University of Zawia Journal of Engineering Sciences and Technology (UZJEST)
Volume 2, Issue 2, (2024), pp 197-207, ISSN 3006-2764

Effect of Fault on the Physical Properties of the Ain Tabi Member: A Case Study of Al-Qwasim Mountain Road Slopes

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Received: 02-05-2024 | Accepted: 10-12-2024 | Available online: 15-12-2024 | DOI:10.26629/uzjest.2024.18

ABSTRACT

In 1983, the slopes of Al-Qwasim (Abu Ghaylan) were excavated to extend the mountain road leading to the Al-Qawasim city which resulted in the exposure of rock formations, including the Ain Tabi rock member characterized by the presence of fractures and joints, as well as a normal fault. The main research problem arose with the primary question: What is the effect of the fault on the stability of Ain Tabi rocks? Another question was whether the fault affects the engineering properties of the fracture and joint surfaces. The objective of answering these questions was to analyze the stability of the Ain Tabi rock slope. To achieve this objective, a field study was conducted, focusing on analysing the physical properties of the fracture and joint surfaces. The results indicated that the location affected by the fault contributed to the weakening of the slope, with a Rock Quality Designation value of 10%, indicating a state of severe weakness in the slope. On the other hand, the RQD value in the unaffected location was 91% and it had two fracture systems (S2, S1), unlike the fault-affected location, which had four systems. The study recommends removing unstable rocks at the location (L-R-A-23).

Keywords: Al-Qwasim Road, Fault, Ain Tobi Member, Joints, fractures, Physical Properties

تأثير الصدع على الخواص الفيزيائية لعضو عين طبي: منحدرات الطريق الجبلي القواسم- دراسة حالة

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ملخـــــــص البحـــــــث

سنة 1983 قطعت منحدرات القواسم (أبو غيلان) لمد مسار الطريق الجبلي المؤدي لمدينة القواسم، مما أدى إلى تكشف التراكيب والتكاوين الصخرية، ومنها صخور عضو عين طبي والتي تميزت بوجود شقوق وفواصل، بالإضافة إلى وجود صدع عادي، وبرزت مشكلة البحث في السؤال الرئيسي: ما تأثير الصدع على استقرار صخور عين طبي؟ وسؤال آخر؛ هل يؤثر الصدع على الخصائص الهندسية لأسطح الشقوق والفواصل؟ وللإجابة على التساؤلات كان الهدف هو تحليل استقرار منحدر صخور عضو طبي ولتحقيق هذا الهدف، تم إجراء دراسة ميدانية، مع التركيز على تحليل الخصائص الفيزيائية لأسطح الشقوق والفواصل، وأظهرت النتائج أن الموقع المتأثر بالصدع ساهم في ضعف المنحدر، إذ بلغت نسبة

متانة الصخر**RQD 10** ٪ مشيرةً إلى حالة ضعف شديد تعتري المنحدر بينما بلغت نسبة متانة الصخر**RQD** في الموقع غير المتأثر بالصدع 91٪ وتتميز بوجود نظامين للفواصل(**S1،S2**) بعكس الموقع المتأثر بالصدع والذي تميز بوجود أربع أنظمة، وتوصي الدراسة بضرورة بإزالة الصخور غير المستقرة في الموقع (**L-R-A-23**).

الكلمات المفتاحية: طريق القواسم، الصدع، عضو عين طبي، الفواصل، الشقوق، الخواص الفيزيائية.

1. Introduction

The shapes and types of slopes vary depending on their locations, causes, and formation conditions, as well as the nature of the materials that constitute them. Some slopes are composed of solid blocks, rock debris, or soil [1]. The materials that make up the slopes can be cohesive or non-cohesive, with non-cohesive materials being less stable on slopes [2] The stability of rock masses and their constituent materials on slopes is determined by their ability to maintain a specific angle known as the angle of stability. This angle represents the maximum slope inclination that ensures the materials and blocks remain stationary. The angle of stability can be influenced by various triggering factors, and rock masses will remain in equilibrium unless there are changes in their engineering Properties [3]. There are catalysts that can cause a change in the angle of stability for slope components as a whole or for parts of them. On the other hand, changes in the engineering properties of rock masses can occur as a result of excavation works used for mountain road construction or artificial blasting by humans [4]. Movement of materials on slope surfaces occurs when the slopes lose their lose stability, due to various factors such as Weathering, Erosion, and Human intervention in the natural environment [5]. There are different types of such movements, where soil or rock creep occurs slowly, while landslides happen rapidly and are less common than movements caused by earthquakes [6]. Rock fall events are considered to be the most dangerous movements because they occur quickly and suddenly, causing significant damage. Climatic conditions play an important role as factors and triggers for material movements on slopes, especially rainfall. Rainfall affects mountain slopes and increases the occurrence of rock fall or sliding [7]. The **i**nternal **c**ohesion of the rock mass is also important for maintaining the stability of rock masses, and Cohesion Weakens over time due to chemical and mechanical weathering factors. The dry-wet cycle is a weathering effect that includes physical and chemical Properties, which has varying degrees of degradation effects on the physical and mechanical properties of rocks [8]. The processes that mechanically disintegrate or chemically decompose rocks are referred to as "mechanical and chemical weathering factors [9]. Temperature variations between day and night cause the expansion and contraction of the minerals that make up rocks, leading to the appearance of fractures and cracks in the rocks [10]. The studied area, represented by the slopes of the abu Ghaylan Area affected by the presence of a fault, is located between the latitudes N32°15'48" and N32°15'44" and the longitudes E13°01'07" and E13°01'14" Figure 1. Geographically, the slope runs parallel to the mountain road connecting the cities of Al Aziza in the north and Al-Qawasim at the top of the mountain in the south-north and Al-Qawasim at the top of the mountain in the south**.**

From a geological perspective, the study area is an integral part of the overall stratigraphic sequence of the Nafusa uplift. The stratigraphic sequence has undergone multiple transgression and regression, respectively. resulting in the deposition of different types of sedimentary rocks. These rocks encompass continental, shallow marine, and deep marine formations, with transitional deposits indicating a transitional environment between the two, Intrusive igneous rocks are also present in the area. [12, 13].

The geological age of the stratigraphic sequence begins in the lower triassic with the kurrush formation Figure 2, and extends until the beginning of the Cenozoic era with the Fm of Zammam [12]. The stratigraphic sequence of the Gharyan area is illustrated in Figure 2. The SIDI AS SID Formation, affected by faults, consists of two distinct members. The upper member called the Yefren Member, is

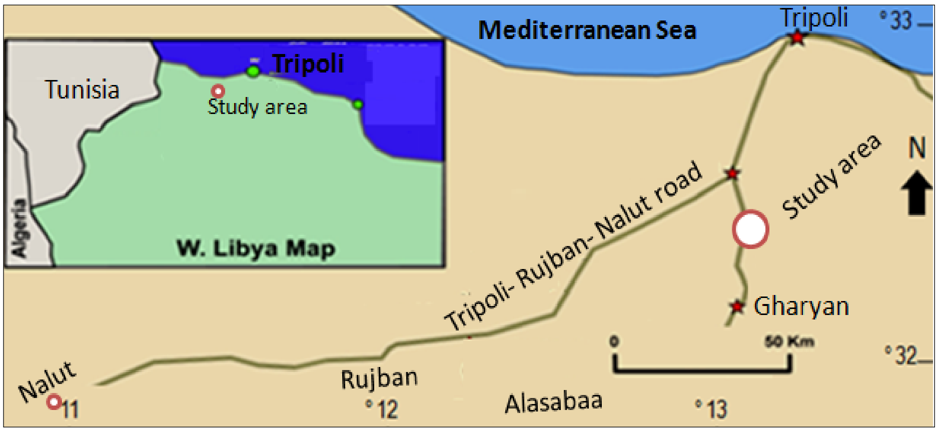

Figure 1. Location of the study area [11]

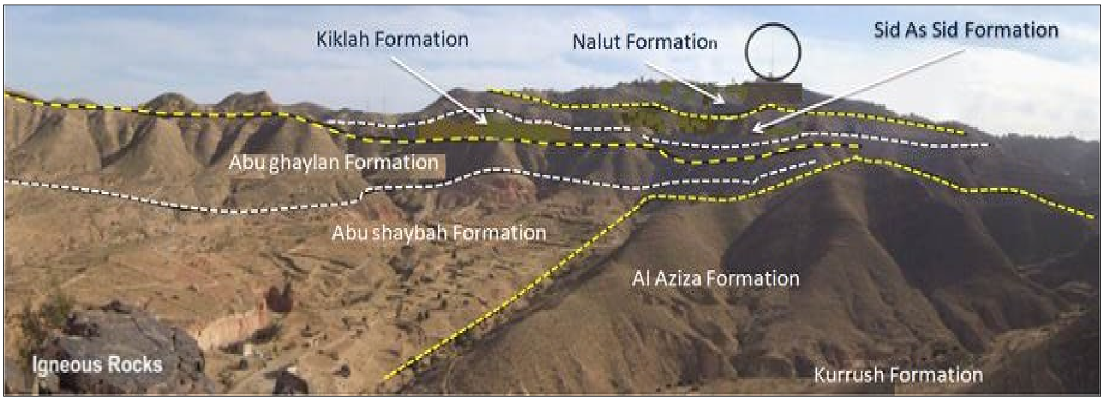

Figure 2: Outcrop formations in the Study Area [12]

primarily composed of marly limestone, 60-80 meters thick, [12,13] with dolomite and interbeds of claystone and gypsum. The lower member, Ain Tobi Member, is 60-70 meters thick and predominantly composed of dolomitic rocks. These rocks exhibit varying crystal sizes, from fine to coarse, and colors ranging from yellow to leaden grey. Thin interbeds of marl are present. The Ain Tobi Member contains fossils indicating a Late Cretaceous age [13]. It has high rock strength, classified as Good to Very Good, due to its composition of Dolostone [14]. The rock composition contributes to increased mechanical weathering, specifically thermal weathering, and reduced chemical weathering activity [15]. According to reference [16], the fault's impact on slope stability varies depending on the nature of the affected rock layer. The fault causes stress concentration and damage to nearby rock masses, while the weak layer leads to stress concentration on the slope above, forming a hazardous sliding zone. Parallel slopes along the Tobi Mountain road have identified a normal fault Figure 3.

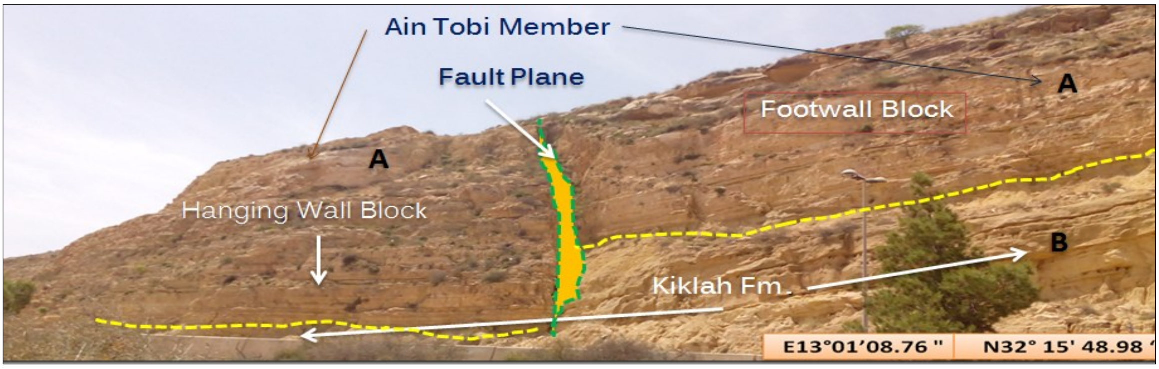

Figure 3: Normal fault at the study area

The exposure of fractures in the Gharyan area is primarily caused by slope-cutting operations during the construction of the Qwasim Mountain Road. These operations have resulted in clear changes in the cut and adjacent rocks, including the presence of numerous random fractures and joints near the fracture. Multiple intersecting fracture systems indicate the weakened nature of the affected outcrop (Road Cut) due to the fault. Instances of collapse within the fracture area have been observed, posing a risk of damage to road users. The objective was to analyze the stability of the Ain Tobi Member outcrop (Road Cut) parallel to the Abu Ghaylan Mountain road, identify influential weathering and exposure factors, and predict common movements by studying the geometric properties of the fractures and joints.

2. Research Methodology

2.1 Stage One

It included gathering information about the research problem and closely familiarizing oneself with the study area by examining relevant books, reports, research papers, and publications to assess their suitability for the research objectives. Preliminary data was then collected from the field through on-site visits, providing support for the research journey.

2.2 Stage Two

Field Study: The field study is the cornerstone for simulating the reality of the slopes. This phase focused on conducting field measurements and carrying out practical descriptive and analytical surveys of the excavated slope. As a result, data and information about the research problem were gathered, and observations were made regarding rock mass weaknesses and anticipated geomorphological hazards. By analyzing field data and evidence, predictions were made about potential occurrences. The field study relied on conducting measurements related to the geometric properties of the rock masses along a 300-meter survey line, which was divided into two sites. The first site represented the slope affected by the fracture, while the second site represented a slope unaffected by the fracture. To evaluate and analyze slope stability and the extent of the fracture's influence on geometric properties, fractures and discontinuities were examined on exposed surfaces. Prominent locations closest to the mountain road were chosen for this purpose. To differentiate this study from previous studies conducted by the researcher, a general code was assigned to the study site (L-R-A-23). This code uses "L" for "location, "R" for "Road," "A" Al-Qwasim" and "23" to represent the year of the study, which is 2023 Figure 2.

2.3 Stage Three

This Stage focused on analyzing and evaluating the stability of rock masses at the two sites (L1-R-A-23) and (L2-R-A-23) by relying on the study of engineering Properties For Discontinuity Surfaces. The key properties included.

2.3.1 Physical Properties for Discontinuity Surfaces (Joints and Fractures)

- **Roughness:** It refers to the shape of the discontinuity surface, and the description depends on the origin of surface formation. There are three primary types of original surface roughness, Smooth surfaces, very rough surfaces, and rough surfaces [17]. Three additional scales have branched out from the three classifications to describe the shape of the discontinuity surface in Table 1. The rougher the surfaces, the lower the cohesion on the discontinuity surface. In the case of smooth surfaces, there is little cohesion, leading to a more frequent occurrence of movement, especially in the presence of collapse triggers.

Table 1: Characterization of the smoothness for discontinuity surfaces [17].

TERM	Description
Very rough	Near vertical steps and ridges occur with interlocking effect on the joint surface.
Rough	Some ridge and side-angle steps are evident; asperities are clearly visible; discontinuity surface feels very abrasive(like sandpaper grade approx.< 30)
Slightly rough	Asperities on the discontinuity surfaces are distinguishable and can be felt.
Smooth	Surface appear smooth and feels so to the touch. (smoother than sandpaper grade approx. 300
Polished	Visual evidence of polishing exists, or very smooth surface
Slicken sided	Polished and often striated surface that results from friction along afault or movement surface.

- **Joint Size and Continuity**: Joint size and continuity have an impact on rock properties. This characteristic allows for differentiation between joints and discontinuities and their influence on the behavior of rock masses. The length of discontinuities can be accurately measured by tracking their extension on the surface and comparing them. In the field, they can be classified into two types: continuous discontinuities that end with other discontinuities, or discontinuous discontinuities that end with large rock masses. Another type of continuity refers to the depth of the discontinuity within the rocks, where the deeper the discontinuity, the weaker the rock becomes [18].

- **Separation**: The term "separation" is used instead of "aperture" to refer to the opening or gap between the surfaces of a discontinuity. It is a measure of the distance or space between the opposing faces of the joint or fracture. The separation can vary in size and has a significant influence on the behavior 4 and properties of rock masses. The field measurements obtained are evaluated using the classification developed by the Geological Society of London (1977) in Table 2 [19].

Table 2: Aperture of discontinuity surfaces **[19]**

Discontinuities	**Aperture (Discontinuities) Thickness (Veins, faults)**
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

- **Infilling materials:** materials between the Joints and Fractures, refer to the substances found within the void spaces. These materials serve one of two purposes: either they contribute to the stability of the rock masses or they play a role in movement. In both cases, the extent of stability or movement depends on the type of materials, their fragmentation, and their size. [20] Refer to Table 3.

Table 3: Main types of filling materials[20]

Type of Filling	**Properties**
Chlorite, talc,	Graphite Very low friction materials, in particular when wet.
Inactive clay materials	Weak, cohesion materials with low friction properties
Swelling clay	Exhibits a very low friction and loss of strength together
Calcite.	May dissolve, particularly when being porous or flaky.
Gypsum	May dissolve

Sandy or silty	Materials Cohesion less, friction materials
Epidote, quartz	May cause healing or welding of the joint

- **Joints Sets No:** It refers to the number of Joint Set No in the rock masses. The more systems there are, the weaker the rock mass. Regardless of whether the Joint Set No is organized or random, it contributes to the weakening of the rock masses.

2.3.2. Mechanical Properties for discontinuity surfaces (Joints-Fractures)

Joints and Fractures in rocks are natural phenomena and are among the most common secondary structures resulting from natural factors. While they may occur individually, they often form in groups and common systems. However, their properties can be measured through the study of physical and mechanical characteristics. The mechanical properties of rock masses can be measured in the field or in the laboratory. In this research, field measurements were relied upon to study the classification of joints and Fractures, as field measurements provide a closer representation of the actual mechanics of rocks.In this research, the (RQD) was calculated at locations (L1-R-A-23) and (L2-R-A-23) to investigate the impact of fractures on the strength of rocks. Additionally, the joints and fractures were classified based on the Joints System

- **Joint Spacing (JS)**:

Refers to the distance, measured in centimetres, within a joint set, in a rock mass. These Joint Set doesn't need to have uniform spacing; they can vary within the same rock mass [21]. Usually, the spacing of joints within a joint SET in igneous rocks is much more than 20 cm and much less than 100 meters in sedimentary rocks. In isotropic rocks (basalt, granite) joint spacing follows an approximately log-normal frequency (the number of joints occurring within a unit length) distribution. In anisotropic (layered, sedimentary) rocks, joint spacing differs according to several parameters such as thickness and lithology. These joints can either run parallel to bedding planes or intersect the primary set at a 90° angle [21]. The joints system is described according to the specifications of the Geological Society of London in Table 4, after measuring the spacing between regular joints along the survey line. Measuring joint spacing is of great importance in evaluating the structure of rock formations, as joints reduce the strength of rocks and can occur in two different patterns.

(i) The first case, if the joints have a single direction or are regular, is calculated using equation (1).

$$Sa = S1 + S2 + S3 + \cdots 1/sn \quad (1)$$

where

Sa = average spacing between joints
S1 = distance between the first and second joint
S2 = distance between the second and third joint.
sn = number of intervals between the joints

(ii) The second case, if three joint systems intersect at different angles, is calculated using equation (2)

$$\mathrm{Sa} = \mathrm{js} = \mathrm{set1} + \mathrm{set2} + \mathrm{set3}/3 \quad (2)$$

where

Set1 first joint system spacing is calculated using equation 1.
Set2 second joint system spacing is calculated using equation 1.
Set3 third joint system spacing is calculated using equation 1.

Table 4: Descriptive terms for joint spacing [22]

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

Through field measurements along a 200-meter scan line and applying Equation 2, the spacing systems at the fault-affected location (L1-R-A-23) had an average measured value (JS) of 45 cm, described as "Moderately widely spaced" according to Table 4. In contrast, at the fault-unaffected location (L2-R-A-23), the average distance between spacing systems (JS) was 220 cm, described as "Extremely widely spaced" according to Table 4. Field evidence confirms that distant locations from the fault were not affected, with only two observed joint systems (S1, S2). Generalizations about the same rock formation cannot be made as JS values differ across locations

• **Rock Quality Designation:** (RQD) is a measure of the rock mass strength and is commonly used in tunneling and road excavation projects. It is determined by taking field measurements based on core samples. The equation (3) was developed by ***Deere et al***. in 1967 as a means to quantify the rock mass strength during excavation processes [23].

$$RQD = \frac{\sum \text{Lengthofcorepieces} > 10\text{cm}}{\text{Totallengthofcorerun}} \times 100 \quad (3)$$

The obtained results from Table 5 are described, and in this study, Equation 4 is utilized taking into account several considerations. These considerations include that the readings and results provide a comprehensive and sufficient description of rock mass strength. Additionally, the results take into consideration the depth of the joints within the rock mass.

$$RQD = 115 - 3.3(JV) \quad (4)$$

where JV represents the total number of joints per unit length for all joint sets. This property is characterized by measuring the number of joints in the field and within the area of the studied sector. The obtained results from Table 5 are described to provide a general description of RQD [24].

Table 5: Descriptive terms for RQD[24]

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

(Jv) serves as an indicator of the potential behavior of Rock masses, as the size of the blocks, shear strength, and internal characteristics contribute to determining the mechanical performance of the rock mass [24]. The value of (Jv) is calculated using two methods:

The first method - is applied when there are 1, 2, or more joint systems. In this case, Eq 5 are used.

$$JV = 1/S1 + 1/S2 + 1/S3 + \cdots 1/SN \quad (5)$$

Where (S1, S2, S3) Represents the average spacing between joints in each respective **Set**.

The second method - is applied when there are multiple joints systems along with the presence of Random Fractures (Nr). It is recommended to input the number of (Nr) and the area of the sector (A). Equation (6) is then applied in this case [24].

$$JV = \frac{1}{S1} + \frac{1}{S2} + \frac{1}{S3} + .1/sn + Nr/5\sqrt{A} \quad (6)$$

To study the Rock Quality Designation (RQD) of the slope affected by the fault at (L1-R-T-23), Equation 2 and Equation 6 for Random Fracture frequency were used. The cross-sectional area showed approximately 450 affected Random Fractures. Measurements were taken along a 200-meter survey line with a sector area of 200 m2. Applying Equation 4, the average RQD value was found to be 10%, indicating "Very Poor" quality according to Table 6. At (L2-R-T-23), equations 2, 4, and 5 were utilized. Through mathematical analysis, the average RQD was determined to be 91%, indicating "Very Good" quality. It is important to note that no Random Fractures were observed in the slope. The impact and interactions between these characteristics will be discussed in the Results and Discussion.

3. Results and Discussion

3.1 The results obtained from the location study .(L1-R-T-23)

Figure 4 illustrates the presence of joint systems and the dispersion of random fractures, with a total of 450 random fractures recorded in Table 6, indicating the effect of mechanical weathering. The research confirms that the presence of these joints and fractures is attributed to the effect of the fault, which directly affected the site's rocks, in addition to considering the blasting operations as a factor weakening the slope. In Figure 4 which represents a section of the slope affected by the fault and also represents the Hanging Wall Block of the fault affected by movement, four joint systems (S1, S2, S3, S4) were observed intersecting at various angles ranging from 45° to 120°. This explains the separation of rock masses at sharp angles, with some rock masses collapsing beneath the slope. The abundance of fracture systems greatly contributed to the weakening of the slope. It is important to mention the presence of a fifth system (S5), which parallels the slope face. This system is responsible for the separation of slope rocks from the original mass, and the abundance of fracture systems also contributed to the separation of rock masses of different sizes, as shown in Figure 4. The roughness of the fracture surfaces, classified as 'Very rough' according to Table 6, played a significant role in maintaining the separated rock masses on the slope, as it increased friction.

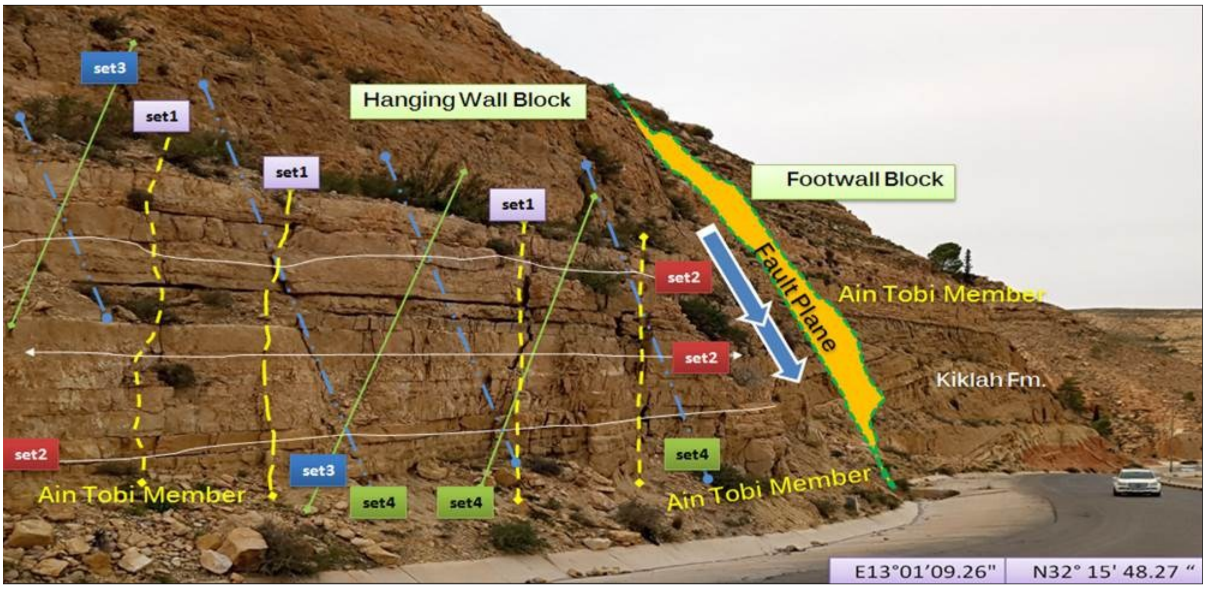

Figure 4: slope affected by the fault (L1-R-A-23).

Based on the study of the engineering properties of Joint-Fracture, as well as the mathematical analysis in Table 6, the separation was classified as "Moderately narrow" with a value ranging from 60 to 200 mm. The joint spacing system, with a value of 45 cm indicated a generally "Widely spaced" distribution of fractures. This contributed to the overall classification and determination of the exposed rock mass strength, with a Rock Quality Designation value of 10 %. This indicates a weak condition of the rock mass. The study confirms that the observed collapses are mainly of the rock fall and toppling types, occurring in specific locations. This is attributed to the influence of the s5 fracture system and the slope's intersecting angle, which ranges from 90° to 85°. The joint spacing system, with a value of 45 cm indicated a generally "Widely spaced" distribution of fractures. This contributed to the overall classification and determination of the exposed rock mass strength, with a Rock Quality Designation (RQD) value of 10 %. This indicates a weak condition of the rock mass. The study confirms that the observed collapses are mainly of the rock fall and toppling types.

Table 6. Data and Measurements Obtained from location (L1-R-A-23).

Sectional area	200 m* height 1m = 200 m^2	Continuity	65cm
random fractures	450	Infilling materials	and Carbonate Mud
jv	31.9	Slope Angle	˚85-˚90
Sa	45cm	Type of Movement	Rock fill and
1/sa	0.02	R Q D	%10
Type Rock	Dolomite - Carbonate	Joint Spacing -Js	cm45Widely spaced -
Type Roughness	Very rough	Separation	60 – 200 mm - Very narrow

3.2 The results Obtained from the Location of Study (L2-R-A-23) .

Figure 5 shows the slope unaffected by the fault. We also notice that the rocks of the slope have been cut regularly, the slope is characterized by the presence of only two joints sets intersect at an of 90°.

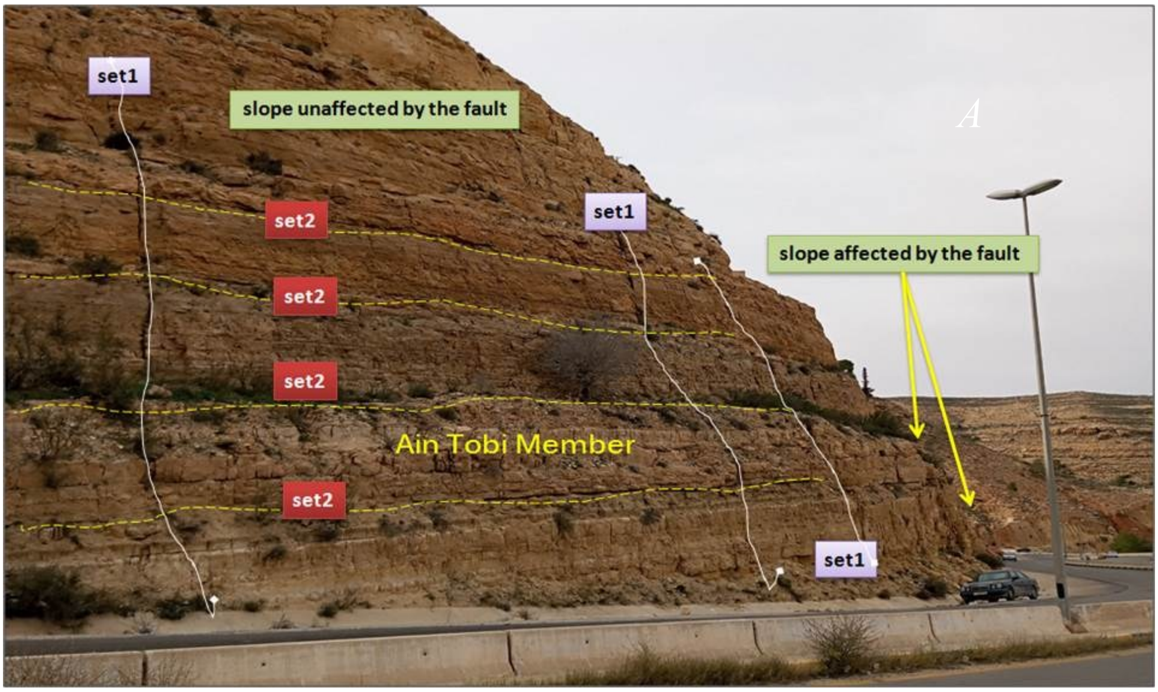

Figure 5: slope unaffected by the fault (L2-R-A-23)

The joint spacing between the joints and their consecutive counterparts within the same system shows significant variation, with an average overall spacing (Sa) of approximately 13.7 m along a 200 m scan line. Further observations indicate that the joint spacing values range between 2 and 6 mm, classifying them as 'Moderately narrow' according to Table 8. This suggests the stability of the slope, which is enhanced by the absence of any infill material within the joints. Moreover, the joint surfaces are characterized as 'Very rough".

Table 8. Data and Measurements Obtained from location (L2-R-A-23).

Sectional area	200 m* height 1m = 200 m ^{2}	Continuity	20cm
Jv.... 1/sa	7.27	Infilling materials	//
Sa	0.1376 cm – 13.7m	Slope Angle	˚85-˚90
Type Rock	Dolomite - Carbonate	Type of Movement	//
Type Roughness	Very rough	R Q D	91% Very Good
Separation	2 – 6 mm - oderately narrow	Joint Spacing (Js	Widely spaced - 45 cm

4. Conclusions

The mountain road of Abu Ghaylanis one of the important roads in the Western Mountains. Its rocks were cut in 1983 to extend the road's pathway, which exposed various rocks, including dolomite rocks representing the Ain Tabi member. The slope rocks were affected by a normal fracture, causing a vertical displacement of about 7 meters. The fracture contributed to a weakened state at the site (L1-R-A-23), altering and weakening the geometric characteristics of the fissure and joint surfaces, particularly the Rock Quality Designation values. A comparison with the unaffected slope rocks (L2-R-A-23) showed higher RQD values. The study confirms that the slope is in a severely weakened state, with its rocks prone to collapse. The anticipated movement is rock falling and toppling. The study recommends the removal of the rocks at risk of collapse at the fault site, along with the placement of warning signs for passersby, especially geology students approaching the area.

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