Role of XRF in the restoration of a prominent architectural monument at the site of Mleiha



2012 IOP Conf. Ser.: Mater. Sci. Eng. 37 012005

(http://iopscience.iop.org/1757-899X/37/1/012005)

# Role of XRF in the restoration of a prominent architectural monument at the site of Mleiha

**Eisa yousif[a] and Atta Attaelmanan[b]**

[a] Directorate of Antiquities, Sharjah, UAE

[b] University of Sharjah, Sharjah, UAE

**Abstract**
The fort at Mleiha is one of the most well known archaeological sites of its period (3rd c. BC to 3rd c. AD) in the United Arab Emirates and has provided much valuable information. The period of its construction and use coincided with the Parthian period, during which there were extensive commercial contacts between the UAE and Mediterranean cities, Egypt, Mesopotamia, Southwest Iran, Pakistan, East Africa, and the southern Arabian Peninsula. It was restored using local materials, and traditional construction methods.
The objective of this study was to utilize XRF techniques for the identification of the elemental composition of building material used to construct an archaeological fort, and to compare it to composition of the restoration material.
Results of the study show strong correlation between the original fort building material and those used for restoration.

## 1. INTRODUCTION
The fort at Mleiha is one of the most well known archaeological sites of its period (3rd c. BC to 3rd c. AD) in the United Arab Emirates and has provided much valuable information. The period of its construction and use coincided with the Parthian period, during which there were extensive commercial contacts between the UAE and Mediterranean cities, Egypt, Mesopotamia, Southwest Iran, Pakistan, East Africa, and the southern Arabian Peninsula.
Although the fort was constructed shortly after the end of the Iron Age, around 300 BC, the inhabitants of Mleiha appear to have no relationship with the Iron Age inhabitants of the area. It is considered possible, therefore, that they may have originated from Arab Bedouin groups that formerly resided in the centre and northern parts of the peninsula. (Hellyer 1999, Potts 2001).
Excavations in Mleiha have uncovered a number of houses, cemeteries and animal burials, as well as other large buildings that may also have been fortified, besides the Mleiha fort itself (Jasim 1999).

### 1.1 Summary of Excavations
The Mleiha fort was first identified in 1990, as a result of the digging of a water pipeline adjacent to the highway that formerly ran directly across the site. Remains of walls and a fragmentary coin mould were among the key finds. Test trenches were initially excavated by the French Archaeological Mission (Mouton et al 1997, Mery and Mouton 2011), followed by detailed excavations in 1992.

These French excavations indicated that the fort had been built on a low, east-facing hill, and that it was constructed entirely of mud-brick. It has been dated to the First and Second Centuries BC.

The fort is square in shape, with eight towers, one at each corner and the others in the centre of each wall. The walls, of considerable thickness, are approximately 55 meters in length, with the entrance being located in the middle tower on the eastern wall. The interior of the fort takes the form of a central courtyard, with a number of small rooms attached to the walls, the walls of the rooms being 80 centimeters in width, and with doorways being 90 and 120 centimeters in width (Figure 1).
The excavations were undertaken in two phases. The first phase examined that part of the fort which was not covered by the tarmac road, while the second stage of excavation, of, the central part of the fort, took place following the diversion of the tarmac road, in accordance with directives from His Highness Dr. Sheikh Sultan bin Mohammed Al Qasimi, Ruler of Sharjah, to preserve the site and to facilitate excavation .


Figure 1. A photograph of the Mleiha fort showing the fort's foundations and its position relative to the main road. The road was moved on the orders of HH Dr Sultan Al Qassimi, ruler of sharjah, so as to preserve the archaeological site. (*Copyright: Diractorate of Antiquities, Sharjah*)

## 2. Mleiha Fort Restoration

Following the excavation of the fort carried out by the French Archaeological Mission, it was decided to restore and preserve the surviving remains, in particular those parts damaged through erosion or by their proximity to the former tarmac road. This work was carried out, in several stages, by the Sharjah Archaeological Team, making use of the plans prepared during excavation and of other data relating to the building.

### 2.1. Stage I

This included excavation and cleaning work next to the walls, to look for any other buildings that might be attached to its outer walls. The following findings were made:
2.1.1 A single room attached to the fort and situated between the North-East tower and the East Tower, with a single entrance. The wall of the room, which is linked to the two towers, and is 12.57 centimeters in width, with an entrance of 95 centimeters. This appears to have been added to the fort after its original construction. The room is divided into two equal parts, with a dividing wall of 2.90 meters in length, with an entrance of 99 centimeters width. A small hearth is present in one of the rooms, which may have been used both for cooking and heating .
2.1.2 A water channel has been excavated in the wall joining the South and South-West Towers, this being lined with stones at its base and on its sides to prevent erosion by the flow of water. It leads into one of the interior rooms, in which the French Archaeological Mission had previously identified another channel through the interior wall to the main internal courtyard of the fort .

2.1.3 A number of stones were found close to the South-East Tower, one of which has a carved image of a standing person. The stone is of sedimentary rock typical of the Jebel Faya and Jebel Mleiha formations.

## 2.2. Stage II

During this stage, of the restoration work, research was undertaken to determine the primary sources for the mud-bricks and pebbles used in the construction of the fort.
Samples of mud were collected from a number of wadis and farms close to the site, but these appeared to be unsuitable or the manufacture of mud-bricks, since they rapidly cracked once dried.
Eventually, an area containing old muddy sediments was identified east of Jebel Mleiha, in the Khatim region . This appeared to represent a now-dried up lake-bed from a period of higher rainfall
The thickness of the muddy sediment in this lake bed is between 15 and 20 centimetres. Sample mud-bricks prepared from the sediment showed a resistance to cracking, while they also had the same properties as the mud-brick from which the fort was constructed.
Sources of small pebbles were located approximately 700 metres from the southern side of the fort and 500 metres to the north-east of the fort.
After testing the lake bed sediment, production of mud-bricks for the reconstruction was commenced.

## 2.3. Stage III :

This stage included the preparation of the mud-brick and the reinforcing of the surviving foundations of the fort's walls. The soil and mud was not subjected to any laboratory test.
It appears that the mud-brick used to construct the original fort was made by mixing the mud with small pebbles and then drying them on mats of palm fronds. Impressions of palm fronds have been identified on some of the bricks. The bricks used were of two sizes, one of 40 centimetres length, 40 centimetres width and 10 centimetres thick, and the other of 40 cm by 20 cm by 10 cm. Bricks of these sizes have also been noted in other buildings in the Mleiha area
On the basis of these specifications, the mud-bricks were made as follows:

### 2.3.1. Mixture Preparation process :

Gravels / small pebbles were collected from an area near the fort and were then sieved to remove fragments of glass. Mud was then added, at a 3:1 ratio, i.e. one load of gravel being mixed with three of mud.
A basin was then made, which was then filled with water. The gravel/mud mix was then added, with the resulting mix being left to stand for a whole day.

### 2.3.2. Preparing molds, adding mixture and making mud-bricks:

Wooden moulds were made of the same sizes as of the ancient mud-brick .
The amount of time during which the mixture of gravel, mud and water was left in the basins varied from season to season, being left for 4 to 5 days in winter, for the larger bricks, and 2 days in the summer, because of varying rates of evaporation .
The wooden moulds were then removed from the mud-bricks, which were left to dry further, for 3 days in the winter and 2 days in the summer .
The mud-bricks were then stood on end for further drying, for 2 days in winter and a day in summer .
The above process indicates that temperature, and the speed of the consequent process of watert evaporation, is of importance for the production of the mud-bricks.

### 2.3.3. Re-constructing Foundations and Restoration

The foundation level was restored prior to the laying of the mud-brick.
This was required because some parts of the foundations had been damaged by bulldozers during the process of removing the old tarmac road that formerly ran across the centre of the site.
Careful examination showed that the original foundations had been laid on the natural surface. These were restored .

## 2.4. Stage IV

After erecting the walls, the interior floors of the fort, both of the internal rooms and of the courtyard, were covered with a thin layer of mud, on which machinery could work during the process of erecting the cover over the whole structure, thus avoiding damage to the original floors. This mud, obtained from wadi silt and then cleaned of extraneous material, was mixed with sand on a 2:1 ratio. This temporary floor was of around 5 centimetres in thickness .

## 3. XRF Analysis of building material

Samples from the fort's building material were analyzed using an X-ray analytical microscope (XGT 7200, Horiba, Japan). XRF analysis were performed using an intense X-ray beam 1.2 mm in diameter, generated from an Rhodium (Rh) X-ray tube operating at 50 kV and 0.5 mA. Four batches of samples were collected. Two batches from the original fort material (O), and the other two batches from the restoration material (R). Each batch contained three samples in powder form. Samples from the original material was collected from drills made in the core of the fort bricks, while restoration material samples were collected from the lake bed sediment used to manufactur the restoration bricks.

The system was calibrated using a brick clay standard (SRM 679) which was analyzed simultaneousely with the four samples. Measured concentrations were very close to the reference values (fig. 2) such that the fitting linear curve had a slope of 0.996 and a fitting factor $R^2$ of 0.9558.

Each sample was analyzed under vacuum for 1000 seconds so as to improve the probability of detecting the trace elements. Collected spectra were deconvoluted using quantification software, that caloculates elemental concentrations according to the fundamental parameter method.

Element oxide concentrations for the 12 samples shows the presence of the same elements in almost equal quantities. Silicon (Si), Calcium (Ca) and Iron (Fe) constitute the major elements, while Magnesium (Mg), Aluminum (Al), Sulfur (S) and Potassium (K) are the minor elements. Even the same trace elements are present in all the samples in almost equal amounts.

## 4. Conclusions

Correlation of the composition of the original fort material and the restoration material shows that the two materials are closely matched. A plot of the elemental concentrations for the original material versus the restoration material (fig. 3) has a slope of 1.01, which indicates a very good correlation between the two materials.

Variations in the concentration levels between the two materials could be explained by the simple fact that changes are expected during the manufacturing of the mud-bricks. However, despite the variations the concentrations, our results indicate that the source of the original building material used in the construction of the fort, almost two centuries ago, was the identified area east of Jebel Mleiha, in the Khatim region.

## 5. Acknowledgment

Our thanks to Dr Sabbah Jasim, for the permission to use the fort's photograph (fig. 1).

The X-ray fluorescence analysis was conducted at the National X-ray Fluoresnces laboratory, Sharajah, UAE.

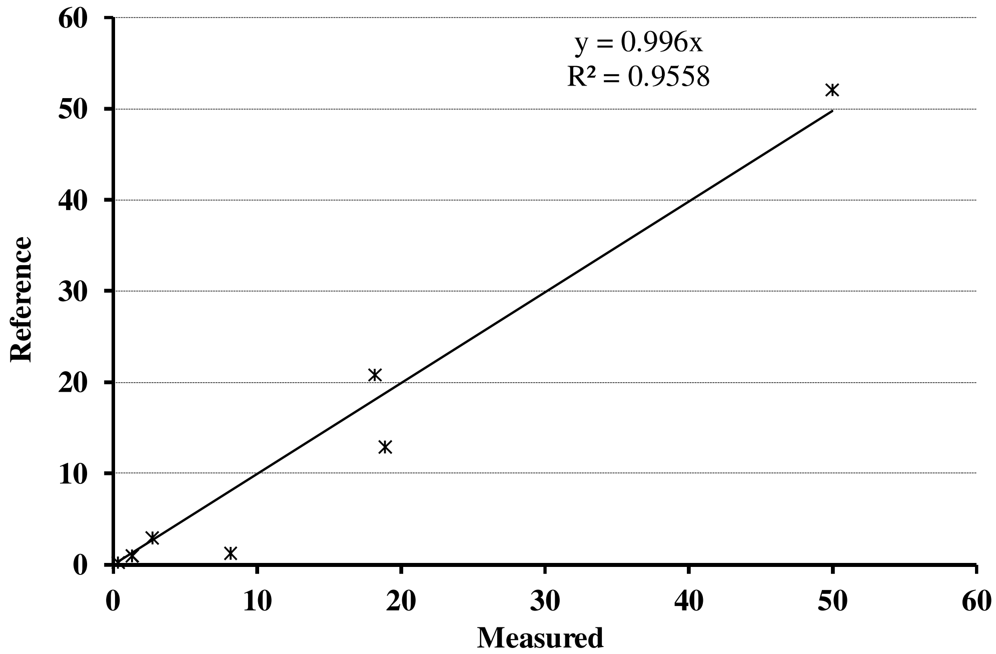


Figure 2. Calibration curve showing reference element concentrations versus measured values.

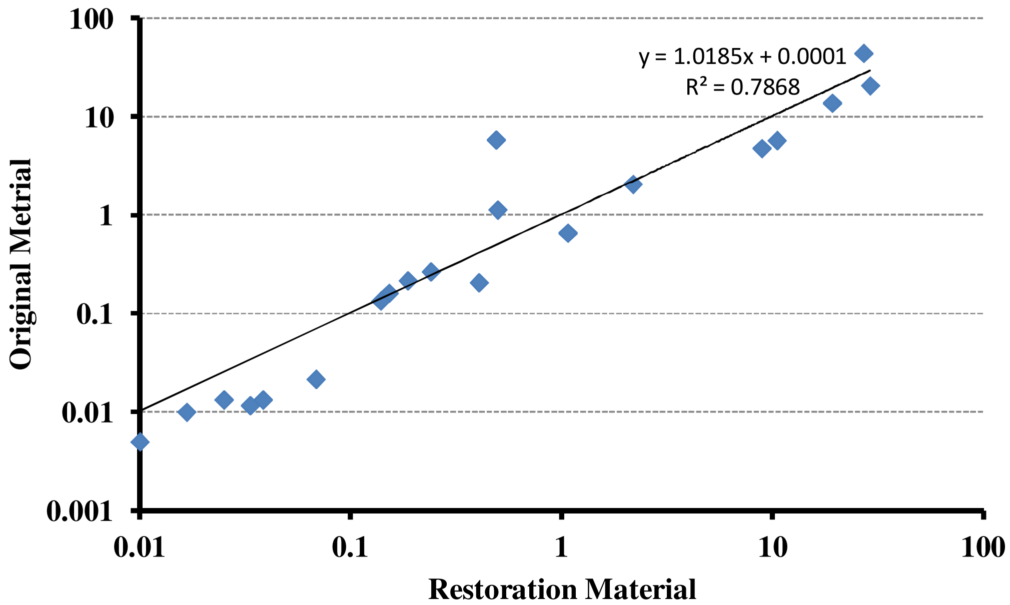


Figure 3. showing average element concentrations for the original fort material versus the restoration material

Table 1. Average element concentration values (mass %) for the 12 samples from the restoration (R) and original (O) building materials used in the Mleiha fort. Error values are 3σ. Elements with concentrations less than 0.1% (Cu, As, Rb and Y) are not shown here.

| | **R1** | **R2** | **O1** | **O2** |
|---|---|---|---|---|
| **MgO** | 11.64±0.74 | 9.31±0.78 | 5.22±0.62 | 6.30±0.59 |
| **$Al_2O_3$** | 10.66±0.21 | 7.11±0.15 | 4.67±0.14 | 4.88±0.17 |
| **$SiO_2$** | 32.13±0.21 | 25.87±0.12 | 20.28±0.1 | 21.10±0.15 |
| **$SO_3$** | 0.45±0.03 | 0.53±0.03 | 5.71±0.03 | 5.92±0.03 |
| **$K_2O$** | 2.13±0.03 | 2.22±0.03 | 2.09±0.02 | 2.03±0.02 |
| **CaO** | 23.45±0.23 | 30.52±0.12 | 45.22±0.13 | 43.29±0.11 |
| **$TiO_2$** | 0.98±0.02 | 1.15±0.02 | 0.72±0.02 | 0.60±0.02 |
| **$Cr_2O_3$** | 0.12±0.01 | 0.25±0.01 | 0.16±0.01 | 0.27±0.01 |
| **MnO** | 0.36±0.01 | 0.45±0.01 | 0.20±0.01 | 0.22±0.01 |
| **$Fe_2O_3$** | 17.02±0.15 | 21.22±0.08 | 13.97±0.05 | 13.60±0.04 |
| **NiO** | 0.20±0.01 | 0.28±0.01 | 0.28±0.01 | 0.26±0.01 |
| **SrO** | 0.42±0.01 | 0.57±0.01 | 1.120.01 | 1.15±0.01 |
| **$ZrO_2$** | 0.15±0.001 | 0.15±0.001 | 0.13±0.001 | 0.19±0.001 |
| **$SnO_2$** | 0.13±0.016 | 0.14±0.026 | 0.14±0.02 | 0.13±0.02 |

IOP Conf. Series: Materials Science and Engineering **37** (2012) 012005 doi:10.1088/1757-899X/37/1/012005

**References**


1. Hellyer P., 1999. Hidden Riches - An Archaeological Introduction to the United Arab Emirates. Union National Bank, Abu Dhabi. 99 (Arabic version) .

2. Jasim S. A., 1999. The excavation of a camel cemetery at Mleiha, Sharjah, UAE. Arab. Arch. Epig. 10: 69 – 101.

3. Mery S., Mouton M., 2011. French archaeological expedition in the United Arab Emirates: Excavations at Mleiha, Sharjah Antiquities Annual Magazine. Vol 13, 64 – 83.

4. Mouton M., Mokaddem K., Garczynski P., 1997. Excavations at Mleiha: 1990 and 1992 campaigns. Sharjah Arachaeology 6th report. 24 – 43.

5. Potts D. T., 2001. Before the Emirates: an Archaeological and Historical Account of Developments in the Region c. 5000 BC to 676 AD. Book chapter in United Arab Emirates: A new perspective. Edited by Al Abed I., Hellyer P., Trident Press Limited, London, UK. ISBN 1-900724-47-2, pp 28 – 69.