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THE EFFECT OF THE GEOLOGICAL NATURE OF SIWA OASIS ON THE DETERIORATION OF ARCHAEOLOGICAL AND HISTORICAL BUILDINGS (THE TEMPLE OF ORACLE AND SHALI CASTLE)

Shaimaa Sayed Mohamed El-Sayed

Conservation Department, Faculty of Archaeology, Luxor University, Egypt
(Egyptianconservators2013@gmail.com; shaimaasayed43@gmail.com)

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ABSTRACT

This research aims to shed light on the effect of the geological nature of Siwa Oasis on the deterioration of the saline building materials in it. The application is made to the Temple of Oracle and the historic Shali Castle. Sampling was made on the saline limestone, Al-Kurshef and its mortar for the determination of their components, elements and current status. Methods used were Scanning Electron Microscope with EDAX (SEM-EDAX), X-Ray Diffraction analysis (XRD), the results have shown that the halite salt is the main component of saline limestone and Al-Kurshef.

The Oasis is characterized by the presence of salt lakes, as the climate is a very dry continental desert. The rain falls many times, and thus salt deposits are formed from halite salts, gypsum and other salts. The salts, mud and other deposits are forming a local saline building material that ancient people from Siwa used extensively in their unique-style buildings (called al-Kurshef), which is a mixture of mud and sediments. It is found that the salty nature and very low rainfall are most prominent in the preservation of the historical Shali castle. It has been shown that the geological nature of Siwa Oasis had the greatest impact on the damage of these materials. The limestone in the village of Aghurmi, Siwa Oasis, the Temple of Oracle contains a large percentage of salts in addition to the clay minerals of Smectite, Illite and kaolin and the presence of marine fossils.

KEYWORDS: Saline Building Materials, Al-Kurshef, Salty Limestone, Scanning Electron Microscope, X-Ray Diffraction, Shali Castle, Temple of Oracle.

1. INTRODUCTION

Siwa Oasis is located in the far western part of the Western Desert in Egypt, 260 kilometers south of Marsa Matruh, and covers an area of 400 square kilometers. The oasis extends to a lower length of 17 meters below sea level, and inside the depression, there are four salt lakes and a group of natural springs used for irrigation (Abdel Fattah *et al*., 2013)- (Figs 1, 2).

The use of saline building materials in Siwa Oasis is one of the unknown building techniques that were used in the village of Shali, where an ancient castle was built in the twelfth century in Siwa in the Egyptian Western Desert called Shali Castle. This architecture is characterized by the use of blocks of salts taken from the nearby salt lakes and covered with a layer from clay mortar filled with salts, and this technology is still present today, as it represents the exploitation of resources from the local surrounding environment (Abdel Hafez *et al*., 2021).

The town of Al-Aghurmi (where the Temple of Oracle to Amun) is built on a rock in the form of a fortified castle overlooking all neighboring sides, and at the bottom of the rock there are a large number of explosive springs, this village is one of the first villages built in Siwa in the Middle Ages in the wake of the end of the Amun temple era and the end of the Roman era, Aghurmi was built of mud and stones on a rocky hillside next to the Temple of Oracle (Abdel Motelib, A., *etal*., 2015) . Ahmed Fakhry mentioned that the oracle of Amun spread his fame in Siwa in all the Mediterranean countries since the beginning of the twenty-sixth dynasty (Fakhry, 1973), and the Temple of Oracle for Amun was established in the oasis and Alexander the Great visited in The Ptolemaic era, where this visit is the most famous of the visits that took place to this temple in the Siwa Oasis, and it was also mentioned that the Temple of Oracle in Siwa was not used for the consecration of Alexander the Great and that the only temple that was used to consecrate Alexander the Great is in the Bahariya Oasis (Darwish, 2010).

Nabhan *et al*., 2015), stated that the Temple of Oracle to Amun is a mixture of Pharaonic, Ptolemaic and Roman architecture.

This research aims to study saline limestone, which is a unique type of limestone, where the proportion of salts exceed 30% of the components of the stone and this type is found in Siwa Oasis only in Egypt. This salt geological nature has caused many deterioration phenomena to the temple of Oracle Amun in Siwa, which threatens the safety and security of this temple.

The study also aims to identify a basic building material in Siwa that is still used to this day, which is Al-Kurshef, where the Shali Castle was built from it. It is found only in Siwa, according to its geological nature. These two building materials have not previously been addressed in any kind of detail.

2. GEOLOGICAL AND CLIMATIC STUDY OF THE SIWA OASIS

Siwa Oasis is located in a homogeneous depression in the Marmaric plateau, the Marmarica plateau consists of limestone from the Miocene era consisting of decomposing marine rocks with carbonates and interferences of marl, the evaporates in Siwa Oasis consist of halite salts and gypsum mainly and other salts, the soil is loam and sandy loam (Powell & Fensham, 2016, 396). According to geological maps, the carbonate rocks from the middle and upper Miocene period are found in the north of the Qattara Depression and the Siwa Oasis (Badawy *et al*., 2015).

Also, there are slabs of limestone, sandstone, pebbles and flint from the Pleistocene era north of the Siwa Oasis, and the geological formations from the Holocene era are fine grains of quartz also, the deposits of sabkha sediments consisting of silt and clay with evaporate sediments (Trudgill, 2011, 209), and the middle Miocene carbonate rocks are located in Siwa oasis in the north of the Western Sahara in an unstable tectonic zone (El Khadraoui, 2012). The geological nature is also characterized by the presence of horizontal layers of porous limestone alternating with marl and clay dating back to the Miocene period. The thickness of the layers of marl and limestone reaches multiple meters, while the thickness of the clay layers reaches a thickness of no more than 10 cm (Rabeh, 2012, 279).

Siwa is characterized by surface saline deposits, where these deposits are formed in a heterogeneous unit of dolomite, black clay, anhydrite salts, halite and other salts, which are among the weakest rock components, and these salts are crystallized after being deposited in a very arid environment and in the presence of shallow lakes (Taher & Abdel Motelib, 2014, 46).

Siwa Oasis is characterized by a desert climate, characterized by mild winters and extremely hot summers, the average daily temperature varies from 10.6 ° C in January to 38.8 ° C in July, the rate of evaporation ranges from 4.32 millimeters to 13.54 millimeters, and the average annual rainfall reaches 10.43 Mm. Siwa is also considered a very dry region, as the annual rates of evaporation are high, reaching approximately 30,000 mm (El-Gammal, 2010; El-Sayed, *et al*.,2020).

3. ARCHITECTURAL & ARCHAEOLOGICAL ELEMENTS OF ORACLE TEMPLE

The temple dates back to the rule of King Ahmose II (Amazis) of the 26th Dynasty (664–525 B.C,) although some additions were added to it in later periods, according to the texts written in the Holy of Holies (Khader, 2014).

The temple opens to the south and consists of two halls, followed by the Holy of Holies, the entrance to which is located on the main axis. There is a narrow corridor on the eastern side of the Holy of Holies and continues behind the back wall, and there is another room on the western side.

The height of the original façade of the temple is about eight meters and is of a simple style, while the entrance to the temple topped by the corniche is 2.22 m wide and has no writings in it, the Ptolemies wanted to make the temple somewhat similar in appearance to the Greek temple, as they erected in front of it a half-column of recessed Doric style on each side of the entrance.

The length of the first courtyard of the temple is 7.47 meters, its width is 4.95 meters, and its entrance is completely in the middle of the walls, while the second courtyard is slightly higher than the first, although their dimensions are roughly the same, and based on recent studies, the temple was built in three stages (Shehab,2006).

The Holy of Holies is the only part that carries inscriptions in the temple, and its dimensions are 3.3 meters in width and 6.1 meters in length, and like the rest of the temple rooms, the Holy of Holies was covered (Figs 3, 4).

Figure 1. Siwa Oasis location on the map of Egypt, quoted from https://en.wikipedia.org/wiki/Siwa_Oasis

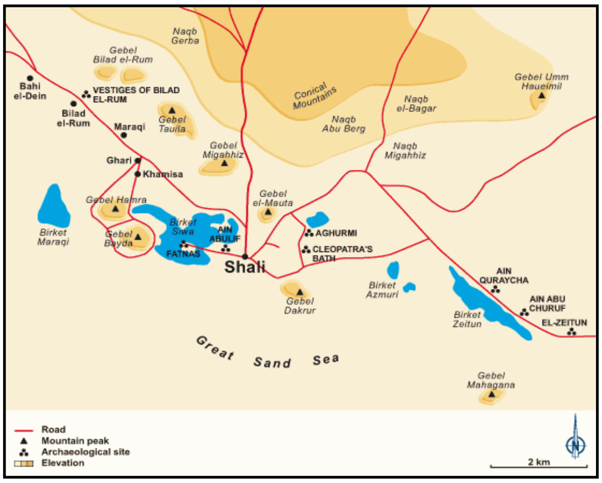

Figure 2. Siwa Oasis centers and villages, quoted from https://en.wikipedia.org/wiki/Siwa_Oasis

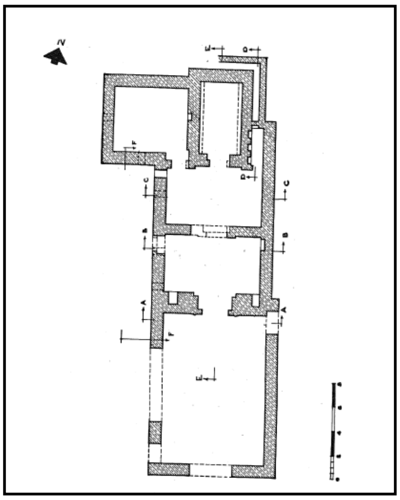

Figure 3. A plan of Oracle temple at Siwa Oasis, according to Ahmed Fakhry (Oasis of Egypt)

Figure 4. The Oracle temple in Siwa, which is built on Aghurmi rock

4. HISTORICAL AND TECHNICAL ELEMENTS OF SHALI CASTLE

The era of salty buildings in Shali dates back to the 12th c. AD and the thirties of the 20th century, and now the castle of Shali looks like a succession of ruins of walls with small windows. Inside the castle, especially in small houses, it is noticed that palm trunks are used in the process of linking the walls, and the outer walls are covered with clay mortar, al-Kurshef is the basic building material for these buildings (Figs 5, 7).

Al-Kurshef consists of crystals of halite salt "sodium chloride" with impurities of clay and sand. It uses irregularly shaped blocks taken from the surrounding salt lakes. It has been cut into smaller blocks, used in construction and attached to a salt-rich clay mortar. During the drying process, a strong link occurs between Salt and mortar blocks, due to NaCl crystals of halite salt inside the mortar itself.

From a survey of the external walls of the building, it is noticed that tree branches are used in the walls, especially the edges, so Siwa Oasis architecture is characterized by its weakness, which exposes it to unexpected damage.

Palm wood is used as wooden bars in building walls, and these woods are distinguished as a material that is easy to perish as it is subjected to vertical displacements in small loads, and the walls are characterized by the presence of cracks and separations especially at the perpendicular walls "the area of edges and corners", as well as under the bars of palm wood and above, and the mechanics of these cracks and separations must be studied to Preserve These Buildings (Fig 8).

The old construction method in al-Kurshef is still used today in building the homes of the people of Siwa Oasis (Rovero *et al.*, 2009, 2492.) (Figs 9,10).

Figure 5. Historic Shali Castle

Figure 6. Building with Al-Kurshef blocks and mortar in the historic Shali Castle

Figure 7. One of the walls in Shali Castle, which was built from Al-Kurshef, and it becomes clear that there are deep cracks and separation in the walls.

Figure 8. The use of wood in joining the walls and roofing of one of the old houses in Shali Castle built from Al-Kurshef

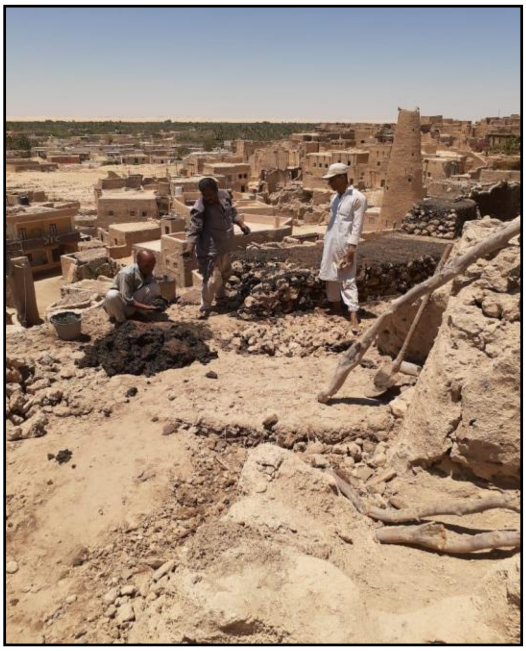

Figure 9. The people used the same old construction technique with Al-Kurshef in building modern houses

Figure 10. Building a modern wall using Al-Kurshef

5. MATERIALS AND METHODS

Samples were taken from al-Kurshef in the historic Shali Castle and samples of saline limestone from Oracle temple.

The for XRD samples that were taken from al-Kurshef and its mortar (Shali Castle), as well as the saline limestone (Temple of Oracle in Siwa) and a sample of salts, were analyzed by an X-Ray Diffraction device to identify their components and proportions (Figs 11, 14).

The Elemental analysis using the Energy-dispersive X-ray spectroscopy (EDAX) unit attached to the scanning electron microscope is used to identify the elements in al-Kurshef samples, Kurshef mortar and the saline limestone; it serves as a confirmation of the X-ray diffraction results (Abdel Kader & El-Sayed, 2019) (Figs 15, 17).

The scanning electron microscope is characterized by that it gives high-quality images, with a magnification power of millions of times to the surface of the samples, and the aforementioned samples were examined with this microscope to study the inner tissue of the samples surface with different degrees of magnification (El-Sayed, 2021; Abdel Kader *et al.*, 2019) (Figs 18, 20).

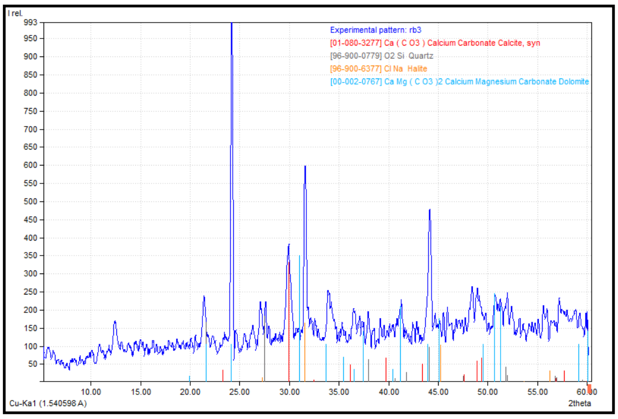

Figure 11. X-ray diffraction pattern of Al-Kurshef sample at Shali Castle

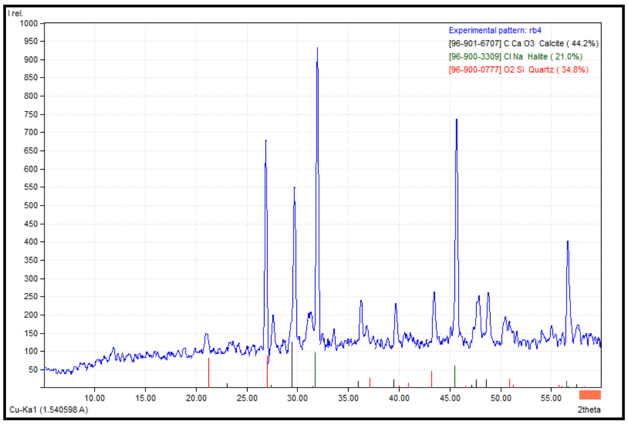

Figure 12. X-ray diffraction pattern of Al-Kurshef mortar -at Shali Castle

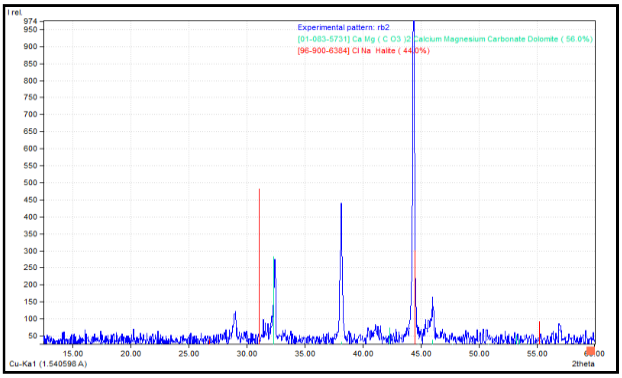

Figure 13. X-ray diffraction pattern of a sample of saline limestone: The Oracle Amun temple

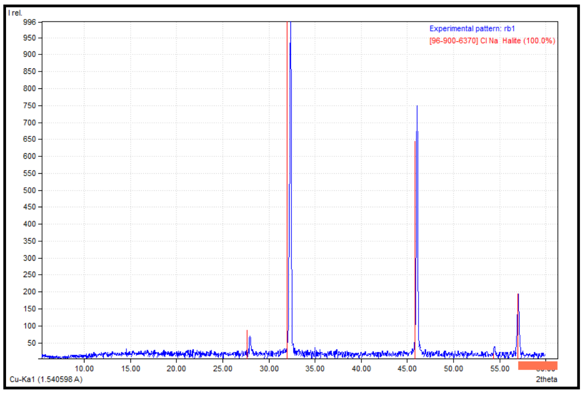

Figure 14.X-ray diffraction pattern of a salt sample: The Oracle temple

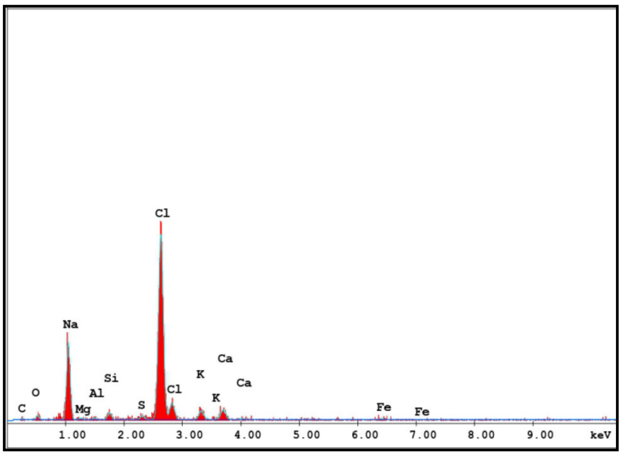

Figure 15.Elemental analysis using the EDAX unit of Al-Kurshef sample

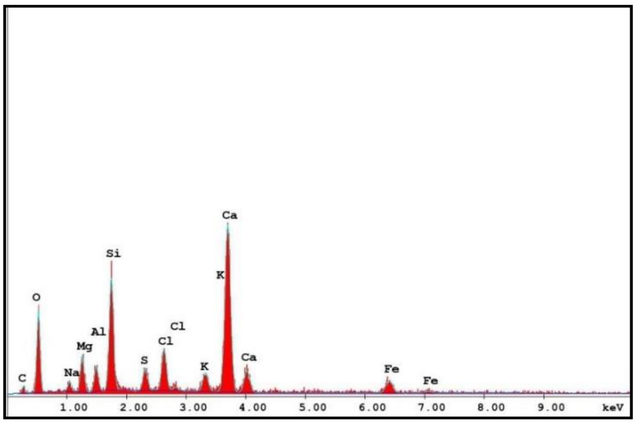

Figure 16. Elemental analysis using the EDAX unit of Al-Kurshef mortar sample

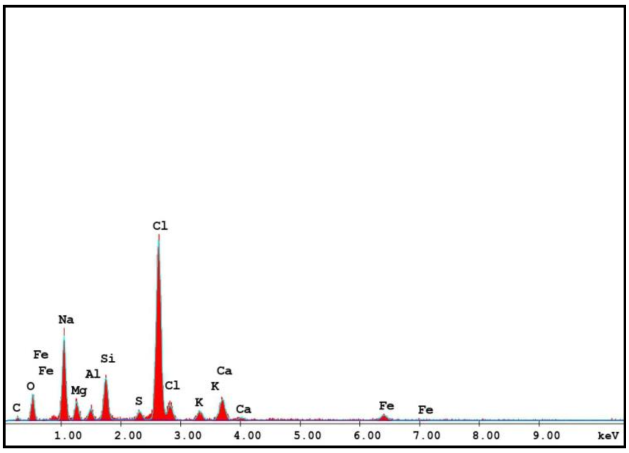

Figure 17.Elemental analysis using the EDAX unit for a sample of saline limestone

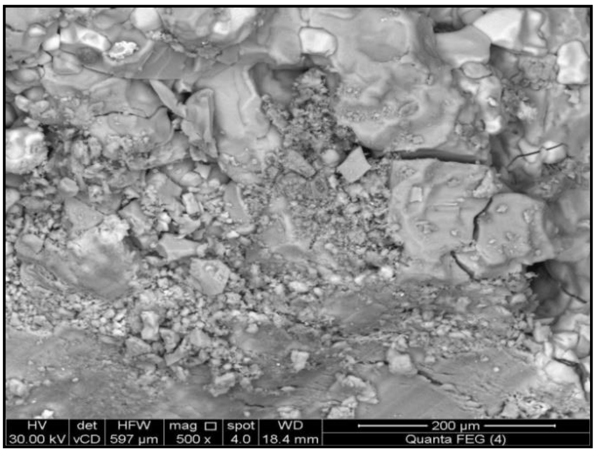

Figure 18. Scanning Electron Microscope examination of Al-Kurshef sample and revealing surface fragmentation and damage (magnification power 500X)

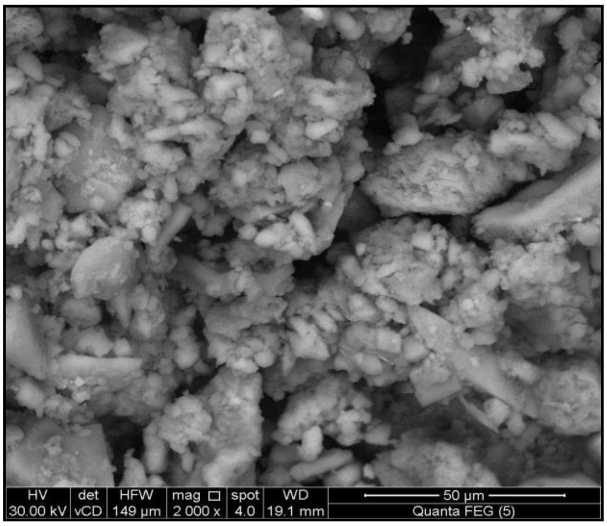

Figure 19. Examination with a scanning electron microscope of Al-Kurshef mortar and the crystals of the halite salt are visible (magnification power 2000X)

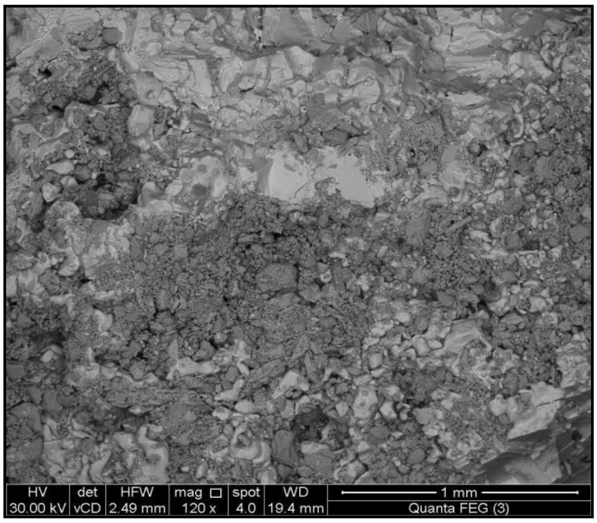

Figure 20.Scanning electron microscope examination of a saline limestone sample (magnification power 120X)

6. RESULTS AND DISCUSSION

A. Through the analysis of X-Ray Diffraction (XRD) of the samples taken, it was found that:

1. Al- Kurshef sample consists of the following compounds: halite salt (NaCl) which is the main component of the sample by 45%, calcite (calcium carbonate, $CaCO_3$) by 22%, quartz (silicon dioxide SiO_2) by 20% and dolomite (calcium and magnesium carbonate) Ca, Mg $(CO_3)_2$ at 10%.

2. As for al-Kurshef mortar, it consists of calcite ($CaCO_3$) with a percentage of 44.2%, which is the main component of the sample, halite salt (NaCl) by 21%, and quartz (SiO_2) by 34.8%.

3. The saline limestone sample taken from Oracle temple consists of dolomite (calcium and magnesium carbonate Ca, Mg $(CO_3)_2$), which is the main component of the sample by 56%, and halite salt (NaCl) by 45%, which is a very high percentage, due to the saline geological nature of limestone, which negatively affects the resistance of this stone to various deterioration factors, and threatens the safety of the temple.

4. The salt sample taken from the Oracle temple was analyzed, and it was found that it consists entirely of halite salt (one of the salts of evaporators) at a rate of 100%, This salt is characterized by its high solubility in humid climates and recrystallization in dry climates, and thus the multiplicity of dissolution and crystallization cycles, which causes crumbling and deterioration of building materials.

B. Elemental analysis using the EDAX unit

Al-Kurshef and its mortar samples consist of many elements associated with the potassium element K. This analysis is a confirmation of the X-Ray Diffraction results, as previously mentioned, and as shown in (Tables 1,2).

Also the elemental analysis of the saline limestone sample was done by the EDAX unit (Table 3).

Table 1. The components that make up Al-Kurshef sample and their proportions

Element	Wt %	At %	K-Ratio	Z	A	F
C K	4.89	10.79	0.0035	1.0815	0.0654	1.0002
O K	6.98	11.56	0.0097	1.0661	0.1308	1.0010
NaK	28.95	33.35	0.1134	1.0014	0.3898	1.0033
MgK	0.89	0.97	0.0027	1.0276	0.2918	1.0057
AlK	0.65	0.64	0.0026	0.9984	0.4044	1.0108
SiK	2.02	1.90	0.0112	1.0285	0.5311	1.0186
S K	0.94	0.77	0.0075	1.0220	0.7473	1.0540
ClK	46.31	34.60	0.3755	0.9790	0.8244	1.0045
K K	3.54	2.40	0.0223	0.9790	0.6415	1.0045
CaK	3.88	2.56	0.0273	1.0018	0.7016	1.0004
FeK	0.95	0.45	0.0083	0.9248	0.9427	1.0000
Total	100.00	100.00				

Table 2. The constituent elements of Al-Kurshef mortar and their proportions

Element	Wt %	At %	K-Ratio	Z	A	F
C K	5.92	10.69	0.0096	1.0441	0.1552	1.0006
O K	39.35	53.34	0.0632	1.0294	0.1559	1.0004
NaK	2.17	2.05	0.0055	0.9669	0.2595	1.0034
MgK	5.42	4.83	0.0197	0.9923	0.3637	1.0050
AlK	2.98	2.39	0.0131	0.9641	0.4509	1.0081
SiK	11.66	9.00	0.0651	0.9932	0.5586	1.0062
S K	2.24	1.51	0.0153	0.9870	0.6803	1.0154
ClK	4.41	2.70	0.0321	0.9455	0.7549	1.0187
K K	2.14	1.19	0.0181	0.9434	0.8600	1.0413
CaK	20.24	10.95	0.1748	0.9653	0.8928	1.0021
FeK	3.47	1.35	0.0298	0.8921	0.9625	1.0000
Total	100.00	100.00				

Table 3. The constituent elements of the saline limestone sample and their proportions

Element	Wt %	At %	K-Ratio	Z	A	F
C K	7.28	14.15	0.0064	1.0646	0.0828	1.0002
O K	18.93	27.62	0.0314	1.0495	0.1577	1.0008
NaK	20.58	20.90	0.0729	0.9858	0.3579	1.0036
MgK	4.90	4.71	0.0162	1.0117	0.3248	1.0052
AlK	2.29	1.98	0.0094	0.9829	0.4126	1.0088
SiK	7.15	5.94	0.0384	1.0126	0.5245	1.0112
S K	1.23	0.90	0.0089	1.0062	0.6930	1.0308
ClK	29.06	19.13	0.2181	0.9639	0.7753	1.0045
K K	1.94	1.16	0.0134	0.9622	0.7147	1.0066
CaK	4.45	2.59	0.0340	0.9846	0.7742	1.0012
FeK	2.17	0.91	0.0191	0.9097	0.9645	1.0000
Total	100.00	100.00				

C. Examination by Scanning Electron Microscope (SEM)

The scanning electron microscope (magnification degree 500X), of the Al- Kurshef sample, the halite salt crystals is clearly shown as a basic component, also the weakness of the inner tissue of the surface of the sample where there are fissures and cracks within the sample, is shown by examining the surface of Al-Kurshef mortar sample that it suffers from severe weakness. (Greater than Al-Kurshef) (Magnification degree 2000X), while full-crystallized halite salt crystals also are present.

As for the saline limestone sample (Magnification power 120X), the building material was significantly weak and the presence of gaps and losses inside the sample, and this shows the extent of the deterioration of the condition of the temple and the presence of cracks in abundance, all of which is caused by the geological nature of the saline limestone and Al-Kurshef.

It has been shown through the previous results that halite salt is the main compound of building materials in Siwa Oasis, whether it is Al-Kurshef or saline limestone, and this reflects the geological nature of the Siwa Oasis, which is characterized by the presence of evaporators (salts), this salt is considered a weak point in the building material of the Shali Castle and the Oracle temple, it is a hygroscopic salt that is soluble in water in humid climates, and this was evident when examining the samples with the scanning electron microscope, so it is necessary to strengthen the building materials and isolate them from the surrounding environment to avoid dissolving these saline materials in the humid climates of Siwa Oasis, and the following are the effects The damage caused by the saline geological nature of the local building materials in Siwa Oasis.

D. The effect of the saline nature of the limestone on the damage and deterioration of the Oracle temple

By analyzing the limestone sample taken from the temple by X-Ray Diffraction, it was found that the percentage of halite salt (sodium chloride) in the sample is 45%, which is a very high percentage as previously mentioned because the halite salt is a component of limestone, and that geological nature resulted in many deterioration phenomena to the temple are as follows:

1.Fragmentation and loss of limestone due to exposure of halite salt to cycles of dissolution and crystallization.

2. The occurrence of many fissures and cracks in the walls of the temple.

3. The temple is built on the Aghurmi rock, which suffers from weakness and cracking, and is structurally threatened by collapse at any time, and therefore this threatens the safety and survival of the temple, and this rock is part of the geological nature of Siwa Oasis (Figs 21,27).

Figure 21. The crumbling and degradation of the saline limestone at the Temple of Oracle in Siwa

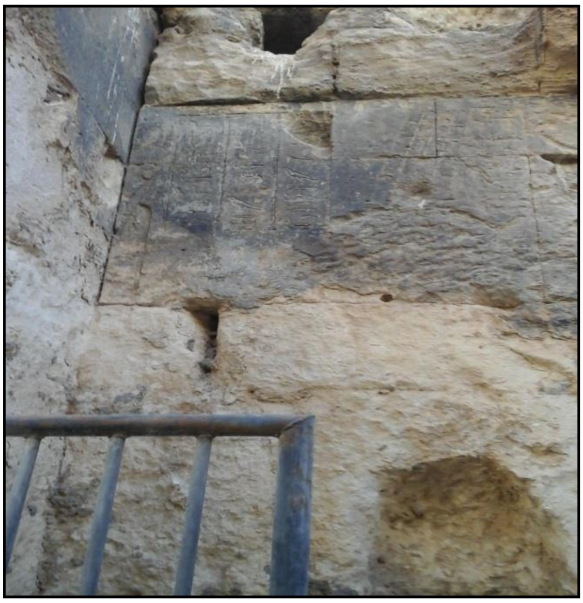

Figure 22. Surface erosion of saline limestone and loss of rock engravings as a result of dissolution and crystallization cycles of halite salt

Figure 23. the crumbling of the saline limestone surface as a result of the saline geological nature of the Siwa Oasis - the Oracle Temple

Figure 24. Saline limestone eroded and cracks spread in one of the walls - the Oracle temple

Figure 25. Salt deposits on the surface of limestone - Temple of Oracle, Siwa

Figure 26. One of the completion of the walls of the Temple of Oracle, as a result of the weakness and erosion of the saline limestone

Figure 27. The Aghurmi rock, on which the Temple of Oracle is built, is threatened with collapse at any time, threatening the security and safety of the temple

Figure 28. Al-Kurshef is damaged and eroded at the bottom of one of the walls of the historic Shali castle, which exposes it to partial or complete collapse

E. The effect of geological nature on the damage and deterioration of the historical Shali castle

Also, by analyzing al-Kurshef sample taken from the Shali castle by X-Ray Diffraction, it was found that the percentage of halite salt (sodium chloride) in the sample was 45% due to the fact that halite salt is the main component of al-Kurshef; also, the percentage of salt in mortar was 21%, and that geological nature resulted in many aspects of damage to the castle, as follows:

1- The fragmentation of al-Kurshef material and its loss in many places in the castle.

2- The presence of clear fissures and cracks in the walls caused by the weakness of al-Kurshef.

3- It was lost in al- Kurshef mortar as a result of its weakness (Figs 28,30).

Figure 29. The weakness and fragmentation of Al- Kurshef in the eroded part of the walls - the historic Shali castle

Figure 30. Salt fluorescence on the surface of the mortar due to the saline nature of Al-Kurshef - Shali Castle

7. CONCLUSION

Siwa Oasis is characterized by the traditional architecture of saline building materials, the effect is the result of its environment, as Siwa Oasis is characterized by unique building materials based on salts and these materials, which in turn are the result of the geological nature of Siwa Oasis. The ancient architect exploited the building materials of saline limestone in the building of Oracle Amun temple, as well as Al-Kurshef in the construction of the Shali castle. The use of local woods such as palm trunks to support these historic buildings, suffers from deterioration, fragmentation and damage due to their weakness caused by the salty nature of the building materials.

As cracks of all kinds and degrees are spread, which exposes them to annihilation and extinction, it is recommended to carry out restoration operations such as reinforcement, as well as isolation of traditional building materials from sources of moisture to preserve this unique cultural heritage for future generations. Sodium chloride salt (which is a major component of these materials) is considered one of the salts. The multiple cycles of dissolution and crystallization - solubility in water and crystallization during drought of this salt - threaten this unique cultural heritage, which is a testament of the ancient Egyptian architecture and the great Egyptian civilization.

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