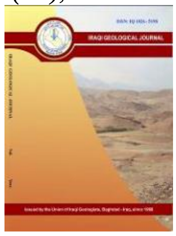
Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org



Industrial Assessment for the Exposed Carbonate Rocks on Safeen Mountain Kurdistan Region of Iraq

Varoujan K. Sissakian[1*] and Ala Ghafour[2]

1 Petroleum Engineering Department, Komar University of Science and Technology, Sulaimani, 46001, Kurdistan Region, Iraq
2 Department of Geology, University of Regina, Regina, Canada.
* Correspondence: Varoujan49@yahoo.com, ala.ghafur@uregina.ca

Received: 2 June 2023

Accepted: 9 October 2023

Published: 31 January 2024

Abstract

The Safeen Mountain is one of the main mountains in the Iraqi Kurdistan Region, it forms one of the long anticlines trending NW – SE. The exposed formations on the top of the mountain are Qamchuqa, Bekhme, and Shiranish, with carbonate rocks of different types and thicknesses. Sampling took place in the exposed rocks on the top of the mountain where a road crosses the mountain, and a total of 20 samples out of 84 m thickness of the outcrop were collected. The distance between sampling intervals was depending on the lithological variation of the bedrock and each sample was collected to represent the sampling interval. The samples were subjected to XRF to indicate the main oxides percentages in each sample. The acquired results from the XRF showed the studied rocks can be used for cement and paper industries based on Iraqi Standards. They can also be considered using it in the sugar industry after a slight modification as well as in the drug industry.

Keywords: Limestone; Industrial assessment; XRF; Cement industry; Paper industry

1. Introduction

Erbil city is the capital of the Kurdistan Region of Iraq (KRI), it is witnessing large expansion in infrastructure, therefore, enormous amounts of cement are required to cover the necessities of those parts of the infrastructure, which are under construction and will be constructed. In Erbil Governorate, there is only one cement plant, which is about 56 km south of Erbil city, it is called the KAR cement plant located in the northern limb of the Qara Chough anticline. Therefore, it is very necessary to establish a cement plant within Erbil Governorate. Accordingly, suitable limestone reserves should be found and estimated within the geographical limits of the Erbil Governorate.

Many researches have been carried out to study industrial assessment of the exposed limestone beds in KRI, among them are Mirza et al. (2016), Merza and Fatah (2018), Sissakian (2018), Sissakian et al. (2018, 2020, 2021a and b), Ghafur et al. (2021 and 2022), Hamawandy et al. (2022). They all concluded that there are enormous amounts of limestone, which can be used as raw material for the cement industry with other industries like paper, paint, and very locally for medical uses. However, only two of those researches dealt with the limestone beds in Erbil Governorate, in Permam Mountain from the Pila Spi Formation (Sissakian et al., 2018,) and Gulley Ali Beg from the Bekhme Formation (Ghafur et al., 2021).

DOI: 10.46717/igj.57.1A.14ms-2024-1-25

Limestone is the main constituent in cement production, whereas the second raw material is claystone, which is available as an economic deposit in different geological formations such as Gercus, Mukdadiya, Injana, and Fatha (Fig. 1). In all cement plants in KRI, the percentage of added clay to the raw mix for the cement productions is about 30-40 % (Personal observation at Mass Cement Company, 2018) (Sissakian et al., 2021, Ghafur et al., 2022, Hamawandy et al., 2022). This is also confirmed by the British Geological Survey (2005). Gypsum is also one of the constituents of raw mix and cement production and is added to about 5% of the weight (British Geological Survey, 2005). The nearest gypsum quarries to the studied area are in Agh Jalar, 50 km southeast of the studied area (Fig. 1). It is worth mentioning that the five cement plants in Sulaymaniyah Governorate at Bazian vicinity use gypsum of the Fatha Formation from Agh Jalar quarries (Sissakian et al., 2020) (Fig. 1).

The location of the studied area is shown in Fig. 1. The possible locations for clay and gypsum deposits are also shown in Fig. 1. This research aims to perform an industrial assessment of the exposed rocks within the Shiranish and Bekhme formations, which are exposed on the top of Safeen Mountain.

2. Materials and Methods

To perform the current research, we have selected a relevant section to collect representative rock samples used in the industrial assessment of the exposed rocks within the selected section. The geological maps of 1:100000 and 1:250000 scales are used to select the studied section. The area was decided after a field investigation to check its suitability for sampling.

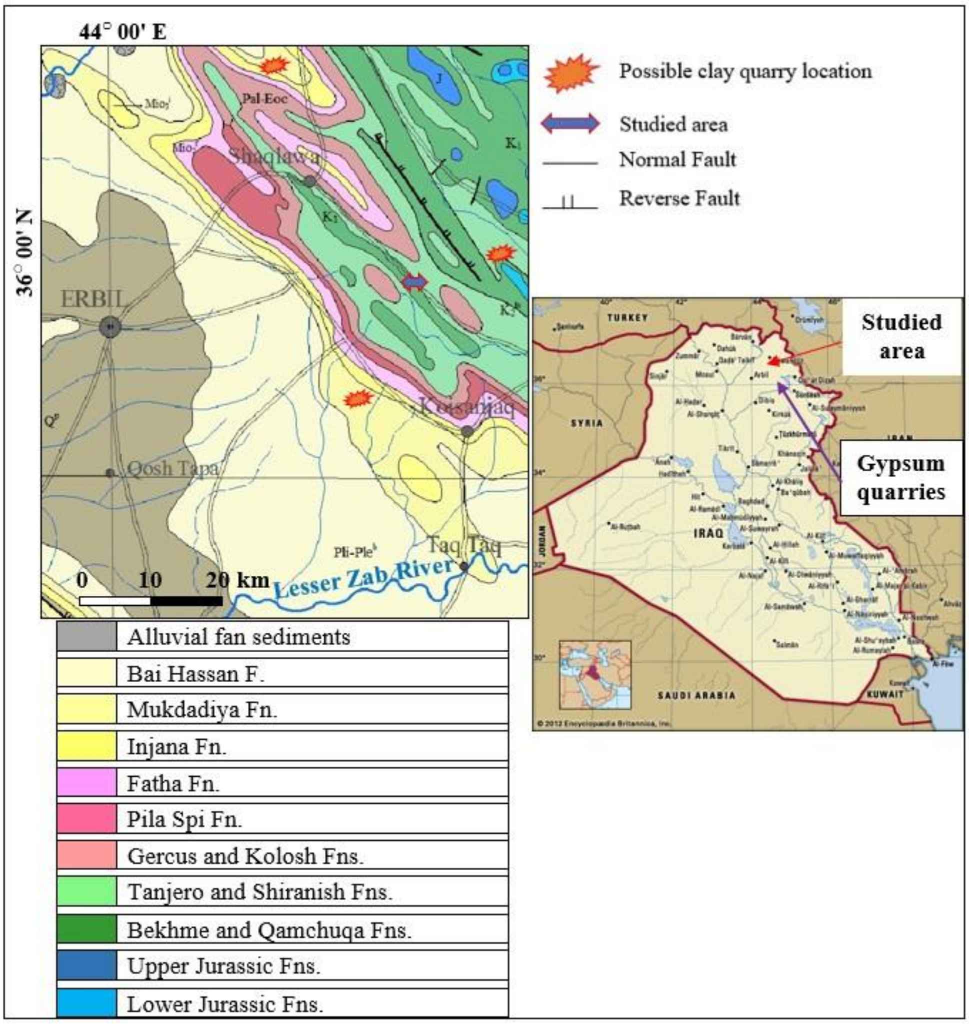


Fig. 1. Geological map of the studied area (After Sissakian and Fouad, 2015), showing the studied area and possible clay and gypsum quarries.

Besides the geological conditions, we have considered the following aspects in selecting the studied section: clear rock exposures without Quaternary cover (Fig. 2a); gentle dipping of the exposed rocks to facilitate quarrying of the rocks as benches (Fig. 2b); thinly bedding nature and none-very hard rocks nature, which will facilitate easy quarrying by bulldozers without blasting (Fig. 2c); existing main roads (Fig.2d); relevant extension of the outcrops to facilitate reserve estimation and opening of a quarry (Fig. 2e); existing clay deposit, which is the second main constituent of the raw mix in cement production (Figs. 1 and 2f); available flat area for construction of the cement plant (Fig.2g), and absence of villages in the studied area.

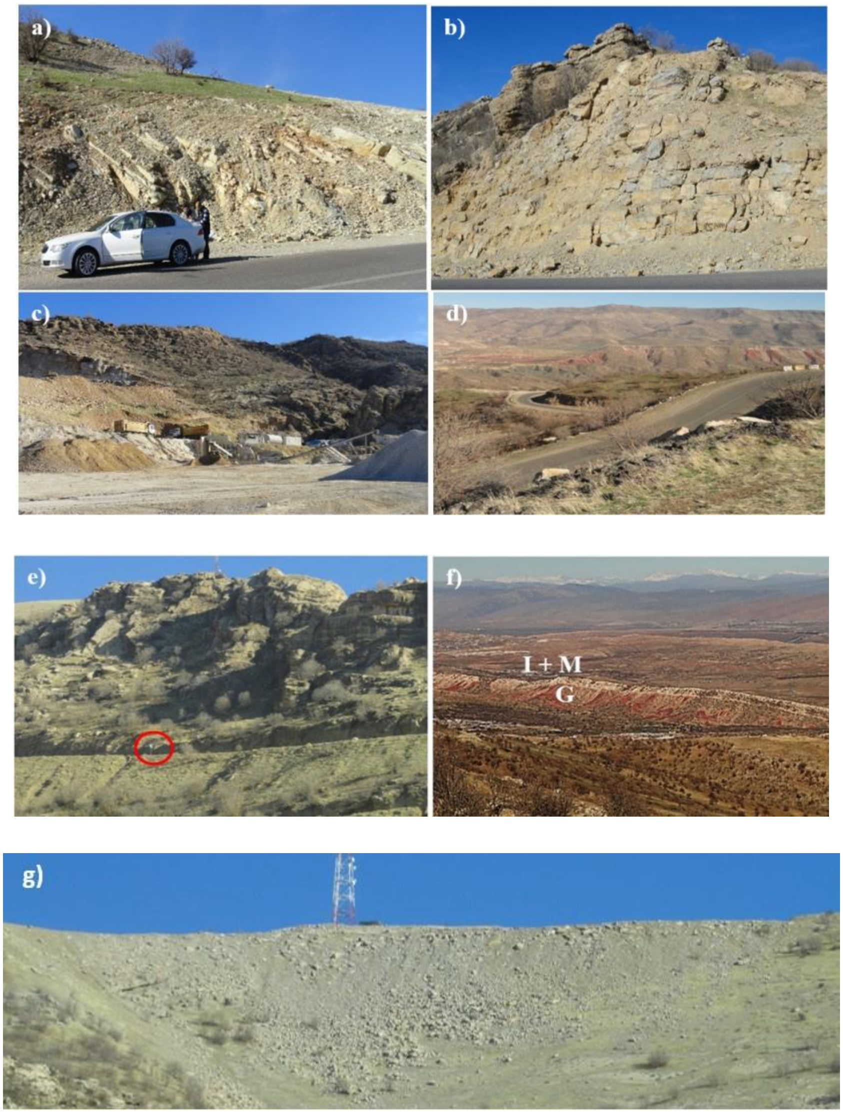


Fig. 2. a) Exposed beds free from overburden sediments, b) gently dipping and intensely jointed beds, c) Easily crushed rocks, d) Availability of roads, e) Extension of outcrops (For scale refer to the traffic signpost, encircled by red color), f) Claystone beds in the Gercus Formation (G) and the Mukdadiya and Injana formations (I + M), and g) A flat area on the top of Safeen Mountain, can be used to construct a cement plant. Note the slope sediments and scree.

In the studied area, 20 rock samples were collected with irregular spacing depending on a change in the lithological characteristics of the bedrock. However, when the spacing was more than 5 m, then a new sample was collected. Totally 84 m of thickness was sampled in the section, each sample was collected as small chips to be representative of the sampled interval. The small chips will also facilitate the crushing of the samples. All the samples were described in the field and tested with HCl acid (Table 1). The sampled interval includes the Shiranish and Bekhme formations, samples with S and B letters represent the Shiranish and Bekhme formations, respectively. The samples were stored in plastic bags, numbered then transferred to a local laboratory, where XRF was applied to indicate the main oxides in each sample (Table 2).

Table 1. Lithological description of the collected samples

S. No.	Thick. (m)	Field description
1S	4	Yellowish white limestone, fairly hard well thinly bedded, fairly reacted by HCl
2S	3	Light brownish-grey limestone, well bedded, hard, thinly jointed, well reacted with HCl
3S	5	Yellowish-white marly limestone, fairly hard well thinly bedded, fairly reacted by HCl
4S	4	
5S	4	Light brownish-grey limestone, well bedded, hard, thinly jointed, well reacted with HCl
6B	5	Light brownish-grey limestone, well bedded, hard, thinly jointed, well reacted with HCl
7B	4	
8B	5	Light brownish-white limestone, well thickly bedded, hard, jointed, highly reacted with HCl
9B	3	
10B	4.5	Greyish-white limestone, thickly bedded, hard, jointed, well reacted with HCl
11B	5	Light greyish-white limestone, thickly bedded, hard to very hard, jointed, highly reacted with HCl
12B	3	
13B	5	Light brownish-grey limestone, well bedded, hard, thinly jointed, well reacted with HCl
14B	4.5	
15B	5	Light greyish-white limestone, thickly bedded, hard to very hard, jointed, highly reacted with HCl
16B	3	
17B	5	Light brownish-white limestone, thickly bedded, hard, jointed, well reacted with HCl
18B	4	
19B	5	Greyish-white limestone, thickly bedded, hard, jointed, well reacted with HCl
20B	3	

For the industrial assessment of the tested rock samples, we have compared the average concentrations of the main oxides with the Iraqi Standards (Al-Bassam and Al-Khafaji, 2014 in Sissakian, 2018) of different industries to check the matching of the oxides in the samples with different industrial uses. However, before checking the matching of the acquired results from XRF with Iraqi Standards, we have indicated the weighted average of each oxide at each sample using the following equation:

N means below detection limits

The weighted average of each oxide is calculated by the following equation (IET, 2021):

$$Weighted\ Average = \frac{\sum C1 + C2 + C3 + C4 + Ci}{\sum T1 + T2 + T3 + T4 + Ti}$$

Where C is the percentage of each oxide multiplied by the thickness of the sample (T).

The weighted averages of each oxide (Table 3) were compared with the specifications of some industries, which use limestone as a raw material to indicate the suitability of the studied limestone beds with those industries based on the mentioned standards.

Table 2. Concentrations of main oxides in the samples using XRF

S. No.	Thick. (m)	Concentration (%)										
		CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	Cl	P_2O_5	SO_3	LOI
1S	4	51.42	1.26	0.32	1.24	0.13	0.14	0.32	N	N	0.81	42.80
2S	3	51.11	1.27	0.33	2.51	0.58	0.03	0.48	N	0.01	0.21	42.96
3S	5	52.75	1.18	0.04	0.39	0.99	0.01	0.32	N	0.02	0.31	43.06
4S	4	53.79	1.12	0.07	0.49	0.02	0.05	0.04	N	0.01	0.41	43.90
5S	4	53.44	1.11	0.66	0.12	0.22	0.14	N	N	N	0.02	43.20
6B	5	53.64	1.37	0.42	0.14	0.74	0.70	0.06	N	N	0.61	43.40
7B	4	52.86	1.16	0.22	0.12	0.22	0.15	N	N	N	0.11	43.20
8B	5	53.86	1.16	0.29	0.10	0.45	0.71	N	N	N	0.09	43.20
9B	3	53.23	0.89	0.11	0.15	0.48	0.02	N	N	N	0.06	44.80
10B	4.5	53.63	1.24	0.51	0.16	0.72	0.07	N	N	N	0.08	43.63
11B	5	53.59	1.19	0.19	0.18	0.49	0.18	N	N	N	0.11	43.00
12B	3	51.44	1.13	0.26	0.35	0.91	0.59	0.30	N	0.29	0.30	44.67
13B	5	53.72	1.06	0.24	0.41	0.11	0.54	N	N	0.01	0.47	42.65
14B	4.5	53.07	1.01	0.32	0.24	0.09	0.26	N	0.20	0.81	N	43.80
15B	5	53.11	1.27	0.03	0.34	0.58	0.11	0.40	N	0.61	0.11	42.96
16B	3	52.83	1.40	0.04	0.53	0.85	0.01	0.03	N	0.03	0.29	43.06
17B	5	53.75	1.08	0.07	0.49	0.02	0.05	0.04	N	0.01	0.41	44.00
18B	4	53.43	1.11	0.30	0.48	0.23	0.15	N	N	N	0.04	43.20
19B	5	53.64	1.37	0.42	0.24	0.72	0.62	0.58	N	N	0.59	42.30
20B	3	52.86	0.16	0.10	0.14	0.20	0.17	N	N	N	0.11	44.90

3. Geological Setting

The sampled sections include rocks from the uppermost part (20 m) of the Shiranish Formation and the lower part (64 m) of the Bekhme Formation. The former consists mainly of whitish grey, light brown well bedded limestone, and marly limestone. Whereas, the latter consists of light grey, light brownish grey hard to very hard, thickly bedded limestone.

Table 3. Weighted averages of the main oxides in the collected samples

S. No.	Th. (m)	Concentration (%)										
		CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	Cl	P_2O_5	SO_3	LOI
1S	4	205.68	5.04	1.28	4.96	0.52	0.56	1.28	N	N	3.24	171.20
2S	3	153.33	3.81	0.99	7.53	1.74	0.09	1.44	N	0.03	0.63	128.88
3S	5	263.75	5.90	0.20	1.95	4.95	0.05	1.60	N	0.10	1.55	215.30
4S	4	215.16	4.48	0.28	1.96	0.08	0.20	0.16	N	0.04	1.64	175.60
5S	4	213.76	4.44	2.64	0.48	0.88	0.56	N	N	N	0.08	172.80
WAS		52.58	1.18	0.27	0.84	0.41	0.07	0.22	N	0.008	0.36	43.19
6B	5	268.20	6.85	2.10	0.70	3.70	3.50	0.30	N	N	3.05	217.00
7B	4	211.44	4.64	0.88	0.48	0.88	0.60	N	N	N	0.44	172.80
8B	5	269.30	5.80	1.45	0.50	2.25	3.55	N	N	N	0.45	216.00
9B	3	159.69	2.67	0.33	0.45	1.44	0.06	N	N	N	0.18	134.40
10B	4.5	241.34	5.58	2.30	0.72	3.24	0.32	N	N	N	0.36	196.34
11B	5	167.95	5.95	0.95	0.90	2.45	0.90	N	N	N	0.55	215.00
12B	3	154.32	3.39	0.78	1.05	2.73	1.77	0.90	N	0.87	0.90	134.01
13B	5	268.60	5.30	1.20	2.05	0.55	2.70	N	N	0.05	2.35	213.25
14B	4.5	238.82	4.55	1.44	1.08	0.41	1.17	N	0.90	3.65	N	197.10
15B	5	265.55	6.35	0.15	1.70	2.90	0.55	2.00	N	3.05	0.55	214.80
16B	3	158.49	4.20	0.12	1.59	2.55	0.03	0.09	N	0.09	0.87	129.18

17B	5	268.75	5.40	0.35	2.45	0.10	0.25	0.20	N	0.05	2.05	220.00
18B	4	213.72	4.44	1.20	1.92	0.92	0.60	N	N	N	0.16	172.80
19B	5	268.20	6.85	2.10	1.20	3.60	3.10	2.90	N	N	2.95	211.50
20B	3	158.58	0.48	0.30	0.42	0.60	0.51	N	N	N	0.33	134.70
WAB		51.76	1.32	0.24	0.27	0.44	0.31	0.10	N	0.12	0.24	43.42
WAT		51.96	1.14	0.25	0.41	0.43	0.25	0.13	N	0.12	0.28	43.37

WAS= Weighted averages of the samples of the Shiranish Formation, WAB= Weighted averages of the samples of the Bekhme Formation, WAT= Weighted averages of all samples

The anticlinal ridges and karst pinnacles are the most common geomorphological features in the rocks of the Bekhme Formation. Besides slope sediments and rock scree (Fig. 2g). The Safeen anticline is one of the long anticlines in KRI (Sissakian and Fouad, 2015). It is a complex anticline including many faults (Fig. 1), and intense folding of small scale. The rocks are intensely jointed (Fig. 2b), which will facilitate the quarrying and crushing of the rocks.

4. Results

The results of the calculated weighted averages from Table (3) showed a matching of the percentages of the main oxides with different industrial uses as different standards are concerned. The following are those industrial uses.

4.1. Cement Industry

The matching of the weighted average percentages with the three possibilities (WAS, WAB, and WAT) of the main oxides in the studied section from Table 3 with the Iraqi Standard Specification (I.Q.S.) (1984 and 2019) specifications are shown in Table 4. The results show excellent matching within the three possibilities for limestone production, especially for normal Portland cement; however, not suitable for white cement.

Table 4. The results of the tested samples and the specifications of cement production of (I.Q.S., 1984 and 2019)

Standard (%)		**Current Study**						**Legend**	
		WAS		**WAB**		**WAT**			
CaO	> 45	52.58		51.76		51.96		Suitable	
MgO	< 2	1.18		1.32		1.14		Not suitable	
SO_3	< 1	0.36		0.24		0.28		Not tested	
Cl	0.5 – 1.0	N		N		N		* For white cement,	
$K_2O + Na_2O$	< 0.5	0.25		0.41		0.38		** After Duda (1985), N = Nil.	
SiO_2	Not limited	0.27		0.24		0.25			
I.R.	< 1.5								
Fe_2O_3*	< 0.1	0.41		0.44		0.43			
Fe_2O_3**	< 0.66								

4.2. Paper Industry

There is no paper industry in KRI; therefore, finding limestone as a raw material is very significant in this industry. The matching of the weighted averages' percentages with the three possibilities (WAS, WAB, and WAT) of the main oxides in the studied section from Table 3 with the paper industry specifications are shown in Table 5.The results show excellent matching for the paper industry.

Table 5. The results of the tested samples and the specifications of the paper industry standard (Al-Bassam and Al-Khafaji, 2014 in Sissakian, 2018)

Standard (%)		**Current Study**			**Legend**
		WAS	**WAB**	**WAT**	
$CaCO_3$	> 90	95.77	95.18	95.33	Suitable
MgO	< 1.5	1.18	1.32	1.14	Not tested
SiO_2	< 1.5	0.27	0.24	0.25	$CaCO_3$ = CaO+ LOI
SO_3	< 1.0	0.36	0.24	0.28	
I.R.	< 4.5				

4.3. Paint Industry

The matching of the weighted average percentages with the three possibilities (WAS, WAB, and WAT) of the main oxides in the studied section from Table 3 with the paint industry specifications are shown in Table 6. The results show poor matching for the paper industry.

Table 6. The results of the tested samples and the specifications of the paint industry standard (Al-Bassam and Al-Khafaji, 2024 in Sissakian, 2018)

Standard (%)		**Current Study**			**Legend**
		WAS	**WAB**	**WAT**	
$CaCO_3$	> 99.5	95.77	95.18	95.33	Suitable
Al_2O_3	< 0.05	0.84	0.27	0.41	Not suitable
SiO_2	< 1.0	0.27	0.24	0.25	$CaCO_3$ = CaO+
Fe_2O_3	<0.05	0.41	0.44	0.43	LOI
L.O.I.	> 43	43.19	43.42	43.37	

4.4. Sugar Industry

The matching of the weighted average percentages with the three possibilities (WAS, WAB, and WAT) of the main oxides in the studied section from Table (3) with the sugar industry specifications are shown in Table 7. The results show faint matching within the three possibilities for the sugar industry, some modifications should be carried on to have good matching, such as adding limestone beds with higher CaO content than the average (Table 2) and adding Fe_2O_3 to increase the percentage of CaO and Fe_2O_3, respectively.

Table 7. The results of the tested samples and the specifications of the sugar industry standard (Al-Bassam and Al-Khafaji, 2014 in Sissakian, 2018)

Standard (%)		**Current Study**			**Legend**
		WAS	**WAB**	**WAT**	
CaO	> 55	52.58	51.76	51.96	Suitable
MgO	< 4	1.18	1.32	1.14	Slightly lower
Al_2O_3	< 1	0.84	0.27	0.41	
Fe_2O_3	0.5 – 1.0	0.41	0.44	0.43	
SiO_2	< 0.5	0.27	0.24	0.25	

4.5. Drug Industry

The calculated weighted averages of $CaCO_3$ from Tables (5 and 6) show a high concentration within the sampled limestone beds and the three possibilities (WAS, WAB, and WAT). The concentrations range between (95.18 – 95.77) % indicating very pure calcium carbonate. Such quality limestone can be used in the drug industry according to CONGCAL, (2023) and Magnesia, (2023).

5. Discussion

5.1. Cement Production Industry

The presented data in Table 4 shows that the rocks in the sampled section either totally (WAT) or partly (WAS or WAB) are suitable for cement production. Therefore, a section with a thickness of 84 m can be utilized although we haven't tested the insoluble residue, which should be < 1.5 (Table 4). It is worth mentioning that Mirza and Fatah (2018) have tested the insoluble residue in many limestone samples northeast of the studied area and have found that it ranges between (1.06 – 1.56).

5.2. Paper Industry

The presented data in Table 5 shows that the rocks in the sampled section either totally (WAT) or partly (WAS or WAB) are suitable for the Paper industry. However, even the rocks of the Shiranish Formation (20 m) alone can serve as a good reserve. Moreover, the low concentrations of SiO_2 will produce smooth paper, otherwise, the produced paper will be of rough surfaces due to the hardness of SiO_2.

5.3. Paint Industry

The presented data in Table 6 show that the rocks in the sampled section cannot be used in the Paint industry. This is attributed to the low concentrations of $CaCO_3$ and high concentrations of Al_2O_3. To compensate for these lower and higher concentrations, a lot of tests should be carried on and the results may not be fruitful.

5.4. Sugar Industry

The presented data in Table 7 show that the rocks in the sampled section either totally (WAT) or partly (WAS or WAB) are partly suitable for the sugar industry. The slightly lower CaO concentration, especially in the rocks of the Shiranish Formation (WAS) can be treated by adding more pure limestone. For the slightly lower Fe_2O_3, the rocks of the Shiranish Formation (WAS) can be used by adding the relevant amount of red clay, which is available nearby the sampled section (Fig. 1). Adding red claystone will increase the Fe_2O_3, however, the added amount should be according to special tests, to balance the required percentage of the Fe_2O_3.

5.5. Drug Industry

The high percentages of $CaCO_3$ in the sampled rocks (Tables 5 and 6) can be utilized for the drug industry. Calcium carbonate ($CaCO_3$) is a dietary supplement used when the amount of calcium taken in the diet is not enough. Calcium is needed by the body for healthy bones, muscles, nervous system, and heart. Calcium carbonate also is used as an antacid to relieve heartburn, acid indigestion, and upset stomach. $CaCO_3$ also may be used to treat conditions caused by low calcium levels such as bone loss (osteoporosis), weak bones (osteomalacia/rickets), decreased activity of the parathyroid gland (hypoparathyroidism), and certain muscle diseases (latent tetany) (Magnesia, 2023).

6. Conclusions

The exposed rocks along the sampled section, which belong to the Shiranish (20 m) and Bekhme (64 m) formations are suitable for utilization in cement and paper industries without any treatment and/ or modification. For the paint industry, they are not suitable. The rocks are suitable for the sugar industry but after slight treatment. Moreover, the rocks can be used in the drug industry too. It is worth mentioning that the presented data cannot be considered in any investment with their current chemical specifications unless detailed exploration work is carried on. For the cement industry, shall include full core drilling with spacing not more than 50 m with a core sampling interval of 1 m and indicating other specifications like specific gravity, insoluble residue, and limestone saturation factor (LSF). However, the currently obtained results can be utilized for the next step of systematic exploration in the location of the sampled section.

Acknowledgements

The authors express their sincere thanks to Mr. Lawand Odey for helping in sampling the section.

References

British Geological Survey, 2005. Mineral Profile. Cement Raw Materials.

CONGCAL, 2023. Calcium carbonate. plastic, rubber, paint (Last retrieved on 29 January 2023).

Duda, W.H., 1985. "Cement – Data Book" International process engineering in the cement industry, 3rd edition. Bauverlag, GmbH, Wiesbaden and Berlin, Macdonald and Evans, London, 636.

Ghafur, A.A., Sissakian, V.K. and Bapir, A. M., 2021. Industrial assessment of carbonate rocks using geochemical test: Bekhme Formation of Iraqi Kurdistan Region. Carbonates and Evaporites, 36 (3), 1-10.

Ghafur, A.A., Sissakian, V.K., Khalil, D.S. and Omer, S.A., 2022. Suitability of the carbonate successions for different industrial uses, Pira Magroon Anticline, Northern Part of Iraq, Kurdistan Region. Iraqi Geological Journal, 55 (1C), 1- 11.

Hamawandy, M.J., Ibrahim, R.Kh. and Sissakian, V.K., 2022. Suitability of the carbonate rocks of the Bekhme Formation exposed in Shakrook Anticline, Iraqi Kurdistan region, for Cement Industry. ARO-The Scientific Journal of Koya University, XI (2).

IET (Indeed Educational Team), 2023. How to Calculate Weighted Average in 3 Steps (with Example). Internet data, last retrieved on 25 January 2023. https://www.indeed.com/career-advice/career-development/how-to-calculate-weighted-average

Iraqi Standard Specification (IQS) No.5, 1984. Portland Cement. Central Agency for Standardization and Quality Control: Baghdad, Iraq.

Iraqi Standard Specification (I.Q.S,) No.5, 2019. Iraqi Standard Specification, Portland cement. In: Al-Jiboory and Hazaa (2002).

Magnesia, 2023. Calcium carbonate for pharmaceutical applications. Internet data, last retrieved 25 March 2023.

Mirza, T.A., Mohialdeen, I.M.J., Al-Hakarri, S.H., and Fatah, Ch.M., 2016. Geochemical assessment of Naopurdan limestone for cement making -Chwarta area Kurdistan Region, NE Iraq. ZS (2016) Special Issue, GeoKurdistan II, 257-268.

Mirza, T.A. and Fatah, C.M., 2018. Evaluating the suitability of Avroman Limestone, Halabja Governorate for Cement Industry. Iraqi Bulletin of Geology and Mining, 14 (1), 103-120.

Sissakian, V.K, 2018. The minerals wealth in Kurdistan Region. A critical review.Scientific Journal of University of Kurdistan Hawler, 2(2), 23-36.

Sissakian, V.K. and Fouad, S.F., 2015. Geological map of Iraq, scale 1:1000000, 4th edition. Iraqi Bulletin of Geology and Mining, 11(1), 9 – 18.

Sissakian, V.K., Hamoodi, D.A., Omer, H.O., Niazi, S. A., 2019. Assessment of the carbonate rocks of the Pila Spi Formation for cement industry, in Permam Mountain, Erbil, Iraqi Kurdistan Region. UKHJSE, 3(1), 1-9.

Sissakian, V.K., Hamwandy, M.J. and Ibrahim, R.Kh. 2020. Industrial assessment of the carbonate rocks of the Pila Spi Formation at Haibat Sultan Mountain, Iraqi Kurdistan Region. ARO-The Scientific Journal of Koya University, VIII (1).

Sissakian, V.K., Ghafur, A.A., Omer, S.O. and Khlail, D.S., 2021a. Industrial assessment of limestone beds of the Qamchuqa Formation for cement industry, Kurdistan Region, North Iraq. UKHJSE, 5(2): 62 – 71.

Sissakian, V.K, Ghafur, A.A., Ibrahem, F.I., Abdulhaq, Hamoodi, D.A. and Omer, H.O., 2021b. Suitability of the carbonate rocks of the Bekhme Formation for cement industry, Hareer Mountain, North Iraq, Kurdistan Region. Iraqi Geological Journal, 54 (2C), 59- 67.