MATERIAL CHARACTERIZATION OF NATURAL AODBE PLASTERS IN THE JORDAN VALLEY: MINING THE PAST FOR A MORE SUSTAINABLE FUTURE

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ABSTRACT

Earthen buildings are inhabited by 30% of the world population; half of which are in developing countries. The techniques of earth building are widely practiced but the mechanics of earthen materials are poorly understood. As vernacular knowledge of this practice is being lost with globalization, so to are the environmental, social, and historic benefits that this technology provides. Nowhere is this more evident than in the Jordan Valley, known as having the oldest continuously inhabited human settlements, has remnants of adobe buildings that have proven durable throughout thousands of years. However, the development of the know-how to build with adobe was limited by the introduction of cement based construction materials to the region. To date, there have been no scientific inquiries into characterizing this important material.

The goal of this study is to focus on the material aspects of the natural adobe plasters by using nanotechnology including Air Scanning Electron Microscopy (AirSEM), Energy-dispersive X-ray spectroscopy (EDX), and X-ray Diffraction (XRD). The underlying hypothesis is that these complimentary techniques will help better understand the morphology of the ancient adobe plaster that has been used throughout different eras in the Jordan Valley, where, the use of multiple nanocharacterization tools overcomes the limitations of a single tool.

The results showed a significant variance in the plaster recipes in different geographical regions of the Jordan Valley. Some additives might have been added to the local soil, like talc that was found in the sample of Hisham's palace, or local soil differences could account for the differences. Finally, the results prove that regardless of the local recipes, people of the Jordan Valley used three different layers in the protection of the exterior walls, each having different ratios of earth materials.

BIOGRAPHICAL SKETCH

Lina Saleh was born in 1987 in Palestine and was raised in the city of Ramallah. She earned her degree in Architecture from Birzeit University in 2010. She was the recipient of a Fulbright scholarship in 2013 and joined the Department of Design and Environmental Analysis (DEA) in the Human Ecology School of Cornell University. Living under occupation, witnessing political impacts, and observing status quo in her country made her question the ethics of the architecture she wants to practice in her career. She, along with Palestinian architects, Danna Masad and Rami Kasbari, co-founded the eco-design firm ShamsArd; “Shams” meaning “sun” and “Ard” meaning “earth” in Arabic. She is focusing on architecture sensitive to the social, economic, and political context and is looking forward to achieving in design. This thesis answers some of the questions she had in mind when she decided to join DEA.

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LIST OF ABBREVIATIONS

BGF - Building Green Futures

CEB - Compressed Earth Blocks

CIWMB - California Integrated Waste Management Board

EB Plaster - Earth Based Plaster

EDX - Energy Dispersive Spectrometry

FEB - Forschungslabor fur Experimentelles Bauen

GHG - Green House Gas

IEQ - Indoor Environmental Quality

LCA Life Cycle Assessment

LOI - Lost on Ignition

PC Plaster - Portland cement Plaster

SEM – Scanning Electron Microscopy

VOC - Volatile Organic Compound

XRD – X-ray powder Diffraction

XRF – X-ray Fluorescence

LIST OF SYMBOLS

$CaCO_3$ - Calcite

CL - Clay Loam

CoSL - Coarse Sandy Loam

$Mg/CaCO_3$ - Dolomite

SiCL - Silty Clay Loam

SiL - Silty Loam

1. Introduction

The success of earth construction has been proven historically as some structures are still sound and durable after thousands of years. In modern times earthen construction has proven durable through tests and experiments (Minke, 2000). Nevertheless, earthen architecture is underestimated because earth buildings often look non-presentable as a result of poor maintenance, the use of inappropriate materials, and inconsistent building codes. Consequently, in different parts of the world a large number of buildings are being demolished with no regulations for preservation.

Cody (1985) used the term ‘two pronged rationale’ to express what builders think they will gain from earth structures; lower cost and simplicity (Cody, 1985, p. 19), which is not always the case. The idea that earthen buildings are primitive, easy to build and cheaper than other types of structures can be frustrating to the builder, both during and after construction, due to the complexity of the soil as a material and the lack of knowledge of the material’s behavior.

The knowledge about the construction of earthen buildings is not just a few hundred years old. It has existed for thousands of years and has a long history of evolution. Nevertheless, there is a recently developed gap in this inherited knowledge due to the abandonment of earth as a construction material in favor of concrete and other modern materials. Times of economic depression often lead to a revived interest in earthen architecture in the “developed world”. The UK, USA, Germany and France were interested in research of earthen construction between the Great Depression and World War II. Nevertheless, governments’ inconsistency towards the durability of earthen construction made it questionable as a sound, reliable or durable building material.

1.1. Purpose of the study

Earthen building material is a forgotten art. Modern science has ignored the subject of earth as a building material and the modern architect has rarely made use of it. This thesis focuses on the microstructure of adobe plasters of the Jordan Valley using modern nano-characterization technology. This study also assesses the existing knowledge of earthen plaster in the Jordan Valley through interviews with local people who witnessed or participated in the plastering process.

A more thorough knowledge of the plastering as a protective layer for the earthen building will help in the standardization of construction documents for newly built earthen buildings in the Jordan Valley as an alternative local building material instead of the use of cement based blocks. Protecting what remains of our inheritance of earthen structure technology is another purpose of this study. Morphological knowledge combined with the stories of the experiences of local people is a reasonable approach for restoring the missing knowledge about the abandoned earthen construction experience.

1.2. Scope of the study

In order to expand the knowledge of this technique, the field study was undertaken in the summer of 2014 and laboratory experiments were done during the fall and spring semesters of 2014/2015 as a master's thesis on Sustainable Design Studies in the Department of Design and Environmental Analysis in Human Ecology at Cornell University, Ithaca, NY.

Although the know-how of local people helps us understand the source of the plaster mix and the application of the plaster and its maintenance, this study focuses on the technical aspects needed to understand the "recipe" of different plaster samples collected from the Jordan Valley.

The technical part of the study covers the nano-characterization of the samples using AirSEM, EDX and X-ray diffraction techniques in addition to other bulk soil tests.

1.3. Justification and background of the study

The Jordan Valley stretches 105 km (65 miles) from the Sea of Galilee along the Jordan River, between Jordan and occupied Palestine. It is a part of a geological rift that extends from Syria-Lebanon to the Red Sea and beyond. It is the lowest valley on earth being entirely below sea level; it drops below 400 m. (Dudeen, 2001), with hills on both the east (Jordan) and west (occupied Palestine) banks which rise up between 600-1200 meters (2000-4000 ft.) above sea level (Ibrahim et al., 1976). Rain is scarce in the Jordan Valley with an average of 6.5 inches of yearly rain. It is considered a desert area. The weather is warm to hot from May to October and cool to warm from November to April. The area is a promising archeological region with major occupations as early as the Neolithic period to the late Mamluk period (Ibrahim. et al., 1976).

The Jordan Valley has great historical importance as it is considered the oldest continuously inhabited human settlement in the world, with some of the remnants extending back ten thousand years. The old buildings are built from traditional earthen materials consisting of a mixture of sand, soil, and straw. However, with the introduction of cement in the region in the1940s, locals shifted away from the traditional building materials to building with concrete motivated by the ideas that concrete is a stronger, cheaper and faster building technique. Most of Jordan Valley's buildings are built of cement blocks and concrete while the old earthen buildings are abandoned or dilapidated, receiving little maintenance. Some local architects and international organizations like The United Nations Educational, Scientific and Cultural Organization UNESCO have recently started to show interest in reviving earthen architecture in the Jordan Valley. However, the image of abandoned earthen buildings makes the challenge even harder for professionals and architects in convincing people to shift to building with earth.

Reviving earthen architecture has many advantages as it is a means of social empowerment for the local society and is an alternative building with lower embodied energy than conventional concrete buildings. With its greater thermal mass, it is better for hot dry areas like the Jordan Valley. Natural earth buildings also show resilience to earthquakes, which are common in the region.

There are a number of promising practices for reviving different earth techniques such as adobe, compressed earth blocks and earth bags. Nevertheless, new earthen buildings in the Jordan Valley are still being plastered with non-earth based plasters. Typically, they are using Portland cement PC plasters. Earth material needs to breathe; PC plasters disallows this resulting in serious structural dangers that can exist but cannot be seen behind the hard cement coating. The advantages for using Earth based EB plasters are the same as for earth architecture; it can be locally produced and it has low embodied energy. Additionally, earth based EB plaster is cheaper than PC plastering, and has more synergistic effects with the earth structures that it covers.

There is a gap in literature of the Earth-based plastering in general. To our knowledge, there is only one study in New Mexico in the USA which characterizes EB plaster samples collected from some old earthen buildings and also collects data by conducting interviews with the local community (Barger, 1995). In the Jordan Valley, despite the new projects that use earth as a building material, there is no evidence of literature about EB plaster in that area.

1.4. Hypothesis

Material characterization of the natural adobe plasters of the Jordan Valley leads to a thorough understanding of the plaster composition that can be used to coat earthen buildings as an alternative of PC plaster.

1.5. Future Opportunities and further research practice

The opportunities to use these research findings in practice are:

A. Testing the soils from different sites in the Jordan Valley,

B. Identifying the local sources of plaster mixes

C. Applying plaster in old buildings as part of the restoration of the mud buildings in the Jordan Valley

D. The application of earth based (EB) plaster in new mud buildings

E. The training of the local people in the creation and application of mud plaster

F. The mainstreaming of the EB plaster industry to create job opportunities

There are opportunities for further research like testing the different mixes of plaster on earthen walls, the standardization of the plaster recipes, the possibility of additional testing by adding additives to the plaster, and the assessment of the environmental and economic impacts concerning the restoration of old earthen buildings.

2. Background

2.1. Introduction

Earth is a common material that has been used in construction for thousands of years (Mellaart, 1964). Statistics show that mud houses are dwellings for 30% of the world population and 50% of these dwellings are in the developing countries (Houben & Guillaud, 1989; Keefe, 2005). Typologies of mud structures were not constrained to houses in the past. Places of worship, city walls and agricultural buildings are examples of earthen construction. Nowadays, earthen buildings are also found in various types of buildings such as hospitals, airports, embassies, museums, and factories. Ronald Rael (1971) mentioned that Seyoun Airport in Yemen is built from concrete columns and beams as structure elements while mud walls were used for filling. Though earth construction is associated with poverty, dry climate, and developing countries, we can find earth buildings in the UK, Canada, Germany, France, and the USA. Ronald Rael (1971) mentioned that Santa Fe, New Mexico's middle class and wealthy houses are built from mud (Rael, 1971, p. 9).

2.2. History of Earthen Architecture

There is no consensus on the origins or the dates of earthen structures. Excavations by Kathleen Kenyon (1957) show 7000 year old sun-dried mud bricks with lime plasters in Jericho. Jericho is said to be the oldest continuously inhabited city in the world with the oldest evidence of mud bricks dating back to 8350 B.C (Batler, 2005; Rael, 1971). Kathleen Kenyon (1957) stated in a more specific description that Jericho is the first large excavated Neolithic site with such walls. Since the 1950s, a number of sophisticated sites with or without walls have been discovered. The Anatolian town of Çatalhöyük in Turkey was found to be a more sophisticated site than Neolithic Jericho. Excavations there in the 1960s by Mellaart (1964), one of Kathleen's trainees at Jericho, showed evidence of earthen bricks that date back to 7000 B.C. and 5000 B.C.. Batler (2005) defined the archeological site as the largest farming community to be discovered. Adobe houses in the Turkestan region dated back to more than 5000 B.C (Pumpelly, 1908). Rael (1971) stated, "the first buildings recorded in history were built from mud like the Ziggurat at Ur, which was constructed in 4000 B.C.E" (Rael, 1971, p. 9). Minke (2000) mentioned that the 4000 years old Great Wall in China was originally built from earth (Minke, 2000, p. 9). In Egypt, some historical sites, like the vaults of the temple of Ramsees II, date back to 3000 B.C. (Rael, 1971, p.9).

Minke (2000) also mentioned that in Europe mud buildings were common. "In Germany, the oldest mud brick house found dates back to 6000 B.C., (…) Spaniards also brought the techniques of building with adobe to pre-Columbian people" (Minke, 2000, p. 9). In Central America, between the 13^{th} -17^{th} centuries, earth was used as filling between timber columns and beams because it is fire resistant (Minke, 2000). Taos Pueblo in New Mexico, as Rael (1971) mentioned, was constructed between 1000 and 1450 C.E. entirely from raw earth (Rael, 1971 p. 9) and is the oldest continuously occupied dwelling in North America.

2.3. Pioneers of Modern Earthen Architecture

The French architect, Cointeraux, born in 1740, is known as the father of modern earthen architecture (Rael, 1971, p. 10). Cody (1985), in his PhD thesis, mentioned that Goiffon, Rozier, and Boulard were considered as three pisé (rammed) theorists between years 1772-1786. Cointeraux, as cited in (Cody, 1985, p. 21), criticized Goiffon for preaching the pisé method in Lyon, France, and never practicing it. Cointeraux had discovered the remnants of rammed earth buildings in the countryside of France and then devoted his life to develop techniques for building with earth especially after several wars in France (Rael, 1971, p.10). Le Corbusier, the French modern architect, was also interested in earth construction, especially after World War II (Rael, 1971). Le Corbusier wrote a book on using rammed earth and compressed earth blocks. He believed that mud houses could solve the refugee-housing problem (Rael, 1971, p.12).

Frank Lloyd Wright was interested in building with earth and believed that the construction should be made of the earth itself and not imposed on the earth (Rael, 1971). The American architect Thomas Crane Young was intrigued with earthen architecture due to his exposure to English rammed earth architecture in the early 1920s (Cody, 1985, p. 318).

The Egyptian architect Hasan Fathy believed in vernacular architecture and researched the Nubian dome, vault and arch. He even included methods of construction of mud roofs (Rael, 1971), and published a book called “Architecture for the poor”. His approach to earthen buildings was more of an economic philosophy than just a building material (Rael, 1971). Local builders were trained by Fathy to build with mud and use passive cooling wind towers that were an essential element in the mud housing in the region (Rael, 1971). William Morgan (2008) stated that in his interview with Louis Kahn, the latter had expressed his appreciation of the Earth’s potential to shape the human environment. The concept of mud represents the collective wisdom of people over ten thousand years using earthen buildings. Le Corbusier in France and Frank Lloyd Wright in America promoted earth construction between 1940-1945, as it minimizes the use of forest products and chemically produced building materials. In World War II people started to think of conserving energy and material resources (Romero & Larkin, 1994, p.229)

Rick Joy is an American finish carpenter and musician who later studied architecture in Arizona. He was thrilled by the desert and worked for three years with Will Bruder who practices architecture without formal university training. Joy used intuition in materials selection and established an office which offers contemporary solutions with sustainable materials like rammed earth. Steven Holl, in his foreword in Joy's book "Desert Works", described the rammed earth constructions of Joy as "hyphenated material-spirit or spirit-materials". He added "the overall phenomenon, which is a result of material, detail, space, texture, light and sound allows architectural form to be almost negligible. I sensed in these small works an engagement with the phenomenal architecture I have lectured and sought to realize." (Joy, 2002)

Wang Shu and Lu Wenyu are the Chinese architects who won the Pritzker Architecture Prize of 2012 for the use of what they call true materials in architecture. Their work is based in China where they use old materials from old sites or low-tech materials. "Sustainable architecture is all about low technology" says Wang Shu in an interview with Bert de Muynck (Muynck, 2015). They believe that architecture is not only a building; "it is the relationship with the context and landscape that is essential as we have forgotten how to build cities that belong," declares Wang Shu (Muynck, 2015, p. 162).

2.4. Technologies

Mud buildings vary according to the technique used in shaping the mud. Adobe buildings are the most common found. Rammed earth is another common building technique. Additionally, other techniques like wattle and daub were extensively used in partitions (Mellaart, 1964, p. 34). Mud, as a building material, dates back to 8000 B.C., sun dried bricks to 6000 B.C. and burnt bricks to 4000 B.C. (Reddy, 2004).

A. *Rammed Earth*

Rammed earth is the most popular technique used in modern earthen architecture. It has been used historically in countries such as China, France, Australia and Germany but not in countries such as Canada or Japan (Rael, 1971, p. 19). Traditionally, soil is chosen according to local people's knowledge of the area; smell, visual inspection, feel and even taste were the simple common methods to decide on appropriate soils. Whereas, standardized proportions of materials have been set to 15-18% clay (sometimes it can be up to 30% clay for good cohesion), 23% coarse aggregate, 30% sand, and 32% silt. The amount of water is critical, as too much water makes the mixture too muddy (Rael, 1971). The formwork of the rammed earth is usually made of timber where the slip forms can be lifted as the wall rises. Wooden or steel tamping devices are used to ram each layer of earth. Rael (1971) mentioned that some lay bamboo parallel to the ground after each layer, which works much the same as steel rebars (Rael, 1971, p. 18).

B. *Earth blocks (Adobe)*

Adobe is a Spanish word that comes from the word Altoob in Arabic, and means sun-dried bricks that are made from clay and sand (Romero & Larkin, 1994). Adobe is the most traditional technique used in the history of earthen architecture (Keefe, 2005). In Persia, the largest vault of unreinforced masonry was totally built of mud blocks in 400 C.E. (Rael, 1971). Jericho, the oldest continuously inhabited city in the world, has the oldest evidence of adobe bricks (Kenyon, 1957). Excavations of Çatalhöyük in Turkey showed evidence of adobe as well. In Egypt, hieroglyphic manuscripts from ancient Egypt describe the tools and techniques of building with mud brick (Rael, 1971). Pit houses were found to be from mud bricks that were plastered and painted (Bogucki, 1999, p. 357). Sesklo, a city in Greece with a population of 3000-4000 people, has houses built from mud brick with stone foundations. Rael (1971) also mentioned that Athens in the 3rd century was built entirely of mud with buildings dating back to between 2600-1900 B.C. (Rael, 1971, p. 17). The largest Pre-Columbian adobe structure in the Americas (140 million mud bricks) is the Pyramid of The Muaca del Sol in the coastal desert south of Trujilion in Peru (Bogucki, 1999). The English also brought mud bricks with them to North America. The oldest house in Boston was built in 1680 and owned by Paul Revere, the American patriot (Morgan, 2008; Rael, 1971)

The process of applying Adobe technology can use any type of soil. Silt, clay, sand, aggregate and straw are used in the mixture. Clay and silt bind the components together while straw acts as the binder and reinforcement, strengthens the brick, and reduces the shrinkage. As Rael (1971) describes the clay: "It allows water to dry evenly by wicking water from the center of the brick" (Rael, 1971, p. 114). Natural additives that Rael (1971) mentioned could be cactus, mucilage, oxblood, paper, cornhusks and manure (Rael, 1971, p. 114). Other additives like cement, bitumen, and lime are stabilizers that are used to protect bricks from erosion, not for structural reasons. Formworks are used as single or multiple wooden or steel molds. The mixture is poured in the mold and leveled and then the form is removed and left to dry in the sun.

C. Compressed Earth Blocks

Compressed earthen blocks are the newest technology of earth construction. Starting in the 18th century, the French architect Cointeraux, the pioneer of rammed earth, developed a mechanical press (Rael, 1971). Cointeraux believed, according to Rael (1971), that rammed earth would be part of the social, economic and environmental changes after the French Revolution and introduced it as an inexpensive and fire resistant material.

In the early 20th century, the development of manual and electric earth compressing machines came to developing countries. In Columbia in 1952, the architect Raul Ramirez developed a manual machine for his low cost housing project, “The Inter-American Housing center in Bogota” (Rael, 1971), where he produced earthen bricks and tiles.

Rael (1971) mentioned that the manual machine for compressing earth is a steel box with a heavy iron lid and a lever. The box is filled with a mixture of earth and the lever compresses the soil. After releasing the lever, the lid is removed and the lower plate is raised to extract the compressed block (Rael, 1971).

D. Wattle and Daub

Wattle and daub is any woven structure from plants or branches with mud as a plastering material to protect from various weather conditions. It typically has smaller aggregate and uses dung to bind it together. Evidence shows that in Jericho and Çatalhöyük, structures of wattle and daub are older than rammed earth or adobe (Rael, 1971). It is a light structure, which is why it is popular in South America and Indonesia for its resistance to earthquakes. Wattle and daub is also found in the UK, other parts of Europe, Asia, and Australia. The technique of wattle and daub has been replaced by metal lath and cement stucco (Rael, 1971). The Chilean Architects, Smilan Radic and Marcelo Cortes, have reinterpreted this technology in modern uses of the material (Rael, 1971).

E. Cob

Cob is a technique that uses more straw than adobe. It was used in the UK between the 13th and 18th centuries (Rael, 1971). The English spread it to Australia, New Zealand and North America. Native Americans had used cob much earlier, building multi-story houses with it. The first prehistoric cultural building to be protected in the USA is the Casa Grande ruins and cob-based structure in Arizona that was set-aside in 1892 according to Rael (1971). In North Yemen, multistory houses are still built from Cob, called zabur there (Rael, 1971).

F. Poured Earth

Poured earth is a combined technology of all the previous technologies and was mentioned as a separate technique by Rael (1971). Poured Earth, or Encanjonado in Spanish, indicates the stuffing of mud in a formwork of lath and waiting for it to dry. A villa in San Francisco was built in 1845 using this technology. In the UK, poured earth techniques are applied as chalk, straw and soil poured in a formwork which is later removed (Rael, 1971).

Rael (1971) mentioned that Nader Khalili, the Iranian architect, used poured earth techniques in a more radical way in California. Sacks are filled with mud and called superadobe or sand bags. Marwan Al-Sayed used gypsum in the poured earth walls in Phoenix, Arizona (Rael, 1971, p. 180).

G. Extruded Earth

This is a 20th century technology where mud is extruded in a die which has hollows and then is cut in different lengths with wires (Auroville Earth Institute website). Some bricks go to the kiln and become more clayey than the bricks that sun dry for several days, called green bricks

(Rael, 1971). According to Auroville, this technique is used in India, New Mexico in the USA, Burkina Faso and France (Auroville Earth Institute website, n.d).

2.5. Stabilization of Earthen structures

Stabilization is the limiting of the brick's capacity to absorb water or moisture or erosion proofing from water (McHenry, 1984, p. 75). It enhances the mechanical characteristics of the earth mixture by increasing the resistance of compaction in dry humid conditions, reduces porosity, and makes clay more resistant to rain and wind. Adding materials is also important to prevent vegetation from growing in the earth structure as argued by Orazi (2000). Soil stabilization has more than 130 different stabilizers. Lime, cement, bitumen and vegetal juices are the most famous, with the choice depending on the soil. Clayey soil, for example, is best stabilized with lime while bitumen is a suitable stabilizer for sandy soils. Some soils need a combination of stabilizers.

On the other hand, McHenry (1984) argues that unstabilized bricks are not as vulnerable as they may seem (McHenry, 1984, p. 74). On the contrary, stabilization is seen as a burden on earth construction as it increases cost and cannot be recycled. Stabilization materials may not bond well and may not provide a homogenous mass in the case of mud to mud. This could be the reason for oxidation and evaporation of the surface after it has been exposed to air and sunlight (McHenry, 1984, p. 75).

2.5.1. Types of stabilizing agents

Traditionally, the simple common method to decide on appropriate soils was local people's knowledge of the area, smell, visual inspection, feel and even taste. However, people through time tested a lot of stabilizing agents to modify the characteristics of the soil. Stabilizing agents are varied and are also selected according to the local people's knowledge as well as the availability and cost of the materials. Nwankwor (2011) tested organic and inorganic stabilizers like cement, rice husk ash and straw. Results of different ratios of additives showed interesting changes on the different properties of adobe like compressive strength, erosion resistance ratio and acid attack resistance (Nwankwor, 2011, p. 241).

A. Portland Cement

Portland cement is a modern common additive to the mix of soil. Terracrete is the name of the earth cement mixtures (Cody, 1985, p. 352). McHenry (1984) stated that if cement was used in small proportions or was not thoroughly mixed, it would cause long-term erosion. The uncemented portions would be removed causing voids in the wall (McHenry, 1984, p. 75). In the cement-soil mix, the addition of 2% lime increases the plasticity while the addition of 2-4% bitumen increases the water resistance. The hardening of this mix requires a period of 16-28 days and constant humidification to prevent fractures (Orazi, 2000).

B. Lime

Lime is an ancient material used to stabilize the soil. It is available in its naturally occurring form as limestone, $CaCO_3$, in raw clay or as an impurity in sand (Glew, 2000) or as quicklime, CaO, which is produced on a simple, low-tech level when limestone is fired in a kiln. Quicklime is a white powder, hazardous, caustic, unstable, and should be used with caution (McHenry, 1984, p. 76). Slaked lime, $Ca(OH)_2$, is obtained by the hydration of quicklime. According to Glew (2000), lime was found in the mud mixture in England. "It might have been found naturally in raw clay or as an impurity in the sand or could have been added. Naturally occurring limestone or chalk could produce the appearance of lime in an analysis" (Glew, 2000,

p. 313). The percentage of added lime to the mix of soil is 6-12%, depending on the soil composition. The drying phase lasts for many weeks to months according to the climate, humidity and temperature (Orazi, 2000).

C. Asphalt Emulsion (Bitumen)

Asphalt emulsion or bitumen is a waste product that binds the granular material together. Silty or clayey soils require more asphalt than sandy soils. The asphalt binds the mix and prevents absorption of moisture. Sandy loam soils need 10-15% asphalt by volume for full stabilization, whereas partial stabilization requires 5% or less (McHenry, 1984, p. 75). Partial stabilization limits rain damage but doesn't make the brick waterproof. Bitumen as an oil base product is argued to be a non-friendly environmental additive, despite it being used historically by Sumerians as an additive material (Morgan, 2008; Rael, 1971).

2.6. Plaster

Plaster is a flat, external coat over a monolithic mass. It provides protection against mechanical damage of mud walls and prevents water penetration (Littman, 1962). The absence of plaster can cause deterioration of the walls and, in extreme conditions, can cause collapse of the building. Plasters range from plant extracts to cow dung to materials like cement, lime or asphalt. Many have been found successful and economical under various climatic conditions (Hammond, 1973). Poor design affects the durability of mud houses to resist water penetration, especially when plaster is not used. Covering of earthen walls is essential in areas where rainfall is erosive. According to Hammond (1973), where annual rainfall is less than 10 inches (254 mm), protection against erosion by rain is not necessary. In the Jordan Valley, where this study takes place, the rainfall is 166 mm/year (Da'as & Walraevens, 2013). However, despite the region's aridity, plastering is still important as the remnants of old buildings show that plastered adobe were the ones that survived.

Plastering is similar to mud architecture in the sense that it is different from one region to another because of different constituents of the soil itself, different available binders and different climates. It is a craft that has been passed verbally from generation to generation. It is important when a researcher wants to analyze plaster to carefully understand the original fabric of historic buildings, do laboratory analysis, search for raw ingredients and conduct experiments (Caron & Lynch, 1988).

2.6.1. Stabilization of earthen plasters

Mud plaster may be stabilized with the same waterproofing used for stabilization of mud bricks and in the same percentage (McHenry, 1984, p. 118). Though it might seem simple, plastering has seen many failures in modern earthen buildings due to reasons such as; incorrect proportions of material, wrong application, and lack of knowledge or expertise. Failures have also been caused by attempting to use the same recipes for different regions regardless of the different mechanical and chemical characteristics of the soils. Earth buildings are rendered with hydraulic binders like cement, lime, bitumen or gypsum plaster with or without additives (Houben & Guillaud, 1989, p. 336). The following plasters as mentioned by Houben and Guillaud (1989):

A. Lime plaster

In non-hydraulic lime, as a result of its sensitivity to frost and heat, some additives like bull's blood could be added to improve waterproofing. Natural soap improves the workability and egg yolks could be added, such as in Morocco, to improve waterproofing and make polishing easier (Houben & Guillaud, 1989, p. 336). Natural hydraulic lime hardens rapidly with water and slowly in air which reduces the sensitivity to frost and heat. Artificial hydraulic lime has similar properties to cement. Lime is permeable which allows the walls to breathe and it also has a softer texture than cement. Lime plaster was first used in Çatalhöyük as crushed calcium carbonate (Mellaart, 1964). When we say "lime plaster", it either means it is used alone as a rendering coat of the earthen building or it is mixed with mud. Woolley (2000) found that lime is a crucial decision as it is not a zero emission, low impact material (Woolley, 2000, p. 354) but it is still greener than cement (low technology, local level, and less energy). In the Jordan Valley, excavations show evidence of lime plasters (Kenyon, 1957).

Hammond (1973) described a recipe of lime plaster in Argentina: "First layer; a coating of thick plaster, consists of one-fourth part of cement, one part of paste lime, three parts of brick dust (or equal quantity by volume of fine sand) is applied to the wall. Second layer; the coarse plaster is given a fine finish by covering it with a mixture consisting of two parts of paste lime to five parts of fine sand by volume" (Hammond, 1973, p. 160).

B. *Soil Cement plaster*

Cement is usually 15% of the mix and has a higher cost than conventional plaster (McHenry, 1984, p. 126). If in inadequate proportions, it will crack and the water will penetrate inside these cracks and make the earth expand (Houben & Guillaud, 1989; McHenry, 1984). Only a proportion of a 1-part cement to 5 or 10 parts sand should be used. It is better to add lime 1 to 1 or 1 to 2 in this mix as well. If applied, it should be on a wire netting to reduce cracking (Houben & Guillaud, 1989).

According to Hammond (1973) a rich cement mix develops shrinkage cracks, as the bond between cement and mud is not satisfactory. Moisture penetrates the cracks and softens the mud wall surface and destroys the bond. On drying, differential shrinkage develops between the cement mortar and the surface of the mud wall.

C. *Earth mix Plaster*

Earth mix plaster is the same mix for the wall in dry climates. For better adhesion of the wall, Houben and Guillaud (1989) claim that it is better to use a wash of cement or lime in addition to the slaked lime for outdoor walls as well as for waterproofing (Houben & Guillaud, 1989, p. 336). Two layers; 1 to 1.5 parts of slaked lime to 10 parts of plaster and 7.5 to 10 parts of sand for the first layer. The second layer is the same but without the sand. Fluoro-silicate can be added for waterproofing after a few days (Houben & Guillaud, 1989, p. 336). On the other hand, Minke (2000) encourages the application of a paint of lime or lime casein to make it waterproof if only earthen plaster is used (Minke, 2000, p.111)

Fibers are added to earth-based plaster for reinforcement. They can be vegetable or animal products or synthetic additives. They could also be wood shavings or sawdust. Straw is used as a binder and reinforcement to the soil paste. Nutshells and seashells have also been tried. They are embedded in mud to resist wall penetration or provide the base for plasters (Hammond, 1973). Table 1 shows the earth based EB plaster stabilization by traditional water proofers in different regions of the world.

Table 1: Soil stabilization by traditional water proofers

Region	Soil stabilization by traditional water proofers	Source
Northern Ghana	An extract of boiled banana stem[1] & lateritic soils are added to the mix.	Hammond, 1973; Lal, 1992
Upper Volta	Am, a plant extract dark red in color and used as a varnish, is added to the mix.	Hammond, 1973; Lal, 1992
Northern Nigeria	Laso, an extract from the vine Vitis pallida, is added to the mix. Makuba that is made from the fruit pods of the common bean tree is added to the mix.	Hammond, 1973 Houben & Guillaud, 1989
Ghana & India	Cow-dung mixed with clay is added to the mix.	Hammond, 1973; Lal, 1992
Sudan	Zibla, which is a local waterproof material made from cow or horse dung is added to the mix	Hammond, 1973; Lal, 1992
Ethiopia	Straw is used in mixing the soil paste	Hammond, 1973; Lal, 1992
Africa Hausa	Natural potash or mimosa is added as a water proofer	Houben & Guillaud, 1989
Mesoamerica	Lime mortar is made with juice of the chocom tree.Sascab[2] replaces sand in making mortar.	Rael, 1971
Chichen Itza	An extract of the bark of the Chacte tree is added to the plaster to give added strength	Littman, 1957
Togo	Kapok oil from kapok seeds is added to the mix to form a powder form with high lipid content. The powder is diluted with water and boiled, then mixed with water	Houben & Guillaud, 1989

Source: The author.

[1] A problem with banana juice is that it should be boiled for a long time (Houben & Guillaud, 1989, p. 339)

[2] Sascab is an unconsolidated form of calcium carbonate found in pockets of limestone (Rael, 1971)

2.7. Sustainability of Earthen Architecture

Vitruvius, in his book “De Architectura” also known as “Ten Books on Architecture”, and translated by Ingrid and Rowland, defines architecture as: firmitas, utilitas, venustas, which means soundness, utility and attractiveness (Vitruvius & Rowland et al. (trans.), 1999, p. 14). The principle of soundness according to Vitruvius is observed by the building materials, which should be chosen carefully (Vitruvius & Rowland et al. (trans.), 1999, p. 26). Rome’s buildings that Vitruvius praised were 6-8 floors, built from mud and timber, with wooden balconies and plastered with mud or lime (Vitruvius & Rowland et al. (trans.), 1999, p. 90). McDonough & Braungart (2002) described sustainable as local. In a project, where McDonough and his professor were in Jordan to work on a long-term plan for the future of the east bank of the Jordan River valley, the team proposed the use of adobe structures. The local people could build these with materials at hand- clay, straw, horse, camel, or goat hair and (not least) abundant sun. The materials were ancient, well understood and uniquely suited to the hot dry climate (McDonough & Braungart, 2002, p.124)

In this chapter we will discuss the effects of earthen buildings on three main criteria: environment, society and economy. Sanya (2007), in his PhD thesis, has identified certain sub-criteria considering the context of Uganda in his critical approach to the research generated in the north, when applied in the southern hemisphere. Though the Ugandan context is different than the context of the Jordan Valley in Palestine, some of his sub-criteria were adopted in this chapter. Social and economic sustainability were discussed as one aspect. A political dimension was added to the criteria to cover the political context of the Jordan Valley where this study is focused.

2.7.1. Environmental Sustainability

Despite the fact that vernacular architecture was replaced by modern architecture, particularly in the third world, the Egyptian architect Hassan Fathy (1986) advocated for earthen architecture, as it is based on a scientific approach, which people evolved intuitively and tested over time. The vernacular architecture, with its form, materials and architectural elements responds to the climate, humans' needs and to the social context. The environmental sub-criteria discussed here consists of Indoor Environmental Quality IEQ, energy, preservation of resources, prevention of Green House Gases GHG pollution, life cycle analysis and durability.

A. Indoor Environmental Quality IEQ

Indoor environmental quality enhances human health, comfort and productivity and is influenced by air contaminants, thermal comfort and psychosocial issues (Mendes & Teixeira, 2014). Fathy(1986) believed that architecture should understand the relationship between microclimate and human comfort. Thermal comfort is related to factors such as: air temperature, air humidity, rate of air movement, level of radiation, and rate of heat production by the bodies of people in the building (Fathy & Walter, 1986, p. 26). We will discuss volatile organic compounds VOCs and air humidity, as they are directly related to the construction material and the finishing layer of the building.

1. Volatile Organic Compounds VOCs:

Earthen construction is not associated with VOCs as there is no use of heavy metals or chemicals, which cause health problems like asthma (Little & Morton, 2001). Related to the use of some building materials, Torgal and Jalili (2012) mentioned symptoms such as itchiness, burning eyes, skin irritation or rashes, nose and throat irritation, nausea, headaches, dizziness, fatigue, reproductive impairment, disruption of the endocrine system, birth defects, immune system suppression and cancer (Pacheco-Torgal & Jalali, 2012, p. 515). In fact, earthen finishes are used as intoxicants especially for people with chemical hypersensitivity.

2. Air Humidity:

Air quality is influenced by: air temperature, air movement, air pollution, and air humidity (Minke, 2000). While fluctuations of temperature are easy to realize, it is hard to notice fluctuations of air humidity. Arundel et al. (1986) show that a humidity level between 40%-70% is acceptable. However, Arens (1996) thinks that even a humidity level between 60%-70% can have negative effects. Unpleasant humidity levels cause the human body to be affected by colds and related diseases and sick building syndrome (Pacheco-Torgal & Jalali, 2012).

Minke (2000) mentioned that mud walls are able to balance a certain amount of humidity and are able to absorb and desorb humidity faster than other building materials. Because of their porosity, earthen walls are able to desorb humidity from the environment and absorb it inside the building. Experiments at Forschungslabor fur Experimentelles Bauen FEB in Germany studied the influence of different unplastered interior wall materials of 11.5 cm thickness on the absorption rate. The wall from mud bricks absorbed as much as 50 times more moisture than solid bricks burnt under high temperature when humidity suddenly rose from 50 to 80% (Minke, 2000, p. 16)

B. Embodied Energy and Life Cycle Assessment

Life Cycle Assessment LCA is a methodology for assessing the environmental performance of products through their whole life cycle (Sonnemann et al., 2004). LCA started as an environmental management tool in the 1960s and as a tool for building assessment in 1990

(Khasreen et al., 2009). One of the major considerations in LCA is embodied energy. Keefe (2005) defines embodied energy as a measure of all energy consumed in extraction, processing, manufacture and transportation of a building component or material up to and including the actual construction process (Keefe, 2005, p. 2). Morton et al. (2001) advocated for earthen buildings for the low embodied energy and CO_2 emissions. In a project in Scotland, it was reported that the embodied energy used to produce bricks that were artificially dried for 2 days, was 14% of the energy used to produce firebricks (Little & Morton, 2001). Embodied energy rises when cement is used in stabilization. Treloar et al. (2001) conducted an LCA study comparing the embodied energy of stabilized compressed earth blocks CEBs with cavity brick construction (to which it is closer in thermal performance), and found that CEBs were approximately equivalent to brick veneer construction.

C. Preservation of Resources

Earth as a building material is considered renewable as it doesn't undergo irreversible change through industrial processing, which makes material either non-biodegradable or incapable of recycling (Keefe, 2005, p. 3). Though it is different from timber, as it is created through the weathering of rock, earth is still available abundantly and thus it is renewable. Keefe (2005) mentioned that contents of earthen buildings are basically all natural materials which, when demolished, could be recycled. Cement addition makes them only recyclable into other earth bricks limiting their options. Another consideration is that the use of loam/mud saves stone or timber from being used in construction.

D. Prevention of Green House Gas Pollution

The building construction industry consumes 40% of materials entering the global economy and generates 40-50% of Greenhouse Gas GHG emissions and agents of acid rain according to the California Integrated Waste Management Board CIWMB[3] (Eaton et al., 2000, p. 2; Asif, Muneer, & Kelley, 2007). Earth gained a significant environmental advantage over other conventional materials after the UN climate change conference in Copenhagen in December 2009, which called for the reduction of CO2 emissions by reducing the use of fossil fuels (Williams et al, 2010).

E. Durability

Durability of earthen buildings is assured by the fact that they have lasted as sound structures for thousands of years. Durability, as defined by the Earth Research and Practice Center in Grenoble, France, CRAterre[4], is the ratio between wet to dry strength (CRAterre website). Minimum dry compressive strength for stabilized earth is 2.4 MPa, while it is 1.2 MPa for saturated earth. CRAterre requires a minimum ratio of 0.5, while Heathcote (1995) suggests a ratio of 0.4-0.5, depending on the severity of rainfall. Rainfall, according to him, is responsible for the kinetic energy, which is influenced by the roughness of the walls. Rammed earth is less affected than adobe, as adobe is likely to be more disturbed due to rain impinging on its rough surface. Stabilized walls resist the breakdown of materials in saturated conditions while in

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[3] Design with vision: A technical manual for materials choices in sustainable construction retrieved from California Integrated Waste Management Board CIWMB

[4] CRAterre is the International center for Earthen Architecture and was established in 1979,it has worked for the recognition of earth materials as a valid response to the challenges linked to the protection of the environment, the preservation of cultural diversity and the fight against poverty (CRAterre website)

unstabilized walls, the bind strength is determined by the force of dry minerals and the permeability of materials. Torgal and Jalili (2012) found that durability is dependent on maintenance that is convenient to the materials and original construction.

2.7.2. Social & Economical Sustainability

A. Social acceptance and Relevance to local culture

The lack of knowledge and standardization of the mud construction makes it more of an alternative technique rather than conventional. In Yemen, for example, Shibam city was described as Manhattan in the Hadhramaut due to the mud skyscrapers in the city. Ronald Lewcock (1986) in his book "The Old Walled Cities of Sana" discussed that the institutions are still not supporting mud as a method of construction because of the regular maintenance it requires and that the preservation of these buildings should be more of a plan of action rather than individual initiatives. This plan should include encouragement, training programs and financial subsidies (Lewcock, 1986, p. 114). In this perspective, CRAterre's three main objectives are centered on optimizing the use of local human and natural resources, improving housing and living conditions, valorizing and promoting cultural diversity (CRAterre website).

B. Decentralizing resources and political context

Sanya (2007) argues that "simple technology of wattle and daub, and adobe construction creates decentralized job creation and reduction of inequity in distribution of resources and power at international and intra-national levels more than CEBs, which are more dependent on non-local centralized production" (Sanya, 2007, p. 196). In a broader context, earth construction decentralizes the dependency on factories and focuses on local communities, as earth is available and work is labor intensive. A comparison between the use of any earth technique, which is abundantly available to the inhabitants of the Jordan Valley, versus conventional techniques using ready cement bricks or concrete walls would be an interesting area of study. Palestinians import cement from Israel or Jordan, and reports show that cement was often not available during times of political crisis. Therefore, a switch to earth-based building could be a shift in the local economy and to a less dependency on the importing of cement. On her paper "Earthen Architecture, Sustainability, and Social Justice" that was published in the 10th International Conference on the Study and Conservation of Earthen Architectural Heritage: TERRA 2008, Avrami (2011) has stated that as a result of the prohibition of earthen construction in building codes in many countries and because of the lack of industry, research, and development, standardization and improvement of earthen materials and techniques are precluded (Avrami, 2011, p.330). CRAterre, on the other hand, has assembled a multidisciplinary team of researchers, professionals, lecturers and trainers, working in collaboration with many partners, as a means to establish creative links between research, on-the-field activities as well as training, knowledge dissemination and sensitization activities (CRAterre website).

C. Enhancement of community

Projects taking place lately in the Jordan Valley show that local communities have been highly involved in the construction process. Training for building with earth opened the horizon for small scale contracting and also has shown a higher involvement of women in the building construction process. Women are rarely found working on conventional projects of cement-based construction. On their criticism of the triple bottom line, McDonough and Braungart (2002) criticized "the champions of "sustainable development" for using a "triple bottom line" approach based on the tripod of Ecology, Equity and Economy" as they stated. According to them, despite the fact that this approach has had a major positive effect on efforts to incorporate sustainability concerns into corporate accountability, in fact its social and ecological benefits are an afterthought rather than having equal weight with the economic profitability. They argue that if the project uses the triple bottom line as a design tool, designers will question how to create a habitat and how to create jobs. This will be financially much more beneficial than only considering purely the economic perspective (McDonough & Braungart, 2002, p.154).

D. Affordability and cost

Torgal and Jalili (2012) discussed the economic benefits of earth. Although it is usually said to be cheaper, it actually depends on many aspects like labor cost, construction techniques, stabilization process and durability. For these reasons it is different from the developed to the less developed countries. In the UK for example, Williams et al., (2010) mentioned that production and construction are the most costly parts, especially when production size is on a small scale, which means a high unit cost. But with higher demand the cost of production will be reduced. Whereas in less developed countries this is not the case because labor is cheaper and most of the cost is in stabilization (Sanya, 2007, p. 55).

E. Job Creation and New Opportunities

After World War I & II, when both building materials and capital were scarce, new houses and entire settlements were built using mud bricks on rammed earth (Rael, 1971). Mud brick construction was a source of job creation and economic development for the countries. Fathy (1986) and some other architects were in favor of earthen architecture, not only because it is a cultural heritage, but also because it is economically sustainable in the sense of intense labor needs and creating jobs for local people.

According to Cheikhrouhou (2000), in their project of building adobe dwellings in the rural areas of Tunisia, the breakdown of the cost of the dwelling was 60% for materials and technical assistance (necessary because the know-how had disappeared in the rural areas), 30% for labor and 10% for transportation (Cheikhrouhou, 2000, p. 306). This as explained earlier, varies from one country to another.

2.8. Characterization Technologies: State of the Art

Houben and Guillaud (1989) explained that earth consists of gases, liquids, and solids. Gases come from air like N, O, CO_2, and from organic materials like CO_2, H_2, and methane. Liquids are water or any other soluble in soil that comes from rain, humidity, and decay of rock as a result of climatic and weathering changes, like sugars, alcohols or organic acids. Solubles could be mineral compounds (acids, bases and salts) like Ca^{+2}, Mg^{+2}, K^{+1}, Na^{+1}, PO_4^{-3}, SO_4^{-2}, CO_3^{-2}, and NO_3^{-2}. Solids are any organic and mineral materials; organic constituents from animals or plants like bacteria, fungi, algae, protozoans, worms and insects, animal wastes, undecomposed dead plants and animals, decomposed organic matter and humus, which is the stable colloidal fraction of organic matter that decomposes very slowly. Finally, mineral constituents like the eroded bedrock or any other act of mankind (Houben & Guillaud, 1989, p. 20).

In classifying the soil as a building material, we are interested in both the mechanical or physical and chemical classification. In later sections in this study, we will thoroughly discuss the chemical classification as the core of the nano-characterization of the materials.

*2.8.1. Mechanical classification of soil*Soil selection is important in earth construction and the plastering. Soil is classified into sand, silt, and clay according to its physical properties. According to Houben and Guillaud (1989), there are four main factors that affect the physical properties of soil; texture, plasticity, compressibility or compactibility, and cohesion (Houben & Guillaud, 1989, p. 32-33).

- Texture: grain or particle size distribution in a soil. The percentage of the grain size is determined by the sedimentation of soil. Main fractions according to size are pebbles (20-200 mm), gravel (2-20 mm), sands (0.06-2mm), silts (0.002-0.06 mm) and clays (less than 0.002 mm).

- Plasticity: the ability of soil to deform without cracking and without disintegration failure.

- Compactability: the ability of soil to be compacted for a given energy and humidity. The less porous it becomes when compacted, the less water penetrates. Greater compactability means fewer disturbances to the structure by water.

- Cohesion: the capacity of grains to stay together when soil is under tensile stress. Cohesion depends on adhesive and cementation properties of coarse grains, which bind the grains together.

2.8.2. Chemical classification of soil

Chemical classification classifies soil as clay and non-clay minerals. The clay minerals are hydrous aluminum silicates and are classified as phyllosilicates, or layer silicate (Moore & Reynolds, 1989, p. 34). Bailey (1980b), as cited by (Moore & Reynolds, 1989, p.117), has classified the clay minerals according to layer type as the main criterion for establishing divisions. Within each division, the layer charge or charge per formula unit is used as the criterion for classification. Within these subdivisions, subgroups are made based on whether they are trioctahedral or dioctahedral.

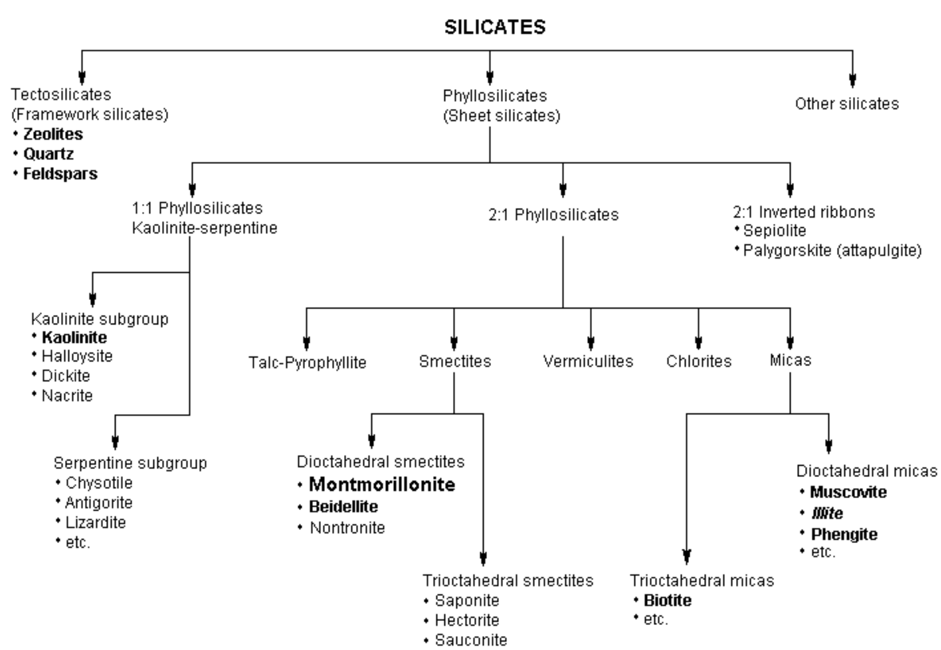

Figure 1: Classification of silicates (Bailey, 1980b; Rieder et al., 1998)
Source: http://www.inchem.org/documents/ehc/ehc/ehc231.htm

Structural classification of clays as classified by Houben & Guillaud (Houben & Guillaud, 1989, p. 27):

1-Kaolinites: These are oxygen tetrahedrons with a silicon center and a layer of oxygen (or hydroxide) octahedrons with an aluminum center. It is generally stable in contact with water. Clays of the kaolinite type are preferable and don't swell in water (Moore & Reynolds, 1989, p.124). Lateritic clays often make good rendering in red or ochre. They are susceptible to swelling (Houben & Guillaud, 1989, p. 338).

2- Illites: This group has a three layer structure, an aluminous octahedral layer between two silicaceous tetrahedral layers. Mg or Fe may replace Al ions in the aluminous layer and Al may replace Si in the Silica layer. When it is not saturated, K ions may replace the negative charges and bond the sheets. It is not stable in contact with water and suffers swelling.

3- Montmorillonites: Mg, Fe, Mn and Ni may replace Al ions in the octahedral alumina layer to form montmorillonite. The ions between the sheets are not K ions but are exchangeable cations (Na, Ca) and water molecules. Montmorillonites are not stable when in contact with water and suffer severely from swelling.

4- Others: These are chlorite, muscovite, halloysite, vermiculite, sepiolite, attapulgite and interstratified materials. These are complex combinations of several types of clay.

Non-clay[5] chemical classification as in (Houben & Guillaud, 1989, p. 24)

[5] Houben & Guillaud (1989) referred to the non-clay minerals as sand. Where as to avoid any confusion, this study uses non-clay minerals term that Moore and Reynolds (1989) and Bailey (1980) used when they studied the chemical properties of the soil

1-Silica minerals: These resist chemical weathering. They are grains of quartz disintegrated from sandstone and crystalline rocks. Quartz, feldspars and zeolites are all silica minerals. Low or alpha quartz is the most common of silica minerals in sedimentation rocks.

2-Silicates: These are grains of mica, feldspar and free minerals disintegrated from crystalline rocks such as granite and volcanic rocks.

3-Limestones: These are sandy soil made of calcium carbonate. Limestone is not always present in the soil, though all soil has calcium in the form of calcium ions or in soil solution in the form of soluble calcium salts.

2.8.3. Typical Soil Tests

Soil identification tests vary from simple tests to more sophisticated lab tests that identify the physical and chemical properties of the soil. Expensive lab tests could be used when simple test results are contradicting. For this research, a variety of tests were conducted including preliminary tests and chemical morphological test analysis using AirSEM, EDX, and XRD. These tests are usually conducted for soil to be tested as a building or a plastering material. Houben & Guillaud (1989) and Minke (2000) are good sources of tests for soil as a building material. However, there are standards for brick recipes of earth mixes but still not for plastering, though it is known that the plaster mix is more critical than the earth mix for structures that will be exposed to the weather. This gap in literature for testing of plasters is what this study seeks to address. In this chapter, preliminary tests will be explained while other lab tests will be mentioned briefly as they are different from one study to another. The tests adopted in this study will be explained in detail in the methodology section.

A. Preliminary Tests

Preliminary soil tests are important for identification of properties of soil and the soil suitability for construction or plastering. This can be done in the field with very low cost and technology. They are not accurate but are done on site and are enough for estimation of composition of loam (soil). Some of the indicative analyses are as listed by (Houben & Guillaud, 1989, p. 48; Minke, 2000, p.22):

- Visual examination: removing the large stones, gravel and coarse sand to enable further examination.

- Smell Test: smelling the soil directly. If the smell is musty, then there are organic materials. Heating or wetting the soil can make the smell stronger.
- Nibble Test: crushing the soil with the teeth. If the soil grinds with a disagreeable sensation, then it is sandy. If it grinds without a disagreeable sensation then it is a silty soil. If there is a floury sensation and it is sticky, then it is clayey.
- Touch test: rubbing the sample with fingers and palm. If there is a rough and has no cohesion when moist then the sample is sandy. If there is a slightly rough sensation and it is moderately cohesive when moistened, then it is silty. If the soil becomes plastic and sticky when moistened or contains lumps or concretions when dry, then it is clayey.
- Washing test: wash the hands after the slightly moistened soil. If the hands rinse easily, then it is sandy. If the soil looks powdery but the hands rinse clean, then the soil is silty. If the hands have a soapy sensation and can be rinsed clean with difficulty, then the soil is clayey.
- Luster test: A slightly moistened ball of soil is cut into halves. If the surface is dull, the soil is silty and if it is shiny, then the soil is plastic clayey.
- Adhesion test: A mass of moist soil should be stuck with a spatula or knife. If the spatula penetrates with difficulty and soil sticks into it, then the soil is extremely clayey. If the spatula can be pushed into it and soil sticks to it, then it is moderately clayey. If the spatula can be pushed into the mass with no difficulties even if soil sticks to it then the soil only has a little clay.
- Sedimentation: It gives an idea of the texture of the soil and relative size of the different fractions. It is done in the field with a transparent cylindrical bottle. After mixing the sample of soil with water and shaking the bottle and leaving it for around 45 minutes, the

sand will deposit to the bottom, a layer of silt above and a layer of clay above according to their different densities. The organic debris will float at the surface of the water.

- Shrinkage: The linear shrinkage test is obtained through a linear wooden box (4 cm w, 4 cm d, and 60 cm l). It is greased and filled with the moist soil, then left in the sun for three days. The amount of shrinkage is determined by measuring the distance of the space left when the dried soil is pushed to one end of the box.

B. Chemical Tests

Chemical tests are important for determining the chemicals present in the sample and their quantity. They are also important to determine the presence of soluble salt and the pH of a soil (Houben & Guillaud, 1989, p. 66). For example, soluble salts, the pH measurement, acid salts, percent carbonate by the acid centralization method, basic salts, and carbonate percentage can be determined through the chemical tests.

C. Mineralogical Analysis

Mineralogical analyses are the physico-chemical reactions based on visual observation. The mineralogy of the fine fraction is studied after the particle size distribution tests to determine the volumetric stability of the soil and its cohesion. These tests, which cost little, are very effective and make it possible to select the samples, which should be subjected to further laboratory analysis (Houben & Guillaud, 1989, p. 64).

D. X-Ray diffraction Analysis

The X-Ray diffraction (XRD) pattern as defined by Atkins (1994) is a plot of the intensity of x-rays scattered as a result of the diffraction at different angles by a certain sample. X-ray intensity is recorded as counts or counts per second when the detector moves in a circle around the sample and records the number of x-rays observed at each angle 2θ. The probe wavelength required to probe atomic distances is 1 Angstrom (1 angstrom=1.0×10^{-10} meters). Peak position is determined by Bragg's Law, which is $n\lambda = 2d \sin \theta$. XRD results are accurate analyses but can be expensive. Clay mineral diffraction has a character that is manifested by the peak's position, intensity, shape and breadth. The sample must be representative of the soil. Only fully equipped labs can perform these analyses, which are mostly qualitative and rarely quantitative (Houben & Guillaud, 1989, p. 66).

3. Methodology

3.1. Approach and importance of the study

Despite the fact that earthen architecture literature shows insights about advances in the preservation of earthen heritage, it has not yet propagated the kind of in-depth scientific research needed in the field (Singh & Arbad, 2014). Susan Barger (1995) discussed that there is very little literature regarding the plastering of adobe structures. She, herself, conducted research in New Mexico where she interviewed local people and then characterized the samples of adobe plasters from different sites. Genestar and Pons (2003) also conducted a study in Islamic and Gothic palaces, Palma de Mallorca in Spain, using the nano-characterization of the plaster and mortars.

This study seeks to characterize adobe plaster in the west bank of the Jordan Valley River where no similar research has been conducted. Even though the United Nations for Education Science and Culture Organization (UNESCO) and Building Green Futures (BGF[6]) partnered in a project called “Reviving Earthen Architecture in the Jordan Valley” which aimed at improving the physical living conditions and housing standards of the Palestinians in the Jordan Valley, it was not similar to this study. Approximately 30 percent of the Jordan Valley inhabitants, including refugees, Bedouins and economic migrants, are deprived of their right to adequate housing (Building Green Futures [BGF] website, n.d). UNESCO still covers adobe with PC plasters instead of EB plasters. The projects of local studios like the ShamsArd design studio, a local alternative architectural firm, aim at using earth as an alternative material. The projects of the studio have failed to use EB plasters due to the lack of knowledge of plastering methods and

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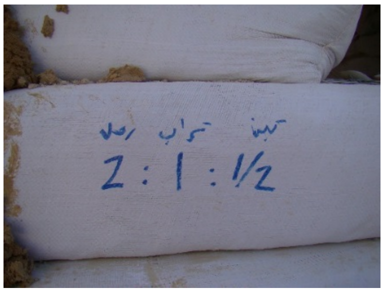
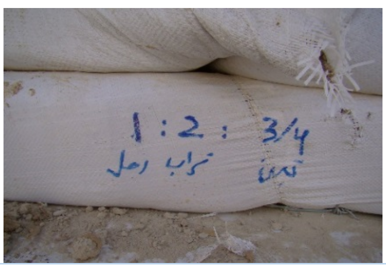
[6] Building Green Futures BGF is a not-for-profit organization created by Mario Cucinella Architects to promote sustainable development through green architecture and urban regeneration

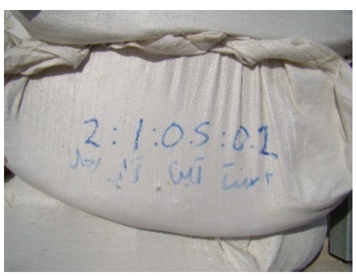
techniques as well as the lack of knowledge of the nature of the earth as a plastering material. The pictures below show the multiple trials of the EB plasters using different recipes of sand, clay, straw and cement. None of them have succeeded, with many cracking.



2 Sand: 1 Soil: ½ Straw



1 Sand: 2 Soil: 3/4 Straw



2 Sand: 1 Soil: 1/2 Straw: 0.2 Cement

Figure 2: Samples of different recipes of soil, sand, straw and cement
Source: Rami Kasbari for ShamsArd Design Studio (2013)

This study will limit its scope to the characterization of the materials used in plasters of old existing buildings in the Jordan Valley. Interviews with residents of the area will help identify sources of soil and plasters and the know-how of plastering. The findings of this study could be a roadmap for architects, contractors and local practitioners, and codes' officials for the application of the EB plasters in new earthen buildings or even for preservation of old structures.

3.2. Hypothesis

Characterization of the adobe plasters using analytical tools to assess the morphological composition of the plasters will lead to a thorough understanding of plaster composition that can be used to coat earthen buildings as an alternative to PC plaster.

3.3. Research questions

A. Could a contemporary viable earth plaster technology be rediscovered through modern nanoscale analysis of ancient earth plasters?
B. Could a recipe of the plaster used in each building be determined and are we able to identify the morphology and the recipe of the different layers of plasters?
C. Do the plasters used in different areas of the Jordan Valley have the same composition or are they different?
D. Could we determine the source of the soil used in the plaster using analytical tools like AirSEM and XRD?

3.4. Research Design

This research adopts a quantitative and qualitative design approach. It includes fieldwork in the western bank of the Jordan Valley River in Palestine that was conducted in the summer of 2014. The fieldwork was divided into unstructured interviews with locals, observation and the collection of samples of plasters from earthen buildings and raw soils. To analyze the collected data, nano-characterization tools were used in some of the facilities on the Cornell University campus, Ithaca, NY. AirSEM, EDX, and XRD analyses were used in addition to the bulk soil tests.

3.4.1. Data collection

Fieldwork includes the interviews conducted with the residents in the Jordan Valley and the collection of samples from ancient sites and raw soils.

A. Oral History Interviews

Two unstructured interviews were conducted with local people at the western bank of the Jordan Valley River. Palestinians who had the opportunity to work in plastering, or at least witnessed the process of earth plastering, were sought out. Meeting with local people who still had knowledge was not easy as some of the practitioners that we identified had passed away. Their children hadn't learned from them. In Jericho city, only one interview was conducted. It was with an old man who still lives in an adobe house, Mr. Samih Zurba. He remembered the process of earth building and plastering but hadn't practiced it himself. In a village called Bardala, in the north of the western bank of the Jordan Valley on the Palestinian side, we interviewed an old woman that had built her adobe house herself. The house had been demolished in the mid of 1940s and was replaced with a cement-block house. The interviewee could still remember the source of the soil, the mixing and the application. Both of the interviews were conducted in Arabic.

The interviews helped generate a better idea of earth construction techniques and the know-how of earth plastering (methods, soil sources, behavior of material and maintenance). The two interviews also helped us identify variable sources of plaster samples and soil sources. For instance, from the interview with Mr. Zurba, the samples were taken from the roof of his house, defined as Jericho 3 in table 3.1 below and another sample from his neighbor's house defined as Jericho 4. From the second interview, it was learned that the locals in Bardala village used to bring white soil from the close-by village of Kardala and used it as their plaster. The Kardala sample, a raw soil sample, was collected for this reason. In Bardala, however, no earthen structures could be found during the field visits; they had all been demolished. Instead, an Ain Beida plaster sample, referring to the Ain Beida village, which is a nearby village to Kardala, was collected from the wall of a remnant of an abandoned adobe room.

The Jericho 1 sample was collected from Hisham's palace, which is an Islamic historical site that was built in the Umayyad period. The sample was taken from a wall that is said to have been an outdoor swimming pool. This sample is particularly important because it is the oldest sample among all the collected samples. Different samples for exterior and interior plasters from Jericho city were marked as Jericho 2, 5 and 6. These were observed from our site visits.

B. Samples' collection and identification

Fragments from plasters, mortars and raw soil from different sites were shipped to Cornell University in Ithaca New York for material characterization using a variety of analytical tools at the Cornell Center for Material Research (CCMR). The samples are identified as follows:

1- A sample from an important historical site, Hisham's palace, which dates back to the Islamic Umayyid Period in the 7th century is identified as Jericho 1.

2- Samples from inhabited earthen buildings in Jericho. Interior and exterior plaster samples identified as Jericho 3 and 4 respectively.

3- Samples from uninhabited earthen buildings in Jericho and other parts of the Jordan Valley are identified as Jericho 2, 5 and 6 and the Ain Beida sample.

4- A sample of a raw soil from Kardala in the Jordan Valley is identified as the Kardala sample.

In some plaster's samples, different layers of exterior plasters have been identified, to be analyzed separately. Some samples from mortars and adobe bricks were collected in addition to interior plasters, adobe brick samples, and raw soil. Table 2 shows 12 different samples showing sample source, age of building, and description.

Table 2: Sample types and locations.

Location	Building Age	Sample Description
Jericho 1	8th century	Exterior, mud plaster, wall of an old swimming pool
Jericho 2	-[7]	Exterior, mud plaster, wall of old uninhabited house.
Jericho 3	1920s	Exterior, mud roof plaster of an inhabited room used as a store
Jericho 3	1920s	Mud roof, inhabited room used as a store
Jericho 4	1920s	Exterior, mortar, inhabited house
Jericho 5	-	Brick, abandoned building
Jericho 6 plaster top	-	Exterior, mud plaster, three bedroom abandoned building
Jericho 6 plaster with color	-	Interior, colored plaster (light green colored), three bedroom abandoned building
Jericho 6 plaster interior	-	Interior, plaster, three bedroom abandoned building
Jericho 6 mortar	-	Mortar, three bedroom abandoned building
Ain Beida	-	Exterior, plaster, abandoned building
Kardala	-	Raw soil, white and grey soil

Source: Data collected by researchers Danna Masad & Lina Saleh

[7] (-) means not enough data

3.4.2. Inventory Analysis

The Methodology of visual observation, bulk and nanoscale tests was conducted by Barger (1995) for the plaster samples she collected in New Mexico, U.S.A. and was adopted in this study with some variances according to the available facilities and convenience. Previous samples were subjected to the following analytical tests in different laboratories of Cornell Campus Materials' Research (CCMR).

The order of the methods of bulk and nano-characterization as conducted in this study:

1. Fractured surface of the plasters was examined using Air operational scanning electron microscopy B-nano (air-SEM). Air-SEM, is a technique that was used to characterize materials' topography and composition. It is one of the main tools for many applications including biotechnology, materials science and nano-characterization. SEM is a powerful tool to see features smaller than the wavelength of visible light and beyond what can be resolved with classical optical microscopes. SEMs provide images with resolution of a few to a few tens of nanometers, which makes them essential for research and engineering. SEMs focus an electron beam to a spot that is a few nanometers in size and scan the beam across a sample surface to form an image. When equipped with EDX to detect element-specific x-rays excited in the sample by the incident electron beam, chemical composition can also be determined and mapped. This was conducted in the David Muller group labs in the building of Applied and Engineering Physics building at Cornell University, Ithaca, NY.

2. Crushing of samples by hand and removing the organic materials, such as straw, was used to make color measurements using visual matching and Munsell system soil color. The

color of the samples was determined using the Munsell soil chart after the samples had been powdered, soaked and dried.

3. Samples were subjected to standard particle size analysis using Pippette Analysis. Particle size analysis is based on the fact that particles of similar density but different size will settle out of suspension at different rates. The rate of settling, V (cm/sec), is given by Stoke's equation: $V = \frac{g(\rho_s - \rho_l)d^2}{18\mu}$, where d is the particle diameter (cm), g is the acceleration of gravity (cm/sec), ρ_s and ρ_l the densities of the soil and liquid respectively, and μ is the viscosity of liquid (dyne sec/cm²). After a certain time, all particles of a given diameter have settled out of suspension, or are below the sampling depth. Particle size analysis data is a powerful tool in soil genesis and morphology, particularly in assessing the presence or absence of argillic[8] horizons and in determining the continuity of parent materials[9].

4. The Percentage of carbonate in the samples was determined by acid neutralization method.

5. The pH of the samples was determined using slurry in water and slurry in a 0.01M solution of calcium chloride.

6. The Weight percentage of organic material fewer than two micrometers in size was determined by ignition. Tests (3-6) were conducted in the Crop and Soil Sciences labs at Cornell University, Ithaca, NY

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[8] Argillic horizon: is a subsurface horizon with a significantly higher percentage of phyllosilicate clay than the overlying soil material.

[9] Data here was obtained from the lab report of Cornell Crop & Soil Science Lab

7. The Structural analysis of the powdered samples was determined using XRD. XRD was performed on a Scintag-Theta-2-Theta- X-ray diffractometer equipped with a primary beam monochromatic and Cu K_α radiation on a running angle of 5° - 60° and 0° – 30°. The clay fraction is analyzed on both dry and glycollated samples for some of the samples where the dry fraction was not enough to determine the clay mineralogy. This test was conducted in the Earth and Atmospheric Sciences labs at Cornell University, Ithaca, NY.

3.4.3. Laboratory Results

Nanotechnology of Air-SEM and EDX were utilized to determine the elemental compositions of the samples. XRD was used to determine the crystal structure. Bulk soil tests like soil fraction, pH, and organic matter content were used as quantitative data to assure the qualitative data from the nano technological tools' tests. The tables (3-10) below show all the conducted test results.

Table 3: EDX showing the elements in each sample[10]

Sample ID	K	C	Ca	O	Fe	Mg	Al	Si	S	Cl	Ti	P	Mn	Na
Jericho 1 [11]														
Jericho 2														
Jericho 3														
Jericho 3 roof														
Jericho 4 mortar														
Jericho 5 Brick														
Jericho 6 plaster top														
Jericho 6 plaster with color														
Jericho 6 plaster interior														
Jericho 6 mortar														
Ain Beida														
Kardala														
Kardala grey sand														

Source: The author.

Table 4: Color Measurement according to Munsell System

Sample ID	Color Code
Jericho 1	10 YR 7/2
Jericho 2 Plaster	5Y 8/1
Jericho 3 plaster	2.5 Y 8/1 white
Jericho 3 roof	2. Y 7/2 light grey
Jericho 4 plaster	2.5 Y
Jericho 4 mortar	10 YR 6/3 Pale Brown
Jericho 5 mortar or plaster	7.5 YR 6/3 light brown
Jericho 6 int. plaster	10 YR 7/2
Jericho 6 mortar	10 YR 7/2 light grey
Ain Beida plaster	10 YR 5/3
Kardala	2.5 y 8/2 Pale yellow

Source: The author.

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10 The intensity of color indicates the significance of the material. The darker the grey color is, the more it is present in the sample as shown in the EDX results.

11 The highlighted samples are the samples that went through all the bulk tests

Table 5: Percent Carbonate $CaCO_3$ determined by acid neutralization method

Sample ID	$CaCO_3$%
Jericho 1	85.72
Jericho 2	43.64
Kardala	73.54
Ain Beida	36.51
Jericho 5	35.18
Jericho 6	37.30

Source: The author.

Table 6: Moisture content and loss on ignition method LOI

Sample ID	Moisture %	LOI
Jericho 1	0.60	0.85
Jericho 2	1.59	4.69
Kardala	2.19	2.80
Ain Beida	2.69	6.05
Jericho 5	2.19	4.32
Jericho 6	1.75	4.11

Source: The author.

Table 7: pH Measurements on the Plaster Sample

Sample ID	pH/H2O	pH/CaCl2
Jericho 1	8.64	6.84
Jericho 2	7.77	7.14
Kardala	8.37	7.81
Ain Beida	8.07	7.65
Jericho 5	7.94	7.71
Jericho 6	7.99	7.94

Source: The author.

Table 8: Weight Percent of Organic Matter

Sample ID	% Organic Matter (OM)
Jericho1	0.37
Jericho 2	3.05
Kardala	1.73
Ain Beda	4.00
Jericho 5	2.79
Jericho 6	2.65

Source: The author.

Table 9: Particle Size Distribution

Sample ID	T Sand	T Silt	T Clay	Texture
Jericho 1	84.67	12.85	2.48	CoSL[12]
Jericho 2	8.70	54.01	37.29	SiCL
Kardala	26.23	42.56	31.21	CL
Ain Beida	21.29	57.04	21.67	SiL
Jericho 5	17.24	55.49	27.27	SiCL
Jericho 6	13.54	47.19	39.27	SiCL

Source: The author.

Table 10: X-ray Diffraction XRD Data

Sample ID	Clay Fraction	Sand and Silt Fractions
Jericho 1	-[13]	Calcite and Quartz
Jericho 2	-	Calcite, quartz and aragonite
Jericho 3	-	Calcite, quartz, feldspar (sanidine)
Kardala	Montmorillonite	Quartz and Calcite
Ain Beda	Montmorillonite	-
Jericho 5	Montmorillonite, Anhydrite, Ankerite	Quartz and Calcite
Jericho 6	Ankerite and Aragonite	Quartz and Calcite

Source: The author.

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[12] CoSL: Coarse Sandy Loam SiCL: Silty Clay Loam

CL: Clay Loam SiL: Silty Loam

[13] - Not enough data from the XRD analysis

3.4.4. Interpretation

Table 3 shows the results of the elements shown in AirSEM. Only selected samples (highlighted in Table 3) were chosen for bulk tests in tables (5-9) based on the variation of elements we noticed from EDX results and the significance these samples showed. Table 4 above shows the different color gradation of the different samples. It is noticed that there is a variety of soil colors according to the Munsell system shown in Table 4. Samples collected from the different locations were located on this map below as well as shown in Figure 3 below. Figure 3 shows the variable soil zones of the Jordan Valley in a map by Gal, Amiel & Ravikovitch(1974), a reason for different colors of soils.

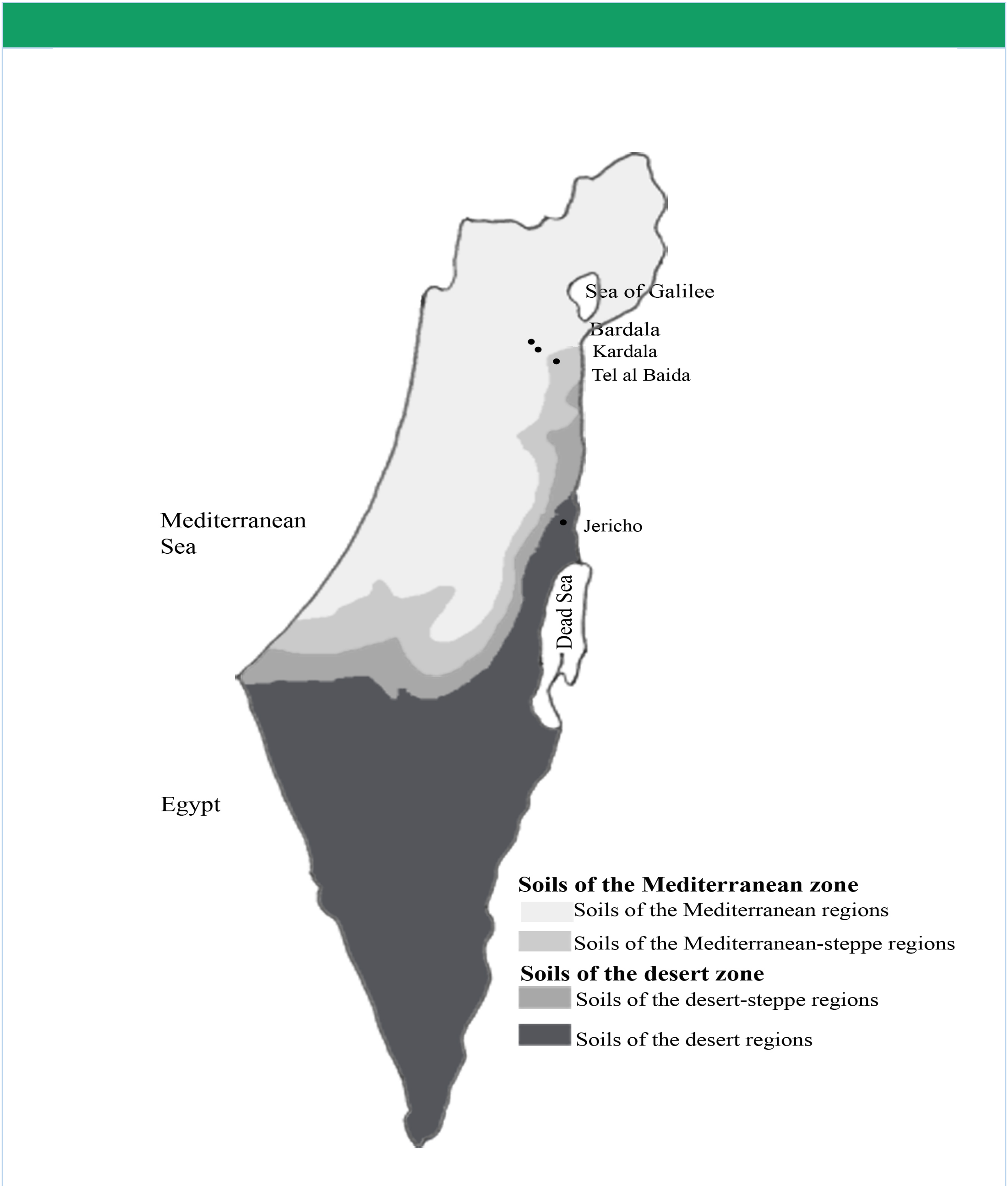


Figure 3: Soil sampling locations & locations of different samples

Source: Gal, Amiel & Ravikovitch(1974) for the soil zones & the author for the samples' locations

Table 5 shows the carbonate percentage of the soil determined by the acid neutralization method. Jericho 1 shows the highest percentage of $CaCO_3$ (85.72%) followed by Kardala soil (73.54%). Other samples of Ain Beida, Jericho 2, 5 and 6 have a percentage of $CaCO_3$ between 35- 44%. Table 7 shows that almost all of the samples are alkaline.

Table 9 shows the particle size distribution (texture) of the samples. Different textures of soil; sand, silt and clay are identified according to their size. It is noticed that Jericho 2, 5 and 6 are Silty Clayey loams. Jericho 1 is a coarse sandy Loam. Kardala is a Clayey Loam while Ain Beida is a Silty Loam.

Table 10 shows the crystal and clay morphological composition of the samples using Energy Dispersive X-ray diffraction XRD. Clay minerals are seldom found as monomineralic material. Non clay minerals are present, often in amounts so small that only their most intense peaks can be seen. Non clay minerals produce sharper peaks than clay minerals do (Moore & Reynolds, 1989, p.228).

The angle used was from 5°-60°. The samples were tested again dry and glycollated with less angle from 0°-30°. The qualitative identification procedure from XRD begins by searching for a mineral that explains the strongest peak or peaks, then confirming the choice by finding the positions of weaker peaks for the same mineral. Once a set of peaks is confirmed as belonging to a mineral, these peaks are eliminated from consideration. From the remaining peaks, again it is searched for a mineral that explains the strongest remaining peak or peaks and then confirms this by looking for its peaks of lesser intensity (Moore & Reynolds, 1989, p.202). For instance, quartz is usually found in clay size fraction though it is not a clay mineral. Its strongest peak is at

26.65 2θ for CuK alpha. If this peak is present we should look at the 20.85 2θ position where the second most intense peak occurs (Moore & Reynolds, 1989, p.203).

According to Gal, Amiel & Ravikovitch (1974), the soils in this region mainly contain Montmorillonite (Al/Mg Silicate clays) in addition to Illites (Al/K Silicates) and Kaolinites (Al Silicates). These soils also contain minerals like Calcite ($CaCO_3$), Quartz (SiO_2) and (Al/Fe/Ti oxides).

When analyzing X-ray signals, we are interested in the elements with energies greater than that of Oxygen. The relative distribution of the elements Al, Mg, Si, Ca, K and Fe in the samples, as revealed by the EDX mapping in the B-nano airSEM, indicates the elemental composition of the samples. Using EDX results along with other bulk soil tests and XRD help determine the mineral composition of the samples giving clues of the plaster recipe. In soil and also plaster, Si is normally found in Silicon oxide SiO_2 and also in clay minerals. Whereas, Ca would normally be found in Calcite $CaCO_3$ or in other calcium carbonate minerals such as dolomite or aragonite. Comparing the distribution of metals such as Mg, Al, and Fe with the Ca/Si map helps us identify clay particles, SiO_2 particles, and Calcium carbonate particles. Therefore, for each sample Ca/Si composite of the sample's map with the overlap of the map of the elements with the highest peaks determines the elemental composition of the element.

Jericho 1- Location 3

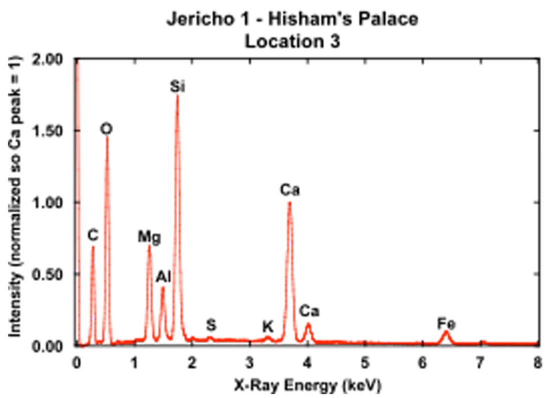
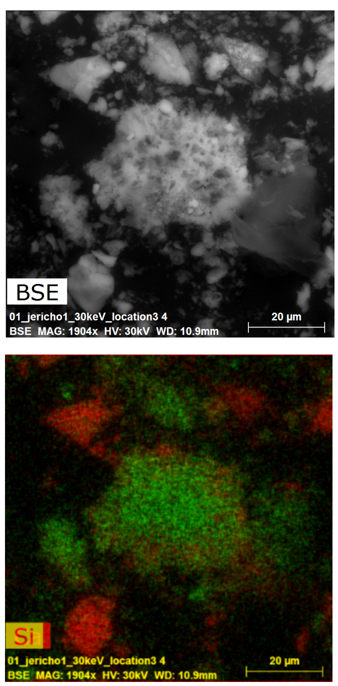
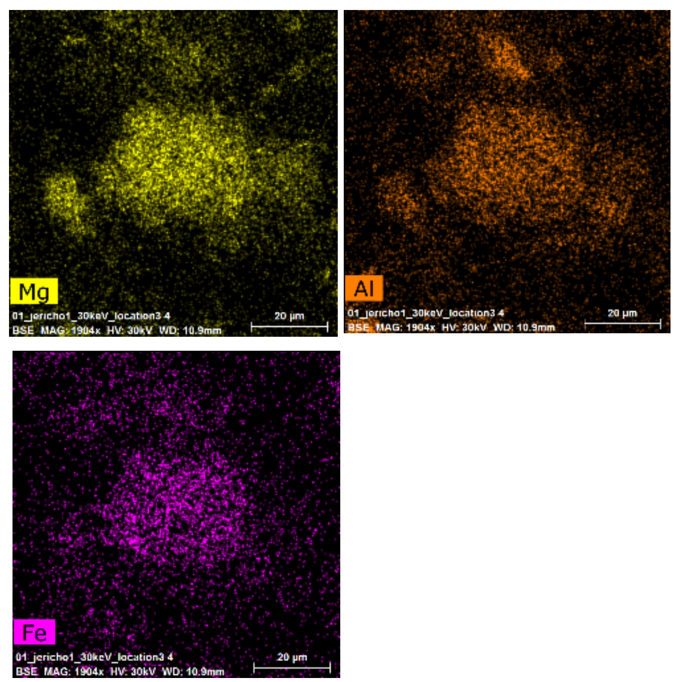


Figure 4: Jericho 1- Location 3 EDX signals

Jericho 1- Location 3





An image of particles from the Jericho 1 sample, location. Ca/Si composite map, with Si in green and Ca in red	The EDX data for metals: Mg, Al, and Fe

Image showing Jericho 1- Location 3 sample with Si/Ca composite map and the most significant elements in EDX

Figure 5: Jericho 1- Location 3 map

EDX signals in Figure 3 show that Ca and Si dominate (excluding O and C), with significant Mg and Al and traces of Fe, K and S. The EDX data was used to produce a Ca/Si composite map as shown in fig. 4, with Si in green and Ca in red next to it.

Comparing the Ca/Si composite image in Figure 4, (Ca red, Si green), with EDX images for Al, Mg, and Fe, it is noted that the Al, Mg, and Fe signals all seem to originate much more from the same area as Si (green in the composite) than Ca. This is consistent with imaging calcite ($CaCO_3$) and clay-silicate particles. The overlap of the Mg and Si signals in EDX would be consistent with the presence of Montmorillonite and/or Chlorite clays. Study by Gal et al. (1947) suggests that most soils in Israel/Palestine region contain mostly Montmorillonite (Mg/Al silicates), and also Kaolonite (Al silicates) and Illite (K/Al silicates).

Jericho 1- Location 4

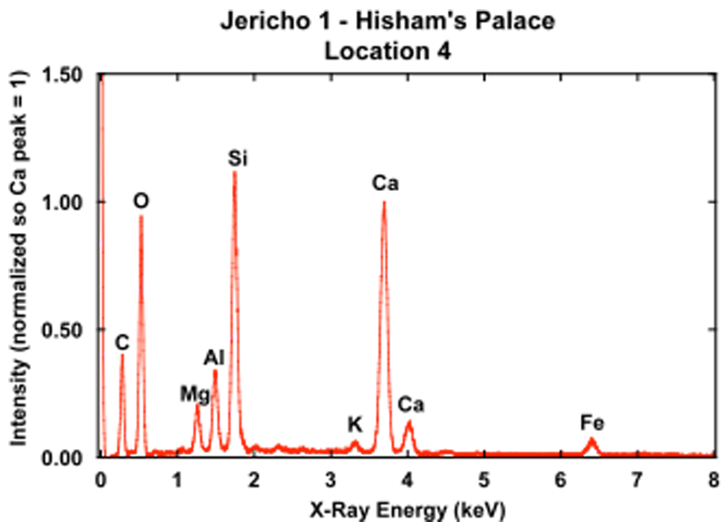
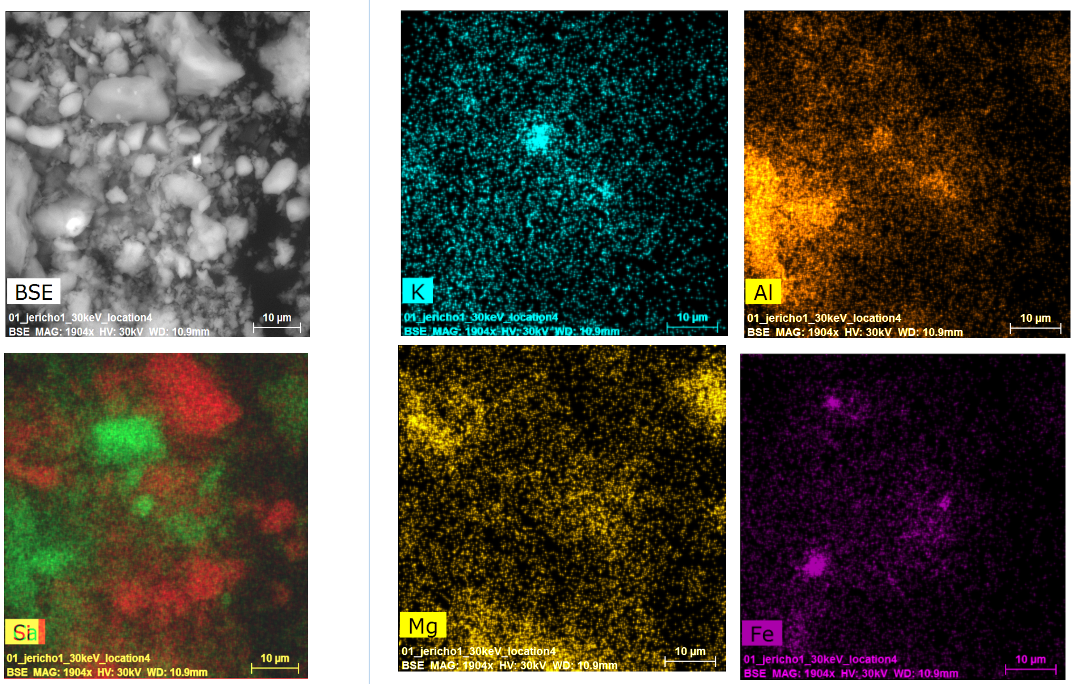


Figure 6: Jericho 1 - Location 4 EDX signals

Jericho 1- Location 4



Ca/Si composite map, with Si in green and Ca in red	The EDX data for metals: Mg, Al, and Fe & K

Image showing Jericho 1- Location 4 sample with Si/Ca composite map and the most significant elements in EDX

Figure 7: Jericho 1- Location 4 map

Jericho 1 - Location 4 EDX signals' in Figure 5 shows that Ca and Si dominate (excluding O and C), with significant Mg and Al, and traces of Fe, K, and S. Mg fraction is about one third of value from the same sample in different location 3.

The overall signal, as shown in the composite map in Figure 6, is dominated by Ca (Red) and Si (Green). Comparing the Al and Mg to the Ca/Si composite map suggests that the bulk of the Al signal originates from regions containing Si but not Mg (Suggesting Al-silicate clay such as Kaolonite). The Mg signal is weaker than Al in this location. Mg in the top right corresponds to Si, suggesting a Montmorillonite type of clay, but Mg in top left corresponds more with Ca. This may suggest small traces of dolomite (Ca/Mg CO_3) that might be found in this region. Fe corresponds to brightest spots in BSE image, suggesting Fe oxides. Concentrated K signal in the center of image corresponds to area with strong Si signal suggesting an Illite clay particle or feldspar. Regions of Si with no other metals are probably SiO_2 (quartz). Regions of Ca with no other metals are probably $CaCO_3$ (calcite or aragonite) particles.

Jericho 2- Location 2

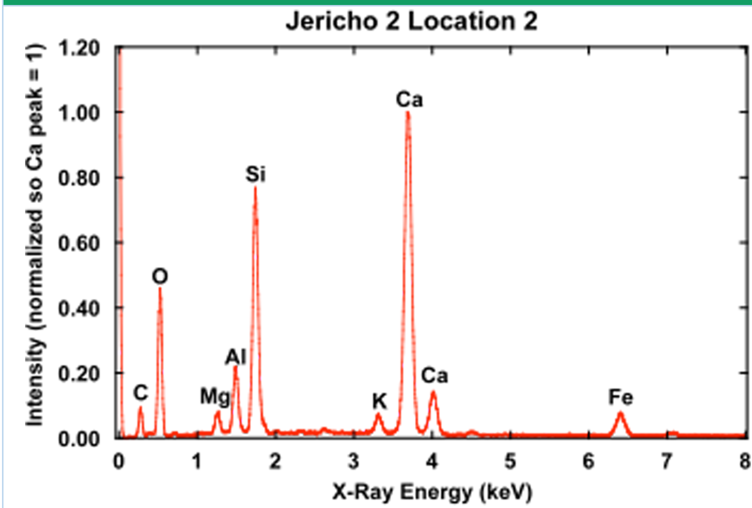
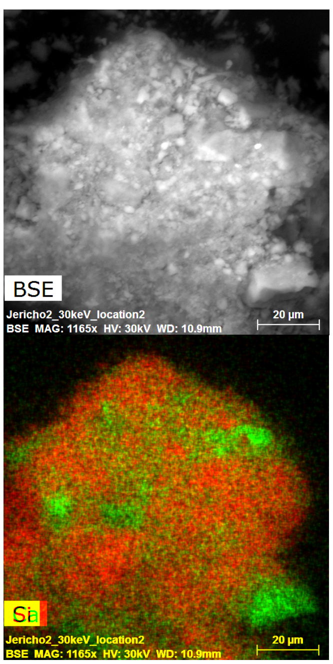
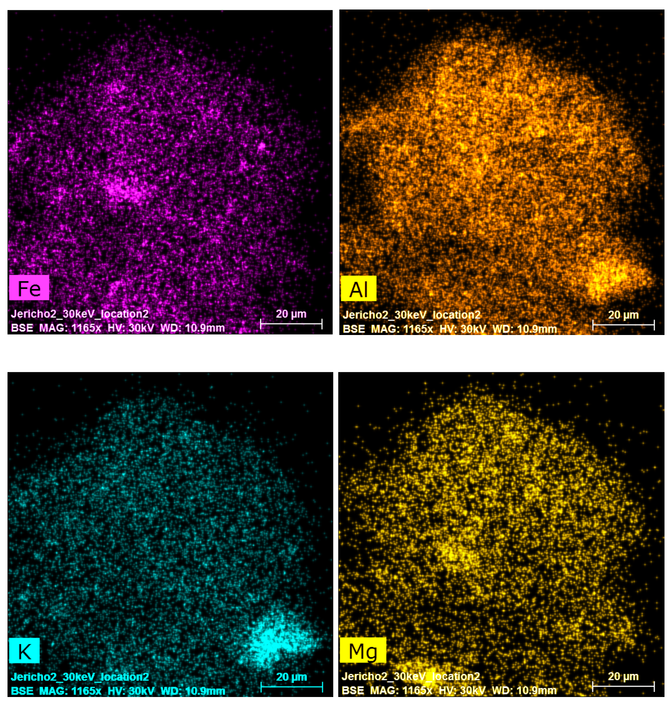


Figure 8: Jericho 2 location 2 EDX signal

Jericho 2- location 2



Ca/Si composite map, with Si in green and Ca in red



The EDX data for metals: Al, Mg, K & Fe

Image showing Jericho 2- Location 2 sample with Si/Ca composite map and the most significant elements in EDX

Figure 9: Jericho 2- Location 2 map

Figure 7, Jericho 2 EDX signals, shows that Ca and Si dominate (excluding O and C), with significant Al, and Mg, Fe, K traces. While in Figure 8, the images showing a comparison of trace element signals to Ca/Si composite seem to suggest trace elements are well distributed in the sample. It is difficult to see whether elements correspond more to Si or Ca. A strong Si signal in the lower right of Ca/Si composite corresponds to Al and K signals. This could be a large Illite particle or feldspar. Other regions of bright Si signal are present which suggest quartz particles.

Jericho 2- Plaster top

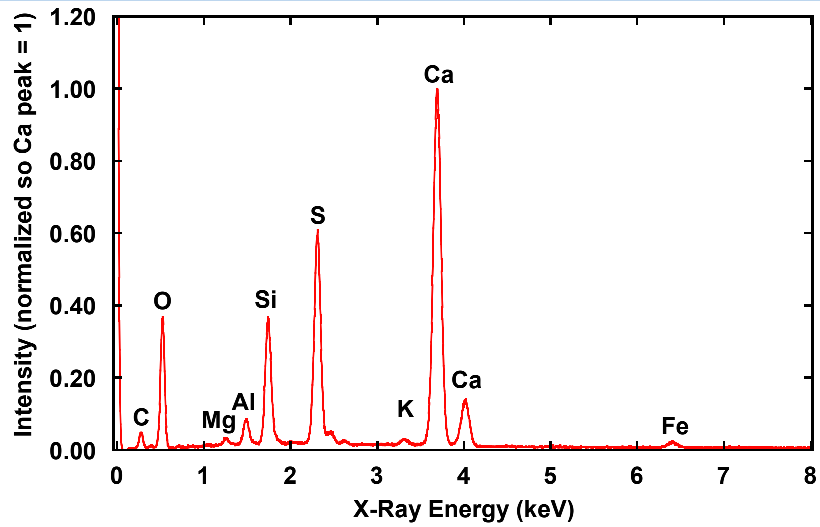
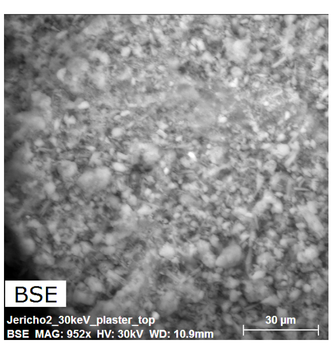
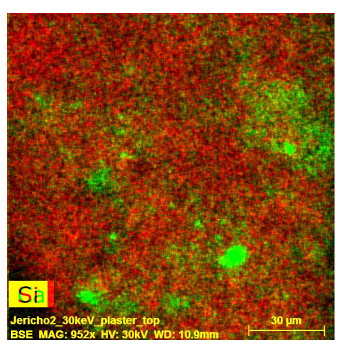


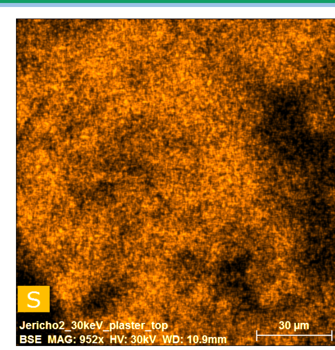
Figure 10: Jericho 2 EDX signal

Jericho 2 Plaster Top





Ca/Si composite map, with Si in green and Ca in red



The EDX data for metal S

Image showing Jericho 2- Plaster top sample with Si/Ca composite map and the most significant element in EDX

Figure 11: Jericho 2- Plaster top map

Figure 9, Jericho 2 EDX signals, shows that Ca and Si dominate (excluding O and C), with significant Al, and Mg, Fe, K, traces. Sulfur has the next strongest EDX signal after Ca. Furthermore, on comparing the Sulfur EDX map (right) in Figure 10 with a Ca/Si composite (center), the sulfur signal overlaps more with the Calcium signal. This could be evidence of a high concentration of calcium sulfate ($CaSO_4$). Hydrated calcium sulfate, also known as gypsum, is an alternative to calcite as an ingredient for plaster/mortar (i.e. gypsum plaster instead of lime plaster). Anhydrite, which is pure $CaSO_4$, is often found in calcite deposits and this could be another source of the sulfur signal.

Jericho 3 - Roof

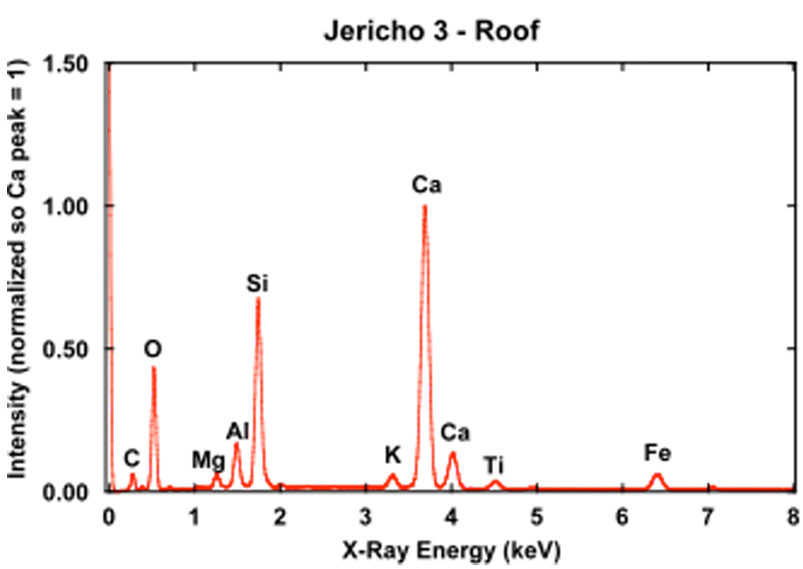
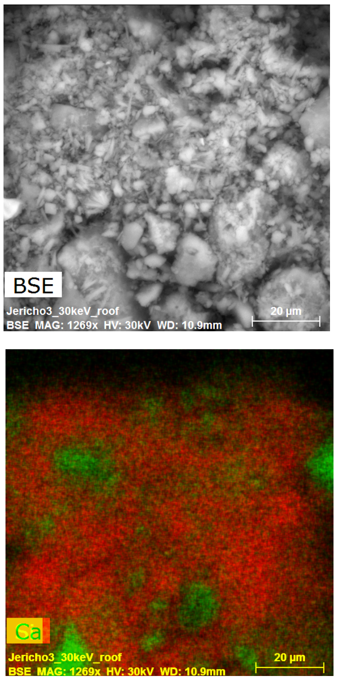
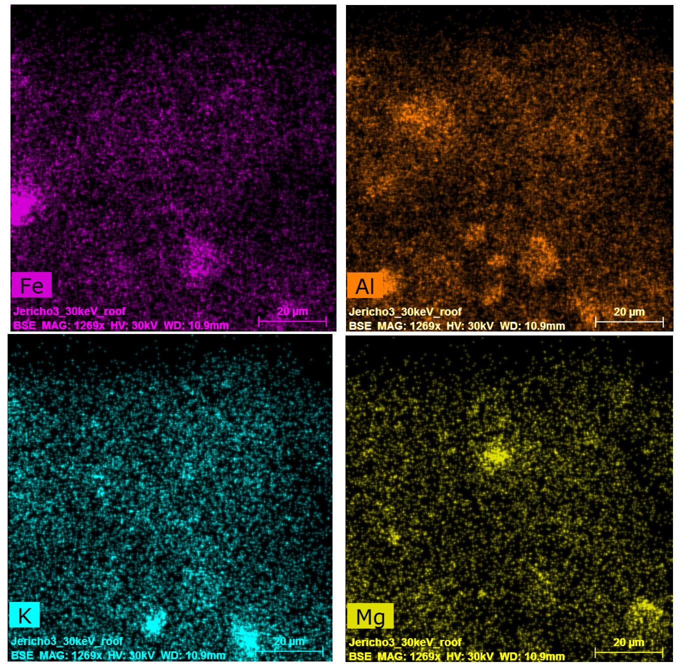


Figure 12: Jericho 3 roof EDX signal

Jericho 3- Roof



Ca/Si composite map, with Si in green and Ca in red



The EDX data for metals: Mg, Al, K and Fe

Image showing Jericho 3- Roof sample with Si/Ca composite map and the most significant elements in EDX

Figure 13: Jericho 3- Roof map

Figure 11, Jericho 3 EDX signals, shows that Ca and Si dominate (excluding O and C), with significant Al, and Mg, Fe, K, and Ti. Mg and Al fractions are smaller than those in the Jericho 1 sample. Low concentration of elements associated with clay would be consistent with a cement material.

Now looking at elemental distribution in Jericho 3 roof shown in Figure 12, Ca/Si composite map suggests mostly $CaCO_3$ by volume. The Al signal correlates with areas of Si signal, is a consistent trace of kaolinite clay. In the lower-center of the image there is some Al-Fe overlap and some Al-K overlap. Al-K overlap suggests clay from the Ilite group. The Al-Fe overlap is consistent with montmorillonite or chlorite clays. There does not seem to be much Mg-Si overlap in this image. Al-K overlap suggests clay from the Illite group. Al-Fe overlap is consistent with montmorillonite or chlorite clays. There doesn't seem to be much Mg-Si overlap in this image.

Jericho 3 – Roof Plaster Top

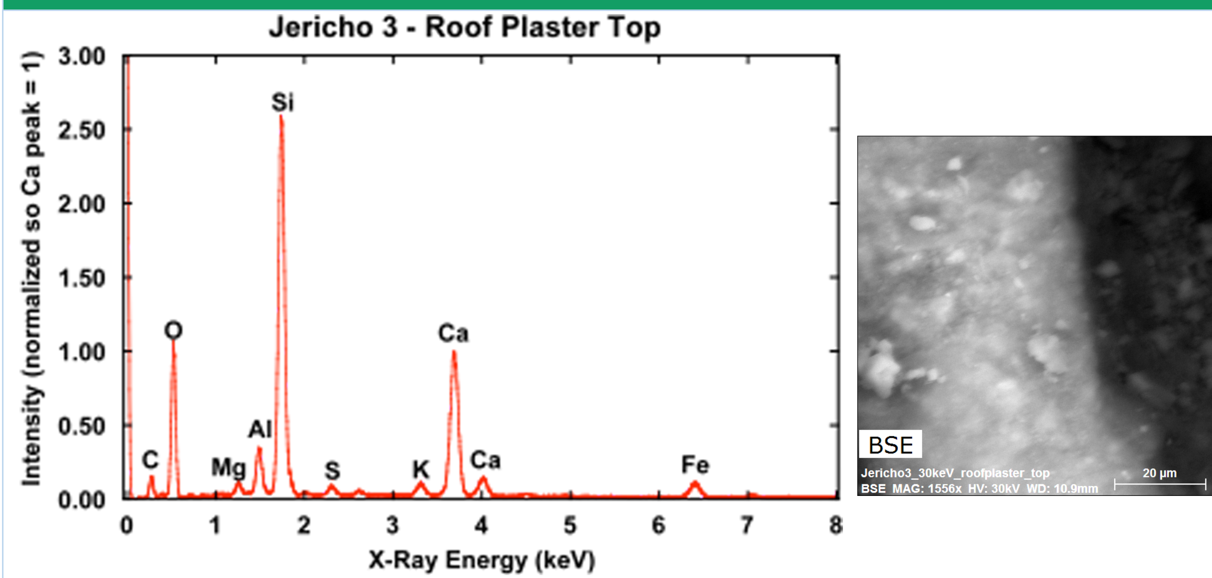


Figure 14: Jericho 3 roof plaster (top) EDX signal and general map

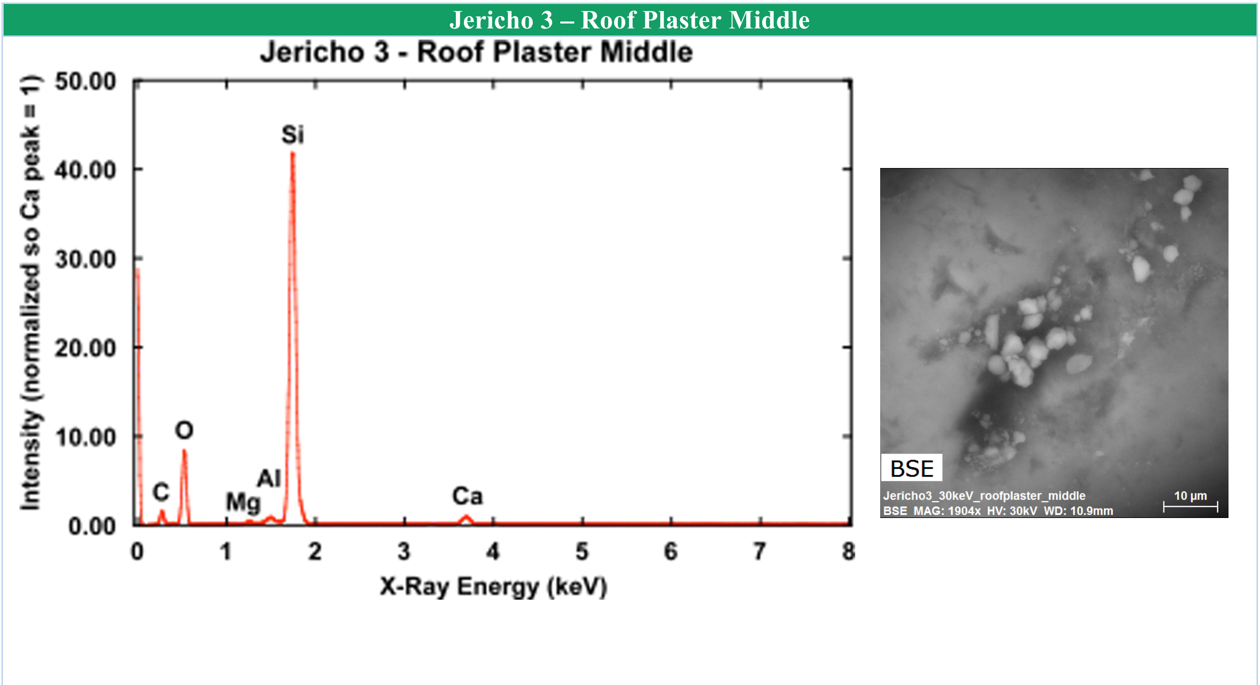


Figure 15: Jerciho 3 roof plaster (middle) EDX signal and general map

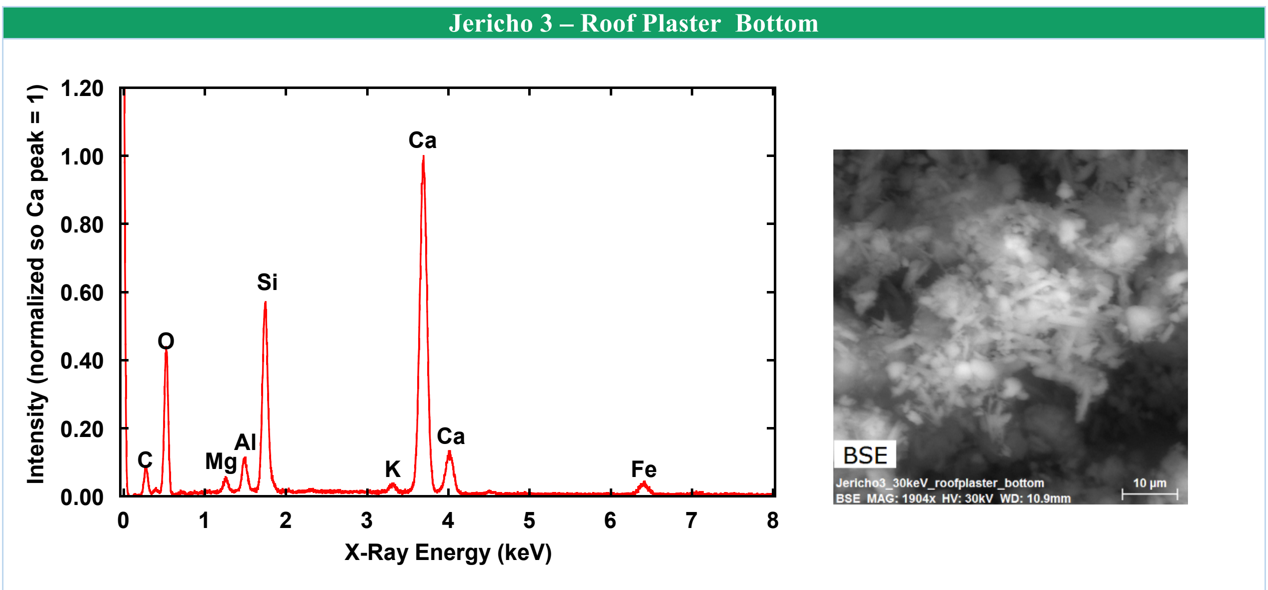


Figure 16: Jericho 3 roof plaster (bottom) EDX signal

Figure 14, Jericho 3 plaster top sample, shows that the smaple is dominated by Si. This is a result of a lot of quartz in the images this was taken from, with much smaller amounts of Ca-containing minerals and clays. Figure 15 shows that Si peak is over 40 times larger than Ca peak and Al peak in the plaster middle of Jercho 3 sample. It is likely that there was a large quartz particle imaged here. This image might not be a representative of the sample as a whole. Figure 16 shows that Ca and Si dominate the elemental peaks with traces of Mg, Al, K, Fe. This is consistent with lime plaster.

Jericho 4 - Plaster

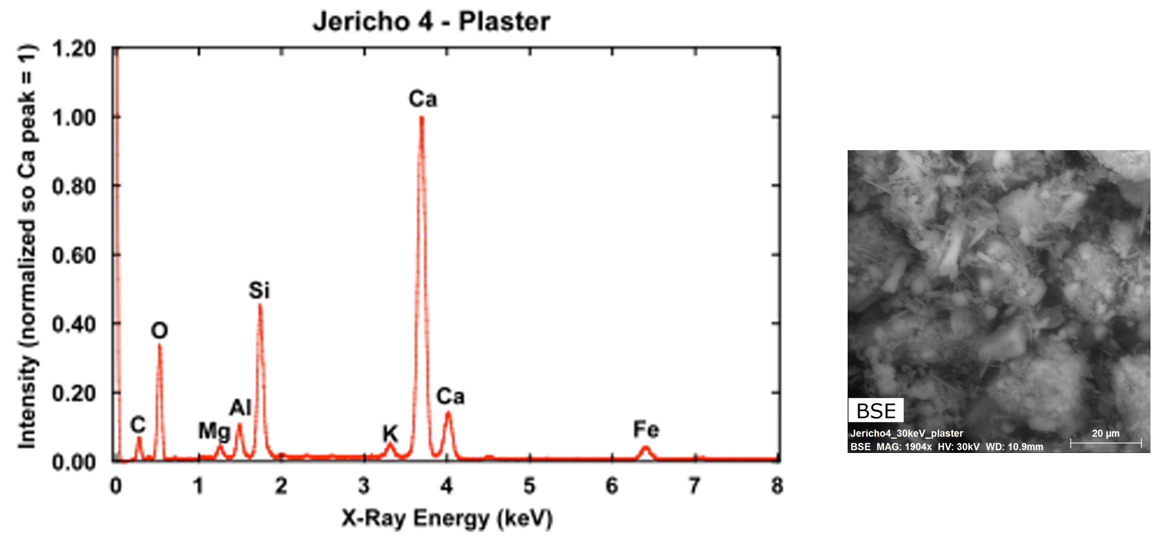


Figure 17: Jericho 4 plaster sample EDX signal and general map

Jericho 4- Mortar

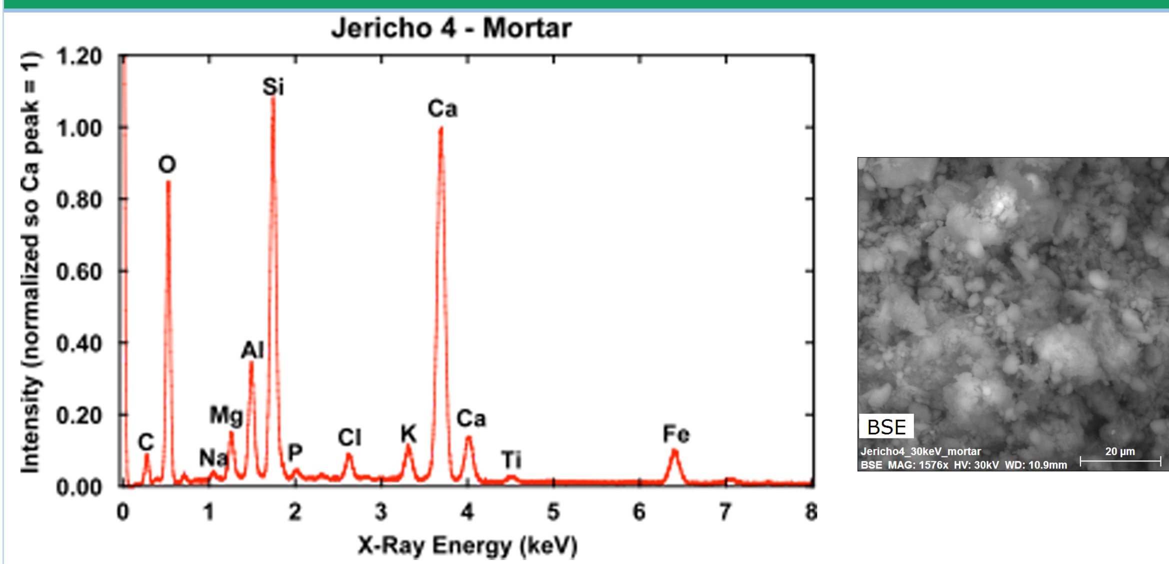


Figure 18: Jericho 4 mortar EDX signal and general map

Figure 17 shows that Ca and Si dominate, with traces of Mg, Al, K, and Fe. This is consistent with lime plaster. It has a similar composition with Jericho 3 roof plaster bottom, and both contain thin-shaped particles. Figure 18 shows that Ca and Si dominate the elemental peaks with significant Al and sizable traces of Mg, Cl, K, Fe. Small traces of Na, P, Ti. Jericho 4 mortar has a different recipe than the plaster of Jericho 4 with less lime, more dirt and quartz.

Jericho 5 - Brick

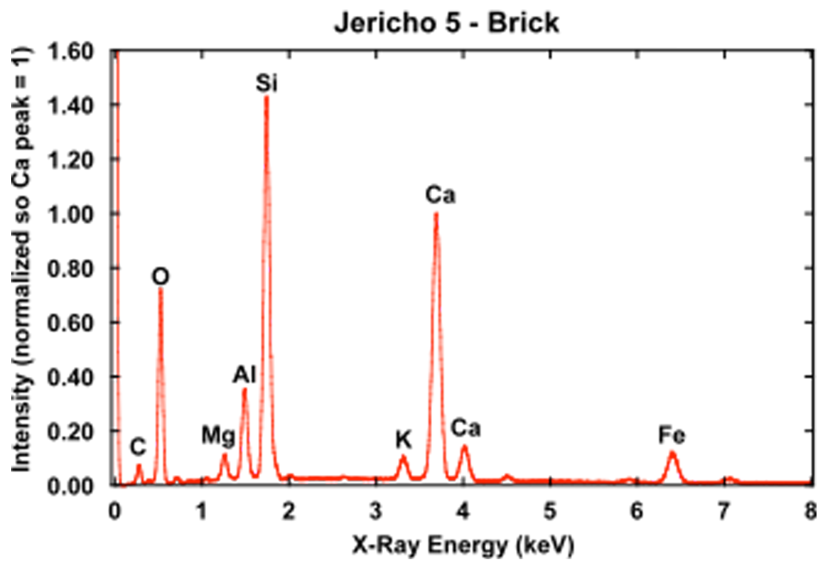
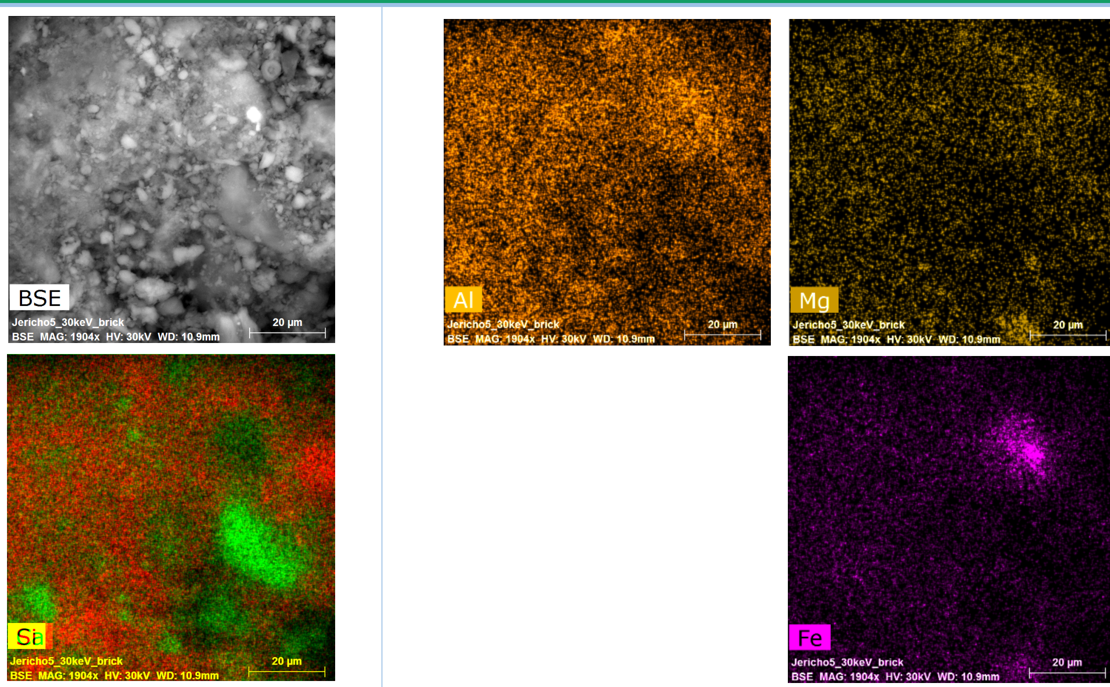


Figure 19: Jericho 5 Brick EDX signal

Jericho 5- Brick



Ca/Si composite map, with Si in green and Ca in red	The EDX data for metals: Mg, Al & Fe

Image showing Jericho 5-Brick sample with Si/Ca composite map and the most significant elements in EDX

Figure 20: Jericho 5-brick map

Figure 19 shows that Ca and Si dominate with significant Al and sizable traces of Mg, K, Fe. In Figure 20, comparison of Ca/Si in composite with trace elements suggests a mixture of calcite, quartz and clays. Al, Mg, and K (which is not shown) are well distributed throughout the sample. A bright Si signal on the right side and lower left do not overlap with trace metal signals, so probably there are quartz particles. Bright Fe signal in the upper right might be an Iron oxide particle.

Jericho 6– Exterior Plaster Top

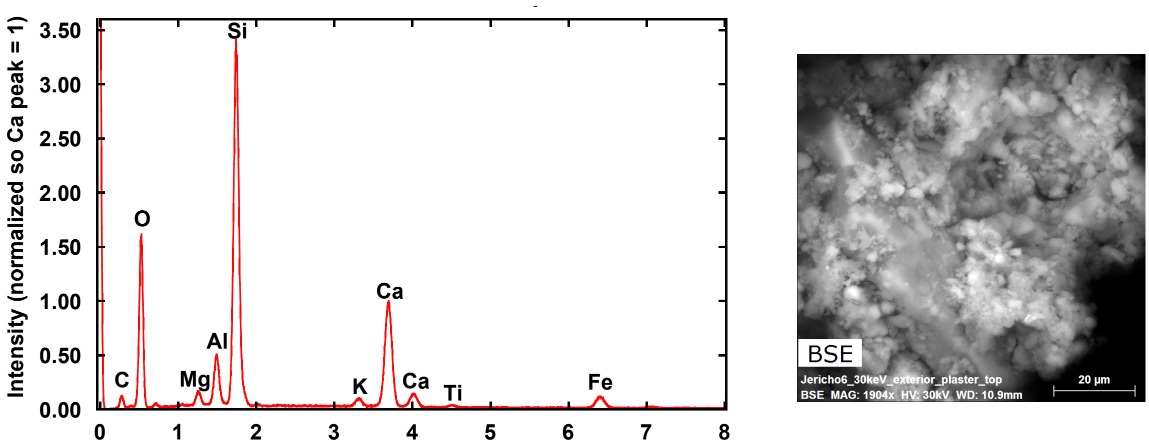


Figure 21: Jericho 6 exterior plaster top EDX signal

Jericho 6– Exterior Plaster Top

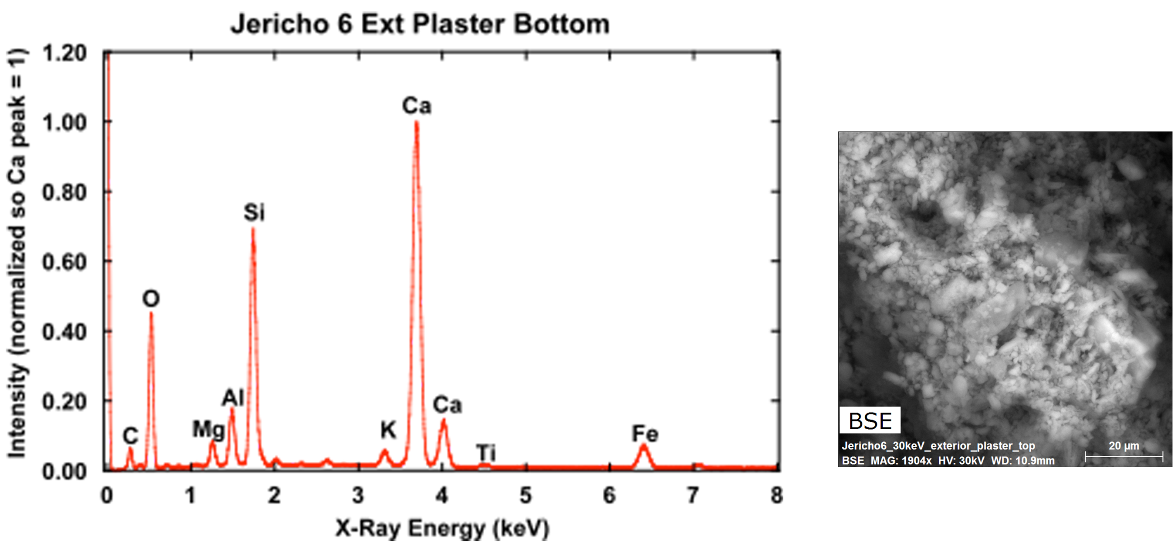


Figure 22: Exterior plaster (bottom) EDX signal and general map

Jericho 6– Interior Plaster

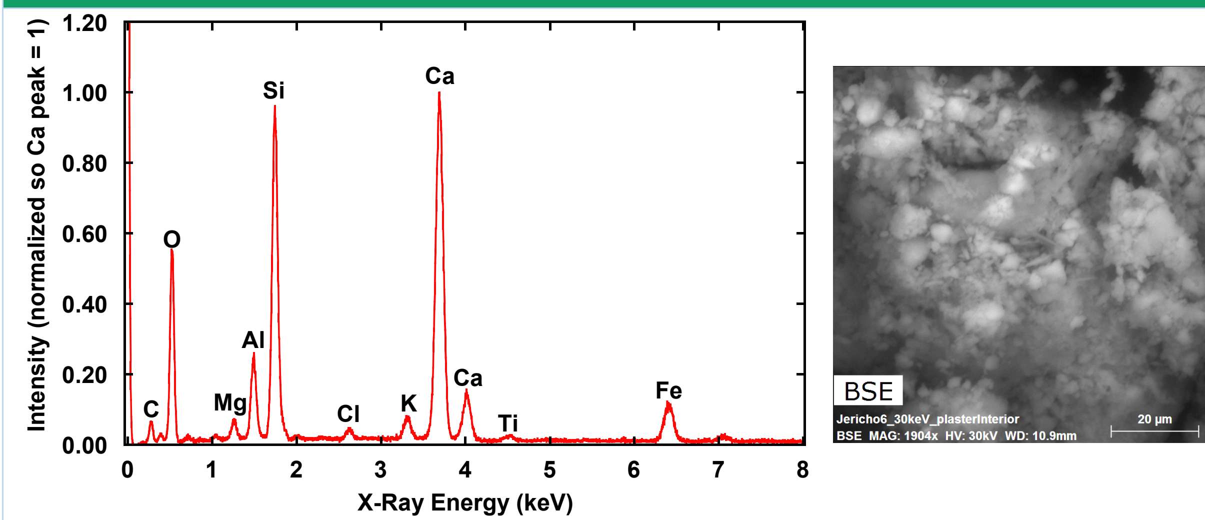


Figure 23: Jericho 6 interior plaster EDX signal and general map

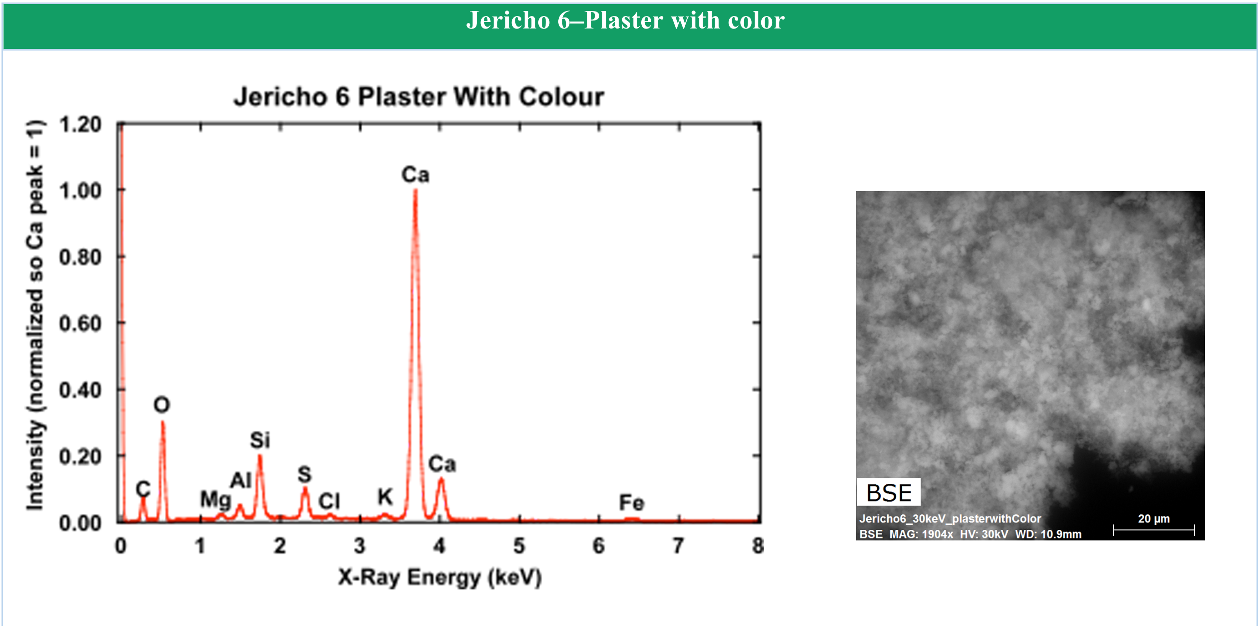


Figure 24: Jericho 6 plaster with color EDX signal and general map

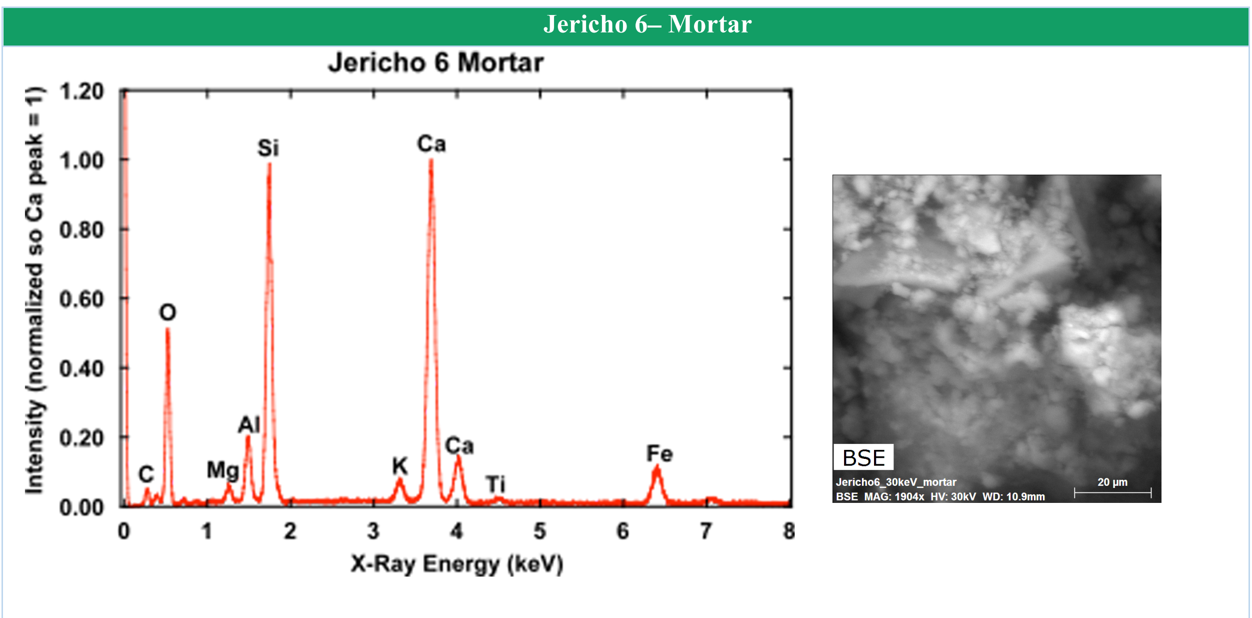


Figure 25: Jericho 6 mortar EDX signal and general map

Figure 21 shows that Si dominates in the Jericho 6 plaster (top layer) sample with significant Ca, Al, and traces of Mg, K, and Fe. The size of the Si peak suggests a lot of quartz in this field of view. Figure 22 shows that Ca and Si dominate in the plaster (bottom layer) of the Jericho 6 sample with Significant Al peak. Traces of Mg, K, and Fe also show in the sample.

Elemental composition is more consistent with other Jericho samples such as Jericho 2, or Jericho 3 roof plaster bottom. Figure 23 shows that Ca and Si elements dominate the interior plaster sample. Significant Al peak and traces of Mg, K, Fe, and a small amount of Cl and Ti are shown in the EDX signals. The Elemental composition of Jericho 6 interior plaster sample is similar to Jericho 4 mortar.

Figure 24 shows that Ca dominates in the sample of Jericho 6 plaster with color. Significant Si and S peaks also show. There are traces of Al, Mg, Cl, K, and Fe. The relative size of the Ca peak suggests high lime content, as the particle sizes in the image are much finer than in other Jericho samples. Additives for coloring might be the reason for the high Sulfur S in the sample.

Figure 25 shows the overall EDX signal for the mortar sample in Jericho 6. Ca and Si dominate the peaks with significant Al particles. There are traces of Mg, K, Fe, and a small amount of Ti. The elemental composition of Jericho 6 mortar sample is similar to Jericho 4 mortar and to Jericho 6 interior plaster, but without the trace of Cl.

Kardala

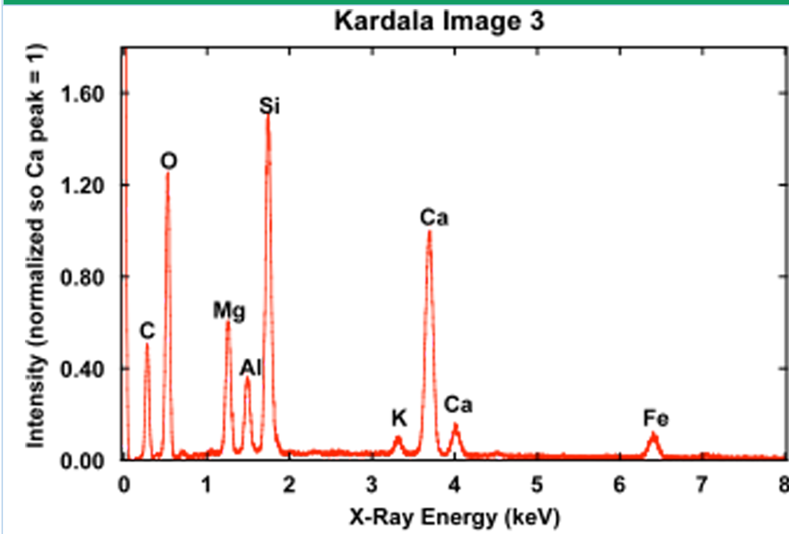
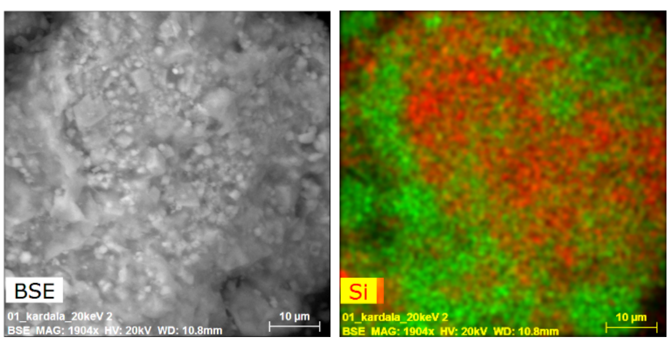
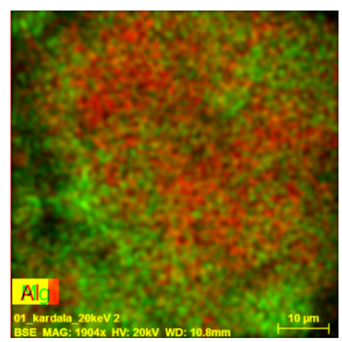


Figure 26: Kardala 1 EDX signal

Kardala





Ca / Si map. Ca red, Si green	Mg / Al map. Mg red, Al green.

Kardala sample with Si/Ca composite map and Mg/Al composite

Figure 27: Kardala map

Figure 26 shows the overall EDX signal of the Kardala sample. The Kardala sample is a raw soil. Of the heavier elements (i.e not C or O), Ca, Mg, and Si dominate, with significant Al, and traces of Fe, K, and S.

In the raw data, it was noted that the Mg distribution appeared to correlate with the Ca distribution, whereas the Al distribution appeared to track the Si distribution. To show this, both a Ca/Si composite, and an Mg/Al composite map have been produced for comparison as shown in Figure 27. Mg/Ca overlap suggests that this particle contains Dolomite $(Ca,Mg)CO_3$. Al/Si overlap suggests some Al-silicate clay (e.g. Kaolonite). Other trace elements appear distributed throughout the sample.

Kardala Grey Sand

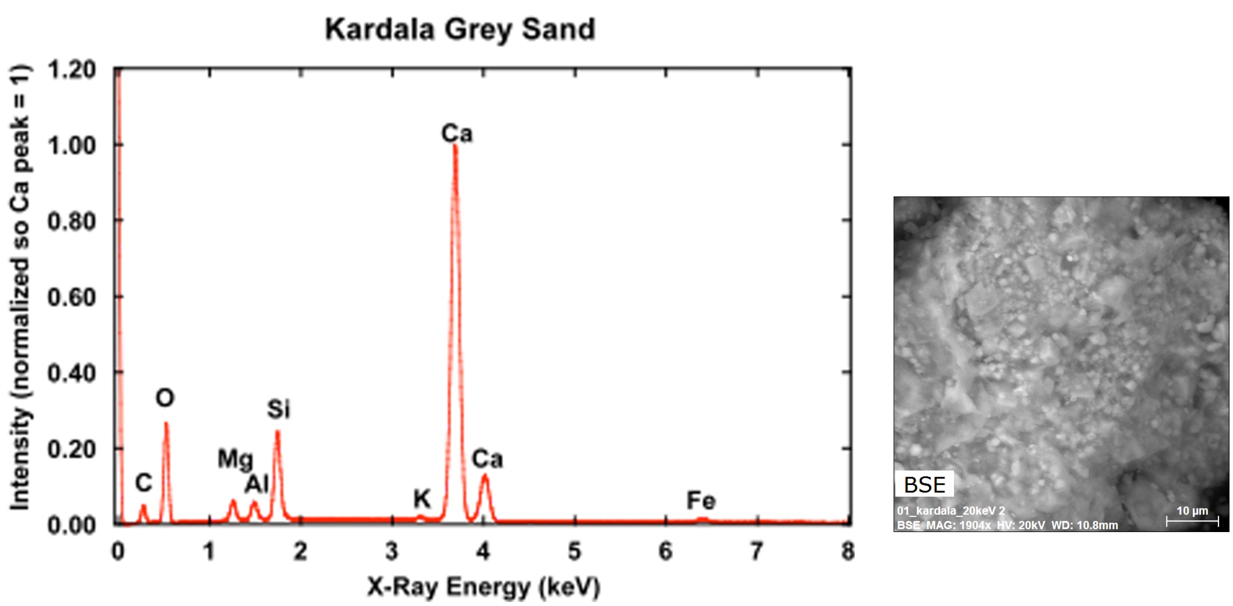


Figure 28: Kardala sample (grey sand) EDX signal and general map

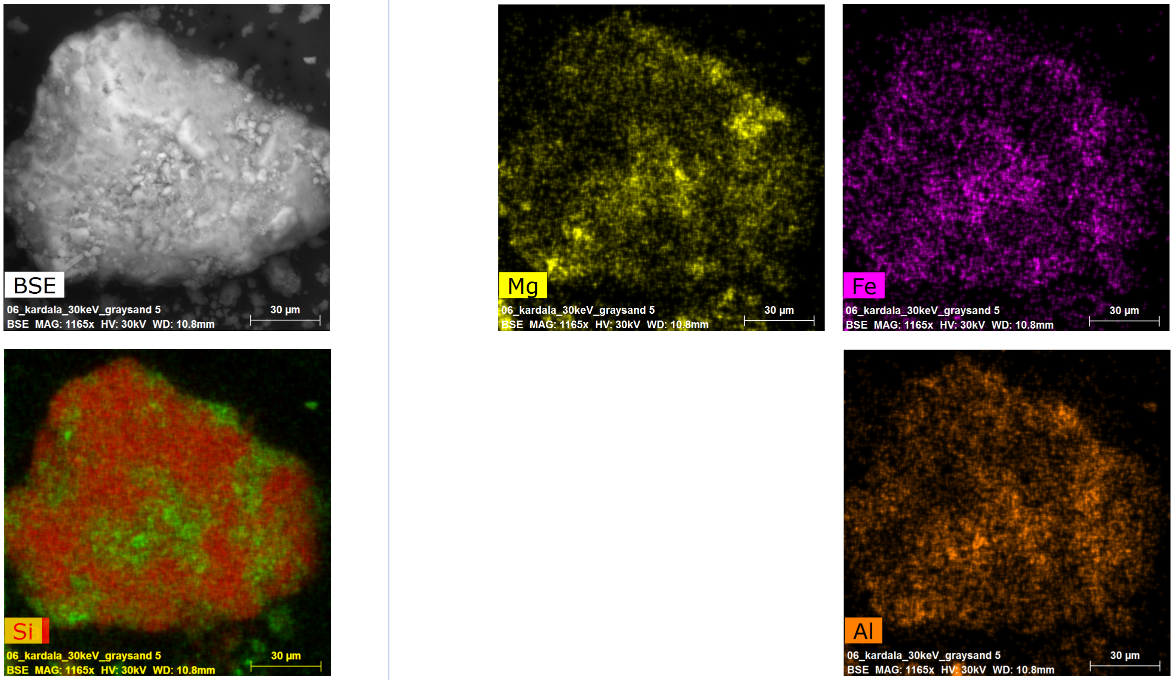
Kardala (grey sand)	
	
Ca/Si composite map, with Si in green and Ca in red	The EDX data for metals: Mg, Al, and Fe
Image showing Kardala raw soil sample with Si/Ca composite map and the most significant elements in EDX	

Figure 29: Kardala raw soil map

Figure 28 shows the overall EDX signal. Of the heavier elements (i.e not C or O), Ca dominates, with significant Si, and Mg, Al, and Fe and traces of K. A very high Ca signal would be consistent with highly calcite-rich sand. In Figure 29, Ca/Si composite image suggests that calcium carbonate makes up the bulk of the particle. EDX maps for trace elements Al, Mg, and Fe are shown on the right. The distribution of these elements appears to match the Si distribution more than the Ca distribution. This is consistent with imaging a large calcite particle with some Al/Mg/Fe clay such as Montmorillonite, and possibly some small quartz particles. Kardala grey sand may have been a useful source of calcite for lime plaster.

Ain Beida

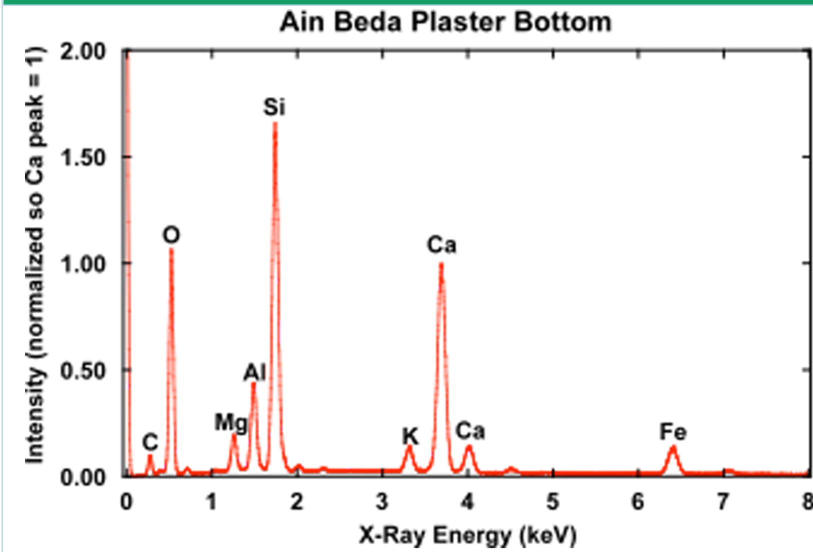
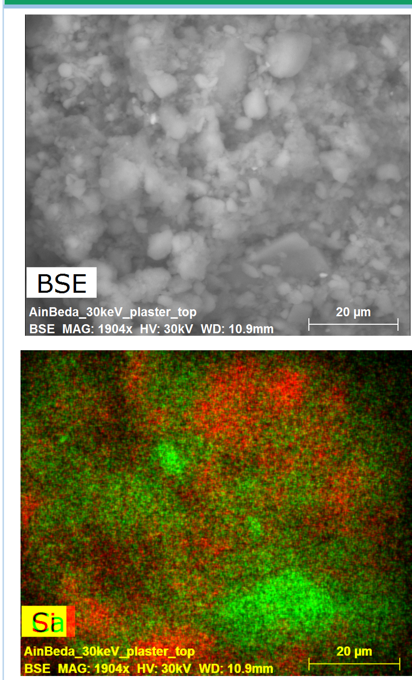
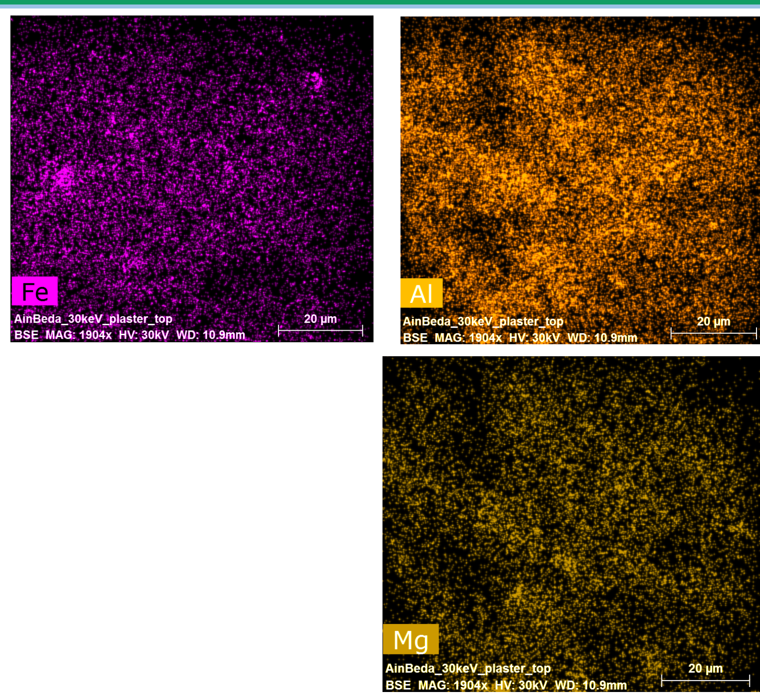


Figure 30: Ain Beida EDX signal and general map

Ain Beida



Ca/Si composite map, with Si in green and Ca in red



The EDX data for metals: Mg, Al, and Fe

***Image showing** Ain Beida-Brick sample with Si/Ca composite map and the most significant elements in EDX*

Figure 31: Ain Beida-Brick sample map

Figure 30 shows the overall EDX signal. Of the heavier elements, Si and Ca dominate with significant Al, and Mg, and Fe and traces of K. The Al signal is greater than Mg signal whereas, in Kardala soils, the Mg signal was greater than Al. In Figure 31, a comparison of trace element signals to Ca/Si composite suggests that trace elements are well distributed in the sample. It is difficult to realize whether elements correspond more to Si or Ca. A strong Si signal in the lower right of Ca/Si composite is not matched by other element signals. This is probably a quartz particle. Strong Ca signals in the lower center and upper center are not matched by other elements. These are probably calcite particles. In this Ain Beida sample, the Al/Mg EDX signal ratio is the opposite of that in the Kardala soils, and the Mg is not obviously mixed with the Ca as dolomite.

3.4.5. Significant Findings

All the bulk tests (tables 4 to 9) of particle size show silty soil to clayey soil, except for Jericho 1 that is coarse sandy loam. All samples are high in montmorillonite. Singh & Arbad (2014) mentioned that the properties of high silt/sand and low clay raw soil can be modified by adding dolomitic lime to enhance its cementing characteristics and that is why it is rare to see pure mud plasters in old buildings. High calcite content soils are used or to overcome the inadaptability of soil by adding some inorganic materials to earth mortar as calcite or slaked lime $Ca(OH)_2$. "By just mixing while preparing mud plaster, it has been observed that adding calcite or lime to clay masses significantly influences their shrinkage; materials such as calcite, silica, ferric oxide and lime act as cementing agents for the earthen mix; they form bridges between the clay micelles and thereby reduce swelling." (Singh & Arbad, 2014).

Lime plaster typically refers to the plaster made using lime, which has been produced, from either Calcium carbonate or Calcium hydroxide mixed with sand[14] and water. The plaster sets as the lime reacts with carbon dioxide in the air and reverts to Calcium carbonate. Small amounts of other material, e.g. horsehair or straw, may be added to give the plaster different properties. An alternative to lime plaster would be a mud plaster made by mixing sub-soil with sand and water. To avoid confusion here, the plaster that uses soil with added lime will be called "lime-earth plaster".

[14] There are many different types of sand. Quartz is normally abundant in sand, but sand can also contain some Feldspars (Ca/K Al-Silicates), Micas (K/Ca Al/Mg/Fe Silicates), and Calcium carbonate. Usually when we refer to Calcite $CaCO_3$ it means that lime was added or soil with rich calcite was used.

The high percentage of Calcite in all the samples suggests that plasters had lime content either as commercial lime, quarried limestone or used local calcite-rich soils like the Kardala soil sample.

Kardala Grey sand is rich in calcite ($CaCO_3$) and Kardala soil shows traces of Dolomite (Ca/Mg CO_3) particles with a small quantity of other minerals, mostly clays. Ain Beida and Kardala don't have identical morphological composition. Kardala grey sand's composition is close to Ain Beida's. From the data we obtained, it is not clear whether the people of Ain Beida used the soil from Kardala or from another local source with high calcite in the village of Ain Beida itself.

The Jericho 1 sample (Hisham's palace) contains calcite and silicate particles. Silicate particles are mostly imaged in EDX, whereas bulk methods suggest Jericho 1 composition of ~85% calcite. Silicate particles in Jericho 1 are rich in Mg compared to silicates from other Jericho samples. One possibility is that some Mg silicate, such as talc, had been added to the plaster for whitening; a common practice at that time.

The Jericho 2 plaster top contains a high sulfur concentration. Its sulfur distribution matches that of calcium, which suggests the presence of calcium sulfate. Possibly gypsum plaster or oil paint was used there. However, the other Jericho 2 samples have no sulfur. Therefore they are more likely to be lime earth plaster.

The Jericho 3 – 6 samples have similar elemental compositions with the ratio of Ca to other minerals varying from sample to sample. An interesting exception is that the elemental composition of Jericho 6 plaster with color is similar to that of Jericho 2 plaster top. The Ca content is very high suggesting a high lime content plaster. This suggests a lime wash rather than a lime plaster was used.

Samples of Jericho 2, 5, and 6 have similar clay composition with a high kaolinite percentage that suggests that they could have used local soil from Jericho or at least the same source.

Different layers of plasters in Jericho 6 samples suggest that the recipe of plaster has different layers, which are different in content. The first layer of the exterior plaster and the interior plaster are identical and they also match with the brick. The exterior layer has more sand content. The fine layer that has color in Jericho 6 and Jericho 2 has a high sulfur content that could be a gypsum layer or oil paint.

Results show that some plasters are earth based and some are lime based. In this study we referred to some plaster mixes as lime earth plasters where calcite was proven present. This could be a result of either adding gypsum or of a soil originally high in calcite, something that this study couldn't prove due to the lack of a variety of soil samples. Only one raw soil sample was studied and showed a high percentage of calcite. For the future, this should be studied more thoroughly.

Table 11 is a brief summary of the results obtained from all the bulk soil tests using the tests from AirSEM, EDX and XRD. The table shows the sample identity with the type of plaster used. The contents of the clay are shown in the table as; Montmorillonite, Illite, and Kaolinite. Though none of the tests obtained in the study show quantitative results of the compounds' compositions, simple mathematical methods were used to estimate the percentages of some significant samples. Different samples show different clay compositions which is a result of multiple soil sources or locations as shown in Figure 2 where the locations of the samples are from different soil zones.

Table 11: Main composition of the samples according to the previous tests

Sample ID	Type of plaster	Montmo rillonite	Illite	Kaolinite	Sand & Silt Fractions	Additives
Jericho 1	Lime plaster	82%	7%	11%	Calcite and Quartz, Feldspar	Talc
Jericho 2 plaster top	Gypsum plaster/ Paint					Sulfur presence maybe in a coloring paint, or lime wash
Jericho 2 Plaster (bottom & middle)	Lime earth plaster				Calcite, no quartz, Feldspar, & aragonite	
Jericho 6 plaster color	Paint/ Lime wash					Sulfur maybe as part of a coloring paint, or lime wash
Jericho 3 -6	Lime plaster				High calcite, quartz, feldspar (sanidine)	
Jericho 5 Brick		42%	15%	43%		
Jericho 6 Interior plaster		34%	14%	52%		
Kardala soil					Quartz, calcite	
kardala grey soil					Calcite, quartz, Dolomite	
Ain Beda bottom plaster		61%	17%	22%	Quartz, calcite	

Source: The author.

4. Conclusion

The results of this study are promising as it was proven that a thorough understanding of the plasters used in the buildings could be obtained through the nanocharacterization of the samples. However, the morphological composition analyzed from these tests are considered only the keystone for further research or field testing of the plasters in the Jordan Valley.

Plaster mixes vary according to the geographical locations in the Jordan Valley and the importance of the building: Despite the small size of the Jordan Valley, different geographical soil zones have been identified in previous studies as shown in Figure 2. Results show that plasters from different sites have different morphological compositions. Plaster mix's morphology is similar in the close locations (i.e. Jericho 2, 5, and 6 samples are similar while different from that of the Ain Beida sample which is in another geographical zone). However, there seems to be a difference in the plaster morphology according to the building's use or historical significance despite the geographical location. For instance, the Jericho 1 sample (located close to the locations of the Jericho 2, 5, 6 samples), a sample that was collected from what used to be a swimming pool of a historical Islamic palace, has a different composition than the other samples included in the study.

Hisham's palace exterior plaster had talc as an additive to the local soil: The sample of Hisham's palace (Jericho 1) is richer with Mg than other samples included in the study. This could be a result of Talc being added to the local soil that was used for plastering, whereas other samples in this study had been collected from simple houses where local people used only the resources they had.

The morphological composition of the plaster doesn't mean a plaster recipe: The soil used is different from one region to another. In a very limited region in the Jordan valley we were able to determine different soil zones and different morphologies of the soil. This affects the recipe of the plaster. Some EB plaster references standardize the ratios of sand, clay and silt. However, clay, sand and silt are only indications of the particle size and not morphological compositions.

The use of multiple nanotechnological tools helps in a more thorough understanding of the morphology of the plaster mix: Most of the data obtained from XRD technology in this study are qualitative. However, the use of multiple tools such as AirSEM, EDX and XRD together, in addition to the simpler bulk soil tests, allowed us to estimate some quantitative data. For instance, we were able to estimate the ratios of clay in some samples using the EDX elemental peak's signal. This kind of data was hard to obtain from XRD as there was a limitation of the quantitative data and even the qualitative data for the clay using the XRD. As usually described, quantitative analysis in XRD is harder to get and requires experience, patience, luck and skill.

Three Different plaster layers have been identified as being used to coat the building from the outside: Exterior plaster has three different layers; the top, middle, and the bottom layer. It was shown that the bottom layer's recipe is similar to the adobe recipe. It was also shown that the mortar samples are similar to those of the adobe and the interior sample. The plaster samples with color show high sulfur content.

5. Recommendations

More comprehensive quantitative studies should have been obtained in this study. As the XRD analyzer was only able to estimate some compositions qualitatively, an additional methodology of the simultaneous methods could have been the use of X-ray Fluoresence XRF as a complimentary technique for quantitative data. Limitations on the availability of XRF on campus hindered us from using this technique in this study.

Further research on soil samples from the Jordan valley should be conducted to be able to determine the local source of the soil used in plaster mixes. A match of the compositions of plaster samples with soil samples will enable us to determine the source of the soil for different zones. Despite the Jordan Valley area being relatively small, different soil zones were identified in previous studies. This means a difference in the ratios of clay content which is a main reason of the chemical behavior of the soil. For the future, this should be studied more thoroughly.

Some field studies should be conducted to determine the suitability of the plaster mixes using the data obtained in this study. The above data, along with the data obtained from the soil sources in the region, are enough of a base point for starting experiments with the soil. This can be translated into various recipes that can be tested by (1m* 1m) patches on the wall and observed until fully dried. The better recipe is the one with less cracks. Only then, a simple recipe could be generalized for local use. It could be as simple as certain ratios of clay, sand and silt that people could figure with low technology and low cost.

Further studies could be done with the determined recipes by adding some additives like lime, learning from other regions of the world where organic or inorganic additives are used, or even using other additives like the ones we found in the Jericho 1 sample. Tests could be done comparing different additives from different sustainability factors.

The methodology of determining the morphology of the soil should be looked at more thoroughly. Most of the standards of plaster mix in adobe manufacturer websites, studies or even earthen architectural firms, standardize the plaster mix according to its chemistry or particle size (clay, sand and soil) without a lot of consideration of the chemical morphology of the soil used. This study shows that what matters in the plaster mix are the elemental compositions that are revealed only by morphological tests. The lack of this kind of research is understandable as characterization tests are unfeasible and inaccessible by local people or even firms, especially in developing countries. However, this kind of research is worth some attention from governments, policy makers and international organizations in the regions where earthen buildings exist and can still be preserved and new buildings can be built learning from the old ones. What should be considered here is that what is standard as a plaster mix in France for instance, where CRAterre's research is based, can't be generalized in the Jordan valley where the soil might have different morphological composition. This is a very specialized kind of research that should be done carefully to achieve the optimal results.

Finally, the methodology of this study was applied to samples of the Jordan Valley. However, as mentioned earlier, this methodology could be applied in any region where ancient earthen buildings still exist. It is helpful for preserving the past and securing the future in a more sustainable way.

APPENDIX

Interview 1: Mr. Samih Zurba, July 31 2014

This was conducted with an inhabitant of a mud house in Jericho, Mr. Samih Zurba. He lives in a two-story house with his wife. The house is still in a good condition with some parts of it plastered with mud. The house was cool, though the temperature outside was above 35C (95 F), a typical temperature at that time of the year as we conducted the interview in July. The house was originally owned by Mr. Zurba's father who plastered it. Mr. Zurba witnessed the plastering and had no need to re-plaster it.

Arch Danna Masad (DM), co-owner of ShamsArd Design studio based in Ramallah city in Palestine and Lina Saleh (LS), co-owner of the same studio and the researcher of this thesis conducted the interview. Mr Samih Zurba (SZ) is in his seventies. The wife (SZ's wife) also showed up during the interview and had some comments. The interview was conducted on the second floor of their two-story mud house in Jericho in July 2014

LS: How old is the house?

SZ: in 1917, or actually in 1920

DM: Who built it?

SZ: My dad did

DM: alone in his hands?

SZ: No, there were workers.

DM: Some people used to build by having others to help.

SZ: Not in Jericho. In villages in the south and north yes.

LS: What family are you from?

SZ: Zurba. We are originally from Nablus city. We came here in 1910, we have been here for 114 years but they still call us Nabulsi people

LS: is the house built from adobe?

SZ: yes

DM: was it built originally as two floors or did it start as one?

SZ: the first floor was built in 1920 and the second one in 1930 or 1928.

LS: all is adobe?

SZ: This flooring was from wood. in 1954 we replaced the floor by concrete floor.

Are you from Jericho (asking us)?

LS: We are from Ramallah, but we have built some projects like a house and restaurant in Dyuk.

DM: we built using compressed earth blocks using a manual machine. But we are trying to build with adobe

SZ: Do you know what is adobe?

DM: Please tell us. We want to learn

SZ: soil, lime, straw used to be mixed with feet and put in moulds.

LS: Wooden moulds.

SZ: yes moulds. Look how the width of the wall is so large.

We didn't use to feel the hot climate because of this climate. Now, it is different, there is humidity. There are no trees or water. So we feel the hot weather

LS: Is this house cooler or hotter in summer?

SZ: It is colder than stone houses. But it used to be better because of the fountains in the streets and the trees and no crowded buildings.

DM: there was nice breeze

SZ: Nowadays water runs in pipes. They (meaning the government) sell us the water. They took it from canals and make us pay for it. Where is the justice? They make us pay taxes. We used to pay 3 shekels in the year for water for gardening, before it was 1, at the jordanians time it was pennies. Nowadays they take for pumping. Why do you make us pay 3 shekels for the canal? They take from me 1400 shekels for pumping. What do you want to ask?

DM: What were the dimensions of the mould?

SZ: Rectangle

DM: And the thickness? 10 cm?

SZ: No. 15 cm. length almost 20*30 or 40. 20 and 30

DM: do you remember how they used to build with it?

SZ: Normally. The same as conventional brick. One brick next to the other and then the other one in the middle…. and then plastering. The plaster is mud. Not cement.

LS: yes tell us about the plaster? How was it mixed?

SZ: exactly the same as the bricks but with no straw, only earth and lime

LS: was the plaster only one layer in the exterior?

SZ: yes. Only one.

DM: is this plaster cement or the original plaster?

SZ: this is cement. We replaced it with cement

DM: how long did the old one use to stay?

SZ: None. Unless there was a reason. Like if a child has damaged it

LS: Did you use to replaster every year?

SZ: No.

LS: Did it use to crack? and how were the cracks?

SZ: It depends on the weather that year. I ll show you the original one in the balcony at the back. Let me show you.

LS: Did you use to color it?

SZ: Yes if you like. Do you see the thickness? And the mortar?

DM; was the mortar the same mix?

SZ: yes

DM: ill take a photo for this. is the roof timber?

LS: how was the roofing? Were tiles for the richer?

SZ: only timber or (Qasab). French tiling also was used. This tiling here is French. I will also show you the roof of the room at the street side.

LS: did it matter when to build or to plaster

SZ: the construction has no time

DM: is there anything between the tile and the timber. Does is it leak water? Did you ever maintain the roof?

SZ: none at all.

DM: is there access to there?

SZ: YES. You know the age for the houses is 50 years. Do you know what is the age for mud houses?

LS: Thousands?

SZ: 200 years. This tile is from 1950. The one downstairs is since 1920.

LS: Did they use to polish the tile?

SZ: it is locally made in Nablus.

LS: why does it look shiny more than new tiles?

SZ's wife: maybe from the manufacturing in the beginning, it was shiny.

DM: do you know of any other people who live in mud houses in Jericho?

SZ: …… too few too few. There was one here which was demolished and bank of Palestine was built instead. Another one that is close to Red Cross and to the graveyards is still inhabitable. Jawad Dajani has demolished his house near the cinema. Maybe you will find only 3- 4 houses.

DM: there is another one in downtown center of Jericho. The 2nd floor looks like mud

SZ: Jamil Sabri Khalaf. The sons of Jamil Sabri Khalaf. The second floor only. This house is abandoned.

DM: There is wood there. This is another technique?

SZ: No. The same. ill show you the timber here in the roof.

DM: it looks like there is timber in the walls too

SZ: just to reinforce the walls afterwards. Only the roof is timber, because it is old, like 60 or 70 years.

DM: in plastering... in the Arabic plastering they used a roller for the roof, it is like a round stone. Nowadays, they use ……..

SZ: You mean here?

DM: no I know here the roof is tiling

SZ: But ill show you the room downstairs which roof is still mud. Above the timber is mud.

DM: Is it still the same? or did you renew it

SZ: nothing. There was an oven that I demolished. There were other two rooms that I demolished. When the guy wanted to demolish it. He said it is harder than stone houses.

LS: how was the foundation made?

SZ: easy. Mud mixed with stone. They used to steal from Hisham's Palace and laid it in the foundation. When I was demolishing the two rooms here they found two stones.

DM: did they use to dig a tunnel or only under the walls?

SZ: All under the house. And for the layout of the house

DM: What is the layout of the house?

SZ: Three bedrooms.

LS: How did you reach to the roof for maintenance? is it accessible?

SZ: Yes. But it is dusty.

DM: Ok I will only take a picture. May I?

SZ's wife: Yes feel free. But watch out!!!

Table moved and the door that accesses to the attic/ the roof opens.

DM: I can see clearly. i don't have to get inside.

SZ: You need a chair to reach also.

SZ's wife: I can move the pots for you so you can walk inside.

DM: No need. I don't want to make a mess for you

(Door closed and table moved again).

DM: It is hot today.

LS: Can we go downstairs to see the store (the mud room)?

SZ: Yes. I want to show it to you from down and up?

DM: Did they use to build the walls as inclined?

SZ: No

DM: French tiling?

SZ: All was French. Not like nowadays.

SZ: Israelis buy the tile for 20 shekels and install it in houses and claim it is theirs…I have sold the tile to a palestinian merchant for 1 shekels. Who knows if he sold them to the Israelis!

LS: What is the thickness of the wall?

(Bringing a scale)

SZ: 50 centimeters.

DM: After drawing the layout of the house. Is this the layout of the house?

SZ: This floor was the court in the 60s and we used to live downstairs

DM: Did the municipality ever visited you or any official …

LS: If you decide to demolish the house. Are there any rules to prevent you?

SZ: No one cares.

DM: Don't demolish it.

SZ: As long as I am alive no. I don't about when I pass away.

DM: Do you know of any people who worked in this field?

SZ: There is no one specifically. Generally you have to see the elders, older than 70 years. There is a grocer called Nasser Aziz Albarham. Near al-Walaji grocery (Abu Saleh). Abbas Zgahri's bakery. You should ask Nasser about old people who used to work with this. I am sure he will know.

DM: Thank you a lot.

LS: Thank you a lot.

SZ: I will show you the room downstairs.

SZ's wife: don't take a photo of us. We are too old.

SZ: Here is the room. Do you want to see the roof? The entire perimeter here in this neighborhood was of mud houses. You see the wood it is all covered by mud.

DM: No straw?

SZ: No, only timber and mud.

DM: We wanted to take samples if possible. do you know if there is poured cement at all above the mud?

SZ: There is no cement at all.

DM: We want to take some of the plaster.

SZ: There is no plaster. This is only roof from mud and timber. It is hard for you to take from here. it is high. Let's go to the neighbor's house.it is also mud.

DM: You mean the roof is not plastered?

SZ: No no, it is only mud

Sample of mortar was taken from the other house (Mariam's house) right across the street.

DM: Can we ask for a ladder from your neighbors so we take a sample also from you room?

Neighbor: are you from preservation institution?

LS: Not really.

Neighbor: There is an architect Usama Hamdan who builds from adobe here in Jericho.

DM: Thank you a lot.

Interview 2: Mrs. Maitha Sawafta, August 3rd 2015

This interview was conducted by Danna Masa (DM), Lina Saleh (LS) and Yaqoub Sawafta (YS) and the interviewee is called Maitha Sawafta (MS). She looks to be in her late eighties. The interview was conducted in Bardala village in the Jordan Valley in their small concrete room.

YS: We know that you witnessed the period when people used to build with mud. so we want to ask you some questions.

MS: Shaar houses (Term used for tents) ??

YS: No mud houses. So you witnessed both ways of buildings

MS: We dig for the foundations. We bring the soil, we seive it, then the tibin, the stones.

YS: ok after we build, How do you plaster?

DM: Oh wait. You have already built. Let's know what is the best soil. Where do you get the soil from?

MS: From here. The red soil is the best. it is stronger than the black. but if there is red soil yes if no then black . We mix it with straw

DM: you don't lay stones?

LS: yes she said they did

MS: yes stones with mud which is already mixed, not dry soil. it is mixed with straw and water

YS: what is the mixture?

MS: we mix it by our hands until it become strong. It becomes like cement. Very strong. Now, After we build the walls. We want to build the roof. So we need timber. Where to get it from? They call it zor. It is at the shree'a. We go to mountains, cut wood and bring timber and lay it. Lay pebbles (sarar) above the timber. Between them a layer of … So we mix the soil with straw and then lay them over the small stones.

YS: Did you mix the stones with mud?

MS: No. You don't mix. You just lay a layer to prevent stones from falling. Or you put bamboo.

YS: yes some people used bamboo. You didn't use lime?

MS: Wait. After we built, we put mud and it looks nice and we want to live. So we want to cover it now. There is white soil, not lime, it is soil. We bring it and put it.

DM: where do you get it from?

MS: From here.

DM: here from the village

MS: there was before. Now everything changed. People mix today

YS: So this is a special soil. Why is it special? It doesn't crack?...

MS: yes. We just put it (nrshuko), we bring cement or lime and mix with water until it becomes white.

LS: So you used to mix the white soil with lime?

MS: no layer by layer. First layer is the white soil, then the lime with water. And for (the mastaba), the flooring, if you have money you would bring sand if not just red soil. Soil from the top of the mountain,

DM: and for the flooring you used the same white soil?

MS: No, not necessarily. But the perimeter of the house is important. So it depends on your budget, if there is white soil it is good. If not and if you have money you would buy lime or cement. You would buy and lay it, if not just the white soil.

YS: My mom had laid a floor of mud in our house. She used to broom it, but the soil would never ... How did it become so strong like cement?

MS's son: because of walking over the flooring

MS: No. This is because of the straw mixed with mud.

YS: So how often do you plaster the walls?

MS: we don't replaster with mud. Only lime. Every one or two years.

DM: Lime is NOT only paint. It looks like lime stregthens the..

MS: Lime is strong. It sticks. It becomes white and strong (beshed), unlike soil which falls in one year.

MS's husband: Because there is straw under it so it sticks.

MS: yes lime gets strong

MS's son: this building that you built here in the village is amazing

YS: it was not me. The architects have designed it

MS's son: it is so cool inside.

M:Halfa, se'ed, we weave them for carpets over the flooring. it grows near the water in Al-Maleh village.

LS: Where do we find halfa now?

DM: next to water

MS's husband: do you know where?

MS: Next to Al-Tamimi house.

YS: I am from this village. Maybe Ibrahim my nephew knows

MS: Ibrahim is your nephew? He will tell you where to get it.

YS: Yes I am from Bardala. I am not a foreigner.

MS: I knew you are from here. I know his mother

YS: I am old now that is why

MS's husband: I should have told you who is this

MS: I knew you are a country boy. And both of you are like my daughters

DM: So what do you do with halfa? do you dry it? i want to learn

YS: She wants to learn

MS: It is so hard. No one knows now. And it takes a lot of time. It took a month or two. You won't be able to. Before we used to help each other and learn from each other. All the girls would gather and help their mothers.

DM: Is there a season for halfa to be ….?

MS: Now no. There is nothing

DM: No I mean earlier. In what time of the year?

M: In the winter.

YS: it needs water

M: yes there used to be water. Now there is no water

M's husband: cows used to eat the halfa

MS: No it all depends on water. There used to be wtaer in winter and summer. Next to the water fountains. Water should always be there.

YS: I dont know it. Maybe there is in the Hamma. Because there is still water

MS: Your mother knew it.

YS: And is the carpet weaved from Halfa strong?

MS: Yes if the woman is clever, it would be strong, and would stay one or two years. They used se'er for ropes also.

YS: Is there still se'er here in Bardala

MS: No. We also used to make pottery. We mixed it with coloring (red color from the tree).

MS's husband: They lied to me. Her father told me she was 20 years younger.

MS: I have 6 kids. I used to go to the farms, milk the cows…. It was a lot of work. Now they are old and successful. Thanks God.

YS: now, the plastering? Did it use to last long?

MS: Every year. The lime. For outside and inside. Without straw it doesn't work.

If you have money you use cement. We used to bring the white soil with buckets from the mountain.

LS: When did people stop building with earth? Is this room from earth?

MS: When the Israelis took over the land. Many people immigrated to Jordan. No this is concrete. Only last year we demolished the earth room.

LS: Did you also leave to Jordan?

MS: Yes, but we came back. But my family stayed there. All my family is there now.

YS: ok I will ask my nephew about the halfa.

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