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# Effect of Discontinuity Sets on the Stability of Rock Masses Parallel to Riyaina Mountain Road, Libya

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**ABSTRACT**

Discontinuity sets are critical geological features controlling the mechanical behavior and stability of rock masses. This study investigates their effects on slopes parallel to Riyaina Mountain Road, NW Libya, focusing on the Ain Toby and Yavern Marl members of the Sidi as Said Formation. Field measurements revealed that the Ain Toby Member contains two closely spaced, high-persistence joint sets 0.30–0.75 cm, despite high intact rock strength 50–100 MPa and excellent RQD 99.6 %, intersecting joints produce small, unstable blocks prone to planar and block failures. The Yavern Marl Member exhibits five joint sets with moderate spacing 30–40 cm and persistence 3–10 m, along with fair RQD 62.5%, forming fragmented polyhedral blocks Prone to falling and rolling failures, Overall slope instability is primarily governed by the geometry, density, and orientation of discontinuities.

**Keywords:** AinToby Member, Yavern Marl members, Discontinuity sets, Joint & Fractures, Slope Stability.

# تأثير مجموعات الفواصل على استقرار الكتل الصخرية الموازية لطريق جبل الرياينة، ليبيا

أبوالقـــــاسم الأخضر

قسم الهندسة الجيولوجية، كلية الهندسة جادو، جامعة نالوت، جادو، ليبيا

**ملخـــــص البحـــــث**

تُعد مجموعات الفواصـل من العوامل الجيولوجية الأسـاسـية التي تتحكم في السـلوك الميكانيكي واسـتقرار الكتل الصـخرية. تهدف هذه الدراسـة إلى تحليل تأثير مجموعات الفواصـل على المنحدرات الموازية لطريق جبل الرياينة في شـمال غرب ليبيا مع التركيز على عضـوي عين طُبي وعضـو يفرن مارل ضـمن تكوين سـيدي الصـيد. أظهرت القياسـات الميدانية أن عضـو عين طُبي يحتوي على مجموعتين من الفواصل متقاربتين ذات استمرارية عالية 0.30–0.75 سم. ورغم قوة الصخور السليمة العالية 50–100 **MPa** وقيمة **RQD** الجيدة جدا بنسبة 99.6% فإن الفواصل المتقاطعة أدت لتكوين كتل صـغيرة معرضـة للانهيار؛ في المقابل يظهر عضـو يفرن مارل خمس مجموعات بفواصل متوسطة التباعد 30–40 سم واستمرارية متوسطة 3–10 م مع **RQD** معتدلة 62.5%، مكونة كتل متعددة الأوجه متصدعة ومعرضة لعملية السقوط والدحرجة؛ بشكل عام يتحكم في استقرار المنحدرات هندسة وكثافة الفواصل.

**الكلمات الدالة:** عضو عين طبي، عضو يفرن مارل، مجموعات الفواصل، الفواصل والشقوق.

## 1. INTRODUCTION

The joints and fractures are among the most significant geological factors influencing the behavior and stability of rocks masses in various engineering projects. These joints represent natural planes of weakness formed as a result of multiple geological processes, including tectonic movements and changes in ground stress conditions [1].

Chemical reactions between water and minerals within the rock also contribute to the breakdown of rock masses and the formation of joints. Additionally, human activities such as road construction can alter internal stress distributions, promoting joint formation [2]. Joints and fractures reduce the cohesion between rock components, thereby diminishing the mechanical properties of the rock mass such as shear and tensile strength making it more vulnerable to failure under various loads and environmental conditions [3]. The presence of multiple joint sets leads to the fragmentation of the rock into discrete blocks, which may become unstable or prone to movement and failure [4]. According to reference [5], the interaction of several joint sets increases the likelihood of different types of failures, including planar sliding, wedge failure, and toppling, depending on the orientation, dip angle, and spatial relationship of the joints to the slope face. Furthermore, joints play a critical role in determining the overall strength and stiffness of rock masses, directly affecting slope stability. On rocky slopes, joints act as inherent weaknesses, breaking the rock into smaller units and thereby increasing its susceptibility to [6]. Systematic sets should be distinguished from non-systematic sets when in the field [7]. Table 1 suggested that the number of sets of discontinuities at any particular location could be described in the following manner. Joint types vary and are typically classified based on orientation, spacing, and size. Joints sets, which appear systematically in the rock, often promote failure, while joints or random Fractions contribute to greater variability and unpredictability in rock mass stability [8].

**Table1.** Classification of Discontinuity sets [7].

| |
|---|
| Massive, occasional random joints |
| One discontinuity set |
| One discontinuity set plus random |
| Two discontinuity sets |
| Two discontinuity sets plus random |
| Three discontinuity sets |
| Three discontinuity sets plus random |
| Four or more discontinuity sets |
| Crushed rock, earth-like |

Field observations and site visits revealed the presence of random fractures and cracks in the rock blocks parallel to the mountain road, indicating a weakened state and the potential for collapses of unstable blocks, few studies have examined the combined effect of persistence, spacing, and Jv on slope stability along Riyaina Road. The study aims to examine the nature and classification of joint sets, assess the durability of the rock mass using the Rock Quality Designation (RQD), and categorize the blocks affected by joint sets. Geologically, this area forms part of the stratigraphic framework of the Nafusa Uplift in northwestern Libya. The lithological diversity observed in this uplift reflects a complex depositional history influenced by multiple marine transgressions and regressions, which resulted in the deposition of mixed continental and marine sedimentary rocks within a transitional environment [9], These processes resulted in the accumulation of a variety of sedimentary rocks of both shallow and deep marine as well as continental origin [9]. In the specific study area, the stratigraphic succession culminates in the Upper Cretaceous Qasr Taghrana Fm Figure1.

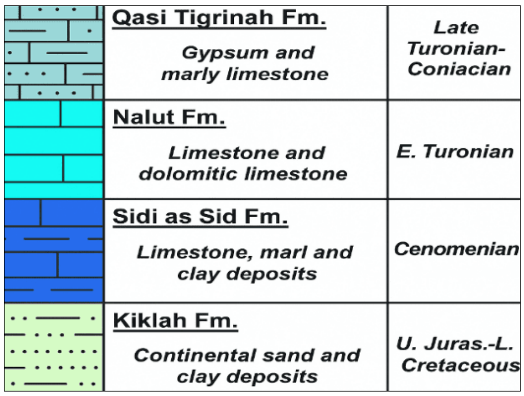


**Fig 1.** Stratigraphic columnar section [10].

The SIDI as SID Formation is composed of members. The upper member, known as the Yavern marl, primarily consists of marly limestone interbedded with layers of dolomite, mudstone, and gypsum. In contrast, the lower member, referred to as the Ain Toby Member, is dominated by dolomitic rocks with crystal sizes ranging from fine to coarse [11].

The Ain Toby Member also contains fossil-rich marly limestone, indicating a Late Cretaceous age [11]. The study area lies along the northern edge of Riyayna Mountain, specifically on the slopes running parallel to the Riyayna mountain road. This road extends northward, connecting to the Aziziya–Nalut road, Figure 2, The slopes within the study area are a popular destination for visitors and are occasionally used for recreational activiti.

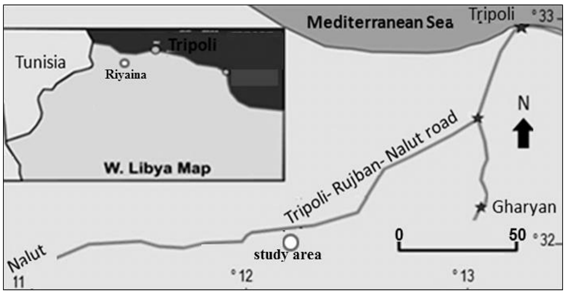


**Fig 2.** Location map of the study area [12].

## 2. MATERIALS AND METHODS

The study primarily relied on fieldwork, which constituted a crucial phase of the research.
For each lithological member (Ain Toby and Yavern Marl), two field stations were established to record joint sets and rock mass characteristics.
Specialized tools were employed, including a geological compass, measuring tape, which constituted a crucial phase of the research. Significantly contributing to the collection of data relevant to the study area. Specialized tools were employed, including a geological compass for measuring the orientation and dip of rock layers and slopes, a geological hammer, a Vernier caliper, and precise measuring scales for determining distances. The analysis also involved examining joint sets through the physical characteristics of fracture surfaces, which are key indicators for evaluating the structure, integrity, and stability of the rocks.

### *2.1 Estimation of intact rock strength*

Field tests were conducted to obtain the engineering properties of both collapsed and intact rock masses. These included manual pressure tests and geological hammer tests to estimate rock strength [13]. The field readings were recorded and compared with the data presented in Table 2.

**Table 2.** Estimation of intact rock strength [13].

| strength MPa | Description |
|---|---|
| **< 1.25** | Crumbles in hand |
| **1.25 – 5** | Thin slabs break easily in hand |
| **5 - 12.5 MPa** | Thin slabs break by heavy hand pressure |
| **12.5 – 50 MPa** | Lumps broken by light hammer blows |
| **50 – 100** | Lumps broken by heavy hammer blows |
| **100 – 200** | Lumps only chip by heavy hammer blows |
| **> 200** | Rocks ring on hammer blows. Sparks fly |

### *2.2 Continuity (Joint Persistence)*

Joint persistence refers to the extent and continuity of a joint surface within the rock mass. The greater the extension of the joint, the weaker the rock mass becomes, increasing the likelihood of failures or fractures in the rock. In this context, Kirsten (1988) [14]. suggested that the trace lengths of joints measured for each joint set can be described as follows Table 3.

**Table 3:** Classification of Joints sets [14].

| Classification | Joints Sets Persistence |
|---|---|
| Very low persistence | Less than 1 m |
| Low persistence | 1 to 3 m |
| Medium persistence | 3 to10 m |
| High persistence | 10 to 20 m |
| Very high persistence | Greater than 20 |

### *2.2 Joint Spacing:*

Joint spacing is a key parameter used to assess the degree of fracturing in a rock mass. It refers to the distance between two consecutive joints that belong to the same joint set. Joint spacing is typically classified based on standard field criteria Table 4, The smaller the joint spacing, the higher the number of joints within a rock mass, which usually indicates a more fractured and less competent rock. The spacing between separators is measured in cm subsequently, the overall spacing of the separators for the detector is calculated using Equation (1) **[15].**

$$Sa = s1 + s2 + s3 + \ldots sn. \qquad (1)$$

**Sa** -The average distance between joints
**S1**-The distance between the first &second Joint
**S2**- The distance between the second &third Joint
**S3**- The distance between the third& forth Joint
**SN**: Joint count per set.

**Table 4**. Descriptive joint spacing [15].

| Intervals (cm) | Description |
|---|---|
| 200< | Extremely widely spaced |
| 200 - 60 | Widely spaced |
| 60 - 20 | Moderately widely spaced |
| 20 - 6 | Closely spaced |
| 6 – 2 | Very closely spaced |
| 2< | Extremely closely spaced |

### *2.3 Separation:*

It refers to the amount of separation of the mass or parts thereof from the original mass. Field measurements obtained from the classification developed by the Geological Society of London (1977) Table 4 [16].

**Table 5.** Classification of separation [16]

| Term | Aperture |
|---|---|
| Wide | >200 mm |
| Moderately wide | 60 – 200 mm |
| Moderately narrow | 20 – 60 mm |
| Narrow | 6 – 20 mm |
| Very narrow | 2 – 6 mm |
| Extremely narrow | 0 – 2 mm |
| **Tight** | **Zero** |

### *2.4 Roughness*:

It means the shape of the slit surface. The description depends on the origin of the surface formation. It includes three original types: smooth surfaces, rough surfaces and very rough surfaces. Other scales that describe the shape of the slit surface branch out of it. The rougher the surfaces, the less the undulations on the surface of the slit, while in soft surfaces there is no cohesion, so the movement is more frequent, especially with the presence of a stimulus for movement such as water [17]. Slit surfaces are classified in Table 6

**Table 6.** Classification of surface shapes [17].

| TERM | Description |
|---|---|
| Very rough | Near vertical steps and ridges occur |
| Rough | Some ridge and side-angle steps are evident; asperities are clearly visible |
| Slightly rough | Asperities on the discontinuity are distinguishable and can be felt. |
| Smooth | Surface appear smooth and feels so to the touch. |
| Polished | Visual evidence of polishing exists, or very smooth surface |
| Slicken sided | Polished and often striated surface that results from friction . |

### *2.5 Block types and jointing characteristics*

Figure 3 illustrates the Effect of Discontinuity sets on the size and geometry of the resulting blocks. Both a small block (min block) and a larger block (max block) can be observed, highlighting the critical role of Joints Sets and their orientations in controlling block size and determining Overall rock mass stability.

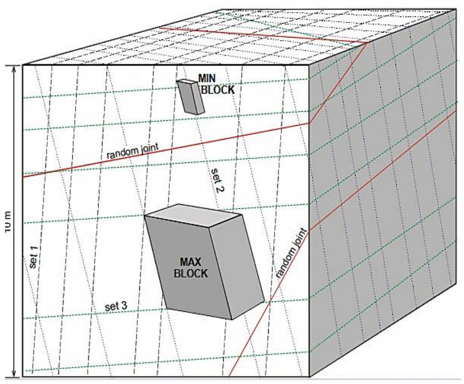


**Fig 3.** Rock Joints sets. Max & Min Blocks1**.**

Table7 shows that the shape of rock blocks is controlled by the number and orientation of joints. Random joints produce multifaceted (polyhedral) blocks, a single parallel set forms plate-like (tabular) blocks, and two or three joint sets generate prismatic or equidimensional blocks. When long inclined or continuous parallel joints are present, rhombic or columnar blocks are formed

**Table 7.** Block types and jointing characteristics.

| Block type | Jointing characteristics |
|---|---|
| Polyhedral | Irregular, small, non-systematic joints |
| Tabular | One dominant parallel set (e.g., bedding) minor non-persistent joints |
| Prismatic | Two dominant orthogonal/parallel sets + one irregular set; thin blocks |
| Equidimensional | Three dominant orthogonal sets + minor irregular joints |
| Rhomboidal | ≥3 oblique joint sets forming equidimensional blocks |
| Columnar | Several (>3) continuous parallel sets; length ≫ other dimensions |

The Joints and their sets contribute to the formation of rock blocks, as shown in Figure 4, which separate from the original rock mass. These blocks vary in shape and size, and their classification is primarily determined by the distance between joints. The stability of the separated blocks and the assessment of their equilibrium depend on field measurements and classifications.

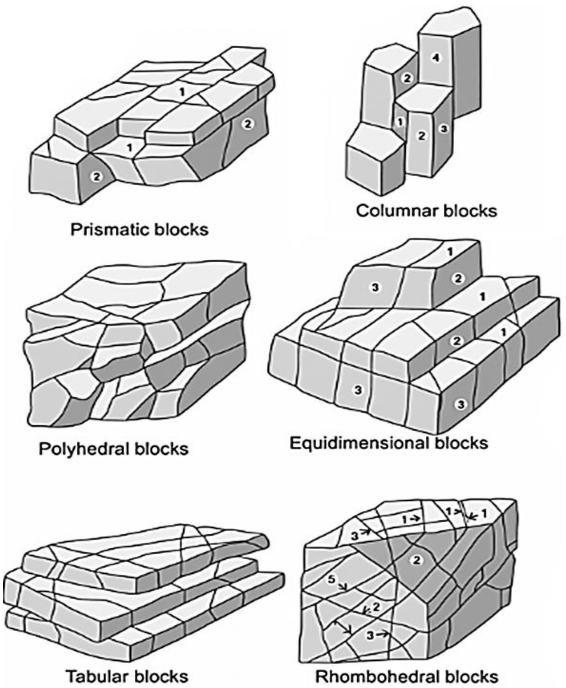


**Fig 4.** Blocks types [18].

### *2.6 Rock Quality Designation*

**(RQD)** is an index used to assess the quality and integrity of rock masses. It Can be measured using methodes such as core drilling, where feasible. However, due to the difficulty of using and transporting the drilling device on the slopes of the study area, RQD was estimated using Equation (2) [18].

$$\mathrm{RQD} = 115 - 3.3(\mathrm{JV}) \ldots\ldots\ldots\ldots..(2)$$

This method was adopted for several reasons. First, the obtained readings and results provide an adequate assessment of the strength of the rock formations. Second, the analysis considers the depth of joints within the rock mass and accounts for the influence of hidden or non-visible cracks, as expressed through the Joints Volumetric (Jv) [19]. The results summarized in Table 8 reflect this parameter, where (Jv) is widely used as an indicator of the expected mechanical behavior of the rock formations. It is calculated as follows:
In the absence of random cracks within the rock mass under consideration, the volumetric joint count (Jv) can be calculated using the following equation:

$$Jv = 1/s1+1/s2+1/s3+.1/sn\ldots\ldots..(3)$$

When random cracks (Nr) are present, the joint volumetric count (Jv) is calculated according toequation (3)

$$\mathrm{JV} = 1/S1 + 1/S2 + 1/S3 + 1/SN\ NR/5\sqrt{A}\ldots(4)$$

**Where**, S1, 2S and S3, are values obtained from Equation (1), A denotes the area of the studied sector, and Nr - random number fractures [19]

**Table 8.** Description of Rock Quality [19].

| RQD % | Descriptive Term |
|---|---|
| 90–100 | Very Good |
| 75–90 | Good |
| 50–75 | Fair |
| 25–50 | Poor |
| <25 | Very Poor |

## 3. RESULTS AND DISCUSSION

### *3.1 Results and Discussion for Ain Tobi Site*

The data presented in Table 9 and Figure 5 reveal the complex geotechnical behavior of the Ain Toby Member.

The results indicate that the intact dolomitic rocks exhibit medium to high compressive strength values (50–100 MPa). The estimation of intact rock strength was onducted on 55 Samples using a geological hammer and manual detection method (Table 1). The samples failed when subjected to heavy hammer blows, indicating a relatively high resistance compared with other sedimentary lithology's.

**Table 9.** Data of Ain Toby Member Site.

| Type Rock | Dolomite |
|---|---|
| Sectional area | 70 $m^2$ |
| Classification of Discontinuity Sets | Two discontinuity sets |
| Classification of surface shapes | Very rough |
| Estimation Of Intact Rock Strength | - MPa 50-100) 55 |
| Random Fractures | 2 |
| Joint Spacing (set1) | 0.75cm |
| Joint Spacing (set 2) | 0.30 cm |
| Descriptive (set 1) | Extremely closely spaced |
| Descriptive (set 2) | |
| Joint Spacing- sa | 0.52cm |
| Joint Volumetric-Jv | 4.6 |
| R Q D | 99.6% Very Good |
| Classification of Joints Sets | Greater than 20 |
| Block type | Polyhedral- |
| Slope Angle | °85-°90 |
| Type of movement | Rock fall |
| Classification of separation | Very narrow |
| separation of (set1) | 40mm |
| Joint Spacing (set 2) | 15 mm |
| separation of (set 1) | Moderately narrow |
| separation of (set 2) | Very narrow |

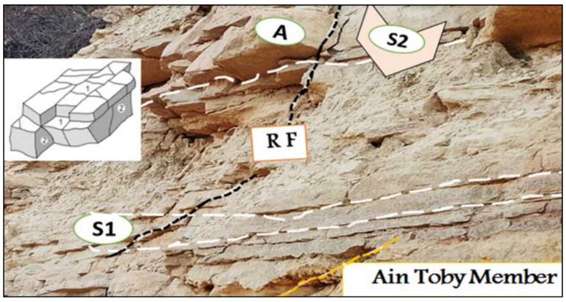


**Fig 5.** A part of the Ain Toby Member.

However, these positive strength indicators do not necessarily translate to high rock mass stability in situ. As shown in Table 9 and Figure 5, two dominant joint sets (S1 and S2), in addition to a random set (RF), were identified, corresponding to the classification provided in Table 1. The joint spacing ranged between 0.30 cm for Set 2 and 0.75 cm for Set 1, which classifies them as extremely closely spaced according to Table 4. This narrow spacing has led to the disintegration of the rock mass into small, discrete blocks.

The average joint spacing was calculated as 0.52 cm, while the volumetric joint density (JV) reached approximately 4.6, reflecting a highly fractured structural condition. The Ain Toby member, the measured RQD value reached approximately 99.6%, indicating a rock mass of fair to good quality. This value reflects the presence of persistent joints with moderate spacing, which contributes to the formation of relatively stable blocks with limited separation potential, Table 8, indicating excellent rock mass quality according to field measurements. Nonetheless, geometric observations (Table 7 Figure 4) revealed that the resulting blocks are predominantly polyhedral–irregular, small, and unsystematic, as clearly illustrated in Figure 6.These forms result from the intersection of multiple joint sets. The surface characteristics were described as very rough, which contributes Moreover, the discontinuity sets display very high persistence (> 20 m) (Table 3), suggesting that large blocks are likely to detach along these continuous planes, particularly along Set2, which is nearly parallel to the slope face Figure 6.

**Table 10.** Data Of Yavern Marl Site.

| Type Rock | Marly limestone-mud stone |
|---|---|
| Sectional area | 70 $m^2$ |
| Classification of Discontinuity Sets | five discontinuity sets |
| Classification of surface shapes | Very rough |
| Estimation Of Intact Rock Strength | ( 25-200) MPa |
| Random Fractures | 5 |
| average Joint Spacing set1,set 2,set3,set 4 | 30 cm Moderately widely spaced |
| Joint Spacing-set 5 | 40 cm Moderately widely spaced |
| Descriptive average Joint Spacing | 35 cm Moderately widely spaced |
| Joint Volumetric-Jv | 15.9 |
| R Q D | 62.53 % Fair |
| Classification of Joints Sets | Medium persistence (3-10 m) |
| Block type | Polyhedral |
| Slope Angle | 65° -90° |
| Type of movement | Rock fall and rolling |
| average separation | 60 – 200 mm |
| Classification of separation | Very narrow |

The slope angles range between 85° and 90°, forming semi-vertical exposures that significantly enhance the potential for planar and block failures, as confirmed by field observations.

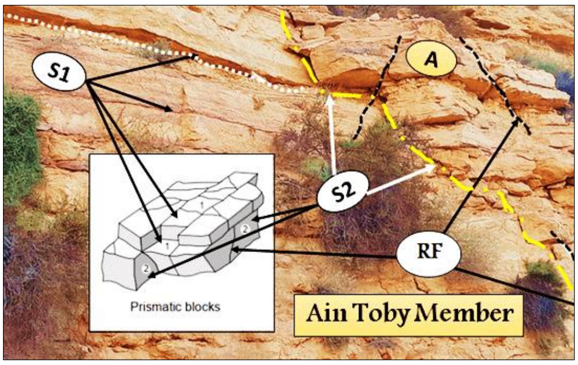


**Fig 6:** Slope Angles and Plane Continuity on slope.

Although the RQD value (99.6%) suggests a very good rock mass quality, the actual field conditions indicate instability due to block fragmentation and potential rock falls. This discrepancy highlights that slope stability in the Ain Toby Member is primarily governed by the geometric configuration of discontinuities their spacing, persistence, and orientation rather than by the intact rock strength itself. Therefore, a comprehensive stability assessment must integrate both numerical indicators (RQD = 99.6%, Jv = 4.6, $\sigma ci$ = 55 MPa) and detailed field observations (Figure 5) to accurately evaluate geomechanical risks and slope behavior. It should be noted that the S2 (set2), which is parallel to the slope, is primarily responsible for the formation of the new slope face. Field studies indicate that the detached rock masses vary in size and are influenced by the intersection of structural systems as well as the presence of random fractures .

### *3.2 Results & Discussion for Yavern marl Site*

The data and measurements listed in Table 10 for the Yavern Marl site, together with Figures 7 and 8, clearly indicate that the rock masses at this site are strongly influenced by the multiplicity and density of discontinuity sets.
The formation consists of marly limestone, clay, and gypsum intercalations, representing medium- to high-strength rocks. Manual field tests using a geological hammer on 55 intact rock samples indicated that the intact rock strength ranges between 25 and 200 MPa (Table 9), suggesting a relatively strong material due to the interbedding of different lithological units. However, the overall structural stability of the slope is mainly governed by the orientation, spacing, and persistence of the joint sets rather than the intrinsic strength of the intact rock. This is evident in Figures 7 and 8, where five main discontinuity sets (s1–s5) intersect to produce polyhedral and irregular blocks that increase the likelihood of block detachment and rolling along the steep slope faces.

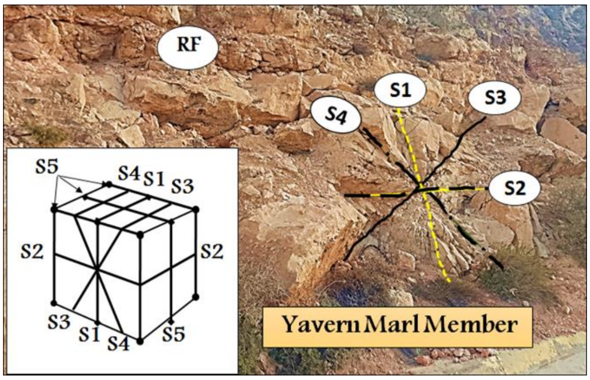


**Fig 7.** Discontinuity Sets in Yavern Marl..

Table 10 shows that the discontinuity sets consist of five main joint sets (s1–s5) and five random fractures Figure 7. The abundance of these discontinuities sets promotes the formation of small to medium-size Polyhedral rock blocksFigure8, which corresponds to the classification in Table 7 and the field observations showing irregular, small, non-systematic blocks. This high degree of structural fragmentation is reflected in the volumetric joint count (Jv = 15.9), indicating a highly jointed and fractured rock mass. The RQD value of 62.53% classifies the rock as fair quality Table 8, confirming that the rock is Moderately fragmented.

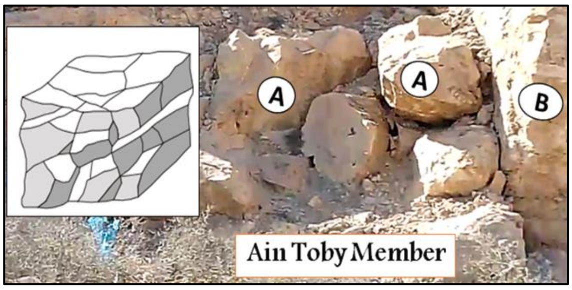


**Fig 8.** Polyhedral Rock Blocks from Discontinuities.

The joint spacing ranges between 30 and 40 cm, with an average of 35 cm and medium persistence (3–10 m), resulting in small, weakly interlocked blocks that are more prone to detachment along the slope Table 3, poorly interlocked blocks of limited stability. These blocks (A), as seen in Figure 8, are prone to mechanical movement dominated by rock fall and Rolling processes. Although the roughness of joint surfaces enhances shear resistance and minimizes the likelihood of large-scale planar or wedge failures, this effect diminishes when blocks are isolated and lose basal or lateral support, leading to toppling or free fall. The recorded joint separations (60–200 mm) are classified as very narrow, Table5 but field observations suggest moderate openings that facilitate water infiltration. This promotes weathering and dissolution, particularly in gypsum-rich zones, ultimately reducing cohesion and long-term stability.

Comparing Figures 7 and 8 reveals that the Yavern Marl Member is characterized by the intersection of five joint sets at high angles, forming small, multifaceted blocks with high fragmentation, while the Ain Toby Member exhibits larger, less regular blocks and a relatively simpler joint network, contributing to slightly higher stability. Overall, the rock mass stability at the Yavern Marl site can be classified as fair to pool Table 8, governed primarily by structural discontinuities rather than intact rock strength. The high joint density (Jv = 15.9), narrow spacing 30–40 cm, collectively control the mechanical response and instability potential of the slope

## 4. CONCLUSIONS

The results of this study demonstrate that the stability of slopes parallel to the Al-Riyayna Mountain Road is primarily governed by the geological engineering characteristics of the Discontinuity sets rather than the strength of the intact rock. Field observations revealed that the Ain Tabi Member contains closely spaced and highly persistent joints, resulting in the formation of small, unstable blocks prone to collapse and fall, despite the rock's high strength and excellent RQD values. In contrast, the Yafran Marl Member exhibits multiple joint sets with moderate spacing and persistence, forming polyhedral blocks susceptible to falling and rolling along steep slopes. Overall, the density, orientation, and persistence of the joints are the key factors controlling slope stability in the study area. Therefore, incorporating detailed joint-set analysis into geotechnical design is essential, particularly for road construction in mountainous regions susceptible to landslides, It is recommended to perform periodic monitoring for block detachment using stereographic projection.

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