

Suitability of the Carbonate Rocks of the Bekhme Formation Exposed in Shakrook Anticline, Iraqi Kurdistan region, for Cement Industry

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Abstract—The Bekhme Formation forms almost the bulk of the Shakrook anticline, especially the limbs. The current research deals with studying the exposed beds within the Bekhme Formation at the Shakrook anticline to check the suitability of the exposed rocks at the northeastern limb of the anticline for the cement industry. Twenty rock samples from a section which lies along a deeply cut valley that crosses the northeastern limb of the Shakrook anticline within the Bekhme Formation were collected. The channel sampling method was applied; therefore, each sample represents the concerned sampling interval and to be representative for the thickness of the sampled interval. The total thickness of the sampled section is 110 m with a covered interval of 15 m, totaling to 125 m. The collected 20 samples were prepared at the laboratory of the Koya University and were subjected to XRF test at the Tarbiat Modares University, Iran, to indicate the concentration of the main oxides (CaO, MgO, Al₂O₃, Fe₂O₃, Na₂O, K₂O, and SO₃), and Cl and L.O.I. The indicated concentrations at each sample, from both universities, were compared and were found to be almost coinciding. The average concentrations at each sample were changed to weighted averages and the results were compared with the Iraqi standards for cement industry. The results revealed that the sampled rocks are excellent for cement production.

Index Terms—Bekhme formation, Cement production, Limestone, Geological reserve, Shakrook anticline, Weighted average, Iraqi Kurdistan Region.

I. INTRODUCTION

There is only one cement factory in the Erbil Governorate, which is the capital of the Iraqi Kurdistan Region (IKR). Since it is witnessing great developments in infrastructure; large quantities of cement are highly needed. Therefore, construction of cement plants in the governorate is very significant. In contrast, there are five cement plants at the

Sulaimaniyah Governorate. This is attributed to the fact that the exposed rocks in Erbil Governorate were less studied as compared to those that were exposed in Sulaimaniyah Governorate. However, the existing reconnaissance studies have proved that there are enormous amounts of limestone that is suitable for the construction of cement plants in the Erbil Governorate.

A. Aim

The aim of this research is to check the suitability of the carbonate rocks that are exposed within the Bekhme Formation for cement production in the Shakrook anticline. The large thickness of the exposed rocks, quarrying conditions, and preexisting data encouraged the research team to select a relevant section within the Bekhme Formation at Shakrook Mountain to perform the current research.

B. Location

The sampled section is located in a deep cut valley along the northeastern limb of Shakrook anticline, about 10 km southeast of Hareer town (Fig. 1) and about 70 km NE of Erbil city. It can be reached from Erbil city through a paved road that leads to Ranya city. The section is limited by the following coordinates (from bottom to top): At elevation of 978 m, coordinates 36° 25' 59.66" N, 44° 27' 36.57" E, and elevation of 998 m with coordinates of 36° 26' 09.59" N, 44° 27' 36.05" E, respectively.

C. Previous Works

Since the past decade, many studies were performed to evaluate the carbonate rocks for different industrial uses, especially for cement production. These studies were briefed hereinafter.

Sissakian, et al. (2019) studied the carbonate rocks that are exposed within the Pila Spi Formation in the southwestern limb of Permian anticline, near Al-Maseef. They reported about the presence of excellent quality and quantity of limestone. Ghafur, et al. (2020) studied and evaluated the exposed beds of the Bekhme Formation at Galley Ali Beg gorge. They concluded that excellent deposit for cement industry exists at the studied location. Sissakian, et al. (2020)



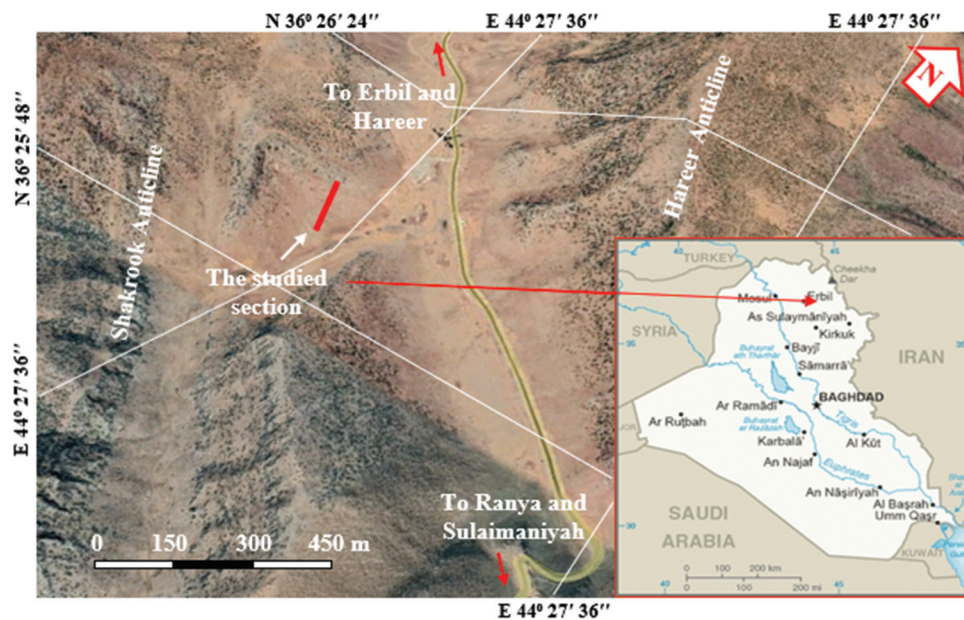


Fig. 1. Satellite image showing the location of the studied section.

studied and evaluated the exposed rocks within the Pila Spi Formation at Haibat Sultan Mountain, along a section that is located 17 km east of Koya town. They concluded that excellent deposit exists for cement production. Sissakian, et al. (2021) studied the rocks of the Bekhme Formation at the Hareer anticline and have found that the rocks are excellent for cement plant.

II. GEOLOGICAL SETTING

The geological setting of the studied section at the Shakrook anticline is briefly described hereinafter including the following main topics based on Fouad (2015) and Sissakian and Al-Jiburi (2014).

A. Geomorphology

The main geomorphological units that are developed near the studied section are as follows:

- Structural denudational unit, the anticlinal ridges are well developed in hard to very hard limestone beds of the Bekhme Formation. The anticlinal ridges represent excellent locations for quarrying.
- Denudational unit, slope sediments are well developed; usually of large fallen blocks that attain few cubic meters.

B. Stratigraphy

The studied and sampled section is within the Bekhme Formation (Fig. 2). The Bekhme Formation is described briefly hereinafter.

Bekhme Formation (Upper Cretaceous) consists of well bedded (30–70 cm) to massive (1–1.5 m) limestone and very rare dolomitic limestone, light gray and brown in color, hard to very hard, usually splintery. The exposed thickness of the formation in the studied site is about 180 m.

A. Tectonics and structural Geology

The Shakrook anticline is located in the High Folded Zone. The High Folded Zone belongs to the Outer Platform of the Arabian Plate. The zone is also a part of the Zagros Fold – Thrust Belt. The belt is developed due to the collision of the Arabian and Iranian plates since the Late Cretaceous Period. It is still ongoing with a convergent plate contact (Alavi, 2004, and Fouad, 2015). The Shakrook anticline is a double plunging anticline with a NW-SE trend, it is very complicated due to four thrust faults (Sissakian, et al., 2022).

III. MATERIALS AND METHODS

The studied section for sampling was chosen along the northeastern limb of the Shakrook anticline with the Bekhme Formation based on the experience of the authors and previously performed works. The exposed rocks along the studied section were sampled and described in the field (Fig. 2a) and tested by HCl acid to indicate their reaction (Fig. 2b). The sampling interval was measured by a measuring tape and kept constant; 5 m, apart from samples No. 19 and 20, where the interval was changed to 10 m (Table 1). Within the section, there is a covered slope (about 15 m) by fallen limestone rocks up to 1 cubic meter (Fig. 3). Each sample was collected in the form of small chips to be a representative sample of the completely sampled interval.

Samples were kept in nylon sacks, numbered, and well documented (Table 1). Totally, 20 samples were collected representing 110 m, beside the covered slope of 15 m, which exists along the uppermost part of the sampled section. The authors believe that the covered slope also includes limestone bed like those above and below the covered interval. The Iraqi Standard No. 5 (1984) (Table 2) for the cement production was used to indicate the suitability of the collected samples for the cement industry.

C. Sample Preparation

The collected 20 samples were ground to powder, using an electrical grinder. The powdered sample was well mixed to have a homogeneous representative sample. Then, 10 g of each powdered sample was pressed into a special pellet. The pressed pellet was dried in an electrical oven for 2 h. The

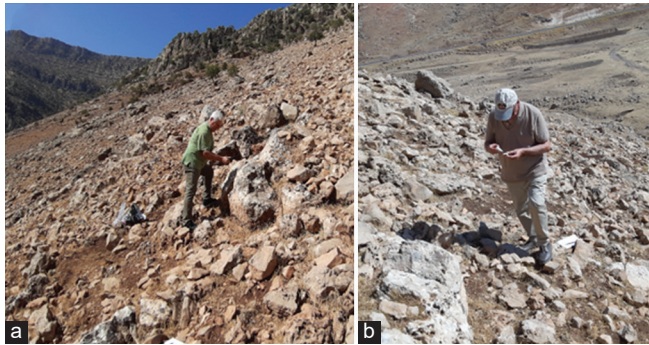


Fig. 2. Sample collection, (a) sample collecting and description, (b) sample testing by HCl.



Fig. 3. General view of the sampled section, note the absence of overburden and the covered space below the top ridge (Photo looking NW).

prepared pellets were mounted in an XRF instrument (XRF PW2404) at the Analytical Laboratories of the Faculty of Science at the Tarbiat Modares University, Iran, to indicate the main oxides (CaO, MgO, Al₂O₃, Fe₂O₃, Na₂O, K₂O, and SO₃), and Cl and L.O.I., which are used to indicate the suitability of the sampled rocks for cement industry. The used XRF instrument is calibrated with Philips Analytical X-Ray B.V. standards and has a certificate of the secondary for the SEMIQ. The detection limit of the instrument is 20 ppm–100%. The monitoring system is repeated every week with SRM samples. Moreover, the internal method of QC is used by means of SRM samples every month.

For the industrial assessment purpose, the concentrations of all indicated oxides, Cl, and L.O.I. (Table 3) of each sample were changed to a weighted average. This is because the sampling interval is not uniform; accordingly, for industrial assessment, the weighted average should be calculated.

To indicate the proper concentration of the oxides, Cl, and L.O.I. within each sample, the weighted percentage of each oxide in each sample is calculated by the following equation (IET, 2021)

$$Weighted\ Percentage = \frac{\sum C_1 + C_2 + C_3 + C_4 + C_i}{\sum T_1 + T_2 + T_3 + T_4 + T_i} \quad (1)$$

Where, C = the percentage of each oxide multiplied by the sample's thickness (T),

The weighted average is calculated as follows:

$$Weighted\ Average = \frac{\sum W_1 + W_2 + W_3 + W_4 + W_i}{\sum T_1 + T_2 + T_3 + T_4 + T_i} \quad (2)$$

Where, W = the weighted percentage of each oxide multiplied by the sample's thickness (T),

TABLE I
FIELD DESCRIPTION OF THE COLLECTED 20 SAMPLES.

Sample No.	Rock name	Color	Hardness	Thick (m)	Reaction with HCl	Description
1	Limestone	Light brown	Very hard	5	High	Well bedded
2	Limestone	Dark gray	Very hard	5	High	Massive
3	Dolomitic limestone	Dark gray	Very hard	5	Low	Thickly bedded
4	Limestone	Light gray	Very hard	5	High	Thickly bedded
5	Limestone	Light gray	Hard	5	High	Well bedded
6	Limestone	Light gray	Very hard	5	High	Well bedded
7	Limestone	Light gray	Hard	5	Low	Well bedded
8	Limestone	Light gray	Hard	5	Low	Well bedded
9	Limestone	Light gray	Hard	5	Low	Well bedded
10	Limestone	Gray	Very hard	5	High	Thickly bedded
11	Limestone	Gray	Hard	5	Low	Thickly bedded
12	Dolomitic limestone	Gray	Hard	5	Low	Thickly bedded
13	Limestone	Dark gray	Hard	5	Low	Massive
14	Limestone	Gray	Hard	5	High	Massive
15	Limestone	Gray	Very hard	5	Low	Thickly bedded
16	Limestone	Gray	Hard	5	High	Thickly bedded
17	Limestone	Light gray	Very hard	5	High	Thickly bedded
Covered slope (about 15 m) by scree of large fallen blocks of limestone						
18	Limestone	Gray	Very hard	5	High	Massive
19	Limestone	Gray	Very hard	10	High	Thickly bedded
20	Limestone	Gray	Very hard	10	High	Thickly bedded
Total thickness of the sampled rocks					110 m	
Total thickness of the sampled section					125 m	

TABLE II
IRAQI STANDARD NO. 5 FOR CEMENT PRODUCTION, 1984 (IRAQI STANDARDIZATION AND QUALITY CONTROL, 2016) AND OTHER SPECIFICATION.

Specifications of industries (%) (After Sissakian, 2018)								
Cement industry			Paint industry			Sugar industry		
	Current study			Current study			Current study	
CaO	>45.00	50.622	CaCO ₃	>99.5	94.042	MgO	< 4.00	1.477
MgO	<2.00	1.477	SiO ₂	<1.00	0.602	CaO	>55.0	54.5
Fe ₂ O ₃	<0.10*	0.101	Al ₂ O ₃	<0.05	0.214	Al ₂ O ₃	<0.27	0.214
SO ₃	<1.00		Fe ₂ O ₃	<0.05	0.101	Fe ₂ O ₃	<0.09	0.101
Cl	0.50–1.00		L.O.I.	>43.00	43.42	SiO ₂	<0.66	0.602
L.O.I.	>43.00	43.42				CaCO ₃ =CaO+L.O.I.		
* For white cement only						MgCO ₃ =MgO L.O.I.		
Glass industry			Paper industry			Legend		
	Current study			Current study				
CaCO ₃	>98.00	99.43	CaCO ₃	>90	99.43			
SiO ₂	<2.00	0.602	MgO	<1.5	1.477			Fit with the standard
MgO	<0.05	1.477	SiO ₂	<1.5	0.602			Near to the standard
Fe ₂ O ₃	<0.06	0.31	SO ₃	<1.0				Out of the standard
L.O.I.	>43.00	43.42	I.R.	<4.5	0.35			Not analyzed or detected

TABLE III
CHEMICAL COMPOSITION OF THE ANALYZED 20 SAMPLES BY MEANS OF XRF.

Sample No.	CaO %	MgO %	SiO ₂ %	Fe ₂ O ₃ %	Al ₂ O ₃ %	Na ₂ O %	K ₂ O %	SO ₃ %	Cl %	L.O.I. %
1	51.561	1.224	2.396	0.27	0.527	0.032	N.D.	0.063	0.015	43.81
2	54.272	1.036	0.345	0.059	0.075	0.029	N.D.	0.040	0.019	43.81
3	48.780	2.269	0.634	0.093	0.264	0.022	0.044	0.082	0.024	46.72
4	54.271	1.362	0.343	0.063	0.075	0.027	0.031	0.037	0.023	43.80
5	54.200	1.108	0.347	0.059	0.075	0.027	N.D.	0.041	0.019	43.78
6	50.454	3.753	0.518	0.096	0.232	0.031	0.035	0.072	0.013	44.76
7	49.745	3.115	0.608	0.115	0.295	0.023	0.031	0.093	0.023	45.88
8	50.886	2.005	0.096	0.062	0.170	0.042	0.027	0.050	0.025	46.28
9	50.745	2.115	0.606	0.117	0.290	0.028	0.033	0.091	0.022	45.83
10	51.443	1.981	1.500	0.338	0.681	0.045	0.145	0.075	0.005	43.73
11	50.637	2.160	1.087	0.127	0.302	0.058	0.052	0.067	0.036	46.40
12	45.567	3.885	1.080	0.145	0.518	0.067	0.062	0.055	0.035	46.87
13	53.495	2.049	0.574	0.058	0.217	0.049	N.D.	0.039	0.031	46.44
14	53.138	1.072	0.723	0.132	0.231	0.040	0.038	0.089	0.006	44.42
15	52.660	1.277	0.788	0.156	0.297	0.031	0.052	0.043	0.018	44.66
16	51.440	2.213	0.430	0.094	0.191	0.029	0.039	0.020	0.014	44.99
17	54.288	1.344	0.341	0.067	0.080	0.032	0.058	0.036	0.029	43.88
Covered slope by large limestone blocks										
18	55.201	0.423	0.240	0.055	0.086	0.028	N.D.	0.044	0.014	55.27
19	54.275	1.358	0.345	0.061	0.073	0.029	0.054	0.039	0.021	43.80
20	55.275	0.358	0.245	0.050	0.083	0.025	N.D.	0.041	0.017	43.82

N.D.: Not detected

The acquired results of the weighted averages of all tested oxides and other elements are presented in Table 4. Then, the results were compared with the Iraqi Standard No.5 (1984) (Table 2) for the cement production to indicate their suitability for cement production.

IV. RESULTS

The acquired results of the weighted averages from the 20 collected and analyzed samples (Table 4) were compared with the Iraqi Standard No.5 (1984) for cement industry, which is shown in Table 2 to indicate the suitability of the sampled limestone beds to be used in cement industry and other industries. Hereinafter are the details of the requirements of cement production; as the raw materials are concerned.

TABLE IV
WEIGHTED AVERAGES OF THE OXIDES IN THE 20 COLLECTED SAMPLES.

Sample No.	Thick. (m)	Weighted averages (%)									
		CaO	MgO	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	Na ₂ O	K ₂ O	SO ₃	Cl	L.O.I.
1	5	257.805	6.120	11.98	1.35	2.635	0.16	N.D.	0.32	0.075	219.05
2	5	271.36	5.180	1.725	0.295	0.375	0.15	N.D.	0.20	0.095	219.05
3	5	243.900	1.345	3.17	0.465	1.32	0.11	0.22	0.41	0.120	233.60
4	5	271.355	6.810	1.72	0.315	0.375	0.14	0.16	0.19	0.115	219.00
5	5	271.000	5.540	1.74	0.295	0.375	0.14	N.D.	0.21	0.095	218.90
6	5	252.270	18.765	2.59	0.48	1.16	0.16	0.18	0.36	0.065	223.80
7	5	248.725	15.575	3.04	0.575	1.475	0.12	0.16	0.47	0.115	229.40
8	5	254.430	10.025	0.48	0.31	0.85	0.21	0.14	0.25	0.125	231.40
9	5	253.725	10.575	3.03	0.585	1.45	0.14	0.17	0.46	0.110	229.15
10	5	257.215	9.905	7.50	1.69	3.405	0.23	0.73	0.38	0.025	218.65
11	5	253.185	10.800	5.44	0.635	1.51	0.29	0.26	0.34	0.180	232.00
12	5	227.835	19.425	5.40	0.725	2.59	0.34	0.31	0.28	0.175	234.35
13	5	267.475	10.245	2.87	0.29	1.085	0.25	N.D.	0.19	0.155	232.20
14	5	265.69	5.360	3.62	0.66	1.155	0.20	0.19	0.45	0.030	232.10
15	5	263.300	6.385	3.94	0.78	1.485	0.16	0.26	0.22	0.090	223.30
16	5	257.200	11.065	2.15	0.47	0.955	0.15	0.19	0.10	0.070	224.95
17	5	271.440	6.720	1.71	0.335	0.4	0.16	0.29	0.18	0.145	219.40
Covered slope by large limestone blocks											
18	5	276.005	2.115	1.20	0.275	0.43	0.14	N.D.	0.22	0.070	276.35
19	10	542.750	13.580	3.45	0.61	0.73	0.29	0.54	0.39	0.210	438.00
20	10	552.750	3.580	2.45	0.5	0.83	0.25	N.D.	0.41	0.170	438.20
Average		50.082	1.557	0.602	0.101	0.214	0.033	0.033	0.052	0.019	43.42
CaCO ₃ =(CaO+L.O.I.)											93.502

N.D.: Not detected

A. Limestone

The acquired results (Table 4) of the 20 samples from the Shakrook anticline showed excellent matching with the Iraqi Standard No.5 (1984) for cement industry (Table 2). The average CaO is 50.082% and that of the MgO is 1.557% (Table 4). However, when adding the average concentrations of CaO and MgO of the covered slope of 15 m from calculation of the average concentrations of the CaO and MgO for the sample Nos. 17, 18, 19, and 20, the average concentrations will be as shown in Table 5. In addition, when adding the acquired averages of CaO and MgO to the covered slope, then the average concentrations will be as shown in Table 6.

It is clear there is a slight positive improvement in the concentrations of CaO and MgO (Table 6) as compared to the results of the concentrations without considering of the covered slope results (Table 4).

The Fe₂O₃ average content is 0.101% which is almost the same as for white cement production (Table 2); therefore, the exposed rocks in the sampled section can be used for the production of white cement too.

B. Clay Deposit

In the cement production, the second main raw material is clay, which may account up to 40% of the raw mix (MRP, 2020). This percentage depends on the chemical composition of the used limestone. Clay is added as raw material to produce the cement clinker as a supplement to the adjusting of a kiln input. The best content of calcium carbonate in the raw material for the clinker firing is 75–80%. When the composition of the raw materials is not the same as these values, then many additives are used. Adding clay

TABLE V
WEIGHTED AVERAGES FOR THE SAMPLE NOS. 17–20.

Sample Thick. No.	(m)	Weighted averages (%)									
		CaO	MgO	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	Na ₂ O	K ₂ O	SO ₃	Cl	L.O.I.
17	5	271.440	6.720	1.71	0.335	0.4	0.16	0.29	0.18	0.145	219.40
Covered slope by large limestone blocks											
18	5	276.005	2.115	1.20	0.275	0.43	0.14	N.D.	0.22	0.070	276.35
19	10	542.750	13.580	3.45	0.61	0.73	0.29	0.54	0.39	0.210	438.00
20	10	552.750	3.580	2.45	0.5	0.83	0.25	N.D.	0.41	0.170	438.20
Total		1642.945	25.995								
Average A		54.765	0.867								

TABLE VI
WEIGHTED AVERAGES FOR THE SAMPLE NOS. (1–20) + THE COVERED SLOPE.

Sample Thick. No.	(m)	Weighted averages (%)									
		CaO	MgO	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	Na ₂ O	K ₂ O	SO ₃	Cl	L.O.I.
1	5	257.805	6.120	11.98	1.35	2.635	0.16	N.D.	0.32	0.075	219.05
2	5	271.36	5.180	1.725	0.295	0.375	0.15	N.D.	0.20	0.095	219.05
3	5	243.900	1.345	3.17	0.465	1.32	0.11	0.22	0.41	0.120	233.60
4	5	271.355	6.810	1.72	0.315	0.375	0.14	0.16	0.19	0.115	219.00
5	5	271.000	5.540	1.74	0.295	0.375	0.14	N.D.	0.21	0.095	218.90
6	5	252.270	18.765	2.59	0.48	1.16	0.16	0.18	0.36	0.065	223.80
7	5	248.725	15.575	3.04	0.575	1.475	0.12	0.16	0.47	0.115	229.40
8	5	254.430	10.025	0.48	0.31	0.85	0.21	0.14	0.25	0.125	231.40
9	5	253.725	10.575	3.03	0.585	1.45	0.14	0.17	0.46	0.110	229.15
10	5	257.215	9.905	7.5	1.69	3.405	0.23	0.73	0.38	0.025	218.65
11	5	253.185	10.800	5.44	0.635	1.51	0.29	0.26	0.34	0.180	232.00
12	5	227.835	19.425	5.40	0.725	2.59	0.34	0.31	0.28	0.175	234.35
13	5	267.475	10.245	2.87	0.29	1.085	0.25	N.D.	0.19	0.155	232.20
14	5	265.69	5.360	3.62	0.66	1.155	0.20	0.19	0.45	0.030	232.10
15	5	263.300	6.385	3.94	0.78	1.485	0.16	0.26	0.22	0.090	223.30
16	5	257.200	11.065	2.15	0.47	0.955	0.15	0.19	0.10	0.070	224.95
17	5	271.440	6.720	1.71	0.335	0.4	0.16	0.29	0.18	0.145	219.40
C. S.	15	821.475	13.005								
18	5	276.005	2.115	1.20	0.275	0.43	0.14	N.D.	0.22	0.070	276.35
19	10	542.750	13.580	3.45	0.61	0.73	0.29	0.54	0.39	0.210	438.00
20	10	552.750	3.580	2.45	0.5	0.83	0.25	N.D.	0.41	0.170	438.20
Average		50.622	1.477	0.602	0.101	0.214	0.033	0.033	0.052	0.019	43.42
CaCO ₃ = (CaO+L.O.I.)											94.042

raw materials will reduce the calcium carbonate content in the mix and increase the contents of SiO₂, Al₂O₃, and Fe₂O₃ (MRP, 2020).

An enormous clay deposit occurs within the alluvial fan sediments, which are developed opposite to the Shakrook anticline, along the whole foot slopes of the Hareer Mountain (Fig. 4). These deposits are rich in limestone fragments of different sizes that derived from the weathering and erosion of the limestone beds of the Bekhme Formation.

The alluvial fan deposits can be divided easily into two main parts, coarse, and fine grained. The former is deposited along and near the foothills of the Hareer Mountain, whereas the latter is deposited after the coarse materials and the break in the slope forming gently sloping areas (Fig. 4). The thickness of these deposits' ranges from 1 m up to about 10 m, but the coverage area (Fig. 4) is huge.

It is worth mentioning that, west of the sampled section, the Gercus, Fatha, Injana, Mukdadiya and Bai Hassan formations are exposed and include huge thicknesses of claystone that has produced reddish-brown clayey soil (Fig. 5), which can be used as the clay raw material. All those cement plants in the Bazian vicinity in the Sulaimaniyah Governorate use claystone from the Injana, Mukdadiya, and Bai Hassan formation as the clay raw material.

C. Gypsum Deposit

Gypsum is added to the clinker by about 5% depending on the chemical composition of the clinker. The main role of the gypsum is to retard the consolidation time of the concrete (Shmitt, 2012). Therefore, gypsum is very essential for cement production. However, no gypsum as deposit occurs neither in the Shakrook Mountain nor nearby areas, and this is the only disadvantage in the studied area as far as cement production is concerned.

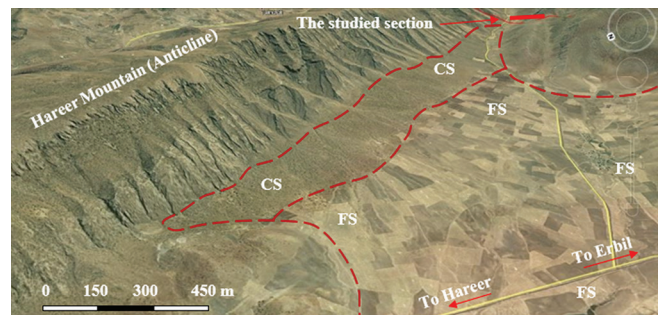


Fig. 4. Satellite image of the Hareer Mountain with the clay sediments, CS= Coarse sediments, FS= Fine sediments.



Fig. 5. The reddish-brown soil developed along the Hareer Mountain (Photo looking NE).

The nearest gypsum to the Shakrook Mountain, which is used as a deposit is at the Aghjalar vicinity; along the Qara Dag Mountain, it is southwest of the Sulaimaniyah city about 100 km away from the sampled section (Sissakian and Fouad, 2015). However, another gypsum deposit occurs at Qara Chough Mountain which is about 50 km south of the Erbil city and 120 km south of the Shakrook Mountain.

V. DISCUSSION

A. Cement Production

In the IKR, there are six cement plants (Fig. 6). Five of them are located in the Sulaimaniyah Governorate, whereas the sixth plant is located in the Erbil Governorate near the Makhmour town, which is about 45 km SW of the capital Erbil. The whole IKR is witnessing an enormous development in the infrastructure besides, tens of the recently constructed residential sites. Accordingly, an enormous amount of cement is required to construct those industrial sites and develop the infrastructure. However, since there is only one cement plant within the Erbil Governorate, it is very crucial to construct cement plants within the Erbil Governorate. To plan locations for cement plants, it should be significant to find limestone beds that are suitable for cement industry and to encourage investors to utilize the found limestone beds for the construction of cement plants.

With the bulk of the carried out work; however, it is not possible to consider the studied section in the Shakrook anticline as a deposit. Detailed exploration should be carried out to estimate the reserve of the deposit following JORC (1999) instructions. Moreover, a relevant location for the cement plant should be considered when choosing a site for sampling, besides the quarrying conditions. Therefore, the selected section for sampling fulfills all the requirements including: (1) The quality of the limestone, (2) the quarrying conditions, (3) available clay deposits, and (4) available and relevant area for the cement plant. The mentioned aspects are discussed hereinafter.

- Quality of the Limestone: The acquired results from XRF of the tested 20 samples (Table 4) indicate excellent quality of limestone for cement production according to the Iraqi specification for cement industry (Table 2).-
- Quarrying Conditions: The selected site for sampling fulfills the following conditions:
 - There is no overburden not only at the sampling site (Fig. 3) but also the whole Shakrook Mountain (Fig. 7)
 - The presence of high cliffs and anticlinal ridges (Figs. 7 and 8) will facilitate the quarrying of the limestone beds,
 - The plunge of the Shakrook anticline can be the start point of the quarry (Fig. 9),
 - The widely exposed Bekhme Formation along both limbs of the Shakrook anticline (Figs. 7 and 8) will give a very high limestone reserve and encourage the construction of a cement plant,
 - The well-bedded nature of the exposed limestone (Fig. 10) will facilitate the quarrying,



Fig. 6. Locations of the six existing cement plants in the IKR. Cement Plants: T= Taslouja, M= Mass, L= Lafarge, D= Delta, G= Gasim, and K = Kar.



Fig. 7. (Top) General view of the Shakrook anticline, note the bare anticlinal ridges (Photo looking toward SE), and (Bottom) the opposite site of the sampled location, note the large valley that can be used as service road to reach the huge reserves of the limestone (above photo) (Photo looking toward SE).

- The absence of villages near the sampled site and near surrounding will decrease the negative environmental impact on the villagers.
- Available Clay Deposit: The clayey soil within the alluvial fans' sediments (Figs. 4-6), and within many geological formations, which has produced red clayey soil due to weathering (Fig. 5) can be used as clay deposit for cement industry.
- Available Site for the Cement Plant: The presence of wide and vast flat area near the plunge of the Shakrook anticline (Fig. 9) can be used as a site for construction of a cement plant. The main road to the Erbil city and to the Hareer and Aqra towns passes just near the recommended site.

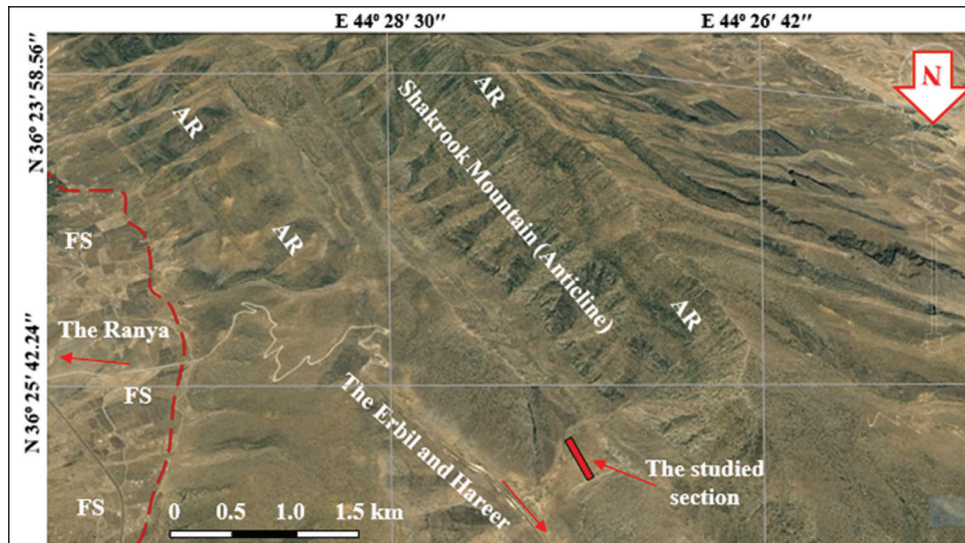


Fig. 8. Satellite image of the sampled section and part of the Shakrook anticline. AR= Anticline ridge, FS= Fine sediments (soil). Note the huge amount of the exposed limestone beds without overburden.



Fig. 9. A wide plain in front of the Shakrook Mountain. The sampled section is behind the plunge of the anticline shown in the left side (Photo looking toward SE).

B. Drug Industry and Human's Health

Pure limestone can also be used in drug industry (CONGAL, 2021). The acquired results from the tested samples showed that the weighted average of the calcium carbonate (CaCO_3) concentration is high 94.042 %, which means a pure calcium carbonate with very low concentrations of other oxides (Table 6). Therefore, such pure calcium carbonate can be used in drug industry (CONGAL, 2021).

Calcium has different functions for the human's health, it helps in having healthy bones, muscles, nervous system, and heart. It is also used as an antacid to relieve heartburn, acid indigestion, and stomach upset. Calcium carbonate is a dietary supplement for the human, especially when the amount of calcium taken in the diet is not enough.

Pure calcium carbonate can also be used for the treatment of cancer cases, it will gradually dissolve in the weak acidic microenvironment of cancer cells, since the loaded doxorubicin can be released over the period of 14 days with pH responsive and sustained manner to treat cancers specifically and significantly (Render, et al., 2016).

C. Miscellaneous

The exposed limestone beds in the sampled section and surrounding area can also be used as mineral fillers in many

industries such as plastics, paper, paint, and rubber industries (Table 2) and are used in various applications from tires, wire cable, flexible PVC, pipes, flooring, coatings, and adhesives.

The main advantages of using the calcium carbonate as filler include a high surface gloss or opacity. Moreover, when the particle size is carefully controlled, then CaCO_3 helps to increase both impact strength and flexural modulus (i.e., stiffness) (CONGAL, 2021).

D. Geological Reserve Estimation for a Cement Plant

We have added this attempt to estimate the reserve of the limestone along the sampled section and near surrounding, since the XRF results are very encouraging (Tables 4 and 6). Moreover, the quarrying conditions are very favorable.

Accordingly, we will assume a quarry area of 1.0 km^2 , then the geological reserve can be estimated as follows:

The surface area = 1,000,000 m^2

The thickness of the sampled part = 115 + 15 (covered slope) m, then the total thickness will be 130 m. We have added the covered area also because the rocks below the slope (sample Nos. 17 and 18) and above the slope (sample nos. 19 and 20) have high CaO content and low MgO content (Table 6).

The volume of the limestone within the supposed quarry = $1,000,000 \times 130 = 13 \times 10^7 \text{ m}^3$

The average density of the limestone is about 2400 kg/m^3 ,

The weight of the limestone which can be quarried = $2400 \times 13 \times 10^7 = 312 \times 10^9 \text{ kg}$
= 312,000,000 tons.

The second significant raw material that is used in the raw mix for cement production is the clay, which is available near to the sampled area where huge alluvial fans cover large flat area (Figs. 4, 5 and 9). The added clay to the raw mix is about 30–40 % of the used limestone.

Therefore, 35% of 312,000,000 tons = 109,200,000 tons

Total used raw mix = 312,000,000 + 109,200,000 = 421,200,000 tons

If the daily production of a cement plant is 5000 tons, then the used quantity of the raw mix is about 10,000 tons/day, this means that the estimated reserve can be used for about

$421,200,000 \div 10,000 =$ about 42,120 days, which is about 127 years. We have considered 330 days, as 30 days are supposed to be for maintenance and other irrelevant working days.

The exposed limestone beds within the Bekhme Formation surrounding the sampled section even in Hareer anticline, which is few hundred meters north of the sampled section, have almost the same chemical composition (Sissakian, et al., 2021). Therefore, the area of the suggested quarry as 1² km can be extended; consequently, the calculated geologic reserve will be more than the estimated. It is worth to mention; however, that this is a preliminary geological reserve estimation with a low level of confidence according to JORC (1999). Therefore, the acquired results cannot be used for investments, unless relevant site investigation is carried out to estimate the true reserve which can be invested with high level of confidence according to JORC (1999). The detailed site investigation should include boreholes' drilling of continuous core with core recovery not <90%, and with spacing not more than 150 m and core sampling of 1 m interval, and the analyzing of all collected samples for the main oxides and other elements as mentioned in Table 2.

VI. CONCLUSIONS

The acquired results from the XRF test, which was applied on the collected 20 rock samples from the Bekhme Formation at the Shakrook anticlines, showed excellent limestone with average concentrations of CaO and MgO at 50.622% and 1.4777%, respectively, that the sampled rocks are excellent for cement production. Moreover, the average concentration of the CaCO₃ is 94.042%, which means that the exposed limestone beds can be used for drug industry and other human's health concerns. From the author's experience, the exposed rocks in the sampled section can also be used for paint, paper, rubber, and plastic industries.

VII. ACKNOWLEDGMENTS

The authors would like to pass their sincere thanks to the authorities at the Faculty of Engineering/Koya University and the University of Kurdistan Hewler for providing logistics during this research work.

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