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RESEARCH ARTICLE

Assessment of the Carbonate Rocks of the Pila Spi Formation for Cement Industry, in Permam Mountain, Erbil, Iraqi Kurdistan Region

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ABSTRACT

The Pila Spi Formation is exposed in Permam Mountain forming its carapace, and continuous ridges for few hundreds of kilometers. The rocks of the formation are mainly dolomitic limestone, dolomite, and limestone with various proportions. The thickness of the formation in Permam Mountain is about 100 m. Nine samples are collected from the Pila Spi Formation along a recently road cut across Permam Mountain. The sampling interval varies from 10 to 15 m. The collected samples were subjected to X-ray fluorescence (XRF) spectroscopy test to indicate the percentages of the main oxides in the samples. The results showed that the chemical composition of samples No. 1 and 9 meet the Iraqi standards for cement industry, whereas the remaining samples (Nos. 2–8) do not meet the Iraqi standards, and their total thickness is 80 m. To evaluate the suitability of the exposed rocks for cement industry in the sampled section within the Pila Spi Formation, different ratios of sample No. 1 were mixed with different ratios of a sample called sample No. A, it represents a mixture of samples No. 2–8. The mixing ratios are: (Sample No. 1/sample No. A) 50/50, 60/40, 70/30, 80/20, and 90/10. The same procedure was repeated for Sample No. 9. Another attempt was performed by mixing equal ratios of samples Nos. 1 and 9 with the same performed ratios with sample No. A.The chemical compositions of the samples were indicated using XRF test. The results showed that the best mixing ratios for the cement industry are 90:10, 80:20, and 70: 30 (samples Nos. 1 + 9: sample No. A).

Keywords: Cement industry, Dolomite, Limestone, Mixing ratios

1. INTRODUCTION

Limestone is the main raw material used in the cement industry, besides, the clay. However, not all kinds of limestone can be used in the cement industry, the chemical composition of the limestone strictly controls its use in this industry. The main oxides which should be considered in the cement industry are CaO and MgO, besides, other oxides and components.

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In the Kurdistan Region, the cement industry is well developed; especially in Sulaymaniyah Governorate at Bazian vicinity where five cement plants are located. All those five plants use limestone of the Sinjar Formation, which is excellent raw material for the cement industry, as the chemical composition is concerned (Al-Bassam, 2007 and Mustafa and Benni, 2014).

The Sinjar Formation is widely exposed in Sulaymaniyah Governorate with thickness ranges from 45 to 65 m and may reach up to 100 m (Sissakian and Fouad, 2014A). In

Erbil and Duhok Governorates; however, only one cement plant is constructed in Erbil Governorate at Qara Chaugh Mountain south of Erbil city. The used limestone in Qara Chaugh Mountain is from the Anah Formation (Sissakian and Fouad, 2014B), which has a low thickness as compared with the Sinjar Formation. The quality of the limestone is also lower than that of the Sinjar Formation; as the specification of the cement industry is concerned.

The cement industry is a vital strategic industry, especially in countries which are under vast development; since all constructions need cement for different uses. Therefore, construction of cement plants in Erbil and Duhok Governorates is very significant and will help and facilitates the development program. To construct a cement plant, the first step is to find suitable raw materials which are limestone and clay with specifications which meet the standards for the cement industry. Besides, the quantity of the raw materials depending on the capacity of the planned cement plant, and the quarrying conditions.

The location of the studied samples is in Permam Mountain [Figure 1]. It can be accessed by a paved road as well as all other exposures of the formation in different parts of Kurdistan Region, which encourages studying and evaluating of the exposed rocks within the formation not only in the current work location, but elsewhere in Erbil and Duhok Governorates where the formation is exposed widely (Sissakian and Fouad, 2012) [Figure 2].

This research work is an attempt to evaluate the rocks of the Pila Spi Formation for their suitability as a raw material in cement industry. The formation is widely exposed in both Erbil and Duhok Governorates in the form of continuous ridges and/or forming the carapace of the mountains, and usually without overburden [Figure 2] (Sissakian and Fouad, 2012; 2014c).

1.1. Previous Studies

The cement industry in the whole Iraqi territory was an interested subject; therefore, the Iraq Geological Survey has been conducting studies to evaluate the exposed limestone beds everywhere since the early seventies from the last century. Those studies which dealt with evaluation of the exposed limestone beds in the Kurdistan Region are briefed hereinafter.

Jaber and Al-Ubaide (1973) evaluated the exposed limestone beds in Kani China area. Al-Rufaie (1976), Al-Rufaie and Muhamad (1976), Al-Murib (1980), and Hafidh *et al.*

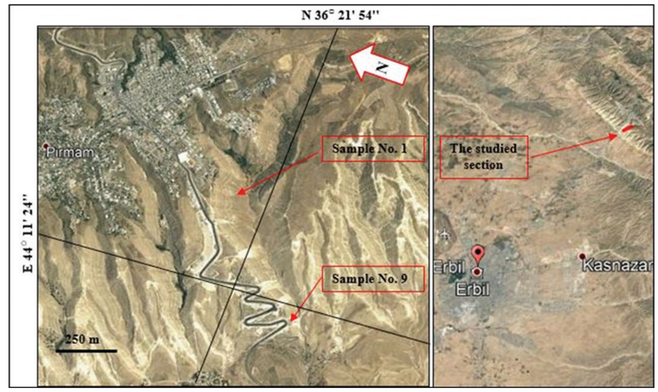

Figure 1. Google Earth image showing the location of the studied section

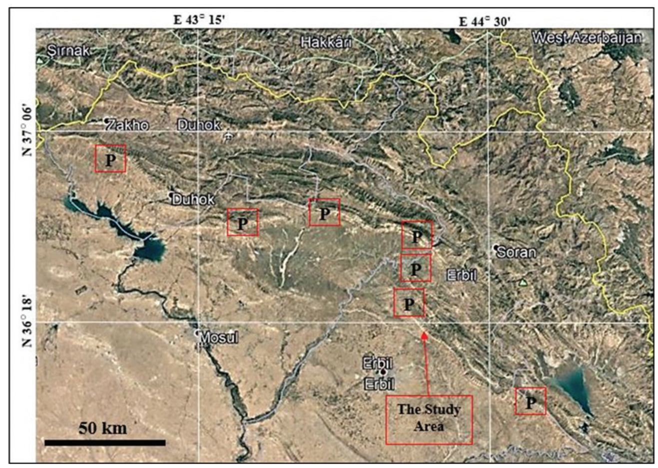

Figure 2. Satellite showing the extension of the Pila Spi Formation (P) as continuous ridge northwestward and southeastward from the study area

(2011) studied and evaluated the exposed limestone beds in the Anah Formation in Qara Chaugh Mountain. They all reported about excellent quality and quantity of limestone for the cement industry. Mansour (1976) evaluated the exposed limestone beds in Kirkuk, Erbil, and Sulaymaniyah Governorates and concluded about excellent qualities and quantities of limestone suitable for the cement industry. Mansour (1977) evaluated the exposed limestone beds for the sake of Al-Tamim (Laylan) cement plant and concluded that the nearest exposed suitable rocks for cement industry are in Qara Chaugh and Bazian. Etabi and Ahmed (1979) studied and evaluated the exposed rocks in Tasluja vicinity for the use of Tasluja cement plant and concluded excellent quality and quantity of limestone beds for the cement industry. Mansour and Petranek (1980) reported about the occurrences of limestone suitable for the cement industry in the whole Iraqi territory. They concluded that the exposed rocks in Bazian and Qara Chaugh vicinities are the only suitable limestone beds for the cement industry in the whole Kurdistan Region. Al-Bassam (2007) compiled the Minerogenic Map of Iraq and presented the exposed limestone beds in the whole Iraqi territory, among those rocks some are suitable for the cement industry in the Kurdistan Region. Hafidh and Khlaif (2007) evaluated the reserve estimation in Category C1 for the limestone of the Sinjar Formation in Bazian vicinity. Hafidh and Abdul Hassan (2008) evaluated the exposed limestone in C1 category in Sartak vicinity south of Darbandikhan on behalf of Meran Company. Hafidh *et al.* (2008a) studied and evaluated the exposed limestone beds in Sartak and Kani Gal vicinity, south of Derbendikhan. Hafidh *et al.* (2008b) studied and evaluated the exposed limestone beds in Agh Jallar vicinity on behalf of Mawlawi Company and reported about excellent quality and quantity of limestone suitable for the cement industry. Hafidh *et al.* (2008c) studied and evaluated the exposed limestone beds west of Sulaymaniyah on behalf of Wash Company.

1.2. The Concept of the Research

The rocks of the Pila Spi Formation are known to be of dolomite, dolomitic limestone, with rare marl and limestone (Wetzel, 1947 and Bellen, 1957 in Bellen *et al.*, 1959 and Sissakian and Saeed, 2012). Accordingly, the bulk rocks of the formation cannot be used for cement production due to high dolomite content. Therefore, we have considered the chemical composition of the collected and analyzed nine rock samples [Table 1] using different mixing ratios which is a well-known concept when the whole rocks in succession are not suitable for a certain industry (Moon *et al.*, 2006; Al-Bassam 2008; Bliss *et al.*, 2008; Goguen, 2014).

The chemical compositions of the samples [Table 1] indicate that samples Nos. 1 and 9 are suitable for cement production since the percentages of the main oxides (CaO and MgO) meet the specifications of cement production according to the Iraqi standards for cement industry (1995) [Table 2]. Apart from samples Nos. 1 and 9, the remaining 7 samples were mixed together with the same ratio, well homogenized, quartered mechanically and from one quarter 200 g was weighed and considered as one sample, it is called sample No. A.

Accordingly, samples Nos. 1 and 9 were considered as two main samples which were mixed alone with sample No. A with different mixing ratios. The mixing ratios between sample No. 1 and sample No. A started with ratio of 1-1 then ratios of 9-1, 8-2, 7-3, and 6-4. The same procedure was repeated for sample No. 9 with sample No A.

Table 1: Concentration of the main constituents in the nine analyzed samples using XRF

S. No	Weight %							
	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	Cl	SO_3	L.O.I.
1	51.1	0.98	0.193	0.576	3.83	0.0036	0.384	42.8
2	25.3	12.7	0.286	0.42	3.61	0.0767	0.35	56.9
3	24.9	12.7	0.314	0.55	3.3	0.0702	0.34	57.1
4	26.6	12.6	0.148	0.45	1.74	0.073	0.43	56.8
5	26.4	13	0.152	0.39	1.6	0.0877	0.31	58.2
6	25.8	11.8	0.269	0.38	4.46	0.098	0.39	56.6
7	25.2	12.5	0.176	0.378	1.61	0.0604	0.41	59.5
8	24.7	12.6	0.244	0.41	5.18	0.0705	0.38	55.9
9	52.1	1.2	0.235	0.425	4.06	0.0032	0.38	41.3

XRF: X‑ray fluorescence

Table 2: Percentages of the main oxides in cement production, following Iraqi standards (1995)

Oxides (%)	Iraqi standard (%)	Main oxides (weight %)	
		Sample No. 1	Sample No. 9
CaO	≥45	51.1	52.1
MgO	≤2	0.98	1.2
SO_3	≤1	0.384	0.38
SiO_2	<2	3.76	4.18
Cl	0.5–1.0	0.0036	0.0032
L.O.I	>43	42.8	41.3
Fe_2O_3 (white cement only)	<0.1	0.259	0.239

2. MATERIALS AND METHODS

Nine samples were collected from the Pila Spi Formation in Permam Mountain (anticline) [Figure 1]. The sampling interval ranges from 10 to 15 m. The starting point of sample collections is in the bottom of the formation at coordinates 36° 21' 774'' N and 44° 11' 605" E whereas the last point is in the top of the formation at coordinates 36°21' 514" N and 44°11' 279" E. The samples were described in the field [Table 3], checked with HCl, numbered, and kept in nylon sacks. To analyze the samples chemically, they were dried (100°C) then crushed and powdered. The prepared samples were subjected to chemical analyses using XRF device in the laboratories of the University of Kurdistan Hewler, Iraq. To prepare the samples for chemical test, they were well mixed to be homogenized, then quartered. From each quartered part of the samples, 200 g was weighed using the electronic balance to be a representative sample, which was used in XRF device. In the XRF method, each sample was subjected 3 times for test, and the average values were used [Table 2].

3. RESULTS

To have the representative sample for the bulk of the sampled section; apart from samples No. 1 and 9, which represent the top and bottom of the sampled section [Figure 1], we have mixed equal ratios from the remaining seven samples, it is called sample No. A. Then, we subjected sample No. A to XRF test. The results are presented in Table 4.

The mixed samples with all five ratios were subjected to XRF test to indicate the percentages of the main oxides and were compared with the Iraqi Standards for Cement Industry (1995) [Table 3]. Each mixed sample was subjected 3 times for XRF test to indicate the chemical composition and the average values were considered [Table 4].

The acquired results from subjecting of the mixed samples with different ratios to XRF test showed that only the results of one mixing ratio (9:1) of sample No. 1 and sample No. A meet the Iraqi standards for cement industry [Table 4]. Whereas for mixing of sample No. 9 and sample No. A, two mixing ratios (9:1 and 8:2) meet the Iraqi standards for cement industry [Table 4]. Therefore, we have conducted a second step of mixing ratios to check whether the more mixing ratios will meet the Iraqi standards for cement industry or otherwise.

In the second step (attempt), we have mixed equal ratios of samples Nos. 1 and 9 with different ratios of the mixed

Table 3: Field description of the collected samples

Sample No.	Sampling interval (m)	Description
1	15	Light yellowish white, hard, and well bedded (0.3–2 m) limestone
2	15	Light yellowish white, hard, bedded (0.3–2 m), and saccharoidal dolomite
3	15	Light yellowish white, bedded (0.1–0.75 m), chalky dolomitic limestone
4	15	Light yellowish white, bedded (0.3–0.5 m), chalky dolomitic limestone
5	10	Light gray, bedded (0.5–1.5 m), hard dolomite
6	10	Light gray, well bedded (0.2–0.4 m), hard dolomite
7	10	Light gray, hard, well bedded (0.2–0.5 m), dolomite
8	10	Light gray, very well thinly bedded (0.05–0.2 m), dolomite
9	15	Light brown, very thinly well bedded (0.05–0.30 m) recrystallized limestone

Table 4: Chemical composition of the mixed samples (First step)

Mixing ratio	S. No.	Weight %							
		CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	Cl	SO_3	L.O.I.
	(A) 10	24.5	12.30	0.201	0.312	2.55	0.01	0.316	59.11
1:A (5:5)	11	38.8	6.81	0.210	0.373	3.53	0.038	0.24	50.69
1:A (9:1)	12	51.0	0.9	0.191	0.413	3.86	0.009	0.21	43.36
1:A (8:2)	13	44.1	1.2	0.188	0.51	3.47	0.006	0.26	50.19
1:A (7:3)	14	39.1	1.23	0.201	0.547	3.5	0.0037	0.23	54.79
1:A (6:4)	15	37.5	5.67	0.175	0.353	3.47	0.0113	0.38	52.18
9:A (5:5)	16	39.8	5.75	0.23	0.315	3.48	0.0123	0.35	50.10
9:A (9:1)	17	50.9	0.98	0.241	0.442	3.97	0.011	0.408	43.39
9:A (8:2)	18	47.5	1.2	0.237	0.411	3.91	0.0127	0.380	46.05
9:A (7:3)	19	34.3	5.6	0.22	0.577	3.43	0.0132	0.332	55.50
9:A (6:4)	20	36.6	7.41	0.246	0.292	3.56	0.0238	0.328	50.58
Iraqi standard		≥45	≤2	<0.1 (White cement)	-	≤2	0.5–1.0	≤1	>43

sample (sample No. A). The mixing ratios are the same as those in the first step. The acquired XRF results from the second step are presented in Table 5.

In the second step of mixing ratios, we have found that three ratios (9:1, 8:2, and 7:3) of samples No. 1 and 9 with sample No. A meet the Iraqi standards for cement industry [Table 5]. Therefore, these mixing ratios will be considered in the current study.

4. DISCUSSION

The Pila Spi Formation is one of the widely exposed formations in the Kurdistan Region, especially in the middle part of the region. The formation forms continuous ridges for few hundreds of kilometers usually without overburden [Figure 2]. However, locally few meters of Oligocene carbonate rocks may cover the formation. Moreover, the Fatha Formation covers the lower parts of the ridges.

Although the main constituent of the Pila Spi Formation is not limestone, we have studied the suitability of its rock for the cement industry. This is attributed to the absence of geological formations in Erbil Governorate which include limestone beds suitable for the cement industry. However, at Qara Chough Mountain south of Erbil city the Oligocene rocks are suitable for the cement industry, and one cement plant is constructed there. The rocks of the Pila Spi Formation in Duhok Governorate may show the same chemical composition, and the quarrying conditions are almost the same as discussed in the current research.

The parameters of evaluating limestone beds for the cement industry and the quarrying parameters are discussed hereinafter.

4.1. Chemical Composition

The applied experiments on the collected samples from the studied section in Permam Mountain showed that without mixing of the limestone beds according to certain ratios will not be suitable for cement industry [Tables 1 and 2]. However, the chemical composition of the lowermost and uppermost beds is suitable for the cement industry. Therefore, we have mixed different ratios of the collected samples in two attempts and found that some of the mixed ratios showed excellent results [Table 5].

4.1.1. Samples No. 1 + 9 with 9:1 Ratio (Sample No. 21)

In this ratio, the percentages of the main oxides (CaO and MgO) meet the Iraqi standard for cement industry which is the same as that of Lafarge (2018) [Table 5]. However, the percentage of the SiO_2 is higher by 1.67%.

4.1.2. Samples No. 1 + 9 with 8:2 Ratio (Sample No. 22)

In this ratio, the percentages of the main oxides (CaO and MgO) meet the Iraqi standard for cement industry [Table 5]. However, the percentage of the SiO_2 is higher by 1.81% and the L.O.I. is lower by 0. 21%.

4.1.3. Samples No. 1 + 9 with 7:3 Ratio (Sample No. 23)

In this ratio, the percentages of the main oxides (CaO and MgO) meet the Iraqi standard for cement industry [Table 5]. However, the percentage of the SiO_2 is higher by 2.08%.

4.1.4. Other Ratios (Samples Nos. 24 and 25)

The acquired results from the other two mixing ratios (6:4 and 5:5) showed that the results of two mixed ratios of the exposed rocks do not much with the specifications of cement industry according to the Iraqi standards.

4.2. Reserve Estimation

Although it is not possible to perform reserve estimation in this stage of work due to the limited used data, we have assumed certain coverage area in the studied section of the Pila Spi Formation, and using the acquired chemical results from XRF test, and the performed mixing ratios,

Table 5: Chemical composition of the mixed samples (Second step)

Mixing ratio	S. No.	Weight %							
		CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	Cl	SO_3	L.O.I.
1+9:A (9:1)	21	50.6	0.998	0.213	0.439	3.67	0.009	0.293	43.88
1+9:A (8:2)	22	50.3	1.12	0.212	0.393	3.81	0.008	0.353	42.79
1+9:A (7:3)	23	48.9	1.098	0.237	0.35	4.08	0.0079	0.404	43.51
1+9:A (6:4)	24	43.7	4.14	0.185	0.267	3.65	0.0053	0.544	47.98
1+9:A (5:5)	25	42.3	4.25	0.174	2.96	3.55	0.0071	0.336	46.29
Iraqi standard		≥45	≤2	<0.1 (White cement	-	≤2	0.5–1.0	≤1	>43

we can have rough reserve estimate which will be of medium level of confidence (Canadian CIM classification code No. NI 43-101) (Kuepper, 2018). If we assume one square kilometer of exposures of the Pila Spi Formation, with the average thickness of 100 m, then the volume of the rocks will be 10^8 m^3. With assuming the average bulk density of the limestone beds to be 2.4 g/cm^3 (Bell, 2007); then the weight of the rocks within the one square area will be 2.4×10^8 tons.

4.3. Required Amounts of the Rocks According to Different Mixing Ratios

For calculating the required amounts of the rocks in the studied section according to the three mixing ratios [Table 5], we have assumed an area of 10 m wide, the length of the sampled section is 750 m; therefore, the cross-sectional area will be 7500 m^2. The total thickness of the rocks is 100 m [Samples Nos. 1–9 in Table 1]; accordingly, the volume will be 7500 $m^2\times100$ m (750,000 m^3). The average density of the limestone beds is 2.4 g/cm^3 (Bell, 2007); and the weight of the assumed slab will be 1,800,000 tons (750,000×2.4). The measured thicknesses of the beds [Table 1] are used in calculations of the required volumes and weights of the rocks according to the three mixing rations. The total thickness of the samples No. 1 and 9 is 30 m, whereas the total thickness of the remaining samples is 70 m. The assumed cross-sectional area is 7500 m^2. Accordingly, the calculated results of the required amounts of the rocks in the three mixing ratios are presented in Table 6.

From the assumed area of 10 m width, 750 m length, 100 m thickness, and density of 2.4 g/cm^3, we can have rocks of 1,800,000 tons. From this weight, 540,000 tons belong to beds Nos. 1 and 9, and the remaining 1,260,000 tons belong to the remaining beds of the section (samples Nos. 2–8).

From the presented data in Table 6, it is clear that the best ratio for utilizing the rocks of the Pila Spi Formation in the sampled section for cement industry is the second ratio (7:3), this is attributed to: (1) The required weights from both parts are almost similar to which is available in the site, but with more wider cross-sectional area than 10 m and (2) This ratio will be more suitable and easier in quarrying of the beds continuously rather than other ratios. However, the quality of the produced cement using the third ratio will be lower than those produced by mixing the first and second ratios. This is attributed to the percentages of the main oxides (CaO and MgO) are lower than those used in the first and second mixing ratios. Moreover, the percentage of SiO2 is higher by 2.08%, which is not favorable in cement industry due to its high corrosive ability (Stefanidou and Papayianni, 2012). However, when considering the chemical composition of the mixed rocks according to the three different ratios, then the first ratio (9:1) will yield the best quality because the chemical composition of the mixed rocks will meet the Iraqi standard of cement industry [Table 5].

4.4. Quarrying Parameters

The following parameters are discussed

4.4.1. Thickness

The thickness of the sampled section is 110 m. The details of the sampled beds are mentioned in Table 1. The calculated volumes and weights per cross-sectional area of 10×750 m are mentioned in Table 6. The thickness of the Pila Spi Formation in the sampled section will supply 1,980,000 tons from a cross-sectional area with a width of 10 m only.

4.4.2. Overburden

One of the main parameters for relevant quarry is the overburden (Bates and Jackson, 2005). As the thickness of the overburden is high as the quarrying will be difficult and/or even not profitable. Another factor in the overburden is the type and hardness of the rocks forming the overburden. In the ridge forming Pila Spi Formation, almost no overburden rocks occur except in the lowermost parts [Figures 3 and 4]. In the lowermost part of the formation, soft rocks of the Fatha Formation occur, mainly of claystone with rare limestone and gypsum. All these rock types can be used either as main raw material (the claystone and limestone) or as an additive (the gypsum). Therefore, even if the thickness is high, then the rocks can be used in the cement industry; however, the thickness ranges up to few tens of meters (Sissakian and Fouad, 2014c).

4.4.3. Dip amount

The dip amount of the beds in the studied section is moderate (28–45°), which is not preferable in quarrying

Table 6: The required volumes and weights of the rocks in the three mixing ratios

Sample No	Mixing ratio	Thickness ratio (m)	Volume ratio (m^3)	Weight ratio (Ton)
21	9:1	9 × 30:1 × 70	607,500:367,500	1,458,000:8,82,000
22	8:2	8 × 30:2 × 70	540,000:735,000	1,296,000:1,764,000
23	7:3	7 × 30:3 × 70	472,500:1,102,500	1,234,000:2,646,000

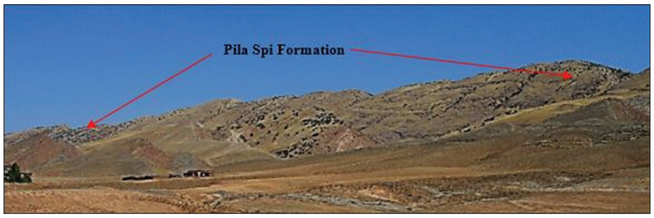

Figure 3. The ridge forming Pila Spi Formation

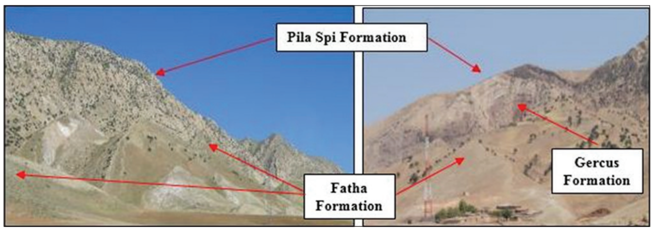

Figure 4. The Pila Spi Formation. (Left) Flat iron morphology, (Right) side view of a flat iron, note the dissected ridge and the developed quarrying face

Figure 5. Part of the exposed rocks in the sampled section of the Pila Spi Formation. Note the nature of the bedding and their thicknesses.

because the beds will pinch down to subsurface; accordingly, the quarrying should be below the ground surface. This will cause a lot of quarrying problems; such as removal of the overburden rocks, facing groundwater problems, and using special trucks to carry the quarried rocks up to the ground surface. However, the height and continuity of the ridges overcome the disadvantage of the dip amount.

4.4.4. Quarrying method

The well bedding nature and thickness of the individual bed of the Pila Spi Formation [Figure 5] facilitate the quarrying method. Accordingly, less energy is used during the quarrying, and even some parts can be quarried by ripping using bulldozers. Moreover, the crushing of the quarried blocks will be easier than those of thickly bedded rocks.

4.4.5. Water supply

The Pila Spi Formation forms one of the best groundwater aquifers in the Kurdistan Region (Al-Jiburi and Al-Basrawi, 2013). Therefore, good quality and quantity of water can be found in the subsurface extension of the formation just along the foothill slopes of the main Pila Spi Ridge wherever is the quarry.

4.4.6. Underlying rocks

The Pila Spi Formation is underlain by the Gercus Formation not only in the studied section but also elsewhere in all exposures (Sissakian and Fouad, 2012; 2014a-c). The Gercus Formation consists mainly of reddish brown claystone with rare sandstone and conglomerate and very rarely thin limestone and gypsum beds (Sissakian and Fouad, 2012). The rocks are soft to fairly hard, especially the gallstones which can be ripped by bulldozers. Therefore, the claystone beds can be used as the second main raw material with the limestone in the cement industry. About 10–15% of the raw mix consists of clay and the gypsum (about 5%) can be used as additive after the clinker (British Geological Survey, 2005).

4.4.7. Morphology

The Pila Spi Formation forms continuous ridges which are dissected by valleys flowing along the dip slope side of the ridge. The dissected valleys of the ridge have formed special morphological form which is called "flat irons." The flat irons have a triangular shape with the base at the bottom of the ridge.This special form will facilitate the quarrying because each dissected segment of the ridge can be reached from three sides: The dip slope side, which is facing to the toe of the ridge, and from both sides of the flat iron [Figure 5].

4.4.8.Accessibility

As the Pila Spi Formation forms continuous ridges along the flat plains in the Kurdistan Region [Figure 2]; therefore, the majority of the main roads run almost parallel to the ridge. Accordingly, this gives excellent accessibility to the exposures of the Pila Spi Formation all over the Kurdistan Region.

5. CONCLUSIONS

From the current research work, we can conclude that the Pila Spi Formation can be used as raw material in cement production. However, not all the limestone and/or dolomitic limestone, dolomite and marl beds of the formation can be used in cement production due to high MgO percentage in the majority of the ricks. Therefore, different mixing ratios can be used to have a mixture which meets the specifications of the Iraqi standard for cement production. In the current study, we performed many mixing ratios between those rocks which meet the standards and those which do not; accordingly, we found that the mixing ratios of 9:1, 8:2, and 7:3 can be used. However, the best mixing ratio is 7:3. Moreover, the quarrying conditions of the ridge forming Pila Spi Formation are excellent, wherever the quarry is in the Kurdistan Region. No overburden rocks and those which occur in the lowermost part of the ridge belong to the Fatha Formation and can be used in the cement production because they consist of claystone with rare limestone and gypsum. Moreover, the underlying rocks belong to the Gercus Formation, which also consists mainly of claystone which can be used as main raw material in the cement production. We also performed a geological reserve estimation and have found that in the studied section an area of one square kilometer will yield 10^8 m^3 rocks, which means 24×10^7 tons of limestone suitable for cement production.

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