glass and the radius of its sphere of influence.

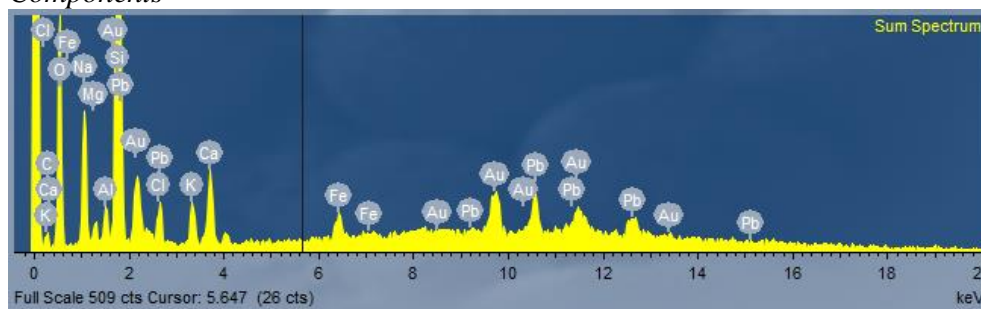
The presence of lead aluminum silicate (Pb<sub>6</sub>Al<sub>2</sub>Si<sub>6</sub>O<sub>21</sub>) in the altered glaze and its absence in the unaltered glaze shows that the alteration process due to attack by H<sub>2</sub>S (liberation and migration of Pb<sup>2+</sup> followed by precipitation of PbS) is accompanied by the modification of the glass (glaze) structure leading to its recrystallization and partial destruction Figure 12 and Figure 13.

**Figure 12.** SEM Image Shows Cracks and Pits on the Glazed Layer



Source: Alawneh 2017

**Figure 13.** EDS Analysis for the Altered Sample Shows Corrosion and Glaze Components



Source: Alawneh 2017

Pits form on the surface of glass during burial, immersion or in the atmosphere. Pits have a distinctive cylindrical shape; they seem to be uniform in size on any given piece of glass; The size of pits varies from one piece of glass to another; and pits form in some glasses but not in others (Lampropoulos and others, 2004).

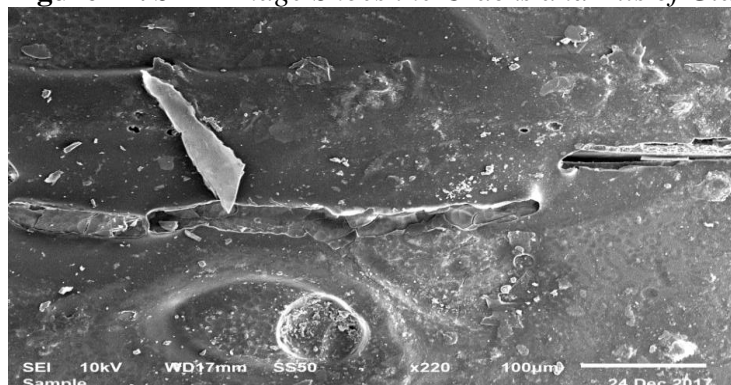
However, it is thought that the size, depth, and distribution of pits are related to the size and distribution of the water droplets on the glass surface and those defects in the glass surface may also play a part in their formation, by holding water in specific sites via surface tension. Fissures in deteriorated glass would enable water to enter pits where it would be held by surface tension and accelerate the attack, see Figure 14.

A fine network of surface cracks that turn glass translucent. Moisture in the air reacts with unstable glass layer, which causes the leaching of alkali materials. The result is a weak surface with a crazed form, where small cracks start to appear. The



structure of weathered glass layer is characterized by high porosity and small amount of modifiers.

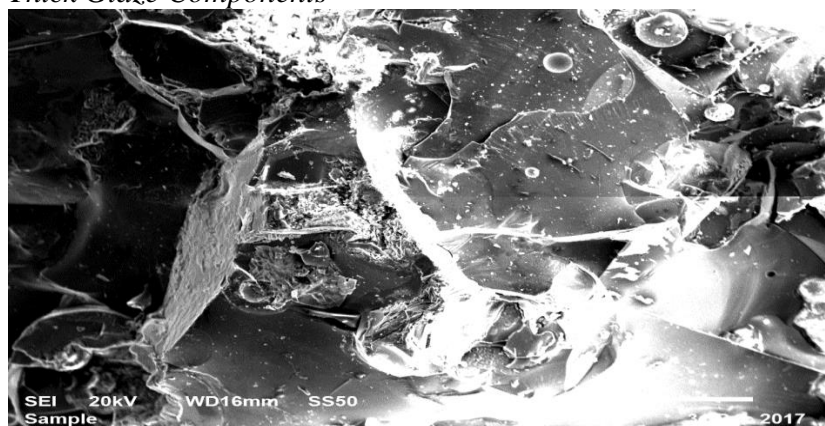
**Figure 14.** *SEM Image Shows the Cracks and Pits of Glaze Layer*



Source: Alawneh 2017

This phenomenon is visible particularly in cracks and bubbles because it is at these sites where the glaze could have come into contact with the surrounding medium Figure 15. The chemical composition of the glaze combined with some of its physical properties such as thickness and occurrence of cracks and bubbles would favor its degradation in aggressive environment. Thus, intrinsic and extrinsic factors combine here to promote this kind of biochemical and physical alteration of the glaze.

**Figure 15.** *SEM Image Shows Glaze Deterioration Combined With Bubbles and Thick Glaze Components*



Source: Alawneh 2017

## Conclusions

Lead glaze was used in ceramic manufacturing, it seems that potter used copper to obtain a green color and iron oxides for a yellow color.

Glass corrosion is the most dangerous phenomena of glazed ceramic that results from defects in chemical composition of glass itself and the effect of moisture or

water. According to visual examination and results glazed layer was damaged and corroded as a result of chemical reaction and ion exchange between glass and wet burial environment. Thus, basic compounds of glass dissolved in water and leached out, especially alkaline compounds of sodium and potassium. Insoluble compounds such as silica oxides and some other impurities deposited on the surface of glass as corrosion crusts.

As for the blackened color samples, the presence of PbS and corrosion products resulted from the attack of the glaze by H<sub>2</sub>S present in its environment.

The type of alteration that concerns lead-glazed ceramics is not exceptional. It results in all anaerobic media of organic decomposition, especially in wet and humid dumps as evidenced by many archaeological cases.

It is understood, however, that the chemical composition of the glaze, especially its lead content and its preparation and firing conditions (which develop the physical aspect: cracks, bubbles, thickness, etc.) are the factors that control the intensity of this deterioration process and consequently the observed features.

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