

## **Rock slope Stability Assessment for Rock Cliffs at Tar Al-Sayyed Area (Karbala Governorate\ Middle of Iraq)**

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### **ABSTRACT**

Tar Al-Sayyed area (a tourist area), locates in the west of Karbala Governorate- Middle of Iraq, it is characterized by a rock cliff with abundance of naturally-forming caves locally known as Al-Tar caves. Field studies revealed the abundance of rock slope failures, the dominant types are rock fall, secondary toppling, and local disintegration followed almost by rolling.

Slope stability assessment was carried out by stereographic projection. Secondary toppling mechanisms (generally due to the effects of differential weathering and \ or erosion, and undercutting) include multidirectional toppling, tension crack toppling and toppling & slumping mechanisms. Some treatment measures are proposed to stabilize the slopes and protect the visitors in the area.

### **الخلاصة**

تعتبر منطقة طار السيد منطقة سياحية وتقع في الجزء الغربي من محافظة كربلاء المقدسة -وسط العراق، تمتاز المنطقة بجرف صخري مع العديد من الكهوف المعروفة محليا بكهوف الطار. اظهرت الدراسات الحقلية وفرة الانهيارات الصخرية والانواع الشائعة هي السقوط الصخري، الانقلاب الثانوي والتكسر الموقعي تتبعهم في الغالب دحرجة. تم تقييم استقرارية المنحدرات بواسطة الاسقاط المجسم. الانقلاب الثانوي يحدث نتيجة وجود نشاط طبيعي في المنطقة (متمثل بالتجوية والتعرية التفاضلية والحت السفلي) يشمل الانقلاب متعدد الاتجاهات وانقلاب الشق الشدي والانقلاب والانزلاج. تم اقتراح بعض الاجراءات العلاجية لتثبيت المنحدرات وحماية الزوار في المنطقة.

### **1-Introduction:**

**1-1 Location of the Study Area:** The study area lies in the west of Karbala Governorate- Middle of Iraq (Fig.1-a&b). It lies (30) km west of Karbala city along rock cliff, locally known as Tar Al-Sayyed.

**1-2 Aims of the Study:** The aims of this study are to:

- 1- Make slope stability assessment at seven sites in the rock cliffs at Tar Al-Sayyed and to determine the modes of failures and the unstable hazardous sites, and to find the roles of different discontinuity sets during slope failure.
- 2- Propose some treatment measures to stabilize the rock slopes in the area and protect the visitors.

**1-3 Methodology:** Stages of research involved:-

- 1- Data collection stage in which maps and references about the study area have been collected.
- 2- Field work stage where the slopes and discontinuities were surveyed and rock samples were collected, rocks are described in engineering geological terms <sup>(1,2)</sup>.
- 3- Laboratory work stage in which the compressive strength of the rock samples at failure sites was found indirectly by point load test.

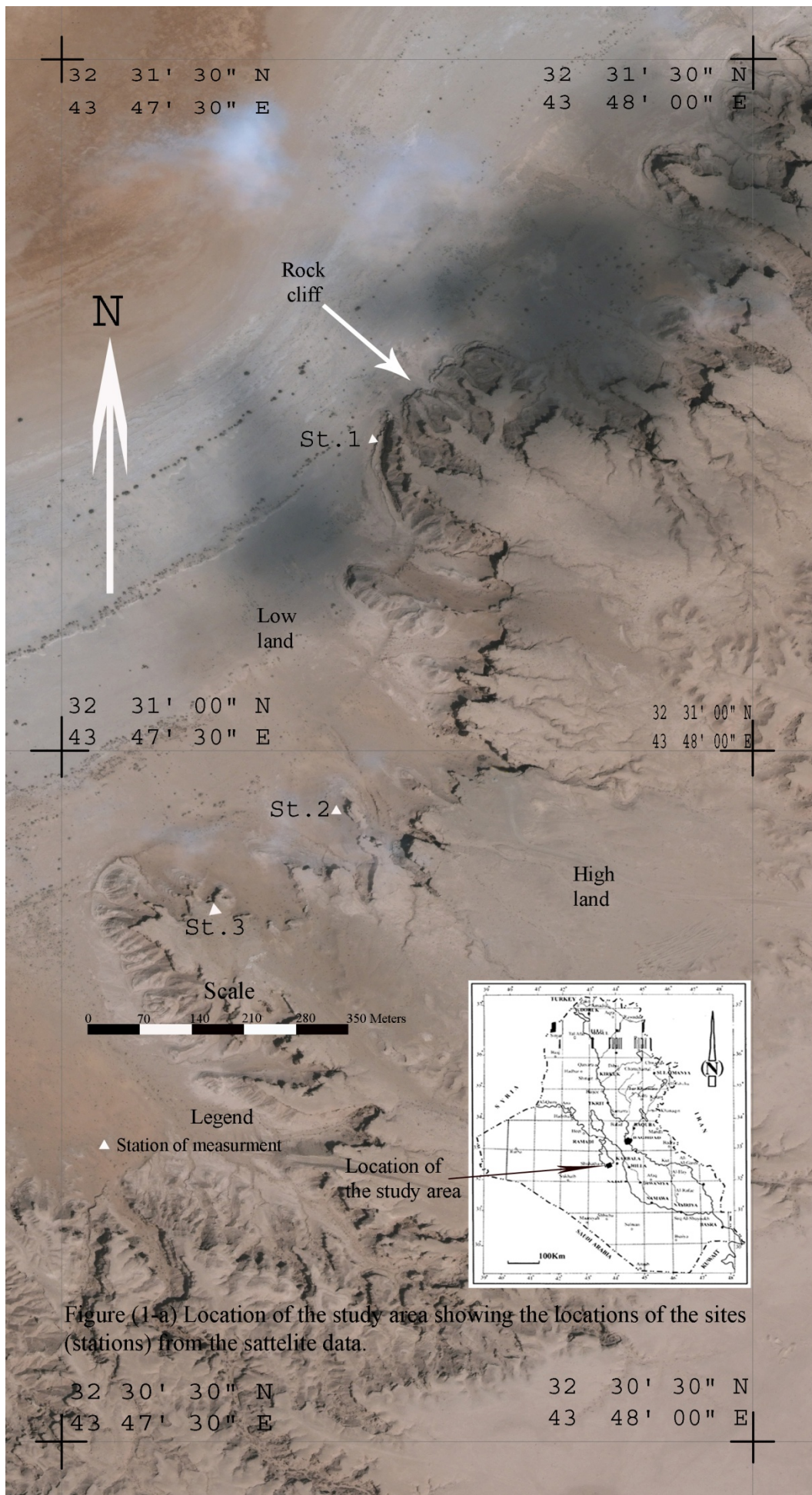


Figure (1-a) Location of the study area showing the locations of the sites (stations) from the satellite data.

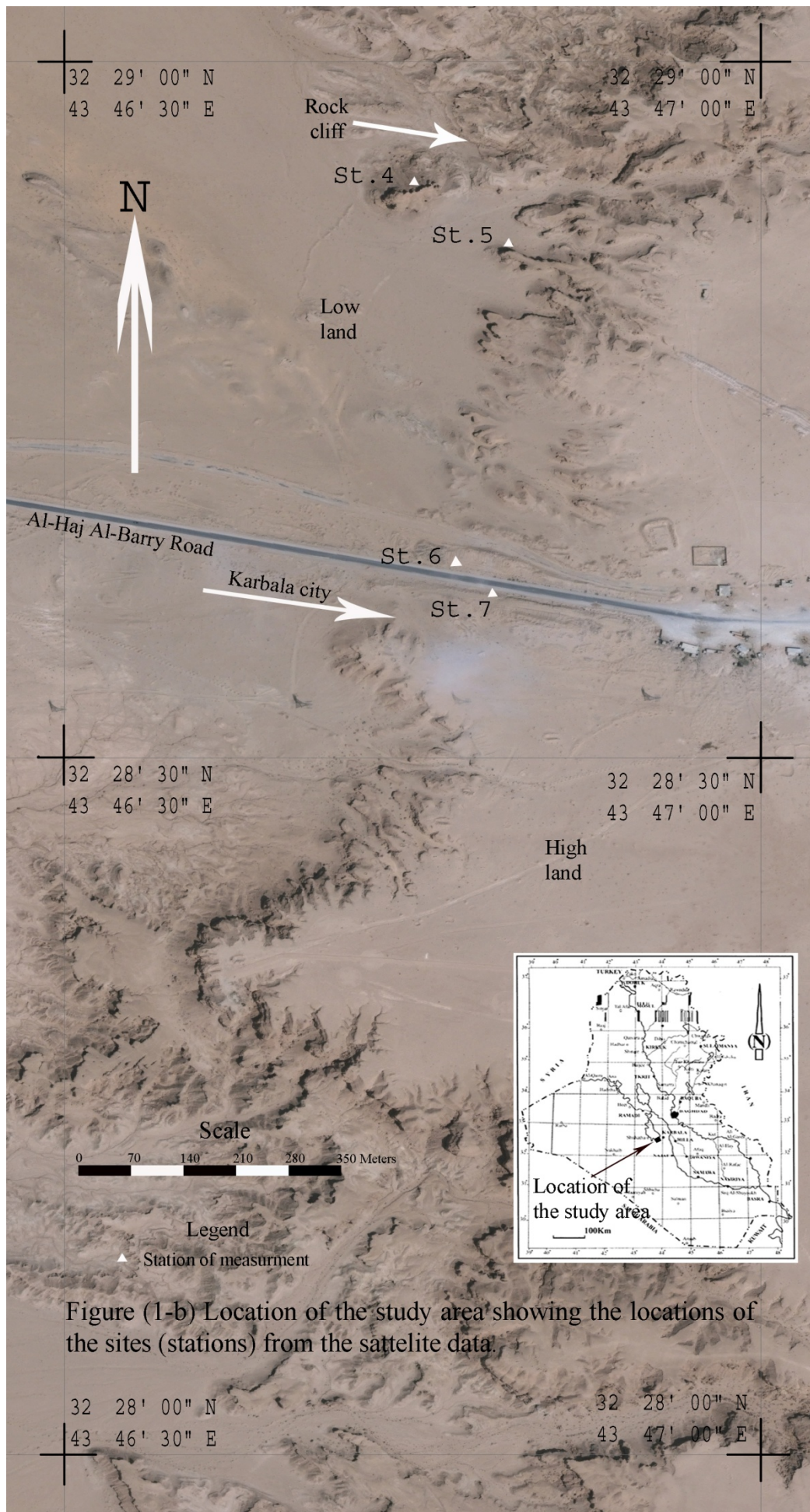


Figure (1-b) Location of the study area showing the locations of the sites (stations) from the satellite data.

In this paper, the slope inclination (or dip of strata or discontinuities) is indicated by two numbers representing the direction (Azimuth to the left) and the angle (to the right) like 220/30°. Moreover, rock slope failures are classified according to the classification of Wyllie and Mah, (2004)<sup>(3)</sup> which is based on Hoek and Bray, (1981)<sup>(4)</sup>. Toppling types are classified according to the classifications of Goodman and Bray, (1976)<sup>(5)</sup>, and Evans, (1981)<sup>(6)</sup>

**1-4 Previous Studies:** Previous studies are almost focused on Stratigraphy, Mineral exploration, Tectonic, and Hydrogeology (Hassan, 2007<sup>(7)</sup>, Al-Khateeb and Hassan, 2005<sup>(8)</sup>, Al-Saadi, 2010<sup>(9)</sup>, Hassan and Al-Khateeb, 2004<sup>(10)</sup>, and Al-Basrawi, 1996<sup>(11)</sup> respectively). There is only one M.Sc. thesis on slope stability of Tar Al-Sayyed area by Al-Hussainy (2011)<sup>(12)</sup>, from which the basic data of this paper are derived.

### **1-5 Geology of the Study Area:**

**A- Stratigraphy:** The stratigraphic units exposed in the study area are:

1- **Injana Formation (Late Miocene):** It is divided into two main units <sup>(7)</sup>.

**(I) -Lower Clastic Unit:** It consists of alternation of different clastic rocks (sandstone, siltstone, and claystone) or admixture of these rocks in different ratios. Thin beds of marly limestone are also recorded, two or three times up to 0.3 m in thickness, some Celestite-bearing beds are recorded in places<sup>(8)</sup>. Cementing materials are clay or carbonate. Some diagenetic processes occasionally led to fill the bedding planes and fractures by solution forming very thin veins of secondary gypsum. Generally, the sequence shows fining upwards cycles. The thickness of this unit reaches up to 25 m. The succession shows some lateral and vertical variations <sup>(7)</sup>.

**(II)-Upper Claystone Unit:** It is informally named the Cave-Forming Claystone Unit <sup>(8)</sup>. It consists of claystone, occasionally silty, brown to reddish brown, conchoidally fractured, massive, tough, cliff-forming, changes laterally or vertically to silty claystone. The thickness of this unit reaches 6.0 m or more in some places. It has wide geographic extension along both Tar Al-Najaf and Tar Al-Sayyed, for about 170 Km. This unit is highly jointed. It is overlain by highly permeable coarse grained sandstone of Dibdibba Formation. Some of these joints are enlarged gradually due to water erosion from the overlying beds forming a well-developed caves, which reach (1×2) m, or more<sup>(8)</sup>.

**2- Dibdibba Formation (Pliocene – Pleistocene):** It is widely exposed in the upper part of Tar Al-Sayyed forming the main plateau. The thickness ranges from one meter or less to more than 18m. Lithologically, the formation consists of sandstone and pebbly sandstone. The sandstone differs from place to another; the main color is brown but it could be gray, yellow and white or yellowish brown <sup>(7)</sup>.

**3- Quaternary Deposits:** These deposits cover most of the study area which consist of aeolian deposits, valley filling sediments and colluvial sediments <sup>(8)</sup>.

**B- Tectonic and Structural Setting:** The study area lies in the Euphrates Subzone of the Mesopotamian Zone of the Unstable Shelf close to the border with Salman Zone of the Stable Shelf. Structurally, the study area is characterized by subhorizontal layers with average dip between (3-5°), therefore all slopes can be classified as subhorizontal layer slopes.

**C- Geomorphology of the Study Area:** The main geomorphological features in the study area are:

**(1) Rock cliff of Tar Al-Sayyed** which trend in general (NE-SW) and its inclination to (NW) ranges between (50-90°) and becomes overhanging (OH) in some places. Nevertheless, Tar Al-Sayyed cliffs trend changes locally to large extent so that they are inclined in all directions (Fig.1). The rock cliffs separate the Najaf - Karbala plateau form Al-Razzaza Low Land as shown in (Fig.1).

**(2)Al-Razzaza Low Land(Depression):**It represents a large depression of internal drainage;this depression is filled by water.The depression is composed of fine sand with silt and clay admixture <sup>(8)</sup>.

**(3) The Najaf and Karbala Plateau:** This plateau occupies the area extending between Al-Najaf and Karbala cities and further to the north of the later. It is bordered from the east by the Mesopotamian plain and from the west by Tar Al-Sayyed <sup>(8)</sup>.

(4) **Scattered Hills including Mesas and Butes** (which are flat topped, and cut on their sides by steep escarpments), generally occur in the lowland. Layers in all these isolated hills are essentially horizontal in attitude in the area between Tar al-Sayyed and the adjacent lowland. The main exposed layers of meses, butes and hills are marl and limestone of Nfayil Formation, and alternation of claystone, siltstone and sandstone of Injana Formation.

These geomorphological landforms are formed due to differential erosion and representing remnants of the plateau because of backward erosion.<sup>(8)</sup>

**D-Hydrology and Hydrogeology:** Rainfall is regarded as a principal source of surface water with very little amount. While most groundwater flow from western desert to Al Razzaza Lake and Karbala city, the presence of claystone layers within Injana Formation act as isolating strata and prevent movement of groundwater to Karbala city<sup>(11)</sup>. Field observations in the study area show that the groundwater table lies almost below the toe of the studied slopes, and restricted to Injana Formation.

**1-6 Climate of the Study Area:** The climate of the study area is characterized by arid, hot and comparatively high summer temperature with low humidity, and high evaporation. The temperature is low in winter<sup>(13)</sup>. The mean annual rainfall is 89.027 mm, the rainfall increases in winter time and becomes nill in the summer (June-September). Moreover all seasons are dusty mainly in the summer when wind speed increases.

**2- Rock Slope Stability Assessment in the Study Area:**

Seven sites (stations) have been chosen in this study where different types of slope failure exist, to assess slope stability in the area. The symbols used in the stereographic projection are shown in tables (1&2).

Table (1): The symbols used in the stereographic projection in this paper, modified from<sup>(14)</sup>.






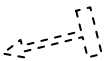





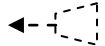

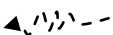


Symbol	Description
GS 	Cyclographic trace (great circle) of a general slope
SS 	Cyclographic trace of a side slope
OH or VS 	Cyclographic trace of vertical slope (VS) or overhanging slope (OH)
S <sub>0</sub> 	Cyclographic trace of mean orientation of bedding plane (S <sub>0</sub> )
S <sub>1</sub> , S <sub>2</sub> 	Pole to joint plane, joint sets
R.m	Rock mass
σ <sub>c</sub>	Compressive strength
MPa	Mega Pascal
BRS, LRS, CBRL	Back release surface, Lateral release surface, Composite back release surface respectively

Table (2): Symbols of types of failure and photo direction used and represented on stereogram, modified from <sup>(14)</sup>.

Types of failure	Symbol	
	Possible	present
Toppling		
Rock fall		
Granular disintegration		
Slumping		
Rolling		
Photo direction		

The seven studied stations are:

**2-1 Station No.: (1):**

This station lies at latitude (32° 31' 14.3" N) and longitude (043° 47' 44.1" E), within Injana Formation, (fig. 1-a, plate 1). The slope is (20m) high, (50m) long along its trend, and its inclination is (270/90°-OH). The average dip of strata is (126/4°), therefore it is subhorizontal-layer slope, (fig. 2).

The rock mass layers consist of light grayish brown, very fine-medium grained, very thickly bedded, moderately widely-very widely jointed, slightly-moderately weathered, SANDSTONES, moderately strong ( $\sigma_c=22.5\text{MPa}$ ), which contain claystone layers.

The sandstone layers are cut by two sets of subvertical joints in (S1&S2), (fig. 2). The spacing of joints in (S1) ranges between (0.5-2.1m), their persistence reaches (5m) on the bedding plane and on the slope and they are open with aperture that ranges between (0.01-0.03m). The spacing of joints in (S2) ranges between (0.5-2.2m), their persistence reaches (5m) on the bedding plane and on the slope and they are open with apertures that ranges between (0.01-0.03m), (plate 1-b).

Rock fall is regarded as the principal failure mode in this station, because of the high steepness of the slope. Some fallen blocks exist at the toe of the slope. Some sandstone slabs subparallel to the slope face may topple where the claystone layers below them are eroded. This toppling will be due to undercutting. Joints in (S1) will act as back release surfaces (BRS) while those in (S2) will act as lateral release surfaces (LRS).

**2-2 Station No.: (2):**

This station lies at latitude (32° 30' 57.6" N) and longitude (043° 47' 42.2" E), within Injana Formation, (fig. 1-a, plate 2). The slope at this station consists of general slope (the first slope) which is (7m) high, (10m) long parallel to its trend and its inclination is (320/90°-OH). This slope changes to the right side forming side slope (the second slope) which is (7m) high, (15m) long along its trend and its inclination is (230/90°-OH). The average dip of strata is (124/4°); therefore, the slopes are subhorizontal-layer slopes, (fig. 3). Below the main rock slope, there is an inclined soil slope.

In the upper part of the slopes (4m) thick layers are exposed. They are light yellowish brown, medium grained, thickly bedded, moderately widely-widely jointed, slightly weathered, calcareous SANDSTONE, moderately strong ( $\sigma_c=26.59\text{MPa}$ ). These sandstone layers are separated from the

underlying claystone layer by a middle layer of (1.5m) thick. It is light reddish brown, very fine grained, thickly bedded, highly weathered CLAYSTONE, which is largely removed by erosion.

The underlying rock layer in the lower part of the slope (lower limit not visible) is exposed up to (1.5m), it is light reddish brown, very fine grained, thickly bedded, moderately widely - widely jointed, slightly weathered, CLAYSTONE.

The sandstone layers are cut by two sets of subvertical joints in (S1&S2), (fig. 3). The spacing of joints in (S1) ranges between (0.4-2m), their persistence reaches (7m) on the bedding plane and the slope, they are almost open up to (0.25m). The spacing of joints in (S2) ranges between (0.4-2m), their persistence reaches (7m) on the bedding planes and the slope and most of them are open up to (0.2m), (plate 2-a).

There is a composite tension crack that consists of joints in (S1) &(S2) in the upper slope. It is (9m) long, (0.2m) wide and (5m) deep, (plate 2-b). Toppling in this station has occurred by tension crack and toppling & slumping mechanisms accompanied by differential erosion in the highly weathered claystone in the middle part of the slope. In the general slope (slope1), joints in (S1) act as lateral release surfaces (LRS), while joints in (S2) act as back release surfaces (BRS), in the side slope (slope2), joints in (S1) act as back release surfaces (BRS) while joints in (S2) act as lateral release surfaces (LRS) also during toppling. There is another failure type in the same rock mass. It is rock fall, from the upper part of the slopes, by differential erosion, which caused the sandstone layers free to fall. The inclined soil slope helps rolling of detached rock blocks.

### **2-3 Station No. (3):**

This station lies at latitude (32° 30' 53.7" N) and longitude (043° 47' 36.6" E), within Injana Formation, (fig. 1-a, plate 3). The slope is (4.5m) high, (20m) long along its trend and its inclination is (312/90°). The average dip of strata is (123/3°), therefore it is subhorizontal –layer slope, (fig. 4). Below the main rock slope, there is an inclined soil slope.

In the upper part of the slope a (2.5m) thick layers are exposed. They are light reddish brown, medium grained, thickly bedded, widely jointed, slightly weathered, calcareous SANDSTONE, moderately strong ( $\sigma_c=33.75\text{MPa}$ ). These sandstone layers are separated from the underlying claystone layers by (0.2m) thick layer of highly weathered claystone which is removed by erosion. The underlying rock layers in the lower part of the slope are (1.8m) thick. They are light grayish brown, very fine grained, thickly bedded, widely jointed, moderately weathered, CLAYSTONE.

The rock mass layers are cut by two sets of subvertical joints in (S1&S2), (fig. 4). The spacing of joints in (S1) range between (0.9-1.8m), their persistence reaches (4m) on the bedding plane and they are almost open up to (0.1m). The spacing of joints in (S2) ranges between (0.9-1.6m), their persistence reaches (4m) on the bedding plane and they are almost open up to (0.1m), (plate 3-b).

Rock block failure has occurred by rock fall or secondary toppling including, multidirectional toppling mode<sup>(15)</sup>, that involves tension crack toppling and toppling & slumping mechanisms. In the first toppling process (T1) joints in (S1) set acted as back release surfaces (BRS) of the toppled block while (S2) joint set acted as lateral release surfaces (LRS), (fig. 4). Then, the toppled block underwent further rotation to the front of the slope. The inclined soil slope (below the main rock slope), and its surface roughness led again to divert the weight vector of the toppled block outside its new secondary base (the resting surface after the first toppling process), leading to a second toppling process (T2) which changed the attitude of the bedding planes within the toppled slab to vertical position. The (S2) joint set acted as back release surfaces (BRS), while the (S1) joint set acted as lateral release surfaces (LRS) during the second toppling movement.

### **2-4 Station No. (4):**

This station lies (580m) NW of cross point of rock cliff with AL-Hij Al-Barry road, at latitude (32° 28' 54.7" N) and longitude (043° 46' 45.7" E), within Dibdibba Formation, (fig. 1-b, plate 4). The slope is (4m) high, (30m) long along its trend and its inclination is (340/90-OH). The average dip of strata is (125/3°), therefore, the slope is subhorizontal layer slope, (fig. 5). Below the main rock slope, there is an inclined soil slope.

In the upper part of the slope a (3.5m) thick layers are exposed, they are light reddish brown, medium grained, very thickly bedded, widely-very widely jointed, slightly weathered, calcareous SANDSTONES, moderately strong ( $\sigma_c=12.6\text{MPa}$ ). The (0.5m) thick layer exposed at the lower part of the slope is light greenish gray, medium grained, highly weathered, SANDSTONE. It is highly eroded.

The upper sandstone layers are cut by two sets of subvertical joints in (S1&S2), (fig. 5). The spacing of joints in (S1) range between (0.9-1.1m), their persistence reaches (2m) on the bedding plane and on the slope and they are open with apertures about (0.01m). The spacing of joints in (S2) range between (1-2.3m), their persistence reaches (2m) on the bedding plane and on the slope and they are open with apertures that range between (0.01-0.07m), (plate 4-a & b).

The sandstone layer in the lower part of the slope is highly weathered and eroded, leaving some parts of the slope overhanging, this has resulted in secondary toppling of sandstone blocks by differential settlement toppling mode. Joints in (S1) acted as lateral release surfaces (LRS), while those in (S2) acted as back release surfaces (BRS) during toppling. Rock fall has occurred in this steep overhanging slope and is likely to occur in the future. The inclined soil slope helps rolling of detached rock blocks.

### **2-5 Station No. (5):**

This station lies (134m) SE of station No.(4) at latitude ( $32^\circ 28' 52.1''$  N) and longitude ( $043^\circ 46' 49.8''$  E), within Injana Formation, (fig. 1-b, plate 5). The slope is (11m) high, (25m) long along its trend and its inclination is ( $018/88^\circ$ -OH). The average dip of strata is ( $140/3^\circ$ ), therefore, the slope is subhorizontal layer slope, (fig. 6). Below the main rock slope, there is an inclined soil slope.

In the upper part of the slope a (8m) thick layers are exposed. They are light grayish brown, very fine grained, medium-thickly bedded, moderately widely-very widely jointed, slightly weathered, CLAYSTONES, moderately strong ( $\sigma_c=28.46\text{MPa}$ ). The (3m) thick layer in the lower part of the slope is light grayish olive, medium grained, very thickly bedded, moderately weathered, calcareous SANDSTONE.

The claystone layers are cut by two sets of subvertical joints in (S1&S2), (fig. 6). The spacing of joints in (S1) ranges between (0.9-1.2m), their persistence reaches (6m) on the bedding plane they are almost open up to (0.05m). The spacing of joints in (S2) ranges between (0.5-2.3m), their persistence reaches (6m) on the bedding plane and they are almost open up to (0.1m), (plate 5-b).

The failure in this station has occurred by secondary toppling type, toppling and slumping mode. Joints in (S1) acted as back release surfaces (BRS), while those in (S2) acted as lateral release surfaces (LRS) during toppling. Rock fall has already occurred and it is likely to occur in the future. The inclined soil slope helps rolling of detached rock block.

### **2-6 Station No. (6):**

This station lies (6m) to the north side of AL-Hij Al-Barry road, at latitude ( $32^\circ 28' 37.3''$  N) and longitude ( $043^\circ 46' 51.7''$  E), within Dibdibba Formation, (fig. 1-b, plate 6). The slope is (2.5m) high, (65m) long along its trend, its inclination is ( $190/64^\circ$ -OH). The bedding planes for this station are not visible. The rocks are massive, (fig. 7).

The rock mass for this slope consists of light orange pink, medium grained, massive, widely-very widely jointed, slightly-moderately weathered, SANDSTONE, weak (crumbles by hand).

The sandstone layer is cut by two sets of subvertical joints in (S1&S2), (fig. 7). The spacing of joints in (S1) ranges between (1.7-2.3m), their persistence reaches (1m) on the slope and they are almost tight. The spacing of joints in (S2) ranges between (0.8-1m), their persistence reaches (1m) on the slope and they are almost tight, (plate 3-b).

With differential erosion at the toe of the slope, in some parts, the slope is overhanging, helping in rock fall, whereas the general slope angle ( $64^\circ$ ) is helping in rock roll of the detached blocks. The other parts have failed by granular disintegration because of the weak rock (friable sandstone) forming the slope.

**2-7 Station No. (7):**

This station lies (4m) to the south side of Al-Hij Al-Barry road, at latitude (32° 28' 36.5" N) and longitude (043° 46' 51.1" E), within Dibdibba Formation, (fig. 1-b, plate 7). The slope is (3.5m) high, (45m) long along its trend and its inclination is (010/OH). The bedding planes for this station are not visible. The rocks are massive, (plate 7). Below the main rock slope, there is an inclined soil slope.

The rock mass for this slope consists of light orange pink, medium grained, massive, widely-very widely jointed, slightly-moderately weathered, SANDSTONE. The sandstone is cut by two sets of subvertical joints in (S1&S2), (fig. 8). The spacing of joints in (S1) ranges between (1.7-2.3m), their persistence reaches (1m) on the slope and they are almost open up to (0.01m). The spacing of joints in (S2) ranges between (0.8-1.1m), their persistence reaches (1.2m) on the slope and they are almost open up to (0.02m), (plate 7-b).

With differential erosion at the toe of the slope, in some parts, the slope is overhanging, helping in rock fall failure, whereas the other parts have failed by granular disintegration because of the weak rock (friable sandstone) forming the slope. The inclined soil slope helps rolling of detached rock blocks.

**3-Conclusions and Recommendations**

**3-1 Conclusions:**

- 1-Tar Al-Sayyed is an arid area where winds are considered as a principal geomorphological factor influencing rock slope geomorphology. Winds help in the differential erosion of weak strata forming overhanging unstable slopes.
- 2-The big variation in lithology and resistance in slope forming strata, leads to disproportion in weathering and erosion rates, forming overhanging unstable slopes.
- 3-Joints have high dip angle (subvertical joints); therefore they act as back release surfaces (BRS), lateral release surfaces (LRS) or composite back release surfaces (CBRS) but not as sliding surfaces. Their spacing and orientation also determine the size and shape of the failed rock blocks.
- 4-Water effect is limited to winter season, because the study area lies near the western desert with long dry period during the year. Rainfall in the study area represents the principal source of water; most of the slopes (stations) contain claystone layers in their sequence. Claystone may be easily eroded and affected by water, helping and forming overhanging unstable slopes.
- 5-Weak claystone and sandstone layers mostly fail by physical weathering and granular disintegration, helping in forming overhanging unstable slopes. While, hard claystone and sandstone layers have failed by toppling and rock fall as rock blocks.
- 6-All the slopes are almost dangerous and liable to toppling and rock fall where visitors move around and close to rock cliff.

**3-2 Recommendations:**

After all factors influencing rock slope stability in the study area are studied and analyzed, and because of the absence of protection works for all slopes in the study area, the following measures are proposed to stabilize slopes and to save visitors:-

- 1-All slopes undergo different types of failure (toppling and/or rock fall...etc), the failing blocks move down slope along cliff's toe and may hit persons, therefore, it is recommended to construct retaining walls to protect the slopes and to reduce the hazard.
- 2-For the falling and rolling pieces of detached rocks for all slopes, it is recommended to use gabions along the inclined soil slopes below the main slope to avoid movement of detaching rocks and their risk.
- 3-Civil structures (if proposed to construct in future) should be constructed far from the rock cliff (if they are constructed on highland or lowland) to keep away from failure hazard.
- 4-Warning signs adverts should be installed along the rock cliff and adjacent to caves, to alert the visitors, and draw their attention to failure hazards in the area.

5-Favorable fence should be constructed at highland to save the visitors and keep them away from the tension cracks, possible rock blocks failure and the dangerous edges of the rock cliff.

Note: In all plates the height of the person is (1.79) m, the length of the geological hammer is (0.3) m, and the length of the bag is (0.31) m.

**Plates**

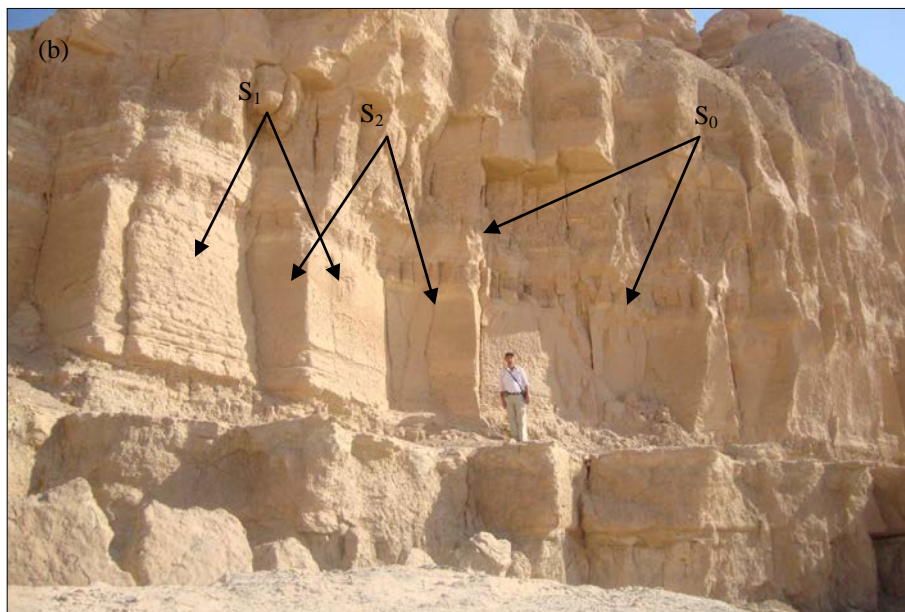
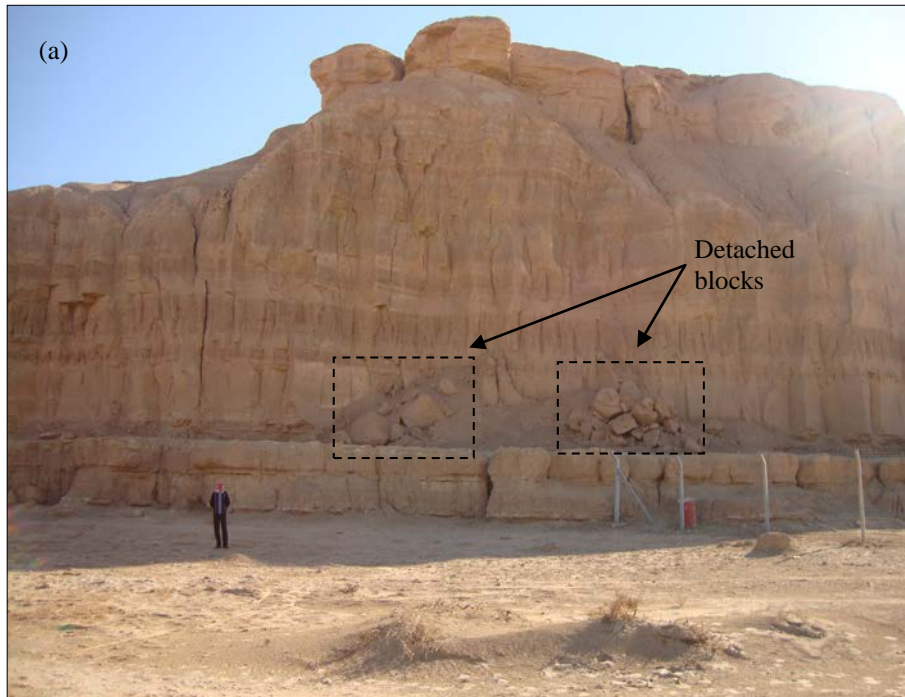


Plate (1) The slope at station No.(1). (a) Front view showing detached blocks, photo direction is E. (b) Side view showing discontinuities, photo direction is SE.

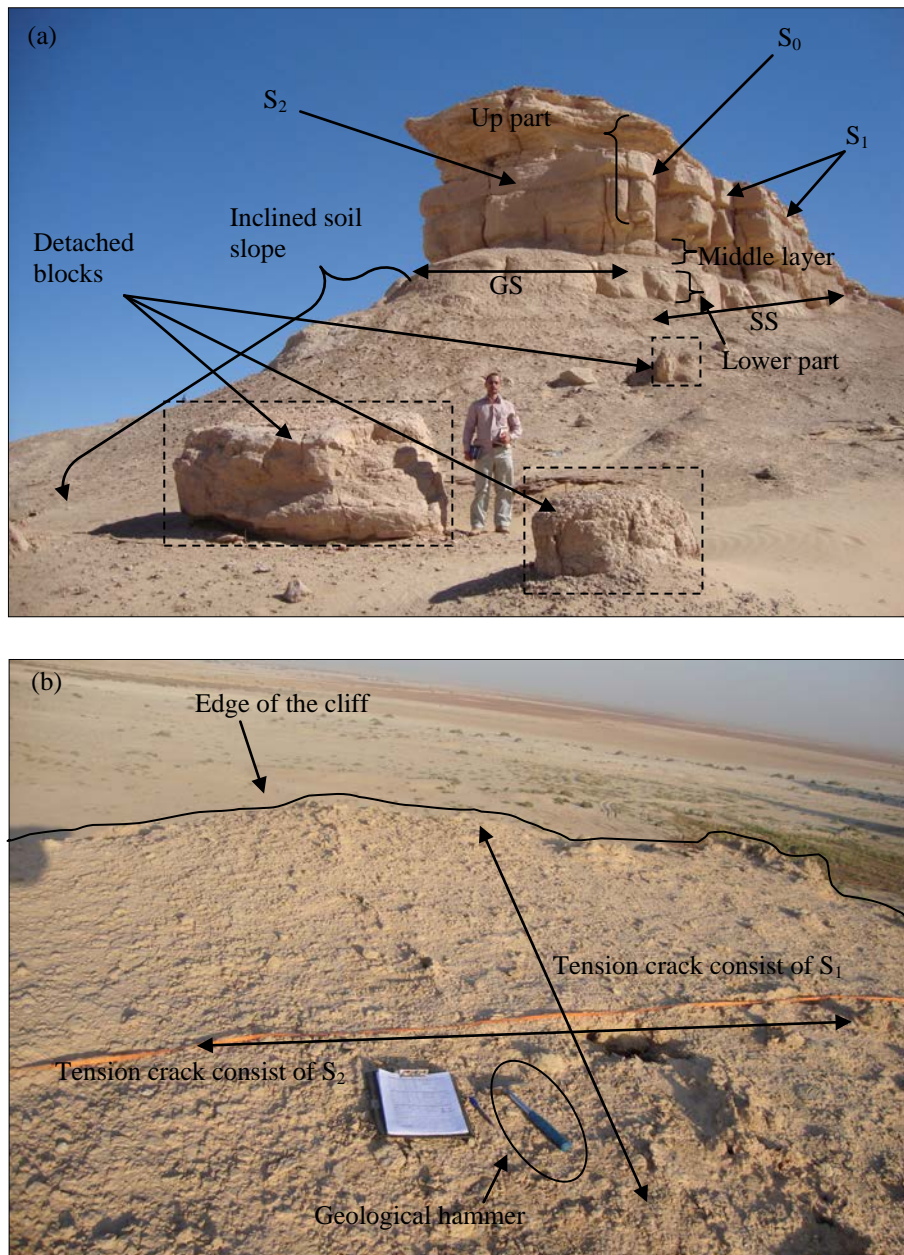


Plate (2) The slope at station No.(2). (a) General view showing general slope, side slope, detached blocks and discontinuities, photo direction is E. (b) Top view showing the trace of composite tension crack (tension crack mostly covered with sediment), photo direction is NW.

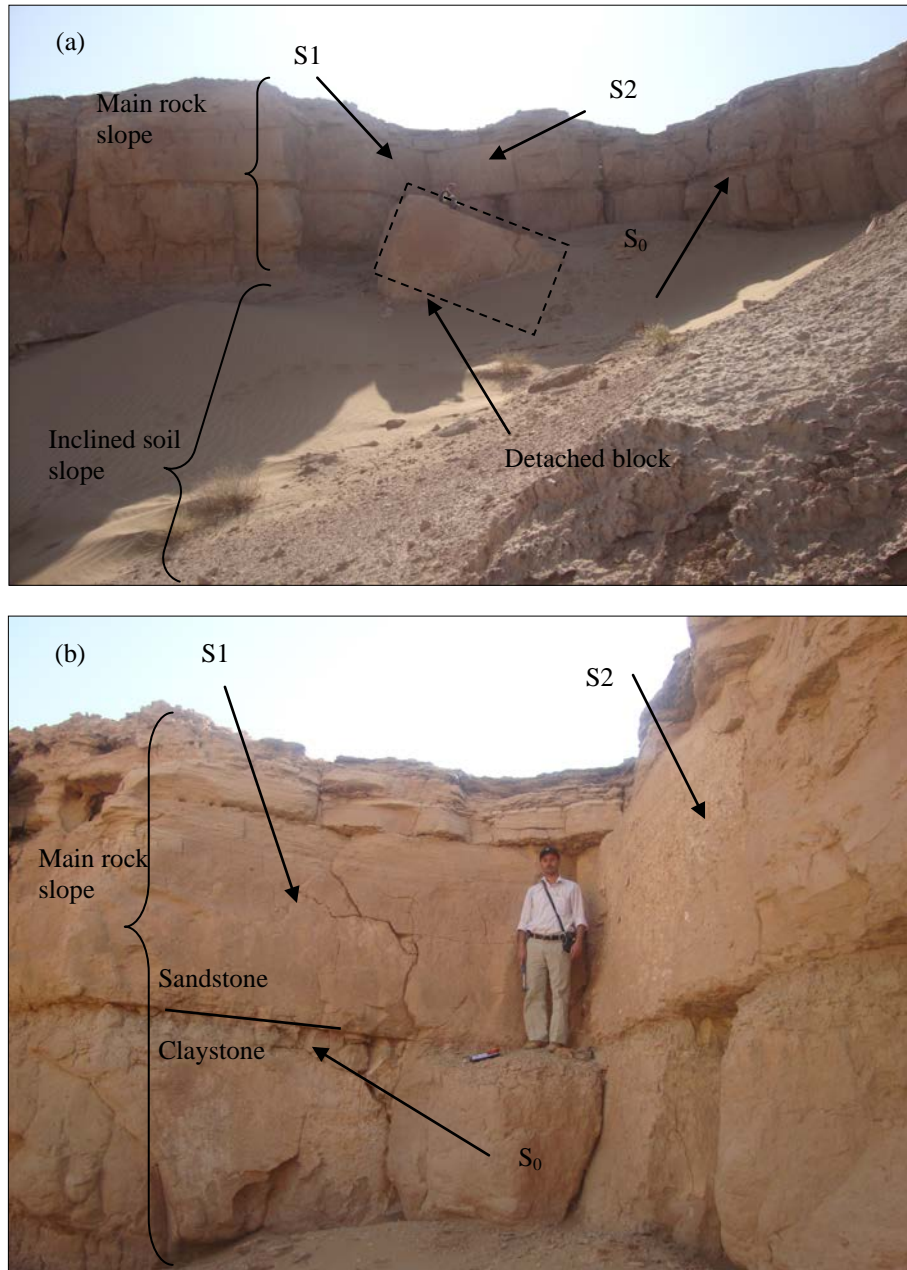


Plate (3) The slope at station No. (3). (a) Front view showing the main slope, rock block detached by multidirectional toppling, and discontinuities. Photo direction is SE (b) Side view showing local slope and discontinuities, photo direction is NE.

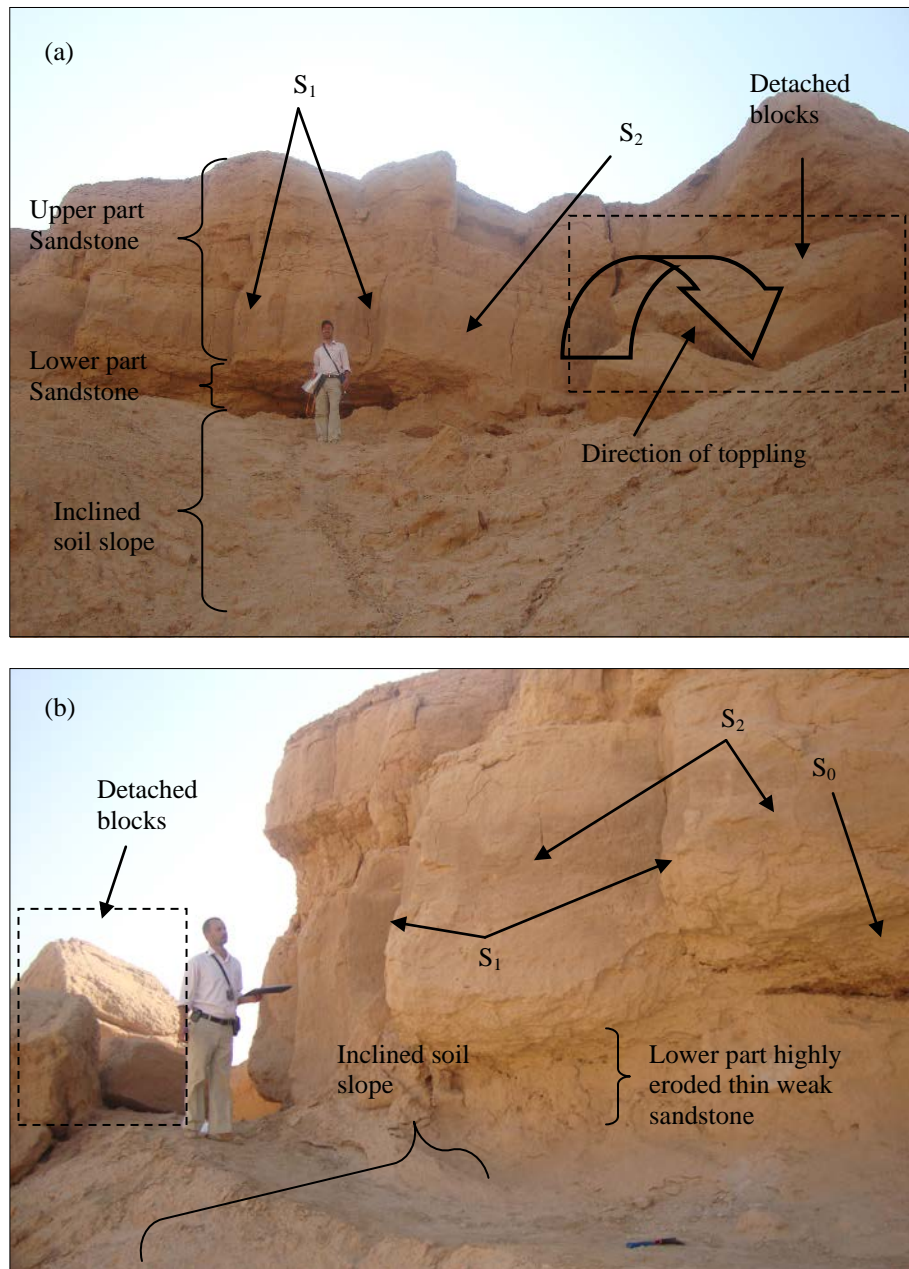


Plate (4) The slope at station No.(4). (a) Front view showing discontinuities and detached blocks, photo direction is SE. (b) Side view showing, discontinuities, an other detached blocks, photo direction is E.

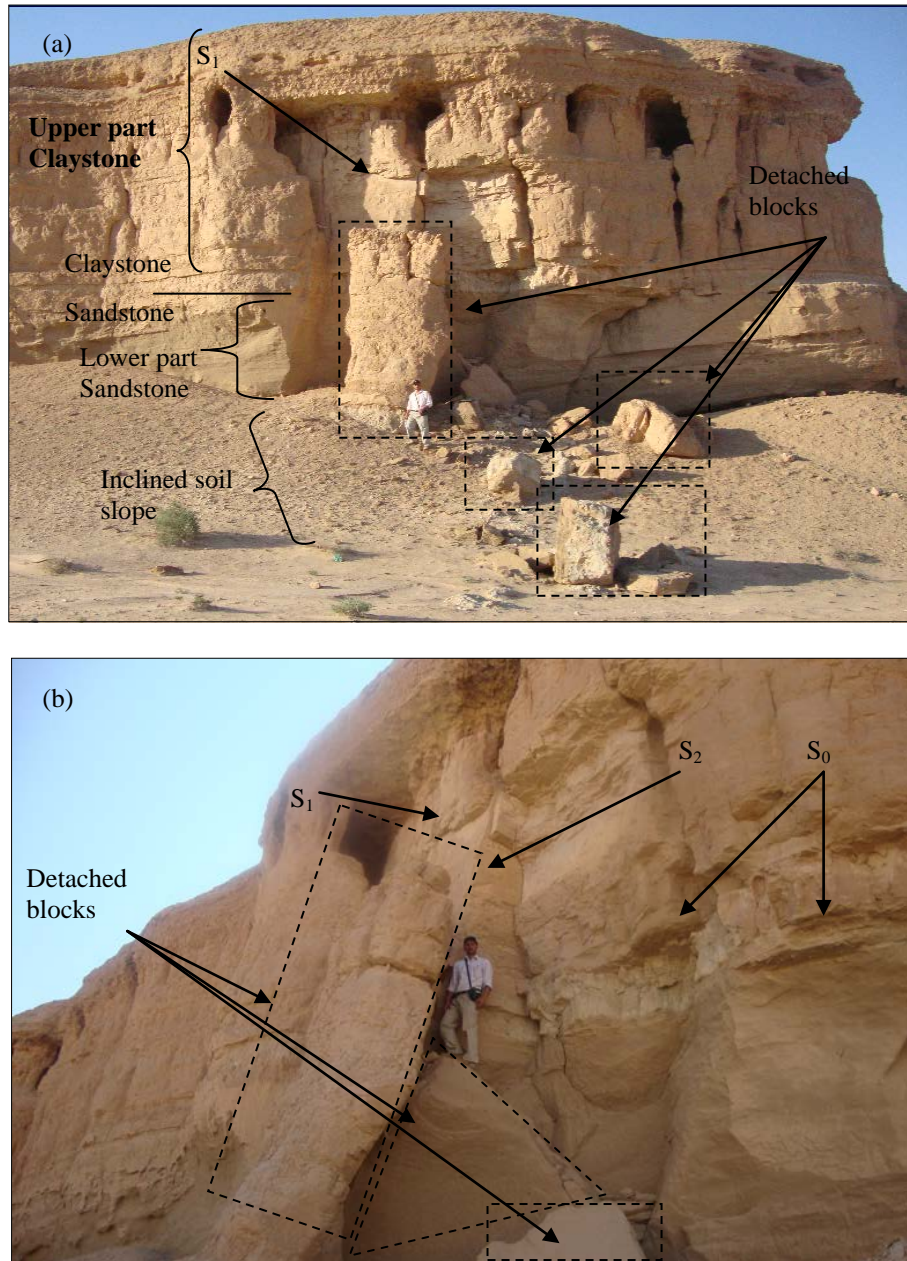


Plate (5) The slope at station No.(5). (a) Front view showing detached blocks, claystone & sandstone contact, and some caves in upper part of the slope, photo direction is SW. (b) Side view showing discontinuities and detached blocks, photo direction is SE.

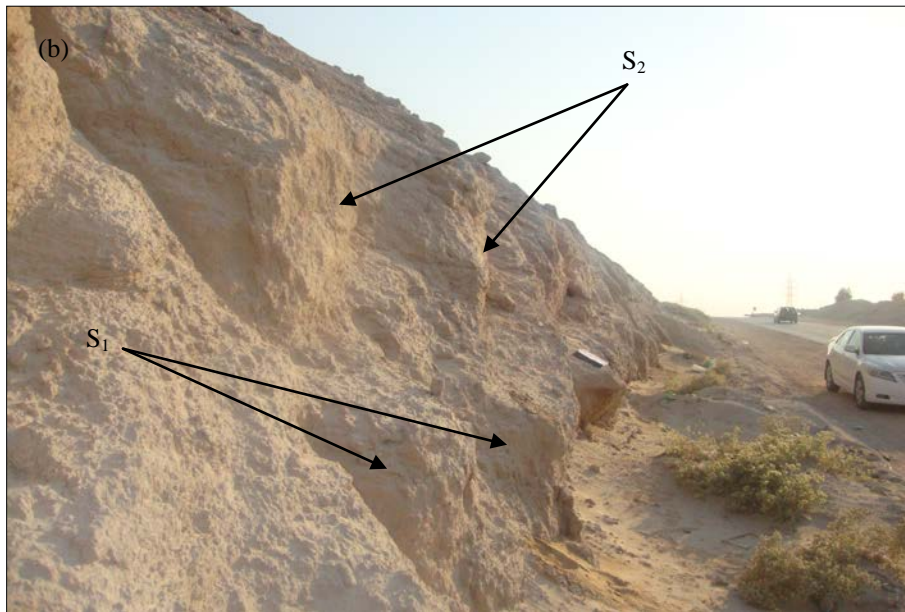


Plate (6) The slope at station No.( 6). (a) Front view showing the slope, photo direction is NE. (b) Side view showing the irregular-overhanging slope, and discontinuities, photo direction is E.

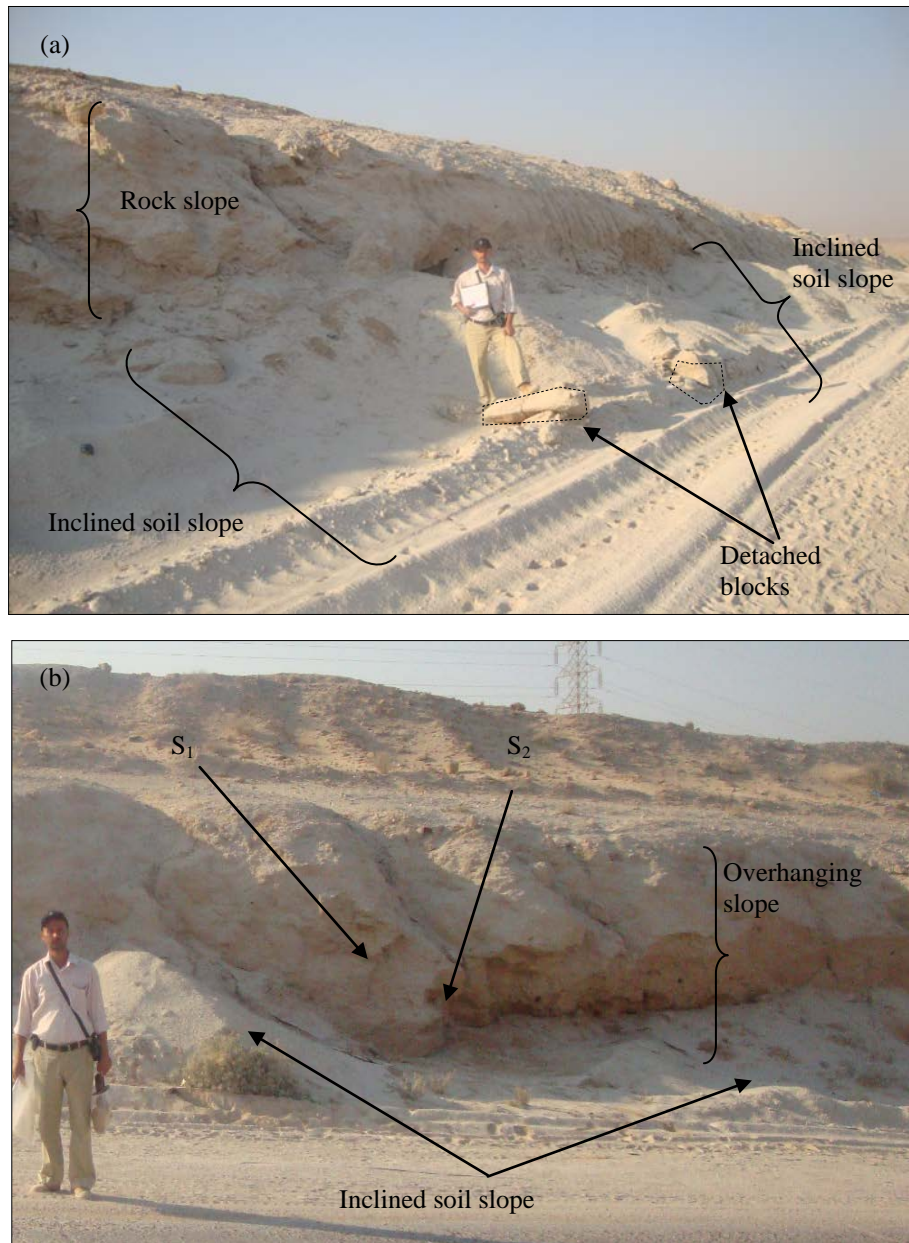


Plate (7) The slope at station No.(7). (a) Side view showing the slope detached blocks and residual sediment (soil slope), photo direction is SW. (b) Front view showing overhanging slope, discontinuities and residual sediment, photo direction is SW.

**Figures**

Note: T.C. is the trace of the tension crack in joint sets  $S_1$  or  $S_2$ .

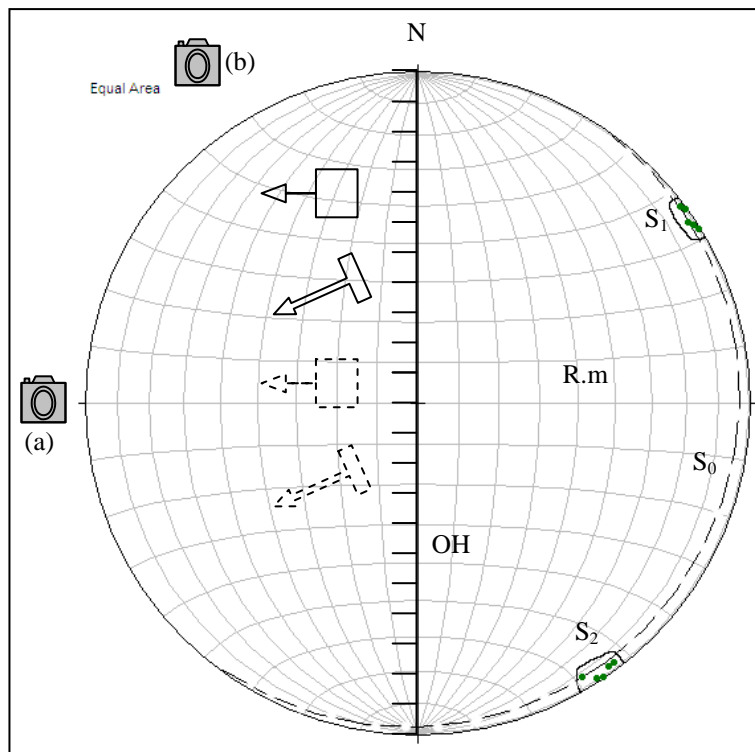


Figure (2) Stereogram of discontinuities, slope and types of failure for station No.(1). In Tar Al-Sayyed area, Karbala Governorate, Iraq.

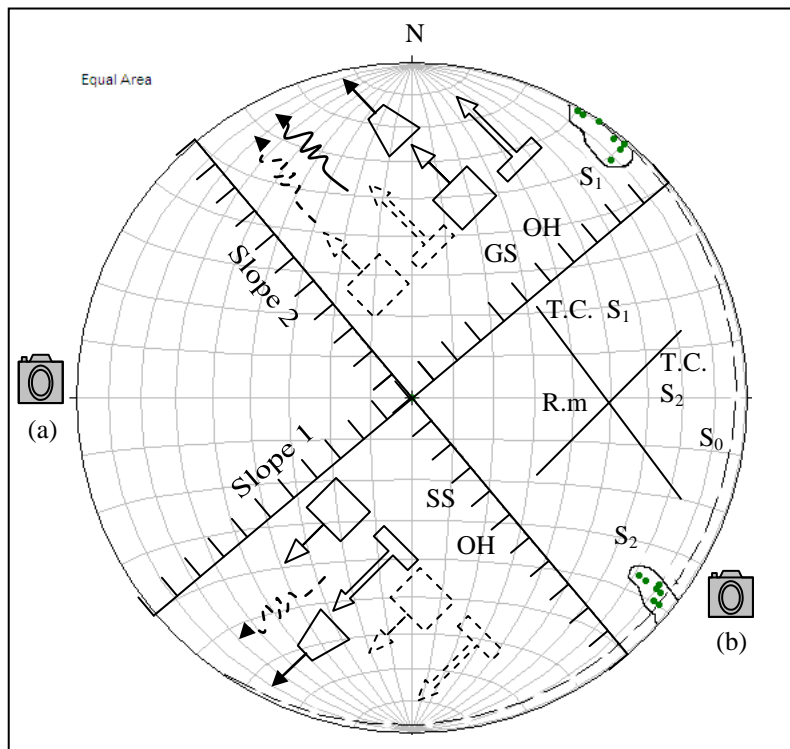


Figure (3) Stereogram of discontinuities, slopes and types of failure including tension crack toppling for station No.(2). In Tar Al-Sayyed area, Karbala Governorate, Iraq.

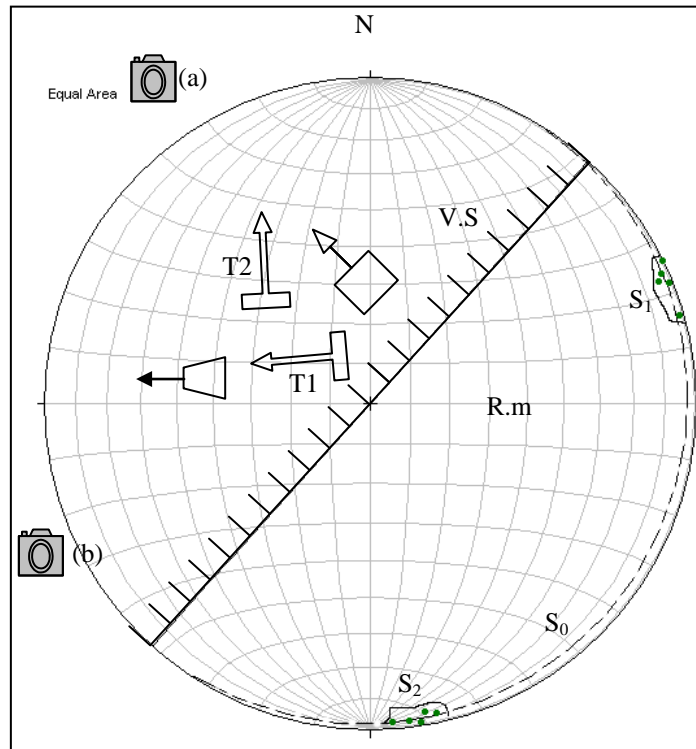


Figure (4) Stereogram of discontinuities, slope and types of failure including multidirectional toppling for station No.(3). In Tar Al-Sayyed area, Karbala Governorate, Iraq.

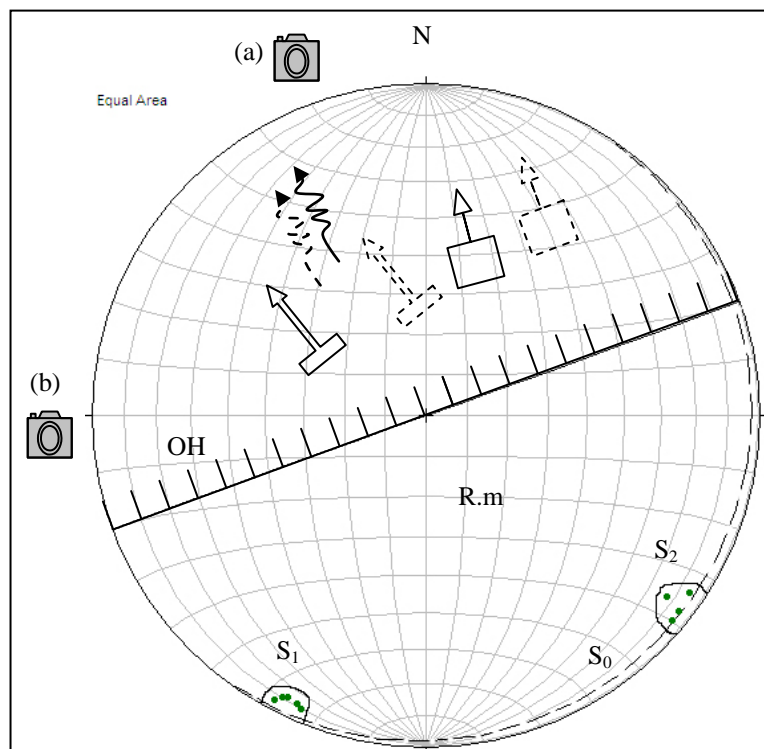


Figure (5) Stereogram of discontinuities, slope and types of failure for station No. 4. In Tar Al-Sayyed area, Karbala Governorate, Iraq.

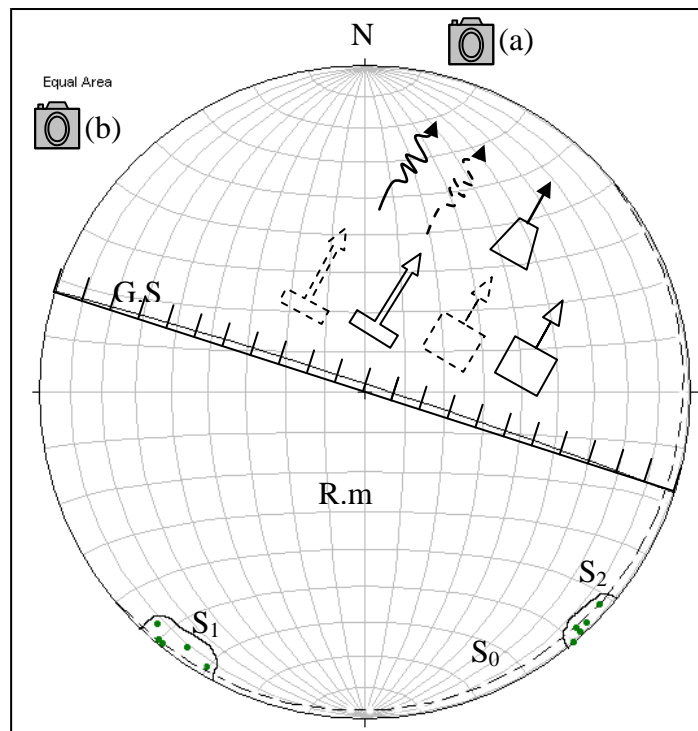


Figure (6) Stereogram of discontinuities, slope and types of failure for station No.(5). In Tar Al-Sayyed area, Karbala Governorate, Iraq.

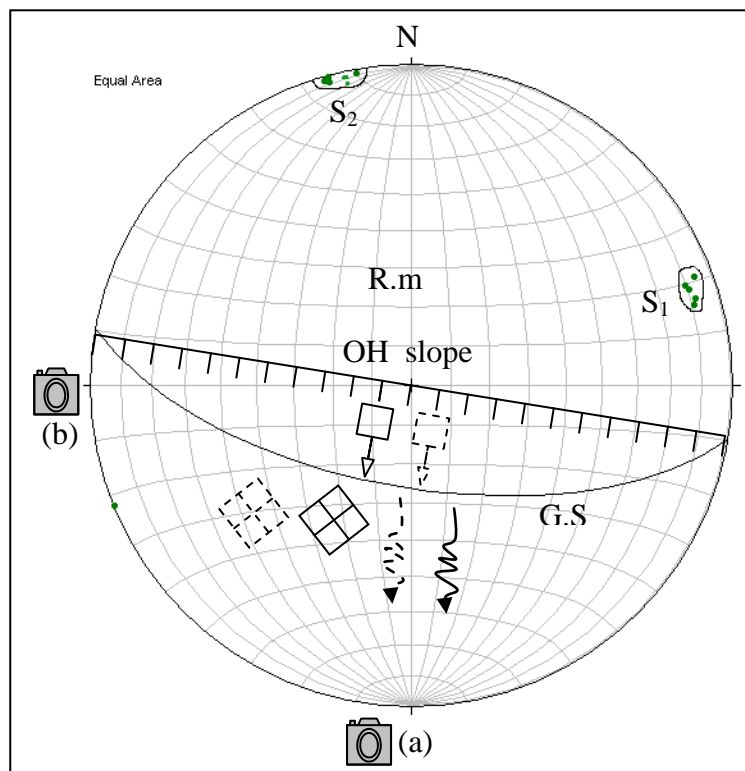


Figure (7) Stereogram of discontinuities, slope and types of failure for station No.( 6). In Tar Al-Sayyed area, Karbala Governorate, Iraq.

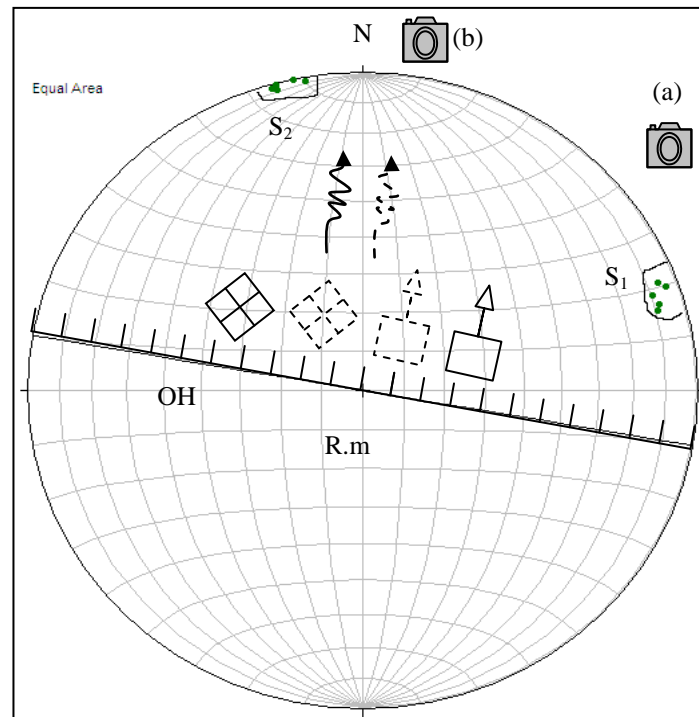


Figure (8) Stereogram of discontinuities, slope and types of failure for station No.(7). In Tar Al-Sayyed area, Karbala Governorate, Iraq.

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