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EVALUATION OF THE ROCKS OF THE PILA SPI FORMATION OF DUHOK ANTICLINE FOR BUILDING STONES – KURDISTAN REGION OF IRAQ

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ABSTRACT:
The rocks of the Pila Spi Formation at the southern limb of the Duhok anticline have been evaluated for use as building stones. The geology of the area and examined rocks are described. Nine samples were collected and tested for physico-mechanical properties (total porosity, water absorption, saturation coefficient, apparent specific gravity, bulk density and uniaxial compressive strength). There was a remarkable variation between the samples in these properties, which showed very high significant relationships with each other. Samples were classified as frost-resistant. According to the Iraqi and American Standards, four samples were categorized as (low density/acceptable), three samples as (moderate density/recommended) and two samples as (high density/highly recommended). According to some classifications, the samples were (moderately strong) except for two of them were (strong), while all of them were (moderately strong) and (high strength rocks) in other classifications. The examined rocks are suitable for interior and exterior wall cladding and exterior fencing, as well as for decoration. Four of them are not suitable for building sections that require high load bearing or in places where they come into contact with water or soil, such as foundations, while only two samples are suitable. The quality and quantity of the rocks and the quarrying conditions encourage their exploitation for building stones, with the necessity of proper planning of the proposed quarry and special treatment during quarrying.

KEYWORDS: Building Stones, Duhok Anticline, Kurdistan Region, Physico-mechanical Properties, Pila Spi Formation, Quarrying.

1. INTRODUCTION

Natural building stones are rocks of sedimentary, igneous or metamorphic origin that are sufficiently hard to be cut into slabs or blocks to be utilized as paving, walling or roofing materials in the construction of modern structures and buildings. Field studies and laboratory examinations are irreplaceable to evaluate the stone quality for construction uses (Saffet, 2010). Building stones must be of high quality for their physical, mechanical and dynamic properties which play a pivotal role in designing civilian construction works (Sharma *et al*., 2006; Bhattarai and Tamrakar, 2017).
Building stones utilized in the interior and exterior designs of buildings are among the most globally common construction materials. They are found extensively in the geological column and have a wide distribution. Their use is restricted when structural complexities or overburden make their production unprofitable or when conservation of nationally or internationally designated heritage sites prevents active quarrying (British Geological Survey, 2005). Building stones exhibit an awfully wide textural and mineralogical composition depending on their origin.
Examination of the physical and mechanical properties of rocks is imperative in deciding their engineering behavior and assessing their use in the numerous sections of the building (Ali *et al.*, 1991; Griffin, 2008). These properties depend primarily on the type and hardness of the mineral constituents, grain size, porosity and pore size, nature of occurrence, degree of weathering, alteration and, in some cases, presence of microfractures (Abd El-Hamid *et al*., 2015). Rocks are classified according to their properties to obtain valuable information in preparing engineering designs for the project to be built.
The Pila Spi Formation (Middle – Late Eocene) covers broad areas and forms prominent ridges between the Gercus and Fatha Formations in the Kurdistan Region of Iraq. Numerous researchers have discussed its suitability for building stones and industrial usages. The present work aims to evaluate the rocks of this formation in the Duhok anticline for building stones based on the laboratory examination of their physico-mechanical properties and some basic quarrying conditions and considerations.

2. PREVIOUS WORKS

Quarries that exploit the rocks of the Pila Spi Formation for various construction and industrial utilizes are located in many areas of the Kurdistan Region of Iraq and other neighboring provinces. The following is a summary of the studies that evaluated these rocks for building and other construction purposes:
Dhaher (2009) concluded that the rocks of the Pila Spi Formation in Shaqlawa area were strong and durable enough to be used as building stones. Saleh (2012) explained that limestone rocks in the Pila Spi Formation in the Nineveh Governorate can be utilized as exterior walls covering, decoration, and as construction aggregate. Khattab and Othman (2012) deduced from their study of the durability and strength of limestone rocks of the Pila Spi Formation from three quarries in the Nineveh and Duhok Governorates that the strength values for these rocks differ between and within the same quarry. They classified the rocks as (medium – strong), (weak – medium) and (weak). The rocks can be used as the main material for the skeleton of buildings or for external cladding purposes. Some types of these rocks can be used in areas that are not exposed to the influence of water or moisture, and one type is not suitable for use as a construction material. Al-Banna *et al*. (2013) reported that the geotechnical characteristics of the Pila Spi and Injana Formations from two limbs of a syncline located in the Shaqlawa area vary depending on plentiful key factors such as water saturation, the relative location of the specimen within the syncline limbs and lithology. Each limb of the syncline has different geotechnical characteristics due to the nature and degree of stresses affecting each limb. Omar and Ismail (2015) evaluated limestone from the Pila Spi Formation in Koya area for use as a building stone and concluded that it has low porosity, high density and is hard enough for use in foundations, wall cladding and building coverings. Mirza and Rashid (2019) assessed the Pila Spi Formation in Qara Dagh area and concluded that the carbonate rocks of this formation can be used as a dimension stone.

3. GEOLOGIC SETTING

The studied area is situated tectonically within the High Folded Zone of the Zagros Foreland Basin according to Fouad (2015), and within the High Folded Zone of the Unstable Shelf according to Jassim and Goff (2006). The investigated rocks are exposed in a sequence at the southern limb of the Duhok anticline (Zawa Mountain), approximately 1 km west of the Sinaye Old village, and 4.25 km northeast of the Sharya District, which is about 11 km south of Duhok city (Figs.1 and 2).

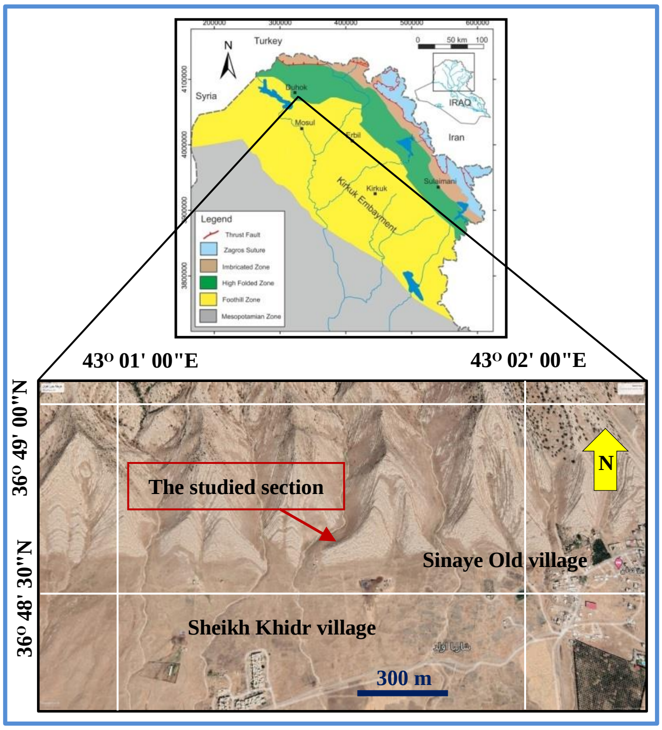

Figure 1. Google Earth image showing the location of the studied section at the southern limb of the Duhok anticline.

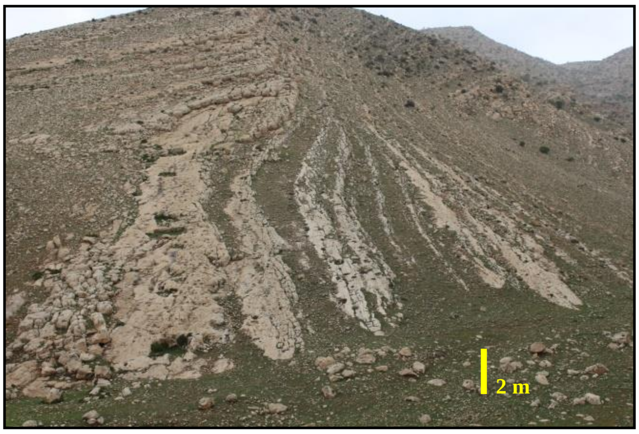

Figure 2. The Pila Spi Formation layers within the studied section.

The Duhok anticline is an asymmetrical fold, extending E – W, nearly 20 km long and 3 – 5 km wide and follows the Taurus folding style (Alkadum, 2009). The dip angle of the northern limb varies between 40° – 79°, and between 14° – 44° at the southern limb (AlKadum, 2009). The anticline has very well exposures of the Pila Spi Formation which forms high anticlinal ridges. The anticline is neighbored on the north by the Bekhair anticline and is separated by a very narrow syncline owing to the high dip of the southern limb of the Bekhair anticline and the northern limb of the Duhok anticline. It is neighbored to the south by the Dahkan anticline, to the east by the Brifka anticline, and to the west by the Sumail anticline (Sissakian *et al.*, 1995; AlKadum, 2009; Al-Saraj Bashi, 2017) (Fig.3).

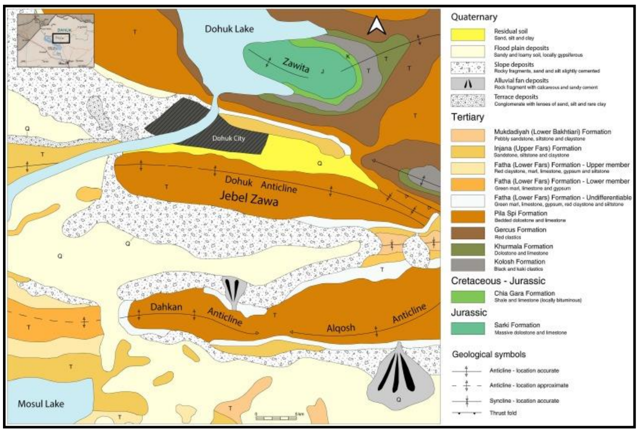

Figure 3. Geological map of the Duhok area. (After Sissakian *et al*., 1995).

The exposed layers include joints of (hko) system overwhelmingly, and (hol) and (okl) to a lesser extent. These joints are filled with carbonate materials due to the processes of weathering and erosion. The main geomorphological units of the area with structural and structural-denudational origins are plateau, anticlinal ridges, transverse valleys, cuestas, karst cavities and flatirons (Fig.4). Landforms resulting from mass movement, such as rock fall, rock toppling and debris flow are also found in the area (Fig.5).

Figure 4. Flatirons within the Pila Spi Formation at the southern limb of the Duhok anticline.

Figure 5. The phenomenon of rock falls in the studied area.

The thickness of the Pila Spi Formation in the studied area is about 150 – 200 m and consists, from top to downward, of a sequence of consolidated, crystallized limestone, well-bedded to massive white or gray dolomitic limestone that is occasionally chalky and cavernous with scattered nodules of chert of different sizes and shapes in some intervals (Fig.6). Small signs of oxidation occur on the surface of the rocks. The thickness of the layers varies between 0.5 – 2 m. Nodules of chert are present in horizons with a maximum thickness of 20 m towards the core of the anticline (Barbaro and Moscone, 2020; Moscone *et al*., 2020). Locally, the formation is overlain by one or more of the Oligocene rocks of the Kirkuk Group and Quaternary deposits (AlKadum, 2009; Karim and Hama, 2019).

Figure 6. Nodules of chert in the dolomitic limestones.

4. MATERIALS AND METHODS

4.1 Sample Preparation and Testing

In this study, nine large, fracture – and void – free samples were collected from a section within the Pila Spi Formation at the southern limb of the Duhok anticline. The rock sampling began from the bottom of the section at coordinates 36° 48' 40"N and 43° 01' 27"E, elevation of 606 m (a.s.l.) and ended at the top of the section at coordinates 36° 48' 41"N and 43° 01' 36"E, elevation of 649 m (a.s.l.). The thickness of the sampled section is 43 m. The sampling interval ranged from 3 to 5 m. Table (1) shows the field description of the collected samples.

Table 1. Field description of the collected **s**ample**s**.

Sample No.	Bed Thickness (m)	Sampling interval (m)	Description
S1	0.90	5	White, well-bedded, chalky limestone
S2	1.10	5	White to light gray, massive, hard dolostone
S3	1.25	5	Light gray, massive, hard calcareous dolostone
S4	1.20	5	Light gray, massive dolostone
S5	1.0	5	Light gray and cherty dolostone
S6	1.15	3	Light brown, jointed calcareous dolostone
S7	1.30	3	White, thickly bedded chalky limestone
S8	1.20	5	White, thickly bedded chalky limestone
S9	0.90	5	White, well-bedded, jointed chalky limestone

The samples were examined for physico-mechanical properties in the Duhok Construction Laboratory in Sumail using the Iraqi Standard No.1387, 1989 and ASTM C97–09–2010. The sample preparation and testing procedures are as follows:

- A portion of each sample weighing about 250 – 300 g was broken into small pieces of 12.5 – 25 mm in size and their normal weight (W_N) was recorded.
- The pieces were dried at 110 °C for 48 hours, placed in a desiccator for 30 minutes to cool to room temperature and their oven-dry weight (W_D) was recorded.
- The pieces were soaked for 48 hours in a basin of distilled water connected to a desiccator, surface wiped with a damp cloth and their saturated weight (W_W) was recorded.
- Finally, the pieces were suspended freely in a wire basket immersed in a distilled water container connected to a 0.01 g precision electronic scale and their submerged weight (W_S) was recorded.

The samples were examined for uniaxial compressive strength using the Iraqi Standard No.2715, 1987. From each sample, three regular cubic-shaped specimens of (100 x 100 x 100 mm) were prepared and polished to obtain a smooth surface for uniaxial loading. The specimens in their natural state were placed perpendicular to the bedding plane in a compression testing machine at a constant rate of loading of 0.6 MPa/mm^2/sec. fixed by the compression machine and compressed until failure. The three breaking point values were averaged for each sample.

4.2 Measurement of Physico-mechanical Properties

The following properties were determined for the samples:

4.2.1 Water Absorption (A_W) (%):

It is the capability of a rock submerged in water for 48 hours to absorb water (McMillan *et al*., 1999; Zeb, 2009). It is calculated as follows:

$$A_W (\%) = (W_W – W_D / W_D) \times 100 \quad (1)$$

Where W_W = saturated weight (g)
W_D = oven-dry weight (g)

The obtained value gives a sign of the service behavior of the stone, in particular its durability, strength, aesthetics, and stain resistance (Spry, 1989; Sandrolini and Franzoni, 2006).

4.2.2 Total Porosity (ϕ) (%):

It is the ratio of the volume of pores to the total volume of the rock, including solid components and pores (Honeyborne, 1982). It is calculated as follows:

$$\phi (\%) = (W_W – W_D / V_t) \times 100 \quad (2)$$

Where V_t = total volume of the rock (cm^3)

4.2.3 Saturation Coefficient (S_c):

It is a measure of the degree to which rock pores are filled with absorbed water under certain conditions (McMillan *et al*., 1999). It is a unitless quantity and is calculated as follows:

$$S_c = A_W (\%) / \phi (\%) \quad (3)$$

$$S_c = (W_W – W_S) / W_D \quad (4)$$

Where W_S = submerged weight (g)

4.2.4 Apparent Specific Gravity (G):

It is the ratio of the weight in air per unit volume of the impermeable portion of the rock (not comprising the permeable pores) to the weight in air of an equal volume of gas-free distilled water at the specified temperature. It is calculated as follows (ASTM C97–09–2010):

$$G = W_D /(W_W – W_S) \quad (5)$$

4.2.5 Bulk Density (ρ_b):

It is the mass of a unit volume of the rock. It is expressed by the mass of rock particles divided by the total volume they occupy which includes the particles, interparticle and intraparticle pores.

Bulk density is calculated as follows (ASTM C97–09–2010):

ρ_b (g/cm^3) = W_N / V_t (6)

$V_t = (W_W - W_S)/ \gamma_W$ (7)

Where W_N = natural weight (g)
γ_W = density of water (g/cm^3)

4.2.6 Uniaxial Compressive Strength (UCS) (σc):

It is the stone's resistance to the vertical compression applied to it at the failure point. It is a measurement of the load that a stone can withstand until it breaks, and therefore it is a measurement of a stone's ability to back load-bearing components of a building (Taylor and Harold, 1991; Quick, 2002).
The uniaxial compressive strength is calculated according to the Iraqi Standard No.2715, 1987 and ASTM C170–90–1999 as follows:

σc = P/A (8)

Where σc = Compressive strength (N/mm^2)
P = Maximum failure load (N)
A = Section area of the cubic specimen (mm^2)

5. RESULTS AND DISCUSSION

5.1 Laboratory Test Results:

Table (2) summarizes the results of the physico-mechanical properties tests of the nine collected samples.

Table 2: Results of the physico-mechanical properties tests of the samples.

Sample No.	A_W (%)	ϕ (%)	S_c	G	ρ_b (kg/m^3)	σc (MPa)
S1	9.61	19.29	0.50	2.0	2036	27
S2	2.74	6.90	0.40	2.52	2517	55
S3	2.81	7.14	0.39	2.54	2554	55
S4	5.07	11.90	0.43	2.35	2357	39
S5	3.33	8.20	0.41	2.46	2467	50
S6	4.11	9.84	0.42	2.39	2410	42
S7	9.13	19.55	0.47	2.14	2146	27
S8	7.84	16.58	0.47	2.12	2179	32
S9	7.40	15.24	0.49	2.06	2063	35
Mean	5.78	12.74	0.44	2.29	2303.22	40.22
Standard Deviation	2.74	5.07	0.04	0.20	199.68	11.08

The samples showed a remarkable variation in the values of their physico-mechanical properties, which can be attributed to the differences in their lithology, depositional texture characteristics, and the degree of their influence by diagenetic and weathering processes. Samples (S1, S7, S8, and S9) have high values of water absorption coefficient and total porosity, and low values of apparent specific gravity, bulk density and uniaxial compressive strength compared to other samples. They are, therefore, more susceptible to increased and decreased humidity, less durable and resistant to weather conditions, and degrade faster.
Samples (S4, S5, and S6) have comparatively lower values of water absorption coefficient and total porosity, and higher values of apparent specific gravity, bulk density and uniaxial compressive strength, while samples (S2 and S3) have low values of water absorption coefficient and total porosity, and high values of apparent specific gravity, bulk density and uniaxial compressive strength. They are, therefore, less susceptible to increased and decreased humidity, more durable and resistant to climatic conditions.
The saturation coefficient of the examined samples varies due to the difference in their total porosity, which in turn varies depending on the lithology and the characteristics of the rock texture. The higher the porosity of the rock, particularly the percentage of narrow and connected voids in it, the faster the water rises through it. Therefore, samples are classified as frost-resistant according to (Honeyborne, 1982).
The statistical analysis revealed that the relationships between the examined properties of the samples are significant and very high. Table (3) shows the matrix of correlation coefficient (*r*) values for the tested properties. Figures (7, 8, 9 and 10) show the diagrammatic representations of these relationships.

Table 3. Matrix of correlation coefficient (*r*) values for the tested properties.

Variable	A_W	ϕ	S_c	G	ρ_b	σc
A_W	1					
ϕ	0.997	1				
Sc	0.957	0.938	1			
G	-0.965	-0.949	-0.998	1		
ρ_b	-0.961	-0.945	-0.998	0.966	1	
σc	-0.968	-0.977	-0.924	0.937	0.931	1

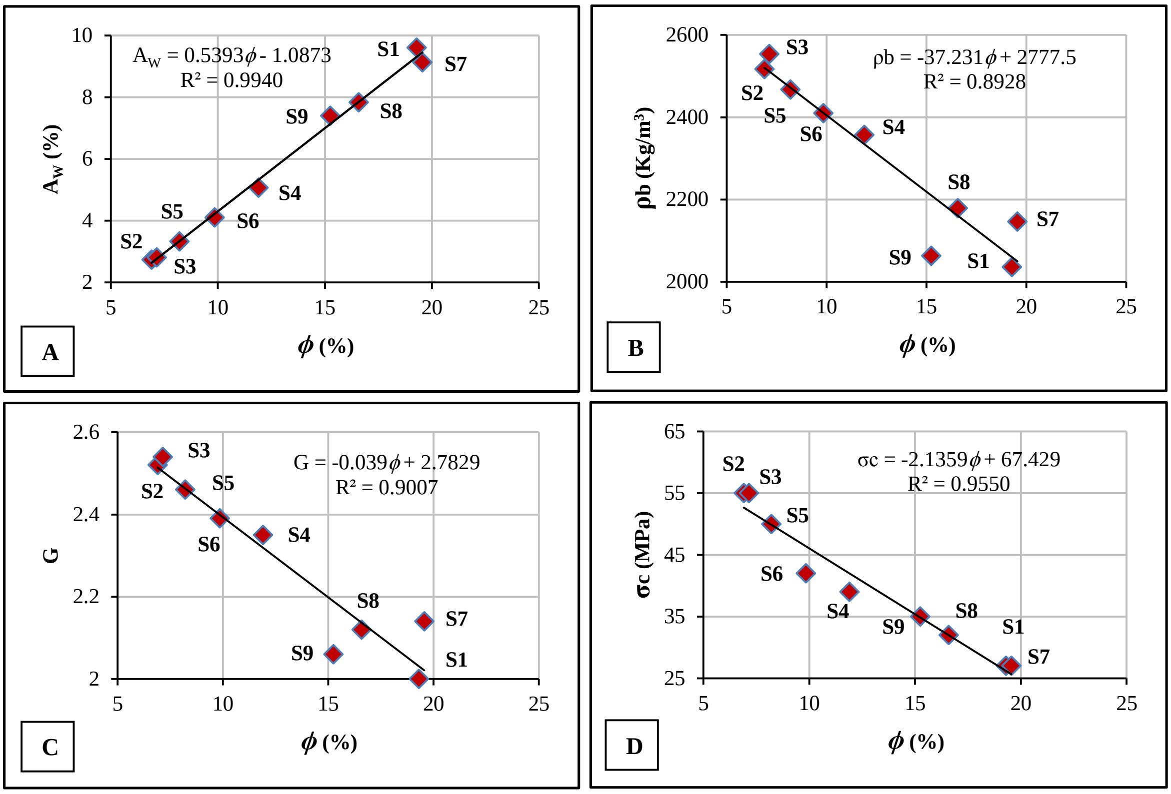

Figure 7. The total porosity versus **A**) water absorption, **B**) bulk density, **C**) apparent specific gravity, **D**) uniaxial compressive strength.

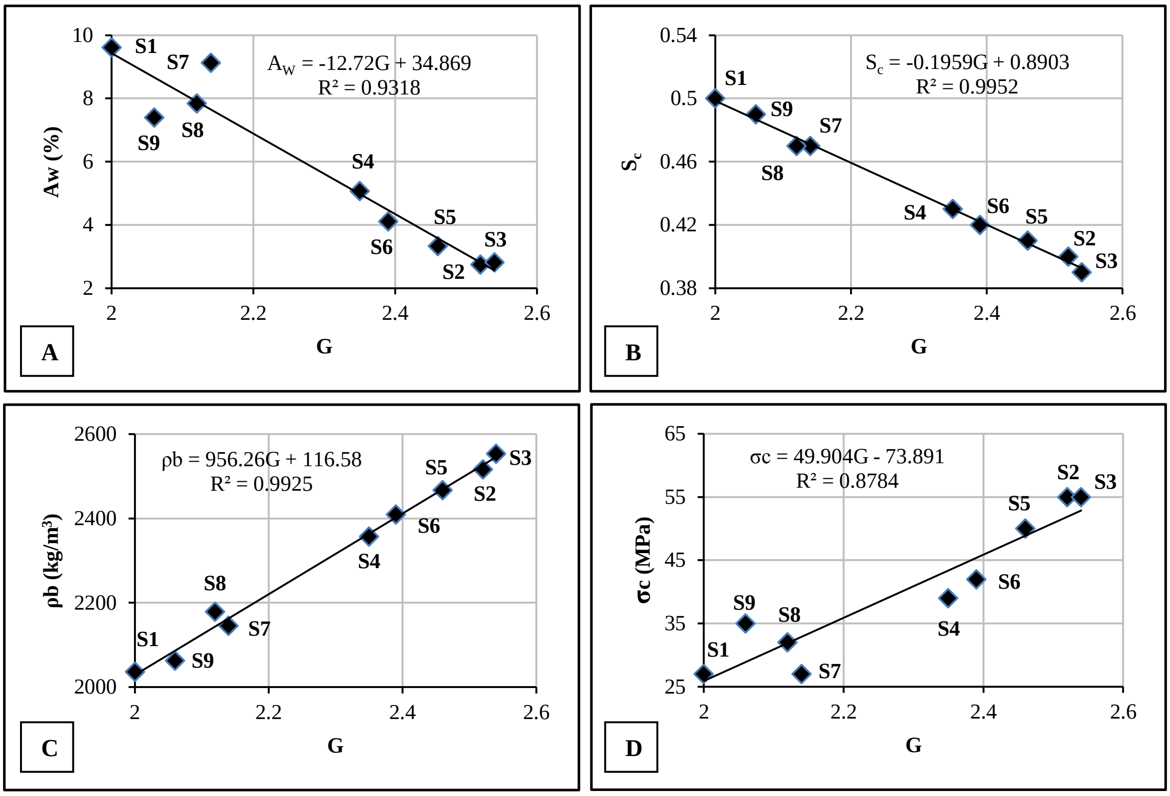

Figure 8. The apparent specific gravity versus **A**) water absorption, **B**) saturation coefficient, **C**) bulk density, **D**) uniaxial compressive strength.

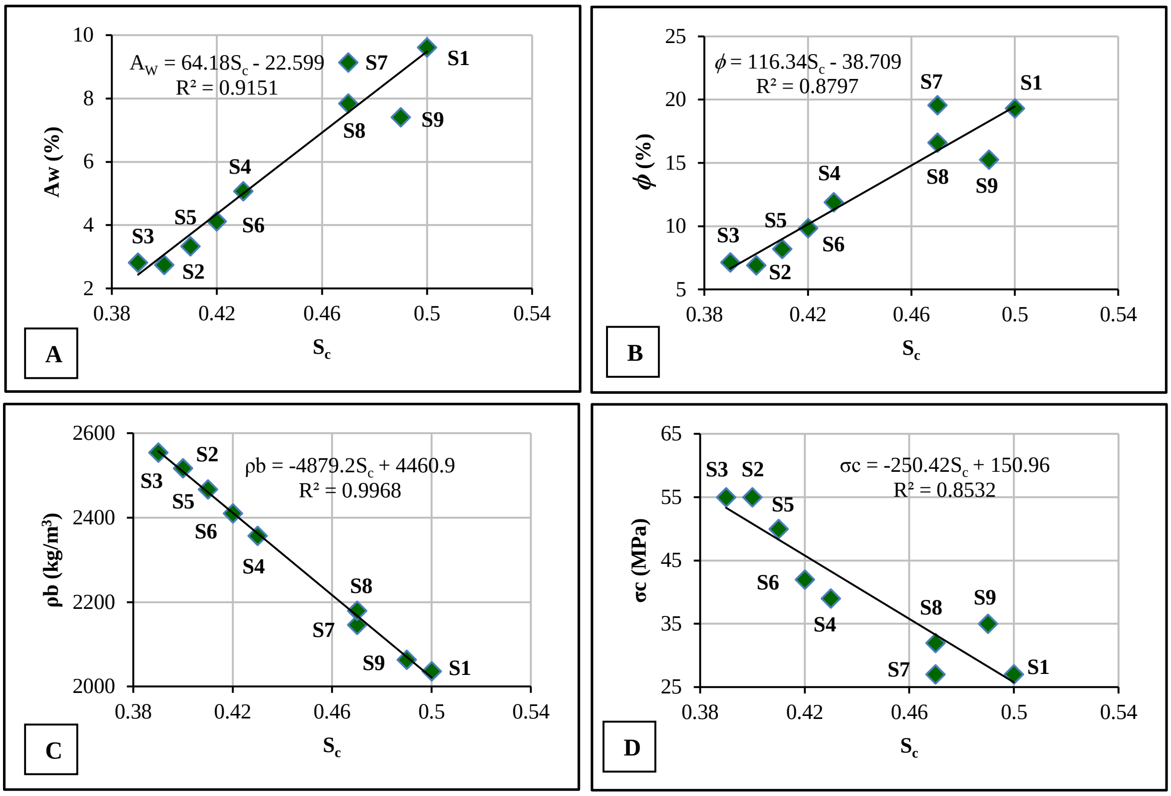

Figure 9. The saturation coefficient versus **A**) water absorption, **B**) total porosity, **C**) bulk density, **D**) uniaxial compressive strength.

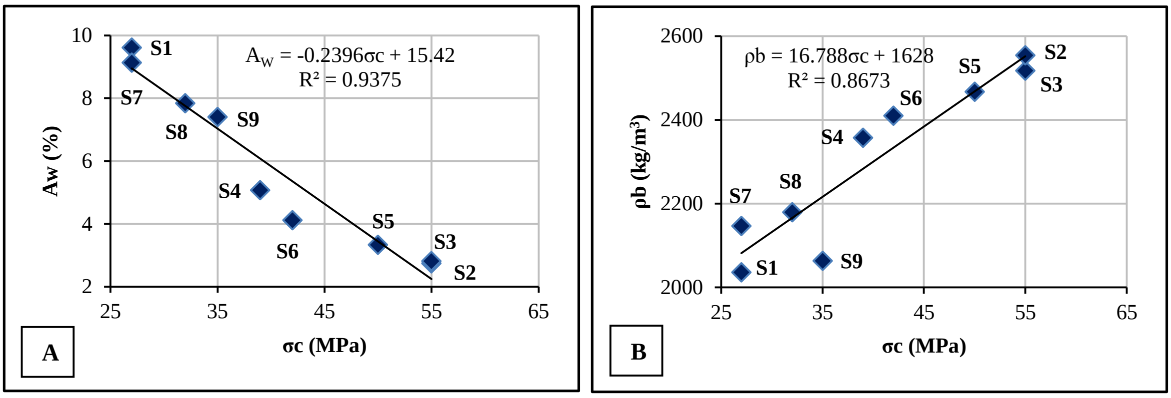

Figure 10. The uniaxial compressive strength versus **A**) water absorption, **B**) bulk density.

The samples were assessed for their suitability for building stones by comparing their measured properties with the Iraqi Standard No.1387, 1989 and ASTM C568–03–2006, which classify them into three categories: i - low density (acceptable); ii – moderate density (recommended) and iii – high density (highly recommended) (Table 4):

Table 4. Classification of the samples according to the Iraqi Standard No.1387, 1989 and ASTM C568–03–2006.

IQ No.1387, 1989	ASTM C568–03–2006	Sample No.
Low density	Acceptable	S1, S7, S8, S9
Moderate density	Recommended	S4, S5, S6
High density	Highly recommended	S2, S3

The samples are classified as (moderately strong) by their uniaxial compressive strength according to (Anon, 1977) and (Geological Society Engineering Group Working Party 1977) except for (S2 and S3) which are (strong) (Table 5).

Table 5. Categorization of rocks by uniaxial compressive strength (MPa) (from Anon, 1977 and Geological Society Engineering Group Working Party 1977).

Category	Anon, 1977	Description	Geological Society 1977
Extremely weak	<1.25	Extremely weak	<1.25
Weak	1.25 – 5.0	Weak	1.25 – 5.0
Moderately weak	5.0 – 12.5	Moderately weak	5.0 – 12.5
Moderately strong	12.5 – 50	Moderately strong	12.5 – 50
Strong	50 – 100	Strong	50 – 100
Extremely strong	>100	Very strong	100 – 200
		Extremely strong	>200

All samples are classified as (moderately strong) according to (ISRM, 1981) and (Franklin and Dusseault, 1989) (Table 6), while they are classified as (high strength) according to (Broch and Franklin, 1972) (Table 7).

Table 6. Classification of uniaxial compressive strength (MPa) (from ISRM, 1981 and Franklin & Dusseault, 1989).

Description	ISRM 1981	Description	Franklin and Dusseault, 1989
Very low	< 6	Extremely weak	2 > σc
Low	6 – 20	Weak	6 ≥ σc ≥ 2
Moderate	20 – 60	Moderately weak	20 ≥ σc ≥ 6
High	60 – 200	Moderately strong	60 ≥ σc ≥ 20
Very high	>200	Strong	200 ≥ σc ≥ 60
		Extremely strong	σc >200

Table 7. Grades of uniaxial compressive strength (MPa) (after Broch and Franklin, 1972).

Grade	Broch and Franklin, 1972
Very low	< 2.5
Low	2.5 – 7.0
Medium	7.0 – 25.0
High	25.5 – 70.0
Very high	70.0 – 225.0
Extremely high	>225.0

The examined rocks can be used as building stones in interior and exterior wall cladding and exterior fencing, as well as for decoration. Samples (S1, S7, S8 and S9) are best suited for use as decorative stones due to their low density, while they are not suitable for building sections that require high load bearing due to their low strength, or in places where they come into contact with water or soil, such as foundations, due to their high porosity and high ability to absorb water. Samples (S2 and S3) can be used in such places as well as areas with high humidity due to their high strength, low porosity and low water absorption capacity.

5.2 Quarrying Conditions:

The following are some of the essential geological and non-geological conditions and considerations for the proposed quarry in the studied area:

5.2.1 Location and Accessibility:

The proposed quarry is located near several villages where labor and tools are available. A new approach road of about 500 m in length will be required to connect the quarry to the Sinaye Old village road off the main road to the Sharya District.

5.2.2 Availability:

The proposed quarry site contains large quantities of rocks of good quality, uniform appearance, and homogeneous light colors suitable for utilize as building stones. Ample space is available for facility installation, site service and stockpiling. A source of electrical power is available for operational and administrative utilizes.

5.2.3 Operations:

The rocks can be quarried using the wedging method or the diamond cutting wire saw method. The presence of natural planes of weakness, such as the joints of different systems and the well bedding nature of the layers, will make the detachment of the stone blocks from their rockbeds easy, fast and economical. They are then taken out, dressed to provide them a pleasing appearance, and transformed into the desired commercial sizes and shapes. The blasting method can be used to a limited extent in times when masses of extractable sizes are difficult to obtain.

5.2.4 Quarry Design:

The geometry of the benched slope of the quarry face must take into account the high dip amount of the beds, therefore, special treatment during quarrying must be carried out by a well-experienced geologist or quarry engineer to ensure the slopes remain stable and operate in a safe system for people and equipment over the long term.

5.2.5 Topography:

The topography of the area plays a vital role in the extraction of rocks and the tracking of layer extensions, which greatly affects the costs of quarrying operations. The layers are well exposed in the transverse valleys that cut across the ridge. The flatirons facilitate the extraction of rocks. The low thickness of the topsoil and the absence of overburden at the studied site are encouraging factors in the exploitation of rocks and reduce the costs of extraction.

5.2.6 Water Supply:

Availability of water resources is a very prerequisite for quarrying operations. The studied area does not have any source of surface water such as rivers or streams. However, groundwater of permissible quality can be found at a depth of 40 – 50 m in carbonate aquifers along the extension of the Pila Spi Formation below the ground surface (Al-Jiburi and Al-Basrawi, 2013). The water will not be utilized to process the stones in the quarrying area, therefore, no effluent will be generated.

5.2.7 Unwanted Materials:

The chert nodules in some layers can be removed during rock cutting and processing. Innerburden or unusable varieties of rocks should be piled outside the boundaries of the quarry for utilize in the rehabilitation of the quarry and not thrown into the valleys which are the natural drainage patterns of the quarry.

6. CONCLUSIONS

1. The Pila Spi Formation in the Duhok anticline consists, from top to downward, of a sequence of consolidated, crystallized limestone, well-bedded to massive white or gray dolomitic limestone that is occasionally chalky and cavernous with scattered nodules of chert of different sizes and shapes in some intervals.
2. The examined rocks showed a remarkable variation in the values of their physico-mechanical properties, which showed very high significant relationships with each other.
3. Samples are classified as frost-resistant.
4. According to the Iraqi and American Standards, four samples were (low density/acceptable), three samples (moderate density/recommended) and two samples (high density/highly recommended). According to some classifications, the samples were (moderately strong) except for two of them (strong), while all of them were (moderately strong) and (high strength rocks) in other classifications.
5. The examined rocks are suitable for use as building stones in interior and exterior wall cladding and exterior fencing, as well as for decoration. Four samples are not suitable for building sections that require high load bearing or in places where they come into contact with water or soil, such as foundations, while only two samples are suitable.
6. The quality and quantity of the rocks and quarrying conditions encourage their exploitation for building stones, with the necessity of proper planning of the proposed quarry and special treatment during quarrying.

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