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EVALUATION OF THE PILA SPI FORMATION CARBONATE ROCKS FOR DIMENSION STONE, QARA DAGH AREA, KURDISTAN REGION, NE IRAQ

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Key words: Dimension stone; Pila Spi Formation; Petrophysical properties; Geotechnical properties; Kurdistan; Iraq.

ABSTRACT

The Kurdistan Region has an enormous number of different carbonate rock units, which vary widely in their geological age and sedimentary depositional environment. Limestone quarried from the exposures has a wide range of usages and applications, such as dimension stone, crushed stone, building stone and paving stones. Since antiquity, limestone was used as building materials in areas where they were naturally available and abundant. Little work has been done to indicate the physical and mechanical properties of the limestone, especially under humid environment. In this study, the physical and mechanical properties of some carbonate rocks of the Pila Spi Formation (Eocene) are investigated. samples are collected from the Pila Spi Formation in the Qara Dagh area at two sites close to each other to assess their suitability for use as dimension stone. Geological, petrographical, geochemical and geotechnical properties of the carbonate rocks in the study area are determined based on field studies and laboratory tests. The field studies indicate that the carbonate rocks of the Pila Spi Formation in the studied area are mostly well-bedded to massive, crystalline, white in color, sometimes become chalky towards the top with small oxidation signs on the surface. Petrographical study reveal that the carbonate rocks are characterized as dolomitic limestone and have a grayish and yellowish-white color after polishing. The carbonate rocks are mostly dolomites or recrystallized dolomitic limestone. Geochemical analyses of the studied samples show that CaO and MgO are the most abundant oxides and the rocks can be classified as impure limestones. According to the American Standard for Testing and Materials, ASTM C568-03 (2006) the carbonate rocks in the studied sites are acceptable for use as dimension stone.

تقييم صخور تكوين البلاسبي كحجر تغليف، منطقة قره داغ، اقليم كوردستان، شمال شرق العراق

تولّه احمد ميرزا و سامان غريب رشيد

المستخلص

يحتوي اقليم كوردستان على كميات كبيرة وأنواع مختلفة من الوحدات الصخرية الكلسيةالتي تختلف باعمارها وبيئاتها الرسوبية. لقد استخرج الحجر الجيري من مقالع مختلفة لمختلف الاستعمالات والاستخدامات مثل حجر التغليف، كسارة الحجر، حجر بناء واحجار اكساء الطرق، وكما هو معتاد منذ القدم كمواد أوليه للبناء لوفرتة في الطبيعية وسهولة الحصول عليه.تعد الدراسات التي تتناول الخصائص الفيزيائية والميكانيكيه للحجر الكلسي وخاصة في المناطق الرطبة قليلة، تتناول

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الدراسة الحالية دراسة هذه الخصائص لصخور تكوين البلاسبي (الايوسين). تم اجراء الدراسات الحقلية وجمع النماذج لمكاشف تكوين البلاسبي في موقعين متقاربين في منطقة قره داغ وذلك لتقييم صلاحيتها للاستعمال كحجر تغليف لواجهات المباني. لقد تم تحديد الخصائص الجيولوجية والبيتروغرافية والجيوكيميائية والجيوتكنيكية للصخور المدروسة من خلال الدراسات الحقلية والمختبرية. تشيرالدراسات الحقلية لهذه الصخور الى انها صخور بيضاء كتلية الى منتظمة التطبق، بلوريه تتحول نحو الاعلى الى صخور طباشيريه مع بعض علامات الاكسدة السطحية. تبين الدراسة البيتروغرافية ان هذه الصخور كلسية – دولوميتية وتتصف بلون ابيض رصاصي او ابيض مصفر عند صقلها، وهي في الغالب اما حجردولوميتي او حجر كلسي – دولوميتي معاد التبلور. اما التحليل الجيوكيميائي فقد بين ان غالبية الاكاسيد تتكون من CaO و MgO وتصنف الصخور على انها حجر جيري غير نقي. بموجب المواصفة الامريكية للفحص والمواد ASTM C568-03 (2006) فان الصخور الكاربونيتية المدروسة صالحة للاستخدام كحجر تغليف للمباني.

INTRODUCTION

Dimension stone is a term which covers an extensive variety of naturally occurring stones used for structural or decorative purposes and monumental applications. Carbonate rocks, such as limestone is one of the most important raw materials for use as dimension stone. A dimension stone is a block, thus, has the value as a result of its dimensions, including a variety of chemical and physical properties, such as strength parameters, workability, polishing ability and resistance to physical and chemical weathering. In addition, it must be free of spalls, cracks, open seams, pits, or other defects that are likely to impair its structural integrity in its intended use. Other factors, which may affect the selection of dimension stone include the cost of quarrying processing and alternative sources of supply **(**Quick, 2000).

There are few minor quarries of dimension stone based on the limestone of the Pila Spi Formation (Eocene), which covers a wide area in the Qara Dagh Mountain. Most of the quarries have been established without detail scientific prospecting and investigation for industrial requirements of the processing industry, just considering demand of the markets. The carbonate beds of the Pila Spi Formation in the study area have a good thickness to be slabbed as blocks of suitable dimensions, as well as huge amounts of this deposit are found in in areas accessible by close transportation to the Sulaimania City.

In assessing the suitability of rocks as dimension stone, the first requirement is the petrographic study to identify its mineralogy, grain size, texture, fabric, and weathering status (Egesi and Tse, 2011). All these characteristics are in turn determined by the geological processes which formed the rock. A good understanding of these characteristics and effects will enable to determine a rock suitability, availability and consistent production (Egesi and Tse, 2011).

The Qara Dagh area is one of the most interesting provinces in the Kurdistan Region of Iraq, which has abundant carbonate rocks that are seemingly suitable for the production of dimention stone. The area includes thick exposures of carbonates-bearing formations of Tertiary age; such as the Pila Spi and Sinjar formations. There are a few studies about the suitability of the Pila Spi Formation in the Kurdistan Region for building stone such as (Dhaher 2009; Hemn and Nawzat, 2015; Hakeem, 2016). Most of them are focused on the sedimentology, stratigraphy and geochemistry. Therefore, this work is an attempt to fill this gap.

The main objective of this study is to assess the carbonate rocks of the Pila Spi Formation in a selected area as dimension stone through field observations, sampling, petrographical, petrophysical, and geochemical analyses. These characteristics of dimension stone are indispensable for the construction industry and will help in selecting the appropriate use of the dimension stone (Ashmole and Motloung, 2008).

GEOLOGICAL BACKGROUD

The study area is located about 15 Km to the southwest of Sulaimania City in the High Folded Zone where vast outcrops of the Pila Spi Formation could be found (Figs.1 and 2).

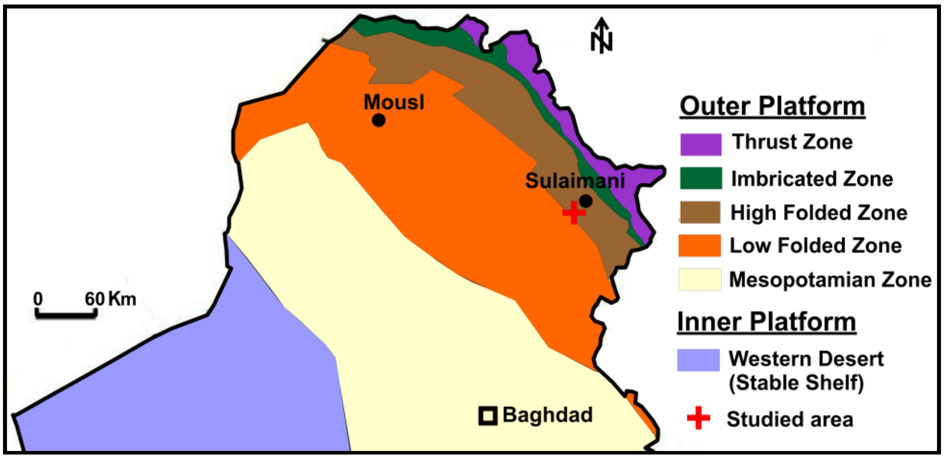

Fig.1: Tectonic and location map of the study area (after Fouad, 2012)

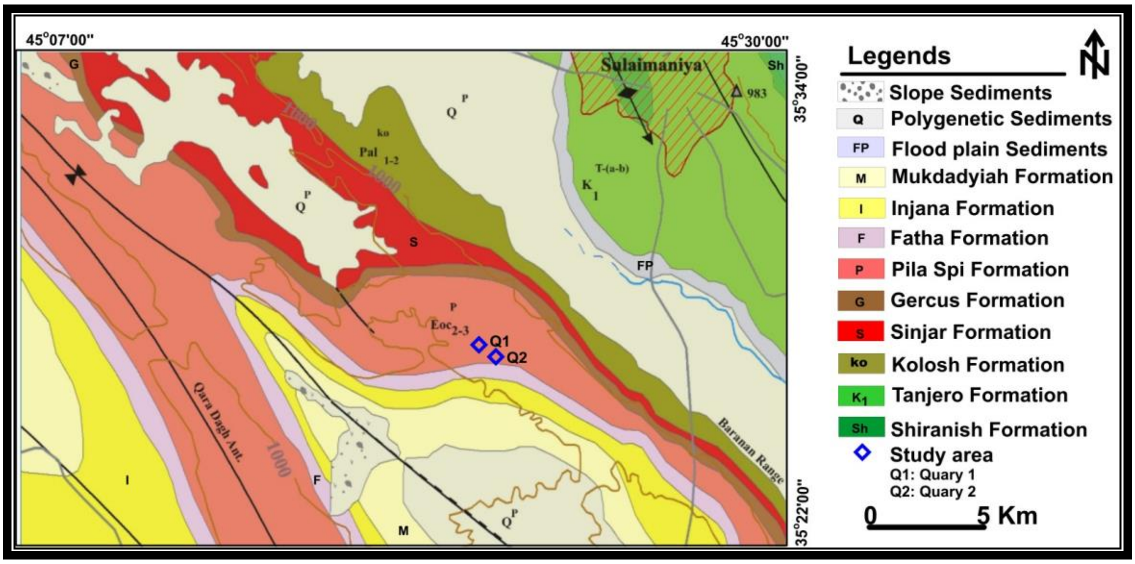

Fig.2: Geological map of the studied area (after Sissakian, 2000)

According to Bellen *et al.* (1959), the Pila Spi Formation was first described by Lees in 1930 from the Pila Spi area of the High Folded Zone. During the sixties of the last century, they found that the original type locality section was inundated under the reservoir of the Darbandi Khan Dam. A supplementary type section was thus described at Kashti, on the Barand Dagh, about 10 Km to the north of Darbandi Khan town (Jassim and Goff, 2006 and Khanaqa, 2011). The resistant and toughness of the rocks of the Pila Spi Formation formed conspicuous ridges between the less resistive Gercus Formation (in lower boundary) and Fatha Formation (in upper boundary) throughout the High Folded Zone. The Pila Spi Formation (Middle – Upper Eocene) is about (100 – 200) m thick (Buday and Jassim, 1987). The upper part of the formation comprises well-bedded, bituminous, chalky and crystalline limestone, with bands of white, chalky marl and increase of chert nodules towards the top. The lower part comprises well-bedded, hard, porous or vitreous, bituminous, white, poorly fossiliferous limestone, with algal or shell sections. In the supplementary type section, it consists of dolomitic and chalky limestone with chert nodules (Bellen *et al*., 1959 and Jassim and Goff, 2006).

The depositional environment of the Pila Spi Formation is reported as a carbonate ramp with a low topographic patchy reef, back reef, and lagoonal facies (Khanaqa, 2011). The evidences for ramp are gradual changes of the facies and absence of high energy facies (reference). The Pila Spi Formation was previously assigned as lagoonal crystallized limestone and poorly fossiliferous, including gastropods, miliolids, and algae. These sections contain intervals (10 – 25 m thick) that are characterized by massive beds (1 – 3 m). The fossil contents can be identified only in polished slabs, while in thin section they are hardly identifiable due to digenetic processes (Khanaqa, 2011).

METHODOLOGY

For this study, sixteen carbonate samples from two sites (Q1 and Q2) of the Pila Spi Formation in Qara Dagh area are collected. The Q1 is located at the intersection of latitude N 35° 26' 39" and longitude E 45° 20' 48" at an elevation of 1158 meters above sea level (m.a.s.l.), while the Q2 is located at latitude N 35° 26' 31" and longitude E 45° 20' 55" at an elevation of 1117 m.a.s.l. (Fig.2). Nine rock samples are collected from the rock exposures of site Q1, represented by samples G1 to G9, while from site Q2 seven samples are collected, represented by samples K1 to K7. The collection of the samples depended on the physical appearance such as color, texture, bedding, the absence nodules (pyrite, chert, etc), lithology, thickness and degree of jointing, and fracturing (Fig.3).

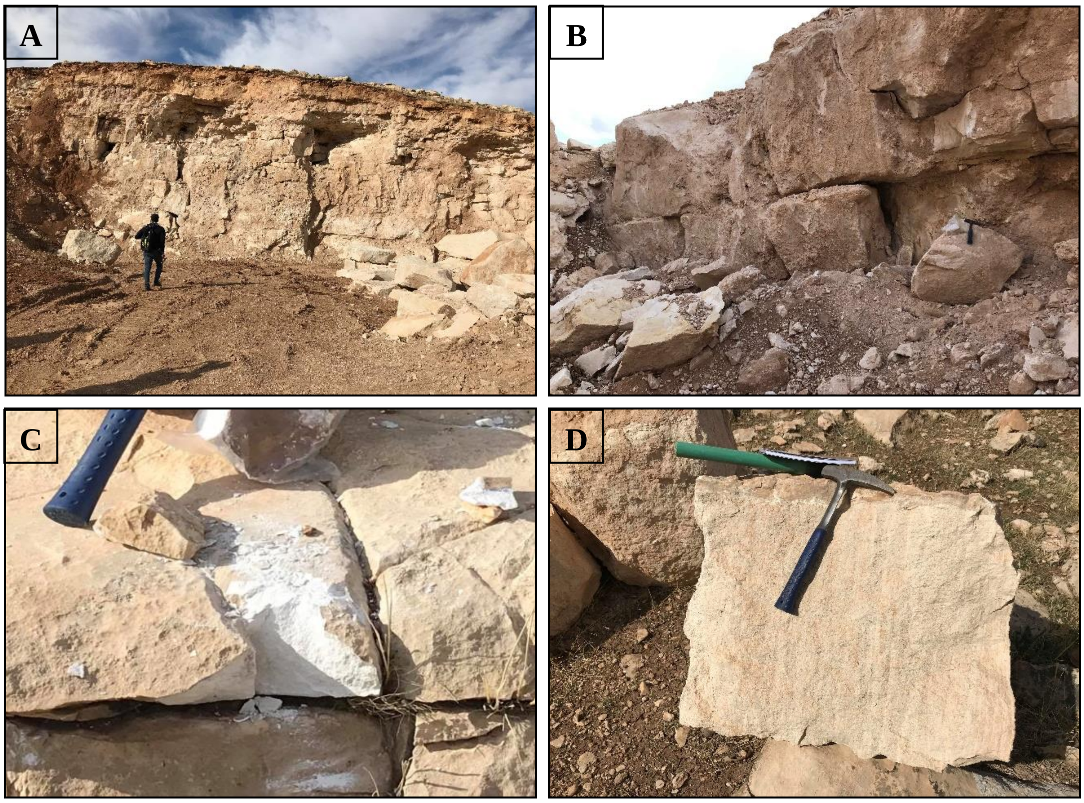

Fig.3: Features of the limestone outcrops in the studied areas. **A)** Thickness of the limestone body, **B)** Thickness of the beds, **C)** Fresh surface color of the limestone showing white to milky color, **D)** Striation due to rain and snow actions on the surface of the limestone

Seven thin sections of the limestone samples from the total of 16 samples are prepared for petrographical study under polarized microscope. Alizarin Red stain (Alizarin red solution) and ferric cyanide (pot ferric cyanide solution) are used to discriminate between dolomite and calcite. Chemical analysis are carried out to determine the major oxides content using X-ray fluorescence (XRF) in the research laboratory of the Geology Department/ University of Sulaimani. Loss on ignition (LOI), which consists principally of CO_2, was determined by igniting the sample at 980°C for 90 minutes. The samples were sawn into blocks for polishing and petrophysical studies, which include apparent porosity, water absorption and bulk density in the Geology Department/ University of Sulaimani according to ASTM C97-02, 2003. The mechanical study (compressive strength and modulus of rupture) were carried out in Aso Brick Factory in- Sulaimania City using ASTM C170-90 (1999) and ASTM C99-87 (2000), respectively. The colors were determined using Geological Rock-Color Chart with genuine Munsell color chips (2009). The color of the studied samples is determined by spinning a small plate of the rock sufficiently to blend the colors of the constituent minerals and comparing the blended color with a standard Rock Color Chart, such as that prepared by Munsell color X-rite (2009). The chart has great value in describing the colors of medium-to fine-grained rocks. Since most of the studied samples are fine crystalline; therefore, the Munsell color X-rite (2009) was used.

RESULTS AND DISCUSSION

- **Field description**

The carbonate rocks of the Pila Spi Formation as noticed in the field are mostly massive, crystalline, and white carbonate, well-bedded, locally becomes chalky, towards the top small oxidation signs occur on the surface. The well-bedded, chalky, appearance and presence of chert nodules in the upper part are characteristic signs throughout the studied area. The upper part of the ridge is covered by a thin layer (less than 40 cm) of residual soil (Fig.3A). In addition, a little variation of the toughness, colors, fracture frequencies and textures are noticed (Figs.3B and 3C). Striations, due to rain and snow actions, are abundant surface features of these rocks (Fig.3D). Generally, the texture of the carbonate rocks in the studied area is characterized by fine grain size and white to milky color (Fig.3C). The field observations show that the carbonate rocks have slightly weathered appearance and thickly bedded (1.5 – 2 m). The beds are roughly spaced at (5 – 8 cm) (Fig.3).

- **Petrography**

Based on the petrographic investigation, the rocks of the Pila Spi Formation in the study area are homogeneous and mostly impure dolomitic limestone and dolomite, having a grayish white to yellowish white color after polishing (Fig.4A). The staining of the thin sections with Alizarin Red solution shows that the carbonate rocks are mainly composed of dolomitic limestone; therefore, they stained with pink color (Fig.4B); except sample No. G5, which is mostly composed of calcite stained with dark red color. The petrographic examination of the thin sections indicated that the samples are mostly recrystallized dolomitic limestone and pure limestone. The recrystallization process caused the fossils deformations, consequently, they cannot be recognized; except some of bioclast and ghost of fossils can be distinguished (Figs.5A and B).

The studied samples are highly affected by dolomitization and most of the skeletal grains have been destroyed. According to the classification of limestone by Dunham (1962), most of the studied samples are formed of mudstone in which the digenetic modifications appeared as micritic cryptocrystalline dolomitic limestone (Fig.5).

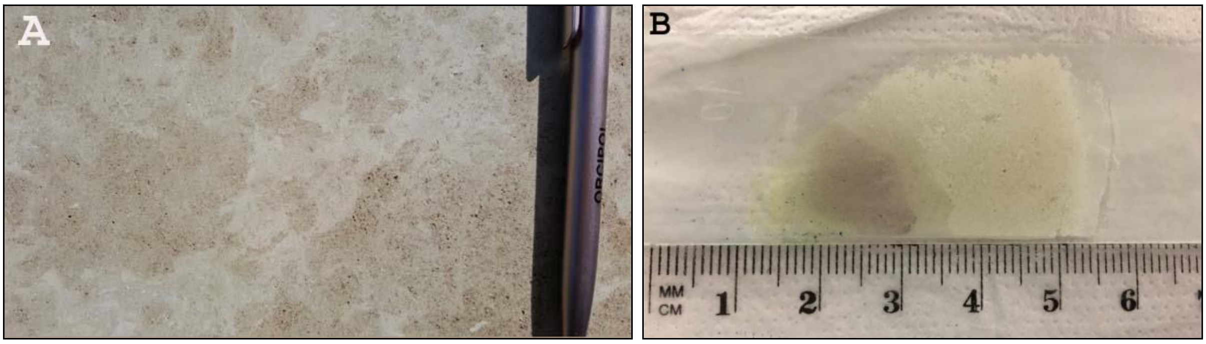

Fig.4: **A)** The grayish whitey yellowish color after polishing of the carbonate rocks of the Pila Spi Formation, **B)** Staining of the studied samples with Alizarin Red solution (Sample No. G5 is stained with pink color)

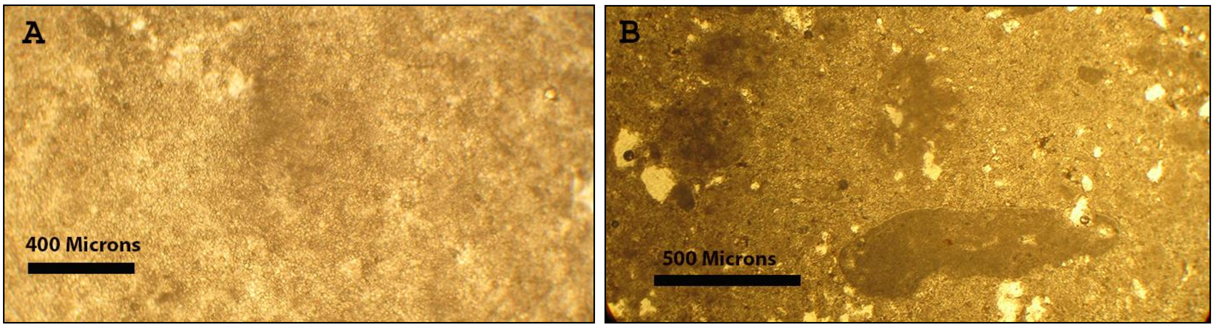

Fig.5: **A)** Recrystallized dolomitic limestone with some bioclasts, **B)** Ghost of fossils within the Pila Spi carbonates in the studied samples

- **Chemistry**

The chemical analysis results (Table 1) show that the CaO concentration in the studied samples ranges from 30.92% to 52.06% with an average of 41.93%, and MgO content ranges from (6.58% – 22.99 %) with an average of 16.63%. In all samples, the CaO average is lower than the reference values reported by Turekian and Wedepohl (1961) for carbonate rocks (42.32%). This is due to the effect of dolomitization process, where the calcium was replaced by magnesium. According to the classification of the limestone purity stated by Teodorovich (1950) most of the analyzed samples of the Pila Spi Formation in the study area are classified as dolomite and dolomitic limestone and as impure limestone according to the classification of Harrison (1993) (Table 2).

In limestone, the average SiO_2 value is usually low (<2%) (Table 1), but when the rock contains a lot of clay minerals, these values will rise, in rare cases up to as much as 30 – 40 % (Hussein and Kadhim, 2016). The K_2O and Al_2O_3 are usually following the variations in the SiO_2 concentration; since these components are also related to clay minerals in the rock (Erlström, 2009; and Jennerheim, 2016). Hence, the low content of SiO_2, Al_2O_3, Na_2O, and K_2O reflects the low content of clay minerals in the studied samples.

Iron, expressed as Fe_2O_3, is commonly found in carbonate rocks rich in clay mineral, such as marl, where it can reach 1 – 3 %, as compared to < 0.5% in other pure carbonate rocks (Jessica, 2016). The average Fe_2O_3 content of the studied samples is 0.76% (Table 1), reflecting the near absence of clay minerals in the studied samples. Table (1) shows very low concentration of phosphorus (average <0.01 % P_2O_5), and this reflects the absence of apatite in the samples (Parekh *et al*., 1977; Cullers, 2002).

Table 1: Chemical analyses of the collected samples from the Pila Spi Formation in the Qara Dagh area

Oxides (%)	Location Q1				Location Q2			Average
	G1	G4	G5	G9	K1	K4	K6	
SiO_2	1.28	0.99	1.42	1.07	2.2	1.34	2.93	1.6
Al_2O_3	0.37	0.34	0.24	0.27	0.26	0.28	0.27	0.29
TiO_2	0.01	0.08	0.00	0.01	0.01	0.01	0.00	0.02
CaO	32.24	48.89	52.06	44.4	40.83	44.14	30.92	41.93
MgO	20.93	13.66	6.58	22.99	18.8	13.12	20.34	16.63
MnO	0.3	1.8	5.31	0.75	1.22	2.76	1.82	2.0
Fe_2O_3	0.13	1.56	0.20	0.20	0.55	0.45	2.4	0.76
K_2O	0.03	0.02	0.01	0.02	0.03	0.01	0.03	0.02
Na_2O	0.13	0.22	0.05	0.09	0.05	0.06	0.09	0.1
P_2O_5	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.01
SO_3	0.07	0.06	0.04	0.08		0.01	0.01	0.04
F	0.12	0.00	0.00		0.03	0.02	0.09	0.04
LOI	44.2	31.89	34.04	29.75	35.4	37.4	40.2	36.13
Cl	0.03	0.01	0.00	0.03	0.02	0.04	0.03	0.02
Total	99.85	99.53	99.97	99.48	99.4	99.64	99.12	99.59
$CaCO_3$	4	38	70	0	14	40	7	24

Table 2: Classification of the limestone purity according to the $CaCO_3$ content, (after Harrison, 1993 and Teodorovich, 1950)

Harrison Classification		Teodorovich Classification	
Purity	$CaCO_3$ %	Type	$CaCO_3$%
Very High Purity	> 98.5	Limestone	100 – 95
High Purity	97.0 – 98.5	Slightly dolomitic limestone	95 – 80
Medium Purity	93.5 – 97.0	Medium dolomitic limestone	80 – 65
Low Purity	85.0 – 93.5	Highly dolomitic limestone	65 – 50
Impure	< 85	Highly calcitic dolomite	50 – 35
		Medium calcitic dolomite	35 – 20
		Slightly calcitic dolomite	20 – 5
		Dolomite	5 – 0

- **Geotechnical properties**

The suitability of a rock to be used as dimension stone is controlled by several quality requirements. The desirable properties of a good dimension stone are: **1)** attractive appearance (colors and textures), **2)** durability (physical and chemical stability, **3)** strength, **4)** other factors such as cost of quarrying, transportation, processing and the availability of alternative sources of supply (Harrison and Bloodworth, 1994). The physical properties of the carbonate rocks collected from the Pila Spi Formation, to be assessed as dimension stone, are compared with the ASTM C568-03 (2006), which cover physical properties of the rock, such as density, water absorption, modulus of rupture and compressive strength. This standard method specifies the minimum requirements for limestone to be used as dimension stone. The analyzed parameters are shown in Tables (3 and 4).

Table 3: Color measurement of the studied samples using Geological Rock color chart with genuine Munsell® color chips version 2009

Sample No.	Color Code	Color Name according to the Geological Rock Color cChart
Location Q1		
G1	5Y 8/1	Yellowish gray
G2	5Y 8/2	Yellowish gray
G3	N7	Light gray
G4	5Y 8/2	Yellowish gray
G5	N9	White
G6	N7	Light gray
G7	N9	White
G8	N7	Light gray
G9	5Y 8 /1	Yellowish gray
Location Q2		
K1	5Y 8/1	Yellowish gray
K2	N7	Light gray
K3	N9	White
K4	5R 8/2	Greyish pink
K5	5Y 8/1	Yellowish gray
K6	N9	White
K7	N9	White

Table 4: Physical properties of the studied samples

Sample No.	Apparent Porosity (%)	Water Absorption (%)	Bulk Density (Kg/m^3)
Location Q1			
G1	9.76	4.85	2010
G2	10.77	5.11	2110
G3	9.85	4.44	2220
G4	7.16	2.82	2540
G5	1.90	0.74	2580
G6	9.67	4.24	2280
G7	1.50	0.55	2700
G8	6.59	2.63	2500
G9	12.44	5.59	2230
Average	7.74	3.44	2350
Location Q2			
K1	6.01	2.42	2480
K2	7.60	2.97	2550
K3	6.27	2.36	2650
K4	5.00	1.53	3250
K5	8.89	3.98	2230
K6	9.57	4.07	2350
K7	8.56	3.03	2520
Average	7.41	2.91	2580

– **Color:** Color is an important property of rocks used for building, monumental, and ornamental purposes. It does not affect the adaptability of a rock to structural use, except insofar as it may indicate the presence of deleterious minerals that influence the textural integrity, durability, or strength of the stone (Pereia *et al*., 2015). The results of color measurement indicated that the colors vary from white to yellowish gray and pinkish gray (Table 3). The slight change of the color of the studied samples can be attributed to the oxidation of organic matter and ferrous Fe-oxides. The whitish-gray color of the fresh surfaces assumes a buff tint upon exposure; and may be due to oxidation of isomorphous ferrous carbonate, which is a common constituent of dolomitic carbonate rocks (Dweirj *et al*., 2017).

– **Porosity, Water Absorption, and Bulk Density:** Total porosity is an important factor in rock strength, since a small change in pore volume can produce an appreciable mechanical effect (ISRM, 1981). The porosity refers to the volume of pore space, and water absorption refers to the amount of liquid that a stone will absorb upon immersion (Aurangzeb, 2009). Absorption is related to the volume of pore space, but these two parameters do not have consistency and directly proportional relationship to each other. Where pore spaces are of sub capillary size, absorption is consequently very low and negligible; capillary and larger spaces promote absorption and, hence, increase susceptibility to frost action and chemical weathering (Mohd, 2002). The porosity depends on the size, shape, crystal system, grading, packing, and binding materials (cementing materials) of the particle (Khalid, 2006, Hussein, 2010 and 2012). Results of porosity, water absorption, and bulk density of the studied samples are listed in Table 4. It shows that the average porosity of the studied samples in both sites are 7.74% and 7.41%, respectively. According to Khanal and Tamrakar (2009) these results reflect a low effective porosity.

The bulk density of specimen is the quotient of its dry weight divided by the exterior volume including pores (bulk volume) (Aurangzeb, 2009). The carbonate rocks of the Pila Spi Formation from Q1 and Q2 sites have nearly similar average values of water absorption (3.44% and 2.91%, respectively). Using the method of correlation coefficient (R^2), correlation equations were determined to correlate between bulk density and apparent porosity (Figs.6A and B). It can be seen that there is a good correlation between porosity and density as R^2 is nearly 0.73.

The carbonate rocks of the Pila Spi Formation have high bulk density in which the average values of both groups of samples are; Q1 = 2350 kg/m³ and Q2 = 2580 kg/m³ (Table 4). According to ASTM C568-03, 2006, the carbonate rocks of the studied area are classified as high density rocks (Table 5). This shows that the samples have low effective porosity. Building stones that exhibit low water absorption or low porosity values are generally found to be relatively more durable. Water will be not able to enter non-porous rock types, therefore, unable to promote damage in construction model structure (Miglio and Willmott, 2010; and Khanal and Tamrakar, 2009). Jacobsen and Aarseth (1999) and Pereira *et al*. (2015) showed that the building material′s surface with low degree of water absorption and porosity will be little or not affected by weathering agents; such as wind or rainfall, which are considered as one of the factors for assessment of the appearance of rocks used as dimension stone. Almost all of the acting weathering processes at structures and buildings are controlled by the presence of water, and thus the characteristics of water have an immense impact on the long-term stability of dimension stones (Awadh and Fadhil, 2016).

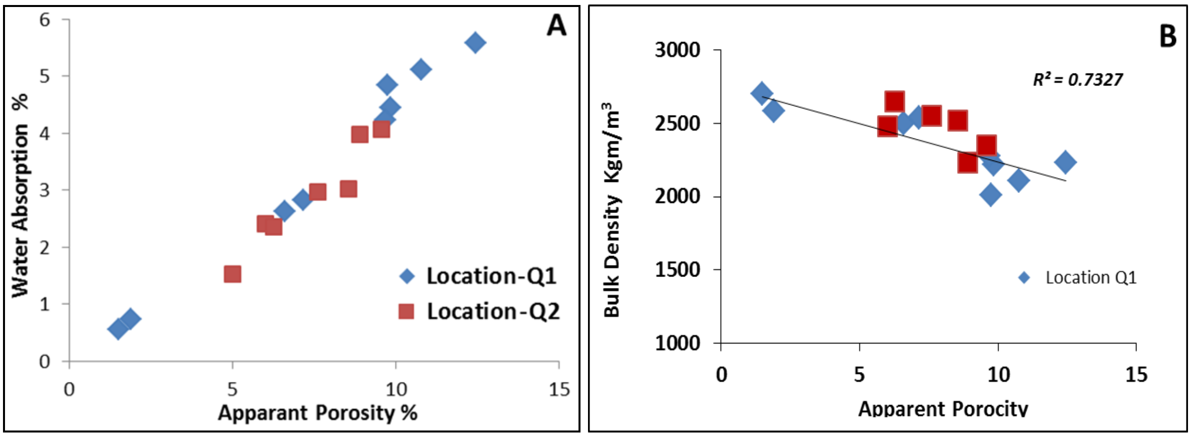

Fig.6: **A)** The relationship between apparent porosity and water absorption for the studied samples, **B)** the relationship between apparent porosity and bulk density for the studied samples

Table 5: The values of physical and mechanical properties of limestone as a dimension stone according to the ASTM C568-03 (2006)

Physical Property	Test Requirement	Classification Test	Test Methods
Absorption by weight, max, %	12 7.5 3	I low-density II medium-density III high-density	C 97
Density, min, lb/ft^3 (kg/m^3)	110 (1760) 135 (2160) 160 (2560)	I low-density II medium-density III high-density	C 97
Compressive strength, min, psi (MPa)	1800 (12) 4000 (28) 8000 (55)	I low-density II medium-density III high-density	C 170
Modulus of rupture min, psi (MPa)	400 (2.9) 500 (3.4) 1000 (6.9)	I low-density II medium-density III high-density	C 99

– **Compressive Strength:** The compressive strength is the measure of a stone ability to sustain a load (Taylor and Harold, 1991). Kessler *et al*. (1940) gave ranges of compressive strength for limestone to be used as a dimension stone (17.926 – 193.053Megapascal Pressure Unit (MPa). The averages compressive strength of the carbonate rocks of the Pila Spi Formation in Q1 and Q2 locations of the studied area are 71.227 MPa and 83.700 MPa, respectively (Table 6). According to the Kessler *et al*. (1940) and ASTM C568-03 (2006), the samples collected from the Pila Spi Formation in the Qara Dagh area are of high density and strong, which confirm their suitability as dimension stone.

– **Modulus of Rupture (MOR):** Tests for modulus of rupture have a more tangible value than those for compressive strength because they measure the flexural strength of stones placed in positions of unequal pressure or bending, such as sills and caps for doors and windows (Currier, 1960). The modulus of rupture (in MPa values) range for limestone, as tested and reported by the Bureau of Standards (Kessler *et al*., 1940), is 3.447 – 1.379 MPa. According to the obtained results, the investigated carbonate rocks of the Pila Spi Formation have acceptable range of modulus of rupture, since the average value ranges from 10.629 to 14.759 MPa (Table 6) and comparing the obtained results with ASTM C568-03 (2006) (Table 5), all the studied samples are suitable to be used as dimension stone.

Table 6: Compressive strength and modulus of rupture of the studied samples

Sample No.	Compressive Strength (MPa)	Modulus of Rupture (MPa)
Location Q 1		
G1	38.720	11.340
G2	36.840	10.510
G3	39.000	12.880
G4	70.240	20.716
G5	142.300	5.995
G6	38.970	9.491
G7	144.650	11.659
G8	95.210	3.037
G9	35.110	10.030
Average	71.227	10.629
Location Q2		
K1	96.000	19.320
K2	71.400	18.110
K3	127.000	13.650
K4	135.000	11.760
K5	49.200	10.740
K6	39.100	12.750
K7	68.200	16.980
Average	83.700	14.759

CONCLUSIONS

- The carbonate rocks of the Pila Spi Formation in Qara Dagh area, are mainly composed of dolomites and dolomitic limestone. They have been highly affected by recrystallization and dolomitization process. Consequently, the fossils cannot be recognized and values of many properties, such as water absorption and bulk density, are low.
- The carbonate rocks of the Pila Spi Formation are homogeneous in color and free from visible defects which may affect their appearance. Their colors after polishing are almost uniform grayish white to yellowish white color, and this reflects their homogeneity in composition and confirms their suitability to be used as a dimension stone.
- Physical properties, namely porosity, water absorption and bulk density, for the tested rocks are very relevant to the specifications of dimension stones, as they exhibited high bulk density, low porosity, and low water absorption.
- The measurement of mechanical properties of the studied samples show that all the studied samples are strong and have an acceptable range of modulus of rupture.
- The comparison of the measured values of the physical and mechanical properties of the studied samples with those specified in ASTM C568-03 (2006) shows that the carbonate rocks of the Pila Spi Formation in the selected studied area can be used as dimension stone.

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