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ASSESSMENT OF THE SUITABILITY OF RAW MATERIALS FOR CONSTRUCTION MANUFACTURERS, FROM ELLAN ANTICLINE, NORTHWESTERN MOSUL CITY, NINEVEH GOVERNORATE, IRAQ

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ABSTRACT

The fast population growth and significant urban development put pressure and demand on raw materials that are used for construction like carbonate rocks, clay, and gypsum. Providing new background information for these raw materials that may be suitable for different industries, such as cement, Juss, plaster, building stone, and bricks is aimed in this study. Therefore, the study includes a field reconnaissance of seven sites within the Ellan anticline, northwest of Mosul City, several twenty-five rock samples were collected and analyzed from the best exposures of the formations. The results show that unit C of the lower member and the upper member of the Fatha Formation are suitable raw materials for the manufacturing of the cement industry. Gypsum strata in the Fatha Formation are suitable for multiple industries such as cement, Juss, plaster, building units, light tile or blocks, and for the protection of columns. The chemical results of major oxides for limestone from Euphrates and lower members of Fatha formations (units A and B) show that the mean concentrations of CaO, MgO, and alkali oxides are higher than the limit values in Iraqi standards. The bulk-rock analysis for major element oxides of unit C demonstrates that rocks are within the limit values. In addition, most of the oxides of limestone and marly limestone of the upper member of the Fatha Formation are within the standard quality for the cement industry. Clays from Quaternary sediments were found to be suitable for the cement industry only, while the pre-Quaternary appears to be not suitable for cement or perforated brick industries.

1. INTRODUCTION

The cement, brick Industry, and decoration stones are important components of the economic sector in Iraq, which has a substantial impact on the financial stability and economic development of the country. In recent years, cement production has become the most important industry in the country and entered into the export market after fulfilling the domestic demand for cement. At present, according to the Ministry of Industry and Minerals, over 20 cement plants are operated in Iraq, and distributed in some governorates in Iraq. Five of these plants belong to the private sector, 6 are invested by deed of partnership and 11 are still managed by the Ministry of Industry and Minerals. These plants produce about 30 million tons per year if they operate at their full design capacity, and this reflects that the private sector is heavily investing in the cement industry. The majority of the production cement in Iraq comes from the northern and southwestern parts.

On the other hand, brick factories are unfortunately less financially supported than cement, and the demand for building materials in Iraq. However, using of recent clays (agricultural soils) in construction industries caused the reduction of large areas of agricultural lands in Iraq, which affected and reduced many agricultural products. Finding another source, such as ancient clays would be of great importance to keep a balance between using land for food and construction.

Nevertheless, clays are considered one of the wide spreading materials found on the earth's surface, depending on their physical and chemical properties, they are used in different kinds of industries; brick manufacturing is one of these. Despite their high quality, bricks are not a desired building material in the northern region of Iraq, where the use of materials that are cheaper and quicker to work with is preferred. Evaporate rocks were used in the sculptures of the ancient civilizations in the Mosul vicinity, and the Assyrian ruins of Namroud are an example. The Evaporate (anhydrite and gypsum) of the Fatha Formation is also used as a decorative building material, especially in Mosul and Kirkuk cities. Moreover, gypsum is the source material for the Juss and plaster industries, and it is used as a retarder in the cement industry.

Therefore, construction materials are in high demand, and the area between the Tigris River valley in the north and east, and Ellan Plain in the south was selected for investigation. Generally, the topographic surface of the study area rises in elevation from the south boundary (about 230 m, a.s.l.) towards the north boundary (300 m, a.s.l.). This area has rugged and rocky terrain, and the exposed formations range in age from Early Miocene (Euphrates Formation) to Middle Miocene (Fatha Formation), with undifferentiated sediments belonging to Quaternary.

2. GEOLOGICAL SETTING

The Zagros fold-thrust belt within Iraq has been divided into several NW–SE trending longitudinal tectonic zones (Al-Kadhimi, J.M.A., Siaaakian, V. K., Sattar, A.F. and Deikran, D.B., 1996; Fouad, 2012; Saad Z Jassim & Goff, 2006; Kassab et al., 1987). The Low Folded Zone represents part of these longitudinal zones; it is part of the Outer Platform in the Arabian plate.

It consists of a thick folded and faulted Paleozoic to Cenozoic sedimentary pile that has accumulated on the northeastern Arabian Plate margin (Alavi, 2004; Sissakian & Fouad, 2015). The Low Folded Zone represents an integral part of the Zagros folded-Thrust belt in Iraq, that is characterized by long, narrow anticlines. The Mesozoic and Cenozoic rocks crop out in their core, separated by wide synclines, where Cenozoic rocks and Quaternary sediment crop out (S Z Jassim & Goff, 2006). The study area is located within the extreme southern boundary of the Zagros Folded-Thrust belt. Thus, The Ellan anticline represents part of the Low Folded Zone as part of the Outer Platform of the Arabian Plate. Moreover, the Ellan anticline is a double plunging anticline oriented in a W – E trend and is dissected by the Tigris River.

The Euphrates Formation is exposed in the core of the anticline and the northern limb of the Ellan anticline, and its total thickness reaches 11 meters. The formation comprises thick well bedded recrystallized chalky limestone (up to 1.5 m) and a medium to thick bed of marl that ranges from 0.5 up to 3 m and is covered by residual soil. The lower contact of the Euphrates Formation is obscured.

The Fatha Formation is originally described in Iran as the Lower Fars Formation. The formation represents the deposits of a relatively strongly sinking basin, which had been often separated from the open sea by rising ridges, considered as an evaporate lagoon facies. The Fatha Formation is diachronous and falls into several sub-basins. The most easterly basin is located in west Iran and extends to the Iraqi-Iranian borders and it is of Early Miocene age. The Kirkuk and the Fatha sub-basin are located in central Iraq. They are of Middle Miocene age. Finally, the Sinjar basin which extends into Syria is in the Middle Miocene age. The studied area represents the extension of the Sinjar basin to the peripheral part of the Kirkuk-Fatha sub-basin (Tamar-Agha & Al-Aslami, 2015). The age of the formation is the Middle Miocene, which belongs to the Tortonian (Middle Miocene) stage (Saad Z Jassim & Goff, 2006). According to (R.Y, 1976), this formation was divided into Lower and Upper Members, the Lower Member was subdivided into A, B, and C units based on their lithologies, and the Upper Member into D, E, and F units. Fatha Formation is exposed widely and can be identified as two members in the study area. The red claystone layer, that well developed in the upper one (Fouad, 2002), is stated to be indicated as the upper member, while the absence of this colored rock is identified as the lower Member. The lower contact of the Fatha Formation in this area is the lower boundary of the first gypsum bed.

The Quaternary sediments are well developed and occupy a wide area, and they cover the southern limb of the Ellan anticline and plain by residual soil and strips of slope sediments, which are well developed along the southern limb of the anticline. Residual soils are well developed, consist mainly of muddy sand, and their thickness reaches up to 5 m.

3. MATERIALS AND METHODS

The study area is about 72 Km^2 which is located within Nineveh Governorate, it's about 25 Km to the northwest of Mosul City. It lay between latitudes 36^o 28' 11" and 36^o 27' 05", and longitudes 42^o 54' 39" and 42^o57' 18" (Figures 1 and 2).

Seven sections were studied within the study area, which represent the sequence exposed in the study area. Each section was studied individually to determine its suitability for several construction and industrial purposes. Moreover, each rock unit was also studied individually in these sections. Therefore, twenty-five samples were selected from pre-quaternary deposits to Quaternary sediments. Sampling was selected depending on lithological change and sedimentary structures. Seven channel samples and sixteen interval samples were collected from the exposed massive and homogenous rock unit. Each of these samples is kept in plastic bags, and enclosed with a unique serial number. The chemical analyses of all studied samples within the basic sections were compared with the (Iraqi Standard Specification, No. 5, 1984) for cement and with several recipes that are used by cement plants in Iraq (Table 2). Chemical analysis for bulk-rock was analyzed for major oxides (SiO_2, Al_2O_3. Fe_2O_3, MgO, CaO, LOI, Na_2O_3, K_2O, P_2O_5, and SO_3), and five samples were identified by XRD for mineralogical content (Table 1), by Shimadzu X-ray diffractometer with Cu tube, Power: 40 kV and current 30 mA.

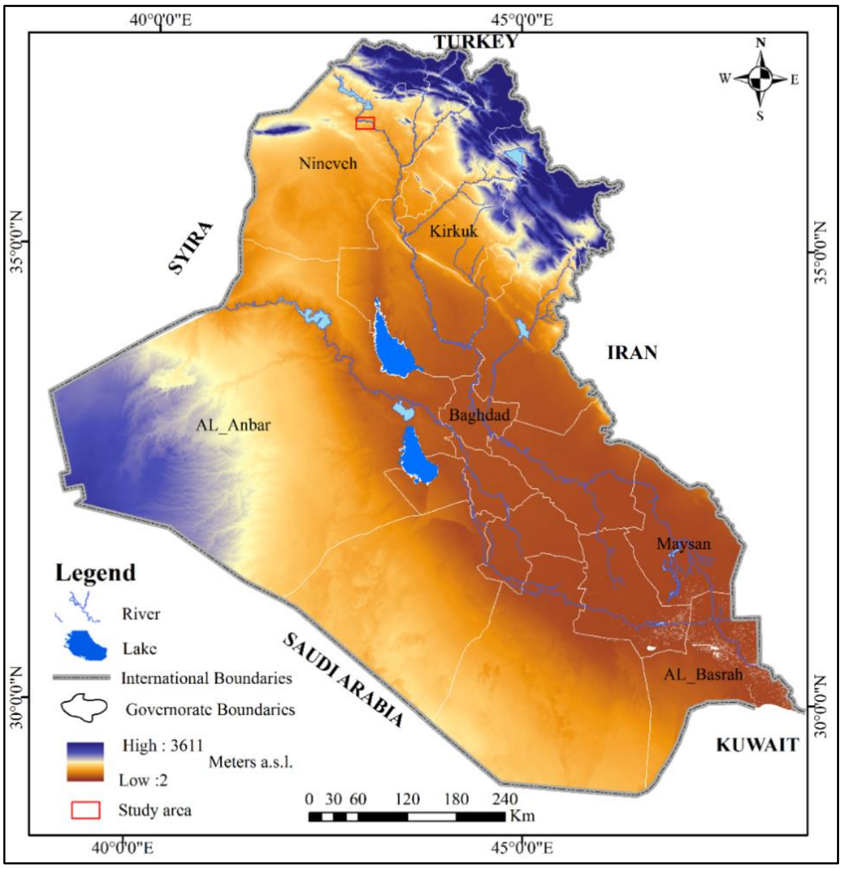

Figure 1: Location map of the project area.

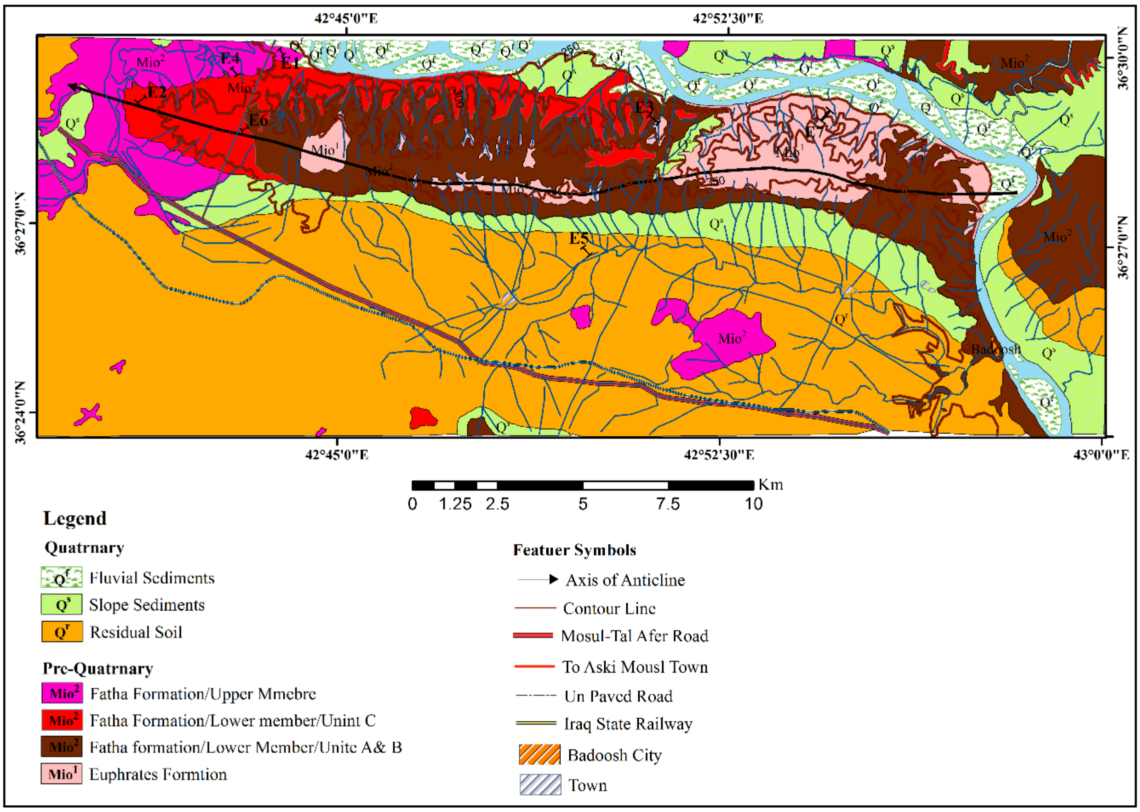

Figure 2: Geological map of the study area shows selected sections, after (Petranic, 1979).

Table 1: Selected samples for chemical and XRD analysis.

No.	Sample cod	Rock name	Th. (m)	Northern	Eastern	Formation
1	E2/Chanel/M2	Limestone	12	4039784	292624	Lower Fatha
2	E3/1	Limestone	1	4039542	307665	Euphrates
3	**E3/2***	Limestone	1	4039542	307665	Euphrates
4	E3/3	Limestone	1	4039542	307665	Euphrates
5	E3/4	Limestone	1.5	4039542	307665	Euphrates
6	E3/5	Limestone	1.5	4039542	307665	Euphrates
7	E3/6	Limestone	1.5	4039542	307665	Euphrates
8	E3/7	Limestone	1	4039542	307665	Lower Fatha/Unit A
9	E3/8	Limestone	2	4039542	307665	Lower Fatha/Unit A
10	E3/9	Limestone	2	4039542	307665	Lower Fatha/Unit A
11	E3/10	Limestone	0.5	4039542	307665	Lower Fatha/Unit B
12	**E3/11 Chanel***	Limestone	8	4039542	307665	Lower Fatha/Unit C
13	**E4/1/Chanel***	Marly Limestone	5	4040775	295115	Upper Fatha
14	E4/2/ Chanal	Limestone	2	4040775	295115	Upper Fatha
15	/ Chanal3E4/	Limestone	4	4040775	295115	Upper Fatha
16	/15E	Marly limestone	2	403837	305122	Upper Fatha
17	2E5/	Gypsum	6	403837	305122	Upper Fatha
18	***3E5/**	Clay	2	403837	305122	Upper Fatha
19	***4E5/**	Soil	4	403837	305122	Upper Fatha
20	E7/ 2	Limestone	5	4038455	312676	Euphrates
21	E7/3	Limestone	2	4038455	312676	Euphrates
22	E7/4	Limestone	0.5	4038455	312676	Euphrates
23	E7/5	Limestone	1	4038455	312676	Euphrates
24	E7/6 /Chanel	Limestone	4	4038455	312676	Euphrates
25	E7/7 /Chanel	Limestone	2	4038455	312676	Euphrates

*****Samples that identified by XRD*

Table 2: The Iraqi standard for the cement industry, including (Iraqi Standard Specification, No. 5, 1984) and other limit values that are used by different cement plants in Iraq.

Standards	CaO%	MgO%	SO_3%	SiO_2%	$Na_2O + K_2O$	Al_2O_3	Fe_2O_3	LOI
Iraqi Standard Specification No. 5 at 1984	45 ≤	2.5 ≥	1.0 ≥	7.0 ≥	1.0 ≥	-------	-------	-------
Kirkuk and Kubaisa Cement plants	46 ≤	2.0 ≥	1.0 ≥	2.0 ≥	-------------	1 ≥	2.0 ≥	--------
Al-Qaim Cement plant	46 ≤	2.0 ≥	1.0 ≥	2.0 ≥	--------------	1 ≥	4.0 ≥	--------
Al-Faluja Cement plant	50 ≤	2.0 ≥	1.0 ≥	--------	--------------	1 ≥	3.0 ≥	--------
Al-Najaf Cement plant	50.56	0.6 ≥	0.8 ≥	5.14 ≥	--------------	1.2 ≥	0.6 ≥	40 ≥
Al-Kufa Cement plant	52.55	1 ≤	0.54 ≥	2.0 ≥	--------------	0.3 ≥	0.3 ≥	42 ≥
Al- Samawa Cement plant	50 ≤	0.1 ≥	0.3 ≥	9.0 ≥	--------------	0.88 ≥	0.2 ≥	38.8 ≥

To assess the suitability of the collected samples as raw materials for cement industries, the samples were compared with the (Iraqi Standard Specification, No. 5, 1984) and most of the limit values that are used by different cement plants in Iraq (Table 2). To determine their suitability of clays for the brick industry based on (Iraqi Standard Specification No. 25, 1993), as well as (Iraqi Standard Specification No. 1387, 1989) for building stone for carbonate and gypsum samples if they have a massive thickness.

Two channel samples were collected from the aforementioned exposed formations. These channel samples are distributed across on southern limb which are selected as the best exposures of clay beds in the Ellan anticline. Each of these samples weighs about 5 kg, in addition to evaluating the economic sediments of the area. The analysis includes; grain size analysis and one-channel samples for brick test from pre-Quaternary clay deposits (Table 3). Three samples were selected for density, velocity of pressure wave (VP), specific gravity, compressive strength, abrasion of friction, and rupture modulus from massive gypsum bed distribution across the axis and northern limb (Table 4). All samples were analyzed at the Central Laboratories of the Iraq Geological Survey.

Table 3: Three selected samples for grain size and brick tests.

N	Sample .no	Rock type	Th. (m)	Grain size		Bricks analysis
				Dry	Wet	
1	3E5/	Clay	2	-	✓	✓
2	4E5/	Soil	4	✓	-	-

Table 4: The three samples that were selected for engineering analysis.

N	Sample Cod	Rock type	Thickness (m)	Density	VP	Specific gravity	Compressive strength	Abrasion of friction	Rupture modulus
1	E1	Gypsum	7	✓	✓	✓	✓	✓	✓
2	E6/1	Gypsum	5	✓	✓	✓	✓	✓	✓
3	E6/2	Gypsum	5	✓	✓	✓	✓	✓	✓

4. RESULTS AND DISCUSSION

4.1. Limestone as raw materials

To assess the suitability of the collected samples as raw materials for the cement industry, it's essential to identify the chemical and mineralogical characteristics of carbonate strata:

4.1.1. Limestone of Euphrates Formation

Chemical results (major oxides, minimum, maximum, and average) of the bulk rock samples of the Euphrates Formation are shown in Table (5).

Calcium oxide concentration ranged from 35.24% to 44.42%, and the mean was 38.87%. Magnesium oxide concentration was between 8.6% and 16.4%, and the mean was 13.36%. The concentration of SiO_2 showed low variation, ranging from 0.52% to 1.3%, with a mean value of 0.92%. Alkali oxide (Na_2O + K_2O) concentration illustrated low variation, between 0.03% and 0.16%, with a mean value of 0.11%. Loss on ignition weights from 44.74% to 46.24%, and the mean is 45.73%. The concentration of SO_3 ranged from 0% to 0.27%, with a mean value of 0.06%. Iron oxide (Fe_2O_3) concentration showed low variation between 0.05% and 0.19%, with a mean value of 0.11% and Al_2O_3 concentration showed low variation as well, ranging from 0.24% to 2.12%, with a mean value of 0.58%.

Comparing these results with the (Iraqi Standard Specification, No. 5, 1984) and limit values used by Al-Qaim, Al-Najaf, Al-Kufa, Al-Samawa, Al-Faluja, Kirkuk and Kubaisa cement factories (Table 6) shows that samples of limestone are not suitable for cement industries due to higher content of MgO, and lower content of CaO.

XRD confirmed the results above and revealed that the studied sample of the Euphrates Formation consists mainly of carbonate minerals, dolomite is one of the main carbonate minerals which were detected by XRD in the investigated rocks. It is the most abundant mineral with a percentage reaching up to 73%. Calcite mineral has a percentage reach of up to 27% (Figure 3).

Table 5: The minimum, maximum, and average of limestone from the Euphrates Formation, compared with different limit values in Iraq for the cement industry.

Component	**Min.**	**Max.**	**Average concentration (wt. %)**	**The different limit values in Iraq***						
				1	**2**	**3**	**4**	**5**	**6**	**7**
CaO	35.24	44.42	38.87	×	×	×	×	×	×	×
MgO	8.6	16.4	13.36	×	×	×	×	×	×	×
SO_3	0	0.27	0.06	✓	✓	✓	✓	✓	×	×
SiO_2	0.52	1.34	0.92	✓	✓	✓	✓	✓	✓	✓
$Na_2O + K_2O$	0.03	0.16	0.11	×	---	--	---	---	---	---
Fe_2O_3	0.05	0.19	0.11	---	✓	✓	✓	✓	×	×
Al_2O_3	0.24	2.12	0.58	---	✓	✓	✓	✓	✓	×
LOI	44.74	46.24	45.73	---	---	--	---	✓	✓	✓

***1)** Iraq standard specification No. 5 in 1984, **2)** Kirkuk and Kubaisa Cement Plant, **3)** Al-Qaim Cement Plant, **4)** Al-Faluja Cement Plant, **5)** Al-Najaf Cement plant, **6)** Al-Kufa Cement plant and **7)** Al- Samawa Cement plant; × Unsuitable; ✓ Suitable

Table 6: The minimum, maximum, and average of limestone from Lower Member of Fatha Formation (A and B), compared with different limit values in Iraq for the cement industry.

Component	**Min.**	**Max.**	**Average Concentration (wt. %)**	The different limit values in Iraq*						
				1	**2**	**3**	**4**	**5**	**6**	**7**
CaO	42.28	53.32	47.43	✓	✓	✓	×	×	×	×
MgO	1.6	10.5	5.56	×	×	×	×	×	×	×
SO_3	0.31	0.68	0.52	✓	✓	✓	✓	✓	✓	×
SiO_2	0.56	3.8	1.53	✓	✓	✓	✓	✓	✓	✓
$Na_2O + K_2O$	0.11	0.28	0.15	✓	---	--	---	---	---	---
Fe_2O_3	0.06	0.54	0.23	---	✓	✓	✓	✓	✓	×
Al_2O_3	0.39	1	0.65	---	✓	✓	✓	✓	×	✓
LOI	41.29	45.32	43.71	---	---	--	---	✓	✓	✓

***1)** Iraq standard specification No. 5 in 1984, **2)** Kirkuk and Kubaisa Cement Plant, **3)** Al-Qaim Cement Plant, **4)** Al-Faluja Cement Plant, **5)** Al-Najaf Cement plant, **6)** Al-Kufa Cement plant and **7)** Al- Samawa Cement plant; × Unsuitable; ✓ Suitable

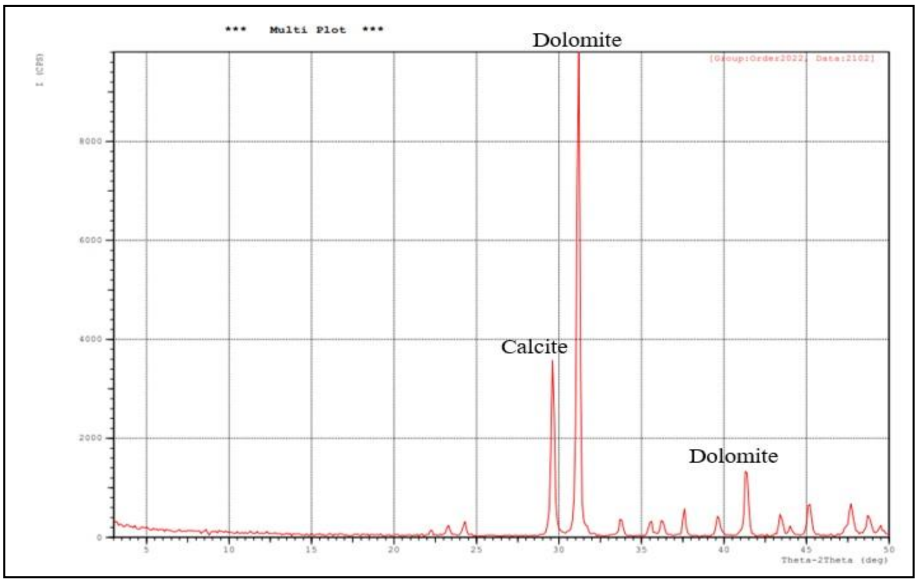

Figure 3: X-ray diffractograms of the bulk samples of the Euphrates Formation.

4.1.2. Limestone of Lower Member of Fatha Formation (units A and B)

The chemical results of major oxides, minimum, maximum, and average of lower members of Fatha Formation (units A and B) as shown in Table (6). The concentration of CaO ranged from 42.28% to 53.32%, and the mean was 47.43%. The concentration of MgO was between 1.6% and 10.5%; with the mean being 5.56%. Silica oxide concentration showed low variation, ranging from 0.56% to 3.8%, with a mean value of 1.53%. Sodium and potassium concentrations illustrated low variation, ranging from 0.11% to 0.28%, with a mean value of 0.15%. Loss on ignition (LOI) was between 41.29% and 45.32%, and the mean was 43.71%. Sulfate oxide concentration ranged from 0.31% to 0.68%, with a mean value of 0.52%. The concentration of Fe_2O_3 showed low variation, with values ranging from 0.06% to 0.54%, and its mean is 0.23%. Aluminum oxide (Al_2O_3) was low variation, ranging from 0.39% to 1%, with a mean value of 0.65%.

The results demonstrated that the mean concentrations of MgO are higher than the Iraqi standard specification. Therefore, the rocks from this unit are also unsuitable for cement industries.

4.1.3. Limestone of Lower Member of Fatha Formation (unit C)

The results of the bulk rock of lower members of the Fatha Formation (unit C) as shown in Table (7).

The studied samples show that CaO concentration ranged from 49.52% to 53.02%, and the mean is 51.27%. While MgO concentration was between 1% and 4%, with the mean 2.5%. The concentration of silica oxide showed low variation, with a value of 1.2%. Alkali oxide (Na_2O + K_2O) concentration was invariability, with an average value of 0.14%. Loss on ignition weight was from 42.65% to 43.18%, and the mean was 42.91%. The concentration of SO_3 was low variation, ranging from 0.19% to 0.24%, with a mean value of 0.21%. Iron oxide concentration reflected low variation, from 0.24% to 0.28%, with a mean value of 0.26%. The concentration of Al_2O_3 showed also low variation, from 1.11% to 1.48%, with a mean value of 1.29%.

Table 7: The average of limestone from Lower Member of Fatha Formation (C), compared with different limit values in Iraq for the cement industry.

Component	Average concentration (wt. %)	The different limit values in Iraq*						
		1	2	3	4	5	6	7
CaO	51.27	✓	✓	✓	✓	✓	✓	✓
MgO	2.5	✓	✓	✓	✓	×	×	×
SO_3	0.52	✓	✓	✓	✓	✓	✓	✓
SiO_2	1.2	✓	✓	✓	✓	✓	✓	✓
Na_2O+K_2O	0.14	✓	---	--	---	---	---	---
Fe_2O_3	0.26	---	✓	✓	✓	✓	✓	✓
Al_2O_3	1.29	---	✓	✓	✓	✓	✓	✓
LOI	42.91	---	---	--	---	✓	✓	✓

1) Iraq standard specification No. 5 in 1984, **2)** Kirkuk and Kubaisa Cement Plant, **3)** Al-Qaim Cement Plant, **4)** Al-Faluja Cement Plant, **5)** Al-Najaf Cement plant, **6)** Al-Kufa Cement plant and **7)** Al- Samawa Cement plant; × Unsuitable; ✓ Suitable

Therefore, the results showed that limestone is suitable for cement, with some values of MgO slightly above the limits.

Carbonates are the major constituents of the lower member (unite C). Calcite is the main mineral with a percentage reach of up to 94%, while dolomite is a subordinate mineral with a percentage reach of up to 4.5%. (Figure 4).

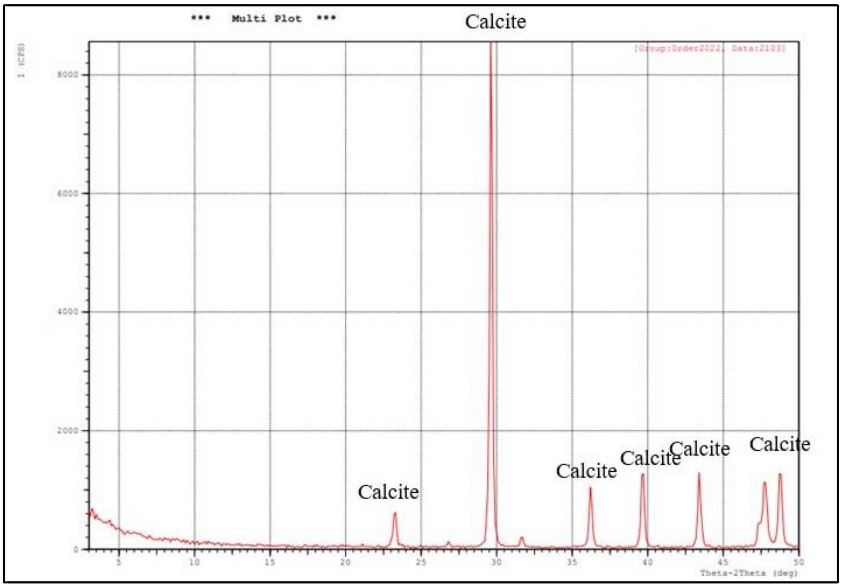

Figure 4: XRD of the bulk samples of Fatha formation, Lower member (unite C).

4.1.4. Limestone of Lower Member of Fatha Formation (unit C)

The chemical results of major oxides and an average of the upper member of the Fatha Formation are illustrated in Table (8) and showed that CaO concentration ranged from 47.2% to 43.06%, with the mean value equal 45.13%. Loss on ignition weight ranged from 38.08% to 36%, and the mean was 37.04%. Magnesium oxide, on the other hand, was between 1.8% and 2.7%, and its average was equal to 2.2%. The concentration of SiO_2 showed low variation, ranging from 7.62% to 12.2%, and the mean value was 9.91%. Sodium and potassium oxides (Na_2O + K_2O) had concentrations with narrow values, from 0.34% to

0.37%, and the mean was 0.35%. Sulfate oxide had very low variation, ranging from 0% to 0.17%, with a mean value of 0.8%. Iron concentration showed also a low variation (1.29% – 1.46 %), with a mean value of 1.37%. Aluminum oxide had very low variation, ranging from 2.71% to 4.06%, with a mean value of 3.38%.

Therefore, these results showed limestone from this part is suitable for cement based on (Iraqi Standard Specification, No. 5, 1984), and also it is acceptable in many Iraqi cement factories such as Kirkuk, Al-Qaim, and Kubaisa factories.

Carbonate minerals are the major constituents of the upper member of the Fatha Formation, and Quartz is a secondary mineral. Calcite is the main mineral with a percentage reaching up to 76%, dolomite is a minor mineral with a percentage reaching up to 9.2%. Quartz has a percentage reaching up to 12% in the carbonate rock, the quartz is of detrital origins, as shown in Figure 5.

Table 8: The minimum, maximum, and average of limestone from the Upper Member of Fatha Formation, compared with different limit values in Iraq.

Component	**Min.**	**Max.**	**Average concentration (wt. %)**	**The different limit values in Iraq***						
				1	**2**	**3**	**4**	**5**	**6**	**7**
CaO	47.2	43.06	45.13	✓	✓	✓	✖	✖	✖	✖
MgO	1.8	2.7	2.2	✓	✓	✓	✓	✖	✖	✖
SO_3	0	0.17	0.8	✓	✓	✓	✓	✖	✖	✖
SiO_2	7.62	12.2	9.91	✓	✓	✓	✓	✓	✓	✓
$Na_2O + K_2O$	0.34	0.37	0.35	✓	---	--	---	---	---	---
Fe_2O_3	1.29	1.46	1.37	---	✓	✓	✓	✖	✖	✖
Al_2O_3	2.71	4.06	3.38	---	✖	✖	✖	✖	✖	✖
LOI	44.74	46.24	45.73	---	✓	✓	✓	✓	✓	✓

***1)** Iraq standard specification No. 5 in 1984, **2)** Kirkuk and Kubaisa Cement Plant, **3)** Al-Qaim Cement Plant, **4)** Al-Faluja Cement Plant, **5)** Al-Najaf Cement plant, **6)** Al-Kufa Cement plant and **7)** Al-Samawa Cement plant; × Unsuitable; ✓ Suitable

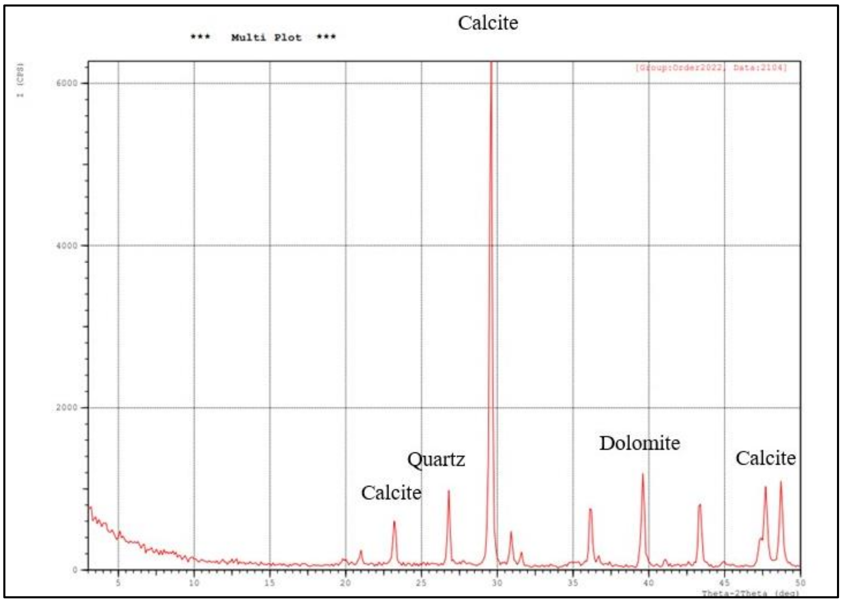

Figure 5: XRD of the bulk samples of Fatha formation, upper member, marly limestone strata.

4.2. Clay as raw materials

To evaluate the clay competency of pre-quaternary Fatha Formation and Quaternary sediments (residual soil) for cement and brick industries, physical properties test, chemical analysis, and X-ray diffraction analysis have been executed as the following.

4.2.1. Grain Size Analysis

Particle grain size is a mixture of clay, silt, and sand. It is very important to determine appropriate grain size distribution, because it influences considerably the behavior of brick bodies during the technological process, like the behavior of the material during the shaping and drying processes (Guzlēna et al., 2017). It has affected the microstructure and the mechanical properties of fired materials as well (Dondi et al., 1998).

The grain size analysis of Quaternary sediments (residual soil) executed by dry sieving technique, shows a variety of mixed constituents. The results reflected a small percentage of clay (~ 20%), silt particles are about 50% and sand grains are 30%. The grain size distribution of the analyzed samples was plotted based on a Folk triangular diagram and showed that the main fractions fill in sandy silt fields (Figure 6 and Table 9). This data confirms that claystone in the study area does not meet the requirements for fired bricks manufacturing (Qaddouri A. A., Razoqi, H. Y. and Sultan, 1999), (Table 10). Claystone of Fatha formation is unsuitable for fired bricks manufacturing class A and B, whereas, a sample from Quaternary sediments is chosen for bricks-making was good for class C. On the other hand, the grain size analysis of samples from clay bed in the upper member of the Fatha Formation analyzed by hydrometer technique (wet sieving), shows a variety of mixture constituents. The lack of sand grains that act as a stabilizer and filler material with a high percentage of clay (55%) and silt particles is 45% (Table 10). The grain size distribution of the analyzed samples was plotted on the Folk triangular diagram, and it was pointed as mud (silt and clay). Inserted each raw clay sample in the diagram to McNally's triangular diagram (Figure 7), and found that grain size was plotted in unstable-all types.

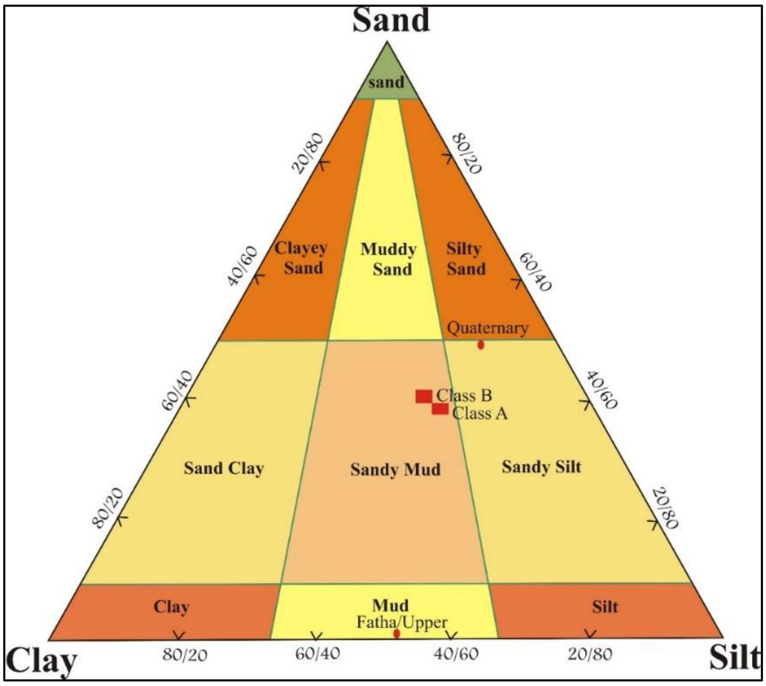

Figure 6: Shows Folk classification of clay bed deposits from the Upper Member of the Fatha Formation.

Table 9: Grain size analysis of Fatha Formation and Quaternary sediments.

Sample no.	Formation	Th.(m)	Sand%	Silt%	clay%
E5/4/Chanal	Quaternary-residual soil	4	30	50	20
E5/3/Chanal	Upper Fatha	2	0	45	55

Table 10: Grain size requirements according to (Qaddouri A. A., Razoqi, H. Y. and Sultan, 1999).

Class (A)		Class (B)	
Sand	12 – 17 %	Sand	18 – 22 %
Silt	43 – 43 %	Silt	38 – 40 %
Clay	40 – 42 %	Clay	40 – 42 %

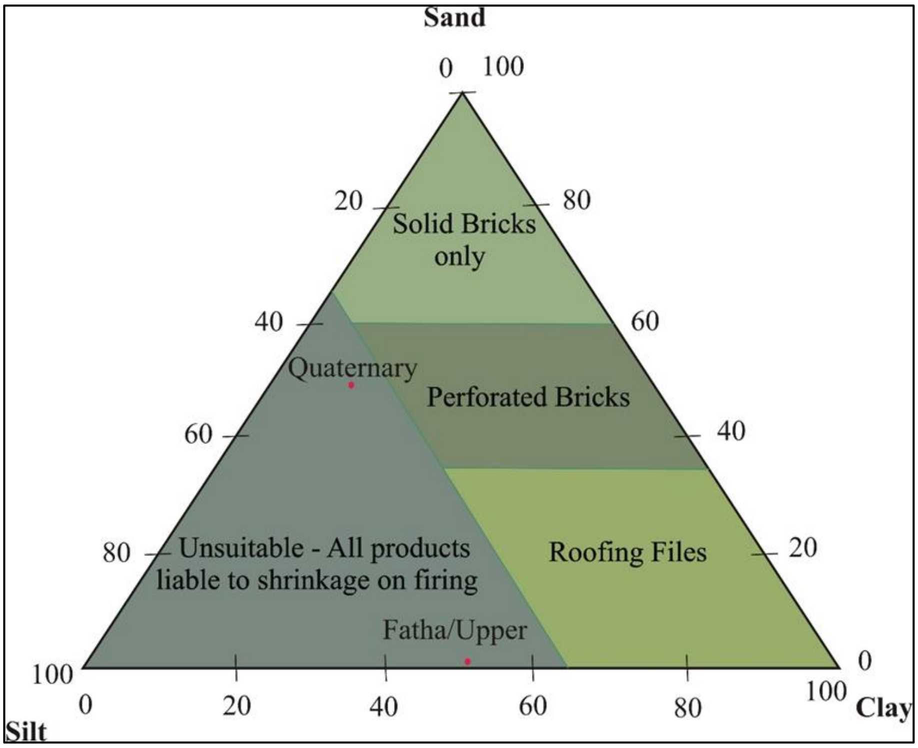

Figure 7: Grain size distribution for bricks and roofing tiles (McNally, 2017).

4.2.2. Chemical Analysis for Claystone

Analyzing the chemical components of clay samples is very important to specify their competency for brick manufacturing (Al-Khafaji, 2011), and the cement industry. The results show that the Quaternary channel sample has a SiO_2 concentration is about 35.2%, Fe_2O_3 concentration of 4.75% and Al_2O_3 concentration is 10.54%. Calcium oxide concentration is 21.28%, MgO concentration is 4.4% and LOI is 20.57%. While Na_2O concentration is 0.79%, K_2O concentration is 1.49%, Cl^- concentration is 0.27%, TiO_2 is 0.65% and P_2O_5 is 0.38%. The pre-Quaternary channel sample has a SiO_2 concentration is 38.6%, Fe_2O_3 concentration is 6.5% and Al_2O_3 concentration is 12.12%. The concentration of CaO is 15.68%, MgO concentration is 6.2% and LOI is 16.05%. The concentration of Na_2O is 0.88%, K_2O concentration is 2.6%., SO_3 concentration is 0.24%, Cl^- concentration is 0.53%, TiO_2 is 0.55% and P_2O_5 is 0.37%.

Comparing the results of these samples with Al-Bassam’s study (2004) (Table 11) shows that the results of Quaternary sediments are higher in $Na_2O + K_2O$. Whilst concentrations of other oxides are within the limit values. The concentrations of $Na_2O + K_2O$, and LOI of the Pre-Quaternary channel sample are higher as well. These samples were compared with the (Iraqi Standard Specification, No. 5, 1984) and limit values of Iraqi cement plants (Table 12), showing that average concentrations of Quaternary channel samples are within the limits of Iraqi standard specification and with the requirement for most cement plants in Iraq. However, the mean concentrations of Pre-Quaternary deposits are slightly above these limits.

Table 11: Oxides limitation for clay suitability for the brick industry from (Al-Bassam, 2004).

Component %	Min	Max
SiO_2	38.15	40.68
Al_2O_3	9.25	11.21
Fe_2O_3	2.08	8.6
CaO	14.54	18.42
MgO	4.44	6.03
$Na_2O + K_2O$	0.54	0.78
SO_3	0.84	3.21
Cl	0.59	0.93
TDS	2.66	6.90
LOI	14.95	18.17

Table 12: Elements limitation for clay suitability for the cement industry standard for each cement plant.

Iraq standard	CaO%	MgO%	SO_3%	SiO_2%	$Na_2O + K_2O$	Al_2O_3	Fe_2O_3	LOI
Iraq Standard Specification No. 5 at 1984	32≥	4 ≥	1.0 ≥	30 ≥	-------------	7.0 ≤	4 ≥	-------
Kirkuk and Kubaisa Cement Plant	33 ≥	4.0 ≥	0.5 ≥	30 ≥	-------------	10 ≥	6.0 ≥	--------
Al-Qaim Cement Plant	33 ≥	4.0 ≥	0.5 ≥	30 ≥	-------------	10 ≥	6.0 ≥	--------
Al-Faluja Cement Plant	33 ≥	4.0 ≥	0.5 ≥	30 ≥	-------------	35 ≥	1.0 ≥	--------
Al-Najaf Cement plant	15 ≥	5.0 ≥	1.3 ≥	40 ≥	-------------	12 ≥	5.50 ≥	17 ≥
Al-Kufa Cement plant	16 ≥	3.0 ≥	0.5 ≥	40 ≥	-------------	12 ≥	5.50 ≥	16 ≥
Al- Samawa Cement plant	19.22 ≥	4.77 ≥	1.0 ≥	36 ≥	-------------	9 ≥	5.48 ≥	23 ≥

X-ray diffraction analysis of claystone deposits of the upper member of Fatha Formation reveals silicate minerals are the main consistent, composed mainly of quartz less than 50%, carbonate minerals less than 28% (calcite) with significant amounts of two or more clay minerals, generally, kaolinite and montmorillonite, with trace amounts of illite and the other minerals that are not phyllosilicates such as gypsum less than 1%. X-ray diffraction analysis of Quaternary sediments reveals silicate minerals are the main consistent, composed mainly of quartz less than 50%, carbonate minerals less than 30% (calcite) with feldspar, kaolinite, and montmorillonite, and trace amounts of illite (Figures 8 and 9).

Illite is essentially a group name for non-expanding, it is a mineral that imparts materials with good plasticity and is characterized as unaltered if it is heated to 400 °C and 550 °C, (Baioumy & Gharaie, 2008), however, it fails by uniaxial compressive strength. Conversely, the kaolinite group can be noticed as non-non-plastic and disappear by heating to 400 °C and 550 °C which causes cracking in the clay sample (Baioumy & Gharaie, 2008).

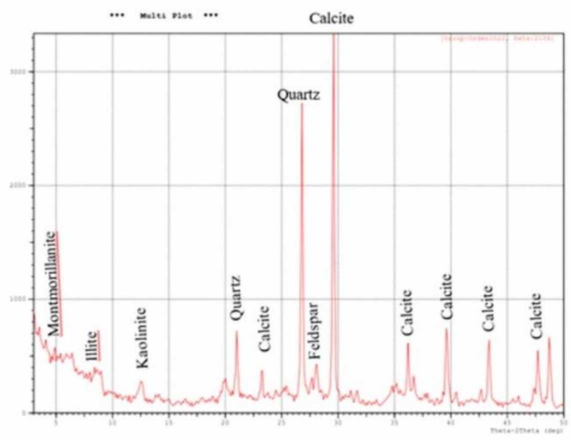

Figure 8: X-ray diffractograms of the bulk sample Quaternary deposits (Residual Soil).

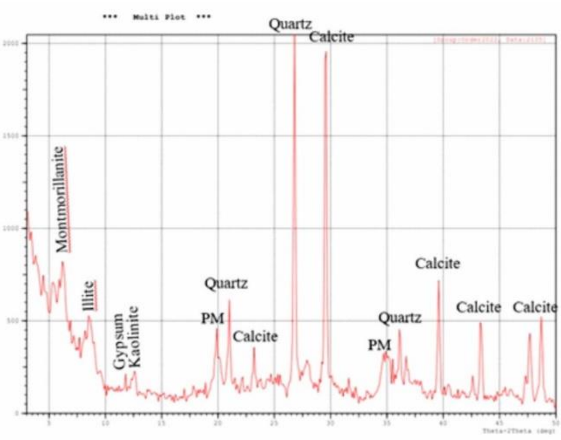

Figure 9: X-ray diffractograms of the claystone deposits of Fatha formation.

4.2.3. Brick test

A brick test was performed for the clay samples to determine their suitability; three tests were executed on the sample (Table 13) as the following: linear shrinkage, volumetric shrinkage, and mechanical and physical properties which include: uniaxial compressive strength (kg/cm^2), water absorption and efflorescence. However, the results were found to be failed by absorption to meet (Iraqi Standard Specification No.25, 1993).

Table 13: Brick test analysis of the selected clay samples.

Lab. No.	Sample No.	Brick class	Efflorescence	Absorption %	Bearing load kg/cm2	Volume Shrinkage %	Linear Shrinkage %	Height cm	Width cm	Length cm
L2101187	E5/4/Chanal	Failed	light	32	--	11.04	2.89	2.31	3.56	6.73

4.2.4. Gypsum

Gypsum is the source material for the Juss and plaster industries in Iraq, and it is used as a retarder in the cement industry. Anhydrite from the Fatha Formation is also used as a decorative building material, especially in Mosul and Kirkuk cities (R. Z. Jassim, 2019).

Four samples have been subjected to chemical analysis for major oxides, and mechanical and physical properties which include; uniaxial compressive strength (kg/cm^2), water absorption, and bulk density.

The studied sample showed that SiO_2 concentration is 1.24%, Fe_2O_3 concentration is 1%, Al_2O_3 concentration is 0.79%, Na_2O concentration is 0.3%, K_2O concentration is 0.61%, Cl concentration is 0.18% and P_2O_5 is 0.09%, (Table 14). While the concentration of CaO is 32.76%, MgO concentration is 0.15%, LOI is 19.49% and SO_3 concentration is about 43.22%.

The results were compared to the (Iraqi Standard Specification, No. 5, 1984) and also with collection data in the study (Razoki, 1980) (Table 15). The results dominated to be within the limits of Razoki, 1985 for multiple industries.

Table 14: Chemical analysis of the selected gypsum sample.

SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	W.O. C	Na_2O	K_2O	Cl	P_2O_5
1.24	1	0.79	32.76	0.15	43.22	19.49	0.3	0.61	0.18	0.09

Table 15: (Iraqi Standard Specification, No. 5, 1984) and study of (Razoki, 1980).

	SO_3%	CaO%	NaCl	H_2O	$SiO_2 + K_2O + Fe_2O_3 + Al_2O_3$ + IR
study of Razoki, 1980 for Multiple industry	35 ≤	23 ≤	2.0 ≥	4 – 9 %	20 ≥
Iraqi standard specification of Gypsum for the Cement industry	40 ≤	23 – 35 %	----	15 ≤	IR 4≤
The result of this study	43.22	32.76	---	19	0.05 without IR

Mechanical tests were performed for the gypsum samples to determine their suitability for building stone, by applying the (Lamond & Pielert, 2006, ASTM C 52 - 54) for gypsum partition tile or block and (Iraqi Standard Specification No 1387, 1989) for building stone (Table 16).

Depending on physical properties (Table 17), gypsum strata are suitable for building units in the form of tile or block for use in non-load-bearing construction in the interior of buildings and the protection of columns.

Table 16: American standard specification No. (Lamond & Pielert, 2006, C 52 - 54) for standard specifications for gypsum partition tiles or blocks.

	Compressive strength (Uniaxial) Mn/m^2
Combustible materials shall not exceed 15, percent of the weight of the dry tile	Shall be not less than 75 psi ($0.517\ Mn/m^2$)

Table 17: Physical tests of selected gypsum samples.

Lab. No.	Sample No.	Compressive strength (Uniaxial) Mn/m^2	Rupture Modulus Mn/m^2	Vp Km/s	Abrasion %	Specific Gravity	Bulk density g/cm^3
L2101198	E1	10.29	19.20	3.59	1.60	2.30	2.18
L2101199	E6/1	22.06	25.96	3.97	3.50	2.25	2.14
L2101200	E6/2	14.71	14.83	3.52	3.20	2.95	2.23

5. CONCLUSIONS

This study concludes that the area contains some layers that should be considered promising raw materials (limestone, clay, and gypsum) and can fulfill the standard specifications of the cement industry. The upper member of the Fatha Formation in addition to unit C of the lower member is suitable for the cement industry. The properties of massive gypsum exposed in the axis of the anticline have been characteristics physically preferable for interior stone, better than at limbs because did not undergo the shear forces. Therefore, the resources in this area can be targeted for cement, juss, plaster, and interior stone industries due to its enormous exposure to uncontaminated strata of the Neogene age.

The main aim of this work was to provide essential information about the spatial distribution of suitable sequence strata exposed in the area to evolution quarries. Grain size analysis of the failed channel samples shows a low content of sand-size grains and a high amount of clay component in the claystone deposits of Fatha Formation, additives sand size fraction requirements appropriate to balance between all fractions.

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