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Geoarchaeological Study of the Doush Temple: Analyzing Human-Environment Interactions, Kharga Oasis- Egypt

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ABSTRACT

The Doush Temple in Kharga Oasis -Egypt- represents a unique case for geoarchaeological study, providing insights into the interaction between human activity and environmental changes in an arid landscape. This research investigates the temple's construction and the surrounding site's historical layers, revealing that the temple was built over earlier, buried structures, potentially an ancient village or fort. The widespread presence of pottery sherds across the site, especially atop sand-buried ruins, suggests continuous human occupation even after desertification affected the area. The study combines archaeological findings with geomorphological analysis to explore how environmental factors, such as sand accumulation and climate shifts, influenced the region's settlement patterns. These findings contribute to a broader understanding of how ancient civilizations in desert regions adapted to and modified their environments to sustain life and culture.

1. Introduction

The Doush Temple is an important example of Roman influence in Egypt during the Hellenistic period. It reflects the cultural and religious intertwining of that era. There are opinions suggesting that the temple was founded during the reign of Emperor Domitian (Domitianus), who ruled from 81 to 96 AD. His rule is considered a vital period in which imperial worship was enhanced and Roman authorities imposed their influence on local religious practices. The construction of new temples was part of the empire's strategies to reinforce loyalty among the populace and affirm its power (Kaper, 1998).

The temple is dedicated to the worship of three primary deities: Isis, Serapis, and Harpocrates. Isis, regarded as the goddess of motherhood and magic, Serapis, representing fertility, and Harpocrates, considered a symbol of healing, all played significant roles in the religious life of the local community. The worship of this triad reflects the blending of Roman and Egyptian traditions. This worship shows the diverse identity of local inhabitants during the imperial rule (Rutherford, 2016).

The temple complex is relatively compact but well-planned. The main building is constructed from local sandstone, a material widely used in the region's architecture. The temple is oriented along a traditional Egyptian axis, with the entrance facing east, aligning the structure with the rising sun, a common feature in ancient Egyptian religious architecture (Peacock & Blue, 2006). The temple consists of several key components: Pylon, Courtyard, Hypostyle Hall, Sanctuary, Storage Rooms, and Side Chambers.

While the basic layout of the Temple of Doush follows traditional Egyptian temple design, it incorporates several Roman architectural elements as well. For example, the use of columns with Corinthian capitals reflects Roman influence, blending Egyptian religious practices with the Roman Empire's architectural language (Schneider, 2012). Beside of that the design of the temple reflects its dual purpose as a place of worship and a symbol of Roman administrative power in the region. The Roman emperors were keen to maintain control over the desert routes and oases, and the presence of temples like Doush reinforced their influence while respecting local religious traditions.

With the emergence of Christianity in later centuries, the Doush Temple underwent a transformation in its use. In the fourth century AD, with the adoption of Christianity by the Roman Empire under Emperor Constantine, many ancient temples were converted into churches or Christian worship sites. Archaeological evidence suggests that the Doush Temple was no exception to this phenomenon. It was used as a church, where the church was built of mud brick, reflecting a shift towards locally available and easily accessible materials in construction, and also demonstrating how ancient temples were repurposed to reflect the new Christian values and beliefs (Bagnall, 1996).

Literature Review

This literature review highlights the significant role of geoarchaeology in understanding the interactions between natural processes and human activities that shape archaeological sites.

- Schild & Wendorf (2001) explore the geoarchaeology of the Holocene climatic optimum at Nabta Playa, Egypt. Their research reveals that the sediment layers corresponding to this period showcase a rich diversity of flora and fauna, indicating the environmental conditions that influenced human settlement and agricultural development. Their findings underscore the necessity of understanding past climates to contextualize archaeological evidence and human adaptation strategies.
- Delannoy et al. (2012) introduce the concept of "archaeomorphology," which examines how human activities affect the geomorphology of rock art sites. Their work emphasizes the necessity of analyzing physical site evolution to comprehend the historical context of places like the Chauvet Cave in France and Nawarla Gabarnmang in Australia. The study argues that anthropogenic factors can significantly alter the landscapes of archaeological importance.
- Aubry et al. (2016) address the preservation challenges faced by the Theban Necropolis in Egypt due to geological and environmental threats. By categorizing the vulnerability of these historical sites, they recommend geotechnical interventions to mitigate the risks posed by natural processes. Their study illustrates the need for integrating geoarchaeological insights into conservation practices.
- Bravard et al. (2016) investigate the geoarchaeological history of the El-Deir oasis in the Kharga Depression, emphasizing how ancient agricultural practices were influenced by climatic fluctuations and erosion. Their research highlights the historical significance of floods and irrigation methods in shaping the agricultural landscape, providing insight into the sustainable practices of past

civilizations.

- Rossi & Magli (2019) analyze the urban planning of late Roman fortifications in the Kharga Oasis, focusing on how natural elements, particularly prevailing winds, influenced site orientation. Their study offers insights into the implications of such "weathervane orientation" on settlement organization and agricultural layout, demonstrating the significance of geoarchaeological factors in historical urban development.
- Bunbury et al. (2020) examine the development and subsequent desiccation of large lakes in the Kharga Basin during the Holocene. Their findings demonstrate how these water bodies played a crucial role in supporting ecosystems and facilitating human migrations before their eventual abandonment due to climate change. This research emphasizes the interconnectedness of environmental changes and human responses in shaping settlement patterns.
- Torab (2021) investigates the weathering processes affecting the rocks of the Pyramids of Dahshur, located approximately 20 km south of the Giza plateau. This research highlights the geological context of the Dahshur area, which houses significant structures such as The Bent Pyramid and The Red Pyramid. The study emphasizes the impact of environmental pollutants on the coarse-grained rocks used in construction and their subsequent weathering, which poses risks to both the monuments and public health. Torab's examination provides insights into the meticulous methods employed by ancient Egyptian masons to ensure the longevity of these materials, showcasing their understanding of rock behavior during the construction process.
- In a recent study, Saber and Elbana (2023) focus on Sabil Muhammad Ali in Cairo, discussing its architectural and cultural significance while analyzing the environmental challenges leading to its deterioration. They identify the specific weathering processes affecting the limestone used in its construction, further emphasizing the need for geoarchaeological insights in conservation efforts.

This comprehensive review illustrates the dynamic interplay between geomorphological processes and human activities in shaping ancient Egyptian landscapes and settlements, highlighting the critical role of geoarchaeology in unraveling the complexities of past human-environment interactions.

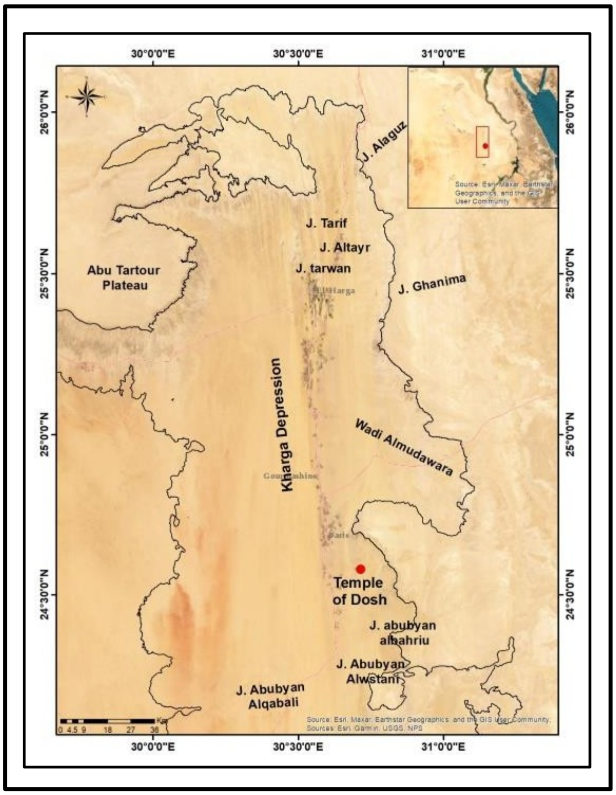
2. Objectives of the Study

The research focuses on the natural and anthropogenic geoarchaeological impacts on the Doush Temple in Kharga Oasis, Egypt, examining the extent of damage it has sustained over time. It investigates the complex interactions between ancient human activities and the environmental conditions that have shaped the region. By analyzing the effects of natural processes such as erosion, sand accumulation, and climate variations, alongside human activities like construction and settlement patterns, the study aims to provide a comprehensive understanding of how these factors have contributed to the temple's current state. This research seeks to highlight the importance of preserving the Doush Temple by elucidating the interplay between human actions and environmental changes that have influenced this significant archaeological site.

3. Temple of Doush location

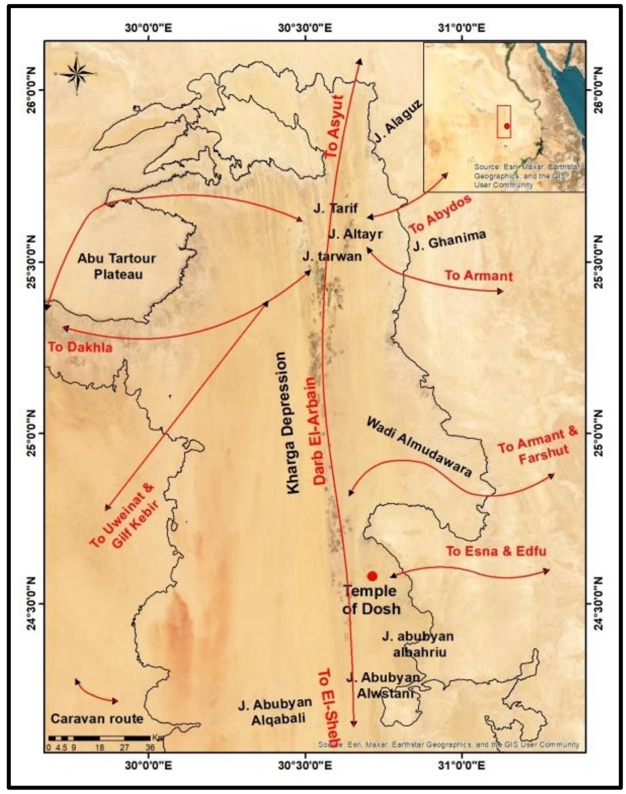
The Temple of Doush is located in the Kharga Oasis, in Egypt's Western Desert, approximately 120 kilometers south of the city of Kharga and about 20 kilometers east of Paris Village at 24°37'14" N and 30°35'00" E (Fig. 1). This positioning, in the southern reaches of the oasis, places the temple within a historically significant region due to its proximity to ancient trade routes and its location along key pathways connecting Egypt with regions to the south and west.

In antiquity, the Kharga Oasis served as a crucial transit point for traders traveling along the Darb el-Arbain (Fig. 2), an ancient trade route that connected the Nile Valley with Sudan and other parts of Africa (Bagnall, 1996). The Darb el-Arbain was one of the most vital caravan routes for transporting goods such as gold, ivory, and other commodities. The strategic placement of Doush at the edge of this oasis made it a critical stop for merchants and travelers moving between the Nile and the far-reaching corners of the African continent (Solieman et al. 2019).



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbis Ds, USDA, USGS, AeroGRID, and IGN.

Figure 1. Temple of Doush Location



Source: After Rossi & Ikram, 2002.

Figure 2. Schematic Map of the major Caravan Routes in the Kharga Oasis.

Doush was not only important for trade but also for its role in the military networks of the Roman Empire. The Romans established a series of outposts in the Western Desert to secure their trade routes and assert control over the region. The Temple of Doush, which dates to the Roman period, would have been part of this larger network of Roman fortifications and settlements in the Kharga Oasis, designed to protect and facilitate the movement of goods across the desert (Rossi & Magli, 2019).

Additionally, the temple's location near the outskirts of the Libyan Desert highlights its strategic importance. The Roman presence in the region sought to stabilize the southern boundaries of the empire and ensure safe passage for goods along the desert routes (Solieman et al. 2019). Being situated near the desert's edge, the temple at Doush would have served as both a religious site and a checkpoint along these trade and military routes.

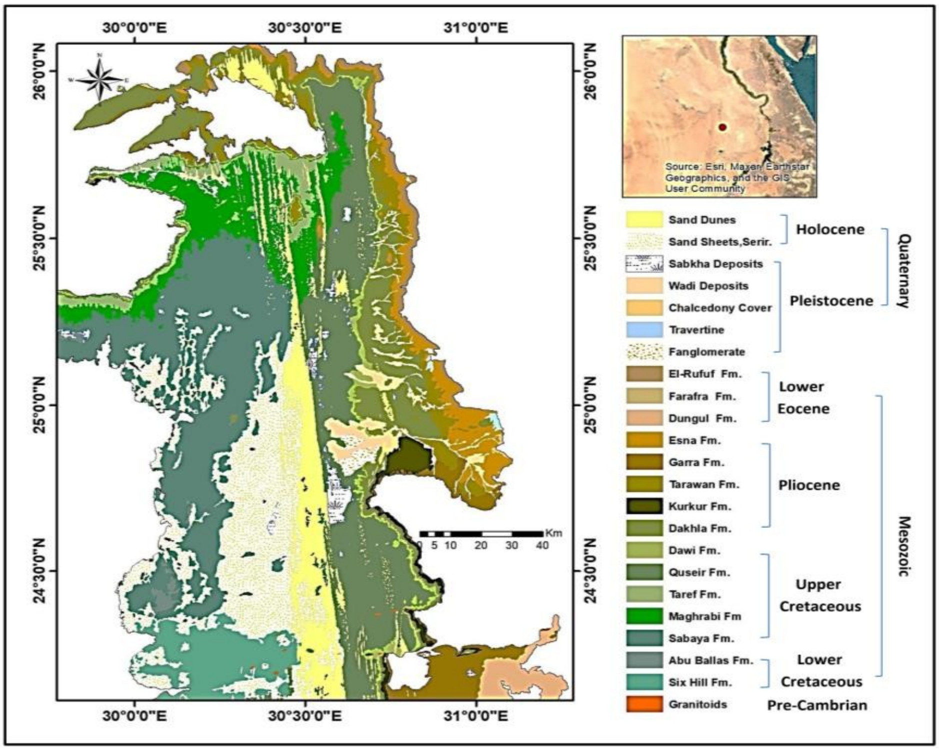
The placement of the Temple of Doush is a reflection of the importance of the Kharga Oasis as a center of connectivity between Egypt and its southern neighbors during the Roman period. Its proximity to vital trade routes and its role in Roman military strategy underscore the significance of its location.

4. Geological Conditions

The geology of the Kharga Depression in Egypt features a complex history that extends from the Precambrian era to the Quaternary period (Fig. 3), characterized by various sedimentary and igneous formations. The region is primarily composed of sedimentary rocks, such as sandstone, limestone, and shale, but it also includes notable exposures of igneous rocks, specifically the pink granite of Gebel Abu Bayan, which dates back to the Precambrian era.

4.1 Precambrian: Igneous Activity

The granite of Gebel Abu Bayan is a significant geological feature in the Kharga Depression, representing some of the oldest rocks in the region. This pink granite, formed during the Precambrian, indicates ancient igneous activity and tectonic processes that predate the sedimentary sequences that dominate the area today (Rossi & Magli, 2019). The presence of such ancient rocks provides insight into the geological evolution of the region and its tectonic history.



Source: Conoco Coral and the Egyptian General Petroleum Company Corporation, 1987.

Figure 3. Geological Overview of the Kharga Depression

4.2 Paleozoic to Mesozoic: Fluvial and Marine Deposition

As we move forward in time the geological history of Kharga transitions into the Paleozoic and Mesozoic eras, where extensive fluvial systems developed during the Jurassic and Early Cretaceous periods. This era is characterized by the deposition of the Nubian Sandstone, which reflects the existence of ancient river networks that shaped the landscape and laid the foundation for the Nubian Sandstone Aquifer, one of North Africa's most significant groundwater resources (Said, 1962).

During the Late Cretaceous, marine transgression occurred, resulting in the deposition of the Dakhla Formation. This shift from continental to marine environments is marked by the presence of fine-grained shales, marls, and limestones, which contain marine fossils such as ammonites and foraminifera, indicating the conditions that prevailed during this time (Kuper & Kröpelin, 2006).

4.3 Paleocene to Eocene: Deeper Marine Environments

The Paleocene and Eocene periods are characterized by deeper marine sedimentation, evident in formations like the Esna Shale and Thebes Formation. These formations primarily consist of shale and limestone, indicating a more stable and deeper marine environment compared to earlier periods. The fossil records from these formations are critical for reconstructing past environmental conditions and understanding the paleoecological dynamics of the region (Said, 1962).

The geological characteristics of the Kharga Depression significantly influence the design and construction of the Dosh Temple. Quartz sandstone, known for its durability and flexibility, served as a primary building material, demonstrating the ancient Egyptians' skill in utilizing local resources. Clay sediments were essential for constructing the fortress, as they were made into mud bricks for walls and structures, enhancing stability. Conversely, sandy deposits can shift due to wind, posing a threat to archaeological sites, but they also help stabilize the environment and reduce erosion, thereby maintaining the integrity of the fortress and its surroundings.

4.4 Quaternary: Climatic Shifts and Aeolian Processes

The geological record of Kharga extends into the Quaternary period, which is marked by significant climatic shifts. During this time, the region transitioned to its current hyper-arid state, where wind and water erosion became dominant processes. Aeolian deposits, such as sand dunes and gravel plains, now cover large areas of the depression, reflecting the desertification that has shaped the landscape over thousands of years (Kuper & Kröpelin, 2006).

In addition to marine and fluvial deposits, the Kharga Depression contains lacustrine (lake) sediments and evidence of playas, which provide indications of wetter climatic conditions during the Pleistocene and Holocene epochs. These deposits, consisting of clay, silt, and marl, suggest the presence of ancient lakes formed during periods of increased rainfall. The playas, characterized by their flat and salty surfaces, indicate areas where water would collect and subsequently evaporate, leaving behind mineral deposits like gypsum and halite. The existence of these lacustrine deposits and playas highlights significant hydrological changes in the region, indicating periods when the climate supported more humid conditions, allowing temporary water bodies to form. The fossil content of these sediments, including diatoms and microfossils, provides crucial data for reconstructing past environmental conditions and climate changes (Koutkat, 2021).

The geology of the Kharga Depression presents a rich tapestry of geological history, from the ancient Precambrian granite of Gebel Abu Bayan to the sedimentary formations spanning the Paleozoic, Mesozoic, and Quaternary periods. The presence of lacustrine deposits, playas, and marine sedimentary rocks highlights the region's dynamic environmental history and provides valuable resources for understanding the evolution of the area. These geological features not only tell the story of climatic and environmental changes but also contribute to the understanding of groundwater resources that have supported human activity in this arid region for millennia.

5. Current Climatic Characteristics

The Kharga Depression, situated in the southwestern region of Egypt, is characterized by a hyper-arid desert climate. Its climatic characteristics have profound implications for its ecology, hydrology, and potential agricultural practices, which are directly related to the geoarchaeological context of the area. A comprehensive understanding of these climatic factors is crucial for studying the region's archaeological significance, particularly in relation to sites such as the Doush Temple.

5.1 Temperature Variability

The temperature in the Kharga Depression exhibits significant seasonal variability. Summer months are characterized by extreme heat, with daily maximum temperatures frequently exceeding 40°C. In contrast, winter months offer milder temperatures, with daytime averages between 15°C and 25°C. Nighttime temperatures can drop considerably, especially in January. One of the notable features of the climate in Kharga is the large diurnal temperature range. The difference between day and night temperatures can exceed 20°C due to low humidity and lack of vegetation, which allows for rapid cooling at night.

5.2 Precipitation Patterns

The Kharga Depression receives very little precipitation, averaging between 10 to 30 mm annually. This minimal rainfall is insufficient to support extensive vegetation, leading to predominantly barren landscapes punctuated by occasional oases.

Rainfall events are sporadic and primarily occur during the winter months, especially in December and January. These rainfalls are often characterized by short, intense bursts, which can lead to rapid runoff and minimal water infiltration into the soil. The unpredictability of rainfall makes agriculture challenging, as crops often rely on rain-fed irrigation.

The scarcity of precipitation has direct consequences for surface water availability in the Kharga Depression. The region largely depends on underground aquifers, particularly the Nubian Sandstone Aquifer, which is one of the largest aquifers in the world. However, over-extraction of this resource poses sustainability challenges.

5.3 Humidity and Evaporation Rates

Relative humidity in the Kharga Depression typically averages between 20% and 30%, contributing to the overall aridity of the region. Low humidity is characteristic of desert climates, where the air is dry, and moisture levels are insufficient for significant plant growth.

The combination of high temperatures and low humidity leads to exceptionally high evaporation rates, which can reach up to 2000 mm annually. This rate far exceeds the low levels of precipitation, resulting in a net loss of moisture and contributing to the arid landscape.

5.4 Wind Patterns and Dust Storms

Winds in the Kharga Depression are generally light to moderate but can vary significantly in intensity. The prevailing winds often originate from the north and northwest, contributing to the region's arid conditions.

The area is prone to dust storms, especially during the spring months. These storms can significantly reduce air quality and visibility, impacting transportation and daily life. Dust storms can also have ecological effects, such as disturbing soil layers and affecting local vegetation.

Understanding the climatic influences in the Kharga Depression is crucial for geoarchaeological studies and sustainable practices in this arid region, as they inform adaptations to past and present environmental challenges.

6. Methodology

This study employs a multidisciplinary approach to investigate the geoarchaeological impacts on the Doush Temple in Kharga Oasis. The methodology integrates archaeological fieldwork, geomorphological analysis, and environmental assessments to provide a comprehensive understanding of the temple's historical context and current condition.

6.1 Field Studies

Field studies played a crucial role in gaining a comprehensive understanding of the Doush Temple and its surrounding area. During this phase, several site visits were made to observe and analyze the architectural elements of the temple, the materials used in its construction, and their current state of preservation. These observations provided critical data on the structural integrity and conservation status of the temple.

Throughout the site visits, detailed observations were made on the temple's structure and design. This involved evaluating the construction techniques and materials, with a particular focus on the types of stones used, especially the "quartz arenite" and other materials that laboratory analyses revealed as part of the temple’s construction. Studying these materials provided deeper insights into their physical and chemical properties and their durability over time.

The current condition of the temple was meticulously documented through high-resolution photography. Various sections of the temple were photographed, including areas showing clear signs of deterioration or exposure to erosion. The images highlighted cracks, surface exfoliation, and discoloration in some sections, offering visual evidence of the natural and human factors that may have contributed to the overall degradation of the temple.

In addition to these observations, fieldwork included the collection of samples from the materials used in the temple’s construction. Samples were carefully extracted from select locations, including portions of the sandstone and quartz arenite, for laboratory analysis. These samples provided a precise understanding of the mineralogical and chemical composition of the materials, which was essential in assessing how natural factors have impacted the structure over time.

The surrounding area of the temple was also studied to identify environmental factors that might affect the stability of the structure. Geological and hydrological observations helped to understand the role of natural conditions in causing erosion or degradation of the temple.

6.2 Material Analysis[1]

The analysis of materials used in the construction of the Doush Temple is essential for understanding the architectural techniques and durability of the structure. This section outlines the methodology and techniques employed in the material analysis, focusing on the primary materials identified: quartz arenite sandstone, lime mortar, and mud bricks.

Samples for analysis were strategically collected from different parts of the temple to represent its varied structural components:

- **Quartz Arenite Sandstone**: Samples were taken from the main walls of the temple to analyze its mineralogical and physical properties.
- **Lime Mortar**: Samples extracted from the joints of sandstone blocks to understand its binding properties and composition.
- **Mudbrick**: Samples collected from the temple and the adjoining fortress to assess their durability and composition.

6.2.1 X-ray Diffraction (XRD) Analysis

The X-ray diffraction (XRD) analysis was performed on samples of quartz arenite, lime mortar, and mudbrick collected from the Doush Temple. This analysis aimed to identify the mineralogical composition of each sample, providing insights into the materials used in construction and their potential interactions.

6.2.1.1 Quartz Arenite Sample

The results of X-ray analysis of the quartz arenite sample (Table 1) indicate that:

Table 1. X-Ray Analysis Results of Quartz Arenite Sample

Mineral	Chemical Formula	Relative Abundance (%)	Peak Intensity (2θ)
Quartz	SiO_2	92	26.6, 20.9
Feldspar (Plagioclase)	$(Na,Ca)Al_{1-2}Si_{3-2}O_8$	4	27.6, 29.5
Mica (Muscovite)	$KAl_2(AlSi_3O_{10})(OH)_2$	2	18.1
Calcite (trace)	$CaCO_3$	<1	29.4, 39.4
Clay Minerals (trace)	$Al_2Si_2O_5(OH)_4$	<1	12.4, 24.8

- **Quartz** is the dominant mineral, comprising 92% of the sample, with strong peaks at 26.6° and 20.9°. This high purity indicates significant weathering and sedimentary sorting, which has left mostly resistant quartz grains. The dominance of quartz also reflects the suitability of this material for structural applications in the Doush Temple, providing durability against environmental weathering.
- **Feldspar (Plagioclase)** is present at 4%, with peaks at 27.6° and 29.5°, suggesting minimal feldspathic input. This can be attributed to the local geology, where nearby igneous or metamorphic sources may have contributed to the feldspar content. However, the low percentage indicates that the sample is predominantly quartz arenite.
- **Mica** constitutes 2% of the composition, with

[1] The samples were analyzed at the laboratories of the Faculty of Science, Cairo University

a peak at 18.1°. The presence of muscovite indicates that finer-grained sedimentary rocks or low-grade metamorphic sources contributed to the material. Mica can enhance flexibility and may improve the workability of the sandstone during construction.

- **Calcite** was detected in trace amounts (<1%), with peaks at 29.4° and 39.4°. This presence likely reflects minor diagenetic processes or secondary cementation that occurred post-deposition. It is not uncommon for sandstone to contain calcite, which can impact the stone's weathering behavior over time.
- **Clay** Minerals are also present in trace amounts (<1%), with peaks at 12.4° and 24.8°. These minerals may have been introduced during deposition or through post-depositional alteration, indicating minor contributions of finer weathered material.

6.2.1.2 Lime Mortar Sample

The results of X-ray analysis of the Lime Mortar sample (Table 2) indicate that:

Table 2. X-Ray Analysis Results of Lime Mortar Sample

Mineral	Chemical Formula	Relative Abundance (%)	Peak Intensity (2θ)
Calcite	$CaCO_3$	70	29.4
Quicklime	CaO	20	32.5
Silica	SiO_2	5	26.6
Clay Minerals (trace)	$Al_2Si_2O_5(OH)_4$	<5	12.4

- **Calcite** is the primary component of the lime mortar, comprising 70% of the sample, with a peak at 29.4°. This high calcite content confirms its role as the primary binding agent in the construction of the temple, providing strength and durability.
- **Quicklime (CaO)** accounts for 20%, with a peak at 32.5°. This indicates the presence of reactive lime, which upon hydration reacts to form calcium hydroxide, contributing to the mortar's binding properties.
- **Silica** is present at 5%, with a peak at 26.6°, which enhances the mechanical strength of the mortar. The presence of silica helps in reducing the porosity of the mortar and increases its resistance to environmental factors.
- **Clay minerals** are present in trace amounts (<5%), indicating potential minor contributions to the plasticity and workability of the mortar mix.

6.2.1.3 Mudbrick Sample

The results of X-ray analysis of the Mudbrick sample (Table 3) indicate that:

Table 3. X-Ray Analysis Results of Mudbrick Sample

Mineral	Chemical Formula	Relative Abundance (%)	Peak Intensity (2θ)
Clay Minerals	$Al_2Si_2O_5(OH)_4$	50	12.4
Quartz	SiO_2	30	26.6
Calcite	$CaCO_3$	10	29.4
Gypsum (trace)	$CaSO_4 \cdot 2H_2O$	<5	20.8

- **Clay minerals** dominate the mudbrick composition at 50%, with a peak at 12.4°. This high content contributes to the excellent thermal insulation properties of mudbrick, making it suitable for the climatic conditions of the region surrounding the Doush Temple.

- **Quartz** makes up 30% of the composition, with a peak at 26.6°. The presence of quartz reinforces the structural integrity of the mudbrick, enhancing its resistance to physical stress and environmental degradation.
- **Calcite** is present at 10% (peak at 29.4°), which may contribute to the bonding properties of the mudbrick.
- **Gypsum** was detected in trace amounts, indicating potential interactions with environmental factors during or after construction.

6.2.2 Microscopic Analysis

6.2.2.1 Quartz Arenite Sample

The results of Microscopic Analysis of the quartz arenite sample (Table 4) indicate that:

Table 4. Microscopic Analysis Results of Quartz Arenite Sample

Microscopic Property	Description/Value	Comments
Sample Preparation	Thin section analysis	Mounted on a glass slide for observation
Magnification Used	500x to 5000x	Varying magnifications for detailed analysis
Main Mineral Phases	Quartz grains (92%), Plagioclase (4%), Mica (2%)	Dominance of quartz, with plagioclase and mica as minor components
Grain Shape	Subangular to Rounded	Indicates varying transport history
Grain Size Distribution	0.2 - 0.5 mm (fine to medium)	Homogeneous distribution suggests a consistent depositional environment
Porosity	Intergranular and intragranular pores	Pore networks visible, facilitating fluid movement
Cement Type	Silica cement (evident under high magnification)	Fine-grained cement filling voids
Presence of Diagenetic Features	Minimal cementation and compaction	Indicates early diagenesis with preservation of primary porosity
Texture	Well-sorted, fine to medium-grained	Indicates high-energy depositional environment

- The quartz arenite sample from Doush Temple exhibits a clear dominance of quartz grains, constituting approximately 92% of the mineral composition. This high quartz content indicates the sample's resilience and durability, making it an excellent building material. The subangular to rounded shape of the grains suggests a complex transport history, where the grains have likely undergone significant weathering and sorting processes before deposition.
- The grain size distribution, ranging from 0.2 to 0.5 mm, is indicative of a well-sorted environment, which is typical for high-energy depositional settings such as river channels or coastal areas. The presence of intergranular and intragranular pores signifies the sample's potential for fluid retention and movement, which can be essential for the structural integrity of the temple, especially under climatic variations.
- The silica cement present, which fills the voids between grains, further enhances the mechanical strength of the stone. However, minimal evidence of cementation and compaction indicates that the sample likely underwent early diagenesis, preserving its primary porosity. The overall texture of the quartz arenite suggests it was deposited in a dynamic environment, reinforcing its

suitability for ancient constructions like the Doush Temple.

6.2.2.2 Lime Mortar Sample

The results of X-ray analysis of the Lime Mortar sample (Table 5) indicate that:

Table 5. Microscopic Analysis Results of Lime Mortar Sample

Microscopic Property	Description/Value	Comments
Sample Preparation	Thin section analysis	Mounted on a glass slide for observation
Magnification Used	200x to 2000x	Varying magnifications for detailed analysis
Main Components	Lime ($Ca(OH)_2$), Quartz, Sand	Dominance of lime with minor sand components
Grain Shape	Irregular and Angular	Reflects the diverse sources of aggregates
Grain Size Distribution	0.05 - 0.2 mm (fine)	Mostly fine particles ideal for filling voids
Porosity	High porosity	Numerous visible voids, indicating good workability
Cement Type	Lime-based binder	Effectively bonds aggregates and allows flexibility
Presence of Diagenetic Features	Moderate carbonation and some shrinkage	Evidence of chemical changes post-application
Texture	Heterogeneous	Varied texture with well-mixed components

- The lime mortar sample showcases a high lime content, which plays a critical role in the bonding of materials used in the temple's construction. The significant presence of lime ($Ca(OH)_2$) suggests that it was mixed with aggregates like quartz and sand, enhancing its adhesive properties. The irregular shape of the grains indicates the use of various local materials, demonstrating a resourceful approach to construction.
- With a grain size distribution primarily between 0.05 to 0.2 mm, the sample comprises fine particles that provide an ideal matrix for filling voids between the larger aggregates. This fine texture enhances the overall workability of the mortar, allowing it to conform to the shapes of the stones it binds.
- The high porosity observed in this sample, characterized by numerous visible voids, indicates that the mortar can retain moisture, which is crucial in a desert environment for maintaining structural integrity. The lime-based binder allows for some flexibility, accommodating minor shifts in the structure without cracking.
- The presence of moderate carbonation and some shrinkage features suggests that the mortar has undergone chemical changes post-application, which can affect its long- term durability. The heterogeneous texture of the mortar reflects a well-mixed composition, essential for effective bonding in ancient architectural practices.

6.2.2.3 Mudbrick Sample

The results of X-ray analysis of the Mudbrick sample (Table 6) indicate that:

Table 6. Microscopic Analysis Results of Mudbrick Sample

Microscopic Property	Description/Value	Comments
Sample Preparation	Thin section analysis	Mounted on a glass slide for observation
Magnification Used	100x to 1000x	Lower magnifications to capture overall structure
Main Components	Clay (70%), Organic Materials (15%), Sand (15%)	Dominance of clay with organic materials for strength
Grain Shape	Irregular	Reflects natural sourcing of materials
Grain Size Distribution	0.01 - 0.2 mm (fine to medium)	Fine particles provide cohesive structure
Porosity	Moderate porosity	Sufficient voids for moisture retention and insulation
Cement Type	None (natural clay cohesion)	Relies on clay properties for bonding
Presence of Diagenetic Features	Some cracking due to shrinkage	Evidence of environmental changes during drying
Texture	Fibrous and Irregular	Presence of straw and organic materials

- The mudbrick sample reveals that clay is the predominant component, constituting about 70% of the material. This composition reflects the use of locally available resources and traditional construction techniques. The organic materials present, which include straw or other fibrous components, enhance the structural integrity of the mudbrick by providing tensile strength.
- The irregular grain shape indicates the natural sourcing of the materials, while the grain size distribution, primarily between 0.01 to 0.2 mm, comprises fine to medium particles that create a cohesive structure essential for construction. The moderate porosity of the mudbrick allows for moisture retention, which is beneficial for temperature regulation within the temple.
- The lack of a specific cement type indicates that the bonding is primarily due to the natural cohesive properties of the clay. However, the presence of cracking suggests that the bricks may have experienced environmental stresses during drying, which can impact their long-term stability.

Overall, the fibrous and irregular texture of the mudbrick signifies a combination of traditional building practices with an understanding of the local environment's challenges, ensuring that the structure remains resilient against climatic variations.

7. Discussion and Results

7.1 Characteristics of building materials used in Doush Temple

The construction of the Doush Temple showcases the use of a variety of building materials, each chosen for its specific properties that enhance the structural integrity and aesthetic appeal of the temple. The primary materials include quartz arenite sandstone, sandstone with cross-bedding (or false bedding), and mudbrick, which was used for the surrounding fortress. Each of these materials offers distinct characteristics that reflect both practical and environmental considerations.

7.1.1 Quartz Arenite Sandstone

The main body of the Doush Temple was constructed using quartz arenite sandstone, a material known for its high durability and resistance to weathering. This particular type of sandstone is composed of over 90% quartz grains, giving it significant strength. Quartz arenite is renowned for its ability to withstand harsh environmental conditions, such as extreme heat and sandstorms, which are prevalent in the desert regions surrounding the temple. The high quartz content also means that the stone is less likely to erode, making it ideal for long-lasting construction. Quartz arenite's natural density offers excellent thermal regulation, helping to maintain cooler interiors in the temple during the scorching desert summers.

The fine-grained nature of quartz arenite lends itself to smooth finishes and intricate carvings, as evidenced by the detailed inscriptions and decorative elements found in the temple. Its light color also enhances the temple's visibility against the surrounding landscape.

7.1.2 Sandstone with Cross-Bedding

Parts of the temple's gates were constructed using sandstone that exhibits cross- bedding. Cross-bedding provides additional structural strength to the stone, allowing it to resist lateral forces more effectively. This feature would have been particularly advantageous for constructing the temple's gates, which would have needed to support the weight and pressure of the overlying structures.

This sandstone is also known for its adaptability to different architectural forms. Its layered structure made it easier for ancient builders to shape and align the stone according to specific design requirements, especially for functional components like gates. The cross-bedding patterns create visually striking effects when light hits the stone, adding to the temple's grandeur. The alternating layers give a dynamic look that enhances the architectural complexity of the entranceways.

7.1.3 Mudbrick

The fortress surrounding the temple was built using mudbrick, a material that has been historically favored in desert environments due to its availability and thermal properties. Mudbrick is made from a mixture of clay, water, and organic materials like straw, all of which were readily available in the region. This made it an economical building material for the extensive walls of the fortress. Mudbrick offers excellent insulation, keeping interior spaces cooler during the day and retaining heat at night. This was crucial for the fortress, which likely housed guards and storage spaces that required protection from the extreme desert climate. Mudbrick construction is relatively fast and straightforward, making it suitable for large-scale structures like the surrounding fortress. The flexibility of the material also allows for repairs and modifications, which would have been important for maintaining the fortress over time.

7.1.4 Interplay of Materials in the Overall Structure

The combination of quartz arenite sandstone, cross-bedded sandstone, and mudbrick in the construction of the Doush Temple and its fortress reflects a sophisticated understanding of material properties. The temple's use of quartz arenite ensured the preservation of its sacred spaces, while the sandstone with cross-bedding added both structural stability and visual flair to the gates. Meanwhile, the mudbrick provided a cost- effective and thermally efficient solution for the fortress.

The choice of these materials not only reveals the architectural preferences of the time but also demonstrates a keen awareness of the environmental challenges posed by the desert climate. The integration of these materials harmoniously balanced the need for strength, durability, and aesthetics, contributing to the enduring legacy of the Doush Temple complex.

The Doush Temple's construction, using a combination of quartz arenite sandstone, sandstone with cross-bedding, and mudbrick, reflects the ingenuity of ancient builders in adapting to the environmental and material resources available to them. The durability of the quartz arenite, the strength and beauty of the cross-bedded sandstone, and the practicality of the mudbrick together create a structure that has withstood the test of time, offering valuable insights into ancient construction techniques.

7.1.5. Building Materials and Bonding Agents in Doush Temple

The bonding agent used between the stones of Doush Temple is **lime mortar**, which was widely utilized in ancient Egyptian architecture for securing sandstone blocks. Lime is produced by heating limestone and then mixing it with water and sand to create a strong, durable mortar. This mortar is notable for its ability to securely bond quartz arenite blocks, like those used in Doush Temple, providing stability and resistance to weathering in harsh desert environments. According to Raju and Ravindhar (2023), the use of lime mortar was a defining characteristic of ancient Egyptian religious structures, contributing to the longevity of these buildings.

In Doush Temple, lime mortar was primarily employed to secure the larger stones, especially in critical architectural areas such as the gates, where sandstone featuring cross-bedding was used. This robust bonding agent is crucial for structural stability, as it has shown notable resistance to environmental factors like winds and sands. Research indicates that ancient lime mortar was cohesive and bonded well to structures, enhancing their durability and requiring periodic maintenance due to external stresses (Manoharan & Umarani, 2022).

Additionally, in the fortress surrounding the temple, which was constructed with mud bricks, clay mixed with sand was used to bond the mud bricks together. According to (El- Gohary & Moneim 2021), clay reinforced with sand or straw was a common bonding agent in earthen buildings in the Western Desert. This mixture aided in achieving cohesion among the mud bricks, ensuring structural stability under the dry desert conditions, as evidenced by the surrounding earthen fortress of Doush Temple.

7.2 Topography and Sand Dynamics

The Doush Temple's strategic positioning atop a small hill, about 17 meters above the local surface level, plays a crucial role in its interaction with the surrounding environment. Geologically, the temple site belongs to the Upper Cretaceous period's Quseir Formation, composed of claystone, siltstone, and sandstone. This unique geological composition provides the site with varied physical properties that influence both the temple's preservation and its vulnerability to natural forces. The surrounding area consists of mudstone terraces and desert plants, which act as natural barriers, trapping windborne sand around the temple. Additionally, the temple lies within the extensive dune fields of southern Kharga, a region where aeolian (wind-driven) processes dominate the landscape.

The temple's topographical and geological features have made it an ideal site for sand accumulation over time. As sand particles are carried by winds, they become trapped by the mudstone terraces and desert flora, forming a natural barrier that encourages the gradual deposition of sand around the temple (Fig. 4). In a study by Wahed et al. (2023) on the morphometry and migration rates of barchan dunes in the Kharga Depression, it was noted that the interaction between natural landforms and wind dynamics significantly influences sand deposition patterns. This is consistent with observations around the Doush Temple, where sand movement is continually reshaping the landscape and interacting with the temple structures.

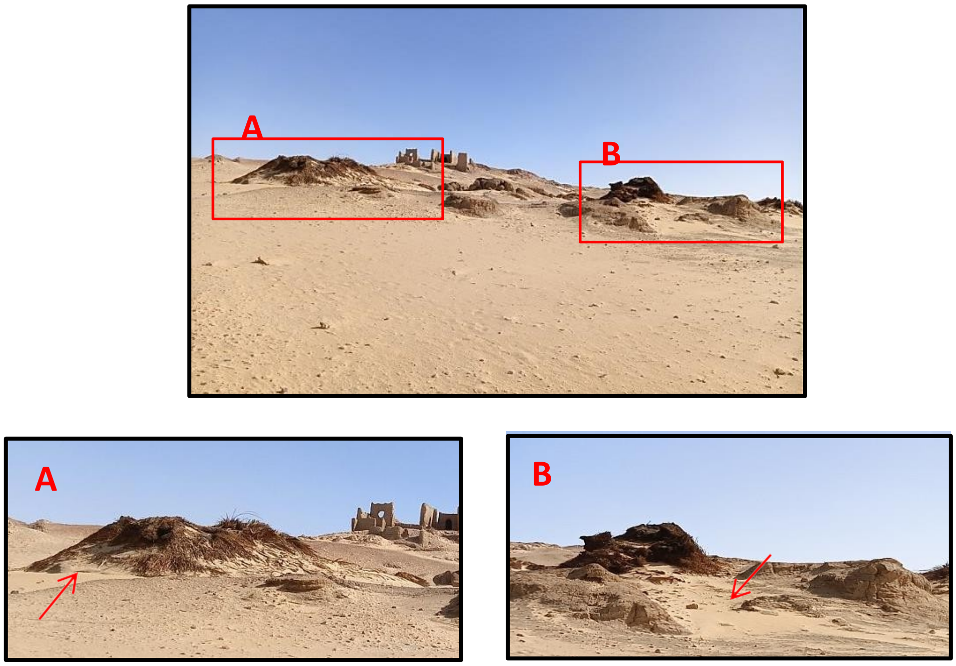


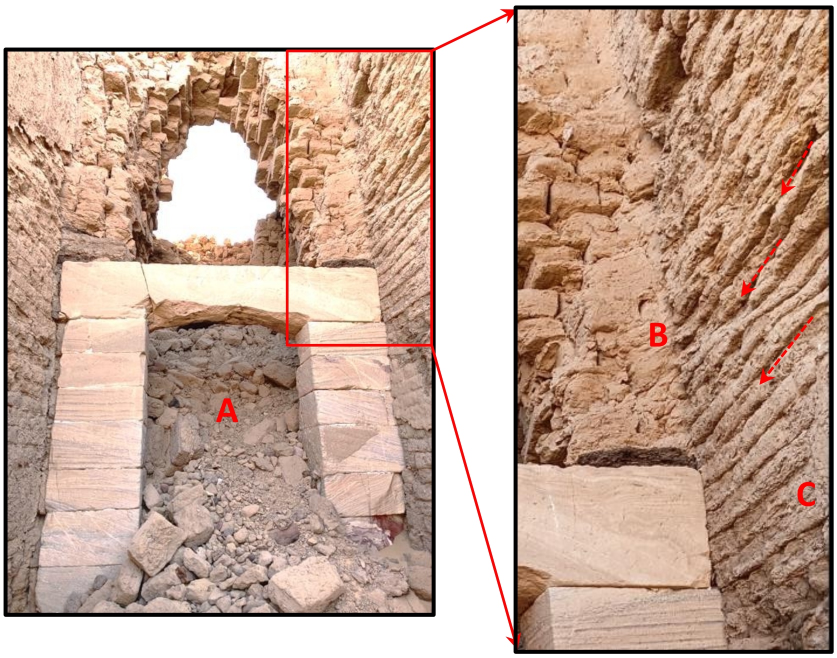
Figure 4. Sand Accumulation Patterns Around the Doush Temple

7.2.1 The Negative Impacts of Sand Encroachment

While sand deposition can act as a form of preservation, it also poses serious risks to the temple, particularly in the exposed areas. Windborne sand acts as a natural abrasive, eroding exposed stone surfaces over time. When the wind carries sand at high velocities, it transforms into an effective erosive agent, gradually wearing down the sandstone and mudbrick that form much of the temple's structure. This abrasive process is particularly detrimental to the more fragile parts of the temple, including its gateways and intricate carvings, which show signs of surface pitting and erosion (Fig. 5).

Figure 5. Erosive effects of windborne sand on the Doush Temple structure

Moreover, the accumulation of sand poses a significant threat to the structural integrity of ancient buildings, particularly through the exacerbation of existing vulnerabilities in cracks and joints. These structural weaknesses are especially prone to degradation from the harsh weathering processes characteristic of desert environments. When sand infiltrates these fissures, it accelerates the erosion of the binding materials that hold the bricks and stones together, leading to a progressive weakening of the overall structure.In desert regions like Kharga, the frequency and intensity of sandstorms contribute notably to the deterioration of historical constructions. The relentless abrasive action of wind-driven sand particles against exposed surfaces heightens the degradation of both the sandstone and the mortar used in joints. This relentless exposure not only wears down the surface but also deepens existing cracks, creating a compounding effect that threatens the stability and integrity of the building (Fig. 6). In the case of the Doush Temple, this continuous cycle of sand abrasion and infiltration presents a significant challenge for preservation efforts.



A- Note the accumulation of fragments and detached sections of the temple structure.
B - C Observe the distinct wind grooves on the plastered areas at the top of the wall, which are more exposed to wind-blown sand compared to the lower sections of the wall.

Figure 6. Impact of Sand Infiltration on Structural Integrity of the Doush Temple

7.2.2 The Protective Role of Sand Burial

Despite the destructive potential of sand, its role in the long-term preservation of the Doush Temple cannot be overlooked. Over centuries, portions of the temple have been buried under layers of sand (Fig.7), effectively shielding them from the harsh desert environment. Sand burial acts as a natural protective blanket, insulating the covered sections of the temple from temperature fluctuations, wind erosion, and even occasional rainfall. This insulating effect has helped to preserve the structural integrity of parts of the temple that would otherwise have suffered from severe weathering.

Figure 7. Parts of the Temple Buried Under Sand

The preservation benefits of sand burial have been observed in various archaeological contexts across arid regions. In Egypt, the phenomenon of desert sands preserving ancient monuments is well-documented, with notable examples such as the burial of the Great Sphinx of Giza under sand for much of its history. Similarly, at Doush, the parts of the temple that remained buried under sand for long periods show far less deterioration compared to exposed sections (Fig. 8). Sand burial can significantly slow down the weathering processes, particularly in arid environments where wind and temperature extremes are the primary agents of decay.

Figure 8. The Protective Effects of Sand Burial on the Doush Temple Structure. “Note that the buried sections still retain their outer plaster layer."

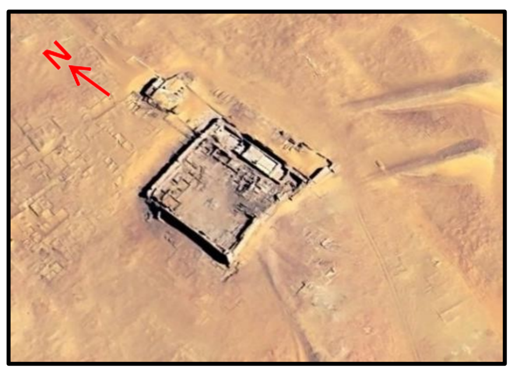
Additionally, sand can protect structures from chemical weathering processes, such as salt crystallization, which are prevalent in arid climates with high evaporation rates. The buried portions of the Doush Temple are less exposed to these salt deposits that accumulate on the surface when water evaporates. As a result, the sections of the temple that remained under the protective cover of sand are better preserved. This protective role of sand burial aligns with findings by El-Gohary and Moneim (2021) on environmental factors affecting archaeological buildings in Egypt.

The interaction between the temple’s topographical setting, the movement of sand, and the environmental forces at play presents a duality in terms of conservation challenges and benefits. Satellite imagery reveals that significant portions of the Doush Temple and its surrounding structures remain buried beneath the sand, indicating a more extensive site than what is currently visible (Fig. 9). While sand encroachment has clearly contributed to the degradation of some exposed sections, it has also played a critical role in protecting other areas by shielding them from direct exposure to environmental stressors.

Figure 9. Satellite Imagery of Sand-Buried Portions of the Doush Temple

Advancements in machine learning and artificial intelligence techniques have been employed to help reconstruct the temple and its ancillary buildings, showcasing the vast size of the temple beyond what is apparent on the surface today (Fig. 10). The challenge for modern conservation efforts lies in managing this balance. Protecting the exposed areas from further erosion while carefully excavating and preserving the buried sections requires a nuanced approach that takes into account both the detrimental and beneficial effects of sand movement on the structure.

AI image



Real image

Figure 10. Reconstruction of the Doush Temple Using Machine Learning and AI Techniques

7.3 Impact of weathering on mortar and sandstone joints

Weathering processes affecting the joint areas containing mortar and adjacent sandstone in the Doush Temple arise from a complex interplay of various interrelated factors, including the physical properties of mortar, the interaction between sandstone and mortar, and the environmental conditions. Understanding these factors is essential in addressing the challenges posed by weathering, ultimately helping to preserve the historical integrity of the Doush Temple and contributing to the field of geoarchaeology in arid environments.

The physical properties of the mortar used in the construction of the Doush Temple are central to the observed weathering processes. Mortar, primarily composed of a mixture of sand and lime, possesses distinct characteristics that differentiate it from the surrounding sandstone. This composition allows mortar to absorb moisture more readily, leading to expansion and contraction due to fluctuations in temperature and humidity. The increased moisture absorption creates an ideal environment for weathering interactions, as humidity facilitates the erosion of the mortar under the influence of wind and rain, resulting in its degradation at a faster rate than the adjacent sandstone. The destructive effects of strong winds on mortar can lead to the formation of cracks and defects on its surface, emphasizing the vulnerability of this material to harsh environmental conditions.

The interaction between sandstone and mortar at the Doush Temple presents additional challenges in the weathering process. Sandstone features a mineral composition that differs from that of mortar, resulting in variations in physical and chemical properties. While sandstone can exhibit resistance to certain erosive forces, it becomes susceptible to weathering when it comes into contact with poorly bonded mortar. The lack of strong adhesion between grains accelerates the weathering process, as the sand grains can separate more quickly, leading to material loss and the development of cracks in the joints (Fig. 11).

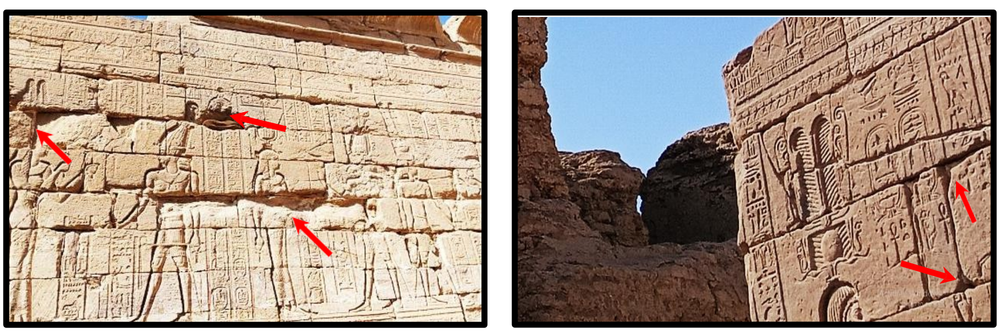


Figure 11. Surface weathering of mortar and adjacent sandstone in the Doush Temple mural

The weathering processes affecting the external courtyard columns of the Doush Temple are particularly evident, as these columns stand isolated, devoid of lateral support and exposed to direct weathering activities. Constructed from cylindrical blocks of quartz arenite, these columns are horizontally bonded using mortar, which forms the structural integrity of each column. Over time, the mortar has undergone significant weathering, impacting the stone blocks that are in direct contact with it. This degradation ultimately leads to the disintegration of the cylindrical masses, causing them to detach from the columns (Fig. 12).

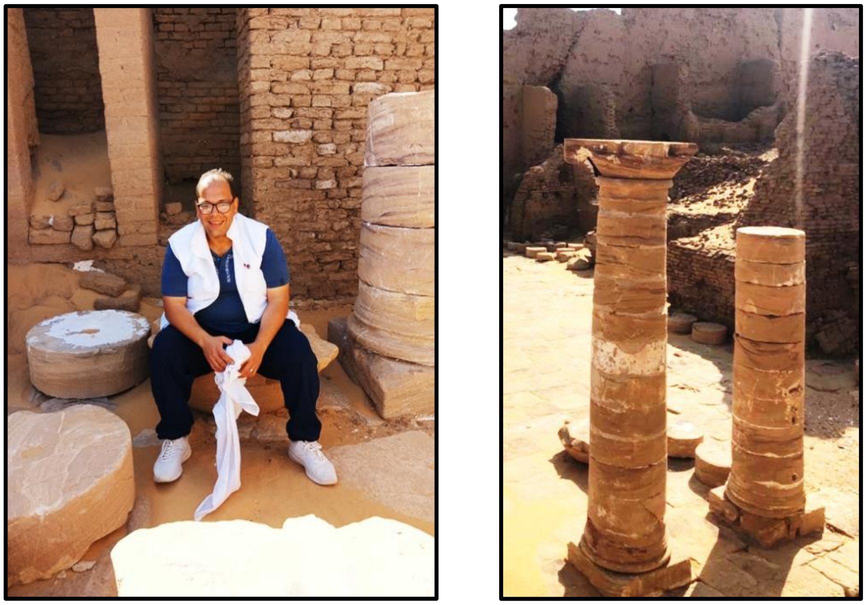


Figure 12. Weathering effects on the external courtyard columns of the Doush Temple

The vulnerability of these columns to environmental stressors amplifies their susceptibility to erosion. Extreme climatic conditions, including high temperatures and strong winds, contribute to the accelerated weathering of both the mortar and the sandstone. Studies have shown that the porous nature of quartz arenite can exacerbate the impact of weathering by allowing moisture to infiltrate and erode the mortar more rapidly (Suttner et al., 1981). The lack of lateral support further intensifies the situation, as these columns are left unprotected against the erosive forces acting upon them.

The interplay between moisture infiltration and environmental conditions leads to a weakening of the bond between the mortar and the stone blocks. As moisture seeps into the joints, it facilitates the disintegration of the mortar, consequently undermining the structural stability of the stone columns. This phenomenon is particularly concerning in arid environments, where the combination of high thermal fluctuations and occasional rainfall can create conditions conducive to rapid weathering. The cyclical wetting and drying can significantly impair the adhesive properties of mortar, thereby heightening the risk of structural failure (Alfano et al. 2023).

Weathering processes in the Doush Temple are significantly influenced by the prevailing environmental conditions in the Kharga Oasis. The local climate, characterized by high temperatures and intermittent rainfall, contributes to the acceleration of weathering. Accumulation of water in the joint areas serves as a contributing factor to the weathering of both mortar and adjacent sandstone, increasing hydrostatic pressure within the joints, which facilitates material disintegration and compromises the cohesion between grains. Additionally, environmental factors such as strong winds and high temperatures exacerbate the erosion of both mortar and sandstone, resulting in structural deterioration.

7.4 Anthropo-geoarchaeology of Doush temple

The anthropo-geoarchaeology of the Doush Temple in Kharga Oasis offers valuable insights into the interplay between human activities and geological processes that have shaped this significant archaeological site. This multidisciplinary approach examines various aspects, including the pottery industry, architectural transformations, and preservation challenges faced by the temple over time. Understanding how ancient inhabitants utilized local resources, adapted to environmental conditions, and interacted with their surroundings reveals the resilience and ingenuity of these communities. Additionally, the impacts of improper restoration methods and modern interventions, such as graffiti, highlight the ongoing challenges in preserving the temple's integrity. Through a comprehensive analysis of these factors.

7.4.1 The Pottery

The pottery industry in ancient Doush was intrinsically connected to the environment, particularly the materials and climatic conditions of the Kharga Oasis. Pottery production relied heavily on the local clay, which was derived from the erosion of nearby sandstone and claystone formations. This geological composition, rich in silts and fine sands, influenced the texture and durability of the pottery produced at Doush. The presence of local clays ensured that potters could create wares suited to the environmental and cultural demands of the region.

The desert environment also played a significant role in shaping the pottery- making process. Given the arid conditions of the Kharga Oasis, potters likely used open firing techniques, utilizing readily available desert wood and plant materials for fuel. These methods allowed potters to achieve high temperatures necessary for durable wares that could withstand the harsh desert climate. Additionally, the wind-blown sand in the region would have been used as temper—a material added to the clay to prevent cracking during the firing process—showing how natural resources were effectively adapted for practical use.

During fieldwork at Doush, a remarkable observation was made regarding the distribution of pottery fragments. Scattered systematically across the site, the pottery shards suggest a deliberate effort to stabilize the sand dunes surrounding the ancient settlement. The evidence of this practice can be seen in several ways. Firstly, the distribution of pottery shards is regular, not indicative of waste disposal, but of purposeful placement (Fig. 13). Secondly, areas with fewer pottery fragments exhibit signs of wind-driven sand ripples, suggesting that in the absence of pottery, the sand is more prone to movement (Fig. 14). Lastly, pottery fragments were found atop structures buried beneath the sand, reinforcing the notion that these shards were actively used to stabilize the dunes rather than being remnants of past activity (Fig. 15).

Figure13. Distribution of pottery fragments at the Doush Site

Figure 14. Wind-Driven sand ripples in areas with fewer pottery fragments

Figure 15. Pottery Fragments atop Structures Buried Beneath the Sand

This method of dune stabilization aligns with modern practices in nearby regions, such as the technique observed near Sana'a village, where dunes are stabilized using rough materials like clay and coarse gravel (Fig. 16). The pottery at Doush was locally produced, further supporting the idea that ancient inhabitants used available resources to manage their environment effectively. These practices show a sophisticated understanding of how to mitigate the effects of shifting sands and highlight the ingenuity of the people in utilizing local materials to preserve their structures.

Figure 16. Dune stabilization techniques near Sana'a village

The combined effect of pottery shards, wind, and sand dunes reflects a complex interaction between human activity and the desert environment. By using pottery fragments to control the movement of sand, the ancient inhabitants of Doush not only stabilized the landscape but also helped preserve portions of their settlement under layers of protective sand, illustrating an adaptive and resourceful approach to environmental challenges.

7.4.2 Church of Doush

The church at Doush is an important element of the site, representing a phase of religious transformation in the region during the early Christian period. Constructed primarily from mudbrick, the church illustrates a shift in architectural practices, contrasting sharply with the adjacent quartz arenite sandstone temple. This transition in material use highlights the availability of local resources, as mudbrick was more accessible and practical for the community during this period

The church at Doush is believed to have been constructed during the Byzantine period, serving as a significant place of worship for local Christians. Its location within the ancient temple precinct underscores the continuity and adaptation of sacred spaces over time. The reuse of the earlier temple site for Christian worship not only reflects a transformation in religious practices but also highlights the resilience of the community as they integrated their faith into the existing cultural landscape. Furthermore, geoarchaeological findings indicate that the church has benefitted from environmental factors similar to those that have preserved parts of the Doush Temple. In some areas, the shifting sands have provided a protective layer for the church, although the upper sections are more vulnerable to erosion from wind and weathering (Fig. 17). This erosion presents a significant concern in the Kharga region, where extreme climatic conditions challenge the preservation of ancient structures. The interplay of these factors illustrates how both human and environmental elements have shaped the historical landscape of Doush.

Figure 17. Erosion patterns affecting the upper sections of the Byzantine Church at Doush

7.4.3 The Impact of Improper Restoration, and Graffiti

The Doush Temple has encountered significant preservation challenges over the years, with improper restoration methods and environmental degradation compromising its structural integrity. One of the more pressing issues was the installation of wooden- framed wire gates at key points within the temple, including the entrance to the hypostyle hall and the sanctuary. These gates, along with their wooden frames, have since been removed, leaving the interior of the temple exposed to environmental elements (Fig. 18). Without these barriers, the temple's chambers are now vulnerable to windblown sand, dust, and small animals, all of which can accelerate the wear and tear on the ancient stonework. This removal represents both a conservation failure and a missed opportunity to study the potential impacts that previous structural modifications had on the preservation of the monument.

Figure 18. Wooden-Framed wire gates at the entrance to the hypostyle hall of the Doush Temple

In addition to the challenges posed by the gate removal, rudimentary restoration techniques have also been applied to damaged sections of the temple's sandstone. Above one of the now-removed gates, sandstone that had suffered significant weathering was "repaired" using a mixture of gypsum and sand (Fig. 19). This method is problematic for several reasons. Gypsum, while easily accessible and commonly used in quick repairs, lacks the long-term durability required for sandstone preservation. Over time, it becomes brittle, deteriorating more quickly than the original stone, and the mismatch in material properties between the gypsum and sandstone accelerates further decay. Additionally, the lack of scientific rigor in mixing the gypsum with sand means the repair is unstable, allowing moisture, wind, and other degrading elements to penetrate deeper into the temple's walls, exacerbating the existing damage.

Figure 19. Improper Restoration Techniques Applied to Weathered Sandstone of the Doush Temple

The temple has also suffered from human intervention in the form of modern graffiti. One of the most notable inscriptions on the temple's ceiling is the name "Hyde 1819," believed to be left by the British archaeologist John Hyde, a significant figure from the early 19th century. His inscription is particularly interesting because it was carved in a neat, organized manner, suggesting it was not a hurried act of vandalism but a deliberate marking (Fig. 20). This has raised questions about how Hyde managed to reach such a high spot on the ceiling of the hypostyle hall. One plausible explanation is the presence of accumulated sand, which may have filled the lower parts of the temple, making the ceiling more accessible. The region around Doush is known for its sand dunes and shifting sands, which can dramatically alter the landscape over time. If sand had indeed filled a large portion of the temple during Hyde's visit, it would have allowed him to carve the inscription with ease, as the upper portions of the temple would have been within reach.

Figure 20. Inscription of "Hyde 1819" on the Ceiling of the Doush Temple

If this scenario holds, it suggests that the sand accumulation provided Hyde with a stable platform from which he could carve his name carefully and deliberately. The fact that the inscription is orderly and meticulously engraved further supports the idea that Hyde had ample time to perform the task, likely aided by the elevated sand covering the lower sections of the columns and reducing the apparent height of the ceiling. The engraving thus becomes a reflection not only of Hyde's presence but also of the environmental conditions that shaped the temple's landscape at the time.

The presence of such inscriptions, though often considered acts of vandalism today, provides valuable historical context. Hyde's inscription serves as a marker of early 19th-century exploration in Egypt, tying the temple to a broader history of European interest in Egyptian antiquities. Similar inscriptions can be found in other prominent sites, such as Karnak in southern Egypt and archaeological locations in southern Jordan, linking the temple to this wider narrative of early archaeology. However, while these marks provide insight into the individuals who studied these monuments, they also represent a violation of the temple's authenticity. Hyde's inscription, though small in scale, disrupts the visual and historical integrity of the temple's original carvings, and its presence may encourage modern visitors to leave their own marks, perpetuating a cycle of damage that undermines conservation efforts.

7.5 Results and recommendations

This study has reached the following results:

- The study revealed that the movement of sands caused by winds, characterized by their ability to shift and transport, led to significant erosion of the temple structure. Notable occurrences of sand slips and accumulations were observed on the temple's sides, resulting in distortion of architectural features and unique artistic details. These dynamics contributed to the formation of cavities and gaps on the surface, increasing the potential for moisture intrusion and exacerbating weathering processes. This poses a significant threat to the temple's preservation, necessitating the implementation of protective strategies.
- An analysis of the materials used in constructing the temple, such as quartz arenite and clay, indicated that these materials have undergone extensive weathering. Erosion and friction effects were evident on the stone surfaces, leading to fractures and degradation in certain areas of the temple. This deterioration underscores the urgent need to understand the geological materials and processes that led to their erosion to ensure effective restoration strategies.
- The study focused on how the temple continuously interacted with surrounding environmental conditions. It was found that rising temperatures and water scarcity in the region heightened the erosion impact on the structure. Climatic changes experienced in the area over the centuries also contributed to altering soil dynamics.
- The study demonstrated that prolonged drought periods in the region directly impacted the temple's longevity. Drought conditions resulted in a scarcity of water resources, which exacerbated erosion and damage to structural elements. Environmental changes resulting from drought also led to fluctuations in the geoarchaeological stability of the temple, indicating the necessity for the development of conservation strategies.
- The study demonstrated that the use of pottery shards in areas of shifting sands significantly helped enhance soil stability. These shards act as stabilizing materials that reduce the movement of sand and diminish the impact of winds on it. This, in turn, leads to a reduction in erosion caused by the continuous movement of sand, thereby protecting nearby archaeological or agricultural structures.
- The results showed that the construction techniques used in the temple reflect the advanced engineering knowledge of ancient inhabitants. Early architects creatively utilized locally available building materials while considering their properties and resistance to desert conditions. The study indicates how architectural design was integrated with the local environment.
- Cultural and Religious Significance of the Temple: The temple represented an important religious and social center in the daily lives of its inhabitants. The inscriptions and architectural details found within the temple reflect the religious rituals and worship traditions practiced during that time. This aspect highlights the cultural depth of the site,

as it constituted an integral part of the social and religious identity of the community.

- The results of the study contribute to enhancing scientific understanding of geoarchaeological dimensions, revealing the complex relationship between the temple and environmental factors. The research highlights how geoarchaeological sciences can aid in developing sustainable strategies for preserving cultural and architectural heritage in desert environments. It also emphasizes the importance of integrating geological and archaeological information to achieve better outcomes in preservation and documentation projects.

In conclusion, this research proposes a set of comprehensive recommendations to enhance the preservation of the Dosh Temple, addressing both environmental challenges and leveraging advanced technologies. These recommendations are as follows:

- Regular Sand Removal and Control: Establishing a consistent sand removal schedule is crucial to prevent sand accumulation around the temple, particularly in areas where wind erosion is accelerating stone degradation.
- Use of Erosion-Resistant Materials for Sandstone and Mortar Restoration: To enhance durability, it is recommended to apply materials that align with the natural characteristics of the temple's sandstone yet resist moisture and erosion, extending the life of the structure under environmental stress.
- Development of Artificial Protection Systems: Implementing natural or artificial barriers around the temple can help mitigate erosion from wind and shifting sands while preserving the archaeological authenticity of the surrounding area.
- Employment of Remote Sensing and Artificial Intelligence: Modern technologies like remote sensing and AI provide valuable monitoring for geomorphological changes, allowing for real-time data collection on sand movement and erosion. These insights enable prompt interventions to better protect the site.
- Enhancing Local Community Engagement in Site Preservation: Empowering the local community to participate in preservation efforts is crucial, fostering a sense of ownership and raising awareness about the temple’s cultural significance and conservation methods.
- Increasing Research Support and Specialized Training: Collaborating with academic institutions and international heritage organizations can bring additional resources and expertise, improving the efficiency of conservation strategies.
- Digital Reconstruction and VR Experiences for Preservation and Accessibility: High-resolution 3D scanning creates precise digital models, capturing the temple's current state. These models can support virtual reality experiences, expanding public and research access while reducing physical impact. This digital approach adheres to best practices in heritage conservation, balancing preservation with accessibility.
- Disaster Response Plan for Cultural Heritage Sites: Establishing a disaster response plan specifically tailored for Kharga's heritage sites can help minimize damage from sandstorms, flash floods, or human impacts. This plan should coordinate efforts between local authorities, cultural organizations, and conservation experts, ensuring a unified response to potential threats.
- Integrating AI and Machine Learning for Predictive Preservation Modeling: AI algorithms and machine learning can model structural vulnerabilities, providing predictive insights for timely interventions. By analyzing factors such as weather patterns, visitor data, and material stress, these tools can help prioritize effective conservation techniques and provide early warnings for required repairs.
- The study recommends conducting further research to assess the effects of environmental factors on the temple over time. This includes employing modern techniques such as 3D imaging and geophysical modeling to better understand structural changes. Such research will contribute to enhancing conservation

efforts for the temple and ensuring its sustainability for future generations.

These integrated recommendations address the multi-faceted environmental, technological, and community-centered challenges surrounding the Dosh Temple, ensuring its long-term preservation and accessibility as part of the region's invaluable cultural and archaeological heritage.

Conclusion

The Doush Temple in the Kharga Oasis offers a profound example of the complex interplay between ancient human activity and the harsh environmental dynamics of the Western Desert. This geoarchaeological investigation has illuminated how environmental forces, architectural choices, and subsequent human interventions have collectively influenced the temple's preservation and deterioration. Built with robust materials like quartz arenite sandstone, lime mortar, and mudbrick, the temple exemplifies the ingenuity of ancient builders who selected locally available resources to endure the extreme conditions of the region. However, the findings underscore how even these durable materials have gradually succumbed to erosion and weathering due to relentless wind-driven sand and fluctuating temperatures. The sand dynamics around Doush Temple are particularly significant, as both a preservation and degradation agent. The study revealed that while sand encroachment threatens exposed surfaces with abrasion and joint erosion, sand burial has paradoxically shielded portions of the structure from further environmental degradation. This dual role emphasizes the necessity for a nuanced approach to managing sand encroachment in conservation efforts, balancing the need to protect exposed sections with the advantages of natural sand coverage.

Additionally, improper restoration techniques and the impact of modern interventions, such as graffiti by early explorers, have introduced new preservation challenges. The use of incompatible materials like gypsum in restorations has. This study not only provides insights into the architectural resilience and cultural significance of the Doush Temple but also highlights the importance of adopting scientifically grounded preservation strategies. By integrating geoarchaeological, architectural, and environmental perspectives, this research contributes to the broader understanding of sustainable preservation practices for desert heritage sites.

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