



THE MORTAR DAMAGE AND ITS HARMFUL EFFECTS ON THE GLAZED CERAMIC TILES IN TERBANA MOSQUE – ALEXANDRIA, EGYPT

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ABSTRACT

This research discusses the damaging factors of the mortar used to affix the glazed ceramic tiles on the walls of Terbana mosque (built in 1685, Ottoman period) in Alexandria, Egypt, and the extension of the damaged impact to the ceramic tiles. This famous, and particularly outstanding mosque with several suspended shops below it, is built in the Delta architectural style, with walls made of limestone blocks and a little red and black adobe for decorative work, a wooden roof and glazed ceramic tiles, with plants and geometric ornaments, adorn parts of the mosque walls.

Salt content in the weather of Alexandria is relatively high; this salt is the largest contributor to the deterioration factor of Terbana mosque with varying degrees of deterioration. Impacts come in different forms; salts caused disintegration of the mortar into soft powder in some places and then pushed the outer surface of the limestone and brickwork.

Where tiles have been installed in a building near the sea, they would be subject to degrees of salt deterioration, making it very difficult to prevent deterioration of the tiles or to the walls. Results from analytic methods such as scanning electron microscopy (SEM-EDX), and X-ray diffraction (XRD), reveal a high percent of crystallized salts of sodium chloride NaCl (Halite) in the fixed mortar, in the body of the tiles, and in the glaze layer on the tiles surfaces. Proposed solutions to mitigate the salts deterioration are provided.

KEYWORDS

Terbana Mosque – Salt Tolerances – Delta Style – Sustain Cracks –The Grout – Affix – Reflective Cracking –waterproof mortar

المخلص

في هذا البحث تم دراسة عوامل تلف المونة التي تثبت البلاطات الخزفية المزججة على جدران مسجد تربانه بالإسكندرية، مصر. وامتداد تأثيرها المتلف للبلاطات الخزفية. أنشئ مسجد تربانه عام 1685م. ويعتبر من المساجد المعلقة، اسفله مجموعه من الدكاكين، بنى على طراز الدلتا، جدرانه بنيت من كتل الحجر الجيري مع طوب صغير الحجم باللون الأحمر والأسود لأعمال زخرفه الجدران، وله سقف خشبي. وهناك مجموعات مختلفة من البلاطات الخزفية المزججة المزخرفة بالعناصر النباتية والهندسية التي تزين أجزاء من جدران المسجد.

تتمثل أهم عوامل التلف في الهواء والأمطار والرطوبة النسبية المرتفعة وما بهم من أملاح بنسب عالية جدا، مما يؤثر بدرجات تلف متفاوتة بأشكال مختلفة على عناصر بناء المسجد بما في ذلك كتل الحجر الجيري- الطوب صغير الحجم باللون الأحمر والأسود - المونة التي تثبت البلاط المزجج على الجدران - البلاطات المزججة نفسها والتي تأثرت بشكل كبير بالتلف الملحي. وقد تسببت الأملاح في تفكك المونة، ودفع السطح الخارجي للحجر الجيري والطوب بعيدا وتدهور عام للسطح.

البلاطات الخزفية المزججة عرضة لدرجات متفاوتة من التلف الملحي في المباني القريبة من البحر. وليس من السهل منع التلف الملحي على الإطلاق للبلاطات المزججة أو الجدران، ولكن يجب إجراء صيانة دورية لها. ومن النتائج التي تم التوصل إليها من استخدام بعض أساليب التحليل مثل الفحص والتحليل بالميكروسكوب الإلكتروني الماسح المزود بنظام تشتت الطاقة (SEM-EDX)، وحيود الأشعة السينية (XRD) وجود نسبة عالية من أملاح كلوريد الصوديوم (الهاليت) في المونة التي تثبت البلاطات الخزفية، وفي أبدانها وعلى طبقة التزجج التي تغطي أسطحها. وتم اقتراح بعض إجراءات العلاج المناسب للمناطق المتضررة.

الكلمات الدالة

مسجد تربانه – التلف الملحي – طراز الدلتا – الشقوق الممتدة – مونة الفواصل – تثبت – الشروخ المنعكسة – مونة عازلة للماء

INTRODUCTION

Many buildings in Alexandria, particularly those near the sea are affected by varying degrees of salt deterioration. This problem will be discussed below; our focus is salt deterioration in Terbana mosque¹, particularly the mortar that was used to affix the glazed ceramic tiles and the grout; a mortar used in the joints between the tiles which easily subject to salt deterioration. The wall tiles on the exterior of the mosque deteriorated by the movement of salt. The salt would flake and delaminate the surface of the glazed ceramic tiles and the limestone blocks, penetrating through the thickness of the blocks either partially or to the fully² (Fig. no. 1).

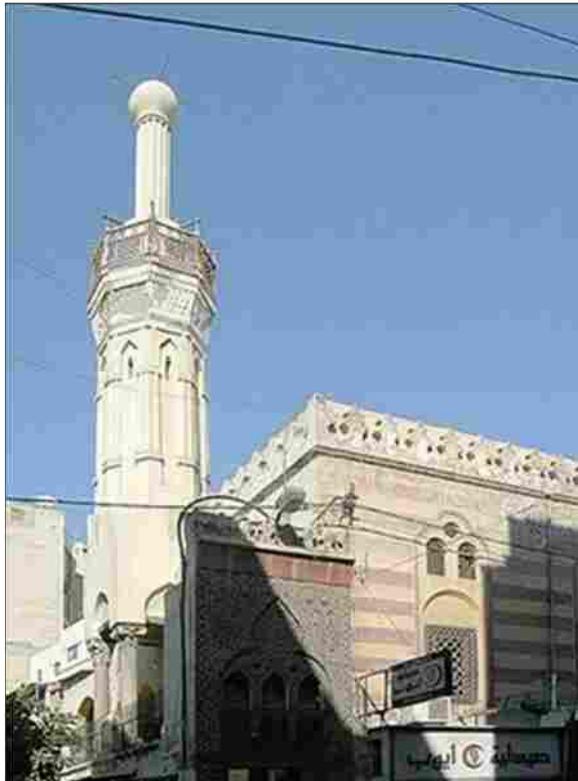


Fig. no. 1a. Terbana Mosque, exterior



Fig. no. 1b. Terbana Mosque, exterior

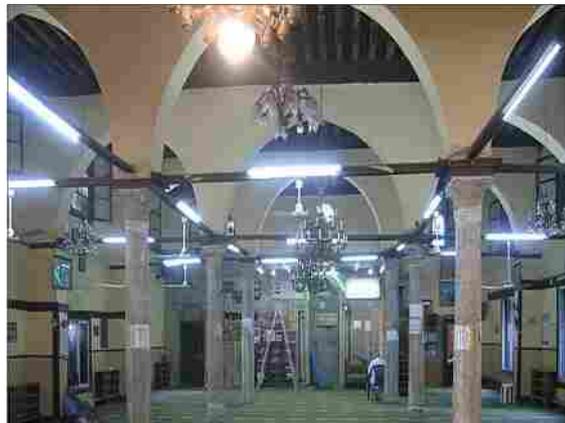


Fig. no. 1c. Terbana Mosque, interior

Chemical degradation occurs in the physical structure of the mortar or tiles when complex compounds break down into simpler compounds created an adverse reaction weakening the stability of the building's structure. This would be further exasperated when exposed to the elements such as water, air, humidity, with its high content of salt, as well as; pollution and heat.³

¹ Duqmāq, *Masājid al-Iskandarīyah al-bāqīyah*, pp.21-24; al-Jazāirī, *Mawsuw'at al-Jazāirī*, part 2, p.706.

² Pearson, *Deterioration of Ceramics*, pp.253-26 ; Feilden, *Conservation of Historic buildings*, p.99; Hemeda, *al-taqwīm al-'Imī limīkanīkāt al-tshwīh al-milḥī w 'ahm maṣadirha*, p.131 ; Hamilton, *Methods of Conserving Archaeological Material*, pp.17-19; Maarleveld, *Manual for Activities directed at Underwater Cultural Heritage*, p.3 ; Abd-Elrhim, *dirāṣah taḥlīlīyah muqārnah fī taḥdīd 'asbāb w mazāhir talaf*, pp.85-88.

³ Hamilton, *Methods of Conserving Archaeological Material*, pp.17-19; Hemeda, *al-taqwīm al-'Imī limīkanīkāt al-tshwīh al-milḥī w 'ahm maṣadirha*, pp.190-193.

MATERIALS AND METHODS

Sampling

The study is carried out using three small samples. The first sample is from the body of the glazed ceramic tile, the second is from the glaze of the ceramic tile, and the third is from the mortar which affixed the tiles on the walls. These samples were taken from samples which had fallen down due to the effect of humidity and crystallization of the salt in the mortar and in the wall tiles, archaeological materials and samples are often complicated compositions.⁴

The tile body was made from pale yellowish clay; it is very common⁵, handmade, and it; contains a high percentage of sand as well as different additives in varying sizes and colours. The tiles have divergent thicknesses ranging between 2.3- 2.5 mm. The tiles are decorated with yellow, green, turquoise, blue, black and white opaque glaze applied on a very thin layer of slip.⁶ The thickness of the glaze layer is approximately 1.0 mm, and decorated with floral and geometrical ornaments applied with a brush.⁷ The Dimensions of the mosque tiles vary 8×8, 10×10, 12×12, and 14×14 cm.⁸

There is an apparent white haze on the surface of Terbana mosque tiles, an obvious indication of soluble salts. The information obtained through visual observation, examination and catalogue documentation was an essential stage of investigation and analysis, which lead to a better understanding of our archaeological material by an experienced conservator's eye.⁹ (Fig. no. 2)

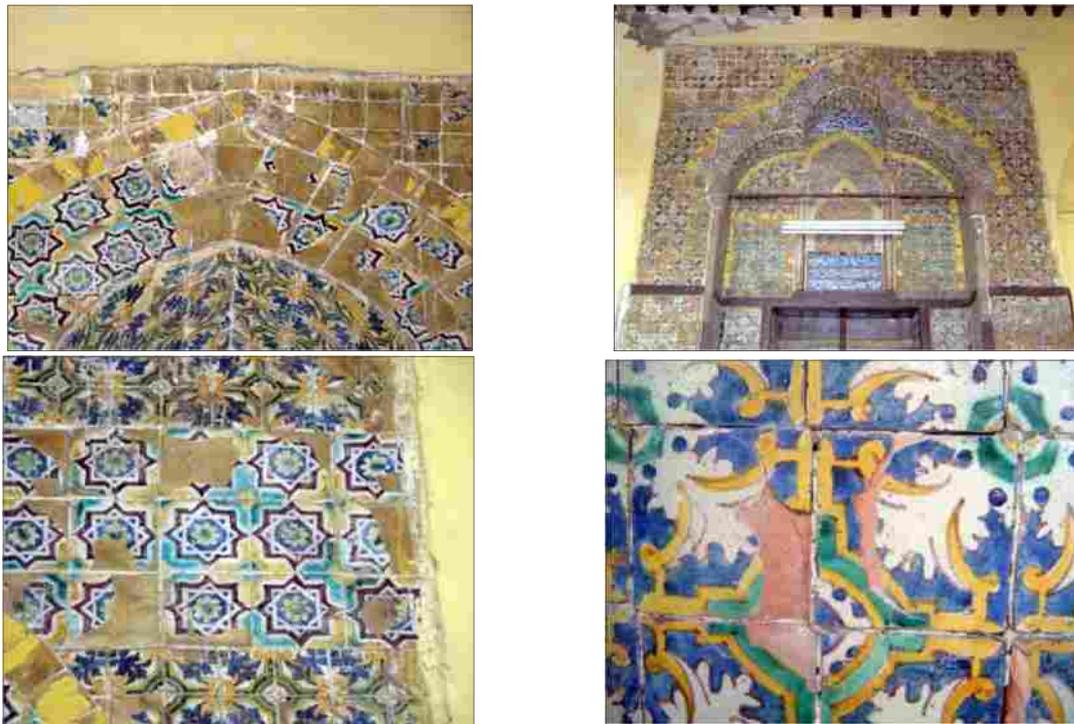


Fig. no.2 Terbana Mosque's mihrab and its glaze ceramic tiles under discussion

⁴ Tykot, *Scientific methods and applications to archaeological provenance studies*, p.416.

⁵ Abd-Elrhim, *dirāsah taḥlīlīyah muqārnah fī taḥdīd 'asbāb w mazāhir talaf*, pp.60.

⁶ Duqmāq, *Masājid al-Iskandarīyah al-bāqīyah*, p.31.

⁷ Porter, *Islamic Tiles*, p.6.

⁸ Duqmāq, *Masājid al-Iskandarīyah al-bāqīyah*, pp.31-33.

⁹ Odegaard, *Evaluation of Conservation*, p.4; Mirti, *statistics applied to analysis of ceramics*.

INVESTIGATION AND ANALYTICAL METHODS

Scanning electron microscopy (SEM-EDX)

Investigation of the samples was carried out using Quanta 250 FEG (Field Emission Gun) attached with EDX unit (Energy Dispersive X-ray Analyses), with accelerating voltage 30 K.V., magnification 14x up to 1000000 and resolution for Gun.1n), with various magnification resolutions ranging between **x. 350-500-1000-3500** for the samples of mortar, the tile body and the glaze. The samples were prepared for the SEM-EDX by fixing a specimen of an appropriate size on stubs with double-sided tape; The SEM investigation was performed to monitor the surface topography and significant changes in these samples¹⁰. In addition, the elemental composition of the glaze layer that covered the tile surface was analyzed using an EDX.¹¹

X-ray diffraction (XRD)

The chemical and mineral composition of the crystalline compound's percentages, and the deterioration rate of damage by salts in the body of the tiles, the glaze layer, and in the mortar which fixed the tiles were identified by X-Ray powder diffraction using a Philips Analytically X-Ray B.V. (Type PW 1840 diffractometer, Netherland) with a Cu tube anode, Generator tension (kv) is (40)- Generator current (mA) is (25). Monochromator used: NO-Wavelength alpha1 (a) is (1.54056), wavelength alpha2 (a) is (1.54439). Receiving slit is (0.2), intensity ratio (alpha2/ alpha1) is (0.500) - Maximum intensity: 590.4900. The full scale of recorder is (kcounts/s): 10) - Time per step (s): 0.100. Start angle {2θ} is (5.025), end angle {2θ} is (60.00), at the x-ray laboratory, Faculty of Archaeology, Cairo University, Egypt.¹²

RESULTS

Analytical data getting from investigating and analyzing the samples can be grouped as follows:

Scanning electron microscopy (SEM-EDX)

The body of the tile appears coarse made because of the high porosity, high sand percentage, and large grain size, in relation to the organic and inorganic additive materials. The core of the tile indicates the firing process during manufacturing was ineffective; this is a manufacturing defect because of the remnants of clay mineral which is susceptible to salt and moisture deterioration. The glaze used on low-fired ceramic - like that in the mosque - does not fully fusing over the tile body. The glaze can then chip off the ceramic easily since it was not chemically bound to the body¹³. During firing, clay and glazes interact; the rates of contraction depend on the composition of the glaze and the clay. Ideally, rates for shrinkage of the body and glaze must be very similar.¹⁴

The crystallized salts embedded in the grains of the fixed mortar, between the tile body and the slip layer, and between the slip layer and the glaze on the tiles, had an overall adverse

¹⁰ Tykot, *Scientific methods and applications to archaeological provenance studies*, p.424; Rice, *Recent Ceramic analysis*, p.155.

¹¹ Abd-Elrhim, *dirāsah taḥlīliyah muqārnah fī taḥdīd 'asbāb w mazāhir talaf*, p.181.

¹² Tykot, *Scientific methods and applications to archaeological provenance studies*, pp.408-412.

¹³ Rhodes, *Clay and glazes for the potter*, p.27,28.

¹⁴ The Conserve O Gram, *Preservation of Low-Fired Ceramic Objects*, pp.1-4.

effect, i.e. flakes, cracks, crystallization in pores, and abrasion in some areas of the glaze (leading to exposure the tile body)¹⁵. Soluble salts either enter the clay body from the

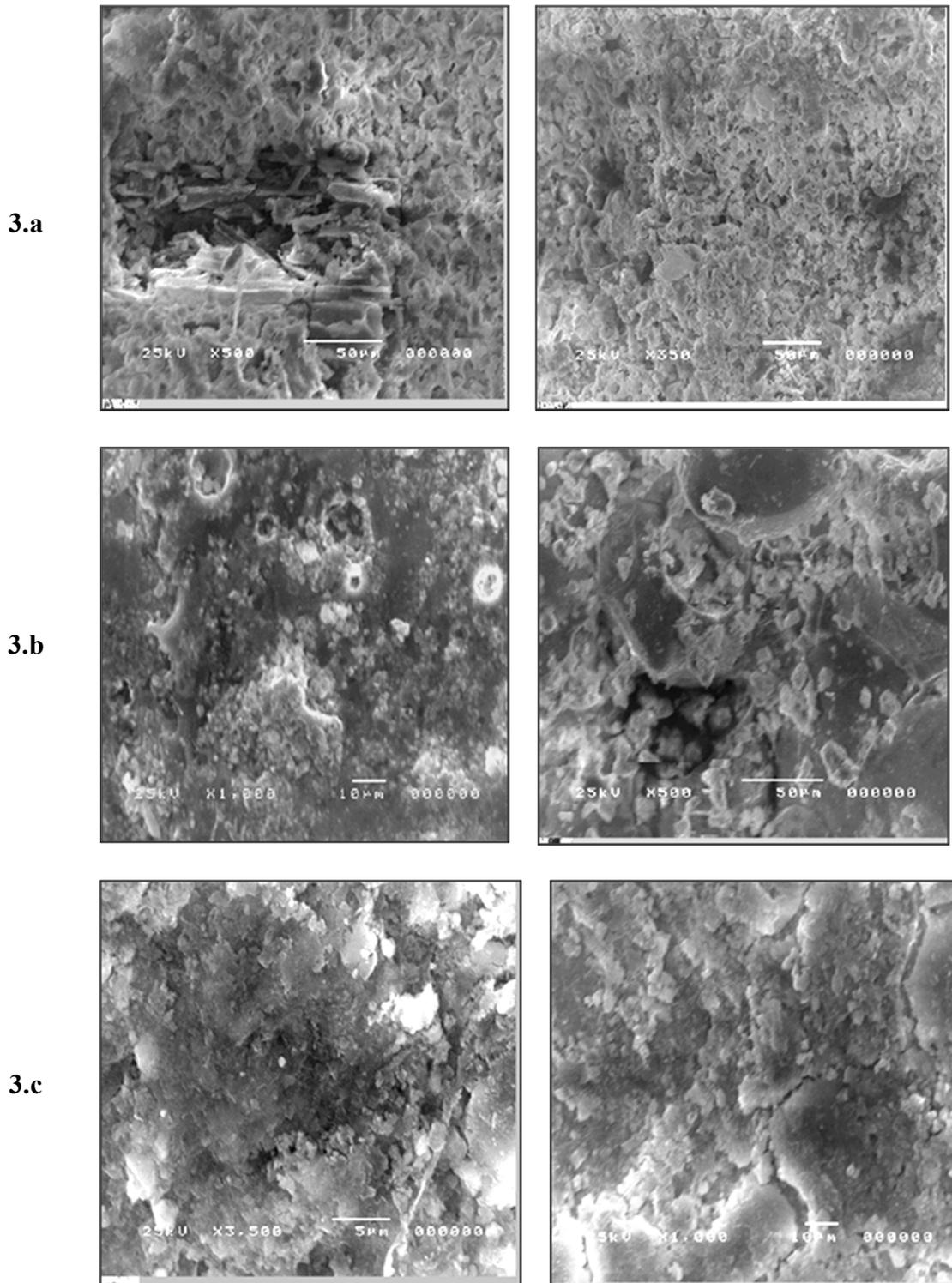


Fig. No. 3 (a, b, c). 3.a: Pictures of the studied sample of the mortar in magnification x. 500,350 ; 3.b/3.c: Pictures of the studied sample of the tile body and the glaze in magnification x. 1000,500,3500,1000, from Terbana Mosque by (SEM).

¹⁵ Duqmāq, *Masājīd al-Iskandarīyah al-bāqīyah*, p.31,33 ; Durbin, *Architectural Tiles*, p.116.

surrounding environment, or they were initially present in components of the clay, from other materials used as additives, or in the glazing materials. Soluble salts respond to changes in humidity both high and low. In high humidity, salts become soluble and in low humidity they crystallize¹⁶, the salts repeatedly dissolve and crystallize. The changes from soluble to crystal and back damaged the surface of the ceramic tiles and the glazed layer, because salt crystals are larger than liquid salt and therefore will shrink and expand inside the ceramic body and glaze layer.

The elemental compositions revealed by the result of (EDX) analysis of the glaze layer by percent at % are: C / 42.14 - O / 30.96 - Mg / 00.70 - Al / 00.49 - Si / 14.27 - P / 00.66 - Cl / 01.85 - K / 01.94 - Ca / 03.42 - Fe / 00.34 - Zn / 01.13 - Pb / 02.10 (Fig. nos. 3/4) (Table no. 1).

X-ray diffraction (XRD)

Analytical X-ray diffraction (XRD) revealed the components of the samples; the deterioration rate of damage by salts in the body of the tiles, the glaze layer, and in the mortar which affixed the tiles:

The mortar which affixed the tiles, and the mortar of the grout consisted of calcium sulfate hydrate $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (gypsum) 16.8%, and a high percentage of (colorless) silicon oxide SiO_2 (quartz) 33.2%¹⁷, keatite SiO_2 14.6% color in gray¹⁸, iron phosphate $\text{Fe}_2\text{P}_2\text{O}_7$ 7.2%¹⁹, as well as a high percentage of sodium chloride salt NaCl (Halite) 15.9% (Fig. no. 5).

The tile body consisted of aluminum silicate hydrate $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ 15.2%, a high percentage of silicon oxide SiO_2 (quartz) 52.7%, and a high percentage of sodium chloride salt NaCl (Halite) (it is colourless or white when pure) 31.9% (Fig. no. 6).

The glaze layer body consisted of calcium silicate hydrate $\text{Ca}_2\text{SiO}_4 \cdot 2\text{H}_2\text{O}$ 13.1%, calcium carbonate CaCO_3 (calcite)²⁰ 31.7%, aluminum silicate $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ 13.1%, a high percentage of silicon oxide SiO_2 (quartz) 22.5%, a high percentage of sodium chloride salt NaCl (Halite) 13.1%, and total of 6.3% of the lead titanium oxide PbTiO_3 (macedonite), boron oxide B_2O_3 , copper magnesium $(\text{CuMg})_2$, and zirconium molybdenum ZrMo_2 (Fig. no. 7).

The components of the mortar, according to X-ray results, reveal a high percentage of sodium chloride salt NaCl (halite), a major cause of the excessive deflection in the glazed ceramic tiles (and consequent cracking) due to the movement of crystals and dissolving salts between the tiles and the grout (grout is the mortar which fills the spaces between tiles). The absorption of water by salt solutions induced relative humidity (RH). The air above water saturated with sodium chloride was maintained at 75 to 76 percent relative humidity at a temperature between 0 and 40 °C (32 and 104 °F)²¹.

¹⁶ Hamilton, *Methods of Conserving Archaeological Material*, pp.17-19.

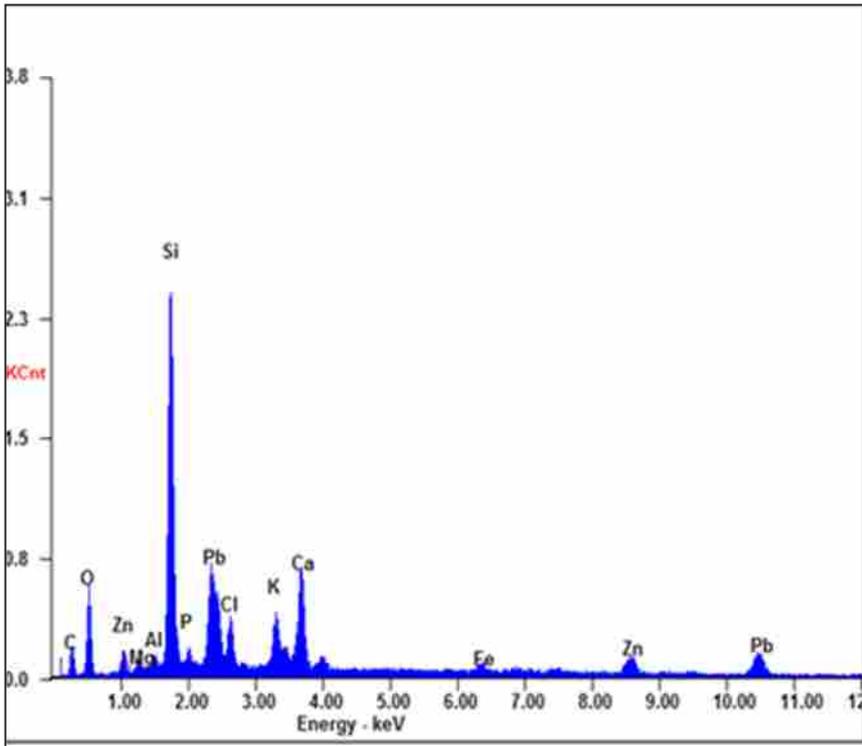
¹⁷ Abd-Elrhim, *dirāsah taḥlīliyah muqārnah fī taḥdīd 'asbāb w mazāhir talaf*, p.146,165,171.

¹⁸ Akhavan, *The Silica Group, Quartz Page*.

¹⁹ Zhang, *Phase Equilibria in Iron Phosphate System*, p.42.

²⁰ Hamilton, *Methods of Conserving*, pp.17-19; Abd-Elrhim, *dirāsah taḥlīliyah muqārnah fī taḥdīd 'asbāb w mazāhir talaf*, p.145.

²¹ Durbin, *Architectural Tiles*, p.116.



<u>Element</u>	<u>Wt %</u>	<u>At %</u>
<u>CK</u>	<u>22.41</u>	<u>42.14</u>
<u>OK</u>	<u>21.93</u>	<u>30.96</u>
<u>MgK</u>	<u>00.75</u>	<u>00.70</u>
<u>AlK</u>	<u>00.58</u>	<u>00.49</u>
<u>SiK</u>	<u>17.74</u>	<u>14.27</u>
<u>PK</u>	<u>00.90</u>	<u>00.66</u>
<u>ClK</u>	<u>02.91</u>	<u>01.85</u>
<u>KK</u>	<u>03.37</u>	<u>01.94</u>
<u>CaK</u>	<u>06.07</u>	<u>03.42</u>
<u>FeK</u>	<u>00.84</u>	<u>00.34</u>
<u>ZnK</u>	<u>03.28</u>	<u>01.13</u>
<u>PbL</u>	<u>19.22</u>	<u>02.10</u>

Fig. no. 4 Chart of the studied sample from the glaze layer by (EDX) of Terbana Mosque.
 KV: 30.00 Tilt: 0.00 Take-off: 35.00 AmpT: 102.4
 Detector Type: SUTW-Sapphire Resolution: 129.66

Table No. 1 shows the elements by EDX Quantification & its concentration in the studied sample from the glaze layer of Terbana Mosque.

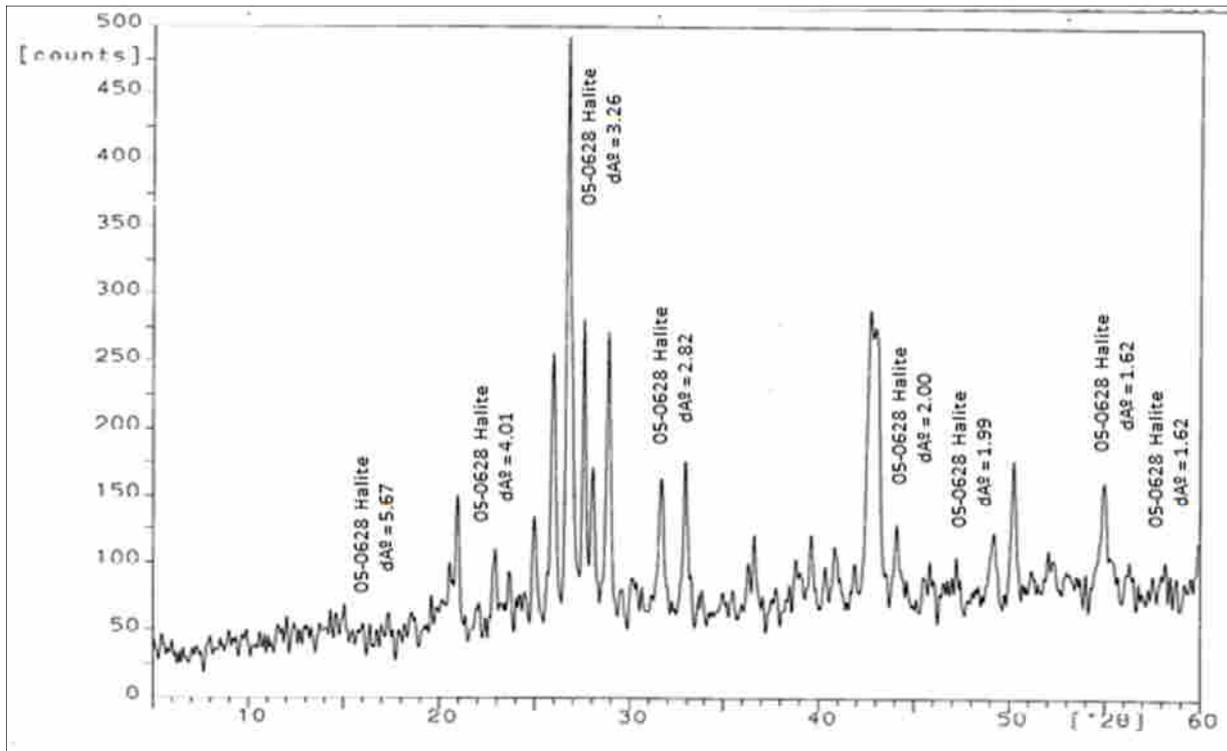


Fig.5

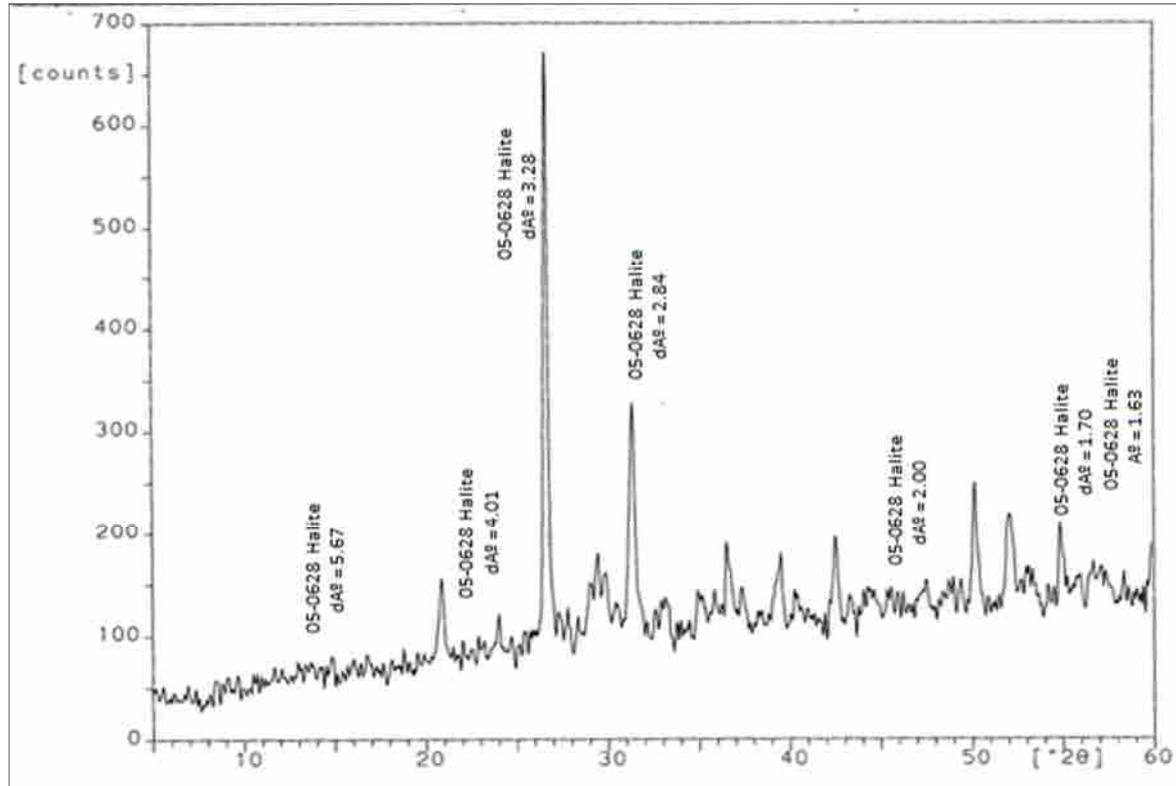


Fig. 6

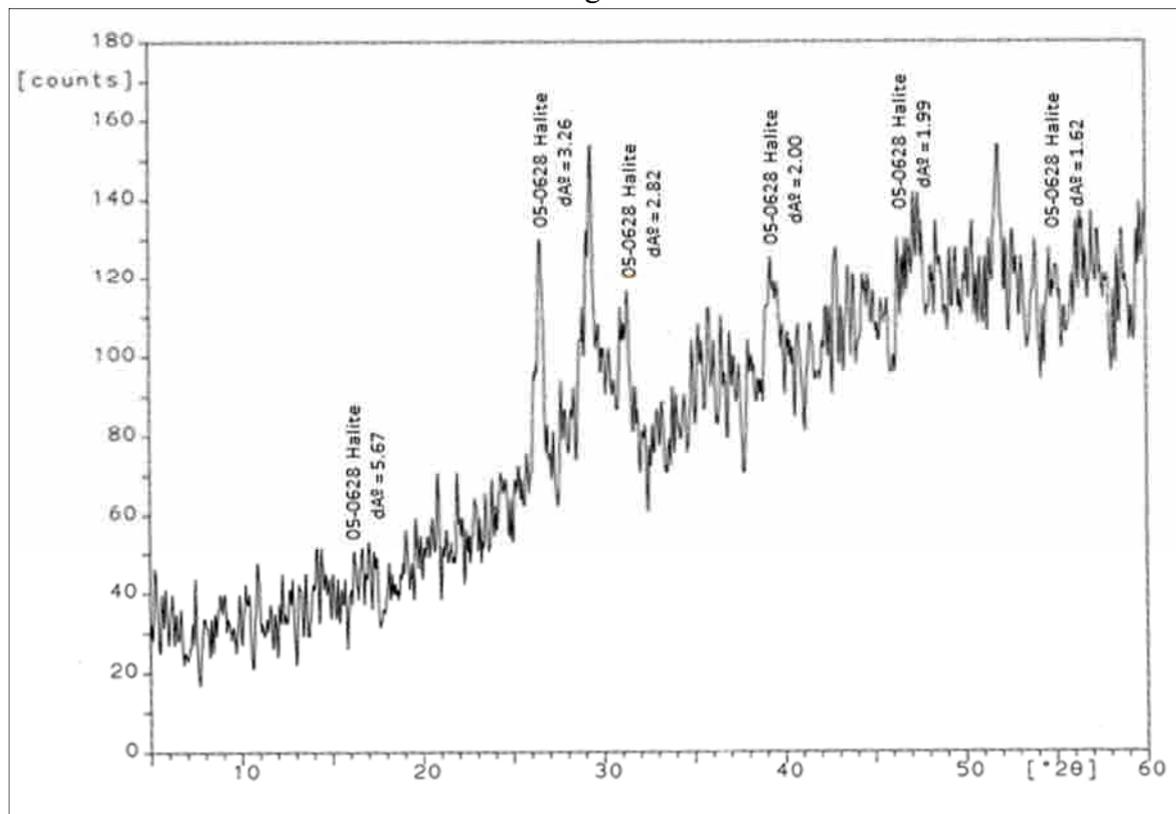


Fig. 7

Figs. nos. 5 –7: Charts of the studied samples from the mortar, the tile body, the glaze in Terbana Mosque and the exits of Sodium Chloride Salt NaCl (Halite) in all samples by (XRD)

There were several causes for the cracking and deteriorate in the grout. Excessive deflection in the mortar would cause the grout to crack and if sufficiently severe could cause the tile to crack. In some cases, the type of the tile (depending on the clay minerals and the firing temperature – high or low) can affect the variability of high or low water absorption in the tile body as the tiles of Terbana mosque.²²

Soluble salts like sodium chloride NaCl (halite) which would penetrate the mortar used to affix the ceramic tiles caused efflorescence of salt minerals as mentioned. Occasionally, tiles installed over a thick mortar bed were subject to efflorescence if sufficient amount of soluble salts were present. The tiles would often fall if high moisture regularly passed through the mortar bed, e.g. moisture from the relative humidity from the sea which contained a substantial amount of salts, or from the underground water below the floor of the mosque. This moisture, which invisible to the eyes, would steadily travel through the wall blocks, the mortar, the glazed tiles, and into the grout. Efflorescence would occur if the mortar and grout were excessively porous. The rain could also cause efflorescence over time under the right conditions, e.g. with poorly compacted or porous mortar or grout, or in exterior installations over mortar or in areas exposed to rain.²³

DISCUSSION

Changes in the stability of a site can occur quickly and with little warning²⁴. Thorough investigation and scientific analysis revealed the cause of deterioration to the glazed ceramic tiles in Terbana mosque. Exposure to the elements was a major contributor; the ceramic tiles also broke down, physically and chemically, depending on the clay type. Water could dissolve the clay minerals in the core of ceramic tiles that have been low fired (e.g. calcite CaCO_3 , a component found in the mosque tiles). The tiles fired at higher temperatures could also be compromised if their mineral particles are soluble in water.

In addition, various compounds in water could react with different kinds of ceramic tiles, e.g. naturally in the running water, carbon dioxide CO_2 dissolved and could create a chemical reaction with minerals in clay bodies to form calcium bicarbonate HCaCO_3 , which is highly soluble, whereas stagnant water is less damaging because the carbon dioxide is not exhausted²⁵. The porous body of the tiles allowed for water penetration causing the tiles to become unstable because of the high percentage of soluble salts which ultimately lead to cracking and breaking of the tile body. If the tiles were more bonded to the mortar, cracks would occur in the mortar causing cracks in the tile layer "reflective cracking".²⁶

In extreme cases of salt damage, the mortar would disintegrate leading to downward stacking of the wall blocks which eventually collapsed sections of the walls. Crystallized soluble salts were a major of degradation in the tiles and the mortar which affixed it. Over

²² Hamilton, *Methods of Conserving Archaeological Material*, pp.17-19; Buys, *The Conservation & Restoration of Ceramic*, p. 20-24; Pessoa, *Removal and analysis of soluble salts*, pp.153-160.

²³ Biczok, *Concrete Corrosion and Concrete Protection*, p.310,368; Byrne, *Setting Tile*, pp.104-107; *Tile Flooring Technical Information*.

²⁴ Maarleveld, *Manual for Activities directed at Underwater Cultural Heritage*, p.70.

²⁵ Hamilton, *Methods of Conserving Archaeological Material*, pp.17-19; Biczok, *Concrete Corrosion and Concrete Protection*, p.368.

²⁶ Byrne, *Setting Tile*, pp.109-111; Durbin, *Architectural Tiles*, p.188.

time the physical structure of the tile body could even crumble until it was completely destroyed, and the mortar would turn into soft powder.²⁷

CONCLUSION

The difficulty to prevent the damage because of the inherent nature within the material renders the phenomenon a natural occurrence. It is advised to treat and reconstruct the damaged areas of the mortar which fixed tiles. The tile systems over inhabited (or in general) space require waterproof mortar/substrate below the tile so that water will not be able to penetrate below the tile layer. Serious consideration must be given to controlling where the water will go and how it will affect the tile and mortar /substrate²⁸.

The setting materials and mortar/substrate must be appropriate for the exterior conditions unsusceptible to crystallization, melt-resistant, and with non-re dispersible polymers. Water exposure from regular cleaning is not enough to cause efflorescence, Saturating the grout joints with water during periodic cleaning generally does not cause efflorescence either²⁹.

The restoration team should use crack isolation membranes (a product made specifically for crack isolation) to prevent cracks, shrinkage of control joints, and to protect the floor mortar from potential cracking.³⁰

²⁷ Biczok, *Concrete Corrosion and Concrete Protection*, pp.313-324; Byrne, *Setting Tile*, p.60.

²⁸ Byrne, *Setting Tile*, p.104-107; Hamilton, *Methods of Conserving Archaeological Material*, pp.17-19; Jaime, *Use Of Clay/B-Cyclodextrin Formulations*, pp.2254-2250; *Tile Flooring Technical Information*.

²⁹ Byrne, *Setting Tile*, p.104-107

³⁰ Durbin, *Architectural Tiles*, p.110,128.

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