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Investigation of Fractures Effect on Building Stone Utilization: a Case Study

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Abstract

One of the significant negative factors involved in exploiting granite stones as ornamental stones is the presence of heterogeneous fractures within the rock mass. Joints can either be destructive or beneficial in the production granite piles and building stone mines depending on their characteristics. This work focuses on evaluating the joints in the Divchal mine area of Kelardasht, north Iran. To get to that point, the main faults are surveyed from the aerial photograph, geological and tectonic maps, and field observations. According to this implementation, a density map of faults is provided for the entire studied area. The characteristics of the main joints including the length, slope, number, and orientation are collected in the mine area. The volumetric percentage of joints (J_v) and joint set spacing (S_{js}) parameters are computed at specific stations to identify suitable locations for granite extraction. The findings of this work suggest that the lower the value of J_v (J_v < 10), the larger the blocks can be extracted. On the other hand, at the high S_{js} values, the width of the extraction block increases. These conditions are typically found in locations far from the main faults where the density of joints is low, and as a result, the distance between joints is higher. The values J_v > 60 indicate a crushed rock mass, and are typically observed in clay-free shear zones. It is recommended that the opening of the working face be avoided in situations near the main faults due to the fragmentation of rocks and denser joint spacing.

1. Introduction

The use of natural stones in various architectural applications has been on the rise. Decorative stones, in particular, are valuable mineral reserves that, if utilized properly, can meet domestic demands, and contribute significantly to non-oil exports. Granite, which constitutes around 50% of the intrusive igneous rocks present in the Earth's solid crust, is abundant and widely used as a decorative stone. In the trade of decorative stones, however, the term granite is used to describe any intrusive, outgoing or metamorphic rock that can be cut, sanded, and polished. The form of the replacement of granite intrusive masses depends on the plasticity of the host rock, which, in turn, depends on the depth of the mass replacement. Infiltration masses replaced at shallow depths are generally associated with numerous annular fractures due to the fragility of the surrounding rocks.

In addition to the visual and mechanical characteristics of the stone, other factors should be taken into consideration to determine the feasibility of exploiting and utilizing granite profitably. Ideally, the extraction of decorative stone from a granite mass should occur in the absence of joints and fractures in the rock mass [1-3]. However, such conditions are rarely found in nature, particularly in regions with high tectonic activity that are prone to numerous fractures due to fault activity and tectonic regime. Joints are the most significant factor involved in producing blocks in building stone mines, and thus tectonic fractures and joints are the crucial geological parameters in ornamental stone quarries. Unlike superficial joints created by

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weathering that have different orientations, tectonic joints follow a particular trend with a proportional distance [2].

The optimal size of granite blocks for extraction depends on the structural parameters that affect the process [4]. A certain level of jointing, indicated by joint density, is required for profitable quarrying [1-3]. Fracturing plays a crucial role in granite exploitation because unsuitable block sizes can limit the extraction process. Although various studies have evaluated block size based on the degree of jointing [5-16], only a few have investigated the impact of joint density on stone exploration [1, 17-25]. As granite quarrying can have a significant environmental impact on the landscape, it is crucial to select quarrying sites carefully to minimize waste generation and prevent damage to the environment [26-29]. Numerical and qualitative indicators, based on the importance of various factors, can be used to determine the appropriate location for granite extraction [1, 3, 25, 30-33].

This work focuses on the investigation of fracturing and jointing in the Kelardasht Divchal granite mine, as these factors significantly affect the production of building stone blocks. Firstly, a fault density map was created to identify the areas that are not suitable for exploitation due to high chances of fracturing. Next, joint sets' distances, strike, and number were measured [34] at specific stations located in low density fault zones. These measurements helped to identify locations with high-quality blocks of proper dimension, which are crucial for profitable extraction. By calculating the volumetric percentage of joints (J_v) and joint set spacing (S_{js}), this study aimed to optimize the extraction of granite blocks with proper dimensions [35]. Extraction can be successful and cost-effective in regions with lower joint density and proper distance between joints.

2. Method

The current systematic and accurate methods for sampling discontinuity parameters include surveyed line and window methods, which are applied to a given area whose width exceeds the size and distance of the discontinuities. In this study, the data was collected using scanline sampling techniques, a reliable technique that involves surveying all traces of discontinuity that intersect the straight scan line over an outcrop. The geometry of the rock mass's discontinuity is characterized by parameters such as the number of discontinuity sets, mean density, local distributions, orientation, size, and spacing/fracture intercept [36]. *n order t*o obtain a comprehensive data sample, at least 200 discontinuities must be attained [37].

The degree of fragmentation in each rock face is calculated based on the effective joints parameter, J_v, which is measured as follows:

$$J_v = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \cdots \tag{1}$$

where S_1, S_2, and S_3 represent the distances between joint sets perpendicular to the strike of the joints [35]. The appropriate size for J_v is considered to be less than 2 in order to extract blocks with suitable dimensions [24, 38]. As the distance between joint sets is measured perpendicular to the strike of the joints, actually, J_v calculates the volumetric percentage of joints within a given length [35]. Higher values of J_v lead to smaller rock mass fragments, while values of $J_v < 10$ can result in single, double, and triple cube blocks. In order to achieve the best results in the shortest amount of time, a quick assessment of the number of joints and fractures in each face is necessary. To accomplish this, the joint set spacing (S_{js}) is calculated according to Equation (2) [39]:

$$S_{js} = \frac{S}{N_{js}} \tag{2}$$

where S represents the mean joint spacing, and N_{js} is the number of joint sets. The value of S_{js} indicates the width of the block that could be extracted. Based on the relationship between the joint set spacing and the volumetric joint count, and considering the threshold of the volumetric joint count mentioned above ($J_v = 2$), the joint set spacing (S_{js}) should be greater than 0.5.

3. Regional geology

3.1. Intrusive masses in region

In Central Alborz, the Paleozoic rocks of the Range contain the Alamkuh (Takht-e-Soliman) group. The Alamkuh granite batholith has formed the peaks of Takht-e-Soliman (4620 m) and Alamkuh (4840 m), with the jagged ridge west of Alamkuh enclosing the glacial circus northwest of Alamkuh. Large uneroded blocks of this granite can be seen in the moraine glacier northeast of Alamkuh (Figure 1). The Akapol quartz-monzonite batholith has been identified southwest of Roodbarak bounded by faults in the west and southeast of Breyer [40]. The eastern sequences of the intrusive batholith are visible in the Mejel valley due to the descending axis of the Akapol dome [41]. Based on the schistosity of Akapol quartz monzonite, it can be inferred that it is older than the granite of Alamkuh [40]. The upper Cretaceous sequence is the youngest metamorphic rock in the northwest of Nater [42]. In the Shekran sheet, tuffs and other associated rocks with the Paleogene age are the youngest deposits altered by the infiltration of Alamkuh granite [43]. Therefore, the age of the intrusive mass is likely Neogene, and possibly Pliocene. To the north of Akapol, between Vendarbon and Breyer, marginal coarse-grained facies (nepheline syenite) have been observed. The darker layer sections of these quartz monzonites in the Naftchal valley are composed of hornblende gabbrodiorite (Figure 2).

The sedimentary deposits found in the Kelardasht plateau are recognized as those of an ancient lake that was formed due to the accumulation of water in the Sardabrood river during the last folding phase. The sedimentary structures observed in the southern Dasht-e Nazir such as the cross-stratification and varve suggest that they were formed from the debris of a deltaic-lake [44].

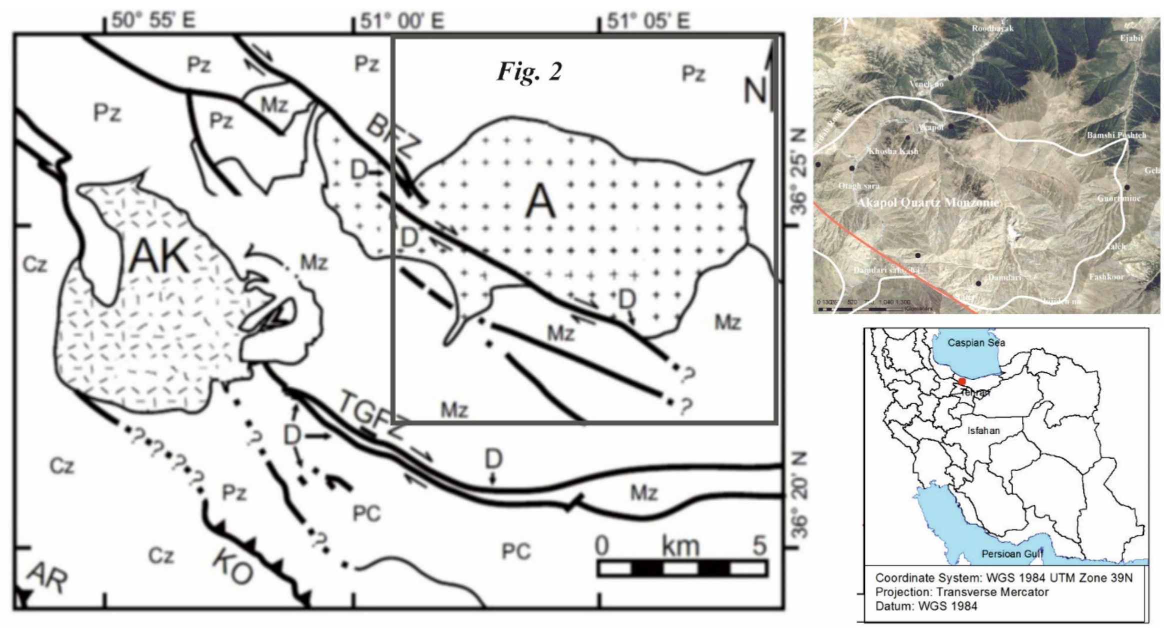

Figure 1. Mine map displays the intrusive mass of Alamkuh and Akapol adapted from Annells *et al*. [43]. Abreviations are A: Akapol quartz-monzonite batholith, AK: Alamkuh granite batholith, BFZ: Bereyer fault zone, TGFZ: Tang-e-Gloo fault zone, KO: Kandovan thrust fualt, D: sense of fault motion, Cz: Cenozoic formations, Mz: Mesozoic formations, Pz: Paleozoic formations, PC: Precamberian formations. The aerial photograph of the Akapol quartz-monzonite batholith and the location of the area are presented at right.

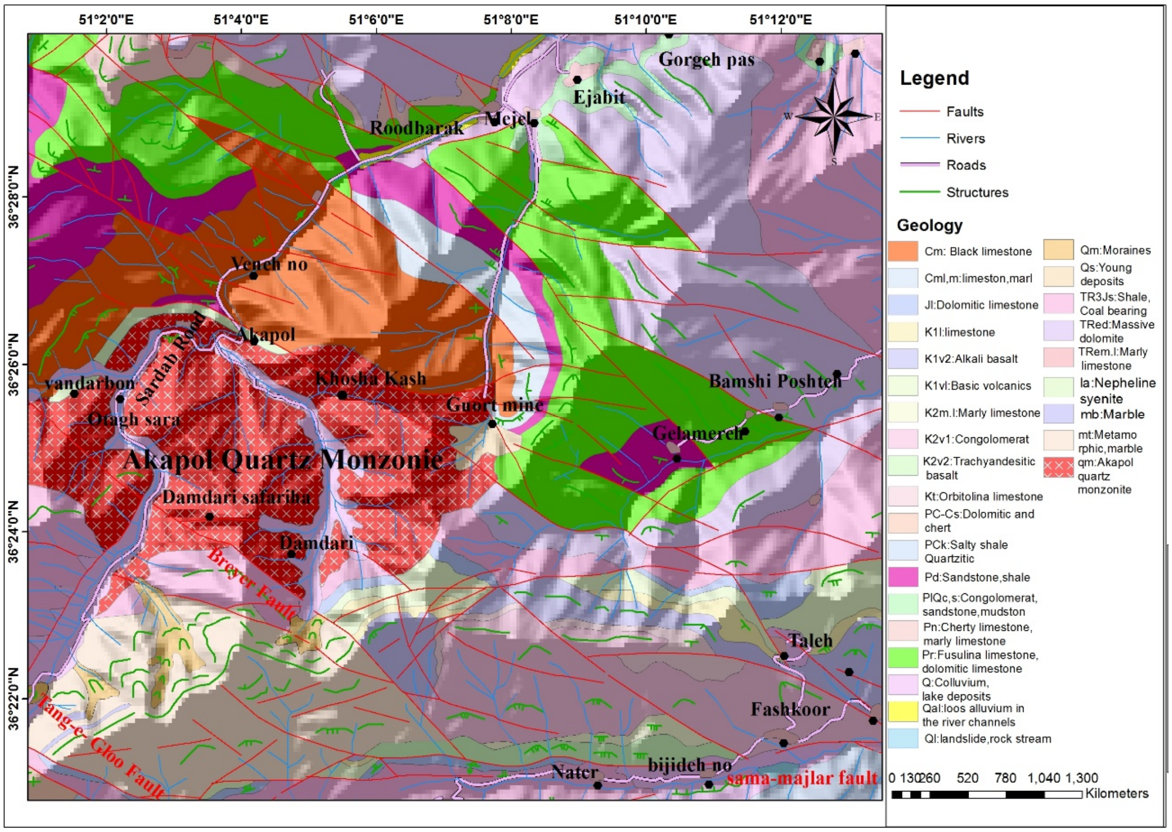

Figure 2. Simplified geological map of the studied area.

3.2. Tectonics

The studied area is geologically situated in the central part of Alborz. The region is characterized by two main faults: the Breyer fault and the Tang-e-Gloo fault. The faults in the Alamkuh area generally have a gentle slope in a flower-structure geometry, indicating a transpressional tectonic regime [42].

The Breyer fault, with a northwest-southeast strike and an estimated length of 20 km, is a right-lateral strike-slip fault that intersects the Akapol batholith (Figure 1). It forms the western boundary of the Akapol batholith and connects with the Tang-e-Gloo fault about four kilometers southeast of the intrusive mass. The Tang-e-Gloo fault, with a NW–SE strike and an approximate length of ~43 km, cuts through the Alamkuh plutonic mass (Figure 1) and extends northwestward [45]. The Tang-e-Gloo and Breyer faults exhibit a right-lateral strike-slip mechanism.

4. Results

The studied area in this research was divided into square cells with dimensions of 500 m using the ArcGIS software (Figure 3). The cell centers that were accessible for surveying were selected as stations for a detailed study to obtain precise results for granite blocking (Figure 4).

Initially, the strike and length of the region's faults were determined using a combination of aerial photographs, geological and tectonic maps, and field observations. Subsequently, a fault density map was created (Figure 5). The mapping of faults and lineaments provides a useful tool for conducting a joint analysis in each part of the mine. Our observations indicate that there is an increase in joint density near the faults.

The length, slope, number, orientation, and vertical distance between joints were measured at the joint study stations, marked as circles in Figure 4. Weathering and erosion contribute to the fragmentation of rock masses and the formation of surface joints [46]. To ensure accurate results, only tectonic joints were surveyed, while sub-joints and fractures caused by erosion and mining activities were ignored [47]. The joint survey began from Roodbarak village, southwest of Hassan Kif, and continued for approximately 13 km until the Khosha Kash valley in Sardabrood. A total of 504 joints including tectonic joints and lineaments were mapped along the navigation path.

At a few stations (numbered 1-10 in Figure 5), penetrative joint sets were observed. At these stations, the joint sets were carefully determined based on their dips and strikes (Figure 6). The distance between joint sets and the number of joint sets were recorded to obtain comprehensive information for subsequent calculations and diagrams. The different geometric characteristics of the joint sets are presented in the rose diagrams shown in Figure 7, which were generated using Polar Plot, an extension for ArcGIS.

The values of J_v and S_{js} in the mine area were calculated using Equations 1 and 2 (Table 1). The amount of rock mass fragmentation in each face was determined by measuring J_v as the effective joints. The values of J_v ranged from 0.03 and 90, indicating significant variation across the mine area. To ensure the accuracy of the results, the parameter S_{js} was also measured. The lowest value of S_{js} observed in the mine area was 0.37 m, while the highest value was 1.92 m.

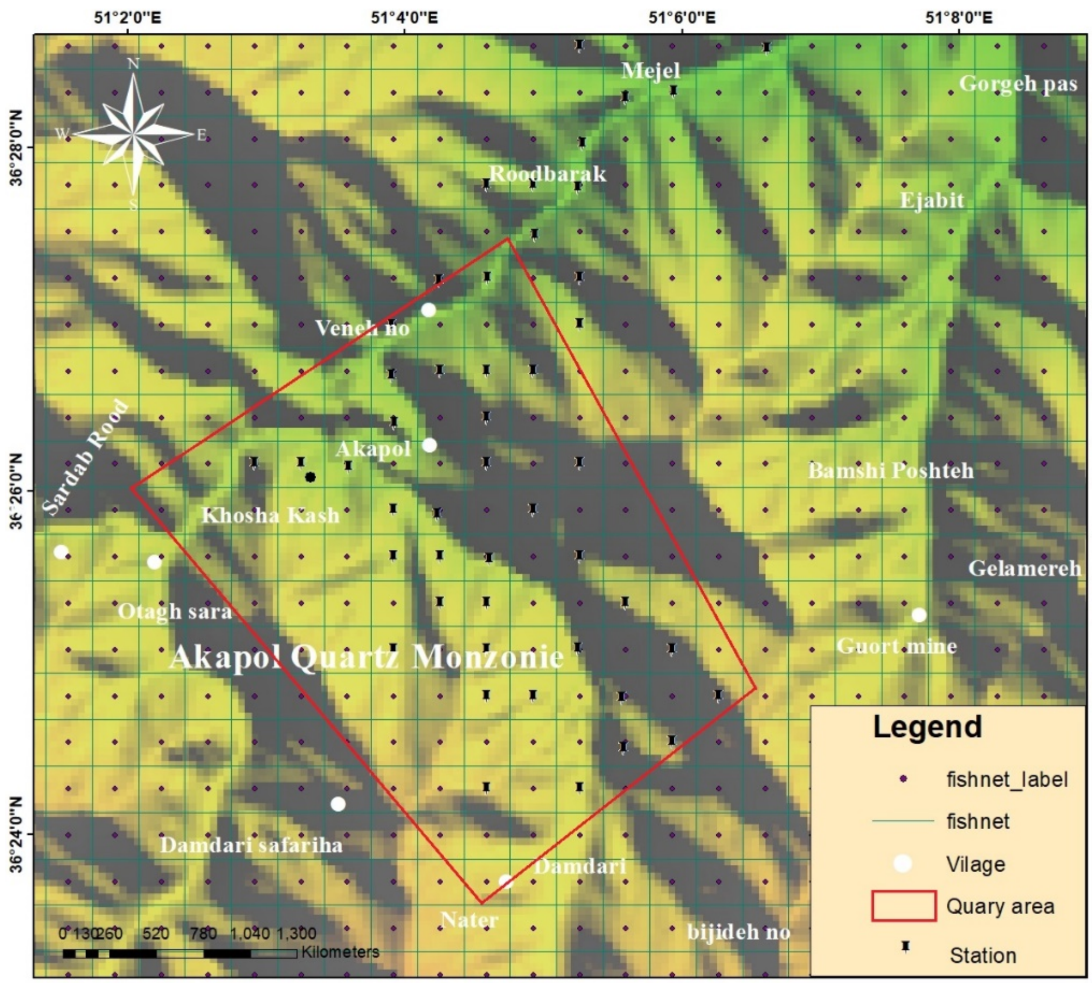

Figure 3. Initial map of mesh centers. The joint study stations in the Divchal mine area are marked as cross-points (circles in the Figure 4). The mine area is depicted as a red quadrangle.

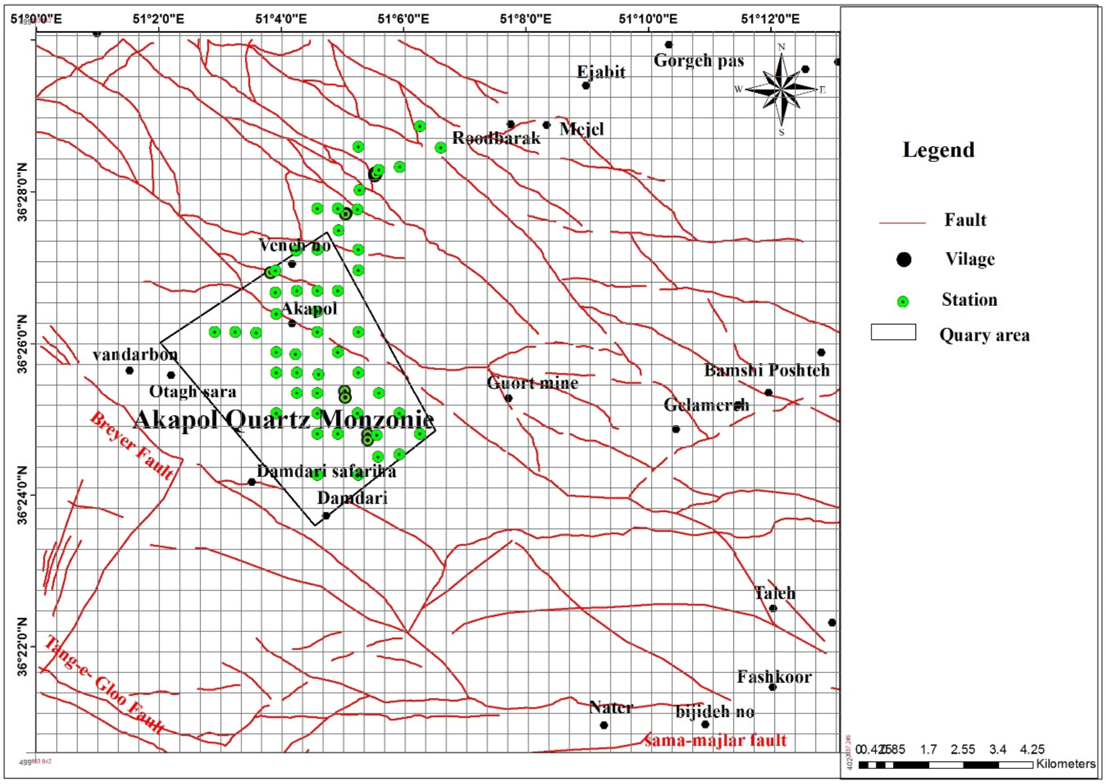

Figure 4. Fault systems and joint study stations in the Divchal mine area. The faults are depicted as red lines, and joint study stations are represented as green circles. The mine area is shown as a black quadrangle.

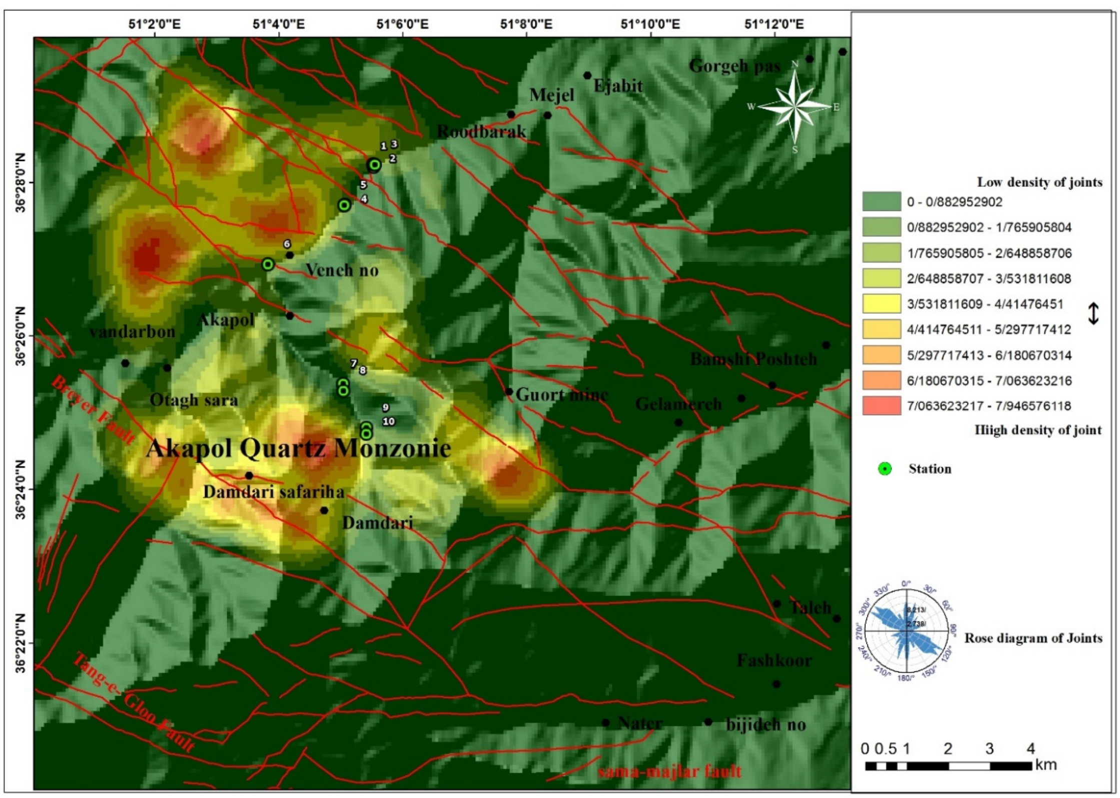

Figure 5. Fault density map of the studied area. The density of faults is represented by color ranking in the main figure, with red areas indicating very high-density regions of faults. Additionally, the rose diagram of the total joint sets is presented in the figure.

Figure 6. Characteristics of joint sets in some stations.

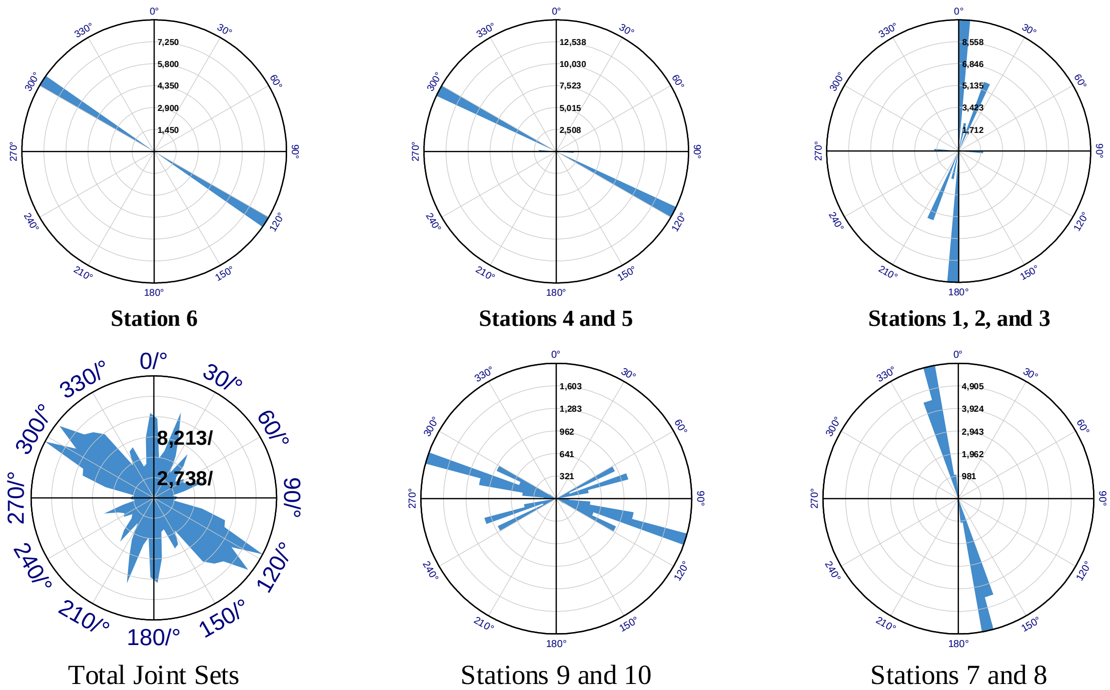

Figure 7. Rose diagrams of the joint sets at various stations.

Table 1. Structural parameters for blocking size at surveying stations in the Divchal Kelardasht mining area.

Stations	Coordinates	Strike of joints	Block size based on S_{js}	Block size based on J_v	J_v
1	Long: 508276 Lat: 4036118	N-S	1.92m	Large pieces	1.87
2	Long: 508280 Lat: 4036122	N-S	0.37m	Very small pieces	90
3	Long: 508286 Lat: 4036130	N-S	0.5m	small pieces	18
4	Long: 507565 Lat: 4035191	NW-SE	3.6m	Very large pieces	0.36
5	Long: 507565 Lat: 4035191	NW-SE	0.75m	Medium pieces	4.99
6	long: 505729 Lat : 4033769	NW-SE	2.1m	large pieces	1.52
7	Long: 507609 Lat: 4030732	N-S	0.51m	Medium pieces	3.25
8	Long: 507551 Lat: 4030718	N-S	0.69m	large pieces	2
9	Long: 508098 Lat: 4029678	E-W	1.65m	Very large pieces	0.03
10	Long: 508098 Lat: 4029678	E-W	1.35m	Very large pieces	0.04

5. Discussion

A total of 504 tectonic joints were surveyed at the stations marked in Figure 4. Sub-joints and fractures resulting from erosion and mining activities were excluded to obtain results solely related to tectonic joints in the area. The predominant strikes of the surveyed joints are N-S and NW-SE. Most of the active faults in the mine region have NW-SE strikes (as shown in Figure 4) that affect the strike of joints near them. This dependence is evident from the rose diagrams plotted in Figure 7. Considering the strikes of joint sets is crucial for optimal locating of the faces and quarrying benches.

Two parameters, denoted as J_v and S_{js}, were determined based on joint studies conducted in several stations labeled 1-10 from the north to the south (Figure 5). The parameter J_v reflects the degree of fragmentation of the rock mass. Stations 2 and 3 showed high values of J_v, indicating that these locations are not suitable for extraction at all. In contrast, station 5 exhibited a larger size of extractable rock mass fragments, as indicated by the value of J_v. Values of J_v less than 1 such as those observed in stations 4, 9, and 10, are very desirable for achieving single, double, or triple cube blocks for the during the extraction process.

The value of S_{js} represents the width of the extractable block from the granite mass. Station 4 exhibited the maximum value of S_{js}, making it a suitable location for producing triple cube blocks that can be cut to appropriate dimensions in a stone-cutting factory. Nevertheless, stations 1, 9, and 10 are also capable of producing single to double blocks.

Integration of the defined values of J_v, and S_{js} with the density map of the faults and lineaments can reveal locations where the density of faults and lineaments is lower and the distance between joints is greater. Such areas may be suitable for opening the face, taking into account other relevant parameters. However, in proximity to major faults, the density of joints tends to increase, which can render the location unsuitable for mining.

6. Conclusions

An essential aspect of quarrying face design is the analysis of joints and fractures in the mining area. The Kelardasht region hosts a building stone mine that holds significant reserves of marble, porcelain, and granite, covering an area of about 600 square kilometers in the southwestern part of Kelardasht plain and the northeastern part of Alamkuh and Takht-e-Soliman highlands in the longitude of 51° 00 to 51° 11´ and latitude 36° 20´ to 36° 30´ [48]. This mine yields a type of rose or pink granite, prized for its unique beauty.

In this study, we investigated the joint characteristics including joint density and structural parameters, in the Kelardasht Divchal granite mine. Our field study revealed that regions close to the main faults exhibited high density and short distances between joint sets, resulting in a high degree of crushed granite mass. In contrast, regions located approximately 1 km away from the faults such as stations 1, 4, 6, 9, and 10, displayed lower joint density and less crushing. Thus identifying the main faults and mapping them can help determine suitable locations for extracting stone blocks of appropriate dimensions. Additionally, rose diagrams of joints can provide information about the strike of joints, which is useful in positioning the quarrying face and benches.

The findings of our study suggest that opening faces in regions where joints are denser and located close to main faults should be avoided. In these areas, rocks tend to be highly fragmented, with tectonic fractures that extend deep into the ground. Attempting to advance and open further steps in such locations to reduce fractures would be time-consuming and costly.

To overcome these challenges, we propose using volumetric joint analysis as an economical solution for quickly identifying suitable faces that yield high-quality, properly dimensioned blocks while also minimizing waste and preserving the environment in the beautiful nature of the Kelardasht region.

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بررسی تأثیر شکستگی‌ها بر استخراج سنگ‌های ساختمانی-مطالعه موردی

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چکیده:

یکی از مهم‌ترین عوامل منفی در بهره برداری از سنگ‌های گرانیتی به عنوان سنگ‌های تزئینی، وجود شکستگی‌های ناهمگن در توده سنگ است. درزه‌ها بسته به ویژگی هایشان می‌توانند در تولید توده‌های گرانیت و معادن سنگ ساختمانی مخرب یا مفید باشند. این مطالعه بر ارزیابی درزه‌های منطقه معدن دیوچال کلاردشت، شمال ایران تمرکز دارد. برای انجام این ارزیابی، ابتدا گسل‌های اصلی از عکس هوایی، نقشه‌های زمین شناسی و زمین ساختی و مشاهدات میدانی به نقشه درآمدند. بر این اساس، نقشه تراکم گسل‌ها برای محدوده مورد مطالعه تهیه شد. مشخصات درزه‌های اصلی شامل طول، شیب، تعداد و جهت در منطقه معدن جمع آوری گردید. در برخی ایستگاه‌ها، پارامترهای درصد حجمی درزه‌ها (J_v) و فاصله سیستم درزه‌ها (S_{js}) جهت شناسایی مکان‌های مناسب برای استخراج گرانیت محاسبه شد. یافته‌های این مطالعه نشان می‌دهد که هر چه مقدار J_v کمتر باشد (J_v<10)، بلوک‌های بزرگتری را می‌توان استخراج کرد. از طرف دیگر، در مقادیر بالای S_{js}، عرض بلوک قابل استخراج افزایش می‌یابد. این شرایط معمولاً در مکان‌هایی دور از گسل‌های اصلی که تراکم درزه‌ها کم و در نتیجه فاصله بین درزه‌ها بیشتر است، دیده می‌شود. مقادیر J_v >60 یک توده سنگ خرد شده را نشان می‌دهد و معمولاً در مناطق برشی عاری از رس مشاهده می‌گردد. توصیه می‌شود در موقعیت‌های نزدیک به گسل‌های اصلی به دلیل قطعه قطعه شدن سنگ،ها و متراکم شدن فاصله درزه‌ها، از باز کردن سینه کار خودداری شود.

کلمات کلیدی: استخراج گرانیت، تراکم درزه‌ها، زمین ساخت، کلاردشت، البرز.