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Slope Stability Analysis Some Selected Sites at Bajalia Anticline in Missan Governorate, Eastern Iraq

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Abstract
In this study, rock stability has been assessed to pinpoint the critical factors affecting slope instability. The discontinuity data collected during the field surveys was evaluated using stereograph projection. Bai Hassan, Mukdadiya, and Injana Formations that were exposed in the research region show slope collapses, ranging in severity from most to least in terms of secondary toppling and rock fall. The characteristics of the rock discontinuities determine the kind and extent of hazards. According to this study, warning signs and fencing should be used to prevent people from walking along the edges of the slopes in the Bajalia anticline and the areas around to alert them of potential failure threats.

Keywords: stability of rock, collapse types, Mukdadiya Formation.

تحليل استقراريه المنحدرات الصخرية لطية البجلية المحدبة – شرق العراق: دراسة حالة

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الخلاصة
تم تقييم ثبات الصخر في هذه الدراسة لتحديد أهم المتغيرات التي تؤثر على عدم استقرار المنحدر. تم استخدام الإسقاط الفراغي المجسم لتقييم بيانات الانقطاعات الصخرية التي تم قياسها خلال المسوحات الميدانية. التكاوين الصخرية باي حسن، والمقدادية وإنجانة والتي تتكشف في منطقة البحث ، مما يدل على وجود انهيارات للمنحدرات تتراوح في شدتها من الأكثر إلى الأقل من حيث الانقلاب الثانوي والسقوط الصخري . تحدد خصائص الانقطاعات الصخرية نوع ومدى المخاطر. وفقًا لهذه الدراسة ، يجب استخدام علامات التحذير والسياج لمنع الأشخاص من التحرك والانتقال على طول حواف المنحدرات وفي المناطق المحيطة لتنبيههم من خطورة الانهيار المحتملة الحدوث.

1. Introduction

In the Al-Teeb region close to the Iraqi-Iranian border, the Bajalia Anticline is situated around 60 km northeast of Amarah City. The Bajalia Anticline's rock slope stability was investigated. Bajalia Anticline is non-cylindrical, asymmetrical, close, sub-horizontal, steeply

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sloped, and linear in form, measuring roughly 29 km in length and 5-7 km in width[1]. The anticline between the Arabian and Iranian plates originated due to a significant reverse fault positioned at the edge of the southwest limb parallel fold axis and measures about 25 km in length during the late tertiary. Failure of slope is a geologic phenomenon whereby rock masses in a slope move downward due to gravity. The rock mass can cause the slope to be stable when it is at its strongest anything that periodically disturbs the rock mass will eventually cause it to collapse and slide down the slope [2][3][4]. Rockslides include both rock falls and landslides. Systems of categorization updated it [5][6]. The first phrase is the kind of rock. The stability of rock slopes is assessed using a detailed understanding of geology and engineering geology, with cuts in the slope's face. The most important components are the discontinuity characteristics of rock masses. The second is called a fall or slide. Engineering aspects of the rock masses that are impacted by the degree and kind of dangers include the height of the rock slope, the weathering of the rocks, the characteristics of the rock discontinuities, the size of the water reservoir pit, and the presence of water[7].

1.1 Objective

According to the field study, one of the major goals of this research is to evaluate how unstable the cut faces of clastic rocks are. All forms of rock fragments and falls are collectively referred to as rock fall. Fieldwork was done to determine the engineering and geological characteristics of the clastic rock present in the Injana, Mukdadiya, and Bai Hassan Formations, as well as the causes of the unstable rock slopes. The most important of them are listed below:

1. Investigating and analyzing the factors contributing to unstable rock slopes in the Injana, Mukdadiya, and Bai Hassan Formations.
2. Gathering information from the formations includes the types of failures, direction, and dip angle of the discontinuities.

2. Location of the study area

The Bajalia Anticline is located about 60 km northeast of Amarah City on the Iranian-Iraqi border in the Al-Teeb region Figure (1). Three formations, the Injana, Mukdadiya, and Bai Hassan exposed in the regions of the low fold zone.

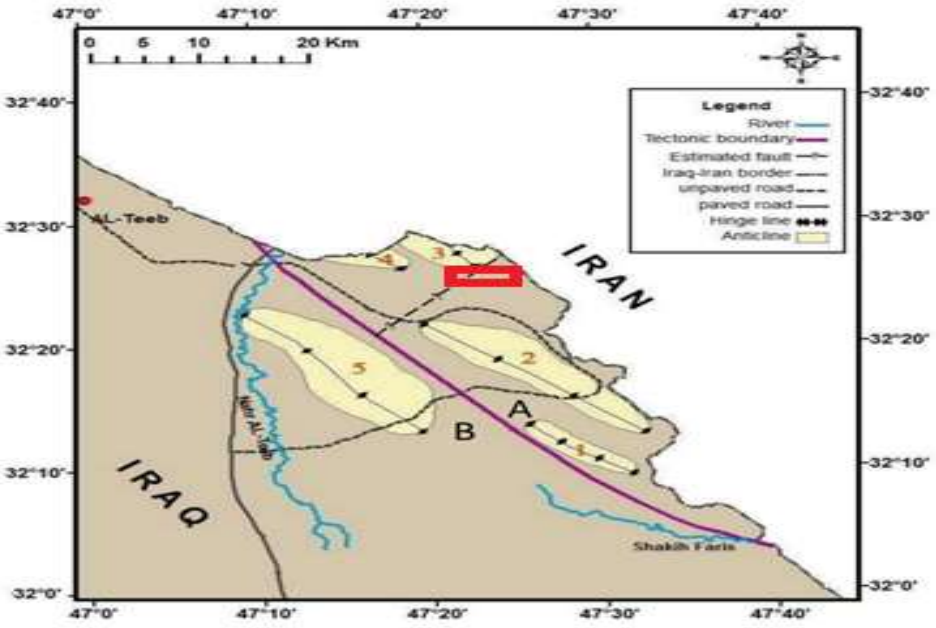


Figure 1: Location of the study area [1].

3. Previous studies

Several studies hint at additional aspects despite the various geological investigations that have been carried out in the research location, such as:

The Iraq Geological Survey suggested that Mukdadiya and Bai Hassan Formations are exposed[8] [9] [10]. Other researchers suggested that only the Injana and Mukdadiya Formations were exposed, and Bai Hassan Formation was not recognized [11].

4. Geology of the Study Area:

Three formations were recognized from oldest to youngest:

-Injana Formation(Late Miocene)

It is exposed in the core of the Bajalia anticline, and the formation is composed of claystone, sandstone, and siltstone sequences.

- Mukdadiya Formation(Late Miocene-Pliocene)

It is exposed on the limbs of the Bajalia anticline. The formation is composed of some clastic deposits, including sandstone, siltstone, and a quantity of gravel.

-Bai Hassan Formation (Pliocene-Pleistocene)

Mixed boulders, conglomerates, pebbles with a sand matrix represent it.

5. Tectonic and Structural Setting:

Asserts that the tectonic collision between the Iranian and Arabian plates [12], which started in the late Tertiary (Eocene-Recent), is what caused the Bajalia anticline [13]. The tectonic deformation in Iraq has shifted from the convergence line to the southwest Figure(2).The Bajalia Anticline has a longitudinal structure of approximately 29 km long and 5-7 km wide. It is a non-cylindrical, asymmetrical, close, sub-horizontal, steeply inclined, linear fold, the dip angle of northeastern flank 40 and southwestern flank 85.

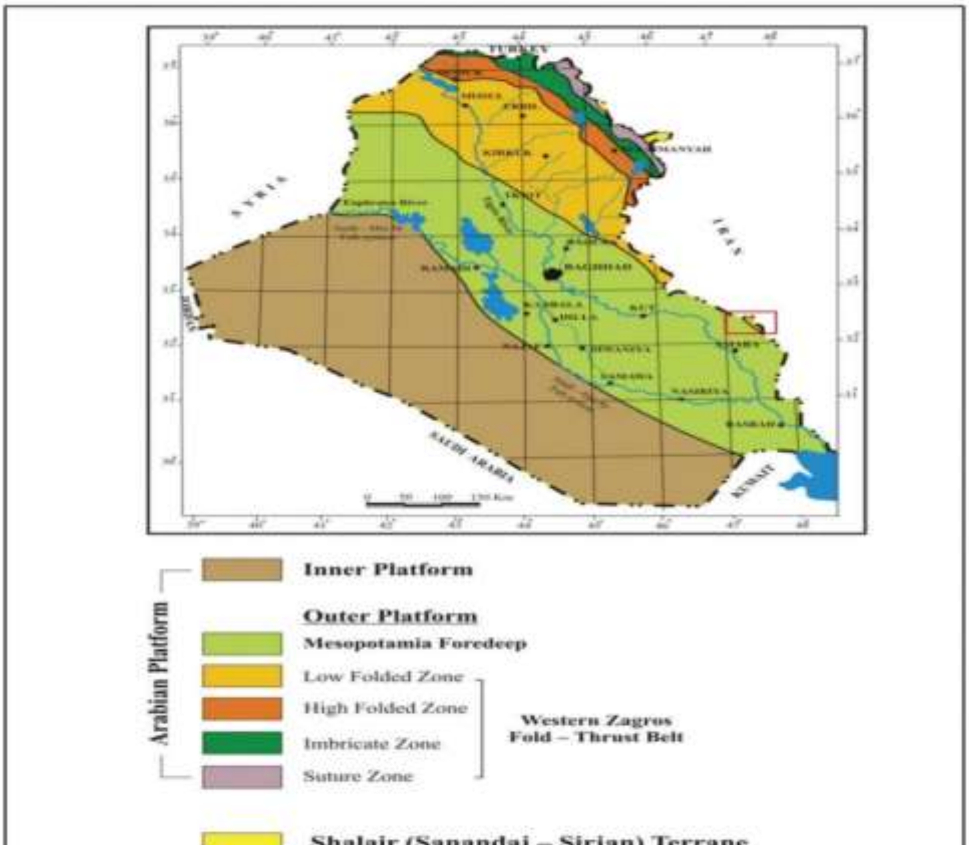


Figure 2: Tectonic division of Iraq shows the study location[14]

6. Climate of the study area

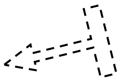
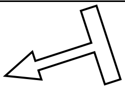
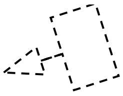
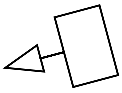
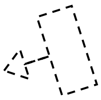
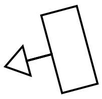
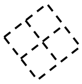
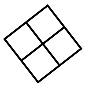
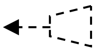
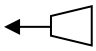
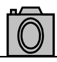
The research location has a hot, dry summer and a cold winter. Long, hot, dry summers, cold winters with a wide range of temperature fluctuations from day to night and limited precipitation are characteristics of the study region's climate. The different climatic elements greatly impact the physical and chemical properties of natural resources and how they are utilized. Soil and sediment are affected in addition to climate influences.

7. Rock Slope Stability Analysis:

Four stations that represented the outcrops and slopes of the Mukdadiya Formation were investigated to ascertain the rock slopes' stability and their engineering studied. By using the relationship between the number of blows and the manual pressure for the geological hammer, the unconfined compressive strength was calculated[15][16] [17] [18]. The slopes of the Mukdadiya Formation are subject to various failures, including rock fall, toppling, and localized disintegration that is immediately followed by rolling.

Tables (1) use the following symbols to indicate field data according to[19].

Table 1: Failure types, slope analysis, and photo direction

Types of failure	Symbol	
	Possible	**Present**
Toppling		
Rockfall		
Plane sliding		
Granular disintegration		
Rolling		
Slumping		
Photo direction		

8. Fieldwork

To assemble information on the engineering properties of rock types and rock masses. The term geological hammer pressure testing is simple. It was applied to calculate the strength of rocks, as indicated in Table 2. A hammer was used to test the rock samples that had weathered the discontinuities. Several assessments of the rock's exposure strength were typically required. Sometimes, averages of more than three values were used. The study area's stations were chosen to create tourist resorts for the geopark.

Table 2: Estimation of the strength of rock [20]

Intact rock strength	Description
< 1.25 MPa	Crumbles in hand
1.25 – 5 MPa	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 MPa	Lumps broken by heavy hammer blows.
100 – 200 MPa	Lumps only chip by heavy hammer blows.
> 200 MPa	Rocks ring on hammer blows. Sparks fly.

8.1 Station 1:

This station may be located at latitude (32° 20' 5'' N) and longitude (47° 25' 10'' E) in the Mukdadiya Formation (plate 1). The slope measures 5 meters high and 8 meters long. The slopes at an angle of 290/88. The average dip layer is (300/85°). A one-meter-thick layer is exposed at the slope's crest. Light gray, massively bedded, and extensively jointed SANDSTONE Strong (c = 30 MPa). The underlying rock strata are 4 m thick at the lower slope. They are SANDSTONE, a light gray, thickly bedded, thick jointed. They have a moderately strong (c = 20 MPa).

(ac) and (bc) two sets of discontinuities intersected the layers of sandstone (Figure 3). The spacing of (ac) 1.5–2.0 m extends along the bedding plane to 4 m, (0.15 m) open up. The distance between discontinuities in(bc) is typically between 1 -1.5 m, extending along the bedding plane to 3.5 m, 0.1 m open up. Rock block failure has occurred by rockfall or secondary toppling.

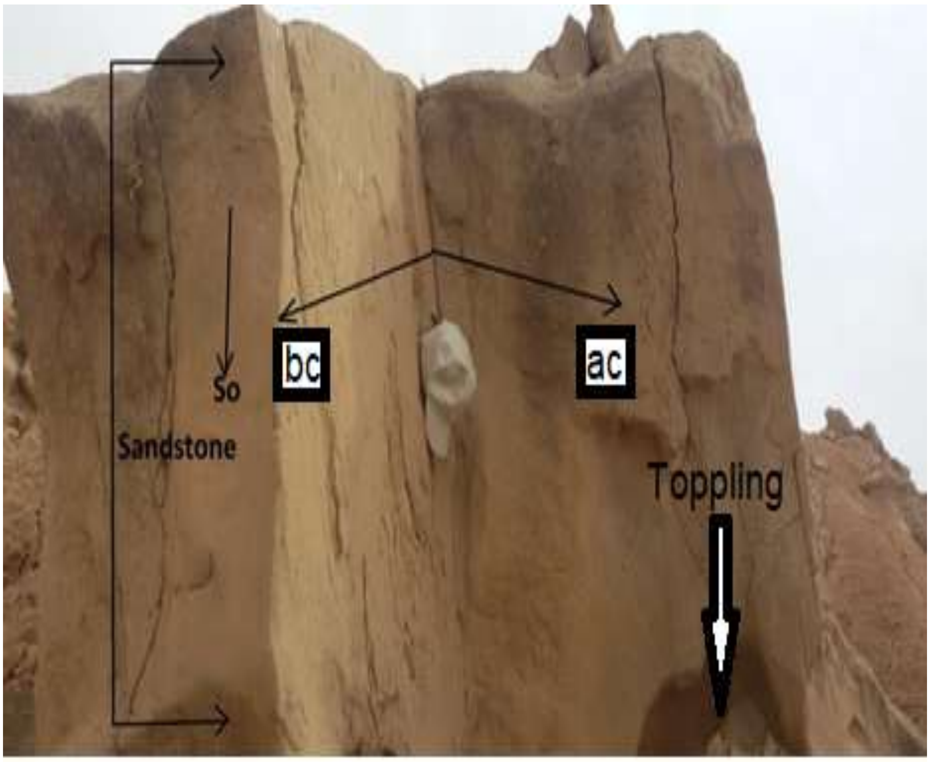


Plate1: Slope and discontinuities of S(1), southwest as the photo's orientation.

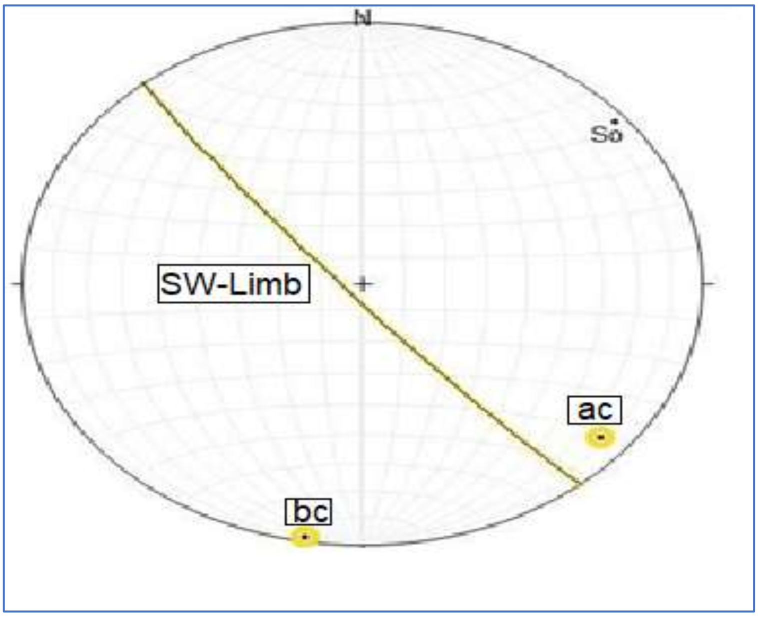


Figure 3: Slope and failure Stereogram of S (1)

8.2 Station 2:

This station may be located in latitude (32° 20' 5" N) and longitude (47° 25' 25" E) in the Mukdadiya Formation (plate 2). The slope measures 6 meters high and 12 meters long. The slope is at an angle of 320/86. The average dip layer is (285/85°). A three-meter-thick layer is exposed at the slope's crest. Pale green, massively bedded, and extensively jointed SANDSTONE Strong (c = 28 MPa). The underlying rock strata are 2 m thick at the lower slope. They are SANDSTONE, a light gray, thickly bedded, widely jointed. They have a moderately strong (c = 26 MPa), with 1 m thick, pale grayish SILTSTONE (c = 20 MPa). Two sets of discontinuities in (ac) and (bc), intersected the layers of sandstone. (Figure 4). The spacing between discontinuities in (ac) is between 0.8 - 1.4 m. They persist up to 3 m along the bedding plane and open up to 0.12 meters. The distance between discontinuities in (bc) is typically between 1 -2.5 m, extending along the bedding plane to 2.8 m, 0.15 m open up. Rock block failure has occurred by rockfall or secondary toppling.

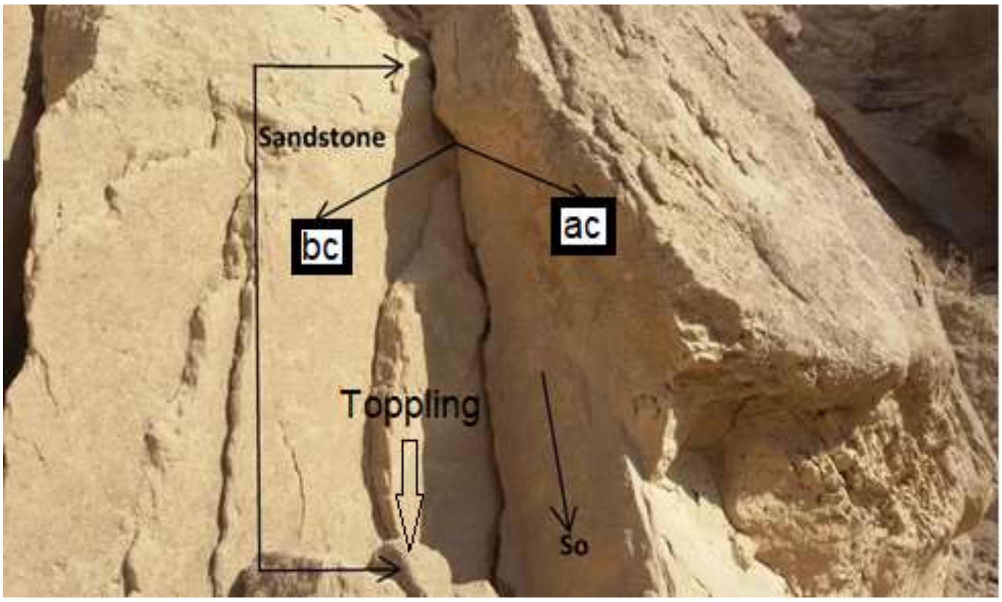


Plate 2: The slope and discontinuities of S(2), photo direction SW

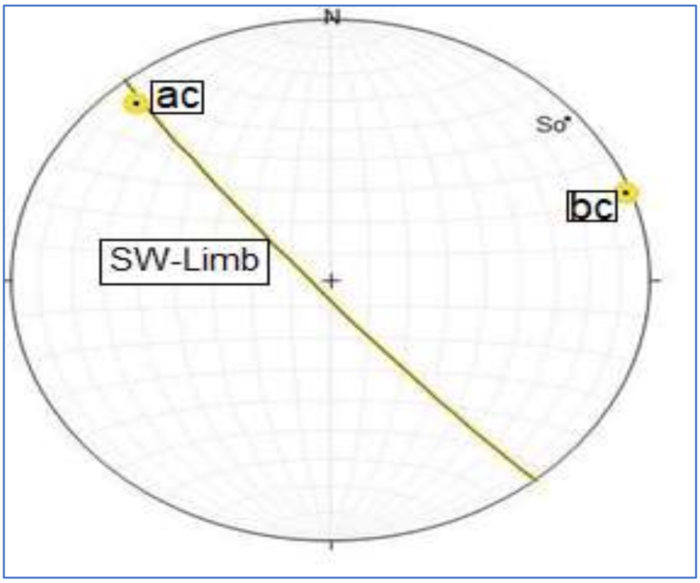


Figure 4: Slope and failure Stereogram of S (2)

8.3 Station.3:

This station may be located at latitude (32° 20' 5" N) and longitude (47° 25' 35" E) in the Mukdadiya Formation (plate 3). The slope measures 3 m high and 8 m long. The slope is at an angle of 250/88°. The average dip layer is (285/85°). The one-meter-thick layer is exposed at the slope's crest. Light green, massively bedded, and widely jointed SANDSTONE moderately strong (c = 26 MPa). The underlying rock strata are 1 m thick at the lower slope. They are SANDSTONE, a light grayish, thickly bedded, widely jointed. They have a moderately strong (c = 21 MPa). Two sets of discontinuities in (hkl) and (bc)), intersected the layers of sandstone. (Figure 5). The spacing between discontinuities in (hkl) is between 1.7-2.3 m. They persist up to 0.6 meters along the bedding plane and open up to 0.17 m. The distance between discontinuities in (bc) is typically between 0.8 -1.3 m, extending along the bedding plane to 1.4 m, 0.01 m open up. The rock mass will fail in the future by rockfall.

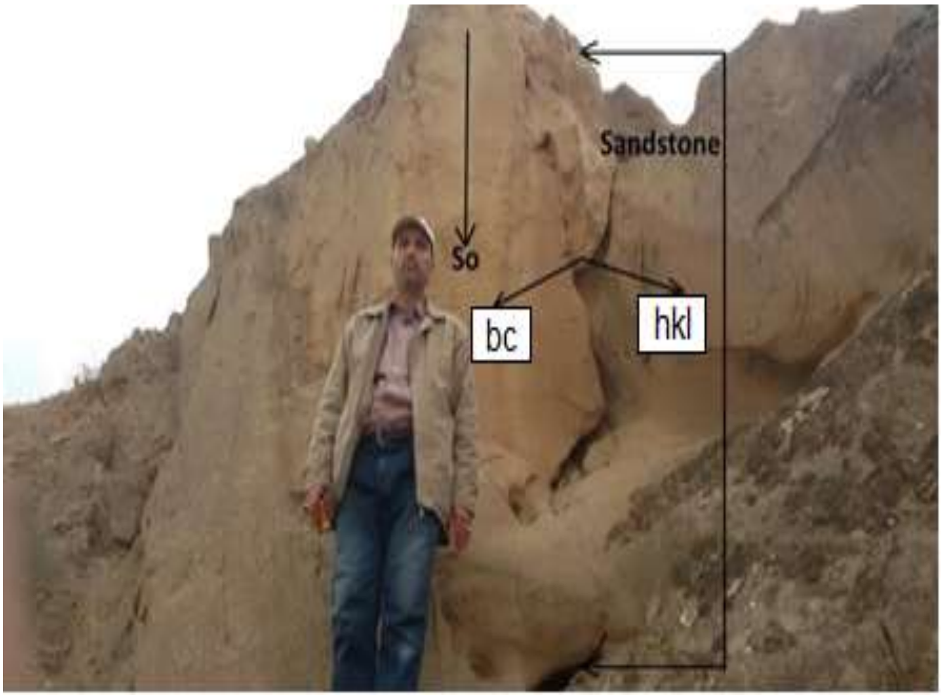


Plate 3: The slope and discontinuities of S(3), photo direction SW

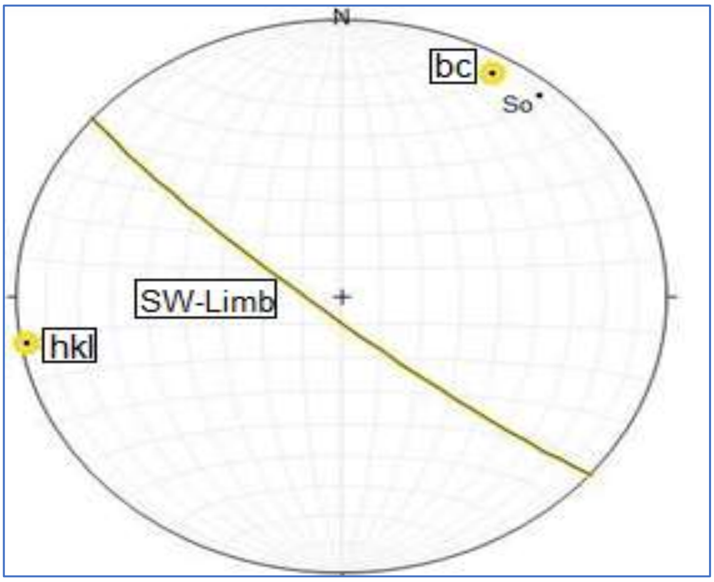


Figure 5: Slope and failure Stereogram of S (3)

8.4 Station 4:

This station may be located at latitude (32° 20' 5" N) and longitude (47° 25' 50" E) in the Mukdadiya Formation (plate 4). The slope measures 2 meters high and 8 meters long. The slope at an angle of 240/88°. The average dip layer is (285/85°). The one-meter-thick layer is exposed at the slope's crest. Light green, massively bedded, and widely jointed sandstone moderately strong (c = 25 MPa). The underlying rock strata are 1 m thick at the lower of the slope. They are sandstones, a light greyish, thickly bedded, widely jointed. They have a moderately strong (c = 20 MPa). Two sets of discontinuities in (bc) and (hol)) intersected as conjugate the layers of sandstone. (Figure 6). The spacing between discontinuities in (bc) is between 1.5 and 2.2 m persisting up to 0.8 meters along the bedding plane, opening up to 0.16 meters. The distance between discontinuities in (hol) is typically between 0.5 -1.0 m, extend along the bedding plane to 1.2 m, 0.01 m open up. The rock mass will fail in future by secondary toppling due to the intersection of (vein1 and vein2).

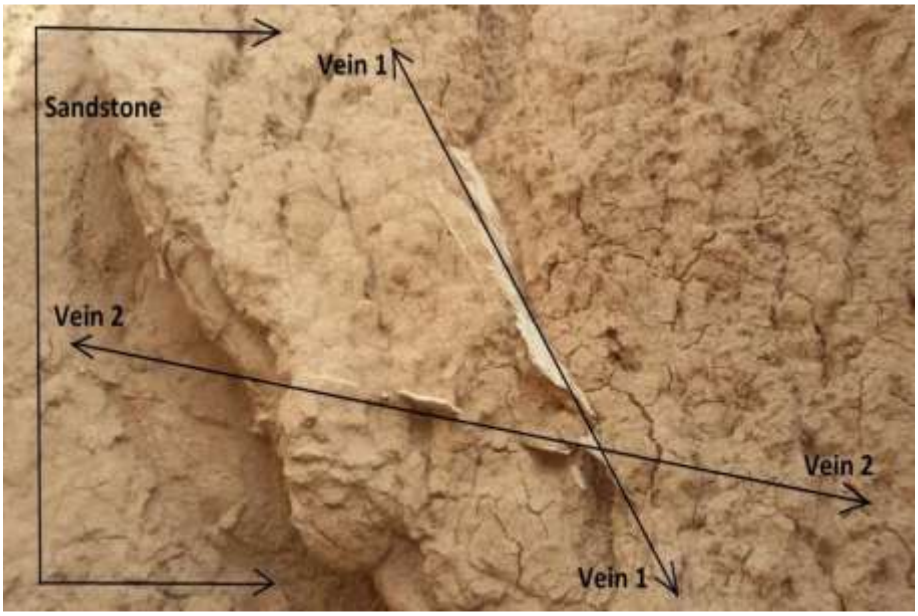


Plate 4: The slope and discontinuities of S(4), photo direction SW

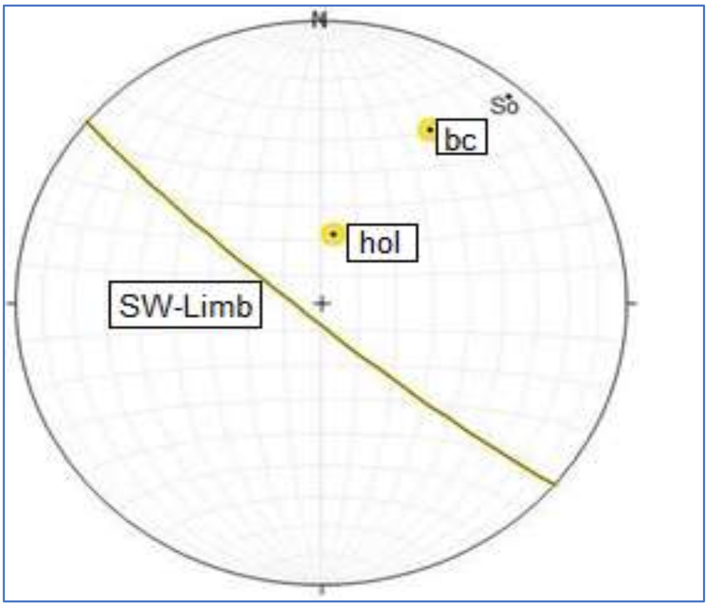


Figure 6: Slope and failure Stereogram of S (4)

9. Conclusions

1. The features of the rock discontinuities, slope height, and rock weathering behaviour are the main determinants of the kind and severity of the slope failure risk in the research location. This type of failure will happen in future secondary toppling and rock fall.
2- The phenomenon of cut faces and rock mass discontinuities should be taken into account for structural position-controlled failures.
3- The relationship between the joint surface and the main tectonic axis of the anticline served as the basis for the categorization and assessment of joints. It was evident from the significance of ac, bc, and hol, especially stations S1 and S4.

10. Recommendations

1. Removing unstable rock from the slope face, especially stations S1 and S2
2. Applying binders to the slopes lower at the toe, such as cement, rock bolts, and chemical sodium silicates. especially stations S1 and S4
3- Use cautionary signs to warn people of potential failure dangers near and on the slopes of the Bajalia anticline for all study stations.

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