



The Impact of Limestone Quarry on Bashiqa Mountain, Nineveh Governorate, Iraq

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ABSTRACT

The primary goal of this study is to investigate how limestone quarries affect the natural environment in the Bashiqa area, Nineveh Governorate, northern Iraq. The research initially employs a long-term satellite image surveillance to track changes in the area and the growth of quarrying operations. Furthermore, fieldwork is done to ascertain the geotechnical characteristics of the rocks, and sample collection is carried out for laboratory analysis to determine the engineering qualities of the rocks and whether they are worthy of the environmental changes that have taken place in the region. Every geotechnical characteristic is measured in the field, including the degree of openness, surface roughness, discontinuity spacing, and rock hardness estimate. The petrophysical characteristics, compressive strength, and slake durability are measured in the laboratory. From an engineering perspective, it is discovered that these rocks are appropriate for construction; however, weathering processes rapidly alter the majority of them. The physical and mechanical characteristics of the extracted stones varied; thus, quarry owners need to identify the different types of rocks and how best to use each type to minimize their influence on the environment.

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تأثير مقالع الحجر الجيري على جبل بعشيقية، محافظة نينوى، العراق

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معلومات الارشفة	الملخص
تاريخ الاستلام: 26- يونيو-2024	الهدف الأساس من هذه الدراسة هو التحقيق في كيفية تأثير مقالع الحجر الجيري على البيئة الطبيعية في منطقة بعشيقية بمحافظة نينوى، شمالي العراق. استخدم البحث في البداية مراقبة صور الأقمار الصناعية طويلة المدى لتتبع التغيرات في المنطقة ونمو عمليات القلع. علاوة على ذلك، تم إجراء العمل الحقلية للتأكد من الخصائص الجيوتكنيكية للصخور وتم جمع النماذج للفحوصات المختبرية لتحديد الصفات الهندسية للصخور وما إذا كانت تستحق التغيرات البيئية التي حدثت في المنطقة. تم قياس كل خاصية جيوتكنيكية في الحقل، بما في ذلك درجة الانفتاح وخشونة السطح وتباعد الانقطاعات وتقدير صلابة الصخور. تم قياس الخصائص البتروفيزيائية وقوة الضغط وماتانة التخفيف في المختبر. من منظور هندسي، تم اكتشاف أن هذه الصخور مناسبة للبناء؛ ومع ذلك، فإن عمليات التجوية تؤثر بسرعة على غالبيتها. تختلف الخصائص الفيزيائية والميكانيكية للأحجار المستخرجة، وبالتالي يحتاج أصحاب المقالع إلى تحديد أنواع الصخور المختلفة وأفضل طريقة لاستخدام كل نوع لتقليل تأثيرها على البيئة.
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Introduction

Bashiq Mountain is located northeast of Mosul City Center in Nineveh Governorate, about 30 km away at a latitude of 36°27'55.3"N and longitude 43°26'11.9"E. According to the geomorphological view, the area is classified as being under the plateau and hills region, and a large number of dry valleys are noticed in this area.

Limestone and gypsum rocks have been used locally in Nineveh Governorate for construction purposes since ancient times, and they are extracted from rock quarries spread around the city of Mosul (Saleh *et al.*, 2023). When limestone quarrying activities are not thoroughly examined from a scientific, engineering, and environmental perspective, a significant amount of waste is produced. Thus, environmental impact assessment is employed to evaluate how effective mining and quarrying activities are (Parthiban *et al.*, 2023). Limestone extracted from the Fatha and Pila Spi formations in northern Iraq has been used in construction for centuries. Their broken pieces were used to build walls and roofs, while stone cut into regular geometric shapes was used to build supports and cover the walls. These stones resist weathering in normal conditions, as the degree of weathering varies depending on weather factors, such as rain, wind, humidity, and temperature variations (Al-Jawadi and Al-Dabbagh, 2020).

Building stones in general, used during the life of construction, are exposed to environmental conditions and weathering processes. Rainwater and temperature variations are among the most important factors affecting building stones' chemical and physical weathering, respectively. The first factor plays a major role in the concentration of the carbonic acid H₂CO₃, which leads to the dissolution and weathering of rocks. There has been a significant, steady

increase in the effect of weathering on building stones in recent decades. This is due to the increase in the percentage of carbon dioxide (CO_2) in the atmosphere due to the excessive use of burning solid and liquid fuels in manufacturing processes, which has led to air pollution (Al-Jawadi and Al-Dabbagh, 2020). Weak carbonic acid is produced from the dissolution of CO_2 gas present in the air and in the soil with rainwater. This acid dissolves rocks and minerals such as limestone and calcite (Baronio and Cancelli, 1981). Dissolution is the first stage of chemical weathering, which can occur via rainwater, running water, or the effect of the thin membrane water around the solid parts of the rock as a result of the surface tension of water. Physical conditions also lead to flaking and breaking of the rocks through mechanical weathering (Baronio and Cancelli, 1981). The amount of solution resulting from dissolution depends on the amount of water passing over the solid areas of the rock and on the ability of the rock to dissolve (Ollier, 1984). As a result of dissolution, the dissolved parts move with the water, leaving voids in their place. This process is responsible for the formation of caves and karsts in limestone (Pesce *et al.*, 2019). Rainwater and temperatures are among the most important external environmental factors affecting the chemical weathering of rocks (Fookes and Hawkins, 1988), while internal factors are represented by the components of the rock and the fabric. Time is also the third common factor, which leads to the weakening of the rock and a decrease in its compressive strength (Dhakal, 1996).

For optimal exploitation, many studies have been conducted to analyze limestone quarries using three-dimensional models to determine the qualitative distribution of these rocks (Friberg, 2023).

This study aims to determine: (1) the engineering properties of the limestone quarried from Bashiqa Mountain, (2) the limestone suitability for construction uses, (3) the effect of rock quarries on the geological environment of Mount Bashiqa, (4) the effect of time and natural conditions on the engineering properties of rocks before and after weathering, and (5) which species are more durable and resistant to weathering.

Geological settings

The geological history of Bashiqa Mountain is associated with the geological history of Iraq. A large part of it was covered with Tethys Sea. Due to the tectonic movements that started in the Cretaceous of the second geological age and reached their peak in the third geological age, especially in the Miocene and the Pliocene, the mountains in Iraq and Bashiqa Mountain are among them, which is tackled in the present study, and were built (Al-Omari and Sadiq, 1997).

Tectonically, the area is located in the Low Folded Zone (LFZ) (Fig. 1) within the Foothill Zone on the Butmah-Mosul Subzone, which constitutes a part of the unstable platform of the northern and the northeastern part of the Nubian Arab Shield (Fouad, 2012). Bashiqa Mountain is a box anticline, whose axis extends in a southeast-northwest direction. A narrow syncline separates Bashiqa and Maqlub anticlines.

The Pila Spi, Fatha, and Injana formations represent the stratigraphic sequence exposed in the area (Fig. 2). Because of their superior resistance to weathering and erosion over the rocks that lie stratigraphically above them, the limestone rocks that serve as the primary structural component of the Pila Spi Formation (Middle-Late Eocene) are exposed in the center of the Bashiqa anticline.

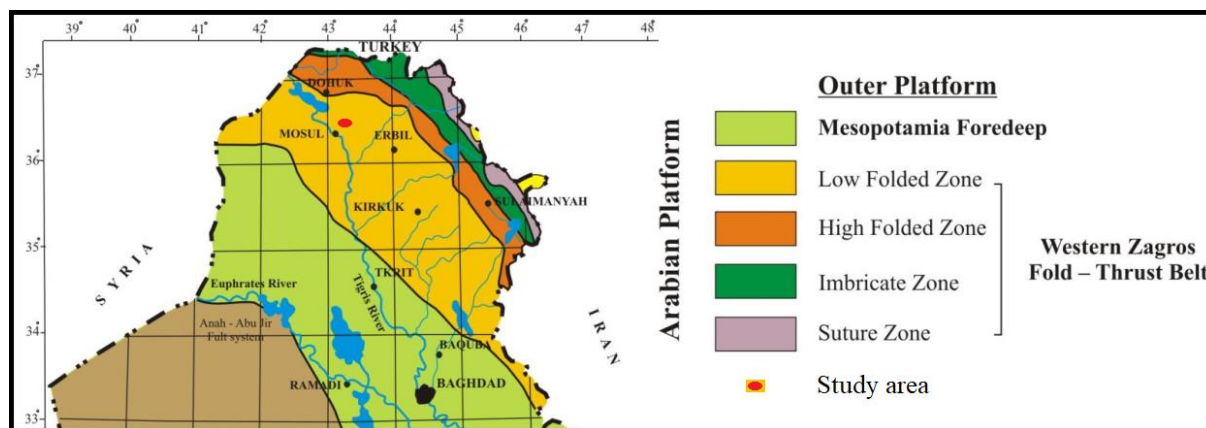


Fig. 1. Location of the study area according to the tectonic map (Fouad, 2015).

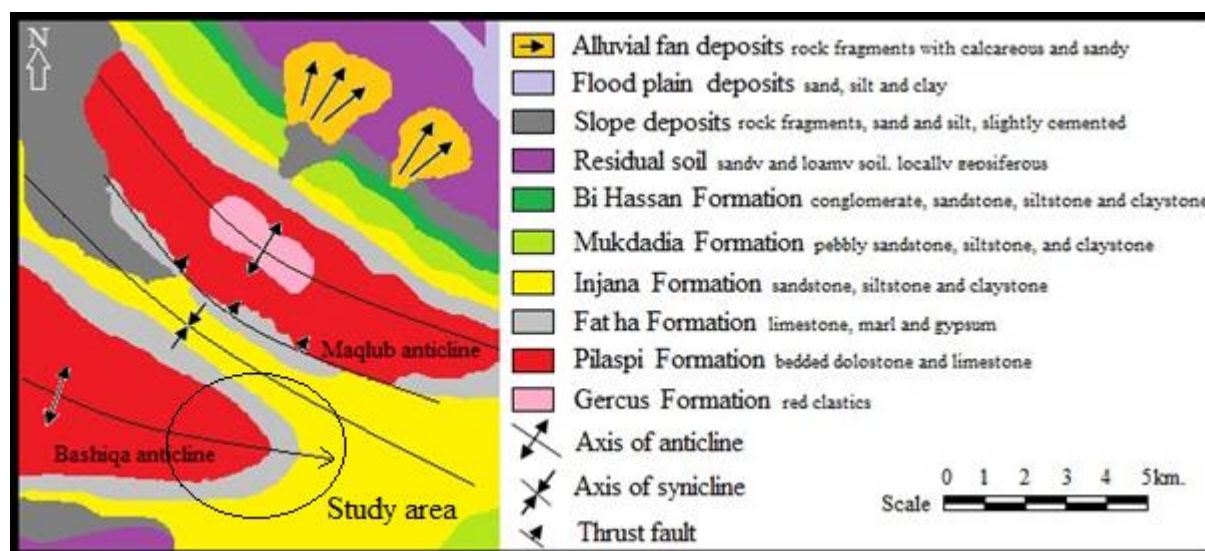


Fig. 2. Location of the study area according to structural and geological formations.

The description of the two important geological formations in this study (Pila Spi and Fatha) (Fig. 2), according to Sissakian and Fouad (2015) is as follows:

The Pila Spi Formation (Oligocene) constitutes dominantly the structure of Bashiq Mountain with an area of 20.304 km² (79.97% of the total area). The lower portion of the formation consists of hard, thick, occasionally dolomitized layers with slightly fossilized limestone. The upper part of the formation is primarily composed of well-stratified limestone rocks enclaving chert nodules. In the study area, the highest thickness of the formation is about 190 m (Bakos, 1982). It is composed of well-bedded white crystallized limestone with pale green marl. Due to the chemical weathering and the fullness of cracks and pores with the solutions, the Pila Spi represents the base of the evolution of the karst aspects in the area of the study (Buday, 1980).

The Fatha Formation (Middle Miocene) is exposed as a narrow ribbon that extends from northeast to southwest at the mountain foot with an area of 2.144 km² (8.45% of the total area), and its thickness is about 200 m (Al-Sayegh and Al-Nuaimi, 2004). The sulfate rocks constitute about 50% of the total formation's thickness. It is composed of anhydrous gypsum with thin beds of lime and clay that are characterized by their solubility in water, which contributes to the formation of caves and karst holes (Al-Juboury and McCann, 2008).

Quarries and their environmental impacts

Quarries greatly affect various environmental elements such as rocks, soil, water, and air. It leads to distortion of the ground, the creation of holes, a shortage of agricultural land, and slips and landslides may occur. It also affects surface water drainage systems; in addition to the air

and noise pollution, it causes to residential communities near quarrying sites as a result of blasting, crushing, and loading. Some of these effects have been identified in some of the quarries spread across Nineveh Governorate, especially those located on the slopes, where waste rocks are pushed into the valleys in the region, which are rainwater drainage systems. As for the damage caused to public roads by trucks transporting raw materials after leaving the quarries, as a result to stuck mud.

Especially in the rainy seasons, a phenomenon that must be addressed as it is done in developed countries. As for the pits resulting from other quarries, it is necessary to ensure that they are filled and that waste is not thrown into them because they risk public health and the possibility of polluting groundwater. Developed countries have issued many legislations that prevent throwing waste except in designated places chosen on a scientific basis to ensure that the environment is not polluted, through full familiarity and knowledge of the nature of the geology of the region, its hydrogeology, and its relationship to the nature of the waste (Thanoon and Mohammed, 2002).

The General Company for Geological Survey and Mining works to oblige the authorities responsible for the quarries to fill the holes and re-level the land, and in the field of extracting sand and river gravel, it obliges the investing parties not to change the course of the rivers and not to affect their flow (Al-Bassam and Mikhail, 1996).

Materials and Methods

Preliminary Work

To ascertain the study's needs for measurements, tests, and software that may be employed, the preparatory work started with a survey of scientific literature on the topic of the investigation. Every study component had a work plan created for it, and the necessary materials were prepared.

Fieldwork

During the fieldwork, reconnaissance tours were carried out to locate the quarries under investigation. Thereafter, the sampling was carried out, and the necessary quarry measurements throughout Nineveh Governorate were accomplished. This work is done according to ISRM (1978; 1981), including:

1. Determination of rock types and discontinuity characteristics.
2. Determining the location of the remaining discontinuity as well as the value and direction of the beds' dips using a Branton and Silva style geological compass to measure the rock beds' orientation.
3. Measuring spaces for each successive discontinuity using a tape measure.
4. Determining the number of discontinuities, including layering surfaces, breaks and random breaking.
5. Measuring the openness of discontinuities, which is the vertical distance between the surfaces of two adjacent rock pieces.
6. Setting the filling material type for the discontinuities.
7. Measuring the degree of roughness and waviness of each discontinuity system.
8. Determining the degree of weathering on the discontinuities and its depth within the body of the rock.
9. Measuring the rock surface hardness and discontinuities using a geological hammer and a Schmidt hammer.
10. Measuring the steepness and direction of the slope using a geological compass.

Laboratory work

Samples were prepared for laboratory work in the Rocks Laboratory at Dams and Water Resources Research Center, University of Mosul, where the collected rock samples from the

study area were drilled using a scoring machine, and the following measurements were carried out:

Physical Properties

Physical tests are conducted after preparing the pulp samples, drying them, measuring their dimensions accurately, and then weighing them. The samples were immersed in water for 48 hours, and the saturated state was reweighed. The physical properties calculations (ultrasonic velocity, dry density, saturated density, void ratio, and porosity) are conducted (ISRM, 1977; 1978).

Compressive Strength

The rock samples are examined at the Materials Testing Laboratory of the Department of Civil Engineering, College of Engineering, University of Mosul, using a general pressure testing machine. This test is done by placing the samples in the device and applying force upon them until they break to know the extent to which the sample can withstand under the stress (ISRM, 1979; Fairhurst and Hudson, 1999).

Slake Durability

The durability examination of the rock samples was conducted at the Soil and Rock Laboratory of the Department of Civil Engineering, College of Engineering, University of Mosul. This test represents the resistance measurement of rock samples subjected to weakness and disintegration resulting from a standard cycle of drying and hydration, and their resistance to weathering is evaluated (Franklin and Chandra, 1972; ISRM, 1977).

Results and discussions

The results are divided into four categories: monitoring satellite images for the years 1998-2020, field results, which revealed the engineering characteristics of the rock mass and discontinuities of the Pila Spi Formation, laboratory engineering characteristics of stones extracted from quarries, and variations in the morphology of the ground surface caused by quarrying operations and their environmental effects. Upon initial observation, the quarry sites in the area exhibit haphazard quarrying practices that lack a proper geo-engineering design foundation (Fig. 3). Satellite images indicate tremendous expansion in extraction operations in recent years (Fig. 4).

The field uniaxial compressive strength values for the hole location ranged from 33 to 40 MPa based on the Schmidt hammer rebound readings (Fig. 5). The GSI classification (Fig. 6) assigns the rock masses in the study area as high-quality classification (Song *et al.*, 2020). According to the Hoek Brown classification, the values of the rock mass classification are 68 for GSI, 35 for the angle of internal friction, 5 MPa for cohesion, 12.6 MPa for uniaxial compressive strength, 19.2 MPa for global strength, and 46.9 GPa for deformation modulus.

Samples are taken from the field to the laboratory for testing after preparing core samples with a diameter of 5.7 cm and suitable lengths of roughly twice the diameter. After the samples underwent physical testing, the dry density values were found to range from 1.923 to 2.228 g/cm³, while the saturated density values were found to range from 2.169 to 2.388 g/cm³, with an average of 2.080 g/cm³ and 2.281 g/cm³, respectively. The Pila Spi carbonate rocks show high porosity ranging between 18.73 to 24.55% with an average of 20.4%. The voids ratio is between 23.05% to 32.55% with an average of 25.7%. Laboratory results of ultrasonic velocity testing of building stones in the study area show that the lowest velocity is in the saturated state, which amounted to 1.79 km/sec, while the highest velocity is in the dry state, which amounted to 3.53 km/sec (Table 1). It is believed that the reason for the decrease in the velocity of longitudinal waves is due to the disintegration of the bonds between the grains and mineral crystals of these

rocks as a result of their exposure to water. The slake durability test shows that the building stones extracted from these rocks are low (ISRM, 1977), less than 25%, as shown in Table 2.



Fig. 3. Exhibition of haphazard quarrying practices in the plunge of the Bashiqa anticline.

Table 1: Physical properties of limestone core samples.

Sample No.	Dry Ultrasonic Velocity (km/sec)	Wet Ultrasonic Velocity (km/sec)	Dry density (gm/cm ³)	Saturated density (gm/cm ³)	Porosity %	Voids ratio %
L1_A			1.961			
L1_B			2.077			
L1_C			2.082	2.276	19.5	24.1
L1_D			1.951			
L1_E	2.75	1.94	1.947	2.178	23.0	29.9
L1_F	2.69	1.79	1.923	2.168	24.6	32.5
L1	2.72	1.87	1.99	2.21	22.37	28.83
L2_A			2.118			
L2_B			2.200	2.388	18.8	23.2
L2_C			2.159			
L2_D	3.20	2.38	2.050	2.255	20.6	25.9
L2_E	3.22	2.13	2.174	2.361	18.7	23.0
L2	3.21	2.26	2.14	2.33	19.37	23.10
L3_A			2.228			
L3_B			2.120			
L3_C			2.136	2.340	20.4	25.6
L3_D	3.53	3.09	2.177	2.379	20.2	25.3
L3	3.53	3.09	2.17	2.36	20.30	25.45
L4_A			2.046	2.240	19.4	24.1
L4_B			2.059			
L4_C			2.064			
L4_D	2.65	2.07	2.039	2.228	19.0	23.4
L4	2.65	2.07	2.05	2.23	19.20	23.75
Average	3.01	2.23	2.080	2.281	20.4	25.7

Table 2: Results of the slake durability test.

Cycle/Sample	L1	L2	L3	L4
1	1.97	2.70	1.87	5.47
2	3.09	3.94	2.54	7.98
3	3.89	5.22	2.75	9.87
4	4.55	5.97	3.59	11.51
5	5.04	6.34	3.90	12.86

According to the results of the stress-strain test, every sample collected from the study site has a high strain at the beginning, or low stress (Fig. 7). After that, the relationship is nearly linear, with the lowest value of the elasticity modulus being 0.5 GPa and the highest value being 11.75 GPa. Uniaxial compressive strength values range from 9.44 MPa to 57.96 MPa (Fig. 7), which are considered moderate in general according to the ISRM (1978) classification.

The aforementioned results make it evident that the construction stones taken from the limestone rocks of the Pila Spi Formation have good durability and average engineering qualities in terms of compression strength.

When using these stones as building stones, they have high porosity because they are considered effective heat insulators and do not disintegrate when water seeps inside them and freezes, causing other problems. This is especially true in environments with a continental climate (Carmichael, 2018).

When samples L1 and L2 are subjected to uniaxial compressive strength tests in both the saturated and dry states, a substantial drop in the modulus of elasticity and a sharp decline in the values are discovered. This indicates that the engineering qualities of these stones are significantly impacted by water saturation, which could be related to the fragile inter-granular bonding in the rock (Fig. 8) (Ciantia, 2018; Abd El Aal *et al.*, 2023).

Satellite images show a significant expansion in the gouging area after 2003 and its spread over a large part of the northeastern limb of the Bashiqa anticline. It is revealed through field work that there is a lack of planning in the extraction operations, as thick layers are removed and thrown away because of their slightly dark color. One of the features of building stones preferred in facades is that they are light in color. However, this does not give the right to throw these stones, but rather they can be used in the manufacture of rock aggregate. Color is considered one of the most important characteristics of building stones, but due to its exposure to weathering processes, it becomes speckled, blotchy, and dark in color (ASTM, STP1394, 2000).

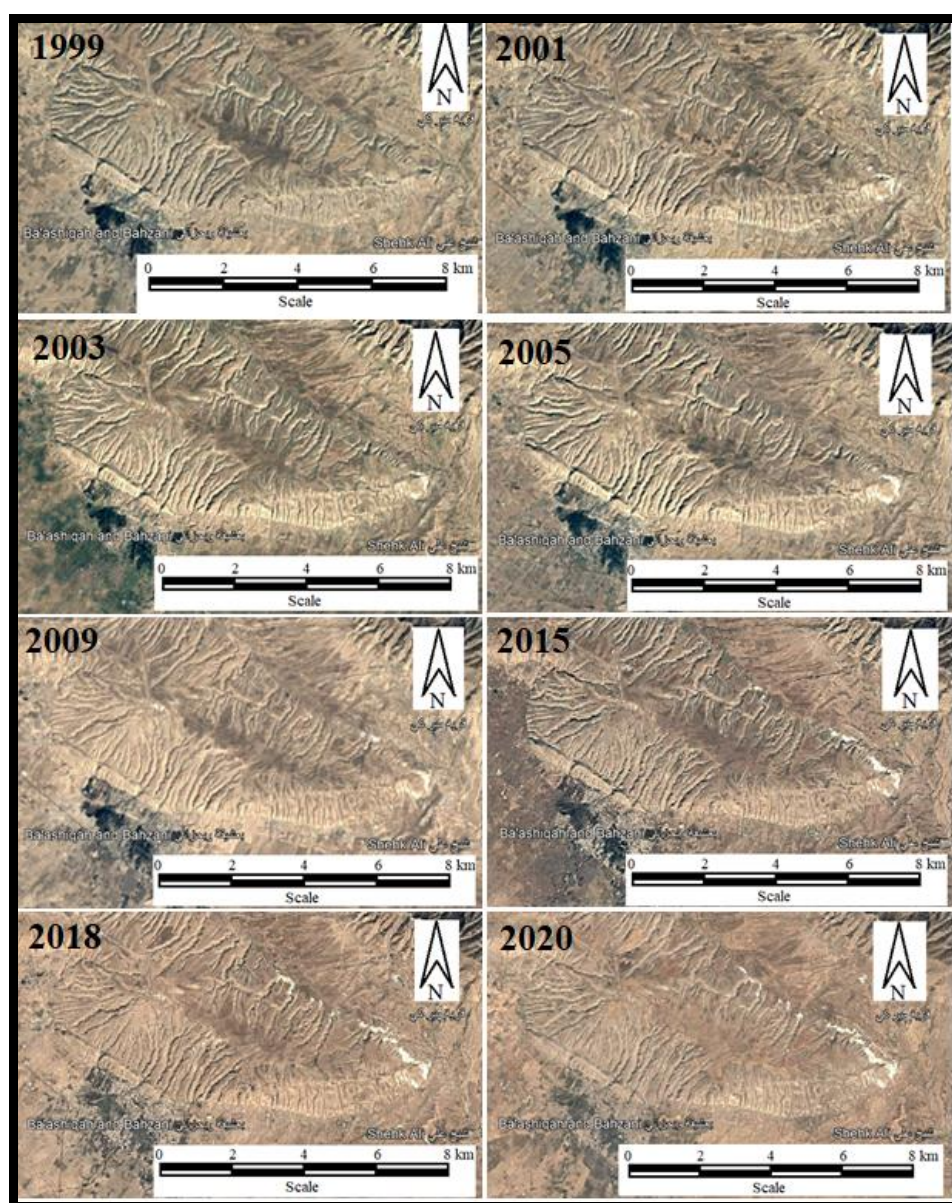


Fig. 4. Satellite images for several years showing the expansion of the quarry area.

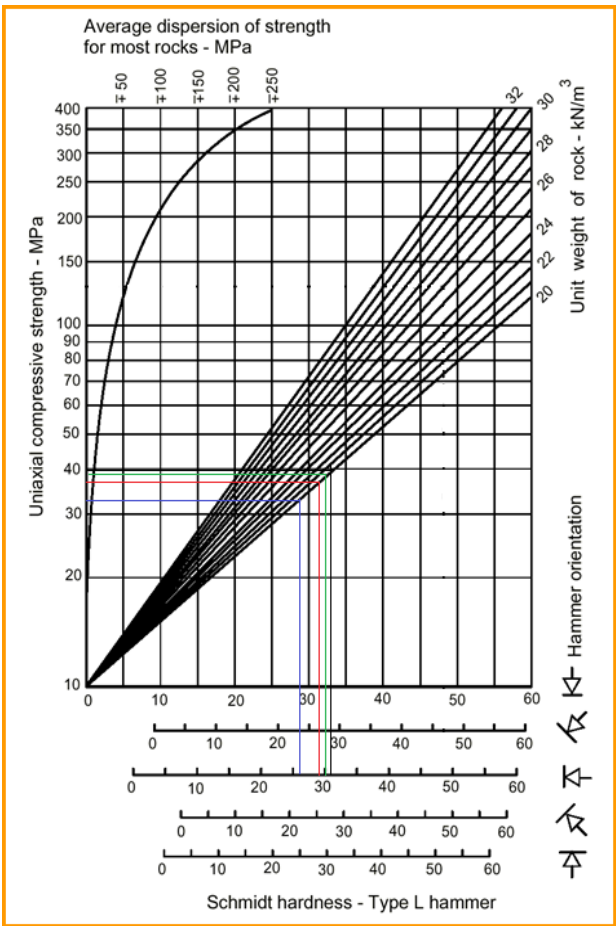


Fig. 5. Estimation of uniaxial compressive strength by Schmidt hammer.

GEOLOGICAL STRENGTH INDEX FOR JOINTED ROCKS (Hoek and Marinos, 2000)				
From the lithology, structure and surface conditions of the discontinuities, estimate the average value of GSI. Do not try to be too precise. Quoting a range from 33 to 37 is more realistic than stating that GSI=35. Note that the table does that apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surfaces in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the fair to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.				
STRUCTURE	SURFACE CONDITIONS	DESCREASING SURFACE QUALITY →		
	VERY GOOD Very rough fresh unweathered surfaces	90		N/A
	GOOD Rough slightly weathered, iron stained surfaces	80		N/A
	FAIR Smooth, moderately weathered and altered surfaces	70		
	POOR Stickensided, highly weathered surfaces with compact coatings or fillings or angular fragments	60		
	VERY POOR Stickensided, highly weathered surfaces with soft clay coatings or fillings	50		
		40		
		30		
		20		
		10		
		N/A	N/A	

Fig. 6. Assessment of rock mass according to GSI System.

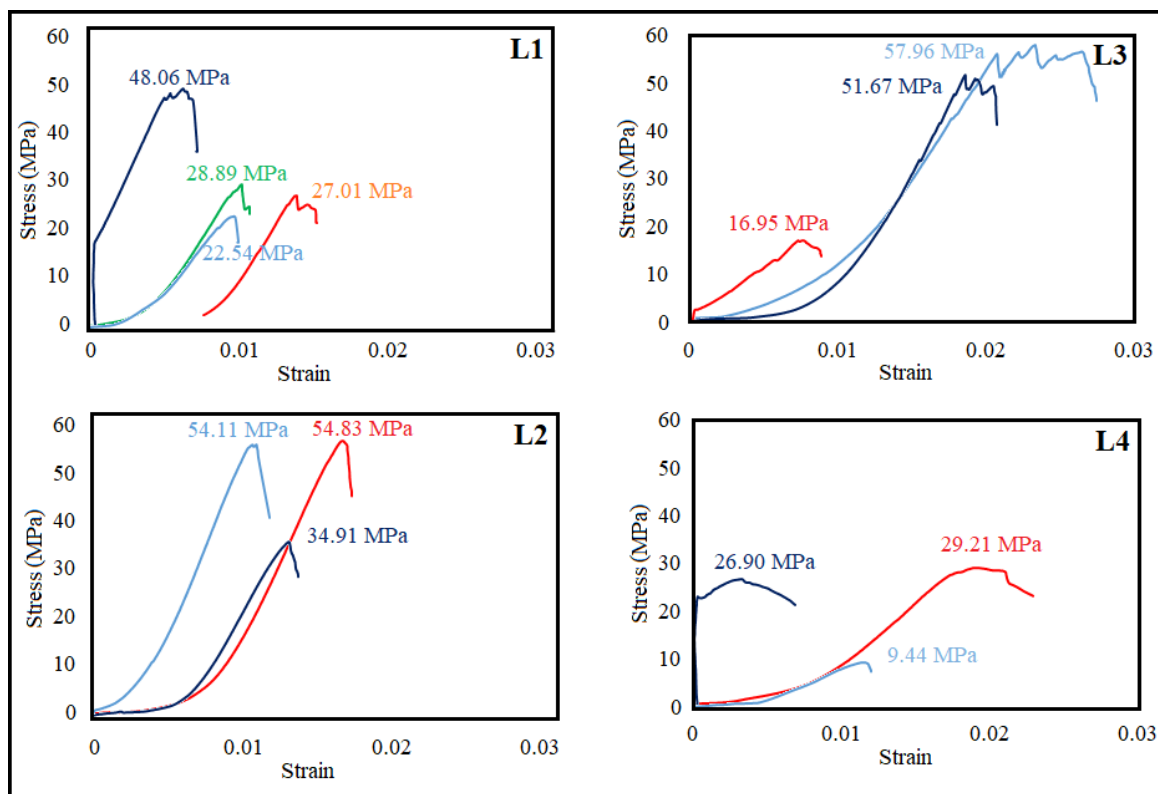


Fig. 7. Mechanical test showing the stress-strain curves, the behavior of the rock under vertical load, and the values of rock strength.

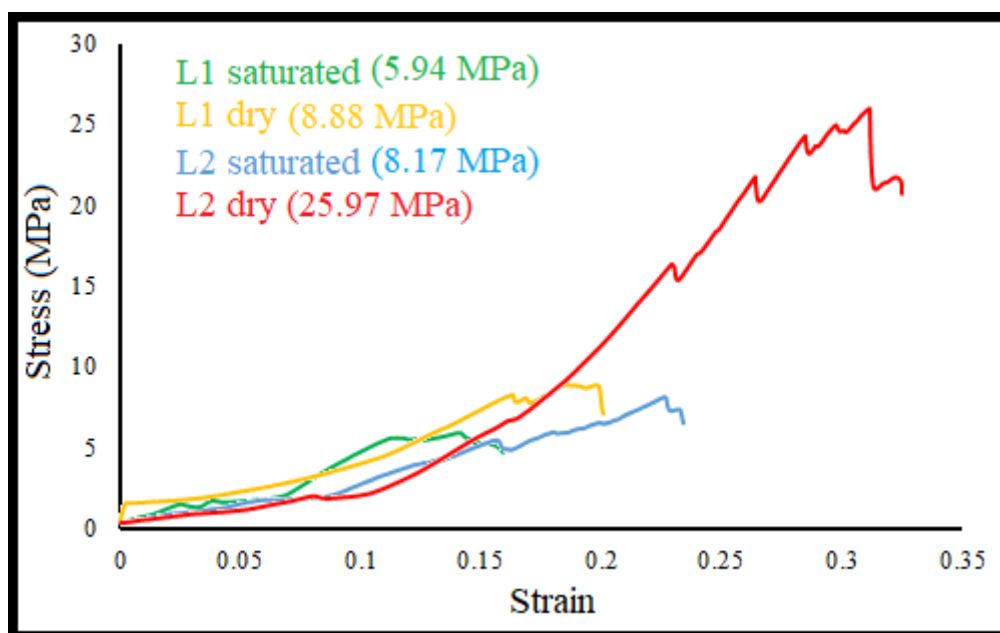


Fig. 8. Impact of saturation on mechanical properties of carbonate rocks.

The petrographic description, porosity, freezing and thawing, water absorption, and porosity are some of the most crucial tests on limestone that are carried out based on European Testing Methods to identify durability (Mialco, 1997). According to the petrographic study, the rocks have high porosity, which leads to secondary mineral precipitation in some cases. Meanwhile, porosity from weathering spreads near the surface of the rock due to fractures, which also lead to secondary precipitation in some cases (Fig. 9).

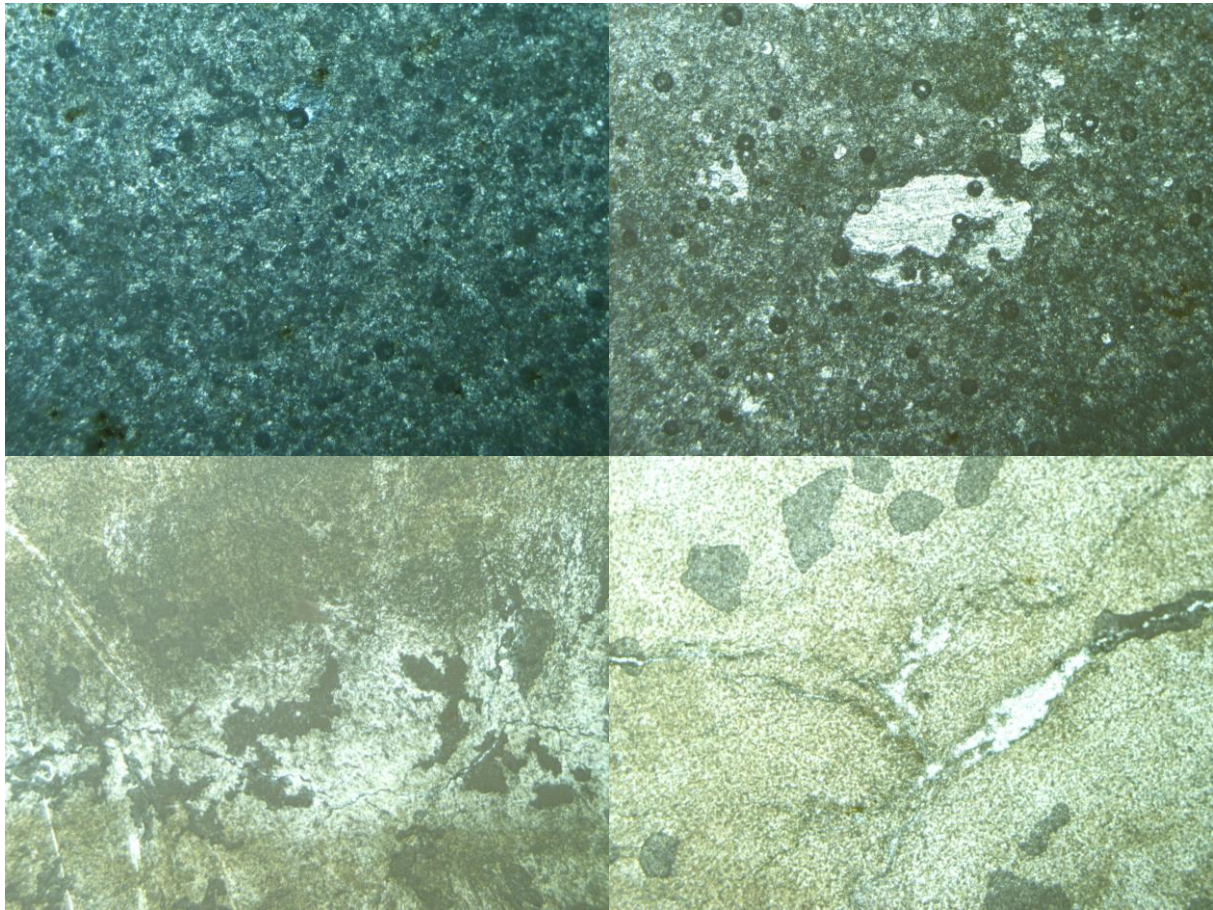


Fig. 9. Petrographic photos showing the porosity and the texture of the rock (up-left), the porosity due to dissolution and precipitation of secondary minerals in the deep of sample (up-right), the dissolution near the surface of the rock due to weathering and fractures (down-left), and the precipitation of secondary minerals in fractures (down-right).

Conclusion

In the last 20 years, the area of quarries in the southeastern plunge of the Bashiqa anticline has increased by more than ten times. In addition to altering the patterns of water drainage valleys and creating holes that could eventually result in the establishment of seasonal wetlands. The limestone quarries have also altered the geological environment and caused deformations that could cause rock slides in the future. This field test may be extensively applied since Schmidt hammer data clearly indicated convergence with the uniaxial compressive strength results. Based on their petrophysical and mechanical characteristics, the rock masses were engineering rated as medium quality overall and GSI assessed them as good to very good. Also significantly impacted by saturation where the building stones are taken from the Bashiqa anticline quarry; these qualities of some stones are significantly diminished, which makes them unsuitable for use in construction. To determine the potential usage of rock beds in the building and construction industries, it is advised to categorize them based on their geotechnical characteristics before quarrying.

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