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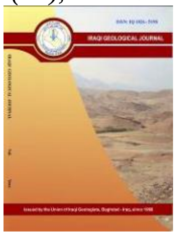

Sutability of Khurmala Formation's Rocks in Galka Smaq Vicinity, Kurdistan Region of Iraq for Industrial Uses

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Abstract

The Khurmala Formation is exposed in restricted areas in the Kurdistan Region of Iraq, usually between the Kolosh and Gercus formations. One of those exposed areas is the Haibat Sultan Mountain which extends from Koya town and eastwards to Sulaymaniyah city with NW-SE trend, where it passes to the Sinjar Formation. The rocks of the latter are used as the raw materials in five cement plants in Sulaymaniyah Governorate. The rocks of the Khurmala Formation were sampled near Kalka Smaq village along the road which crosses Haibat Sultan Mountain to perform an industrial assessment of the rocks. The sampled section is 65 m thick; 13 samples were collected as channel samples with regular intervals of 5 m. In the field, the samples were lithologically described and checked with HCl acid. The samples were powdered, and subjected to XRF to detect the main oxides in the samples. The obtained results of CaO, MgO, Fe_2O_3, Al_2O_3, Na_2O, K_2O, SiO_2, SO_3, Cl, and L.O.I. as weight percentages were checked with Iraqi standards to find for what industrial uses can be suitable. Accordingly, the samples were found to be suitable for the cement industry and for the paper industry, but after slight treatment.

Keywords: Cement production; Khurmala Formation; Limestone; XRF; Reserve estimation; Raw materials.

1. Introduction

The Khurmala Formation (Paleocene-Lower Eocene age) consists mainly of limestone (Sissakian and Al-Jiburi, 2014). The equivalent of the Khurmala Formation is the Sinjar Formation, both formations pass to each other east of the studied area, the latter extends east wards and extends to Iran. The Sinjar Formation is the source of the material used in cement production at Bazian vicinity in Sulaymaniyah Governorate; where five cement plants (Fig. 1) were constructed (Sissakian, 2018). The Kurdistan Region of Iraq (KRI) is witnessing huge development in the infrastructure and residential sites; therefore, huge quantities of cement are required to perform the planned infrastructure; accordingly, more cement plants are required.

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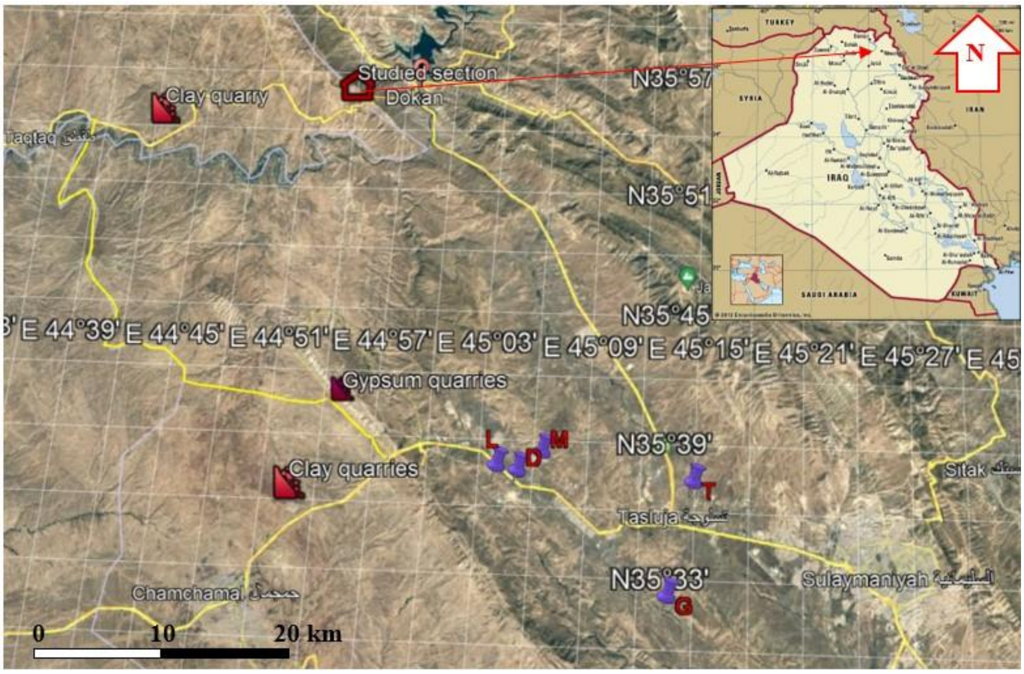

Fig.1. Locations of the studied section and constructed five cement plants in Bazian vicinity. Cement plants: T= Tasluja, M= Mass, L= Lafarge, D= Delta, G= Gasin

Although many studies were performed to check whether rocks of many formations are suitable for the cement industry in KRI; like Sissakian et al. (2019, 2020 and 2022), Ghafur, et al. (2021) however, the rocks of the Khurmala Formation were not evaluated from the industrial point of view. Therefore, we have studied the rocks of the Khurmala Formation aiming to evaluate their suitability for cement production and other possible industries in which limestone is used as a primary raw material. The studied section is along the road which crosses the Haibat Sultan Mountain near Kalka Smaq village leading to Dokan town (Fig. 1). The beginning and ending points of the studied section have the following coordinates: 35◦55' 38.6" N and 44◦ 55' 00.3" E, and 35◦55' 42.2" N and 44◦ 55' 82.3" E, from top to bottom (Fig. 2).

2. Materials and Methods

We have used geological map of 1:250000 scale to select a relevant section where the Khurmala Formation is exposed with considerable thickness and favorable quarrying conditions. The sampled section is 65 m thick, 13 samples were collected with regular 5 m spacing (Fig. 2); as channel samples, where small chips were collected from each 5 m; so that the collected sample represents the sampled 5 m interval. The distance of samples' spacing was measured by a measuring tape considering the dip amount which is (10 – 15) degrees. Lithological description of the samples was carried out in the field (Table 1) using a field lens and HCl acid to check the reaction with the collected samples, some of the collected samples showed strong reactions (Table 1). The collected samples were numbered and kept in double nylon sacks with their serial numbers marked on them. The samples were crushed and powdered, then XRF test was run in local laboratories; to indicate the main oxides in each sample (Table 2).

Because the sampling interval was kept in equal interval, which is 5 m; therefore, there was no need to indicate the weighted average of the samples. The obtained averages of the tested oxides in each sample (Table 2) were compared with standards (Table 3) to perform industrial assessments of the sampled rocks in the studied area.

Fig.2. Locations of the collected 13 samples

Table 1. Field description of the collected samples

Sample No.	Thickness (m.)	Description
1	5	Well bedded, light grey, very hard limestone, thickness of individual bed ranges from (10-50) cm, fairly reacts with (HCl) acid
2	5	Interbedding of light brown papery shale, poor toughness, well bedded, with light grey, very hard, limestone, thickness of individual bed ranges from (10-50) cm, fairly reacts with (HCl) acid
3	5	Well bedded, light greyish brown, very hard limestone, thickness of individual bed ranges from (10-50) cm, strongly reacts with (HCl) acid
4	5	Well bedded, light grey, very hard limestone, thickness of individual bed ranges from (10-50) cm, strongly reacts with (HCl) acid, in the lower part there is of 0.5 m of shale
5	5	Well bedded light grey to brown, very hard limestone thickness of individual bed ranges from (1.0-1.5) m, strongly reacts with (HCl) acid
6	5	Well bedded, light grey, very hard limestone, thickness of individual bed ranges from (5-20) cm, strongly reacts with (HCl) acid
7	5	
8	5	Well bedded, light grey to light brown, very hard limestone, thickness of individual bed ranges from (10-50) cm, strongly reacts with (HCl) acid
9	5	Well bedded, light greyish brown, very hard limestone, thickness of individual bed ranges from (5-20) cm, strongly reacts with (HCl) acid
10	5	
11	5	
12	5	Well bedded, light grey and brown, very hard limestone, thickness of individual bed ranges from (5-20) cm, strongly reacts with (HCl) acid, the upper part shows karstification
13	5	Well bedded, light brown, very hard limestone, thickness of individual bed ranges from (10-50) cm, strongly reacts with (HCl) acid

The sampled section was selected to have continuations in different directions (Figs 3 and 4) and to be without overburden. These conditions will give favorable quarrying for the studied rocks if they show suitable properties for industrial uses.

Table 2. Main oxides' percentages in the collected 13 samples

Sample No.	Concentration (%)										
	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	Cl	P_2O_5	SO_3	LOI
1	36.42	9.66	10.32	1.24	3.13	0.14	0.12	N	N	0.81	36.80
2	31.11	8.27	15.33	2.51	5.58	0.03	0.48	N	0.01	0.21	35.96
3	49.75	3.48	2.04	0.39	0.99	0.01	0.02	N	0.02	0.31	42.06
4	50.75	2.48	3.07	0.49	1.02	0.05	0.04	N	0.01	0.41	41.60
5	53.44	1.11	0.66	0.12	0.22	0.14	N	N	N	0.02	43.20
6	53.64	1.37	2.42	0.84	4.74	0.10	0.06	N	N	0.61	36.70
7	52.86	2.16	0.82	0.12	0.22	0.15	N	N	N	0.11	42.20
8	53.86	1.16	0.89	0.10	0.45	0.11	N	N	N	0.09	43.20
9	53.23	1.89	1.11	0.15	0.48	0.02	N	N	N	0.06	42.80
10	51.63	1.24	4.51	0.16	0.72	0.07	N	N	N	0.08	41.63
11	53.59	1.19	0.99	0.18	0.49	0.18	N	N	N	0.11	42.20
12	48.48	2.49	2.54	1.87	3.97	0.03	0.18	N	0.01	0.37	40.30
13	50.72	1.66	4.64	0.41	1.11	0.04	N	N	0.01	0.07	40.65
Average1	49.19	2.94	3.79	0.65	1.78	0.08	0.07	N	0.003	0.24	34.58
Average2	51.99	1.84	2.15	0.43	1.31	0.08	0.03	N	0.002	0.19	34.25

Table 3. Iraqi and International Standards of some industries (Al-Bassam and Al-Khafaj, 2011)

Limestone Uses in Different Industries					
	Cement Industry			Glass industry	
1	CaO	> 45 %	1	$CaCO_3$	> 98 %
2	MgO	< 2 %	2	SiO_2	< 2.0 %
3	SO_3	< 1 %	3	Fe_2O_3	< 0.06 %
4	Cl	0.5 - 1.0 %	4	MgO	< 0.05 %
5	$K_2O + Na_2O$	0.05 %	5	L.O. I	> 43.0%
6	Fe_2O_3	< 0.1% (white			
	Paint Industry			Sugar Industry	
1	$CaCO_3$	> 99.5 %	1	SiO_2	< 0.66 %
2	SiO_2	< 0.1 %	2	Al_2O_3	< 0.27 %
3	Al_2O_3	< 0.05 %	3	Fe_2O_3	< 0.09 %
4	Fe_2O_3	< 0.05 %	4	MgO	< 0.4 %
5	L.O. I	> 43.5 %	5	CaO	> 55 %
	Paper Industry				
1	$CaCO_3$	> 90 %			
2	SiO_2	< 1.5 %			
3	MgO	< 1.5 %		$CaCO_3$ = CaO + L.O.I.	
4	SO_3	< 1.0 %			
5	I.R. (in HCl)	< 4.5 %			

Fig.3. Long cliff of the Khurmala Formation underlain by the Kolosh Formation

Fig.4. Anticlinal ridges of the Khurmala Formation, which can be used for quarrying of the limestone

3. Geological Setting

The sampled section is within the Khurmala Formation of the Paleocene age, it is underlain by the black clastics of the Kolosh Formation of Paleocene age (Fig. 3) and overlain by the red clastics of the Gercus Formation of Eocene age (Fig. 5) (Sissakian and Fouad, 2015)

The main geomorphological unit in the studied area is the anticlinal ridges (Figs. 3 and 4), they extend for a few kilometers as the southwestern limb of the Bustana and Khalikan anticlines, and they form excellent locations for quarrying of the limestone beds.

Fig.5. The Khurmala Formation overlain by the red clastics of the Gercus Formation

The area under consideration is within the High Folded Zone, which belongs to the Outer Platform of the Arabian Plate. The zone belongs to the Zagros Fold – Thrust Belt, which is a part of the Zagros Foreland Basin (Alavi, 2004 and Fouad, 2015). The exerted forces from the collision of Arabian and Eurasian plates have formed folded beds, which are locally highly jointed (Fig. 6). The intense jointing of the rocks will facilitate the quarrying and also will be easily crushed before being mixed with clay and then entering to the furnace for clinker production before the last step of cement production.

Fig.6. Jointed and deformed beds of the Khurmala Formation in the studied section

4. Results

The obtained averages of the tested oxides of the studied 13 rock samples (Table 2) were compared with the required chemical specifications of some industries (Table 3), which use limestone as raw material. We have the following results:

4.1. Cement Production

This is the most common industry in KRI that use limestone as the main raw mix (Sissakian, 2018). The acquired data of the tested oxides percentages of the analyzed samples were compared with the standards for cement production and the results are shown in Table (4).

Table 4. Comparison of the acquired data of the analysed rocks with the requirements of cement industry (Al-Bassam and Al-Khafaj, 2011)

Oxides %					**Suitability**	
Iraqi Standard		Analyzed samples				
			First choice	Second choice	First choice	Second choice
CaO	> 45 %	CaO	49.19	51.99	Yes	Yes
MgO	< 2 %	MgO	2.94	1.84	S. M.	Yes
SO_3	< 1 %	SO_3	0.24	0.19	Yes	Yes
Cl	0.5 – 1.0 %	Cl	N	N	Yes	Yes
$K_2O + Na_2O$	0.05 %	$K_2O + Na_2O$	0.15	0.11	S. M.	S. M.
Fe_2O_3	< 0.1% *	Fe_2O_3	1.78	1.31	Yes	Yes

* For white cement only, S.M. = Slightly more than the specification

4.2. Paper Production

In KRI, no paper industry is presented hitherto, therefore, we have compared the required specifications with the obtained results of the collected 13 samples (Table 5). The results showed that the concentrations of the required oxides for paper industry in the collected and analyzed rocks samples does not meet the standards for paper production.

4.3. Paint Industry

Although there are many paint plants in KRI; however, all those plants import limestone for pain industry. Therefore, we have compared the required specifications with the obtained results of the analuzed 13 samples (Table 6). Unfortunately, the results were negative.

Table. 5. Comparison of the acquired data of the analysed rocks with the requirements of paper industry (Al-Bassam and Al-Khafaj, 2011)

Oxides %					**Suitability**	
Standard		Analyzed samples				
			First Choice	Second choice	First choice	Second choice
$CaCO_3$	> 90 %	$CaCO_3$	83.77	86.24	S.L.	S.L.
SiO_2	< 1.5 %	SiO_2	3.79	2.15	NO	S.M.
MgO	< 1.5 %	MgO	2.94	1.84	NO	S.M.
SO_3	< 1.0 %	SO_3	0.24	0.19	YES	YES
I.R (in HCl)	< 4.5 %	I.R (in HCl)	3.79	2.15	YES	YES

*CaCO3 = CaO + L.O.I., S.L. = Slightly lower than the specification, S.M. = Slightly more than the specification

Table 6. Comparison of the acquired data of the analyzed rocks with the requirements of paint industry (Al-Bassam Al-Khafaj, 2011)

Oxides %					**Suitability**	
Standard		Analyzed samples				
			First Choice	Second choice	First choice	Second choice
$CaCO_3$	> 99.5 %	$CaCO_3$	83.77	86.24	No	No
SiO_2	< 0.1 %	SiO_2	3.79	2.15	No	No
Al_2O_3	< 0.5 %	Al_2O_3	0.65	0.43	S.M.	Yes
Fe_2O_3	< 1.0 %	Fe_2O_3	1.78	1.31	S.M.	S.M.
L.O.I.	> 43.5 %	L.O.I.	34.58	34.25	No	No

*$CaCO_3$ = CaO + L.O.I., S.L. = Slightly lower than the specification, S.M. = Slightly more than the specification

5. Discussion

The acquired results of XRF analyses, which were applied to the collected 13 rock samples (Table 2) showed different possibilities for their use in different industries. We have discussed them hereinafter.

5.1. Cement Industry

Although the comparison of the acquired results of the samples with the specifications of Iraqi Standards (Table 4) showed suitable matching; however, we have noticed that the first two samples (No.1 and 2) have low CaO percentages and high MgO percentages (Table 2). Therefore, we have presented two choices when checking the results with the standards (Table 4). The first choice is for the whole sampled section with a total thickness of 65 m, whereas the second choice is for 11 samples (No.3 – 13), with a total thickness of 55 m. Since the first two samples showed high MgO; therefore, the lower 10 m (Sample Nos 1 and 2) can be easily excluded from quarrying. The results of the second choice showed excellent matching between the Iraqi standards and the acquired results from XRF test (Table 4).

5.2. Paper Industry

Table 5 showed that the results of the second choice are near to the Iraqi specifications for the paper industry. However, the slightly lower percentage of $CaCO_3$ can be treated by adding more limestone of high CaO percentage to the raw mix; like beds from sample Nos. 5, 6, 8, 9, and 11 (Table 2) to increase the percentage of $CaCO_3$. When adding such limestone to the raw mix, the percentage of MgO and SiO2 will decrease in the raw mix. Accordingly, the raw mix will show good matching with the Iraqi Standards.

5.3. Paint Industry

Table 6 showed that the results cannot be treated to match the Iraqi Standards. Therefore, the sampled rocks cannot be used in the paint industry.

6. Quarrying for the Cement Industry

6.1. Quarrying Requirements

During the selection of a site to indicate the industrial uses of the exposed rocks in the section for cement industry, the quarrying conditions should be considered, besides many other necessary aspects, which are very necessary for quarrying, which will facilitate quarrying. Those aspects are mentioned below and are available in the studied section:

- The overburden should be very thin or even without overburden (Figs. 2, 3, 4, and 6),
- No innerburden (Fig. 2 and Table 2),
- Clear and well bedding of the rocks (Figs. 2 and 3) and intense jointing of the rocks (Figs. 2 and 6) which will facilitate quarrying,
- Low dipping amount of the beds is preferable (Fig. 6) for quarrying and true thickness indication,
- Suitable area for plant construction, which should be easily accessible (Fig. 7),
- The thickness of the exposed limestone beds is suitable for quarrying and assuring relevant reserve (Figs. 3, 4, and 6),
- No need for blasting, which means quarrying can be done by heavy machines due to fine to medium bedding nature (Fig. 2, 3, and 6),
- The presence of paved roads near the quarry area (Figs. 2, 6, and 7) and close to the main roads, which join the main cities near the study area.
- The Khurmala Formation has wide exposure areas, which can be used for quarrying and future extension of the quarry (Fig. 3 and 4).
- Clay deposits which are the second raw material in the cement industry are present within the Mukdadiya and Injana formations (Fig. 1).

Fig. 7. The main paved road between Erbil – Koya – Dokan – Sulaimaniyah passes through the studied section and shows the available area for the construction of the cement plant

6.2. Geological Reserve Estimation for a Cement Plant

The limestone beds of the Khurmala Formation in the studied section are very homogenous and have almost similar chemical composition; except the lower 10 m (Table 2). Therefore, the present limestone beds in the area under consideration (Fig.2) were considered as one unit for industrial use and can be quarried systematically. Besides, the present quarrying conditions are very relevant to open a quarry.

The obtained result (Table 2) showed excellent limestone beds for cement production. Accordingly, a relevant quarry should be opened to extract the limestone beds providing a relevant reserve, which can supply a cement plant for 30 – 50 years. To establish such a quarry, we have considered the following scenario.

The used density of the limestone for industrial uses is 2,400 kg/ m3 [12], Accordingly, the weight of 1 m3 of limestone is 2.4 tons (1 m3 X 2400 kg. m3). Clay is the second raw material in cement production. Clay deposits can be quarried from the south of the area under consideration within the Mukdadiya and Injana formations (Fig. 1), The required clay amount for cement production is about 30 – 40 % of the used limestone, which means 0.84 tons of clay should be added to each 2.4 tons (1 m3) of limestone. Accordingly, the total used raw mix = 2.4 + 0.84 = 3.24 tons.

We will suggest a cement plant with a daily cement production of 5000 tons. Therefore, the needed raw mix amount will be about 7,000 tons/day. Accordingly, the annually required raw mix will be = 300 working days X 7000 tons of raw mix = 2,100,000 tons

We will assume 50 years of production, then the total amount of the raw mix = 2,100,000 X 50 years = 105,000,000 tons, which means 43750000 m3 (105750000 ÷ 2.4). Because the sampled section is 55 m thick, we will assume 50 m only, therefore the required area to provide such reserve will be: 43750000 m3 ÷ 50 m = 875000 m2 = 0.875 km2.

However, we have to emphasize that this scenario cannot be considered for investment. This is attributed to the fact that this is an assumed geological reserve estimation with a Low Level of Confidence according to[13]. Therefore, to indicate a reserve estimation for investment with a High Level of Confidence according to[13] detailed site investigation should be performed. This should include the drilling of boreholes with a continuous coring method with spacings between boreholes not to be more than 150 m for the first stage of the investigation. The extracted cores should be sampled in one-meter intervals, the core should be cut longitudinally, the first half should be crushed and sent for chemical analyses, and the second half should be kept in the core box for future uses. From the chemical analyses, the concentration of the main oxides (Tables 2 and 3) should be calculated, accordingly, the suitability of the tested rocks can be estimated whether are relevant for the cement industry or otherwise.

7. Conclusions

From the achieved results from this research including the averages of the main tested oxides and the measured thickness (except the lower 10 m), we can conclude that the studied limestone beds in the studied section are suitable for the cement industry, and partly for paint industry; providing some additions to the main raw. Moreover, according to a preliminary geological reserve estimation, a quarry area of 0.875 km^2 can yield a reserve for a cement plant with daily cement production of 7000 ton/ day for 50 years. The exposed limestone beds in the studied area also can be used for the paper industry after slight treatments and modifications of the quality of the limestone.

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