



Industrial assessment of carbonate rocks using geochemical test: Bekhme Formation of Iraqi Kurdistan Region

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Abstract

Korek Mountain is one of the outstanding mountains in the Iraqi Kurdistan Region; located north of Erbil city. It faces the entrance of the famous Galley Ali Beg gorge with its beautiful waterfall. The exposed rocks at the entrance of the gorge belong to the Bekhme Formation which consists of many types of carbonate rocks with a total thickness of around 100 m. The current study is concerned with the industrial assessment of the exposed carbonate rocks in the Bekhme Formation and to indicate the most relevant industrial uses of the exposed rocks. To perform the industrial assessment, samples were collected from the exposed rocks. The first sample was collected from the bottom of the Bekhme Formation within the Korek anticline and the last one was collected from the top of the formation; at systematic intervals. The collected samples were dried, crushed and ground to powder and were subjected to a XRF test. Upon receiving the chemical composition of the analyzed rocks, it was found that the rocks are very suitable for cement production and could be used in other industries such as paper, paint and sugar with little modification. Accordingly, the weighted averages were calculated to estimate the geological reserve in the studied site.

Keywords Bekhme Formation · Cement industry · Geological reserve · Carbonate rocks

Introduction

The Bekhme Formation (Upper Cretaceous) is one of the widest spread formations in the Iraqi Kurdistan Region. However, it is not exposed at east of the Lesser Zab River (Sissakian and Fouad 2014). The formation consists of carbonate rocks; limestone and dolomite (dolostone) with different proportions (Sissakian and Saeed 2012). Due to extensive facies changes and dolomitization as a diagenetic process, the percentage of limestone to dolostone is not constant and it is not easy to indicate a constant ratio for such large areas. Both limestone and dolomite are very common industrial rocks and are used in different industries. The

main uses are summarized by Al-Bassam and Al-Khafaj (2012) and are assigned in Table 1.

The study area is located in the Korek Mountain (anticline) located approximately 80 km north east of Erbil city, between Khalifan and Soran towns, at the entrance of Galley Ali Beg gorge (Fig. 1). The sampled section is marked by the following coordinates with elevation of 663 m (a.s.l.): N 36° 37' 6.46" E 44° 25' 0.84" and N 36° 37' 1.1" E 44° 25' 0.2" with an elevation of 669 m (a.s.l.).

The main aim of this research is to evaluate the carbonate rocks of the Bekhme Formation for possible industrial usage with special attention paid to cement industry. As there is existing demand on cement plant in the Erbil Governorate. The assessment took place using XRF technique for indicating the chemical composition (especially the main oxides) of the sampled rocks, to calculate the weighted average of the oxides, and accordingly compare the acquired results with the standards mentioned in Table 1.

Carbonate rock has many industrial uses, especially limestone. It can be mined and processed into a wide variety of products, as it is the raw material for a large variety of agricultural, environmental, industrial and construction material such as in cement plants, building stone and/or as

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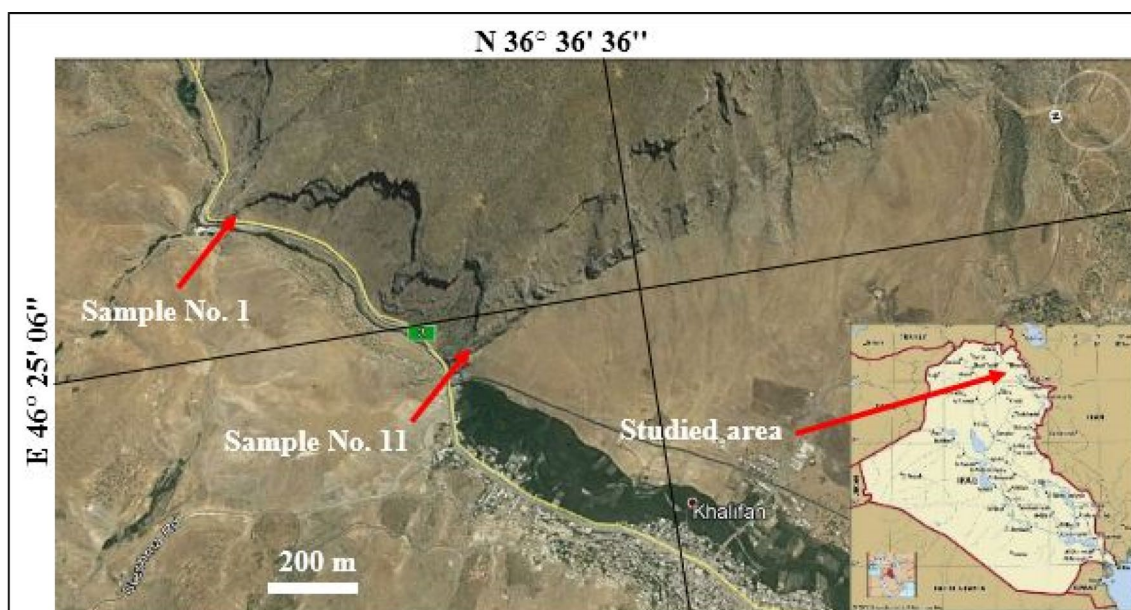
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Table 1 The main uses of the limestone and dolomites in different industries (after Al-Bassam and Al-Khafaj 2012)

Limestone		
Glass industry	Cement industry	Paints
CaCO ₃ > 98%	MgO < 2%	CaCO ₃ > 99.5%
SiO ₂ < 2.0%	CaO > 45%	SiO ₂ < 1.0%
Fe ₂ O ₃ < 0.06%	SO ₃ < 1%	Al ₂ O ₃ < 0.05%
MgO < 0.05%	Cl 0.5–1.0%	Fe ₂ O ₃ < 0.05%
LOI > 43%	K ₂ O + Na ₂ O 0.05%	LOI > 43.5%
	Fe ₂ O ₃ < 0.1% (white cement)	
Steel	Sugar industry	Paper industry
CaCO ₃ 92–95%	SiO ₂ < 0.66%	CaCO ₃ > 90%
MgCO ₃ 1.3–1.9%	Al ₂ O ₃ < 0.27%	SiO ₂ < 1.5%
Al ₂ O ₃ 1–2%	Fe ₂ O ₃ < 0.09%	MgO < 1.5%
CaSO ₄ 0.5–0.8%	MgO < 4.0%	SO ₃ < 1%
P 0.05–0.09%	CaO > 55%	IR (in HCL) < 4.5%
SiO ₂ 1.5–3.5%		
Dolomite		
Magnesia	Metallurgy	
MgO > 20%	MgO 15–20.5%	CaO 28–35%
	SiO ₂ 1.5–3.5%	Al ₂ O ₃ 1–3%
	SO ₃ 0.5–1.5%	Moisture 2–10%

**Fig. 1** Satellite image of the study area (facing west)

aggregates, etc. One of the main uses of limestone rock in the Iraqi Kurdistan Region and globally is in cement production, it is considered as an essential material in construction (Bliss et al. 2008; Abdel Moneim et al. 2013; Tseni et al. 2013; Ozgunar 2014; Bouazza et al. 2016; Hussain et al.

2018; Sissakian et al. 2019, 2020; King 2020). Six cement plants have been built in the Kurdistan Region of Iraq, with five of them are in the Sulaimaneyah Governorate and one in the Erbil Governorate. Therefore, it is very necessary to build a cement plant in the Erbil Governorate to cover the

requirements of the construction industry in the governorate and even in the nearby Duhok Governorate. Accordingly, a relevant reserve of limestone should be available to locate a cement plant with other quarrying conditions; beside the presence of clay which is the second main raw material in cement production.

The Bekhme Formation was studied by several researchers with special attention paid to petrography, sedimentology and stratigraphy (Ali 2005; Sissakian and Al-Jiburi 2014; Al-Dulaimi and Abdallah 2019) including lithostratigraphy, biostratigraphy and sequence stratigraphy of the formation (Al-Mutwali et al. 2008; Al-Mutwali and Al-Haidary 2012; Al-Dulaimi and Al-Obaidy 2017) in addition to diagenesis (Shingaly and Al-Juboury 2013; Mansurbeg et al. 2016; Salih et al. 2019) without focusing on the economic value that Bekhme Formation may have.

Although Limestone has many industrial uses but the main use of limestone beds in the Iraqi Kurdistan Region is mainly in cement production in addition it is locally used as an aggregate but without any scientific studies. Iraqi Geological Survey conducted many studies since the early seventies of the nineteenth century to evaluate the exposed limestone beds everywhere in Iraq. The main aim of those studies was the evaluation of the limestone beds for the cement industry. Among those studied which are in the Kurdistan Region are: Jaber and Al-Ubaidi (1973), Al-Rufaie (1976), Al-Rufaie and Muhamad (1976), Mansour (1976, 1977), Etabi and Ahmed (1979), Al-Murib (1980), Hafidh and Khlaif (2007), Hafidh and Abdul Hassan (2008) and Hafidh et al. (2008, 2011) in addition to works of Sissakian et al. (2019, 2020). They all evaluated the exposed limestone beds for the cement industry at different parts in the Kurdistan Region and used the same method used in the current study.

Many studies took place internationally on the assessment of carbonate rocks, especially limestone as the main constituent of raw material used in the manufacturing of cement. Bliss et al. (2008) stated that Portland cement is one of the most important products made from limestone and it is essential in many construction applications. They also claimed that the United States is not self-sufficient in cement and has to import it from other countries to make up for shortfalls. Abdel Moneim et al. (2013) studied raw materials of the Drunka Formation in Egypt for the cement industry using geological and geochemical investigations. They reported that cement manufacturing depends greatly upon the chemical and physical characteristics of raw materials, its quality and quantity, simplicity of its extraction and its costs. Tseni et al. (2013) studied the suitability of carbonate rocks from the Kataraktis Passage Member in western Greece to evaluate them based on their petrographic and geochemical characteristics, in addition to their physical properties. Based on the percentage of the oxides from the geochemical test indicates that

these carbonate rocks could be suitable as raw material for cement production. Ozgunar (2014) and Bouazza et al. (2016) conducted geochemical assessment of limestone deposits in Turkey and Morocco, respectively, to evaluate the suitability of the deposits for the cement industry using XRF and XRD. They concluded that indicating the main oxides like CaO, MgO, SiO₂, Al₂O₃, Fe₂O₃ is the best method for the evaluation. Hussain et al. (2018) studied limestone deposits of the upper Hunza Valley in Pakistan to evaluate their suitability as a raw material for the cement industry. Result shows that there is good potential for industrial-grade limestone, the composition of this limestone can be generally expressed in terms of CaO, MgO, Al₂O₃, and SiO₂. This is used in place of similar commodities of good quality cement raw materials. King (2020) mentioned that limestone is a rock with an enormous diversity of uses. It could be the one rock that is used in more ways than any other. Most limestone is made into crushed stone and used as a construction material. It is used as a crushed stone for road bases and railroad ballast. It is used as an aggregate in concrete and it is fired in a kiln with crushed shale to make cement.

Geological setting

The study area is located within the Korek anticline, north of Erbil city. The main geological aspects are briefly described emphasizing the significant features, which have a direct and/ or indirect effect on the current study.

Geomorphology

The study area is located; physiographically within the High Mountainous Province (Sissakian and Fouad 2012). The main geomorphological units are:

Structural geological units: Among them are the anticlinal ridges, which extend along the anticline. They are developed within the Bekhme Formation. These can be used for the quarrying of limestone beds although the dip amount is 45°, but they can serve as relevant quarry faces. As the rocks are hard to very hard and thickly bedded to massive; therefore, they form stable slopes (showing very rare unstable slopes) which is a positive aspect in selecting quarry locations.

Structural–denudational units: Among them are the flatirons, which are well developed within the Bekhme Formation. The flat irons can be used as quarry faces; since they are huge masses of rocks without any overburden and can be used as quarrying faces from three directions (Fig. 2). Other units are the fault scarps and erosional scarps which are developed within the Bekhme Formation.

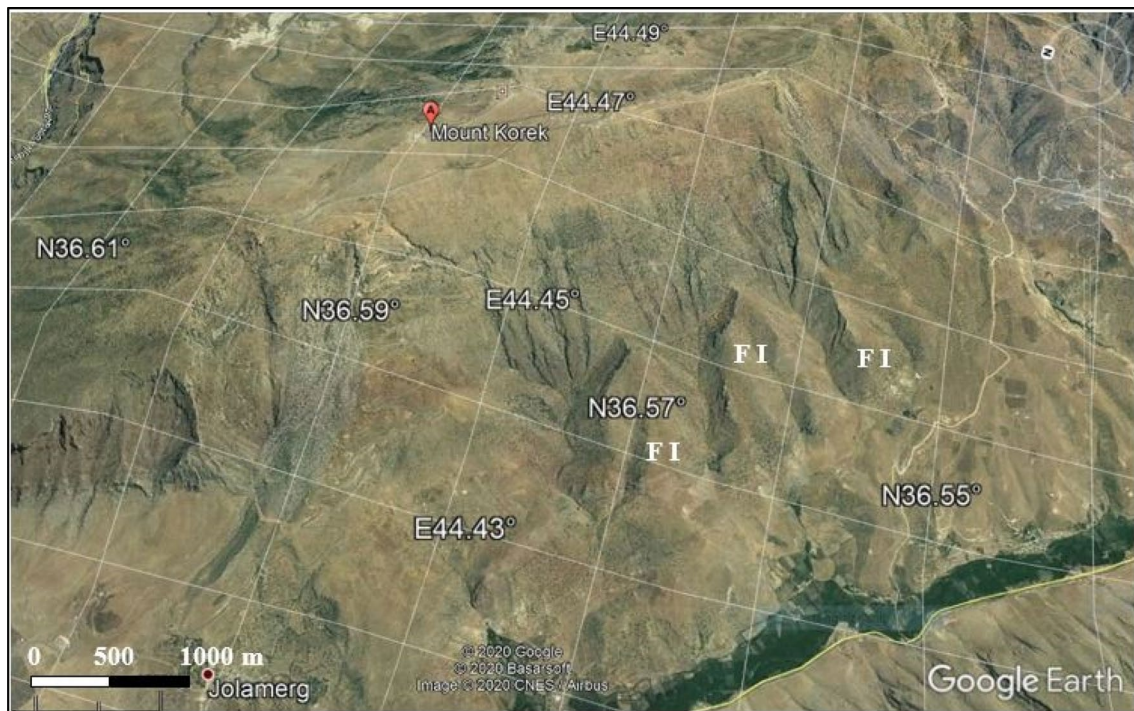


Fig. 2 Google Earth image showing flat irons (FI) in the Bekhme Formation

Tectonic and structural geology

The study area is located within the High Folded Zone, Outer Platform of the Arabian Plate. It belongs to the Zagros Thrust–Fold Belt (Fouad 2012). One anticline occurs in the study area; it is called the Korek anticline. The anticline is located east of the Peris anticline, forming the bulk of Korek Mountain and the continuation of the Bradost anticline. Its length is 20 km with a NW–SE trend and a steeper northeastern limb, but eastwards it becomes almost symmetrical. The north-western plunge is truncated by a reverse fault.

The northeastern limb can serve as good quarry face because it is overlain by fairly hard marl and marly limestone beds of the Shiranish Formation. Moreover, the uppermost part of the anticline (the axial part) is very wide with horizontal beds (Fig. 3), which also can serve as a location for the quarry. The highly jointed rocks due to the exerted compressional forces during the collision of the Arabian and Iranian plates (Alavi 2004; Fouad 2012) will facilitate the quarrying of the rocks, because the jointing planes will form weakness zones and accordingly can be quarried easily.

Stratigraphy

The Bekhme Formation is widely exposed in the study area. It forms the uppermost cliffs in the study area; locally forming hanging slopes and hudoos, which are chimney like isolated geomorphological forms. The upper contact of the

formation with the overlying Shiranish Formation, is conformable. The lithological composition of the formation is almost constant throughout the anticlinal area and it is limestone with a presence of dolomitic limestone at the base of the formation. This constant lithological character serves the quarrying of the beds and encourages extending the investigated site farther east wards where quarrying conditions are better and also suitable site is available for a cement plant. The thickness of the formation is highly variable, in the sampled site it is 110 m, in the Bekhme gorge (westwards) it is 315 m, in the Rawandooz (northwards) it is 75 m, but usually it ranges from to 300–500 m. However, the maximum thickness is 1050 m between Bekhme gorge and Dohok city, west of the sampled site. The formations become thinner relatively to the NE and SW line, passing into the Tanjero and Shiranish formations, respectively (Sissakian and Fouad 2014; Sissakian and Al-Jiburi 2014).

Materials and methods

Several materials were used including geological maps of different scales, satellite images of high resolution, in addition to samples which were collected from the outcrops of the Bekhme Formation, along the road at the entrance of Galley Ali Beg gorge. Sampling took place based on lithological variations recognized in the field.



Fig. 3 The axial part of Korek anticline, note the well-bedded nature of the beds and highly jointed rocks. For a scale, the Hoodo's are (3–4) m in height

To perform industrial assessments on the carbonates of the Bekhme Formation at Korek Mountain, 11 samples were collected, prepared and subjected to a XRF test. After the acquired results from the XRF test, the weighted averages for each oxide were calculated and compared with different standards (Table 1) to indicate the suitability of the studied carbonates for industrial use.

Sample collection

After selecting the study area at the Korek Mountain; fresh rocks from the exposed carbonate outcrop were sampled with different sampling intervals (Table 2). The sampling

interval was changed, with main change recognized in lithological characters and/or bedding nature. Accordingly, 11 samples were collected starting from the bottom (Fig. 4, left) to the top (Fig. 4, right) of the Bekhme Formation.

Sample preparation and analysis

The collected samples were prepared for an XRF test by the following steps:

- The samples were dried in an oven with a temperature of 110 °C for 1 h (Fig. 5, left).

Table 2 Field description of the collected samples from the study area

Sample no.	Color	Hardness	Thickness (m)		Reaction with acid
			Sample interval	Individual bed	
1	Gray	Hard	10	1–2	Reactive
2	Grayish white	Hard	10	1	Reactive
3	Light gray	Hard	25	0.5	Highly reactive
4	Light gray	Hard	25	1	Highly reactive
5	Grayish white	Hard	10	1	Highly reactive
6	Light gray	Hard	5	0.5	Highly reactive
7	Gray	Hard	3	0.5–1	Highly reactive
8	Dark gray	Very hard	3	1	Highly reactive
9	Dark gray	Vary hard	3	0.5–1	Highly reactive
10	Dark gray	Very hard	3	1	Highly reactive
11	Dark gray	Very hard	0.5	0.5–1	Highly reactive



Fig. 4 Exposures of the Bekhme Formation. Left—bottom, right—top of the formation



Fig. 5 Left—drying of the samples in the oven, middle—a crushed sample, right—XRF equipment

- Samples were crushed using a samples crusher (Fig. 5, middle).
- The crushed samples were ground to powder using a Mill machine for 5 min.
- From each sample, 12 g was weighed. 2 g of methyl cellulose in addition to 0.5 g of steric acid with a concentration of 95% were added to homogenize the powdered sample to make it ready for the XRF test.
- Finally, the samples were subjected to the XRF test (Fig. 5, right). XRF is an acronym for X-ray fluorescence, a process whereby electrons are displaced from their atomic orbital positions, releasing a burst of energy that is characteristic of a specific element. This release of energy is then registered by the detector in the XRF

instrument, which in turn categorizes the energy by element.

Results

The collected samples after being prepared were subjected to the XRF test to determine the percentage of main oxides with some other components, so that the studied carbonate successions can be assessed for different industrial uses. The acquired results are assigned in Table 3.

After that, the weighted averages of each oxide and some other components was calculated and tabulated in Table 4. Finally, weighted averages were compared with

Table 3 Concentration of oxides in the collected samples (indicated by XRF test)

Sample no.	CaO (%)	MgO (%)	SiO ₂ (%)	Fe ₂ O ₃ (%)	Al ₂ O ₃ (%)	Na ₂ O (%)	LOI (%)
1	33.17	11.75	1.62	0.49	0.52	0.57	46.70
2	50.44	4.46	0.75	0.39	0.30	0.56	43.80
3	53.52	1.75	0.36	0.35	0.20	0.59	43.79
4	53.95	1.26	0.34	0.37	0.18	0.55	43.77
5	53.11	1.15	1.00	0.42	0.30	0.55	43.08
6	53.92	1.07	0.50	0.37	0.19	0.55	43.35
7	54.23	1.70	0.70	0.35	0.26	0.07	43.40
8	53.86	1.29	0.37	0.37	0.20	0.54	43.76
9	53.57	1.20	0.55	0.37	0.29	0.54	43.60
10	52.75	1.29	0.96	0.41	0.42	0.56	43.36
11	52.27	1.53	1.92	0.43	0.67	0.52	43.30

the standards of Table 1, to indicate the suitability of the samples for certain industries. However, to have an industrial assessment for the bulk of the studied rocks not for individual sample, the weighted average was calculated for each oxide using the following equation:

Weighted average = concentration of each oxide (%) × thickness of each sample (m),

Total weighted average = sum of all weighted averages (of each oxide) / total thickness of the samples (m).

Discussions

The acquired weighted averages of the analyzed oxides from Table 4 were compared with some industrial standards of Table 1, to indicate the suitability of the collected samples (Table 5) which represents the rocks of the Bekhme Formation. Accordingly, the following discussion is based on the analysed results:

- Cement industry: The weighted averages of the oxides and some other components in the collected rock samples match those required for cement production, although the MgO concentration is slightly high at the base of the formation, so that the first 10 m of the formation was eliminated in the calculation to become 1.75% within the standard range. However, SO₃ and Cl were not detected. This means the concentrations are very low, and accordingly, they will match the specified standards (Table 5).
- Paper industry: The weighted averages of the oxides in the collected rock samples match those required by the paper industry, except the MgO concentration is slightly high at the base of the formation. So that the first 20 m of the formation was eliminated in the calculations to become 1.41% within the standard range. Since the concentration of the SiO₂ is 0.62% (Table 5), then the IR %

is less than 4.5%, which means it will match the required specifications.

- Paint industry: The weighted averages of the oxides in the collected rock samples match (almost) those required by the paint industry, although the Al₂O₃ and Fe₂O₃ con-

centrations are slightly higher than the specified standard (0.05%) (Table 5). These slightly higher concentrations will effect the brush-ability of the produced paint. However, in many types of paints there is no need for such smoothness, which means the exposed rocks can be used for certain paint industries, especially out side door paints.

- Sugar industry: The weighted averages of the oxides in the collected rock samples match those required for the sugar industry, although the Fe₂O₃ and CaO concentrations are slightly higher for the former oxide and lower for the latter (Table 5). These slightly different concentrations can be solved by adding more limestone of a high CaO content, whereas the slightly higher Fe₂O₃ content will effect the color of the produced sugar during the bleaching of sugar cane.
- Other industries: The specifications needed for: (1) steel industry, (2) glass industry, (3) metallurgical uses, and (4) magnesia production, are very far from those of the exposed rocks of the Bekhme Formation (Table 5). Therefore, those rocks are not suitable for the mentioned industries and/or uses. However, they can be used as: aggregate (after crushing to desired sizes), in different agricultural activities including protection from freezing of the agricultural yards, in stabilizing the (pH) of the

Table 4 Weighted averages of the analyzed oxides in the collected samples

Sample no.	Thickness (m)	CaO		MgO		SiO ₂		Fe ₂ O ₃		Al ₂ O ₃		LOI	
		Conc. (%)	W.A. (%)	Conc. (%)	W.A. (%)	Conc. (%)	W.A. (%)	Conc. (%)	W.A. (%)	Conc. (%)	W.A. (%)	Conc. (%)	W.A. (%)
1	10	33.17	331.70	11.75	117.50	1.62	16.20	0.49	4.90	0.52	5.20	46.70	467.00
2	10	50.44	504.44	4.46	44.60	0.75	7.50	0.39	3.90	0.30	3.00	43.80	438.00
3	25	53.52	1338.00	1.75	43.75	0.36	9.00	0.35	8.75	0.20	5.00	43.79	1094.75
4	25	53.95	1348.75	1.26	31.50	0.34	8.50	0.37	9.25	0.18	4.50	43.77	1094.25
5	10	53.11	531.10	1.15	11.50	1.00	10.00	0.42	4.20	0.30	3.00	43.08	430.80
6	5	53.92	269.60	1.07	5.35	0.50	2.50	0.37	1.85	0.19	0.95	43.35	216.75
7	3	54.23	162.69	1.70	5.10	0.70	2.10	0.35	1.05	0.26	0.78	43.40	130.20
8	3	53.86	161.58	1.29	3.87	0.37	1.11	0.37	1.11	0.20	0.60	43.76	131.28
9	3	53.57	160.71	1.20	3.60	0.55	1.65	0.37	1.11	0.29	0.87	43.60	130.80
10	3	52.75	158.25	1.29	3.87	0.96	2.88	0.41	1.23	0.42	1.26	43.36	130.08
11	0.5	52.27	26.13	1.53	0.76	1.92	0.96	0.43	0.21	0.67	0.33	43.30	21.65
Total	97.5		4992.95		271.40		62.40		37.56		25.49		4286.28
Weighted average (%)			51.20		2.78		0.64		0.38		0.26		43.96

Conc. concentration, W.A. weighted average

soil and water, in haphazard dumping, and many other uses; as building-stone and decorate stone.

Geological reserve estimation for cement plant

The analyzed samples showed very interesting results (Table 3), especially for use as a raw material in cement production. Accordingly, a geological reserve estimation can be considered by ignoring the first 10 m, which are represented by sample no.1. The remaining sampled succession will be of 87.5 m in thickness with a 53.45% average weighted CaO, whereas that of MgO will be 1.71%. Both percentages are very relevant for cement production (Table 1).

If we consider an area of half a square kilometer in which the sampled succession (apart from the 10 m located at the bottom of the sampled section) will be quarried as limestone for raw material and used for cement production, the geological reserve estimation will be calculated as follows:

$$\text{Half square kilometer} = 250,000 \text{ m}^2(\text{surface area}).$$

The used thickness will be about 85 m.

The volume of the limestone in the concerned area for quarrying = $250,000 \times 85 = 2125 \times 10^4 \text{ m}^3$.

If we consider the average density of the limestone is 2400 kg/m^3 , then the weight of the limestone which can be quarried will be = $2400 \times 21,250$ tons, which is 51,000,000 tons.

If we consider a cement plant with a daily production of 5000 tons, then the required limestone amount will be 10,000 tons/day, which means:

$$51,000,000 \div 10,000 = 5100 \text{ days.}$$

If we consider 300 working days per year, then the quarried amount of the limestone will be sufficient for:

$$5100 \div 300 = 17 \text{ years}$$

Because the chemical composition of the sampled beds (apart from the first 10 m) is almost homogeneous (Table 3); therefore, the coverage area of the supposed quarry can be enlarged; accordingly, the estimated geologic reserves will be sufficient for additional years. It is worth mentioning that the minimum years of service for a cement plant, is 30 years; therefore, twice of the supposed area will be enough for a planned cement plant with a annual production of 5000 tons/day. However, it is worth mentioning that this is a geological reserve estimation with low level of confidence (according to JORC Code 2012) and cannot be used for future consideration. A detailed site exploration is required to discover the true reserves with a high level of confidence

Table 5 Specifications of some industries as compared with the results of the current study

Specifications of Industries (%)															
Cement Industry		Current Study		Paint Industry		Current Study		Steel Industry		Current Study		Sugar Industry		Current Study	
CaO	> 45.00	51	Green	CaCO ₃	> 99.5	95	Yellow	CaCO ₃	92 – 95	95	Green	MgO	< 4.00	2.8	Green
MgO	< 2.00	2.8	Yellow	SiO ₂	< 1.00	0.6	Green	MgCO ₃	1.3 – 1.9	47	Red	CaO	> 55.0	51	Yellow
Fe ₂ O ₃	< 0.10	0.4	Green	Al ₂ O ₃	< 0.05	0.3	Red	Al ₂ O ₃	1 – 2	0.3	Red	Al ₂ O ₃	< 0.27	0.3	Green
SO ₃	< 1.00		Yellow	Fe ₂ O ₃	< 0.05	0.4	Red	CaSO ₄	0.5 – 0.8		Yellow	Fe ₂ O ₃	< 0.09	0.4	Red
Cl	0.50 – 1.00		Yellow	L.O.I.	> 43.00	44	Red	SiO ₂	1.5 – 3.5	0.6	Red	SiO ₂	< 0.66	0.6	Green
L.O.I.	> 43.00	44	Green	CaCO ₃ = CaO + L.O.I.				P ₂ O ₅	0.05 – 0.09		Yellow				
				MgCO ₃ = MgO L.O.I.											
Glass Industry		Current Study		Metallurgy		Current Study		Magnesia		Current Study		Paper Industry		Current Study	
CaCO ₃	> 98.00	95	Yellow	CaCO ₃	92 – 95	51	Red	MgO	> 20	2.8	Red	CaCO ₃	> 90	95	Green
SiO ₂	< 2.00	0.6	Green	MgO	1.3 – 1.9	2.8	Red					MgO	< 1.5	2.8	Red
MgO	< 0.05	2.8	Red	Al ₂ O ₃	1 – 3	0.3	Red					SiO ₂	< 1.5	0.6	Green
Fe ₂ O ₃	< 0.06	0.4	Yellow	SiO ₂	1.5 – 3.5	0.6	Red					SO ₃	< 1.0		Yellow
L.O.I.	> 43.00	44	Green	SO ₃	< 1		Yellow					I.R.	4.5		Yellow
Fit with the standard		Red		Out of the standard				Not Analyzed or detected				Near to the standard			

(according to JORC Code 2012) which can then be used to gain investment.

Quarrying conditions

Besides the excellent quality of the exposed limestone at the studied area, the following positive quarrying conditions encourage using of the studied area and near surroundings as a quarry for a cement plant:

- No overburden and/ or inner burden exist within the studied succession, although the uppermost 10 m are unsuitable due to high MgO %, but they can be ignored easily during the quarrying. Moreover, those beds are not present in the axial part of the anticline (Fig. 3).
- The bedding nature and highly jointed rocks (Fig. 3) will facilitate the quarrying process and needs less explosives and/or medium sized bulldozers and shovels.
- The long extension of the anticlinal ridges with thickness of 80–100 m will serve to locate the quarry in best favorable place, as the other quarrying facilities are concerned; like infrastructure, remoteness from habituated and/ or tourist sites.

- The presence of high ridges and flat irons (Fig. 2) can serve as good quarrying faces along the structural ridges.

Conclusions

The current study has been conducted to indicate the suitability of the exposed rock in the Bekhme Formation at the entrance of Gulley Ali Bed gorge of the Korek Anticline, northeast of Erbil city. To fulfil the main aim of the study, rock samples were collected and subjected to the XRF test, and the acquired results of the oxides were converted to weighted averages. The weighted averages were compared with specifications of limestone and dolomite required for different industrial uses. The results showed that the studied rocks are suitable for the cement industry. The rocks also can be used for the paper, paint and sugar industries; however, slight modifications are necessary, to match the used standards. The first bed at the bottom of the formation with thickness of 10 m, can be used either as dolomite alone, or can be quarried and mixed with beds of high CaO content, in the remaining part of the formation.

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