

**Ministry of Higher Education and
Scientific Research
University of Babylon
College of Science
Department of Applied Geology**



**Chemical, Mineral and Engineering
Evaluation of the Ancient Building Materials
at the Archaeological Site of Dilbat, South of
Hilla**

**A Thesis Submitted to the University of Babylon, College of
Science, Department Applied Geology for the Fulfillment of
the Requirements of Master Degree in Geology**

By

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَقُلْ أَعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ

وَالْمُؤْمِنُونَ

صدق الله العظيم

سورة التوبة (الآية ١٠٥)

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I thank God for giving me the strength to complete what I aspire to:

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Supervisor Certification

We certified that this thesis entitled "**Chemical, Mineral and Engineering Evaluation of the Ancient Building Materials at the Archaeological Site of Dilbat, South of Hilla**" and have examined the student (**Ghadeer Ahmed Abed**) in its content and that were prepared under my supervision at the College of science as a partial fulfillment for the degree of Master in Geology University of Babylon.

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Dedication

To My father and mother with all love and gratitude.

To My dear fiance saif.

To My dear supervisors , Prof.Dr. Jwad Kadhum Manii , To Prof.Dr. Jaffar Hussain Ali Alzubaydi.

To All my loyal friends.

To Everyone who supported me in these difficult times.

Ghadeer Ahmed Abed

Summary

Archeology is one of the most important cultural landmarks left to us by previous civilizations and nations, as it reflects their culture, religious beliefs and general daily life. This research aims to study the city of Delbat, or what is known locally as Tel Daylam, which is located in the southern part of Babylon Governorate within the Kifl district, and is considered one of the most important archaeological areas because it contains the temple of the god Urash, which dates back to the Middle Babylonian period 1500-600 BC. This temple represents an important part of the religious beliefs of the inhabitants of ancient Babylon.

Ten samples from separate areas of the temple. These samples included 3 brick samples were analyzed, 3 mud bricks samples, and 4 clay samples. The results showed that the rate of each of the chlorides Cl is 0.9%, the organic materials 2.65%, TDS 6.62% , carbonate CO_3 24.96% and sulfate SO_4 1.33%, which is relatively close to the ratios found in bricks at the present time.

X-ray fluorescence (XRF) analysis was conducted for all samples of bricks, mud bricks and clay, and the results showed high percentages of each of the elements Ferrum (Fe), Cobalt (Co), Nickel (Ni), and strontium (Sr).

Also, X-ray diffraction (XRD) analysis was conducted for the three brick samples and one samples of mud bricks only. The results showed mainly quartz, feldspar and calcite minerals. It was found that the bricks have good physical and engineering properties due to the quartz content and feldspar.

As for the physical and engineering tests, they were conducted for ten samples of bricks. The physical tests included the density test, which was at the rate 1.09 gm/cm^3 , the porosity at the rate 23.06% and the water absorption at the rate 20.86%. As for the engineering tests, they were carried out using an ultrasonic device by measuring the speed of V_p waves. The compressibility

of the bricks was at a rate 5.10 N/mm^2 and this is due to the exposure of the bricks for weathering factors for long periods of time.

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Chapter One

Introduction

1.1 Preface

Settlement in ancient Mesopotamia was characterized by huge cities in which the greatest kings and large numbers of people lived, as well as the priests of the temples and the gods that those people worshipped. From the end of the Uruk era until the end of the Old Babylonian period 1500-3500 BC. The cultural landmarks in Mesopotamia were very impressive patterns that amazed archaeologists and researchers in terms of the huge advanced architecture of temples, buildings and palaces with impressive artistic forms and administrative organization. Through these remaining material effects from previous times, an image of political and social institutions and their role in managing society at that time was formed, as they maintained the cohesion of society within cities among the various members of society. Without these institutions, society is divided and conflicts that are difficult to solve (Ur, 2013).

There were different patterns of settlement in Mesopotamia, while other societies in many parts of the world lived at the village level, which is defined by the frequent division of settlement. The development of this society was not an accident, but rather the outcome of many lives, political, social and economic experiences that these societies went through. With the development of cities, areas arose that had a special significance in the life of society, which had a connection with gods, kings and other events. Therefore, many major cities during the third and fourth millennium BC are still being rebuilt, restored, and settled by residents (Ur, 2013).

Population density and the construction of cities were closely related to the existence of surface water sources in the sedimentary plain, such as the Tigris and Euphrates rivers and lakes (Ur, 2013). Ancient Mesopotamia can be illustrated in Figure 1-1

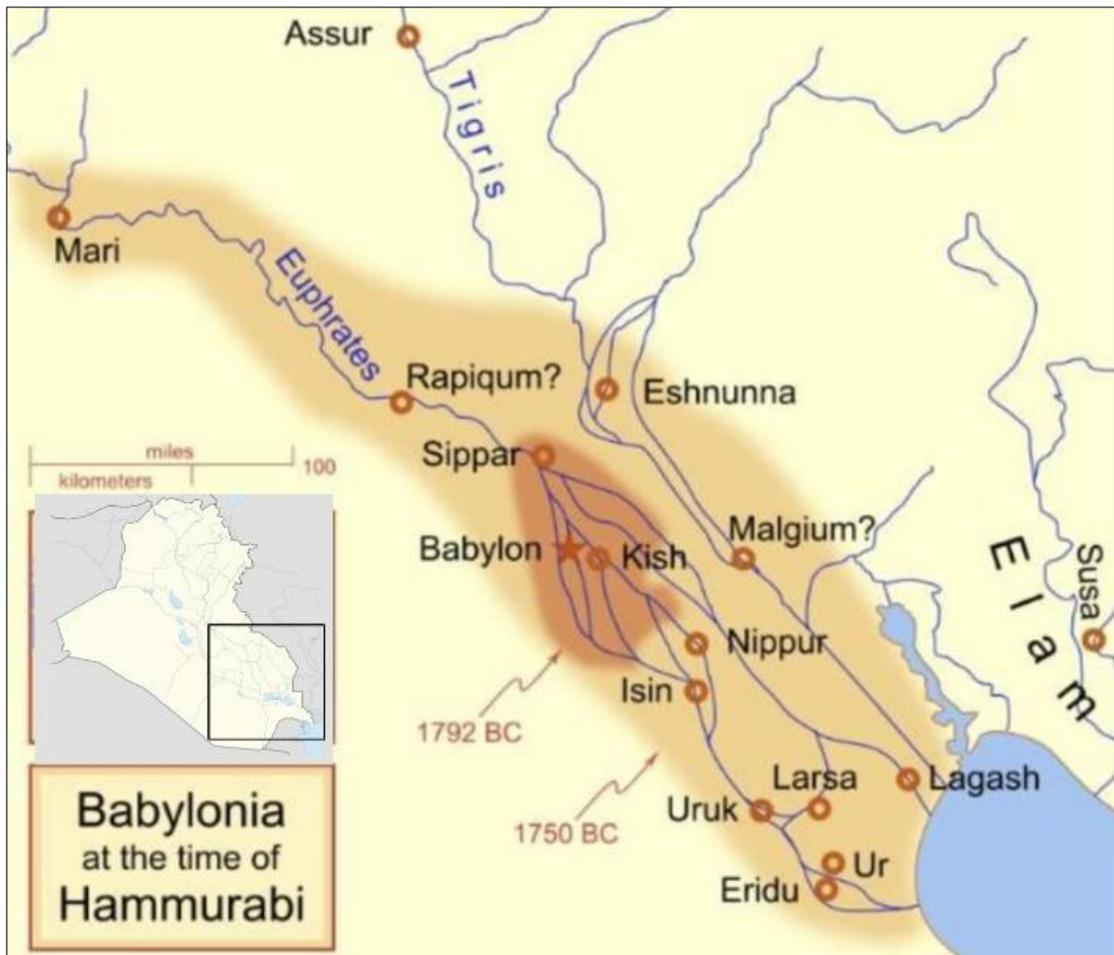


Figure 1-1 : Ancient Mesopotamia (Crawford, 2013)

Archeologists in Mesopotamia are at the forefront of developing remote sensing and surveying methods. Therefore, the methods and methods of text analysis and excavation have a great role in understanding the evolution of society and the events that it went through (Ur, 2013).

The first excavations carried out in Tell Al- Deylam Figure (1-2) were by Hormuzd Rassam for the British Museum in 1897 A.D. Through his study of some of the tablets found by the local population, it became clear to him that Tell Al-Deylam is the remnants of the ancient city of Dilbat, and on its track he carried out excavations in the hill, that were not scientific but for the purpose of searching for artifacts and cuneiform tablets (Wenger, 2012).



Figure (1-2): Aerial view of the newly excavated of the study area. The picture was taken by a drone on February 15, 2020 (Almamori and Bartelmus, 2021)

After that, the most important excavations of Tell Daylam were carried out by Armstrong in 1989-1990 AD for the benefit of the University of Chicago, USA. Where three sensors A, B, and C were excavated, the most important of which was the probe B, which represents the architectural legacy, where the remains of houses from the ancient Babylonian era were discovered, as well as tombs, several pottery vessels and kilns of these pottery vessels, which date back to the late seventeenth and eighteenth centuries. Due to the sporadic results, it has not been possible until now to create a comprehensive map of the city, which means that data related to population density and the size of the city is not possible until further notice (Wenger, 2012).

The talking about Dilbat means a significant part of Babylon history and its great civilization, it represent the remains of an ancient temple of the god Urash the god of agriculture and war and he is the local god and protector of the city along with his wife, the goddess Nin Gal, and It is worth noting that the god Urash was mentioned in the cuneiform texts with two genus sometimes as male and other as female this city has great importance to the Babylonians, as they called one of the eight gates on the inner walls of the city of Babylon the name of "the gate of the god Urash", perhaps this name intended because it is the gate that overlooks the city of Dilbat (Musa,et al. , 2017).

The temple of the god Urash goes back to the middle Babylonian era (1500-600 B.C) and it is one of the main temples of the Babylonian civilization. This site is considered one of the most important archaeological sites located within the borders of Babilon Governorate, which includes more than a thousand archaeological and heritage sites, according to the latest statistics of the babilon

antiquities department, this hill stands at the forefront of those sites for its importance in the archaeological milieu, and this was reinforced by its location on the Al-Arakhtum Cannel, one of the branches of the Euphrates River, to be in direct contact with its most famous neighbors at that time, such as the city of Babylon located in the north side, while on the northwest side it is located the city of Borsippa, known as Tall Pers Nimrud, and to the southeast is the city of Mard, known as Tall Wanh and Al-Sadum, and from the southern side , it is located in the direction of Al-Kifl (Musa, et al, 2017).

1.2 Aims of study

It is a study of chemistry and engineering for building materials in the archaeological site of Tell Al- Deylam , buildings properties of the fired bricks, include

1 – physical properties

A – porosity

B – apparent density

C – water absorption

2 – mechanical properties

A – compressive strength

3 – chemistry of clay bricks general composition

1.3 Study area

Dilbat or Tel Daylam is located in Babilon Governorate, Figure (1-3), in the district of Kifl, Abu Samij, in a plain area confined between Shatt Al-Hilla on one side and Shatt Al-Hindiya (the current Euphrates) on the other side . It is located 30 km south of the ancient city of Babylon (the ruins of Babylon. It is only 25 km away from the city of hilla the capital of Babilon Governorate, while it is 15 km southeast of Perss Nimrud, the remains of the ancient city of Borsippa. The site obtained its present day name, Tell Al-Deylam, because of a Muslim shrine on the western aspect of the site that – in accordance to belief of the nearby people – belonged to Muḥammad Ibn Yaḥya Al-Deylami, a grandson of Ali ibn Abi Ṭalib (the cousin of prophet Muḥammad). It used to be recorded as an archaeological web site in the Al-Waqiah al-Iraqiya newspaper (no. 2283) in 1937(Al-Mamori and Bartelmus, 2021).

Dilbat occupies an area of more than 150 dunums, which is located between longitudes (44°10'30")E and (45°3'0") E and latitude(31°37'30") N and (32°51'0") N, Figure(1-4).

The height of the hill above the level of the adjacent plain is about 6.5 meters, its current boundaries are represented by the presence of two irrigation channels split from the Majariah River at the end of the seventies of

the last century, bordering it from the north and west. on the eastern side, it is bordered by a group of fields and orchards. As for the south, it is bordered by apaved street. (Musa, et al, 2017)



Figure (1-3): Location of the study area

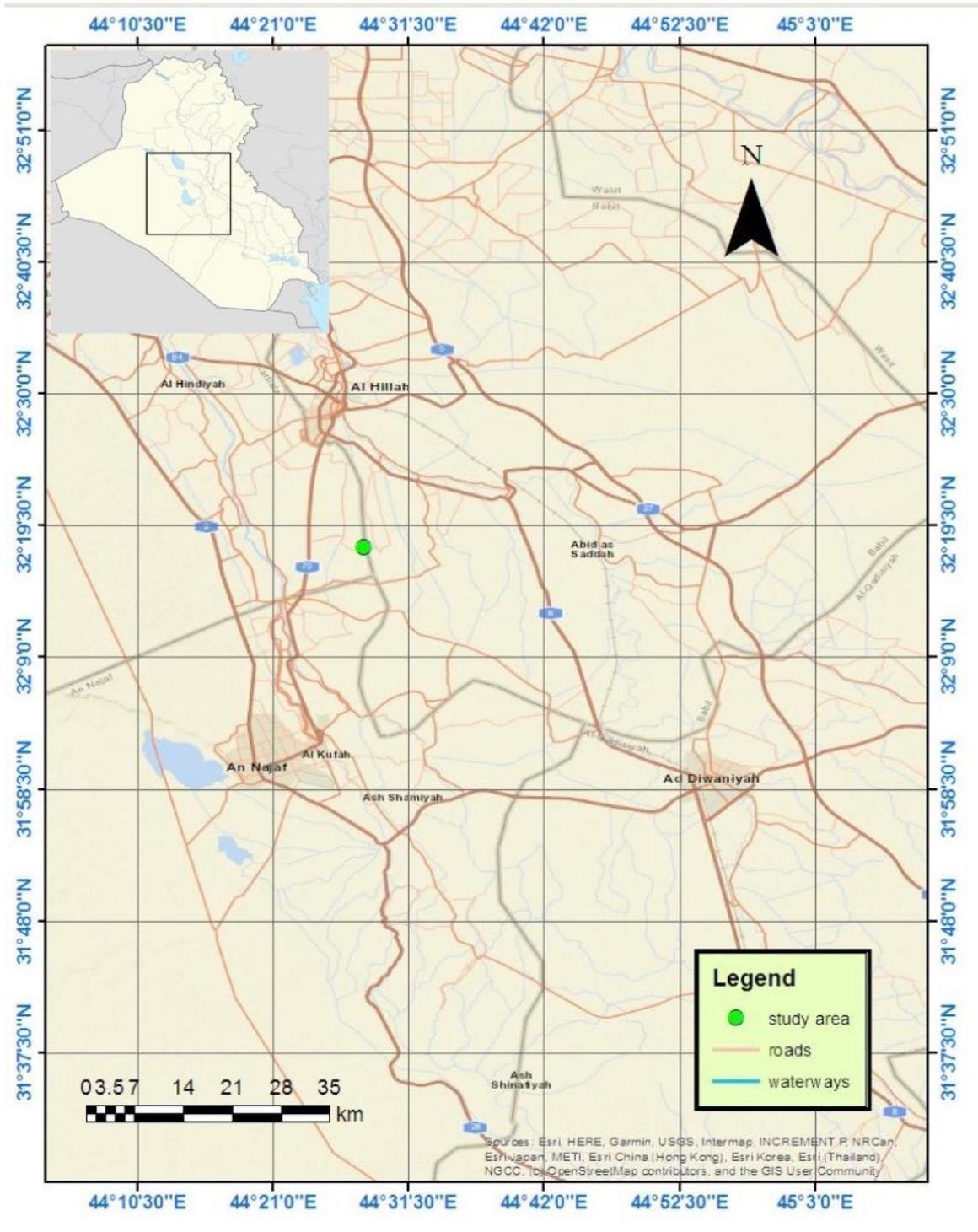


Figure (1-4): A map of the location of the study area

1.4 Climate of the study area

The climate of the sedimentary plain is generally characterized by severe differences in temperatures between summer and winter, for example the

average temperature is in July 36 C° and January 11 C° (Domas, 1983). The plain has a hot, dry climate in summer and cold semi-arid winter, and the prevailing winds in the study area are hot-dry winds not raining. As for the relative humidity, its average during winter and in the month of January in particular is around 70% and this rate decreases during summer, reaching in the July to (19-25)% (Al-Ani, 1986)

The alluvial plain's climate is characterized by relatively few monsoon rains, which are concentrated during the winter and spring seasons. The rate of rain fall in the alluvial plain ranges between 50 mm in the south and southwest and (200)mm towards the north and northeast of the alluvial plain and is characterized by a high rate of evaporation. (Al-Ani, 1986)

1.5 Field work and sample collection

An exploratory trip was conducted in the Tel Daylam area of Babelon Governorate in order to become acquainted with the characteristics of the area and the general nature of the place. Experienced people and professors from the University of Babylon Department of Archeology assisted in providing more information about the ancient city of Dilbat, and the best areas to collect samples were chosen.

1.6 Previous studies

Until the 1980s, no scientific excavations were conducted at this ancient city, but Eckhard Unnger gathered a lot of information from the texts in the 1990s. Most of this information came from tablets obtained previously by Hurmouzd Rassam and elicited diggers, but it was also obtained from the occasional boundary stone stela that mentioned the site. According to the textual source Unnger was unable to determine whether Dilbat played significant historical roles in ancient times. He did suggest that Dilbat may

have been an important distribution center for agricultural products, and that proper excavation could demonstrate that texts originating or referring to Dilbat are primarily old Babylonian (first half and second millennium B.C) and new Babylonian (first half and second millennium B.C), Assyrian Persian (first millennium B.C) (metropolitan museum journal 29). Many previous studies for the area were conducted, the most notable of which was the archaeologist's (Armstrong, 1989-1990) study for the University of Chicago, in which the city of Dilbat (Tell Al-Deylam) was studied by surveying the site topographically and examining the pottery on the surface of the site and the discovery and study of cuneiform tablets, as the latest excavations confirmed that Tell Al-Deylam is The remains of the ancient city of Dilbat.

Helen (1974) describes the prominent cultural landmarks in the Mesopotamian civilization, such as the main temples, huge palaces and homes inhabited by the people, including the civilizations themselves such as Babylon, Assyria, Ur and Sumer, all according to the archaeological evidence found by archaeologists.

Pollock and Susan (1999) present to us the early urban societies and the beginnings of the emergence of the state in Mesopotamia from about three thousand years ago (since 5000 to 2100) BC, based on his interpretations on the study of animal remains, as well as the settlement pattern of the population, the activity of the population, the remains of artifacts and their distribution, cuneiform texts and tombs it examines the ways in which the people of Mesopotamia from different social classes and races have done and how they have adapted to economic and political changes.

George (1993) presented a study on the Mesopotamian temples. His study includes developing special lists of ancient temples in Mesopotamia with official names for these temples, not common names. He also mentioned the location and god of that temple and other information about each temple.

Lilyquist (1994) presented a very important and wonderful collection of jewelry that was discovered in the city of Dalabat, which reflects the luxury and sophistication of that civilization. These jewelry include necklaces, seals, seals covers, two figures of small gods, beads, etc., during the ancient Babylonian era (1894- 1595 B.C). A treasure that dates back to the seventeenth century.

A wide amount of information is presented by Nemet (1998) on a variety of important topics in Mesopotamia such as education, especially science and mathematics, as well as literature, and it shows us rural life versus city life. public life in Iraq today and Mesopotamia has also been compared previously.

Pottery in Babylon was studied in detail by Armstrong and Gasche (2014), on which the most late excavations were focused on. The excavation of pottery was conducted, and it was divided into groups relative to the shape of these pottery vessels, the groups were arranged according to geographic location and time so that developments are observed over time.

Bretman (2005) laid out a blueprint for public life in Mesopotamia in terms of history, literature, culture and economy, and the struggle of the people from 3500 until 500 B.C, in a broad and detailed study of the most important industries, architecture and military organizations at that time.

Baqer (2009) chronicles the ancient history of Iraq from the most distant prehistoric times until the Sasanian era, in which he presents a summary of civilizational and political events, as well as the countries and dynasties that ruled them and the accompanying social, economic and artistic changes, in short the cultural and civilizational characteristics of each of its historical roles.

Oppenheim (2013) shows us the power and economy of the ancient and integrated civilizations of Assyria and Babylon in brief by solving the

mysteries of the ancient records and tablets, as his study took more than thirty years, and this created his extensive experience that helped him draw a clear and integrated picture of Mesopotamia more than three thousand years ago.

Musa, et al., (2017) studied the city of Dilbat by conducting excavations for Tell Al- Deylam. These excavations revealed a huge building that contains large walls, a rather long corridor and a number of rooms, including two rooms that may be sacred, and this indicates that the building could be considered Temple; pieces of jewelry and clay vessels were also discovered.

1.7 Geology of the study area

The exposed rocks in the area include sediments of the quaternary period covering the study area, and the pre-quaternary rocks that form a small part of the discoveries in the study area and which belong to the pliocene and the upper miocene (Figure 1-5).

1.7.1 Quaternary deposits

The Quaternary deposits were divided into several geological units depending on the origin of those deposits and their geomorphological status.

- Fluvial deposits:

These sediments were divided into four types, including :

1. fluvial terraces deposits: it is specifically located in the northwestern side of Al-Escandaria in an elevated area. It is due to the pleistocene deposits of the Euphrates (Domas 1983). It consists of pebbles, which are usually lenses with a thickness not exceeding 1 meter, the size of the pebbles is 5cm and in various shapes and its main components are quartz and flint stone, as well as deposited in the form of lenses up to 2m which are fine to coarse granules containing clay balls (Slewa and Barawry, 1995).

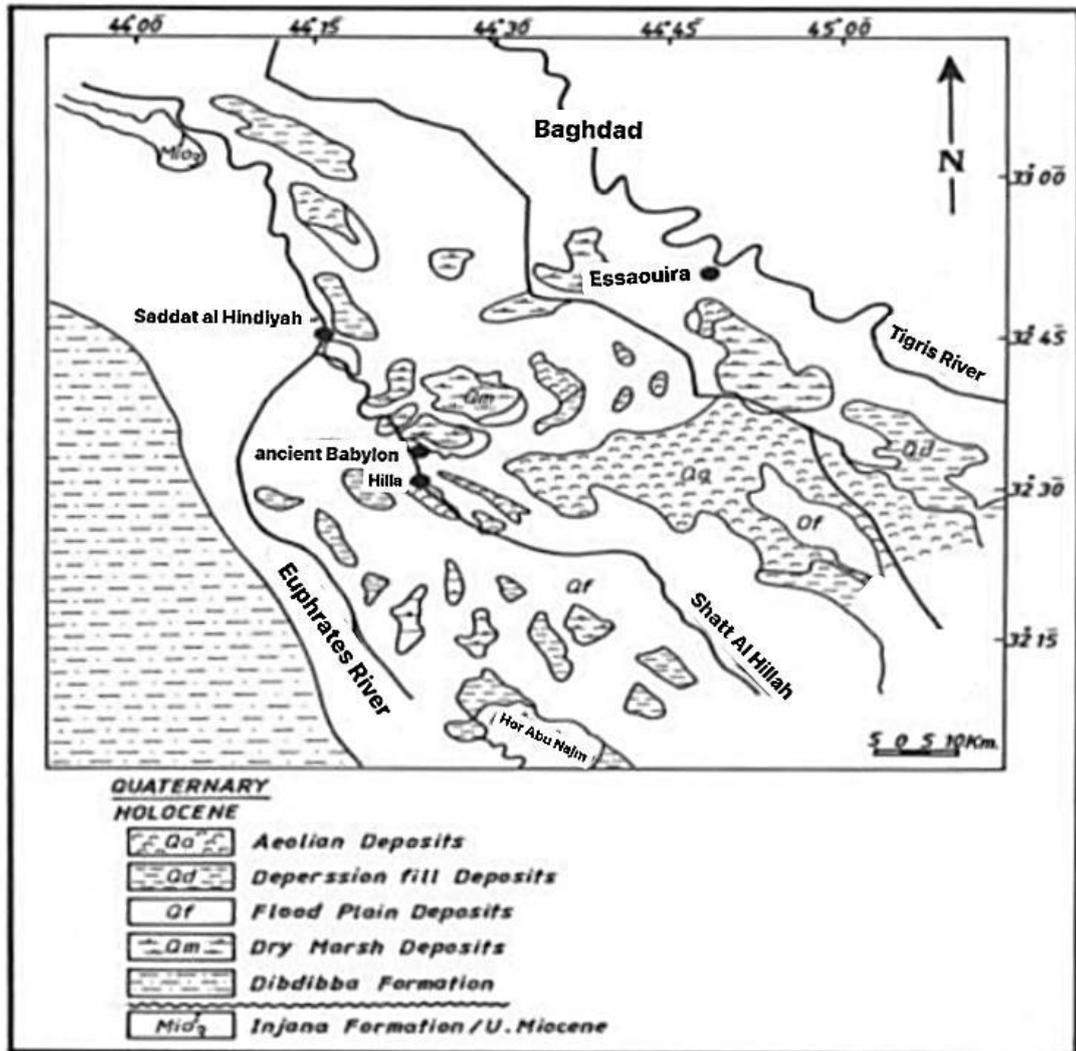


Figure (1-5): Geological map of the study area (Sissakian, 2000)

2. flood plain deposits: the flood plain is the largest sedimentary geomorphological unit originating from the Euphrates River and Tigris River and their tributaries (Hamza 1997). The floodplain sediments are spread in most of the study area, especially the central and northeastern region. It is composed of alluvial clay deposits, the largest part of which is the flood plain sediments, followed by silt and sand. The floodplain sediments are contaminated to a large degree by the sediments of irrigation channels, which are less coarse than the natural sediments of the floodplain (Slewa and Barawry, 1995).

3. depression fill deposits: these sediment are accumulate by floods and generally consist of thin layers of fine sand and clay silt (Parsons , 1957). They are found in dry depressions most of the year except for rainy periods when they are filled with water and accumulate sediments transported by rivers and streams(Domas , 1983). These deposits spread in different areas of the study area, for example in the city of Al-Musayyib and west of Hilla .

4. dry marsh deposits: these deposits are found in different places of the study area, and their deposits consist of clay and silt with organic matter(Domas ,1983).

Aeolian deposits:

Wind deposits spread in the eastern part of the study area. The reason for this deposits is due to the lack of rain fall in it and it consists of sediments transported by the wind from alluvial fans and pre-quadernary rocks, and they are found in various forms : sand sheets, sand dunes (Domas, 1983).

These sandy sediments may be delicate and may reach a thickness of more than 2-3 cm , and in the field of sand dunes it may reach 5m , and some of them are moved due to the winds carrying these deposits (Slewa and Barawry, 1995).

1.8 Topography and geomorphology of the study area

The study area is located in Babilon governorate (Figure 1-6) within the alluvial plain, which is characterized by its flat surface, flatness and general lack of slope, where the degree of slope is about 22 cm per kilometer, and there are secondary slopes (Al-Jubouri, 2002). where the land slopes from the northern and western sides in it and towards the eastern and southeastern parts and there are some sand dunes in some areas, such as south of the city of

Hilla these dunes have fixed bases, but their peaks are mobile, from which the winds form shapes according to their directions (Al-Saadoun, 1988).

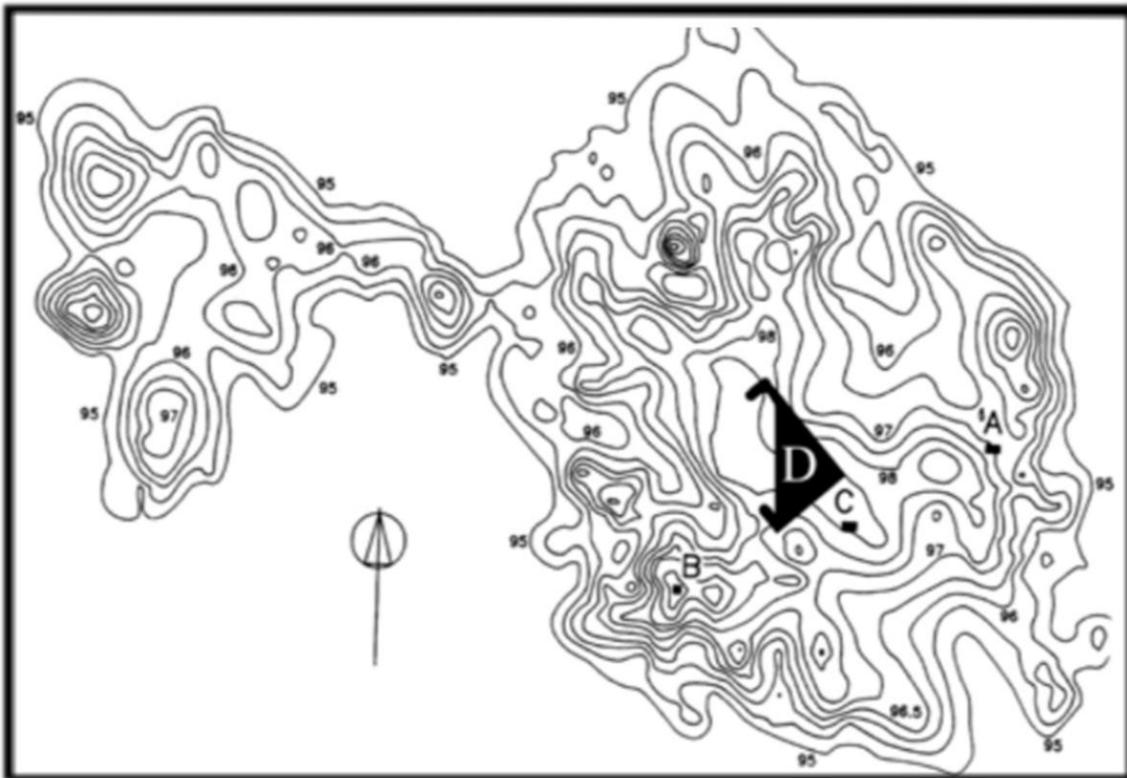


Figure (1-6): Map showing the topography of Tell Al-Deylam, the soundings of Armstrong’s team (A–C) and the newly excavated area D (Almamori and Bartelmus, 2021)

1.9 Ancient streams of the Euphrates within the Babylon region

The Euphrates River enters the governorate in its northwestern part, and its flow direction is northwest to southeast, and the river’s twists are clearly visible in it, as several rivers that pass in the late-maturity stage of the geomorphological cycle (Karbal, 1981).

The Euphrates River changes its main course over time, it is natural for rivers that flow in the flood plains, which may occur due to erosion and sedimentation processes, or what happens when the river deepens its course as

a result of its rejuvenation phase. Archaeological and geological studies in the middle and lower Euphrates Valley indicated that the river passes through five phases in which its course has changed from one place to another within the alluvial plain in Babilon Governorate. It was flowing in the first phase during the period between 4000 and 5000 years before the present in the far east of the governorate in the ancient eastern course known as the Kothi stream that runs along the Tigris River (Susa, 1945), and that course changed from one location to another in the area bounded between Fallujah and Al-Musayab. As for the second phase, located between 4000 years before the present and the sixth century A.D, the Euphrates River started flowing in the course of the city of Hilla, which is now known as the Shatt Al-Hilla, after an increase in Kothi stream due to an increase in sediments and as a result, the ancient river dried up until it becomes impossible to bring back the water to it (Susa, 1945).

The Euphrates River preserved in this Babylonian course for a long time, which become the longest and most valuable phase in terms of irrigation regulation, as it lived up to the second Babylonian role during which irrigation projects witnessed a development that is the greatest that Iraq witnessed in its long history (Al-Hadithi, 1969) .

The third phase extends during the Arab era between the seventh century A.D and about the thirteenth century A.D in which the course of the river shifted from the direction of the Babylonian direction to a branch side with the ancient Balacobas, which was mentioned by Babylonian texts as Nar Balukat or Shatt Al-Hindiya now.

The Euphrates River returned in the fourth stage to the course of the city of Babylon from the fourteenth century to the late nineteenth century AD, and this period lasted about six centuries, during which the Euphrates River

entered the period during which the irrigation projects were most neglected (the period of the role of Hulagu).

In its fifth and final phase, which began in the late nineteenth century AD, it returned to the Balakobas (current Shatt Al-Hindiya stream), where the accumulation of sediments in the Shatt Al-Hindiya course during that period had a role in preventing it from absorb the flood water of the Euphrates, which made the Euphrates River change its course towards Shatt Al-Hindiya. There are not long ago all the waters of the Euphrates flowed into it (Susa, 1945).

The transformations that the Euphrates River underwent in the area between Heet and the Arabian Gulf, which falls within the alluvial plain in the Babilon Governorate, is more severe than the transformations that the Tigris River suffered in the corresponding area due to the geological and geographical nature of the Euphrates flowing areas since ancient time. The course of the Euphrates River, which used to start from the north of the ancient city of Sippar, which passes through the city of Kothi and Kish, is confirmed by satellite imagery, which indicates the presence of newly formed river sediments in the form of a long tongue occupying the position of the ancient course and up to the current Al-Saqlawiyah River, which was the turning point of the current course of the Euphrates from the old hungarian (Al-Mousawi, 1989).

The geological factors are what led to the drought and shifting of this stream from its old direction to its current course towards Al-Musayyab, as this course intersects with the southeastern extensions of the sub-surface installation of Fallujah, which has been scientifically proven through geophysical surveys, as well as seismic surveys conducted by the National Oil Company recently (Al-Sakeni ,1986). The shift of this course towards its current course towards Al-Musayyab began when the impact of the recent

tectonic activity of the composition of Fallujah appeared on the surface of the earth in that part of the course, with the height of the river bed at a point of intersection with the structure, that lies roughly north of Fallujah, which led to the lack of slope of the old course, and consequently a lack of drainage and inspection for a new stream that falls outside the influence of the structure, this was the current Euphrates course that runs through the cities of Fallujah and Al-Musayyab, and the Euphrates River continues in its main course in the governorate until the dam of Al-Hindiya, as it branches into two main branches: Shatt Al-Hilla and Shatt Al-Hindiya (Al-Mousawi, 1989).

Civilization began in Mesopotamia and flourished over the land of the alluvial plain where, throughout historical ages, it was associated with the existence of rivers. The most important and largest of these civilizations is the Babylonian civilization, which appeared and developed on the banks of the great Euphrates River .

1.10 Temples

Mesopotamian architecture is the ancient architecture of the Tigris–Euphrates river system encompassing several distinct cultures and spanning a period spanning from the 10th millennium B.C, when the first permanent structures were built, to the 6th century B.C. Among Mesopotamian architectural achievements are the development of urban planning and the courtyard system. Archaeological evidence, pictorial representations of buildings, and texts on building practices are used to study ancient Mesopotamian architecture. the Uruk period pictographs indicate that "stone was scarce, but was already cut into blocks and seals". Brick was the most common building material, and it was used to build cities, forts, temples, and houses. The city had towers and stood on an artificial platform; the house had a tower-like appearance as well. It had a door that turned on a hinge and could

be opened with a key of some sort.; The city gate was on a larger scale, and appeared to be double. Demons with bird-like wings were feared, and the foundation stones – or rather bricks – of a house were consecrated by certain objects deposited beneath them (Crawford, 2004).

Temples are religious and intellectual symbols of communication with the deities for the purpose of sanctifying them and drawing closer to them and their purpose is not limited to the religious aspect only .They rather include other purposes in the life of the ancient Iraqi society , as they also have judges in addition to that, they have an economic system as a bank to give loans to people and to deposit their money (Baqer, 1947).

The architecture and construction of temples developed through different eras in Mesopotamia the first temple was found in the city of Eridou southern Iraq that goes back to about 5000 B.C. The construction of this temples is very simple it is a whole one room with an era of about 11 by 16 feet this room is preceded by a small hallway. The room in the middle contains a table for the oblation and on the wall there is a place that maybe designated to hold the statue of the god . the statue was not found and the type of deity is not known yet (Bertman, 2003).

In the later periods 4000 B.C, the shapes and designs of temples changed as they increased in size. The internal part has become in a certain way as there is a hall in the middle and on both sides of it a number of rooms. The sanctuary is at a high of 42 feet or more which is accessed via stairs. The outer walls surrounding the temple are also of strong pillars in order to protect the temple from the natural disasters such as floods , as well as to protect the god from the external hazards as they thought (Bertman, 2003).

Later, in the empire of Assyria and new Babylon another certain changes occurred in the construction of temples as the temple structure was merged

with the palaces , the reason behind this merging method to reinforcement the king's status. The city may have several temples, which will form a sacred complex , aided by the presence of large empty spaces, several gods are present in these temples, but the largest temple is for the god of the city (Bertman, 2003).

The temple in ancient Mesopotamia is divided into two distinct separate parts, whether it is in the building, name, or aim, where one is called the high temple or ziggurat on which the temple is built, and the other type is the temple built on the flat ground, which is adjacent to the ziggurat when it is present in the city (Baquer, 1947).

As for the ziggurat (Figure 1-7), its first appearance is in southern Iraq; it can be described as a high construction of non-hollow, solid mudbrick which may be covered by brick, they are in the form of terraces or square or rectangular layers that are gradual in capacity so that the upper layer is smaller than the lower layer. The number of these layers or terraces varies in different cities it ranges from 3 to 7 or 8 layers; they are similar to the pyramids in Egypt, but this similarity does not exceed the external shape (Baquer, 1947).

The temples are built on top of the ziggurats, the remains of which have not been found in any of the ziggurats due to their great height, which may exceed one hundred meters, which made them susceptible to atmospheric influences for thousands of years. Therefore the only evidence of their existence is the accounts of historians (Baquer, 1947).

There are several characteristics that distinguish temples from other buildings, which lie in method of planning and design, especially the presence of the sacred room, which contains the altar and the offering table, as well as

the method of building and decorating the temple walls, especially the external ones, such as batter and recesses (Baqer, 1947).

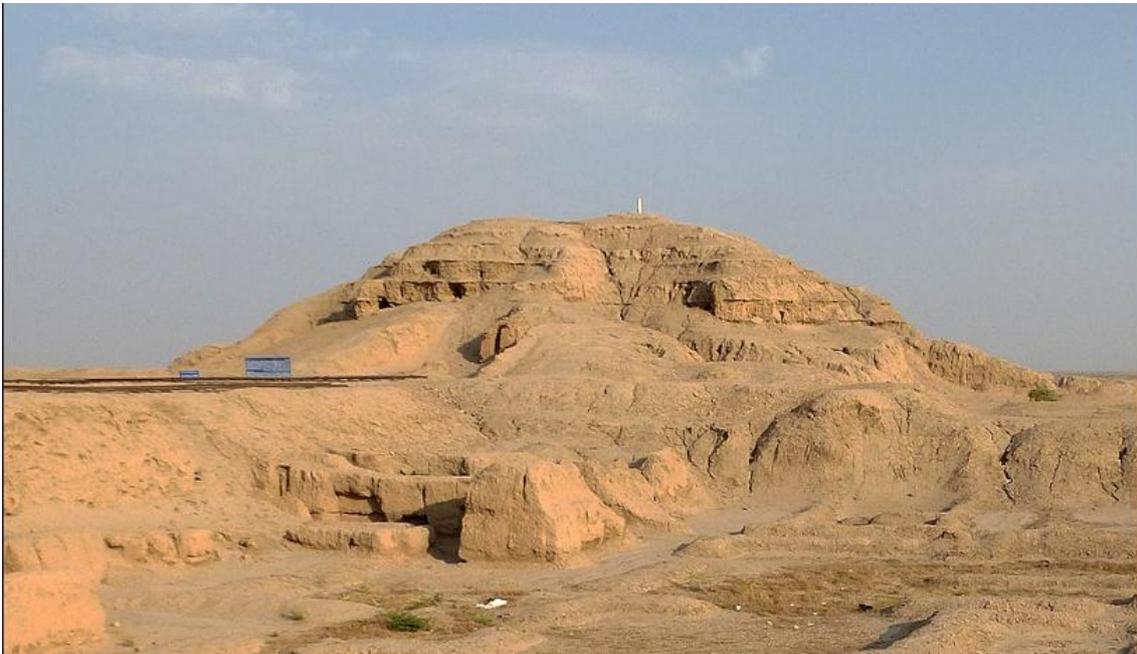


Figure (1-7): White Temple ziggurat at Uruk. The original pyramidal structure, the "Anu Ziggurat" dates to the Sumerians around 4000 B.C, and the White Temple was built on top of it circa 3500 B.C (Crüsemann, et al, 2019)

1.11 Bricks

Bricks can be defined as a mass of regular proportions of relatively solid dimensions made of clay mainly and other secondary materials used for construction purposes of all kinds. As for the axes of the bricks, the length is considered the longest axis, then the width, and finally the height, which is the smallest axis. There are several types of bricks, some of which are solid and some are perforated with holes (Stuart, 2005).

Brick is one of the most important building materials used in a large number of buildings since ancient times until the present time. This is due to the availability of raw materials that are of relatively low value and ease of

manufacture. The durability of bricks depends on the manufacturing technique and the type of raw materials that go into its manufacture, namely sand, clay and water. Moreover adding an amount of straw helps reduce cracks during the drying process of bricks (Silveira, et al, 2012), although the straw will reduce the resistance of the bricks when it decomposes (Oates, 1990).

Architectural engineering is one of the most important backgrounds that reflect ancient cultures. Architecture, especially bricks, is no less important than any archaeological piece. The decorations and designs of different buildings can express the classes of society, the prevailing system, the social status of peoples (Stuart, 2005).

The main characteristics of mud bricks as a basic building material are that they can be built easily and quickly adapted, as simple changes can be made in the building structure such as changing the place of a window or making another entrance. Mud bricks, in particular, have some characteristics that distinguish them from concrete and burnt bricks, the most important of which is that they insulate heat and cold better than them (Oates, 1990) Also, the advantage of bricks in that they can be arranged easily and that they are lighter than stones made them used in building ceilings (Hnaihen, 2020).

In the ancient archaeological buildings, two different colors of bricks were found, gray and reddish-brown. This indicates that the type of soil used was different. The reddish-brown bricks were commonly used in buildings with a large area, and the soil used in its production is from agricultural land far from the settlement, while the clay used In the production of gray bricks, it is from the remnants of the old buildings or it contains ash, and the builders believe that the gray bricks are of greater strength than the brown bricks (Oates, 1990). When building public buildings, especially temples, with bricks in the past, they were accompanied by special rituals with the purpose

of pleasing the god. Also, before or at the beginning of the project, celebrations are held in which the kings participate (Hnaihen, 2020).

Brick is one of the oldest building materials used to construct a large number of buildings, as it was used extensively and helped by the availability of raw materials and its somewhat simple production steps and raw materials are often found near the work site. The bricks are produced in several stages, first the raw materials represented by the clay are collected and placed in a specific place in the open air where this clay is cleaned of unwanted impurities to avoid the presence of soluble salts that affect the quality of the bricks to the least possible extent. After that, the clay is ground, then water is added and mixed; this process is called temper. Then, the material are mixed either manually, which is an ineffective method, or by wheels in later periods. The mixture must have adequate plasticity because the increased plasticity causes cracks or twists, so the amount of water added to the mixture must be taken into account. Plasticity can be reduced by adding sand (Fernandes, et al., 2010).

Then the mixture is usually placed in wooden molds (Figure 1-8), the drying process takes a long time, especially if the weather is cold, so it is preferable to make bricks in the summer. However, it is necessary to avoid exposing the molds to direct rays of the sun. This causes the surface of the bricks to dry out while the inside remains wet. The bricks are then placed in kilns at a temperature of 900-1000 C to increase the durability of the bricks (Bertman, 2003).

Baked bricks manufactured in kilns are of higher durability than bricks made by drying by the sun only, although it is similar, simple and cheap to manufacture, and the quality of bricks depends mainly on the nature of the raw materials used in its production. It is important to know the physical and

chemical properties of the bricks and its raw materials (Fernandes, et al., 2010).

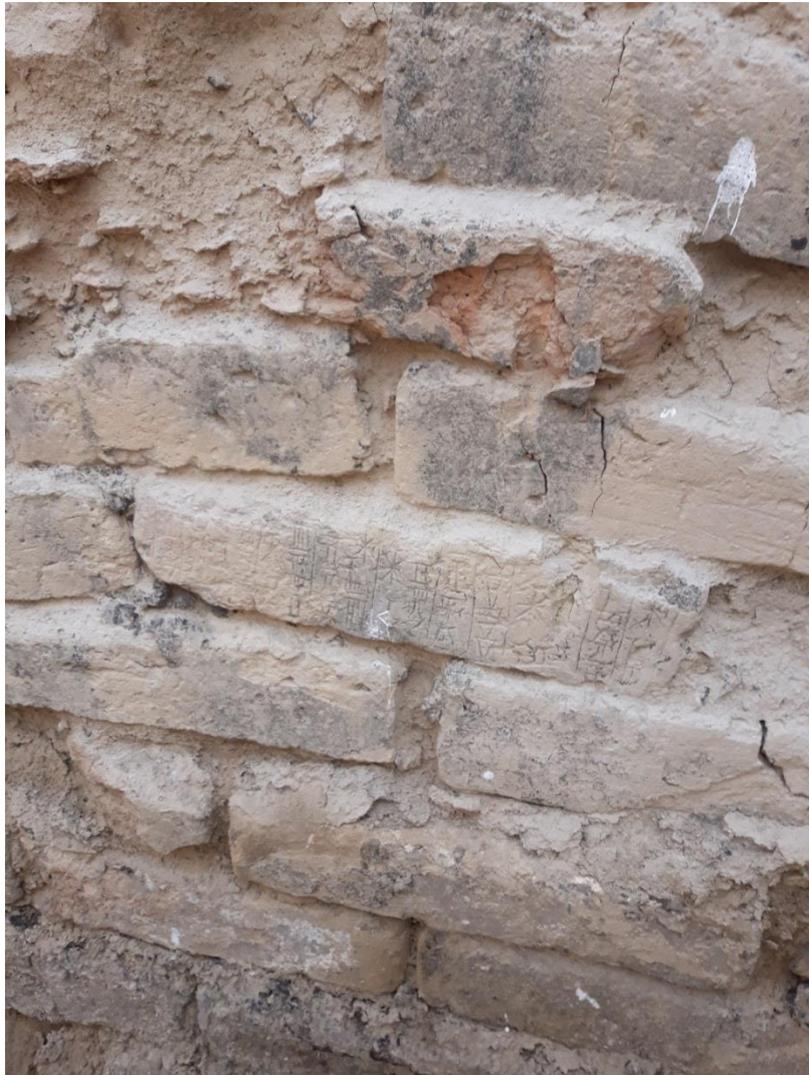


Figure (1-8): The ancient bricks at study area

The physical poroperties affect the quality and durability of bricks, for example porosity is one of the most important of these factors, which is about 15-40% in old bricks. The size and distribution of these pores depend on the type of clay used, the temperature, the presence of impurities, the amount of water, where the proportion and size of pores increase as the temperature increase and vice versa, the pores decrease and become smaller at the lower temperature. Large pores are better than small pores for the quality of bricks,

when the pores are large , the bricks become less affected by the soluble salts, while the small pores negatively affect the durability of the bricks as they increase the property of water absorption and retention. The causes of the deterioration of old bricks can be determined through knowledge of the chemical composition, as it allows to know the substances that affected the quality of the bricks such as impurities and soluble salts and others, as impurities and salts are the most important factors that reduce the quality of the bricks (Fernandes, et al., 2010).

Finally, attention must be paid to preserving and protecting archaeological and cultural buildings as much as possible, because they may be exposed to several risks that may be caused by man or nature-made (Binici, et al., 2020).

Chapter Two

Materials and Methods

2.1 Introduction

The excavations at the Tell Al- Deylam revealed a huge building that contains large walls, a rather long corridor and a number of rooms, including two rooms that may be sacred, and this indicates that the building could be considered Temple, the researcher conducted an exploratory tour in the temple of the god Orash in order to determine the areas needed for sampling. The areas were identified by specialists from the Department of Archeology at the University of Babylon.

Three samples of bricks (B1, B2, B3), three samples of mud bricks (M1, M2, M3), and four samples of clay soil (C1, C2, C3, C4)

Necessary analyzes on these samples were performed, which included: examining the proportion of chlorides (Cl%), sulfates (SO₄%), total dissolve solids (TDS%), carbonates (CO₃%) for brick, mud bricks and clay samples, , and the percentage of organic matter (OM%) for mud bricks and clay.

Likewise, an X-ray fluorescence (XRF) test was performed for bricks, mud bricks and clay ,and X-ray diffraction (XRD) test for bricks.

2.2 Chlorides (Cl)

10 grams of crushed soil was taken and then dry it in oven at 105 °C to make sure that there is no moisture, then put it in a baker and add 250 ml of distilled water and put it in the vibrator for one hour then filter it on filter paper. then take 50 ml of the soil extract and add 3 drops of potassium chromate guide (K₂CrO₄ 5%) to it. put silver nitrate (AgNO₃ 0.1 N) in the burette. open the burette on the soil extract until the color changes from yellow to reddish brown, (Figure 2-1) (Korkmaz, 2001).

$$\text{Cl}\% = \left[\frac{(V \times N \times F)}{1000} \right] \times \left(\frac{V1}{V2} \right) \times \frac{100}{W} \dots\dots 2_1$$

Where:

V= Volume of AgNO₃

N=Normality of AgNO₃ (0.1N)

F= m.wt of Cl (35.5)

V1= total volume of the soil solution (250 ml)

V2=volume that we used of soil solution (50 ml)

W= Soil sample weight (10 g)



Figure (2-1): Determination of chlorides in the soil

2.3 Total dissolve solids (TDS)

Ten gram of the sample was taken after that crushed it well and dried in oven, then put it in the conical flask and add 250 ml of distilled water and put

it in the vibrator, then filter it and take 50 ml of the filtrate after that leave it on the heater until it dries completely (Figure 2-2) (Corwin and Yemoto, 2020)

$$\text{TDS}\% = 1000 \times \frac{a - b}{V} \dots\dots 2_2$$

Where:

a-b= the difference in weight of the beaker

V=the volume of soil extract



Figure (2-2): Determination of the TDS in the soil

2.4 Sulfate (SO₄)

The percentage of sulfates in the soil is determined in many ways, but the weighted method is performed by using soil extract; it gives more accurate results, but it requires a longer time for implementation (Odeh and Shamsam, 2008)

One gram of the sample was weighed and dried well to get rid of moisture, then added 100 ml of hydrochloric acid (HCl) at a concentration of 10% and then put it on the heter until it boiled, then filter it into a 500 ml conical flask and add 400 ml of distilled water, then add 120 ml of barium chloride($BaCl_2$ 5%) and leave for 24 hours. after that, 50 ml was taken and filter on ashless paper, wash well, then put in a jar and burn (Figure 2-3) (Richared, 1954).



Figure (2-3): Determination of the sulfites in the soil

$$SO_4 = \left(\frac{\text{m. wt of } (SO_4)}{\text{m. wt of } (BaCl_2)} \right) \times \left(\frac{100}{w} \right) \times \left(\frac{w1}{w2} \right) \times \left(\frac{v1}{v2} \right) \dots\dots 2 - 3$$

Where :-

w = wight of soil

w1 = wight of the impty jar

w2 = wight of the jar with SO₃ precippitated

v1 =total volume of the soil solution

v2 =the volume we used of the soil solution

2.5 Carbonates (CO₃)

The volumetric method was used to determine carbonates in the soil, (Richared, 1954). Two grams of dry soil completely free of moisture was weighted and put in a 250 ml conical flask, add 10 ml of hydrochloric acid (1 N) and stir it well. To cool it down, add 50 ml of distilled water, filter in an Erlenmeyer flask, add 3 drops of phenolphthalein to the filtrate, then titrate it with a sodium hydroxide solution until it turns pink (Figure 2-4 a and b) (Richared, 1954). For the purpose of knowing whether or not carbonates are present in a certain section of the soil, hydrochloric acid (HCl) at a concentration of 10% is used, as we notice an effervescence when sprayed on the soil (Al-Hassan, 1995).

$$\text{CaCO}_3\% = [(N_{\text{HCl}} \times 50) - (N_{\text{NaOH}} \times R)] \times 0.05 \times \frac{100}{w} \dots\dots 2 - 4$$

Where:

N_{HCl} = normality of the HCl

N_{NaOH} = normality of the NaOH

W= weight of the soil sample

R= NaOH we used for titration



Figures (2-4): Determination of the carbonates in the soil

2.6 Organic matter (OM)

One gram of dry soil sample was weighted in a 500 ml beaker, add 10 ml of potassium dichromate solution (1N) using a pipette, then add 20 ml of concentrated sulfuric acid using a graduated cylinder and stir well, then leave for 30 minutes. Then add 200 ml of distilled water, add 10 ml of concentrated phosphoric acid and leave the mixture until it cools. The researcher add 15 drops of diphenylamine, add the magnetic rod and put the cup on the magnetic stir device. Titrate with a solution of ferrous sulfate FeSO_4 (0.5 M)

until the color changes from blue-violet to green, (Figure 2-5,aandb) (Walkley, 1947).

$$\text{Soil organic matter (M\%)} = \frac{10}{V_{\text{blank}}} \dots 2-5$$

$$\text{Oxidized organic carbon\%} = \frac{(V_{\text{blank}} - V_{\text{sample}}) \times M \times 0.3}{W} \dots 2-6$$

$$\text{Total organic carbon\%} = \text{oxidized organic carbon\%} \times 1.334 \dots 2-7$$

$$\text{Organic matter\%} = \text{total organic carbon\%} \times 1.724 \dots 2-8$$

Where:

M= molarity of ferrous sulfate solution

V_{blank} = volume of FeSO₄ required for a blank titration

V_{sample} = volume of FeSO₄ required for sample titration

W= dry sample weight



Figures (2-5): Determination of the organic matter in the soil

2.7 X-RAY fluorescence

The X-ray fluorescence examination requires the preparation of samples before starting the examination.

- 1- Unwanted impurities must be removed from the sample, then we dry them in an oven at a temperature of 105 degrees Celsius to get rid of excess moisture to obtain accurate results.
- 2- Then the soil is well ground to get rid of soil clusters and it is preferable to sift it
- 3- Press soil samples well, remove the air voids from them and place them in the sample cup for XRF so that the sample will be accurate and orderly to be ready for examination.

These steps may require effort and time, but will provide accurate results (Shefsky, 1997).

It can be asserted that the X-ray fluorescence examination is the ideal way to find out the chemical composition of antiques or artifacts of great value because it does not cause damage to the model and gives accurate results, (Janssens, et al., 2000).

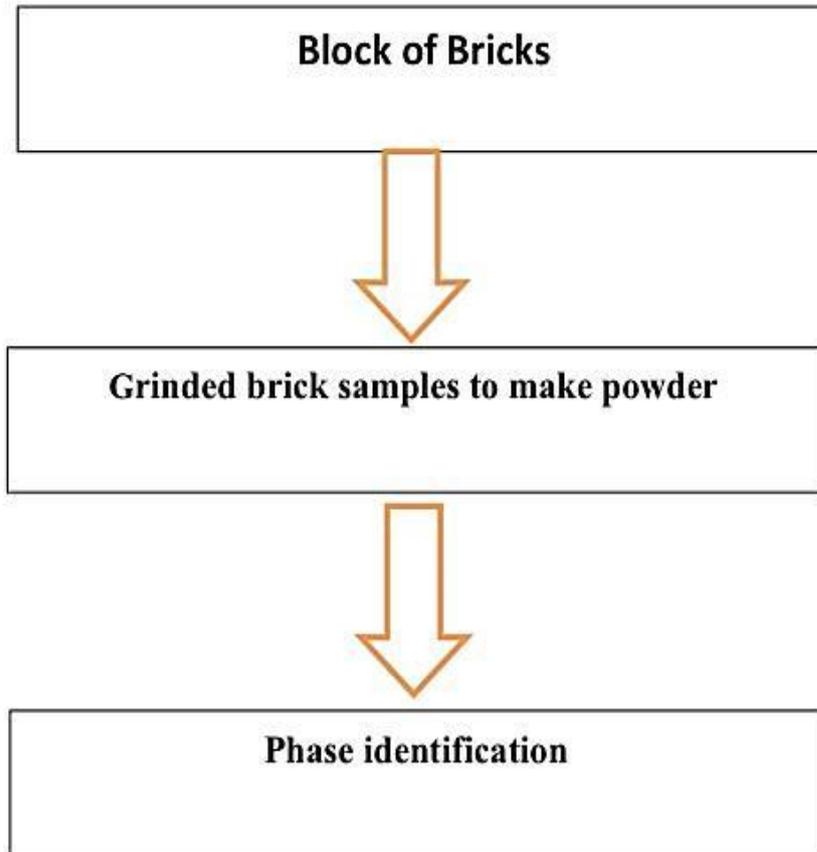
2.8 X-Ray diffraction

This technique is also considered among the non-destructive techniques for the models to be measured, which may be of great importance, the technique of X-ray diffraction depends on the flexible scattering of X-rays from structures of sufficient regularity (Azaroff, et al., 1974).

The work is done in this way for the purpose of identifying and knowing the minerals of the main elements in the soil, as well as the complex mechanism of the elements that make up the soil, as well as the identification of potentially toxic compounds. Working with X-ray diffraction technology may not be that easy due to a number of obstacles such as the changing structure, chemical compositions of soil minerals, including the interactions that occur with the interlayer with defects and bulges that lead to a clear and large difference that occurs in the intensity of the reflection of X-ray diffraction between different species of the same mineral, as well as particle size and distribution, sample thickness and weight, etc (Singh and Agrawal, 2012).

2.8.1 Sampling Site and Sample Preparation

Four fire clay brick samples were collected from the site buildings of the Dilbat or Tel Al-Daylam temple, which is located in Babilon Governorate, an ancient city, to characterize their chemical and mineralogy. As shown schematically in Figure (2-6), small broken pieces of the brittle bricks potsherds were thoroughly hand ground to fine powder in agate mortar.



Figure(2-6): Schematic representation of preparation of the sample specimens for analyzing XRD of the fire clay bricks

2.9 Physical and engineering tests :

2.9.1 Physical test of bricks

It included: bulk density, porosity and water absorption according to ASTM D2487-11 (2011)

2.9.1.1 Bulk density

It can be determined by dividing the mass by volume. (Scott, 1994)

$$\mathbf{Bulk\ Density} = \frac{Mass}{Volume} \dots 2-9$$

Bulk Density unit is kg/m³ or lb/ft³

$$\text{Bulk Density} = \frac{W_0}{B_v} \dots 2-10$$

Where:

W_0 = dry sample weight

B_v = total sample volume

2.9.1.2 Porosity

The definition of porosity in general is in the form of the ratio of the volume of the gaps or voids within the sample to the total volume of the sample and the symbol (n) refers to the porosity. The porosity ratio is measured from the equations below (Duggal, 2008).

$$n\% = \left[\frac{W_3 - W_1}{W_3 - W_2} \right] \times 100 \dots 2-11$$

$$n\% = \left[\frac{V_v}{V_t} \right] \times 100 \dots 2-12$$

While :-

n = porosity (%)

W_1 = dry sample weight (gm)

W_2 = weight of the saturated sample immersed in oil (gm)

W_3 = weight of the oil-saturated sample (gm)

V_v = void volume, = ($w_1 - w_3$) (cm²)

V_t = total volume, = ($w_2 - w_3$) (cm²)

2.9.1.3 Water Absorption

It is the percentage of the absorbed water weight to the total weight of the sample (brick) (Al-Saad, 2014). The following specification was adopted (ASTM C20-00, 2010) according to the following :-

$$\text{W.A \%} = \left[\frac{W_2 - W_0}{W_0} \right] \times 100 \dots 2-13$$

Whereas :

W.A% = percentage of water absorption.

W_2 = Weight of the sample saturated with water (g).

W_0 = Weight of the dry sample (g).

2.9.2 Engineering test of bricks

2.9.2.1 Ultrasonic method

This technique is used as one of the most common methods for examining mortar, concrete, building materials and wood by knowing their mechanical properties such as the modulus of elasticity as well as examining the homogeneity of the material and the compressive strength. The waves are generally divided into two main types: mechanical waves and electromagnetic waves.

Ultrasonic waves are considered among the mechanical waves because this type of waves requires a physical environment for the purpose of its propagation and thus to transmit that energy. It is also possible to divide mechanical waves into two parts: surface waves and body waves. Body waves include P waves or those called longitudinal waves, which are waves Compressive waves, as well as S waves or transverse waves, which are vibrational waves .As for surface waves, they are those waves whose motion

on the surface of the Earth includes Rayleigh waves and Love waves. The longitudinal P and S transverse mechanical waves can propagate at different speeds independently of each other inside solid materials that are homogeneous. This test depends mainly on the measurement of the length of time it takes for ultrasonic waves to travel from one point to another through a specific medium or substance (Araújo, et al, 2020).



Figure (2-7): The ultrasonic device used in the study area.

The value of the longitudinal waves V_p was measured and through it the transverse waves V_s were calculated according to the equation (2-14) : (Araújo, et al, 2020)

$$\mathbf{V_s = 0.7 \times V_p \dots 2-14}$$

Through the relationship between the V_p and V_s , the following modulus were calculated:

poisson's ratio (μ) as in the following equation :

$$\mu = \frac{V_p^2 - 2V_s^2}{2V_p^2 - V_s^2} \dots 2-15$$

Young's modulus (E) :as in the following equation :

$$E = \frac{\rho \times V_p^2 (1 + \mu)(1 - 2\mu)}{(1 - \mu)} \dots 2-16$$

While ρ is density that can be calculated according to the following equation

$$\rho = \frac{m}{V} \dots 2-17$$

Where :

m: weight of sample

V: volume of sample

Shear modulus (G) : as in following equation :

$$G = \rho \times V_s^2 \dots 2-18$$

Bulk modulus or Incompressibility (K) : as in following equation :

$$K = \rho \times V_p^2 - \frac{4}{3} G \dots 2-19$$

Therefore, the compressive strength(F_c) of the bricks of the study area can be calculated according to the following equation (Araújo, et al, 2020) :

$$F_c = 2.7718 \times e^{0.533} \times V_p \dots 2-20$$

Chapter three

Chemical and Mineral Properties

3.1 Chloride (Cl)

Chlorides are found in wide and various places , as it extends from different types of water bodies and in different concentrations to the air and soil, where it is found in the form of compounds such as sodium chloride (NaCl), calcium chloride (CaCl₂) and others (Al-Zubiady and Al-Khalidi, 2019).

It can be said that the amount of chloride in the soil contains is similar to the sulfur content in the lithosphere, about (500 mg / kg), while the swamp soil that is salty can contain chloride at a rate of about (800 mmol / liter). (Xu, et al., 1999)

Types of soils contain varying amounts of chloride. Fertilizers added to the soil as well as soil minerals can be considered important sources for the presence of chlorine in the soil. The water of the oceans and seas supplies the soil with the element of chlorine through the winds that carry it in the form of sodium chloride. The chlorine concentration is always high. In the soils of arid and semi-arid regions, as a result of the low rate of leaching into the lower strata due to the lack of rainfall (Odeh and Shamsham, 2008).

Through the results of the examination, the highest percentage of chlorides was 1.67% in the C2 sample , and the lowest percentage was 0.47% in the C3 sample, with an overall average of 0.9% as shawing in the Table (3-1).

Table (3-1): Chemical analysis results of bricks Cl, OM, TDS, CO₃, SO₃.

Sample	Cl%	O.M%	TDS%	CO ₃ %	SO ₃ %
C1	1.08	3.51	11.60	31.20	3.69
C2	1.67	2.9	10.19	24	2.23
C3	0.47	1.8	2.57	27.40	1.08
C4	1.10	2.22	8	31.8	1.59
M1	0.55	2.22	5.04	18.8	0.69
M2	0.73	1.11	6.53	20	1.06
M3	0.63	4.81	1.27	22.4	0.71
B1	0.67	_____	5.43	20.8	0.61
B2	0.86	_____	6.92	28.2	0.91
B3	1.24	_____	8.74	25	0.81
Range	0.47-1.67	1.11-4.81	1.27-11.60	31.8-18.8	0.61-3.69
Average	0.9	2.65	6.62	24.96	1.33

3.2 Organic matter (OM)

Soil organic matter is formed as a result of the transformation of dead plants into organic products by means of chemical, biological and physical transformation processes. The organic carbon present in the soil is more than the organic carbon present in the vegetation cover and the atmosphere combined (Lehmann and Markus, 2015).

Organic matter has a great role in the nutritional process of plants, as it is important for plant development and growth through its great ability to absorb water. There are many forms of carbon present in the soil, and this organic matter may be animal or plant residues or microscopic organisms. The percentage of organic matter in arable soils ranges from less than 1% to more than 10% (Odeh and Shamsam, 2008).

According to the Table (3-1) the greatest percentage of organic matter is 4.81% in the M3 sample and the lowest percentage is 1.11% in the M2 sample, and the general average of organic materials in the region is 2.65%.

Organic matter is considered one of the solid parts of soil, and the main components of this organic matter are carbon in the first class as well as nitrogen. Organic matter has several advantages, the most important of which is that its specific weight is low, while its surface area is relatively large.

The amount of organic matter accumulated on the surface of the soil varies, and the highest percentage of it is in the cool humid areas, followed by the temperate rainy areas. There is a special type of soil called Muck soils , where this type of soil is characterized by a high percentage of organic matter ranging between 30-70% and in general the organic matter is composed of

carbohydrates, protein and lignin as well as fats, waxes and resin (Al-Sultani, 2016).

3.3 Total dissolved solids (TDS)

There are dissolved salts in the soil in different shapes and quantities. The main source of these salts is the primary minerals in the soil, such as carbonaceous minerals, feldspar, mica and others. These salts are found in a greater percentage in soils of dry areas, while their percentage decreases in soils of moist areas. This is as a result of the climatic conditions prevailing in

those areas, which plays an important role in the amount of the salt content of the soil, when the annual rainfall is low, there is no opportunity to wash the soil from salts, and the rise in temperature leads to an increase in the evaporation process and as a result, the water that contains salts in this soil will be raised to the upper layers of it by capillary property and thus the salts will be deposited on the outer surfaces of the soil (Figure 3-1).

The salts in the soil are mainly produced from chemical weathering processes or as a result of irrigating the lands with highly saline water or because of the spray of the oceans and seas that the winds carry to the neighboring soils, and in any case, the increase in the percentage of salts in the soil has harmful effects on plants such as growth retardation or other toxic damage (Odeh and Shamsam, 2008).

According to the results of the analysis listed in Table (3-1), the highest value of total dissolved salts is 11.60% in sample C1 and the lowest value is 1.27% in sample M3 and that the general average of salts is 6.62%.



Figure (3-1) : The salts in this soil of study area

3.4 Carbonates (CO₃)

Carbonates are found in the soil in different types, such as sodium carbonate, magnesium carbonate (Magnesite), calcium carbonate (Calcit), calcium and magnesium carbonates (Dolomite) and others. The total carbonate ratio in the soil varies according to many factors, including the mother rocks that make up the soil and the prevailing climate. The carbonate content is low in soils in humid areas, while its percentage increases dramatically, reaching 50% in soils of dry areas (Al-Khouri and Al-Hassan, 2019).

Calcium carbonate is the most common type of carbonate in the soil in terms of its presence. This type of soil is called calcareous soils and it is common in dry areas. The presence of calcium carbonate in the soil helps to improve its fertility and build it even by a small percentage, but when it is

present in very high rates, it will negatively affect plants and soil, where their productivity and fertility will decrease. (Al-Khouri and Al-Hassan ,2019).

The percentage of carbonates can be observed as shown in the Table (3-1) where the highest value was in the C4 sample, which amounted to 31.8%, while the lowest value of carbonates in the M1 sample, which amounts to 18.8%, and the general average of carbonates is 24.96%.

3.5 Sulfates (SO₄)

One of the sources of sulfates in the soil is the mineral pyrite, where it is found in the form of sulfide, and in the process of weathering in the soil, it will turn into sulfate. Sulfur is present in the soil of dry and semi-dry areas precipitated in the form of calcium sulfate (gypsum) CaSO₄.2H₂O also in the form of magnesium sulfate MgSO₄.7H₂O , the rise in its percentage in the soil leads to To the toxicity of some types of plants (Odeh and Shamsham, 2008).

Sulfates are sensitive to the processes of reduction and oxidation, and although sulfates are present in the soil in a small percentage, they may cause serious problems for the environment and agriculture. These environmental problems are related to sulfate minerals as well as sulphides, which work on the liberation or emission of sulfuric acid in the water and soil, when the sulfide is oxidized to sulfate. Likewise, when the hydrolysis of ferric sulfate occurs, it will lead to the formation of minerals such as iron oxides (Jarosite).

The most prominent problems in soils that have a high acid sulfate activity are the lack of growth of plants and crops or their poor growth in general. Sulfate minerals are created in the soil from several sources, including fertilizers, building materials and irrigation water.

Although sulfates are present in a very small amount in the soil in the form of minerals such as pyrite, rozenite and others, it will produce sulfuric acid when exposed to oxidation conditions and thus will lead to severe acidity in the soil as well as corrosion in concrete and minerals that are in contact with water and soil containing these acids (Fanning, et al., 2002).

The percentages of sulfates in the region were shown in Table (3-1), as the maximum percentage 3.69% in sample C1 and the lowest percentage 0.61% in sample B1, and the general rate of sulfates in the area was 1.33%.

3.6 X-ray fluorescence analyses

This technology is mainly used for the purpose of the structural analysis of archaeological materials or any substance of high value without the need to destroy it, which is considered one of the non-destructive techniques that give fast and high-accuracy results, so this technique was used to conduct an analysis of research samples (C1, C2, C3, C4, M1, M2, M3, B1, B2, B3) (Table 3-2). Many Archaeologists and those interested in artifacts worked for long periods of time with the X-ray fluorescence technique, but it has spread on a larger scale when this technique appeared in a simple, inexpensive and most importantly, portable form.

When analyzing the samples to be examined, the X-rays are shed on the sample for a relatively short period of time, and this will lead to the movement of the electrons inside the atoms within the material to be examined, and when the shedding of these X-rays is stopped, the electron will stabilize and release the energy obtained from the X-rays in the form of photons. The X-ray fluorescence device will measure the energy released by the electrons when they are stable.

Table (3-2): XRF test results of bricks

Minerals ppm	Clay Samples				Mudbricks Samples			Bricks Samples		
	C1	C2	C3	C4	M1	M2	M3	B1	B2	B3
Mn	606	591	691	648	657	680	646	809	672	713
Fe	27.7 k	28.1 k	31.1 k	30.1 k	32.6 k	29.4 k	29.7 k	36.0 k	29.6 k	30.6 k
Co	168	279	200	187	177	179	176	303	219	197
Ni	240	240	198	228	225	227	202	238	0	196
Cu	38	40	39	39	35	43	40	60	72	57
Zn	74	74	74	75	0	63	72	1217	799	185
As	7	10	10	9	8	9	7	7	9	6
Se	2	1	2	2	1	1	2	1	1	2
Rb	43	46	39	40	43	38	38	27	34	37
Sr	420	429	355	381	324	328	340	395	371	403
Zr	88	87	106	97	0	94	93	112	93	104
Mo	4	6	3	3	4	3	4	4	2	5
W	12	29	24	22	33	29	29	17	34	30
Au	5	3	8	5	5	4	4	5	3	5
Hg	2	5	2	2	0	1	4	3	2	0
Pb	13	13	13	13	14	11	11	8	16	15

The X-ray fluorescence device can measure more than one element at the same time and it will be displayed on a screen in the form of several peaks, as

these peaks depend on the concentration of that element in the sample. The units are measured by parts per million, symbolized by (ppm), and there is a direct relationship between the elements that have the largest atomic number and the peaks, the higher the atomic number elements will have higher peaks (Nostrom, 2014). Clay brick masonry is one of humanity's oldest and most durable construction techniques. Masonry is made up of manually constructed stable stacks of small elements, with or without mortar. It was an important building material during the Mesopotamian, Egyptian, and Roman eras. Clay brick masonry was still used in medieval and modern times, despite several clay brick modifications.

X-ray fluorescence (XRF) is a technique that uses X-rays to identify and quantify the elemental composition of several solid materials, allowing for chemical characterization of the analyzed material and correlation with other properties (Gazley and Fisher, 2014; Weindorf, et al, 2014). High energy X-rays reach the atoms that make up the structure of the analyzed materials, causing electrons to be dislodged from their original orbit. As the electrons return to their original orbit, they emit energy in the form of fluorescence that is unique to each element. As a result, the elements found in the analyzed materials can be identified (Weindorf, et al., 2014). Technological advancements enabled the development of portable X-ray fluorescence (pXRF) equipment, which has been demonstrated to be a precise, accurate, low-cost, rapid, non-destructive, and environmentally friendly method for determining the elemental composition of soils and other materials. The XRF is based on measuring the intensities of X-ray emissions that are characteristic of each chemical element that makes up the sample. To produce this emission, the sample must be exposed to enough energy to excite the electrons of the elements that make up the sample. The technique requires that species be irradiated with extremely energetic photons, and the atom is excited when it is struck by particles produced in particle accelerators, electromagnetic waves,

or through X-ray tubes of Ta/Au, Rh or Ag (Kalnicky and Singhvi, 2001). The latter is the most common method.

The X-ray technique is widely used in various fields of science around the world. The dispersion technique is used by X-ray diffraction (XRD), which is widely used in soil science, to determine the crystalline composition of minerals in soils and sediments, whereas XRF is an example of an X-ray absorption/emission technique used to determine the chemical composition of the sample (Kalnicky and Singhvi, 2001; Gazley and Fisher, 2014). Today, two kinds of XRF are available: wavelength dispersion X-ray fluorescence (WDXRF) and energy dispersive X-ray fluorescence (EDXRF) (EDXRF). Normally, each measurement takes up to 60 seconds, but the user can set the scanning time. Some factors may influence the XRF results and must be carefully considered, as summarized below:

a) Moisture content of the soil: Water absorbs a portion of the X-rays that would otherwise strike soil particles or scatter the primary X-rays in wet soil samples (Stockmann, et al, 2016).

b) The particle size distribution obtained when a soil sample is ground and sieved may influence the results. Because of the smaller incident angles, the XRF intensity increases for smaller soil particles (Maruyama, et al, 2008). Then, for fine soil particles, a higher elemental concentration may be expected. It is recommended to use air-dried soil samples passed through a 2 mm sieve for inlab determination (Laiho and Perämäki, 2005). Various papers have been published in recent years in several research areas, such as geology, archeology, and paleontology, whereas not much has been published in terms of soil characterization for various purposes pXRF in soils for environmental, pedological, and agronomic applications, in an effort to provide insights and stimulate future tests, primarily in tropical countries with limited soil data. Every 10 m along the enclosure wall, brick samples weighing at least 100 g were collected. A total of three mud brick, soil, and grilled brick samples

were studied. Field data were collected for all samples. All geochemical analyses were performed in the field at the Dilbat site and are summarized in Table (3-2). For a total of 17 elements, the NITON unit produced measurements in parts per million (ppm). It was used in bulk sample mode, with the entire list of element concentrations and depositions. Each sample was tested for at least 60 seconds. Measurements were taken directly from unpowdered samples.

The resulting strontium (Sr), rubidium (Rb), and iron (Fe) measurements were graphed in triangular relation using Delta Graph 5. (Fig. 3-2). The triangular scattergram was designed in such a way that one corner, represented by Sr, represents carbonate content, one corner, represented by Rb, represents volcanics, micas, and illitic mud, and one corner, represented by Fe, represents noncarbonated silt detritus (dominantly derived from igneous rocks). To plot all three elements at a reasonable scale on the same graph, rubidium (ppm) was multiplied by 10, and iron (ppm) was divided by 100 (Morgenstein and Redmount, 2005). Comparison of the geochemical and analyses of the surface sediments and the mud brick on the other hand (Table 3-2) suggests that there are one potential source areas for the mud brick sediments. Geochemical brick type two correlates with sediment sample locations portable XRF spectrometer was employed to acquire trace element geochemistry; of the elements measured, Sr, Rb, and Fe were utilized to fingerprint the mud bricks and the surface sediments for provenance analysis. That process revealed that one distinct geochemical brick types were used to construct the temple.

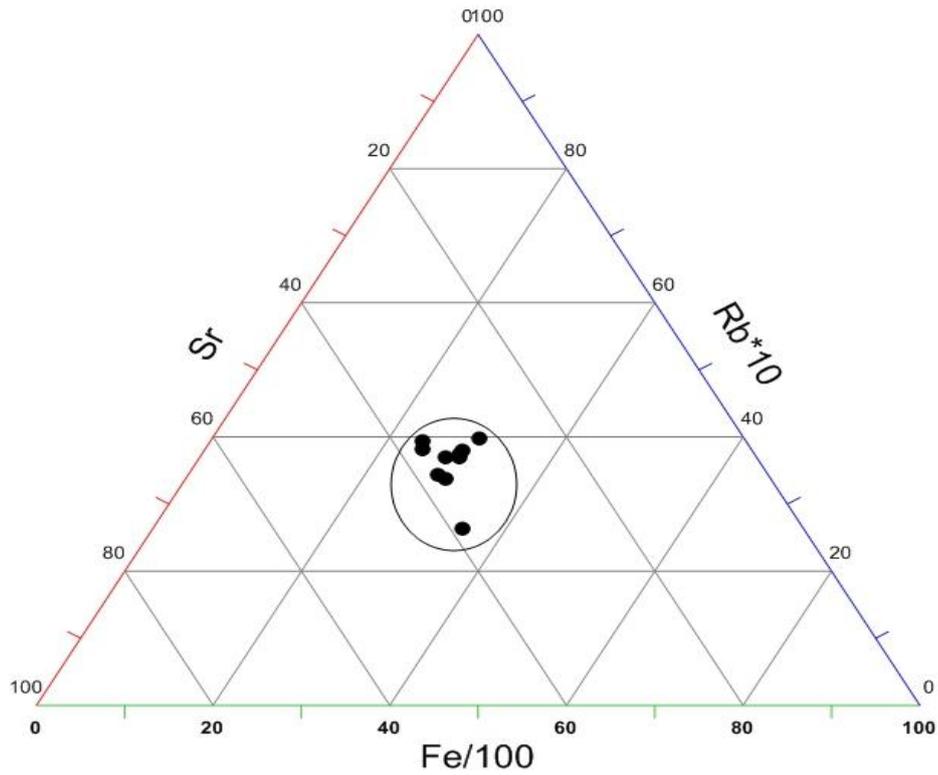


Figure (3-2): Rb-Sr-Fe scattergram showing the brick geochemical groups. Rb,Sr,Fe scattergram showing the potential source surface sediment geochemical group

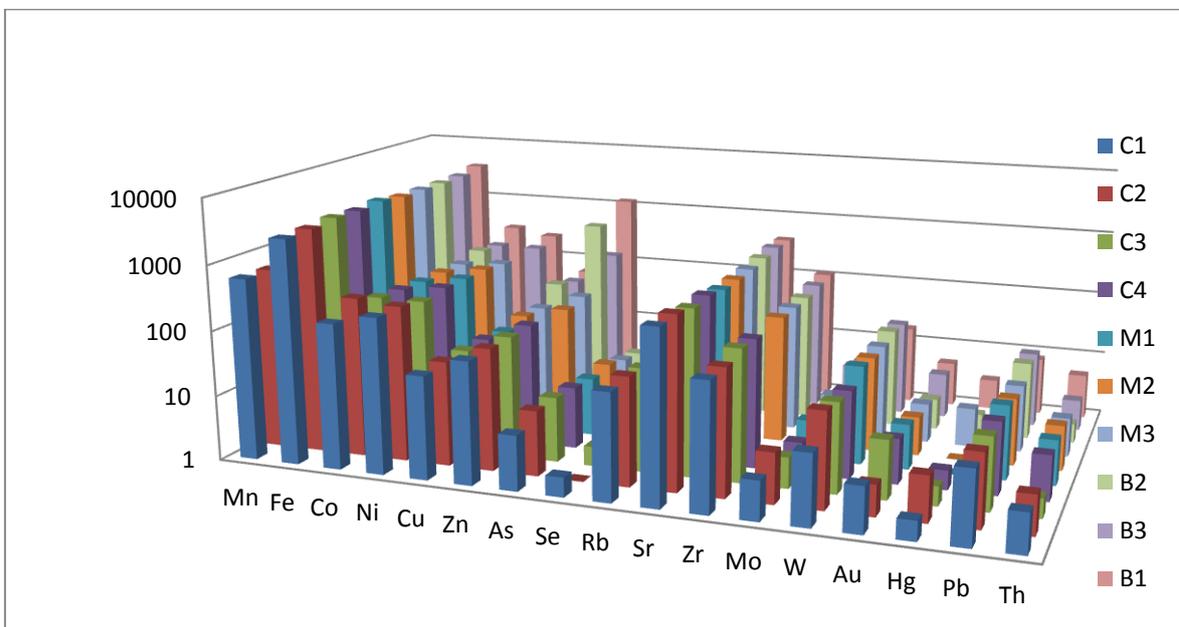


Figure (3-3): Comparison of the concentration difference of miner and trace elements

3.7 Introduction

Clay bricks are one of the most basic examples of a traditional ceramic body, made from clays, silica, fluxes, and other raw materials. They are usually prepared at room temperature by grinding, sieving, mixing, moistening, and shaping by pressing, casting, or other processes. They are then dried before being fired at a high temperature. Bricks are widely used in construction, foundation walls, and boundary walls.

The chemical/mineralogical, physico-chemical, mechanical, and thermal properties of ceramic bodies vary depending on the degree of high temperature firing. All of the properties of clay ceramic bricks are interconnected. The primary raw materials for manufacturing various clay bricks are various clay minerals, which have a large impact on their technological properties (Cultrone, et al, 2001). To ensure maximally high brick product parameters, the water content and solid phase dispersion of the clays used for the production of clay bricks should be optimized while taking subsequent drying and sintering into account. One of the primary indicators for selecting a component for the final mixture is the chemical composition of the clay raw materials. The most significant effect on the properties of ceramic articles is exerted by Al_2O_3 .

The refractoriness and mechanical strength of the material increase as the Al_2O_3 content increases. SiO_2 , on the other hand, reduces shrinkage as well as the refractoriness of ceramic products. Fluxes such as feldspars, sodium, potassium, calcium, magnesium, iron, and titanium oxides are strong fluxes that reduce the viscosity of the ceramic products' liquid phase. Clay with a high Fe_2O_3 and TiO_2 content reduces product quality while increasing plasticity and mechanical strength.

3.8 XRD of Bricks

The clay brick samples are analyzed chemically and mineralogically at the University of Babylon using X-ray diffraction (XRD) analysis on a D8 Advanced Diffractometer (Bruker, Germany) with Cu K radiation ($\lambda = 0.15418$ nm) at a scanning speed of 20 minute in 2θ mode between 10° – 70° .

Mineralogical Analysis of Clay Bricks

In the current study, the mineralogical analysis of four fired clay bricks was performed using the powder X-ray diffraction (XRD) technique..

XRD Patterns of Clay Bricks.

The XRD technique is one of the most commonly used methods for identifying various minerals and compounds found in fired clay bricks (Chung and Smith, 1974). Although qualitative identification of the phases present in clay bricks using XRD patterns is relatively simple, several factors complicate accurate identification.

Although several factors makes complication for accurate In this context, present research was focused to identify the phase compositions of four collected clay bricks from site buildings of the Dilbat or Tel Daylam temple,using XRD patterns and the results are shown in Figs.(3-4, 3-5, 3-6, 3-7). Crystalline phases present in the analyzed four fired clay brick samples were identified mainly of quartz, feldspars, calcite, with the help of the corresponding JCPDS (Joint Committee on Powder Diffraction Standards) database files (JCPDS, 1999). Due to the fact that the ceramic systems are non-equilibrium systems, different phases develop as the heating temperature varies both in time duration and degree. Consequently, it becomes difficult to predict the exact final phases of the end products of the fired ceramic bodies like bricks. Due to the presence of impurities in some raw materials of the ceramic bodies, attached minor phases inevitably develop that had negative

effects on the mechanical properties. In general, the mechanical properties of the fired clay bodies are worsening in presence of undesired phases like calcite and dolomite observed in XRD patterns of the fired clay bricks(Cultrone, et al, 2004). indicated that these a ancient old brick samples have good mechanical and physico-sintering properties. It is considered that the mechanical strength of the ceramic bodies can attribute to residual quartz content and its particle size, and amount of glassy phases present in it (Sveda, M., 2000).

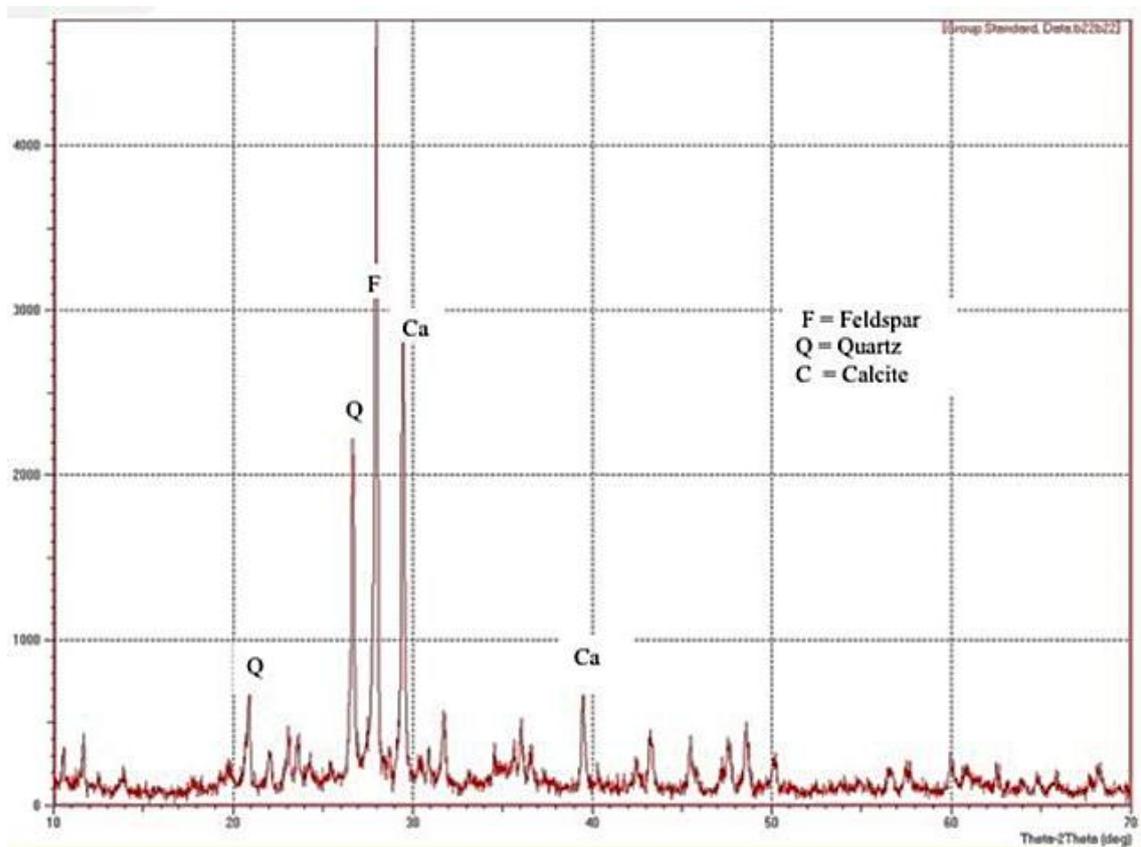


Figure (3-4): XRD patterns of clay bricks-B2

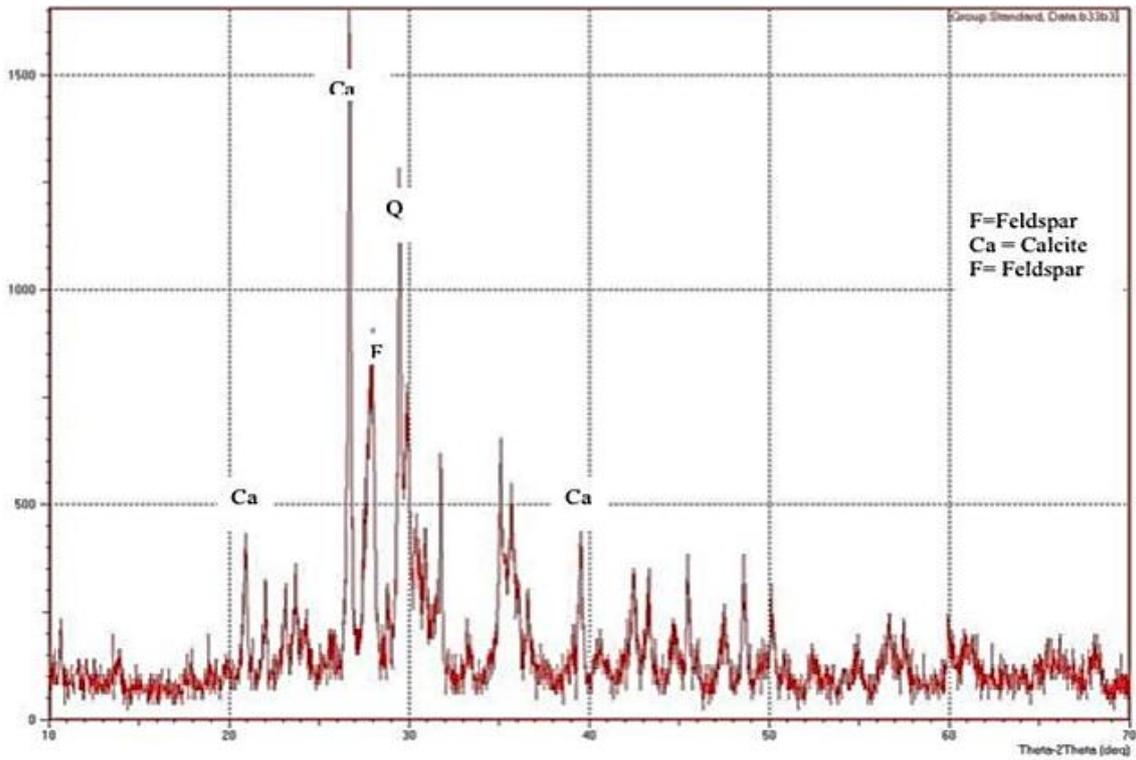


Figure (3-5): XRD patterns of clay bricks-B3

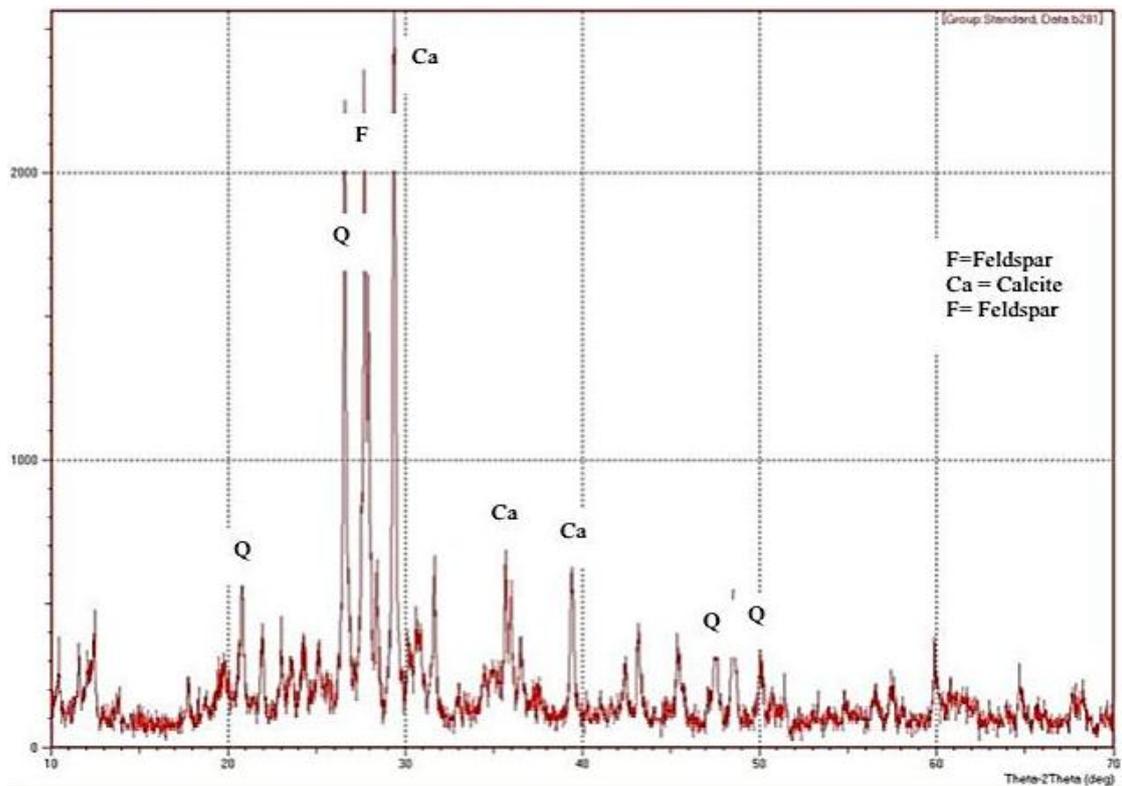


Figure (3-6): XRD patterns of clay bricks-M2

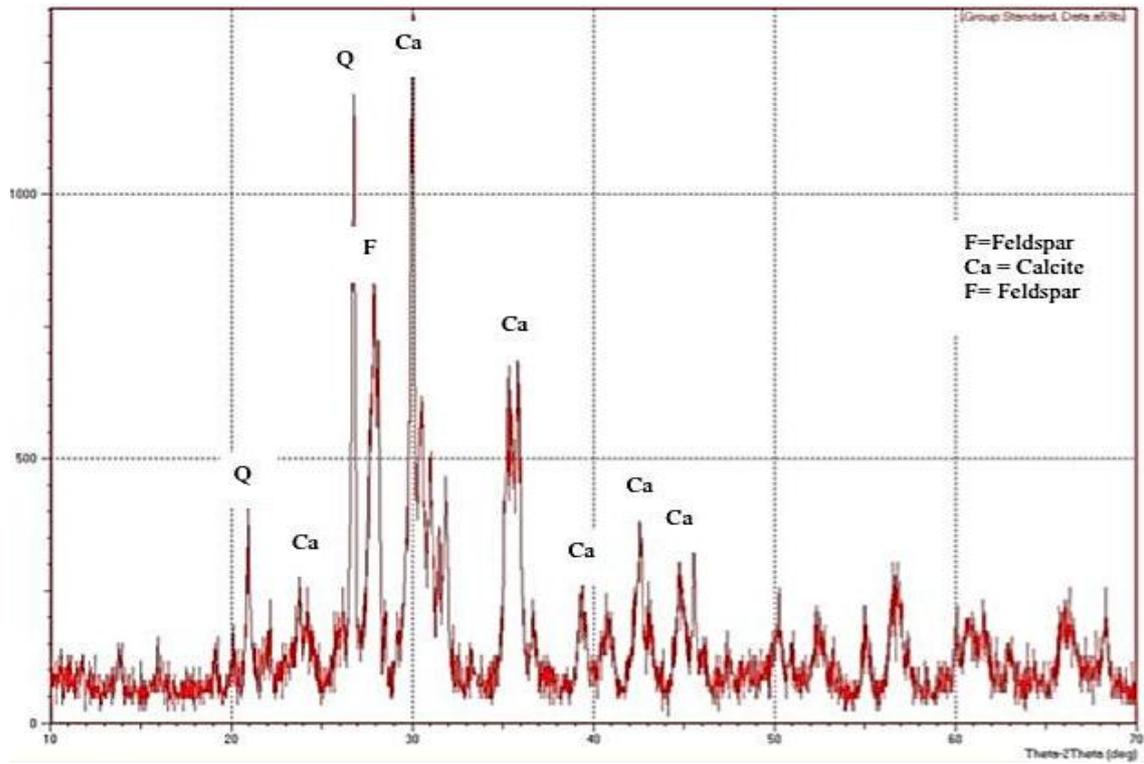


Figure (3-7): XRD patterns of clay bricks-B1

Chapter Four

Physical and engineering properties

4.1 Introduction

A number of physical and engineering tests were carried out on the mud bricks for the purpose of describing it. These tests included (ultrasonic test, density, absorption ratio , porosity). Through the results that obtained from the tests, the bearing capacity of the building materials at the ancient site of Dilbat can identified, this will help understand of the preservation of this archaeological site. This is done by taking into account the physical characteristics as well as the cultural value in addition to the physical behavior of them under environmental influence and loading.

The obtained information related to mechanical and physical properties and durability is important in order to understand the behavior of these building materials related to their rehabilitation, maintenance and preservation. Such buildings must be taken care of when conducting examinations for them to avoid any damage that may be caused to the building, as they are of historical and archaeological importance and must be preserved as much as possible, Through the use of non-destructive examination methods such as ultrasonic examination (Araújo, et al, 2020).

4.2 Physical tests results

it includes bulk density, porosity and water absorption.

4.2.1 bulk density

It is an important parameter. The bulk density for Dilbat bricks (Table 4-1) ranging from the maximum value of 1.52 gm/cm^3 in S5 to the minimum value 0.89 gm/cm^3 in the S3 and the average is 1.09 gm/cm^3 .

Table (4-1): The results of physical properties of Dilbat bricks

Sample No.	Bulk density gm/cm³	Porosity%	Water Absorption
S1	1.12	24.61	22.10
S2	1.03	27.30	26.17
S3	0.89	18.53	15.94
S4	0.94	20.14	18.22
S5	1.52	27.26	25.72
S6	1.35	26.15	23.45
S7	0.93	19.24	16.80
S8	1.24	25.17	22.38
S9	0.90	19.87	17.15
S10	0.98	22.40	20.68
Range	0.89-1.52	18.53-27.30	15.94-26.17
Average	1.09	23.06	20.86

4.2.2 Porosity

The presence of pores in rocks and other materials depends on the shape and size of the crystals or grains that make up the sample or rock, as well as the degree of gradation of these grains, how they are stacked and arranged, and the type of bonding material (Safok, 2010). Porosity is one of the most important properties that affect the mechanical and physical properties of a rock or sample, such as durability (Sabatakakis ,et al, 2008) . Porosity is classified into two types. The first type is called (primary porosity) this type of porosity arises during the formation of the rock. The second type of porosity is (secondary porosity) this type is related to natural accidents that the rock may be exposed to, such as cracks, fractures, breaks, and others (Wyllie, et al, 1958). Porosity affects the quality of bricks and is considered one of the important factors because it affects many properties of bricks such as durability and mechanical strength. Old bricks contain high values of

porosity that may reach about 15 to 40% of the volume of bricks (Fernandes, et al, 2010).

The quality of the raw materials used to produce bricks such as clay and straw as well as the added amount of water and the degree of burning of the bricks will greatly affect the distribution and size of the pores. There is a relationship between the temperature of burning bricks and the pores. The higher the burning temperature, the larger the pores will increase, which reach about 3-15 micrometers, and the contact of these pores will be little, while the small pores will reduce their percentage. It was shown through the studies that were conducted that large pores are better than small ones because Less affected by the cycles of thawing and freezing, as well as soluble salts.

The small pores (1 micron or less) in the bricks result from the presence of some low-quality materials in the clay such as carbon, as well as from burning bricks at a temperature of 800-1000 degrees Celsius. In general, these pores in bricks have negative effects such as decreasing the durability and quality of bricks. (Fernandes, et al, 2010).The porosity for Dilbat bricks (Table 4-1) ranging from the maximum value of 27.30% in the S2 to the minimum value 18.53% in the S3 and the average is 23.06.The porosity values depend on the size, shape of grains ,mineral crystals, degree of grading and the nature of packing (Sabatakakis, et al, 2008).

4.2.3 Water Absorption

Absorption is defined as the percentage of absorbed water that occupies in the bricks through its pores (Al-Saad, 2014).

The water absorption for Dilbat bricks (Table 4-1) ranging from the maximum value of 26.17 in S2 to the minimum value 15.94 in the S3 and the average is 20.8

4.3 Engineering test results

5.3.1 Ultrasonic method

Ultrasonic is one of the non-destructive techniques that are important in describing building materials, especially those that are related to the archaeological and historical field, due to the need to preserve them as a heritage. Other advantages of non-destructive measurements are that they can be performed within a short period of time and with remarkable ease.

From Table (4-2) the value of V_p for Dilbat bricks ranges from the maximum value of 2410 m/s in S5 to the minimum value 350 in the S3 and the average is (1053)m/s.

The value of V_s for Dilbat bricks (Table 4-2) ranges from the maximum value of 1687 m/s in S5 to the minimum value 245 in the S3 and the average is 737.1 m/s.

Poisson's ratio for Dilbat bricks (Table 4-2) is 0.013 for all samples.

Young's modulus ranging from the maximum value of 8.82 Mpa in S5 to the minimum value 0.11 Mpa in the S3 and the average is 1.89 Mpa.

Shear modulus ranges from the maximum value of 4.32 Mpa in S5 to the minimum value 0.05 Mpa in the S3 and the average is 0.92 Mpa.

Bulk modulus ranges from the maximum value of 8.82 Mpa in S5 to the minimum value 0.11 Mpa in the S3 and the average is 1.89 Mpa while compressibility (F_c) ranges from the maximum value of 9.96 Mpa in S5 to the minimum value 3.31 Mpa in the S3 and the average is 5.10Mpa.

Table (4-2) shows the results of engineering properties of Dilbat bricks

Sample No.	Vp m/s	Vs m/s	Poisson's ratio (μ)	Young's modulus (E) Mpa	Shear modulus (G) Mpa	Bulk modulus (K) Mpa	Compressibility (Fc) N/mm ²
S1	1290	903	0.013	1.86	0.91	1.86	5.47
S2	1050	735	0.013	1.13	0.55	1.13	4.80
S3	350	245	0.013	0.11	0.05	0.11	3.31
S4	650	455	0.013	0.40	0.19	0.40	3.89
S5	2410	1687	0.013	8.82	4.32	8.82	9.96
S6	1470	1029	0.013	2.91	1.42	2.91	6.04
S7	560	392	0.013	0.29	0.14	0.29	3.70
S8	1430	1001	0.013	2.53	1.24	2.53	5.92
S9	520	364	0.013	0.24	0.11	0.24	3.63
S10	800	560	0.013	0.62	0.31	0.62	4.21
Range	350- 2410	245- 1687	0.013- 0.013	0.11- 8.82	0.05- 4.32	0.11- 8.82	3.31-9.96
Average	1053	737.1	0.013	1.89	0.92	8.82	5.10

Figures (4-1) (4-2) (4-3) (4-4) show the relationship between the Bulk modulus (K) with Compressibility (Fc), the secondary waves (Vs) with Compressibility (Fc), the bulk density (ρ) with porosity (n), the bulk modulus (K) with bulk density(ρ) as the relationship between (Fc-K,Vs) is a good

directive relationship $r=0.977$, $r=0.968$, also the relationship between $(\rho-n,K)$ is also a good directive relationship $r=0.64$, $r=0.84$

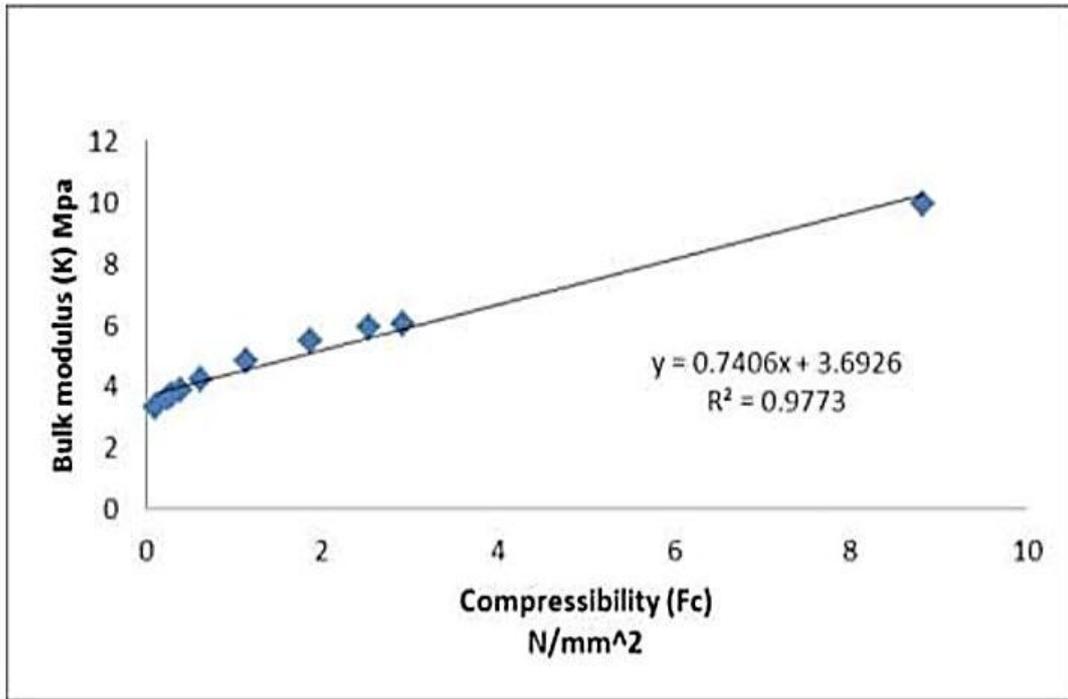


Figure (4-1): Relationship between (K) and (Fc)

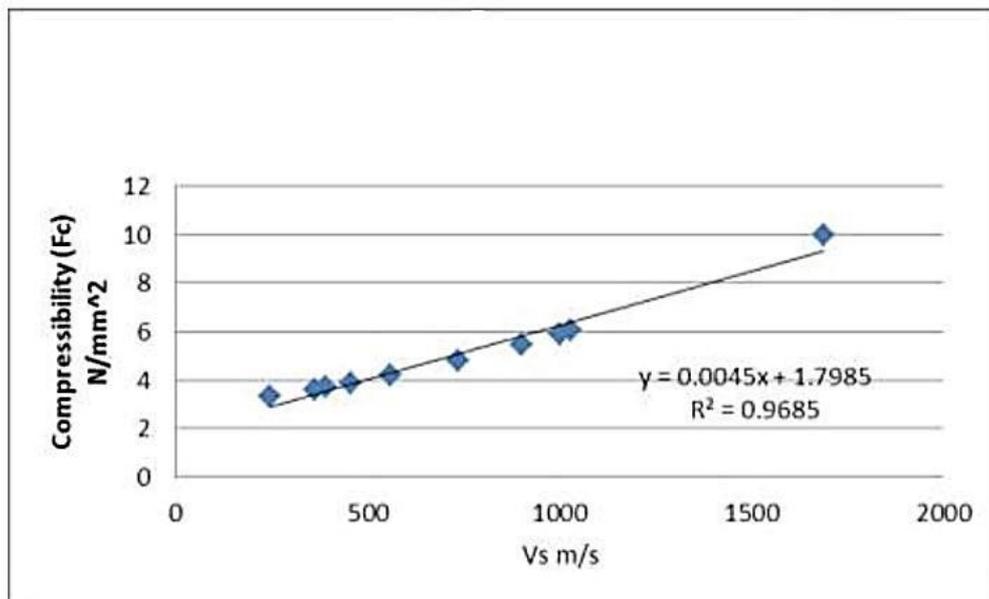
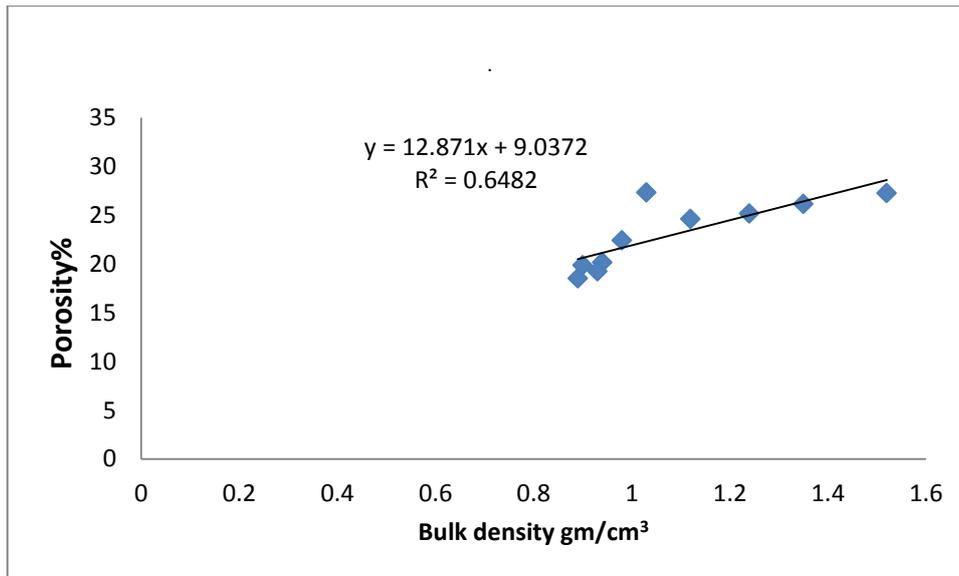
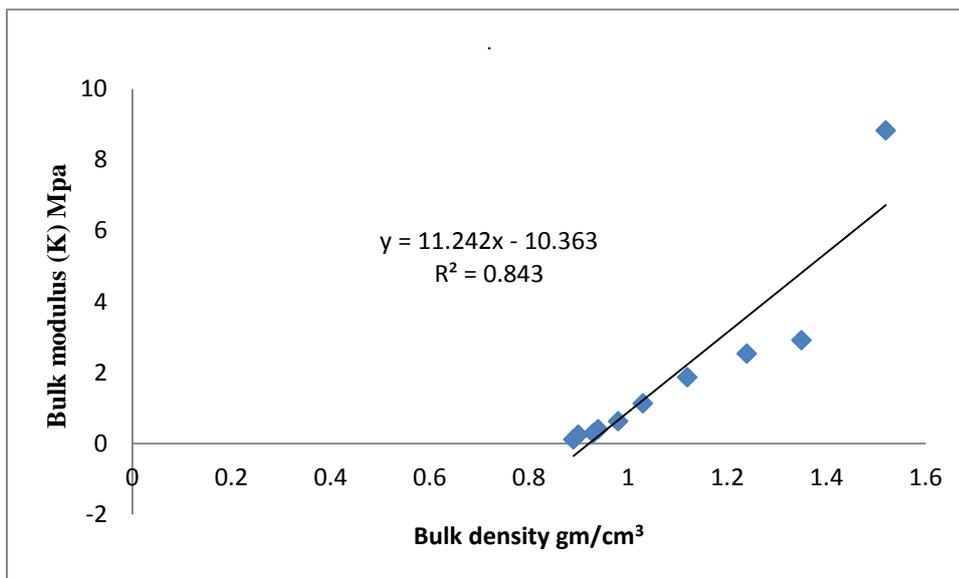


Figure (4-2): Relationship between (Vs) and (Fc)



Figure(4-3): Relationship between (ρ) and (n)



Figure(4-4): Relationship between (ρ) and (K)

When comparing the results of the compressive strength of the bricks of the study area according to the Iraqi standard specification (IQS 25-1993) Table(4-3) (ASTM C62-10, 2010) Table (4-4) (shows that the bricks of the study area are a type of (C) according to (IQS 25-1993) and a type of (C) according to (ASTM C62-10, 2010).

Table (4-3) the Iraqi standard specification(IQS 25-1993)

Classes	Minimum brick pressure N/mm ²	Maximum Absorption Percentage % of bricks
A	16	22
A-10 bricks	18	20
B	11	26
B-10 bricks	13	24
C	7	28
C-10 bricks	9	26

Table (4-4) the (ASTM C62-10 , 2010).

Classes	Minimum brick pressure N/mm ²	Maximum Absorption Percentage % of bricks
A	17	20
B	15	25
C	9	-

Chapter Five

Conclusions and Commendations

5.1 Conclusions

1. The old building materials (bricks, mud bricks and mud) at the site of Delbat date back to the Middle Babylonian period (1500-600 BC).

2. The results of the chemical tests showed that the rate of chlorides, sulfates, carbonates and organic matter is within the normal limits, but there was a slight increase in the TDS ratio, which may be due to the increased movement of groundwater (which may contain a high percentage of salts) to the soil surface due to capillary action. These salts negatively affect the resistance of the bricks and cause it to break easily.

3. The results of the XRF examination of bricks, mud bricks and clay showed the presence of high percentages of the elements Mn, Sr, Ni, Co and other elements in lower percentages. The percentages of each of these elements are similar for all samples, and this indicates that the building materials for the Urash temple are from a single source area (imported).

4. The results of XRD analysis of brick powder showed that it contains feldspar, quartz and calcite minerals, where calcite negatively affects the mechanical properties of bricks, causing cracks, while quartz and feldspar cause an increase in the durability of bricks.

5. Through the results of the physical and engineering tests, the bricks were classified as Class C according to the Iraqi and American specifications

5.2 Recommendation

1. Conducting a comprehensive study on the city of Delbat before starting any study project, as new discoveries must be made about the temple of the god Urash, which in turn may affect the results of the study.

2. Use non-destructive techniques as much as possible, such as ultrasonic , to perform the necessary examinations because the area is antiquated and therefore no sample should be destroyed.

3. Addressing some problems that may negatively affect the durability of building materials in the temple of the god Urash, such as weathering factors, by building roofs and others to avoid rain and wind.

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المستخلص:

تعتبر الاثار من اهم المعالم الحضارية التي خلفتها لنا الحضارات والامم السابقة فهي تعكس ثقافتهم ومعتقداتهم الدينية والحياة اليومية العامة، يهدف هذا البحث الى دراسة مدينة دلبات او ماتعرف محلياً بتل الديلم والتي تقع في الجزء الجنوبي من محافظة بابل ضمن مقاطعة الكفل وتعتبر احد اهم المناطق الاثرية بسبب احتوائها على معبد الاله اوراش والذي يعود الى العصر البابلي الوسيط (١٥٠٠-٦٠٠) قبل الميلاد وهذا المعبد يمثل جزء مهم من المعتقدات الدينية لسكان بابل القديمه.

للفحوصات الكيميائية اجريت على 10 عينات من مناطق متفرقة من المعبد شملت هذه العينات 3 عينات طابوق و 3 عينات لبن و 4 عينات طين حيث اظهرت النتائج ان معدل كل من الكلوريدات Cl هو 0.9% والمواد العضوية % 2.65 والمواد الصلبة الكلية المذابة % 6.62 والكاربونات CO₃ % 24.69 والكبريتات SO₄ % 1.33 وهي نسبيا مقاربة للنسب الموجودة في الطابوق للوقت الحالي.

اجراء تحليل الاشعة السينية المفلورة (XRF) لكل عينات الطابوق واللبن والطين واطهرت النتائج نسب عالية لكل من عناصر المغنيسيوم Mg والحديد Fe والكوبلت Co و النيكل Ni و السترونتيوم Sr.

وكذلك تم تشخيص المحتوى المعدني لعينات الطابوق الثلاثة ونموذج واحد من اللبن فقط واطهرت النتائج بشكل اساسي معادن الكوارتز والفلدسبار والكالسايت حيث تبين ان الطابوق يتمتع بصفات فيزيائية وهندسية جيدة ترجع الى محتوى الكوارتز والفلدسبار.

الفحوصات الفيزيائية والهندسية اجريت لعشرة عينات من الطابوق، شملت الفحوصات الفيزيائية فحص الكثافة والتي كانت بمعدل 1.09 غم/سم³ وفحص المسامية بمعدل % 23.06 وامتصاص الماء بمعدل % 20.86 اما الفحوصات الهندسية فقد اجريت بواسطة جهاز الموجات فوق الصوتية عن طريق قياس سرعة الموجات Vp وتبين من النتائج ان انضغاطية الطابوق كانت بمعدل 5.10 نيوتن/مم² وهذا يرجع الى تعرض الطابوق الى عوامل التجوية لفترات طويلة من الزمن.



وزارة التعليم العالي والبحث العلمي

جامعة بابل

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وهي جزء من متطلبات نيل درجة الماجستير في العلوم/ علم الارض التطبيقي

من قبل

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بكالوريوس علوم علم الارض- جامعة بابل

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بإشراف

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