ENGINEERING GEOLOGICALSTUDY OF ROCK SLOPE STABILITYALONG THE DOKAN – KHALAKAN ROAD,

KURDISTAN REGION, NE-IRAQ

A THESIS SUBMITTED TO THE COLLEGE OF SCIENCE, UNIVERSITY OF SULAIMANI, IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GEOLOGY

BY

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Abstract

An engineering geological study was carried out for the rock slope stability along Dokan- Khalakan road in Sulaimani Governorate to assess the stability of slope in area. Four stages of work have been involved in this study: (1) Preliminary stage of collecting data (maps and references about the study area), (2) Field work stage of measurements and samples collection, (3) Laboratory tests stage, and (4) Office work stage.

Slope stability assessment covered twenty stations along Dokan-Khalakan road at which a wide survey of slopes and discontinuities was performed. Those data have been represented and analyzed by stereographic projection on Schmidt equal-area net using Dips software.

Field observation revealed the presence of different types of (present or probable) failures in the area. Failure types in the slopes of the strong well bedded Kometan Limestone Formation (from most to least abundant) are rock fall, plane sliding, toppling, wedge sliding and rockroll. Rock slopes of the weaker Shiranish marly limestone and marl are characterized by plane sliding, rockfall and wedge sliding. One steep major fault having highly cemented slickensided surface due to intense friction along the fault walls was observed forming steep scarp. This slope is stable because of its high cohesion in contrary to the well-known role of faults as element of instability.

Joints of different types acted as lateral, back or composite back release surfaces during slope failure, while the bedding planes acted almost as sliding surfaces (except in discordant slopes where they acted as back release surfaces).

Direct shear tests on some interlayers clay for saturated undrained condition indicate that the friction angle (**Ø**) values range between (10-11°) and the cohesion

values(c) range between (32-64)kPa which help largely in sliding along clay filled bedding planes.

The unconfined compressive strength values of the rocks (determined indirectly from point load test) ranged between (85-125)MPa for Kometan limestone and between (49-53)MPa for Shiranish marly limestone.

For failure hazard assessment, data were collected from 37 stations and a failure hazard map for the study area has been drawn for the first time, with 1:20000 scale, depending to landslide possibility index (LPI) which is based on ten parameters. This (LPI) shows various hazard categories that range between "No hazard" to "very high" LPI categories or low to high hazard categories.

Road failure hazard map (in the same scale above) has been drawn for the first time. It depends on three factors, which are: (1) size of the detached blocks, (2) distance from the road to the nearest slope toe, and (3) availability of protection work. The range of hazard categories in the studied area is between "very low" to "High".

Road widening operations along Dokan-Khalakan road were going on actively in the summer of 2009, leading to the creation of unstable daylighting slopes which were left without stabilizations and protection treatment. Therefore, some measures are proposed in this study to protect the natural or man-made slopes from failures.

CHAPTER ONE
INTRODUCTION

1-1 Location:

The study area is located 60km NW of Sulaimani city, northern Iraq. The site is located along the main road between Dokan town and Khalakan town about (15.7) km long, between latitudes ($35^{\circ}\ 56^{\prime}\ 34^{\prime\prime}$ - $36^{\circ}\ 00^{\prime}\ 10^{\prime\prime}$) N and longitudes ($44^{\circ}\ 51^{\prime}\ 30^{\prime\prime}$ - $44^{\circ}\ 57^{\prime}\ 25^{\prime\prime}$) E Fig (1-1).

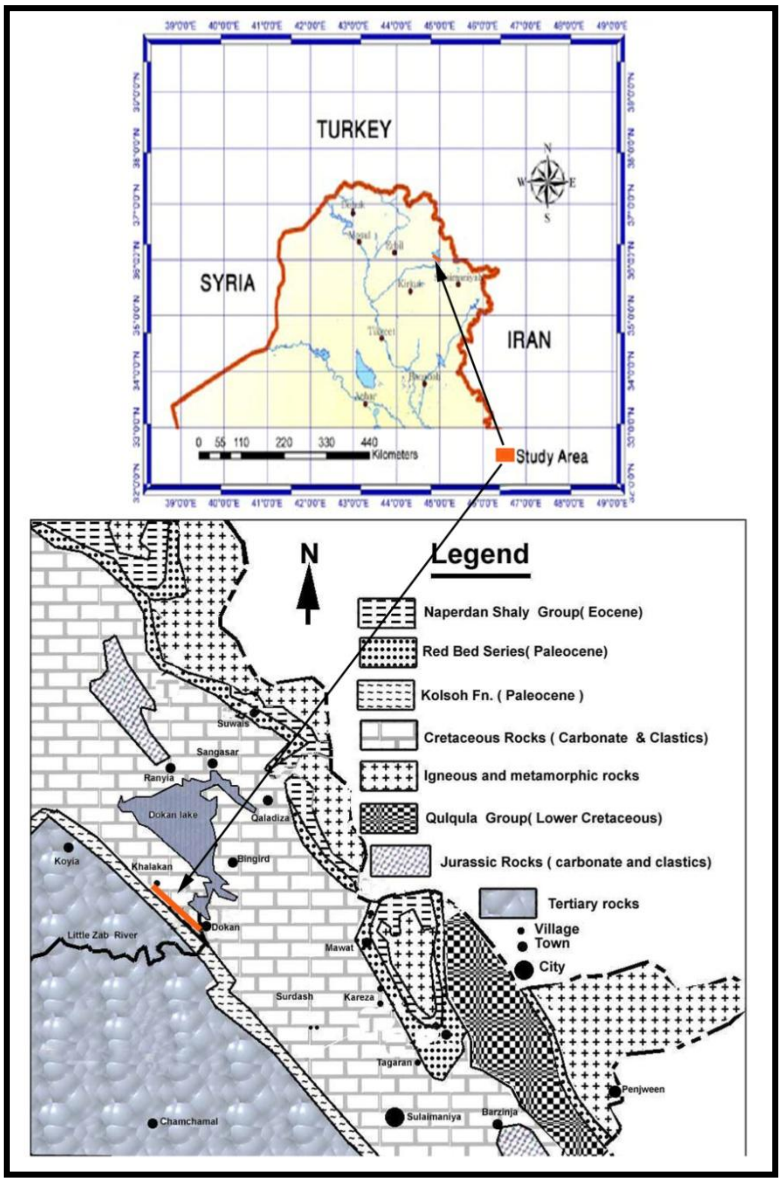


Figure (1-1): Location and geological map of the studied area (after Al-Barzinjy, 2008) without scale

1-2 Scope and Aims of the study:

The selected road for this study is considered a very important road connecting Dokan and Sulaimani city, with Hawler city, Raniya and Qladzeya areas. Also the presence of daylighting slopes along the road results from road cut.

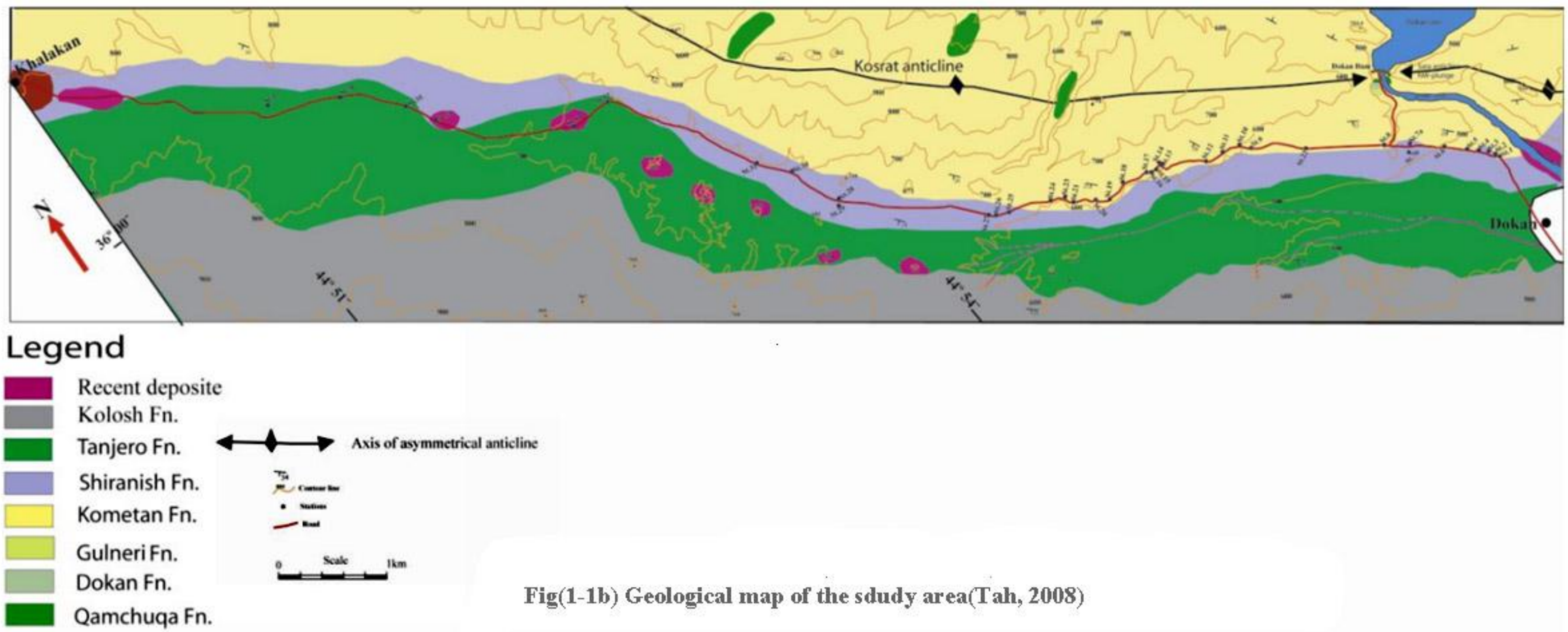
The study aims at:

1- Determining the types of failures (present or probable),
2- determining the factors that affect slope stability around the road in both sides in the area,
3- determining the degree of hazard along the road, making hazard map,
4- finally, proposing curative measures to treat the failures along the road to protect the road user, also construction of geological map Figure (1-2)along Dokan-Khalakan road at a scale of (1:20000).

1-3 Previous Studies:

The previous studies about the study area include:

1- Al-Shaibani, et al. (1986) studied the satratigarphic analysis of Tertiary Cretaceous contact in Dokan area
2- Taha, et al. (1995) studied Microtectonics of Dokan area, involving field measurement of the Microtectonic elements in Kometan Formation exposed at Kosrat Anticline
3- Stevanovic, et al. (2001) presented a report on climate, hydrology, Geomorphology and geology with geological sections and columns of the northern Iraq including the study area.



Fig(1-1b) Geological map of the sdudy area(Tah, 2008)

4- Al-Khafaf, (2005) studied the stratigraphy of Kometan Formation in Dokan area

5- Al-Barzinjy, (2008) carried out a sedimentological study of chert nodules in Dokan area.

6- Karim, et al.,(2008) studied the lithostratigraphy of the contact between Shranish and Kometan Formations.

7- Sharbazheri, (2008) studied Sequence Stratigraphy of Cretaceous (Dokan section) Successions.

There are several studies of rock slope stability in different parts of Iraq The following tables illustrate the previous accomplished studies:

Table 1-1 Previous studies on rock slope stability in Iraq

No.	Author	Subject	Year
1-	Hamasur	Engineering-Geological study of rock slope stability in Haibat Sultan area, NE Iraq	1991
2-	Al-Saadi and Al-Tokmachy	Rock slope instability including new modes of failure from Sidoor area, East of Iraq.	1998
3-	Karim and Ali	Origion of dislocated limestone Blocks on the Slope Side of Baranan (Zirguoez) Homocline: An attept to outlook The development of Western part of Sharazoor plain.	2004
4-	Ali	Effect of slide masses on Ground water occurrence in some areas of Westren part of Sharazoor plain/NE Iraq.	2005
5-	Al-Obaidi	Engineering-Geological study of rock slope stability for Shiranish, Kolosh, Gercus and Pilaspi Fns. around Shaqlawa area N-E of Iraq.	2005
6-	Al-Barzani	Engineering-Geological study of rock slope stability in Harir area, Kurdistan region, Iraq.	2008
7-	Ghafoor	Slope Stability Analysis along (KIRKUK-KOYA) Main Road Kurdistan Region – Iraq	2008

There is no publication about stylolite role in slope stability , but Al-Saadi (in Press under publication) found in 2007 that stylolite surfaces in the Kometan

Formation in Bakhtiari area of suliamani city behave in two diffrent ways; first, those that are parallel to the bedding planes act as stabilizing agents due to interlocking of their peaks, and second, those that are perpendicular to the bedding planes , weathered and tension- cracked act as destabilizing release surfaces that help detachment and slope failure.

Some studies on landslide in the world include the provided list in table (1-2):

Table 1-2 Some world studies on landslide

No.	Author	title	year
1	Zhou et al.,	The spatial relationship between landslides and causative factors on Lantau Island, Hong Kong	2002
2	Lee et al.,	Rock cut slope stability analysis in Sinpal-Ildong region using distinct element method	2003
3	Braathen et al.,	Rock-slope failures in Norway; type, geometry, deformation mechanisms and stability	2005
4	Eberhardt et al.,	Slope instability mechanisms in dipping interbedded conglomerates and weathered marls—the 1999 Rufi landslide, Switzerland	2004
5	Rainer et al.,	Geomechanics of Hazardous	2005

		Landslides	
6	Claessens et al.,	Modelling landslide hazard, soil redistribution and sediment yield of landslides on the Ugandan footslopes of Mount Elgon	2007
7-	Demoulin and Chung	Mapping landslide susceptibility from small datasets: A case study in the Pays de Herve (E Belgium)	2007
8	Brideau et al.,	Geomorphology and engineering geology of a landslide in ultramafic rocks, Dawson City, Yukon	2007
9	Li et al.,	Stability charts for rock slopes based on the Hoek–Brown failure criterion	2008

1-4 Methodology:

The method used in this study included the following stages:

1-4-1 Data collection:

This study were started by collection of papers and review of the literature and reports on the study area (Dokan- Khalakan area) to assess slope stability in addition to the collection of basic topographic maps with a scale of 1:20000 of the study area for use in next stages.

1-4-2 Field work:

The field work of this study is divided into three stages:

- The first stage started before making road widening between Dokan and Khalakan in January 2009, during this stage the selected stations were photographed in order to compare with the second and final stages of field work. The location of each station was determined by using Garmin GPS
- The second stage was performed during the process of road widening in April 2009 and during it, stations were photographed and the new road was determined by using Google earth (GOOGLE EARTH) software and Over-lapping old topographic map of study area on Google earth.
- The third stage (in March-June 2010) involved detailed study of 21 stations for slope stability assessment and comparison of each station with the first and second stages. At each station the required data was measured which include slope height, slope angle, attitudes of beds, thickness of the beds, attitude of discontinuities, their spacing and persistence and determination of colour, grain size and degree of weathering of rocks. All orientations were measured by Silva compass. Other field work that was performed during (March-June/2010) consisted of detailed engineering geological survey of all(37 stations) slopes from Dokan to the Khalakan.Failure hazard map for whole study area is derived from Landslide Possibility Index (LPI) which s based on ten parameters (which will be explained in chapter five). Failure hazard map for road is based on other parameters including (1) size of the detached blocks, (2) distance between the road and the nearest slope toe, and (3) availability of protection work. This stage also involved locating the position of contact between geological Formations on the base map. Also during this stage of field work the rock samples for laboratory testing were collected.

1-4-3 Laboratory work Stage

Strengths of the collected rock samples from the study area were determined by the Point Load test on irregular lump samples and were classified according to the Anon (1977) classification. The friction angle (Ø) of the failure surfaces and the cohesion of soil(c) were carried out by using the (shear box test).

1-4-4 Office work Stage:

At this stage the collected data were represented stereographically using software DIPS version 5.103 software, rocks in the chosen stations were described according to the reports of Anon (1972, 1977). The slopes in stations were classified according to Al-Saadi's classification (1981). The mode of failure at each station was determined depending on the geometry of the slope and discontinuities in the rocks and the related stereograms and classified according to and Varnes (1978),and Hunt (2006),. Also at this stage failure hazard map, road failure hazard map and geological map of the study area with a scale of 1:20000 were constructed.

1-5 EARHQUAKE HAZARD:

Strong ground shaking duration has triggered landslides in many different topographic and geologic settings. Rockfall, soil slides, and rock slides from steep slopes, involving relatively thin or shallow disaggregated soil or rock, or both have been the most abundant type of landslide trigged by historical earthquake (Wieczorek, 1996). The seismic hazard for the investigated area shows that the studied area is located in minor damage zone which covers intensities of (IV-V) (Al-sinawi and Al-Qasrani, 2003) which means that this area is affected by earthquake activity.

1-6 Climate of the study area:

Kurdistan region is located in semiarid climate zone, mountainous region, cold winter and dry summer. The area is affected by Mediterranean climatologically system, so its precipitation occurs during winter and spring seasons. Climatological factor plays an important role in rock slope stability especially rainfall intensity, rapid snowmelt and temperature. Crozier (1997) discussed different climatic signal types responsible for the triggering of landslides including (1).Frequency, (2).magnitude, and (3.) duration of rainfall, and he emphasized different changing climatic conditions responsible for a change in these rainfall attributes.

1-6-1 Rainfall:

The studied area is characterized by seasonal rainfall especially in January, February, March and April and dry season in June, July, August and September. Generally, we have change in annual rainfall from year to another year. In 1990 the annual rainfall was (719mm) while in 1996 the annual rainfall was (1139mm). The mean average annual rainfall in the area is (774mm), the maximum average monthly precipitation recorded for the period(1984-2005) was (148.9mm) in December and (148.1mm) in January figure (1-3) (Stevanovic et al., 2003). The data were obtained from the meteorological station in Dokan dam area.

Intense rainfall is the most common triggering mechanism of landslides worldwide, sites are most susceptible to landsliding during wet antecedent condition (Sidle, 2007).Slope saturation by rainfall water is a primary cause of landslide. This effect can occur in the form of intense rainfall, Snow melt, change in ground-water level, and water level change in earth bank of lake, reservoir, canals, and rivers. Unless the pore pressure within the slope adjacent to the falling water level can dissipate quickly, the slope is subject to higher stress and potential instability (Wieczorek, 1996).All these events help to increase pore water pressure, which leads to reduce the friction angle, which assists to increase the probability of sliding.

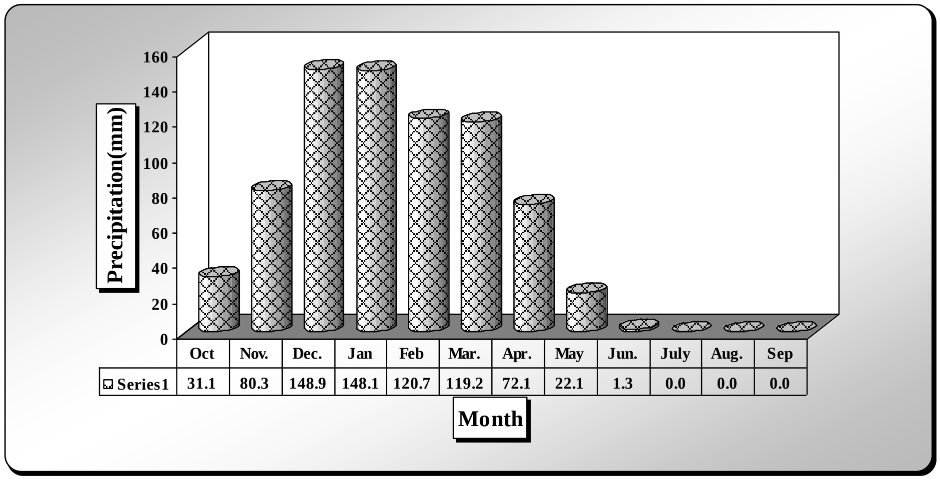


Fig (1-3) Average Monthly Precipitation of Dokan Station for the Period of (1984-2005) after (Al-Manmi, 2008)

1-6-2 Temperature and Humidity:

In the study area the average monthly temperature value for the period (1984-2005) was (19.1°C), and the maximum average monthly temperature was (33.3 °C) in July, while the minimum was (5.7 °C) in January; Figure (1.4) shows the annual average monthly temperature for the period (1984-2005). Based on Dokan station's data the average annual relative humidity is (56.5 %), the average minimum and maximum values of this parameter in the studied area are (33.5 %) and (74.6 %) in July and December respectively. Figure (1-5) shows the average monthly relative humidity for the period of (1984-2005).

The temperature and humidity can cause gradual change in the strength of earth material that may become important in stability analyses. In cold climate, freezing and icing are important processes in slope stability evaluations because ice is effectively impermeable and can cause the buildup of hydrostatic pressures. Rapid melting of a frozen slope can create an equivalent rapid drawdown condition causing slope movement (Keaton and Beckwith,1996).

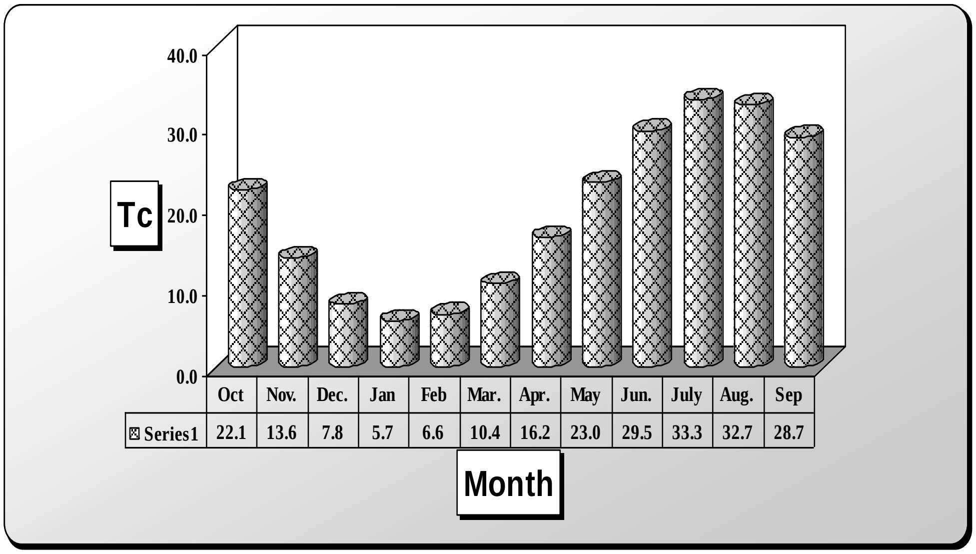


Figure (1-4) The annual monthly average temperature of Dokan Station after (Al- Manmi, 2008)

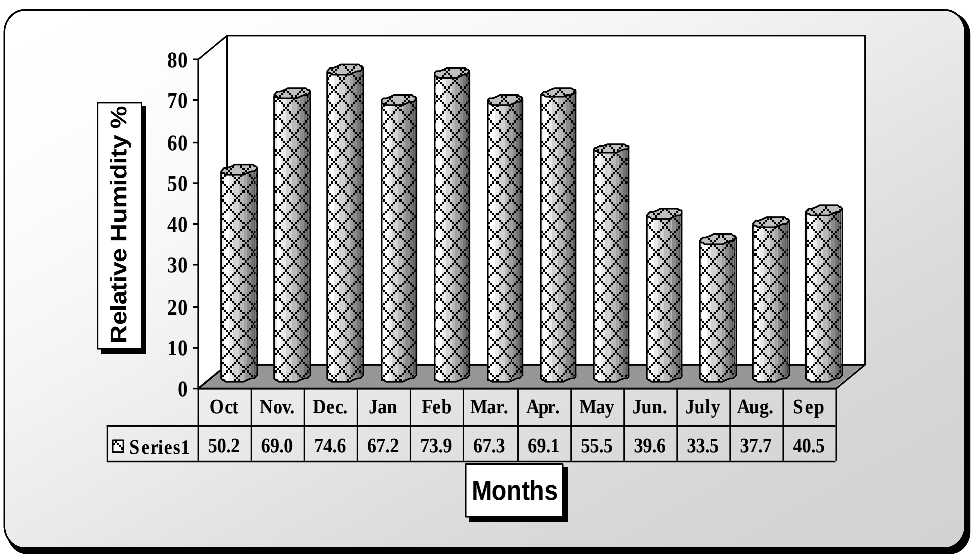


Figure (1- 5) Average Monthly Relative Humidity of Dokan Station for the Period of (1984-2005) after (Al-Manmi, 2008)

CHAPTER TWO

GEOLOGY OF THE STUDY AREA

2-1 Stratigraphy:

The exposed formations in the study area start with Cretaceous succession including Qamchuqa, Dokan, Gulneri, Kometan, Shiranish and Tanjero Formations then followed by Tertiary successions that include Kolosh, Sinjar, Gercus and Pilaspi Formations. Following are brief lithologic descriptions of theses rock units:

2-1-1**Qamchuqa Formation (**Hauterivian-Albian)**:**

This formation was described for the first time by Wetzel in 1950 in (Bellen et al.,1959) in High Folded Zone NE Iraq. It consists mainly of the neritic limestone generally coarse crystalline, granular, rhombic and mosaic dolomite of the Huterivian-Albian(Lower Cretaceous)age (Buday,1980).This formation consists of well bedded limestone with massive dolostone and dolomitic limestone. It forms the carapace of some of the more impressive anticline mountains in the folded belt, including Dokan ,Pirmagrun, Safin Dagh,etc(Bellen et al.,1959).This Formation laterally changes to Balambo Formation (Buday, 1980)and the lower contact of the Qamchuqe Formatin is conformable and graditional with the underlying Sarmord or underlying Balambo Formations; The upper contact is marked by a break which is unconformable; it is an unconformity in N and NE part of Iraq (Jassim and Goeff,2006).

2-1-2 **Dokan Formation** (Cenomanian)**:**

Dokan Limestone Formation(Cenomanian) at first was described in Dokan dam area, as a separate formation by Lancaster and Jones in 1957 (Bellen et al., 1959), it is about 3.75 m thick and represents light grey or white-weathering oligosteginal limestone, locally rubble, with glauconitic coating of constituents pebble , like masses, locally worm riddled. In the subsurface, the limestone has dark grey and often argillaceous. The thickness of the Formation increases towards the Low Folded Zone and reaches 150m in Chemchamal well; the lower contact with Qumchuqa Formation is unconformable and erosinoal . The upper contact with Gulneri Formation is unconformable and erosional (Bellen et al., 1959).

2-1-3 **Gulneri Formation** (Turonian)**:**

This Formation is (Turonian) in age, it was first described by Lancaster and Jones in 1957 from the site of Dokan dam in the High Folded Zone NW of Sulaimani city (Bellen et al., 1959), where it consists of about 1.5m of black bituminous, finely laminated, calcareous shale with some glauconite and collophane in the lower part with very thin bed of glauconite at upper part with the above Kometan Formation. The underlying Formation is Dokan Formation this contact is an erosional unconformity; the overlying formation is Kometan Formation; the contact is an erosinal unconformity too (Bellen et al., 1959).

2-1-4 **Kometan Formation(** Turonian-Lower Campanian)**:**

This Formation was first described by Dunington, (1958) and it is of the Turonian-Lower Campanian age. The lower part is glauconitic with a thin bed of shale within the Formation, the upper part is stylolitic and contain chert lenses or nodules. The overlying Formation is Shiranish Formation the contact is unconformable indicating non-depositional hiatus. Karim et al. (2001) studied ichnofacies at this boundary in details and they proved that it is an indicator of unconformity surface and hard ground features during slow sedimentation.

2-1-5 **Shiranish Formation(**Upper. Campanian):

This Formation is of Upper campanian age; The Formation was first defined by Henson in 1940 from the High Folded Zone of N Iraq near the village of Shiranish Islam, NE of Zakho city (Bellen et al., 1959). The Formation in the type section consists of thin bedded argillaceous limestone (locally dolomitic) overlain by blue pelagic marls, of Late Campanian Maastrichtian age (Bellen et al., 1959). Shiranish Formation in Dokan section consists of a thick unit about 250 m thick of bluish marly limestone at lower part and marlstone at the upper part. The lower contact with the underlying Kometan Formation is non-depositional unconformity. The upper contact with the overlying Tanjero Formation is gradational and conformable(Bellen, et al 1959).

2-1-6 **Tanjero Formation**(Upper Senonian):

The Tanjero clastic Formation is of (Upper Senonian) age. It is present in the Balambo-Tanjero Zone of NE Iraq, (Jassim and Goeff, 2006).The Formation was defined by Dunnington,in 1958.The type locality of the Formation lies in Sirwan valley, southeast of Sulaimani, and belongs structurally to the Imbricated Zone (Buday,1980). It comprises two divisions, the lower division comprises pelagic marl, occasional beds of argillaceous limestone with siltstone beds in the upper part, the upper division comprises silty marl, sandstone, conglomerates, and sandy or silty organic detrital limestone; it interfingers with Aqra limestone (Bellen et al ., 1959). The lower contact with the underlying Shiranish Formation is gradational and conformable placed at the lowest occurrence of silt-grade clastics, which corresponds to a change colour from blue (Shiranish Formation)below to olive green (Tanjero Formation) above. There is a major unconformity with the overlying Kolosh clastic Formation of Tertiary (Paleocene) age (Bellen et al ., 1959). Figure (2-1) shows the stratigraphic column of the study area.

2-1-7 **Quaternary deposit** (Pleistocene and Holocene)**:**

They represent sediments of Pleistocene and Holocene ages (Buday, 1980) that consist of river terraces, slope deposits, alluvial deposits and composed of mud, silt, sand and pebbles.

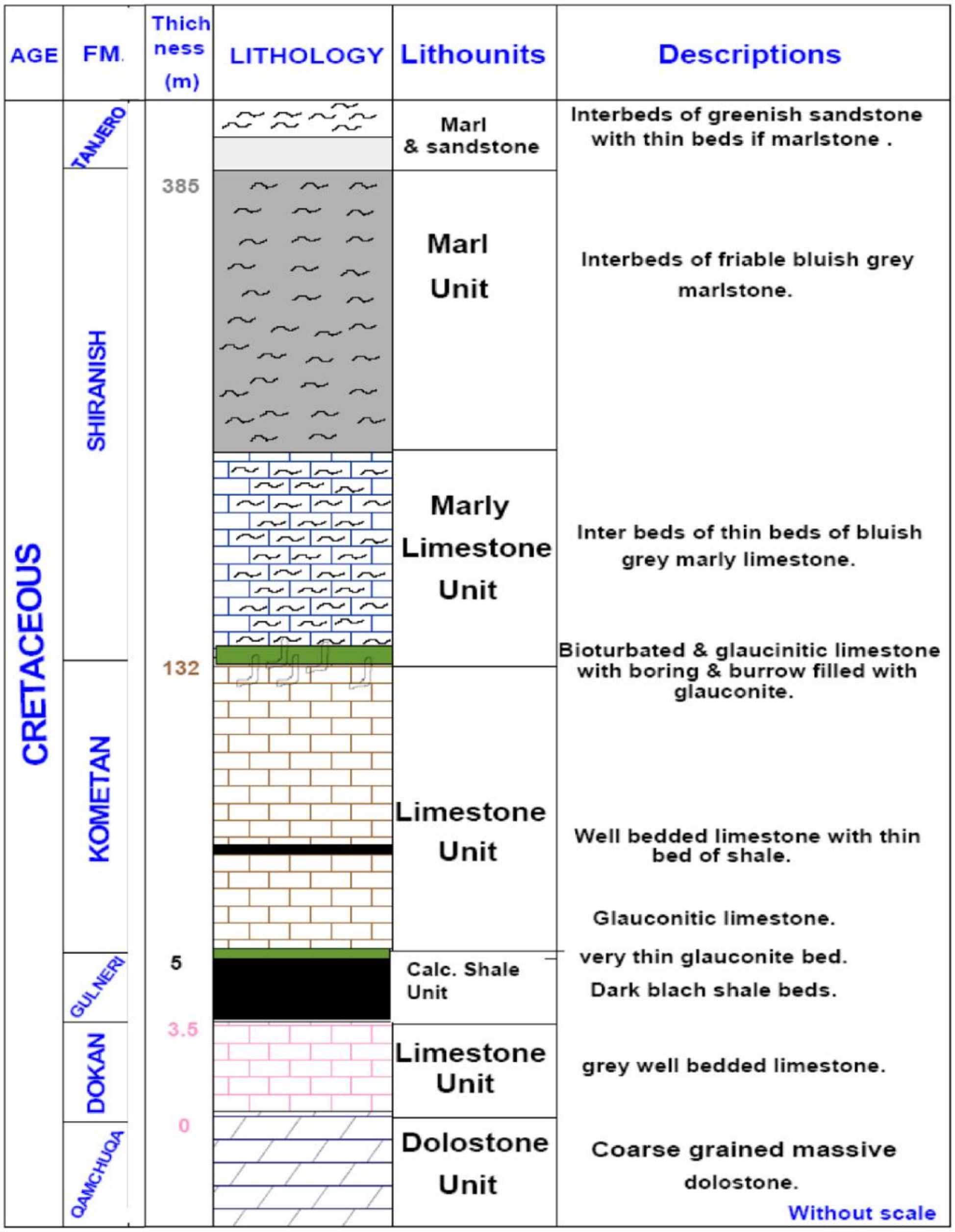


Figure (2-1) Stratigarphic column of the study area after (**Sharbazheri, 2008)**

2-2 **Regional Tectonic Setting:**

According to Jassim and Goff, (2006) Iraq is divided into three tectonically different areas:

1- The Stable Shelf with major buried arches and antiforms but almost no surface anticlines.
2- The Unstable Shelf with surface Anticlines.
3- The Zagros Suture, which comprises thrust sheets of radiolarian chert, igneous and metamorphic rocks.

These three areas contain tectonic subdivisions which trend N-S in the Stable Shelf and NW-SE or E-W in the Unstable Shelf and the Zagros Suture. The N-S trend is due to Paleozoic tectonic movements; the E-W and NW-SE trends are due to Cretaceous-Recent Alpine orogenesis.

1-The Stable Shelf consists of:

a-Rutba-Jezira Zone

b-Salman Zone

c-Mesopotamian Zone

2-The Unstable Shelf Zone consists of:

a-Foothill Zone

b-High Folded Zone

c-Balambo-Tanjero Zone

d-Northern Thrust (Ora)Zone

3-The Zagros Suture Zone consists of:

a-Khuakurk Zone

b-Penjween-Walash Zone

This division shows that the selectd study area is located in the High Folded Zone which is characterized by anticlines of high amplitude with Paleogene or

Cretaceous carbonate rock exposed in their cores. The zone was uplifted in Cretaceous, Paleocene and Oligocene times (Jassim and Goff, 2006), figure (2-2).

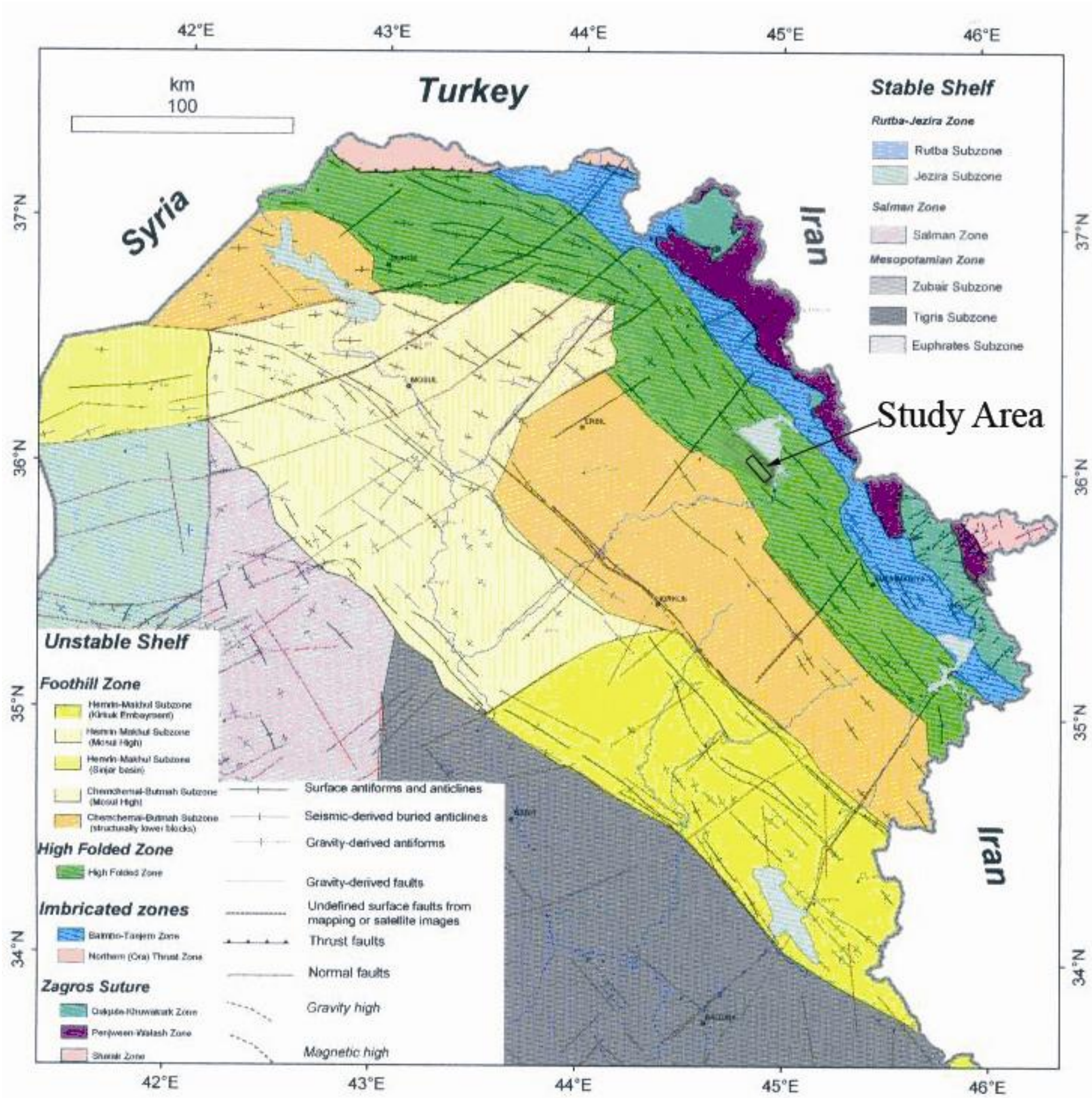


Figure (2-2) Tectonic map of Iraq by (Jassim and Goff, 2006) Showing the location of the study area

2-3 **Structural Features:**

The studied area lies in the High Folded Zone, it was subjected to two major compressive tectonic phases during which the maximum principal stresses led to the formation of Microtectonic elements in the area which include faults, joint and the stylolitic peaks as well as sheared zones of en echelon veins, these tectonic elements were acting along the following trends:

(A)-NNE-SSW and

(B)- E-W (Taha., et al.1995) .

The major structure in the area is:

- Kosrat anticline:

  The study area lies in the southwestern limb of Kosrat anticline. The Kosrat anticline is trending in NW-SE direction. The south- western limb is steeper with average dip of 53^{o} while the average dip of northeastern limb is about 17^{o} (Stevanovic, et al., 2003).Figure (2-3) geologic cross section (NE.SW) in the Dokan Gorge(Directly to the south of the dam site) is a geologic map of the studied area showing the major structure in it (after Karim , et al., 2009).

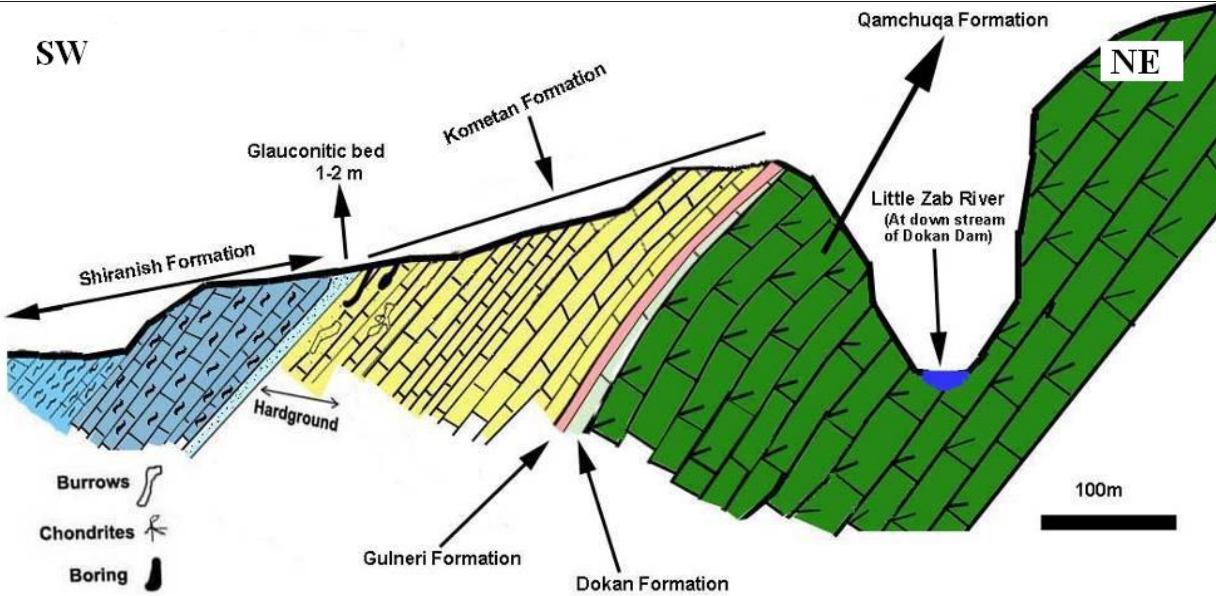


Fig (2-3) Geologic cross section (NE.SW) in the Dokan Gorge (Directly to the south of the dam site) modified after (Taha, and Karim, 2009)

2-4 Geomorphological features:

The geomorphic features are considered as important criteria to estimate landslide hazard. Recognition of existing and past landslides events represent an active way for study and classification of landslide hazards (Cardinali, et al, 2002). The geomorphology of the study area is characterized by three geomorphological features: These are

1. Structural unit: This reflects the influence of structure on the landform. This unit is represented by the presence of the dip slopes in the strong limestone layer of Kometan Formation, and the fault scarps especially in Kometan Formation, which form steep stable slopes, cuestas and hogbacks in Kometan Formation and Shiranish Formation.
2. The denudational unit: This shows the influence of denudation processes on the landform. This unit includes the steep toe slopes of Kometan and Shiranish Formations, which are formed naturally or by man activities during road widening processes. The steep cliffs or slopes (rock wall) of the hard

limestone layers of Kometan and Qumchuqa Formations in the valleys are also involved, in addition to rock debris at the toe of most steep and hard limestone slopes. These represent forms of gravitational origin. The rounded smooth moderate to gentle slopes of the weak marl and marly limestone of Shiranish Formation are examples of denudational landforms. Erosional forms also include gully erosion in Quaternary sediment in the valleys near the main road

3. The fluvial unit: It involves all drainage lines (valleys) that form different drainage patterns and some valleys with narrow flood plains. Some stream courses are braided reflecting high stream load that leads to deposition of sediment and diversion of channels. Meanders in the valley are also noticed reflecting lateral erosion. The prevailing drainage pattern in the study area is dendritic pattern due to the homogeneity of rocks specially the weak rock of Shiranish Formation. Some parallel and sub-parallel drainage patterns are also noticed. Trellis pattern exists in strike valleys between cuestas and hogbacks.

CHAPTER THREE

LABORATORY WORK

3-1 Strength test:

The shear strength developed along potential rupture surface within a slope has an important influence on the stability of rock slope (Norrish & Wyllie, 1996). All geological materials have some ability to resist failure under the action of stresses; this is their strength, and it is an important parameter in the classification of rocks table (3.1). Most values quoted as the 'strength of' a certain material are the stresses at failure, the ultimate failure strength. Usually, testing is done on small samples in the laboratory. Strengths measured are:

_ uniaxial (or unconfined) compressive strength, which is the stress at failure of a sample under compression;

_ uniaxial (or unconfined) tensile strength which is the stress at failure of a sample under tension;

_ triaxial strength, which is the stress at failure of a sample that is confined. This is usually accomplished by placing the sample under compression while it is restrained laterally by a minor horizontal confining pressure. The units of strength are force/area, for example Nmm^{-2}, $kN\ m^{-2}$, $MN\ m^{-2}$. Recently it has become fashionable to use Pascal, particularly for compressive strength (1 Pascal (Pa) = 1 $N\ m^{-2}$) (David, 2009).

Table3.1 Grades of unconfined compressive strength Bell(2007)

(Anon, 1977)		(Anon, 1981)	
Term	**Strength(MPa)**	**Term**	**Strength(MPa)**
Extremely strong	> 200	Very high	Over 200
Very strong	100 – 200	High	60–200
Strong	50 - 100	Moderate	20–60
Moderately strong	12.5 – 50	Low	6–10
Moderately weak	5.0 - 12.5	Very low	Under 6
Weak	1.25 – 5.0		
Very weak	< 1.25		

The point load test is an appropriate method to estimate the compressive streangth table (3.2) in which both core and lump samples can be tested, this equipment is portable, and tests can be carried out quickly and inexpressively in the field (Norrish & Wyllie, 1996).

Table 3.2 Point load strength classification (after Anon, 1972)

Term	**Point load strength index (MN/m^2)**	**Equivalent uniaxial Compressive strength. (MN/m^2)**
Extremely strong	>12	Over 200
Very strong	6–12	100-200
Strong	3–6	50-100
Moderately strong	0.75–3	12.5–50
Moderately weak	0.3–0.75	5-12.5
Weak	0.075–0.3	1.25–5
Very weak	<0.075	<1.25

3-1-1 Shear box test:

The main requirement for occurrence of plane or wedge sliding along failure surfaces is that, the dip angle of failure plane (θ) must be equal or greater than the friction angle (Ø).due to the presence of clay seams between the failure surface , so the direct shear tests for undrained condition were carried out to determining the friction angle of clay . The shear box apparatus is shown in Fig (3-1). For this test, disturbed soil samples between rock layers were used (3 samples per each station), fig(3-2A and B). In this test both the friction angle (Ø) and the cohesion of soil(c) are determined table (3-3).

Figure (3-1) Shear box test apparatus

Table (3-3): The results of shear box tests

Station No.	Friction angle (Ø)	Cohesion (c)
5	10^{0}	32
10	11^{0}	64

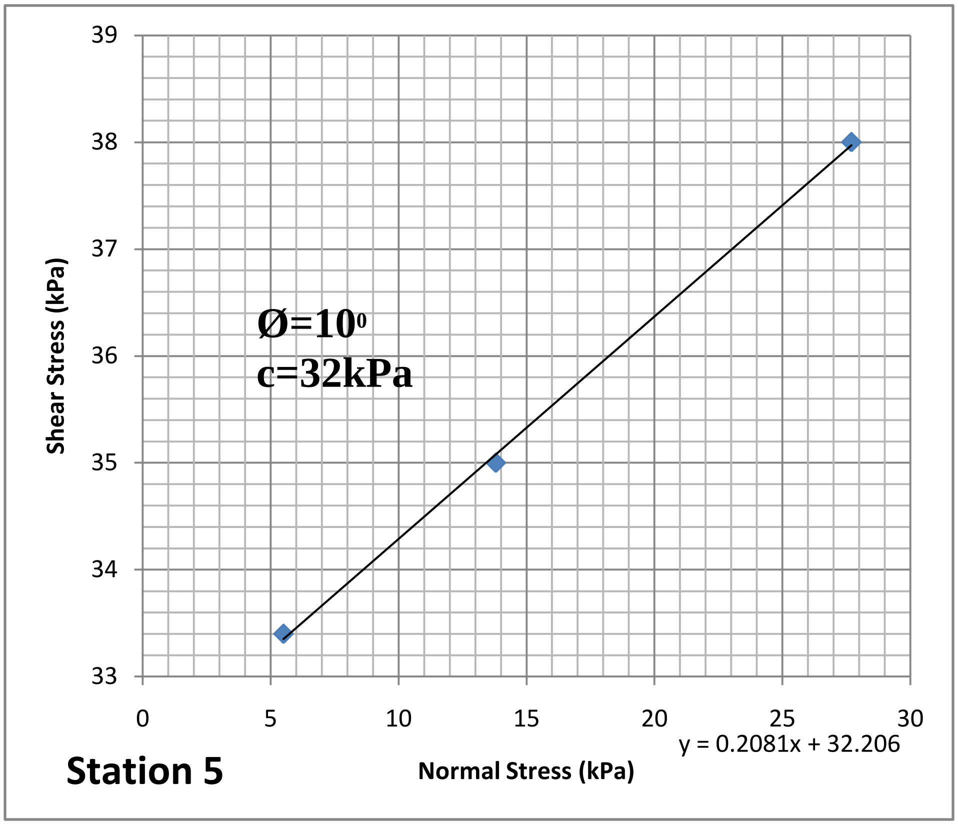


Figure (3-2A) Shows the relation between shear stress and normal stress at station No.5. Different vertical and horizontal scales apparently exaggerate the angle (Ø)

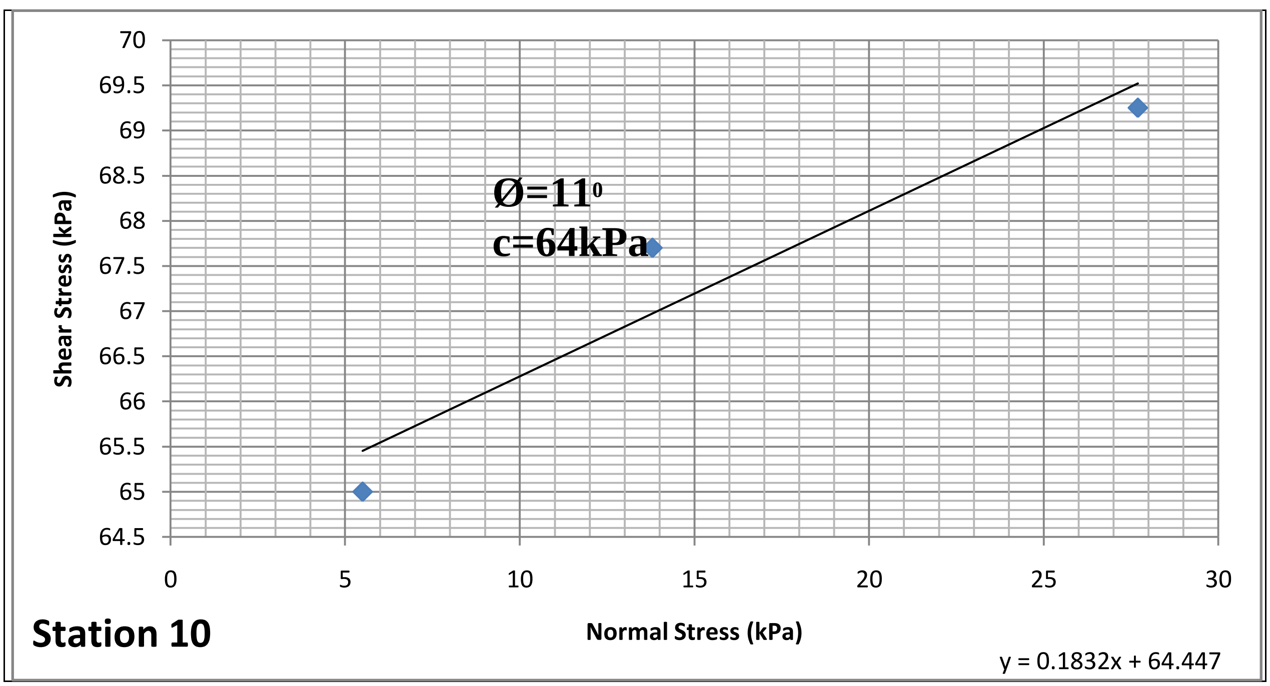


Figure (3-2B) Shows the relation between shear stress and normal stress at station No.10 Different vertical and horizontal scales apparently exaggerate the angle (Ø)

3-1-2 Point load test:

The point load test (PLT) is an accepted rock mechanics testing procedure used for the calculation of rock strength index figure(3-3) .This index can be used to estimate other rock strength parameters; The PLT is an efficient method to determine intact rock strength properties from drill core samples. It has become an accepted test in geotechnical evaluations (Rusnak and Mark, 2000) .The Point Load test (Broch and Franklin 1972) has been used since 1960 and has become the most popular of the simpler techniques. A core is loaded between two 'points' which are steel cones subtending an angle of 60° and terminating in a hemisphere of 5 mm radius Fig(3-3). The core is usually loaded across a diameter. The test specimen length should be at least 1.5 times the length of the diameter.

Figure (3-3) Point load test apparatus (ELE)model

The strength value obtained from the Point Load test varies according to core diameter, and the influence of the sample size upon UCS has been widely discussed (e.g., Hoek and Brown, 1980; Hawkins, 1998); it is generally assumed that there is a significant reduction in strength with increasing sample size, with a constant ratio of height to diameter of the cylindrical rock cores (Tsiambaos and Sabatakakis, 2004).

The test was performed according to the procedure of ISRM (1985), in which the point load strength allows the determination of the uncorrected point load strength index (Is), which can be derived as follows:

$I_s = F / De^2 = \Pi F/4A = \Pi F/4*D*W$

where: **I_s:** Uncorrected Point Load Strength Index, in MPa or psi

F= Force at Failure

De= Equivalent core diameter, in meters or inches which is given by:

1-De = D for diametral tests) and
2-De=√((4A/Π) for axial ,block or irregular lump tests, Fig(3-4)
Where A=D*W,   A=is minimum cross sectional area of a plane through the platen contact points.

D is the thickness of specimen and **W** is the horizontal width of specimen.

This index must be corrected to the standard equivalent diameter (De) of 50 mm as follows:

$Is_{(50)} = f*(F/De^2) = f*Is$……………….ISRM(1985)

Where : $Is_{(50)}$ =point load strength index of a specimen of 50mm diameter. f=size correction factor = $(De/50)^{0.45.}$

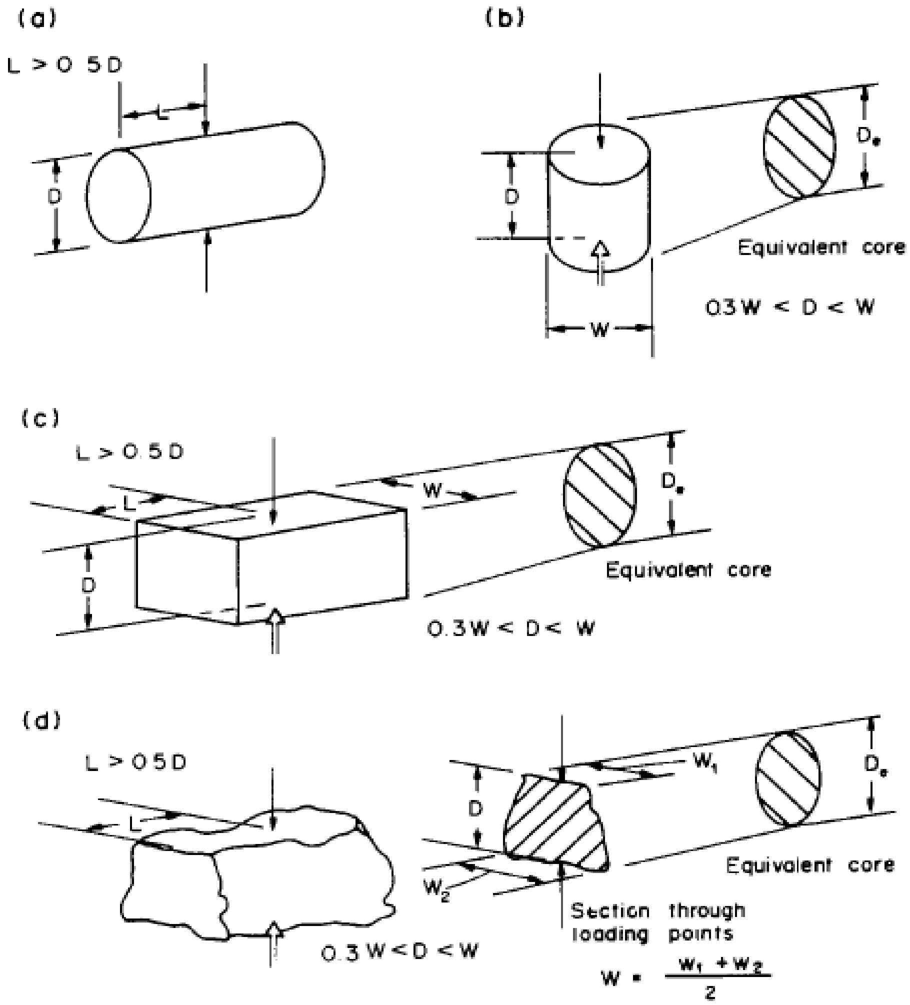


Figure (3-4) Specimen shape requirements for (a) the diametral test, (b) the axial test, (c) block test, and (d) irregular lamp test(ISRM 1985),

Early studies (Bieniawski, 1975; Broch and Franklin, 1972) were conducted on hard strong rocks, and found that relationship between uniaxial compressive strength (UCS) and the point load strength could be expressed as:

UCS = (K) Is_{50} = 24 Is_{50}

where K is the "conversion factor." The conversion factor between point load and uniaxial compressive strength varies from 13 for soft sedimentary rocks (exhibiting a value of $Is_{(50)} < 2$ MPa) to 28 for harder rocks with values of $Is_{(50)}$ greater than 5 MPa (Tsiambaos and Sabatakakis,2004) figure (3-5). The conversion factor can be determined by a graph Figure (3-6)

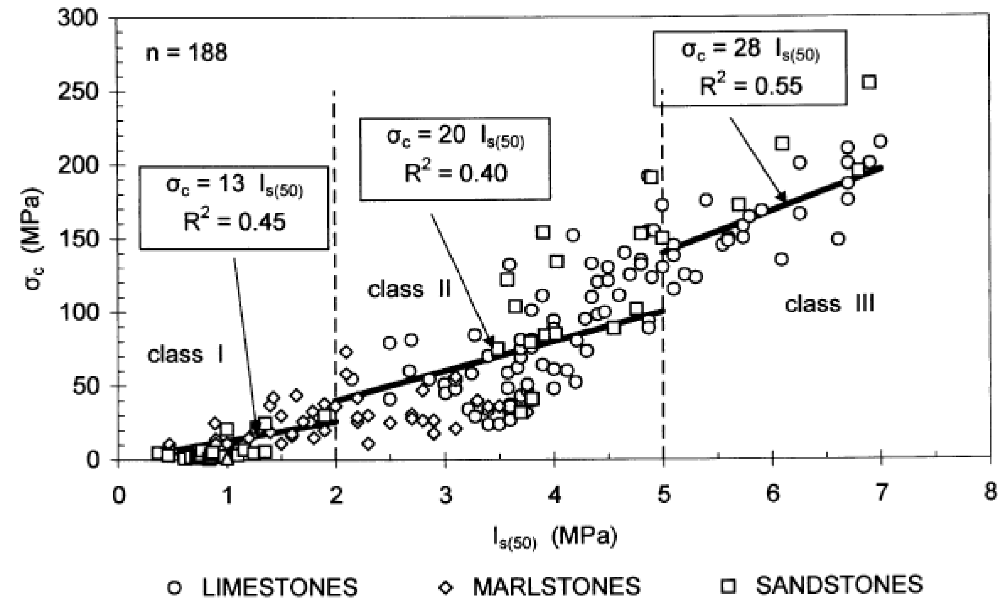


Figure (3-5) Conversion factors correlating point loading and uniaxial compressive strength for soft to strong sedimentary rocks (Tsiambaos and Sabatakakis, 2004).

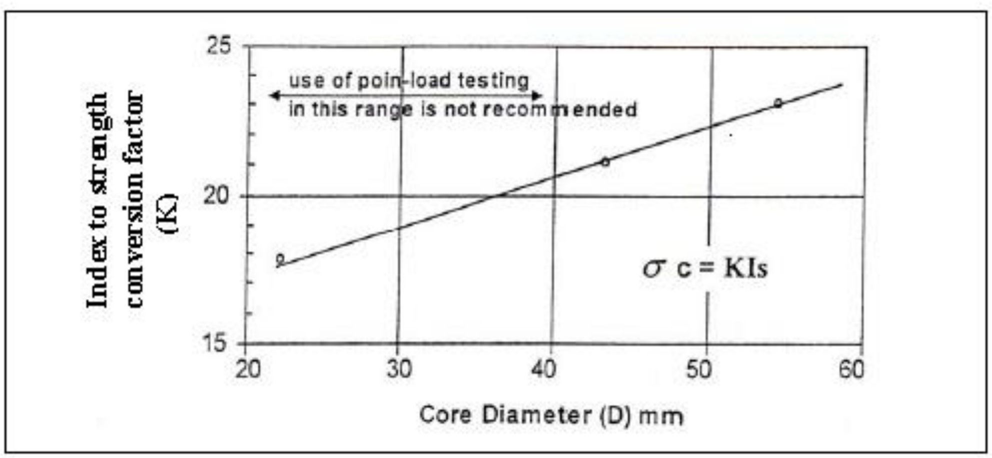


Figure (3-6) Graph showing the relation of diameter and conversion factor (K) to the strength (Bieniawski, 1975)

In this study, because of similarity in lithology within each of Kometan and Shiranish Formations, 14 stations were chosen to collect samples for test (3 samples per each station) Each of those samples was cut by saw machine in the Department of Geology to have a specific geometrical shape nearly (blocky) irregular lump .The value of σc for each sample was determined, then the rocks were classified depending on Anon (1977) table (3-4).

Table (3-3) The results of point load tests and the related UCS of collected samples from study area.

St.No	F(kN)	D mm	Is=F/(D^2)	f= (D/50)^0.45	Is 50mm	σc=22.5*Is (50) (MPa)	Lithology	Average (MPa)
1+2	30	78	4.93	1.22	6.02	135.53	Limestone(Kometan)	125.84 Very strong
1+2	26	88	3.36	1.29	4.33	97.43	Limestone(Kometan)	
1+2	32	78	5.26	1.22	6.42	144.56	Limestone(Kometan)	
3+4	10.5	70	1.02	1.16	1.18	53.71	MarlyLimestone(Kometan)	53.89 strong
3+4	10	74	0.91	1.19	1.17	49.51	Marly Limestone(Shiranish)	
3+ 4	11	74	0.94	1.19	1.19	58.51	Marly Limestone(Shiranish)	
5	26	88	3.36	1.29	4.33	97.43	Limestone(Kometan)	99.30 Strong
5	27	88	3.49	1.29	4.50	101.17	Limestone(Kometan)	
6	26	86	3.52	1.28	4.49	100.96	Limestone(Kometan)	104.84 Very strong
6	28	86	3.79	1.28	4.83	108.73	Limestone(Kometan)	
7	10	80	1.56	1.24	1.93	43.44	Marly Limestone(Kometan)	49.80 Moderately strong
7	9	72	1.74	1.18	2.05	46.03	Marly Limestone(Shiranish)	
7	10	65	2.37	1.13	2.66	59.93	Marly Limestone(Shiranish)	
9+10+8	29	97	3.08	1.35	4.15	93.44	Limestone (Kometan)	112.82 Very strong
9+10+8	28	75	4.98	1.20	5.97	134.42	Limestone (Kometan)	
9+10+8	29	87	3.83	1.28	4.92	110.61	Limestone (Kometan)	
12+11	17	65	4.02	1.13	4.53	101.88	Limestone (Kometan)	90.44 strong
12+11	21	85	2.91	1.27	3.69	83.04	Limestone (Kometan)	
12+11	18	75	3.20	1.20	3.84	86.41	Limestone (Kometan)	
13	16	49	6.66	0.99	6.60	148.58	Limestone (Kometan)	104.95 Very strong
13	24	78	3.94	1.22	4.82	108.42	Limestone (Kometan)	
13	20	104	1.85	1.39	2.57	57.85	Limestone(Kometan)	
14	33	83	4.79	1.26	6.02	135.39	Limestone (Kometan)	112.25 Very strong
14	21	83	3.05	1.26	3.83	86.16	Limestone (Kometan)	
14	24	75	4.27	1.20	5.12	115.22	Limestone(Kometan)	
15	18	94	2.09	1.33	2.78	62.58	Limestone(Kometan)	85.51 Strong
15	28	85	3.88	1.27	4.92	110.71	Limestone(Kometan)	
15	23	90	2.84	1.30	3.70	83.23	Limestone(Kometan)	
16	20	74	3.65	1.19	4.36	98.03	Limestone(Kometan)	91.40 Strong
16	24	90	2.96	1.30	3.86	86.85	Limestone(Kometan)	
16	23	86	3.11	1.28	3.97	89.31	Limestone(Kometan)	
17	25	107	2.18	1.41	3.08	69.19	Limestone(Kometan)	91.44 strong
17	30	90	2.84	1.30	3.70	83.23	Limestone(Kometan)	
17	28	106	2.49	1.40	3.49	78.63	Limestone(Kometan)	
20+19+18	24	80	3.75	1.24	4.63	104.25	Limestone(Kometan)	92.13 strong
20+19+18	25	82	3.72	1.25	4.65	104.51	Limestone(Kometan)	

CHAPTER FOUR

SLOPE STABILITY

PART 1-Theoretical Background

4-1 Landslide and Rock slope Stability:

Landslides and related slope instability phenomena plague many parts of the world. A wealth of experience has been accumulated in recent years in understanding, recognition and treatment of landslide hazards but knowledge on this field in Kurdistan Region is still fragmentary. Particular area requiring attention concerns the selection and design of appropriate, cost-effective remedial measures, which in turn require a clear understanding of the conditions and processes that caused the landslide. Much progress has been made in developing techniques to minimize the impact of landslides, although new, more efficient, quicker and cheaper methods could well emerge in the future. Landslides may be treated or controlled by one or any combination of four principal measures: modification of slope geometry, drainage, retaining structures and internal slope reinforcement. There is a number of levels of effectiveness and levels of acceptability that may be applied in the use of these measures, for a while one slide may require an immediate and absolute long-term correction, another may only require minimal control for a short period (Popescu, 2002). Landslides are recognized as the third type of natural disasters in terms of worldwide importance (Zillman, 1999). Due to natural conditions or man-made actions, landslides have produced multiple human and economic losses (Guzzetti, 2000). This is illustrated in Table 4.1, which shows the statistics of landslides disasters per continent from April 1903 till January 2007 from the Emergency Disaster Database, EM-DAT, (OFDA/CRED, 2007). In this period landslides have caused 57,028 deaths and affected more than 10 million people around the world. The quantification of damage is more than US$5 billion. These losses have driven the politicians and the scientific community to produce disaster risk reduction plans for landslides, which imply first of all landslide risk assessment.

4-2 Landslide elements:

Stated simply, slope failures are the result of gravitational forces acting on a mass which can creep slowly, fall freely, slide along some failure surface, or flow as a slurry. Stability can depend on a number of complex variables, which can be placed into four general categories as follows (Hunt, 2006):

1. Topography — in terms of slope inclination and height
2. Geology — in terms of material structure and strength
3. Weather — in terms of seepage forces and run-off quantity and velocity
4. Seismic activity — as it affects inertial and seepage forces

Table (4-1) World statistics for landslide from (Castellanos, 2008)

Continents	Events	Killed	Injured	Homeless	Affected	Total Affected	Damage US (000's)
Africa	23	745	56	7,936	13,748	21,740	No data
Average per event		32	2	345	598	945	No data
Americas	145	20,684	4,809	186,752	4,485,037	4,676,598	1,226,927
Average per event		143	33	1,288	30,931	32,252	8,462
Asia	255	18,299	3,776	3,825,311	1,647,683	5,476,770	1,534,893
Average per event		72	15	15,001	6,462	21,478	6,019
Europe	72	16,758	523	8,625	39,376	48,524	2,487,389
Average per event		233	7	120	547	674	34,547
Oceania	16	542	52	18,000	2,963	21,015	2,466
Average per event		34	3	1,125	185	1,313	154
Total	511	57,028	9,216	4,046,624	6,188,807	10,244,647	5,251,675

4-3Types of rock slope failures:

The most important factor for rock slope failure is the presence of discontinuity surfaces, such as faults, joints and bedding planes, within the rock mass. When these discontinuities are vertical or horizontal, simple sliding can not take place, and the slope failure will involve fracture of intact blocks of rock, as well as movement along some of the discontinuities (Hoek and Bray, 1981). On the other hand, the presence of discontinuities having angles between 30º and 70º and dipping towards the slope face can produce sliding of rock masses. Slope failures in rocks for which factors of safety can be calculated (Hoek and Bray, 1981) are:

4-3-1 Plane failure (Figure 4.1):

It occurs in cases where a geological discontinuity, such as a bedding plane, joint or a fault, strikes parallel to the slope face and dips into the excavation at an angle equal or greater than the angle of friction (Hoek and Bray, 1981). Five necessary structural conditions for planar failures can be summarized as follows (Norrish and Wyllie, 1996):

1- The dip direction of the planar discontinuity must be within 20 degrees of the dip direction of the slope face. This is an empirical criterion and results from the observation that plane slides tend to occur when the released blocks slide more-or-less directly out of the face, rather than very obliquely.

2- The dip of the planar discontinuity must be less than the inclination of the slope face and thereby must daylight in the slope face.

3- The dip of the planar discontinuity must be equal or greater than the angle of friction of the surface.

4- The lateral extent of the potential failure mass must be defined either by lateral release surfaces or by the presence of a convex slope shape that is intersected by planar discontinuity.

5- Cohesion (c)=zero

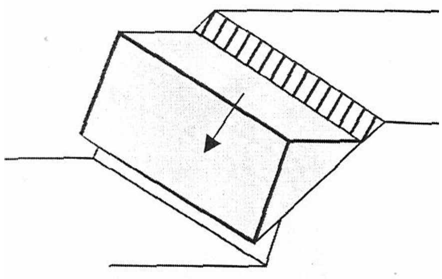


Figure (4-1) Plane type of failure in rocks (Hoek and Bray, 1981)

4-3-2 Wedge failure (Figure 4-2):

It occur when two discontinuities strikes obliquely across the slope face and their line of intersection daylights in the slope face. The wedge of rock resting on these discontinuities will slide down the line of intersection, provided that the inclination of this line is significantly greater than the angle of friction (Hoek and Bray, 1981). Necessary structural conditions for wedge failure can be summarized as follows (Norrish and Wyllie, 1996):

1. The trend of the line of intersection must approximate the inclination direction of the slope face.
2. The plunge of the line of intersection must be less than the inclination of the slope face and thereby the line of intersection must daylight in the slope.
3. The plunge of the line of intersection must be equal or greater than the angle of friction of the intersecting surfaces (discontinuities).
4. Cohesion (c)=zero

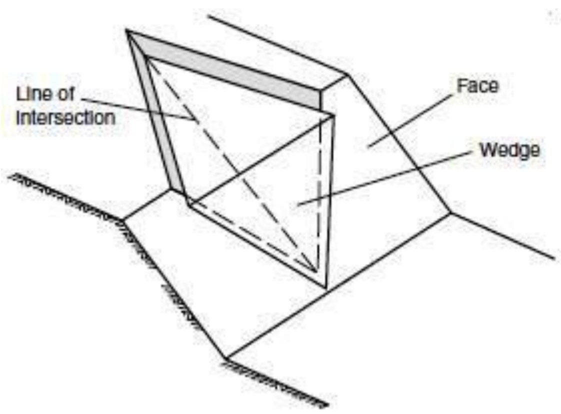


Figure (4-2) Wedge type of failure in rocks (Wyllie and Mah, 2004)

4-3-3 Circular failure (Figure 4-3a):

This type of failure occurs mainly in soils, but also in weak rock mass, when the rock mass is heavily jointed or fractured. In this case, the failure will be defined by a single discontinuity surface but will tend to follow a circular failure path. This path will follow curved surface of least resistance within the rock mass or soil. The conditions under which circular failure will occur start when the individual particles in a soil or rock mass are very small as compared with the size of the slope and when these particles are not interlocked as a result of their shape. Hence, crushed rock in a large waste dump will tend to behave as a “soil” and large failures will occur in a circular mode (Hoek-Bray, 1981).

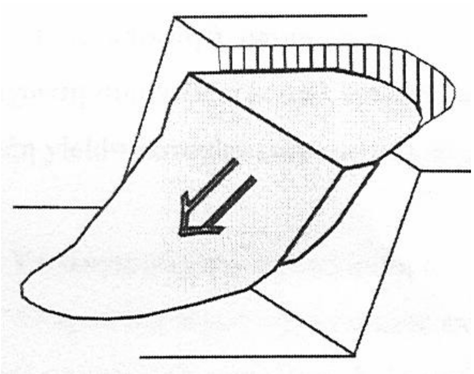


Fig (4-3a) Circular type of failure in heavily fractured rocks or soil (Hoek and Bray, 1981)

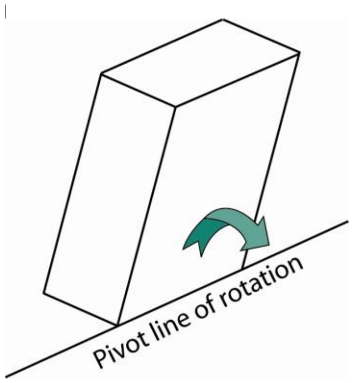


Fig (4-3b) Block rotation around pivot line at lower front edge of the block

4-3-4 Toppling:

A toppling is overturning of a rock block about a pivot point located below its center of gravity (Hunt, 2006) but Al-Saadi believes that toppling occurs due to rotation about pivot line(not pivot point)located at the lower front edge of the block Figure(4.3b)[1]. Toppling failure most commonly occurs in rock masses that are subdivided into a series of slabs or columns formed by a set of fractures that strike approximately parallel to the slope face and dip steeply into the rock mass (Norrish and Wyllie, 1996). Toppling will occur if the vector representing the weight of the block falls outside the base and this will occur if the ratio of base to height (b/h)< tan Ψp where Ψp is the inclination angle of the basal plane fig(4-4a). When this happens, the block will rotate about its lowest contact edge and will topple (Wyllie and Mah , 2004).Toppling failures in rock are structurally controlled, and occur under very strict geometric conditions (b/h

[1] The opinion of Prof.Dr.Saad Al-Saadi who supervised this research is taken from his lectures on Slope stability, and by personal communication with him.,2010

relations, dip angle and spacing of the joint sets), Toppling phenomena are almost independent of the shear strength of the rock joints. The Figure (4-4b) shows the conditions by which a block resting on an inclined plane whether slides or topples.

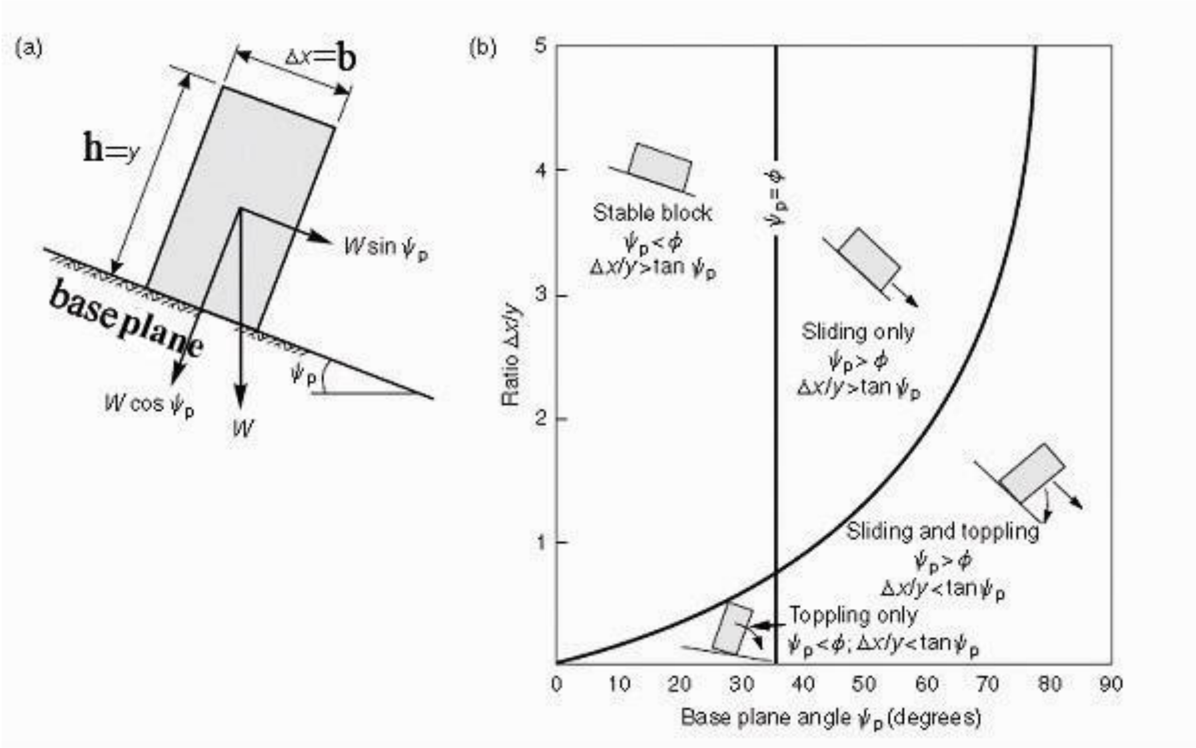


Figure (4-4) Identification of sliding and toppling blocks: (a) geometry of block on inclined plane; (b) conditions for sliding and toppling of block on an inclined plane (Wyllie and Mah, 2004)

4-3-4-1 TYPES OF TOPPLING FAILURES:

Goodman and Bray (1976) have described a number of different types of toppling failures that may be encountered in the field, three principal types of toppling failure and five secondary types of toppling failure:

A- Block toppling:

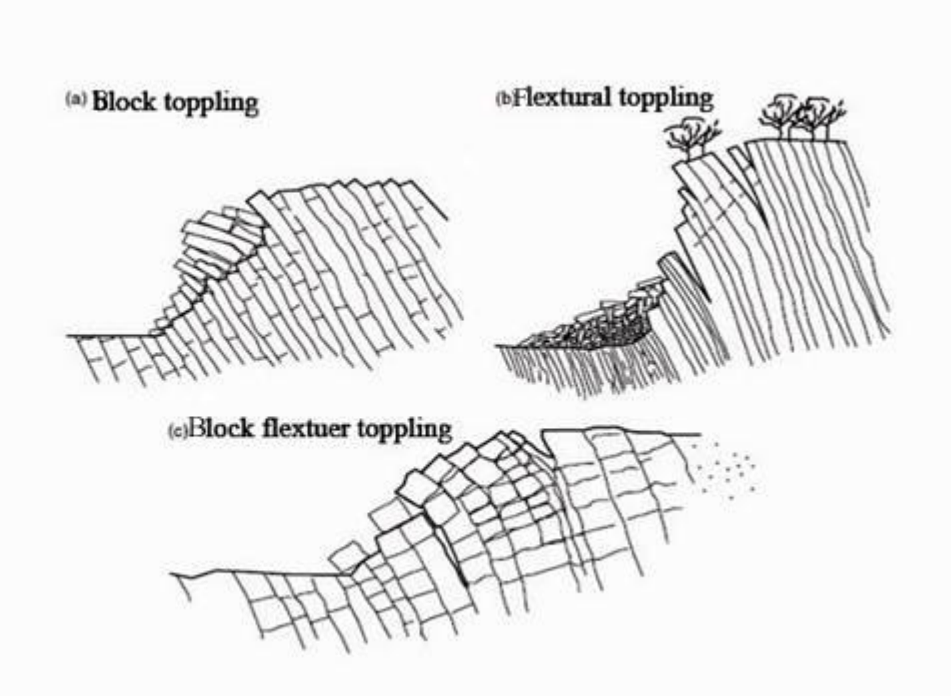
Block toppling occurs when, in strong rock, individual columns are formed by a set of discontinuities dipping steeply into the rock mass, and a second set of widely spaced orthogonal joints defines the column height. The short columns forming the toe of the slope are pushed forward by the loads from the longer overturning columns behind, and this sliding of the toe allows further toppling to develop higher up the slope. The base of the failure generally consists of a stepped surface rising from one cross joint to the next. Typical geological conditions in which this type of failure may occur are bedded sandstone and columnar basalt in which orthogonal joints are well-developed (Wyllie and Mah, 2004) Fig (4-5a).

B-Flexural toppling:

Continuous columns of rock, separated by well developed, steeply dipping discontinuities, break in flexure as they bend forward. Typical geological conditions in which this type of failure may occur are thinly bedded shale and slate in which orthogonal jointing is not well developed. Generally, the basal plane of a flexural topple is not as well-defined as in block topple (Wyllie and Mah, 2004) Fig (4-5b)

C-Block-flexure toppling:

Block-flexure toppling is characterized by pseudo-continuous flexure along long columns that are divided by numerous cross joints. Instead of the flexural failure of continuous columns resulting in flexural toppling, toppling of columns in this case results from accumulated displacements on the cross-joints. Because of the large number of small movements in this type of topple, there are fewer tension cracks than in flexural toppling, and fewer edge-to-face contacts and voids than in block toppling (Wyllie and Mah, 2004)Fig(4-5c).



Fig(4-5)Common classes of toppling failures: (a) block toppling of columns of rock containing widely spaced orthogonal joints; (b) flexural toppling of slabs of rock dipping steeply into face; (c) block flexure toppling characterized by pseudo-continuous flexure of long columns through accumulated motions along numerous cross-joints (Goodman and Bray 1976)in(Wyllie and Mah, 2004)

D-Secondary toppling:

Goodman and Bray (1976) suggest five secondary types of toppling failure. These failures are initiated by some undercutting of the toe of the slope, either by human activity or by natural processes such as weathering and erosion.

I- Slide-toe-toppling:

Layers on the toe of the slope topple by the effect of loads, which come from the sliding materials higher up the slope. Figure (4-6I).

II-Slide-base-toppling.

Shear movement (slumping) on the upper slope material causes toppling of the steeply dipping layers below it. Figure (4-6II).

III- Slide-head-toppling.

Sliding on the toe of the slope cause instability and then toppling of blocks higher up the slope. Figure (4-6III).

IV- Toppling and Slumping:

Toppling and Slumping of rock columns occur by weathering of the underlying materials. Figure (4-6IV).

V- Tension crack toppling:

The formation of extension cracks in the crown of a landslide may create blocks capable of toppling.

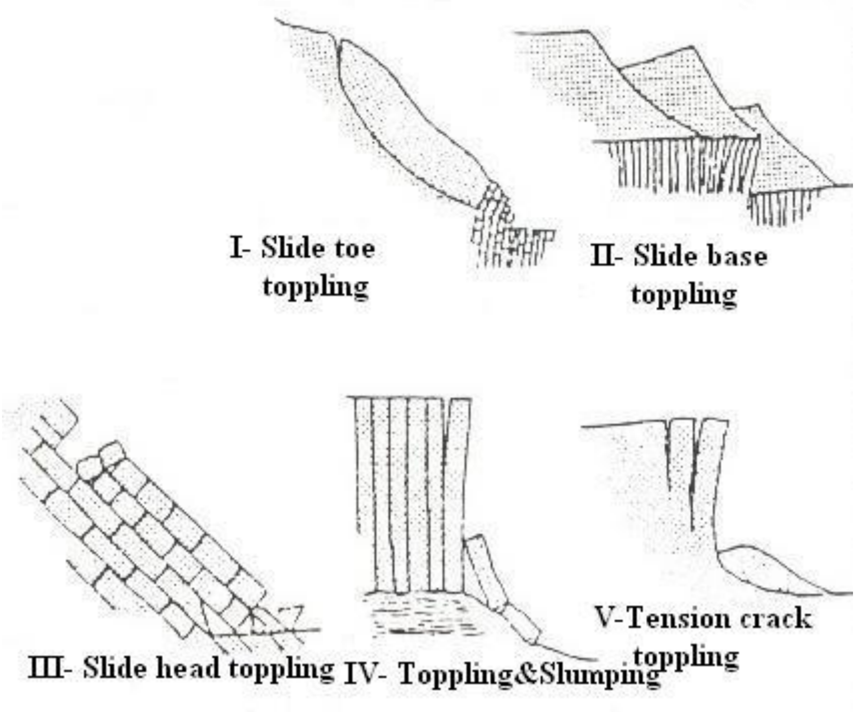


Fig (4-6) Secondary toppling modes: I- Slide toe Toppling, II-Slide base toppling, III- Slide head toppling, IV- Toppling and Slumping, V- Tension crack toppling, from (Goodman and Bray, 1976).

4-4A: Classification of landslide:

A. Varnes (1978):

Varnes (1978) emphasized that classification of mass movement must include the types of movement and material; movement are thus classified as fall, flows, slides, spreads and topples and the type of material as bedrock and engineering soil (Table 4.2), the types of landslides classified by Varnes (1978)in (Giani 1988).

Table (4.2): The types of landslides classified by Varnes (1978)

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOIL	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDE	ROTATIONAL	Rock Slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock Spread	Debris spread	
FLOWS		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow (soil creep)
COMPLEX (Combination of two or more principal types of movement)				

B. **(Hunt, 2006)**:

Hunt has defined, described and classified landslide types table (4.3)

Table (4.3): Classification of Slope Failures (Hunt, 2006)

Type	Form	Definition
Falls	Free fall	Sudden dislodgment of single or multiple blocks of soil or rock which fall in free descent.
	Topple	Overturning of a rock block about a pivot point located below its center of gravity
Slides	Rotational or slump	Relatively slow movement of an essentially coherent block (or blocks) of soil, rock, or soil–rock mixtures along some well-defined arc-shaped failure surface.
	Planar or translational	Slow to rapid movement of an essentially coherent block (or blocks) of almost rock along some well-defined planar failure surface.
	Subclasses: Block glide	A single block moving along a planar surface.
	Wedges	Block or blocks moving along intersecting planar surfaces.
	Lateral Spreading	A number of intact blocks or masses moving as separate units with differing displacements.
	Debris slide	Soil–rock mixtures moving along a planar rock surface.
Avalanches	Rock or Debris	Rapid to very rapid movement of an incoherent mass of rock or soil–rock debris wherein the original structure of the formation is no longer discernible, occurring along an ill-defined surface.
Flows	Debris Sand Silt Mud Soil	Soil or soil–rock debris moving as a viscous fluid or slurry, usually terminating at distances far beyond the failure zone; resulting from excessive pore pressures (subclassed according to material type).
Creep		Slow, imperceptible downslope movement of soil or soil–rock mixtures.
Solifluction		Shallow portions of the regolith moving downslope at moderate to slow rates in Arctic to sub-Arctic or non arctic climates during periods of thaw over a surface usually consisting of frozen ground or in semi arid climate
Complex		Involves combinations of the above, to another during failure with one form predominant

Underlined words are modified

4-4B: Classification of Rock Slopes :

A-Al-Saadi's Classification of Rock Slopes (1981)

It depends on three parameters as described below:

1) Divergence angle (d): It is the angle between slope's trend and the strike of the layers. According to this parameter, three types of slopes could be recognized:

a- Parallel Slope, If: $0° \leq d \leq 20°$

b- Oblique lateral Slope, If: $20° < d \leq 70°$

c- Orthogonal Slope, If: $70° < d \leq 90°$

2) Laterality: It is the emergence of the strikes of the layers to the lateral sides (right or left) of the observer who faces the slopes. Accordingly, if the strike of the layers emerges to the right of the observer, the slope will be right emergent and if it emerges to the left it will be left emergent.

3) Concordance: This parameter depends on the direction of the slope inclination with respect to dip direction of the layers. The slopes are concordant if the layers are dipping in the same general direction of slope inclination, and if not, it will be discordant.

Depending on the different slope classifications the most common types of landslides are described and can be illustrated in Figure (4.7)

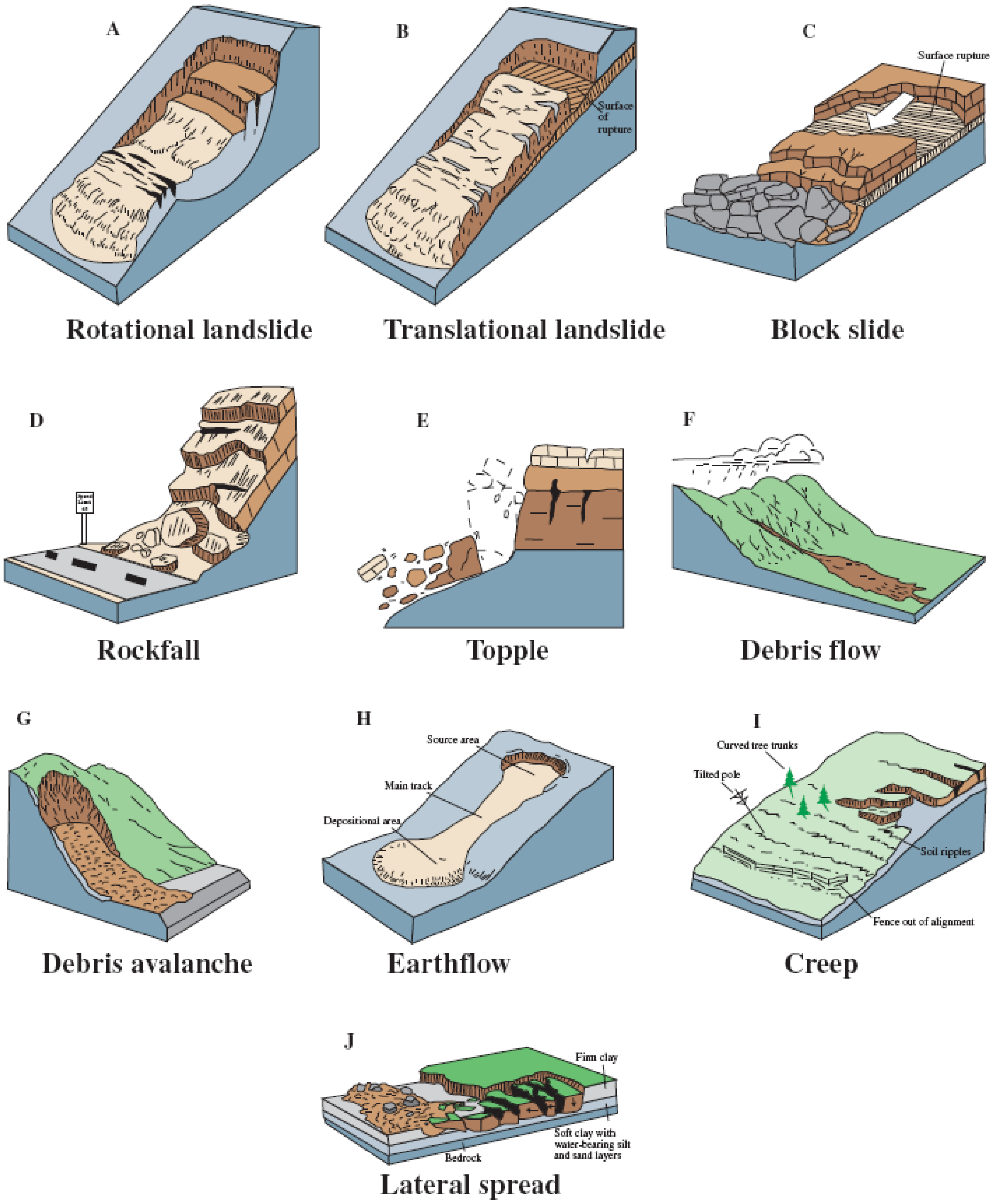


Figure (4-7) Illustrations of the major types of landslide

The supervisor and the researcher think that D type more likely represents Toppling and E type more likely represents Rockfall.

Source - http://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

4-5 Landslide causal factors:

In order to classify or describe a slope as safe or unsafe, the factor of safety has been used. In general, a factor of safety is defined as the ratio between (the resisting forces to sliding) to the disturbing forces of sliding.

$$FS = \frac{\text{resisting forces}}{\text{disturbing forces}}$$

The factor of safety must be greater than 1, to get stable sope. Usually, a FS (factor of safety) of 1.3 up to 1.5 is required for a slope to be characterized as safe. On the other hand, Varnes (1978) points out that there are a number of external or internal causes which may give rise either to the reduction of the shearing resistance or to the increment of the shearing stress. There are, also, causes which affect both factors of the FS ratio. In order to facilitate a better understanding of landslide causes, Figure (4.8) shows an example of factor of safety variation as a function of time, for a given slope. Seasonal rainfall and evaporation are reflected in seasonal variations in the factor of safety. Should there be a long-term trend in groundwater levels, or changes in strength due to weathering, these will show as a trend imposed on the seasonal variation. Sudden changes will be due to short-term variation in either the strength of the materials or the forces applied to the slope (Popescu, 2002).

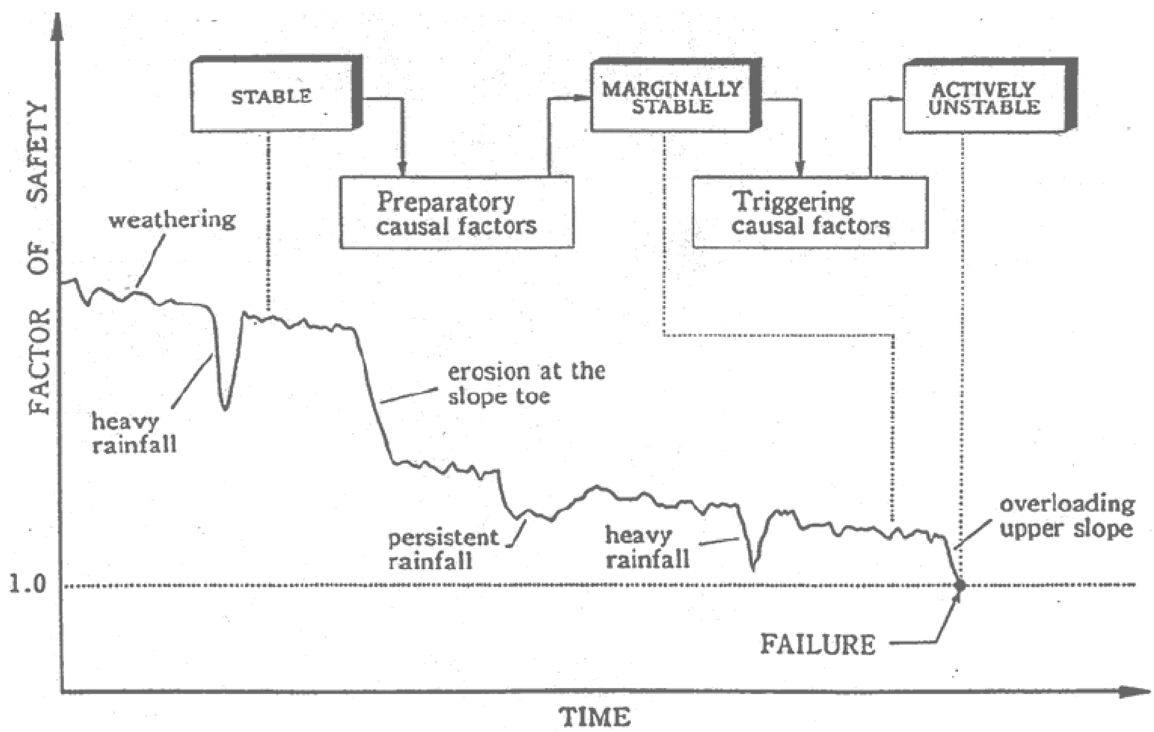


Fig (4.8) An example of changes in the factor of safety with time (Popescu, 2002)

(Crozier, 1986) in (Popescu, 2002) suggests that a slope must be characterized by the words *stable*, *marginally stable* and *actively unstable. Stable slopes* are those in which the factor of safety is sufficiently high to stand with all destabilizing forces. *Marginally stable* is a slope which will fail at some time, in response to the destabilizing forces achieving a certain level of activity. Finally, *actively unstable* slopes are those in which destabilizing forces produce continuous or discontinuous movement. The limits of these stability changes can be seen in Figure (4.8).

A list of the landslide causal factors is given in Table: 4.4 (Popescu, 2002).

Table (4.4) Brief list of the landslide causal factors (Popescu, 2002)

1. GROUND CONDITIONS
(1) Plastic weak material
(2) Sensitive material
(3) Collapsible material
(4) Weathered material
(5) Sheared material
(6) Jointed or fissured material
(7) Adversely oriented mass discontinuities (including bedding, schistosity, cleavage)
(8) Adversely oriented structural discontinuities (including faults, unconformities, flexural shears, sedimentary contacts)
(9) Contrast in permeability and its effects on ground water contrast in stiffness (stiff, dense material over plastic material)
2. GEOMORPHOLOGICAL PROCESSES
(1) Tectonic uplift
(2) Volcanic uplift
(3) Glacial rebound
(4) Fluvial erosion of the slope toe
(5) Wave erosion of the slope toe
(6) Glacial erosion of the slope toe
(7) Erosion of the lateral margins
(8) Subterranean erosion (solution, piping)
(9) Deposition loading of the slope or its crest
(10) Vegetation removal (by erosion, forest fire, drought)
3. PHYSICAL PROCESSES
(1) Intense, short period rainfall
(2) Rapid melt of deep snow
(3) Prolonged high precipitation

(4) Rapid drawdown following floods, high tides or breaching of natural dams
(5) Earthquake
(6) Volcanic eruption
(7) Breaching of crater lakes
(8) Thawing of permafrost
(9) Freeze and thaw weathering
(10) Shrink and swell weathering of expansive soils
4. MAN-MADE PROCESSES
(1) Excavation of the slope or its toe
(2) Loading of the slope or its crest
(3) Drawdown (of reservoirs)
(4) Irrigation
(5) Defective maintenance of drainage systems
(6) Water leakage from services (water supplies, sewers, stormwater drains)
(7) Vegetation removal (deforestation)
(8) Mining and quarrying (open pits or underground galleries)
(9) Creation of dumps of very loose waste
(10) Artificial vibration (including traffic, pile driving, heavy machinery)

4-6 Stability Assessment:

At this study, in order to assess the stability along the slope, a number of sites were chosen and at all of them, the rock slope, rock mass and discontinuities were surveyed including slope attitude; and orientation, persistence and frequency of discontinuities in addition to stereographic projection of the collected data at each site. Also the rock slopes were classified according to Al-Saadi's classification (1981) of rock slopes, and the rock mass were described from engineering point of view according to Anon (1972, 1977) and Hawkins (1986).

4-6-1 **Engineering Description of Rocks**

The description according to the report of the working party of the engineering group in the geological society of London (Anon, 1972, 1977) and to the description given by Hawkins (1986) is in the following order:

a- Colour

b- Grain Size

c- Texture and Structure

d- Discontinuities within the rock mass

e- Weathering state

f- Rock name

g- Rock materials strength

Rock description of Anon (1972) is slightly modified here so that the rock strength precedes the rock name.

Described features and used terms are shown in tables,(4-5),(4-6),(4-7),(4-8),(4-9),(4-10) and (4-11).

a- Colour: Rock colour is described in terms of three parameters as shown in table (4-5)

Table (4-5): Terms used for description of rock colour (Anon, 1972)

<table>
<tr><th>Lightness of Colour</th><th>Supplementary Colour</th><th>Basic Colour</th></tr>
<tr><td rowspan="10">Light

Dark</td><td>Pinkish</td><td>Pink</td></tr>
<tr><td>Reddish</td><td>Red</td></tr>
<tr><td>Yellowish</td><td>Yellow</td></tr>
<tr><td>Brownish</td><td>Brown</td></tr>
<tr><td>Olive</td><td>Olive</td></tr>
<tr><td>Greenish</td><td>Green</td></tr>
<tr><td>Bluish</td><td>Blue</td></tr>
<tr><td rowspan="3">Grayish</td><td>White</td></tr>
<tr><td>Gray</td></tr>
<tr><td>Black</td></tr>
</table>

b- Grain Size: The same grain size ranges of soil are used for rock types (Table 4-6).

Table(4-6): Grain sizes of rocks and descriptive terms (Anon, 1972)

Equivalent soil grade	Term	Size of component particles
Boulders and Cobbles	**Very coarse**	**> 60 mm**
Gravel	**Coarse-grained**	**2 mm – 60 mm**
Sand	**Medium-grained**	**60 microns – 2 mm**
Silt	**Fine-grained**	**2 microns – 60 microns**
Clay	**Very fine-grained**	**< 2 microns**

c- Texture and Structure:

As sedimentary rocks occur in beds, the descriptive terms are used for the spacing of planar structures including bedding and lamination (Table 4-7).

Table (4-7): Terms and scales used for description of sedimentary beds (Anon, 1972)

Term	Spacing
Very thickly bedded	**> 2 m**
Thickly bedded	**600 mm – 2 m**
Medium bedded	**200 mm – 600 mm**
Thinly bedded	**60 mm – 200 mm**
Very thinly bedded	**20 mm – 60 mm**
Laminated (Sedimentary)	**6 mm – 20 mm**
Thinly laminated (Sedimentary)	**< 6 mm**

d- Discontinuities within the rock mass:

The properties of discontinuities of great importance to slope stability are orientation persistence and spacing of discontinuities, (Wyllie and Mah 2004). The shear strength of a rock mass and its deformability are influenced very much by the discontinuity pattern, its geometry and how well it is developed. Observations of discontinuity spacing, whether in a field exposure or in a core stick, aids appraisal of rock mass structure. In sedimentary rocks, bedding planes are usually the dominant discontinuities (Bell, 2007). Table 4-8 lists the scales and relative terms used for the description of spacing between discontinuities.

Table (4-8): Scale and descriptive terms used for spacing of discontinuities (Anon, 1972 and Hawkins, 1986)

Term	Spacing
Very widely spaced	**> 2 m**
Widely spaced	**600 mm – 2 m**
Moderately widely spaced	**200 mm – 600 mm**
Closely spaced	**60 mm – 200 mm**
Very closely spaced	**20 mm – 60 mm**
Extremely closely spaced	**< 20 mm**

e- Weathering state:

Weathering of both soils and rocks is one of the most important problems in slope stability assessment. Weathering implies decay and change in state from an original condition to a new condition as a result of external processes Weathering takes place in all environments but is most intense in hot wet climates where weathering may be expected to extend to great depths. While weathering may reach great depths in limestone, and rocks containing halite and gypsum, it is slow to do so and the style of weathering may change if climatic conditions change. The weathering state of rock has a significant influence on the engineering properties of rock mass, so that it results in the reduction of strength of the rock mass (Bell, 2007) table (4-9).

Table (4-9): Terms and symbols used for the description of the degree of Weathering (Hawkins, 1986).

Term	Grade	Diagnostic features
Fresh	**G**	**Parent rock showing no discoloration, loss of strength or any other weathering effects**
Slightly weathered	**SW**	**Rock may be slightly discolored, particularly adjacent to discontinuities, which may be open and will have slightly discolored surfaces; the intact rock is not noticeably weaker than the fresh rock**
Moderately weathered	**MW**	**Rock is discolored; discontinuities may be open and will have discolored surfaces with alteration starting to penetrate inwards; intact rock is noticeably weaker than the fresh rock**
Highly weathered	**HW**	**Rock is discolored; discontinuities may be open and have discolored surfaces, and the original fabric of the rock near to the discontinuities may be altered; alteration penetrates deeply inwards**
Completely weathered	**CW**	**Rock is discolored and changed to a soil but original fabric is mainly preserved**

f- ROCK NAME:

It must be written in capital letters and should be technically correct and simple enough for general and field use. It may be preceded by minor lithological characteristics.

g- Strength of the rock materials:

For description of the strength of intact rock as a fundamental quantitative engineering property, a scale based on the value of uniaxial compressive strength is recommended as shown in (table 4-10):

Table 4-10: Scale of strength and descriptive terms (Anon, 1977)

Term	Unconfined compressive strength (MPa)
Extremely strong	**> 200**
Very strong	**100 – 200**
Strong	**50 – 100**
Moderately strong	**12.5 – 50**
Moderately weak	**5 – 12.5**
Weak	**1.25 – 5**
Very weak	**< 1.25**

4-6-2 Stereographic Projection:

The most important parameters in rock slope stability analyses are the orientation of discontinuities and the slope inclination. Interpretation of these parameters requires the use of stereographic projections that allows the three dimensional orientation data to be represented and analyzed in two dimensions. Information on discontinuity orientations may be displayed by plotting on a stereonet. Figure (4-9) outlines the basic principles of the construction and use of stereonet. More detailed descriptions may be sought in Hoek and Bray (1981). The stereographic projection consists of a reference sphere in which its equatorial plane is horizontal, and its orientation is fixed relative to north Planes, and lines with a specific plunge and trend are positioned in an imaginary sense so that the axis of the feature passes through the center of the reference sphere. The rotated lines and points are unique locations on the stereonet that represent the dip (plunge) and dip direction (trend) of the feature. In slope stability analysis using stereonet, planes are used to represent both discontinuities and slope faces (Wyllie and Mah, 2004). Depending on stereographic projection all types of rock failure can be projected depending on data that are obtained in field measurement and each of them has its own properties, figure (4-10).

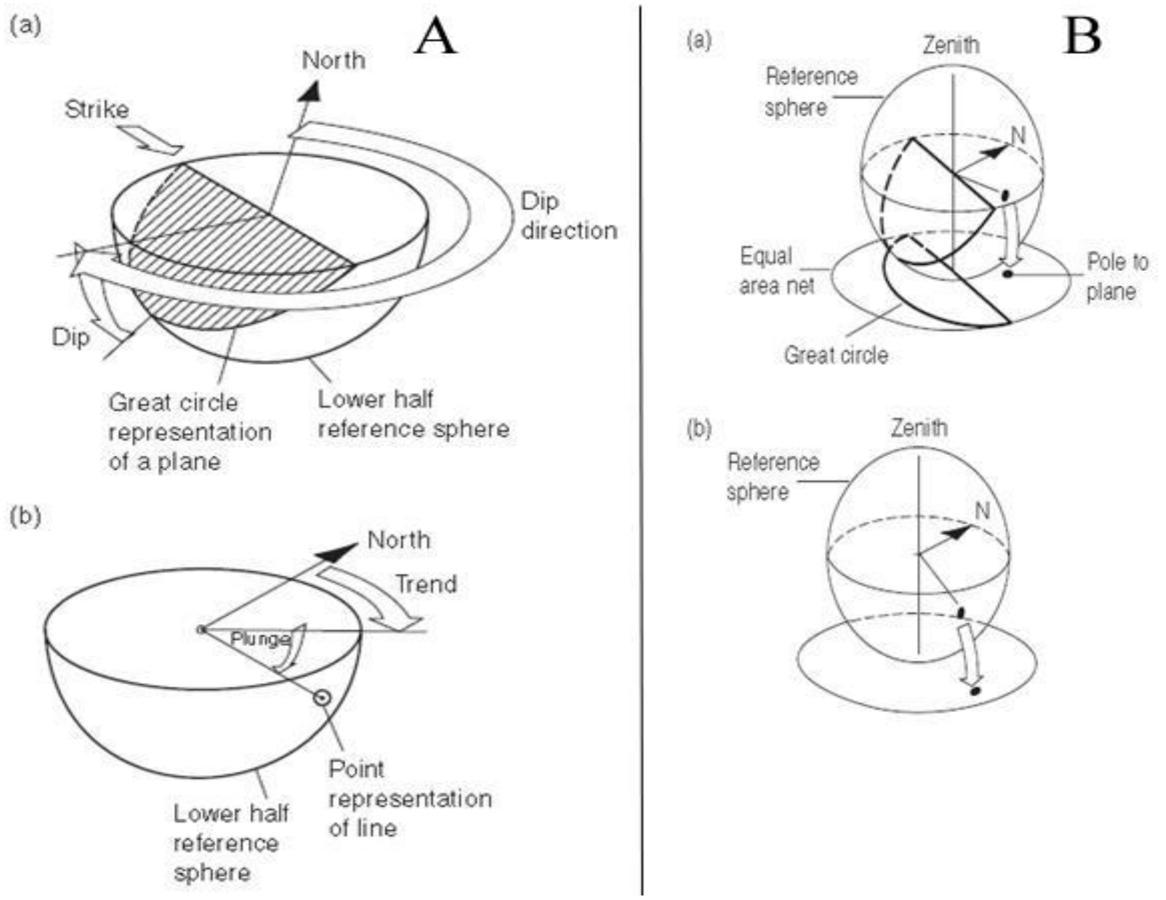


Fig (4-9): **A**) Stereographic representation of plane and projections of line on lower hemisphere of reference sphere:

(a) Plane projected as great circle;

(b) Isometric view of line (plunge and trend).

(Wyllie and Mah, 2004)

Fig (4-9): **B)** Equal area plane and line:

(a) Plane projected as great circle and corresponding pole;

(b) Line projected as pole.

(Wyllie and Mah, 2004)

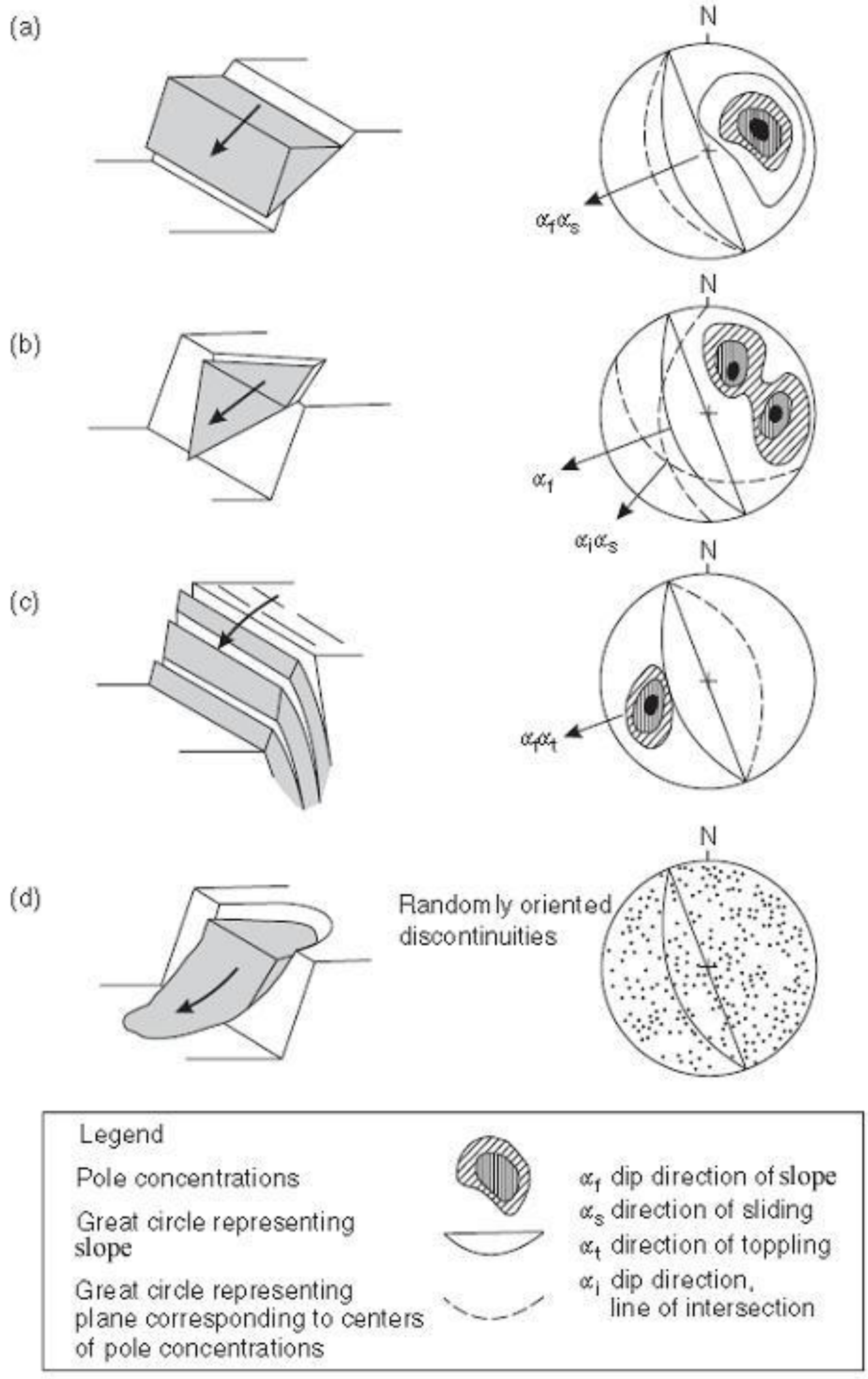


Fig (4-10) Main types of block failures in slopes, and structural geology conditions likely to cause these failures:(a) plane failure in rock containing persistent joints dipping out of the slope face, and striking parallel to the face; (b) wedge failure on two intersecting discontinuities; (c) toppling failure in strong rock containing discontinuities dipping steeply into the face; and(d) circular failure in rock fill, very weak rock or soil or closely fractured rock with randomly oriented discontinuities(Wyllie and Mah, 2004).

PART 2- SLOPE STABILITY ASSESSMENT OF THE STUDY AREA

4-7 Terms and Symbols used in the Assessment of Slope Stability

Orientation: is the attitude of a discontinuity which is defined by two angular parameters of dip direction and dip angle. Dip direction is represented by a 3-digit whole number from 000 to 360 indicating the azimuth direction in which the discontinuity being examined is dipping, while the dip amount is represented by a 2-digit whole number from 00 to 90 indicating the degree of tilt of the discontinuity from the horizontal layer (For example: 200/30°). The same method of representation is used for the slope inclination except the term of OH which is used for representing an overhanging slope, for example: 250/90°-OH.
Persistence: refers to the continuity or areal extent of a discontinuity.

Spacing: refers to the distance between two discontinuities of the same set measured, normal to the discontinuity surfaces. The size of blocks in a rock mass could be defined by spacing and persistence of discontinuities.

Frequency: refers to the number of discontinuities of the same set, per one meter, measured normal to the discontinuity surfaces. This term could be used instead of the spacing.

Daylighting slope: refers to slopes in which the discontinuities dip at an angle less than the slope angle and at the same direction of slope inclination.

Release surface: refers to the surface along which, a block is detached from the rock mass and provide negligible resistance to failure. Based on their position with respect to the failed block and according to (Al-Saadi, 1981, 1991), the following types of release surfaces are recognized:

a) Upper release surfaces (U.R.S.): enclose the block from its upper sides

b) Back release surfaces (B.R.S.): enclose the block from its back sides

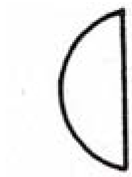
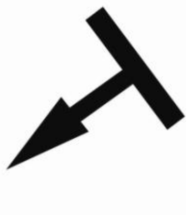
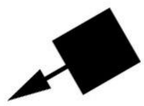
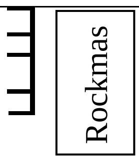
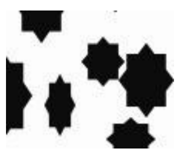
c) Lateral release surfaces (L.R.S.): enclose the block from its lateral sides

d) Basal surfaces (B.S.): surfaces on which the toppled block rests before toppling.

e) Sliding surfaces: surfaces along which, the sliding takes place

The symbols used in stereographic projection are shown in table (4-11).

Table (4-11): Symbols used in stereographic projection after (Al-Saadi , 1981).

Description	Symbol	Type of failure	Symbol
Pole of bedding plane (So)	+	Planar sliding	
Pole of discontinuity plane	*,Δ,▫,○,◊,□	Wedge sliding	
Great circle of a general slope	**g.c or G.c** 	Toppling	
		Rockfall	
Geart circle of bedding plane	**So** 	Rolling	
Cyclographic trace of vertical slope (v.s.) or overhanging (OH)	(v.s,OH) 	Disintegration	

4-8: Slope stability assessment in the study area:

The stability of 21 chosen sites at the study area (Fig. 4-11) is assessed and is described in the following pages:

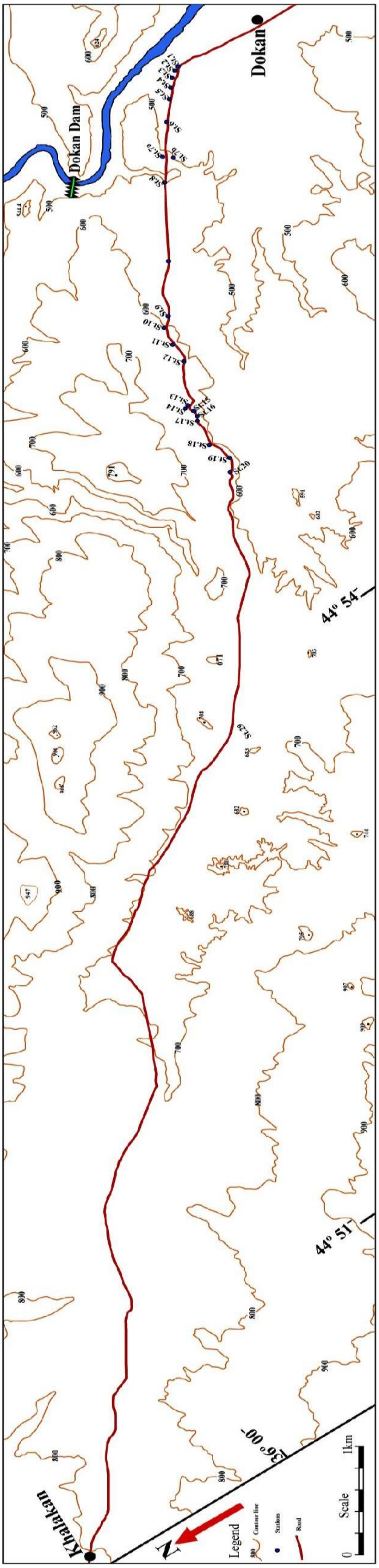


Fig. 4-11: Map showing location of the selected stations for study of slope stability in the study area

4.8.1 Station No.1

The station is located on the SW limb of Kosrat anticline at the end of Dokan city toward Khalakan village along the main road between Dokan to Khalakan at latitude 35° 56′ 34″ N and longitude 44° 57′ 25″ E(Fig.4-11). It lies within Kometan Formation which is exposed at the Southwestern limb of Kosrat anticline. The slope at this station exposes inclined layers rock mass, it is about 5m to 7m high and 15m long parallel to its strike, having attitude 238/90° to overhanging.

The average bedding plane attitude is 200/25° plate (4-2)Figure(4-12). So the slope is Oblique lateral, (d=38), left emergent and concordant type depending on (Al-Saadi, 1981), classification.

The exposed rock is composed of white to grayish white, fine grained, thinly bedded to medium bedded(10-40cm) , closely spaced to widely spaced joints, slightly weathered and Very strong(σc =125.84MPa)LIMESTONE.

The joints in the rock have various structural directions and their persistence ranges from 1-15m. Joints orientations are variable in two main directions so that joint poles in the stereogram (Fig.4-12) are divided into two main sets (ac and hkO).

Mode of failure: The slope at this station is a man-made slope that was excavated due to road widening it means that the slope at this station before road widening was stable (plate.4-1a), but after widening of the road this slope became unstable due to removing toe of the slope (plate.4-1b).Two main types of rock failures have occurred and are likely to occur in the future, small failure types of plane sliding and rockfall occurred. The main slope is Daylighting (the dip angle of bedding plane is less than the slope angle at the same direction), therefore the slope is geometrically favorable for sliding. Joints in ac act as lateral release surfaces and hkO joints act as back release surfaces.

Plate (4.1): a) Shows the process of destabilization at station No.1 due to road widening and removal of the toe

Plate (4-1): b) Unstable slope after cutting its toe at station No.1

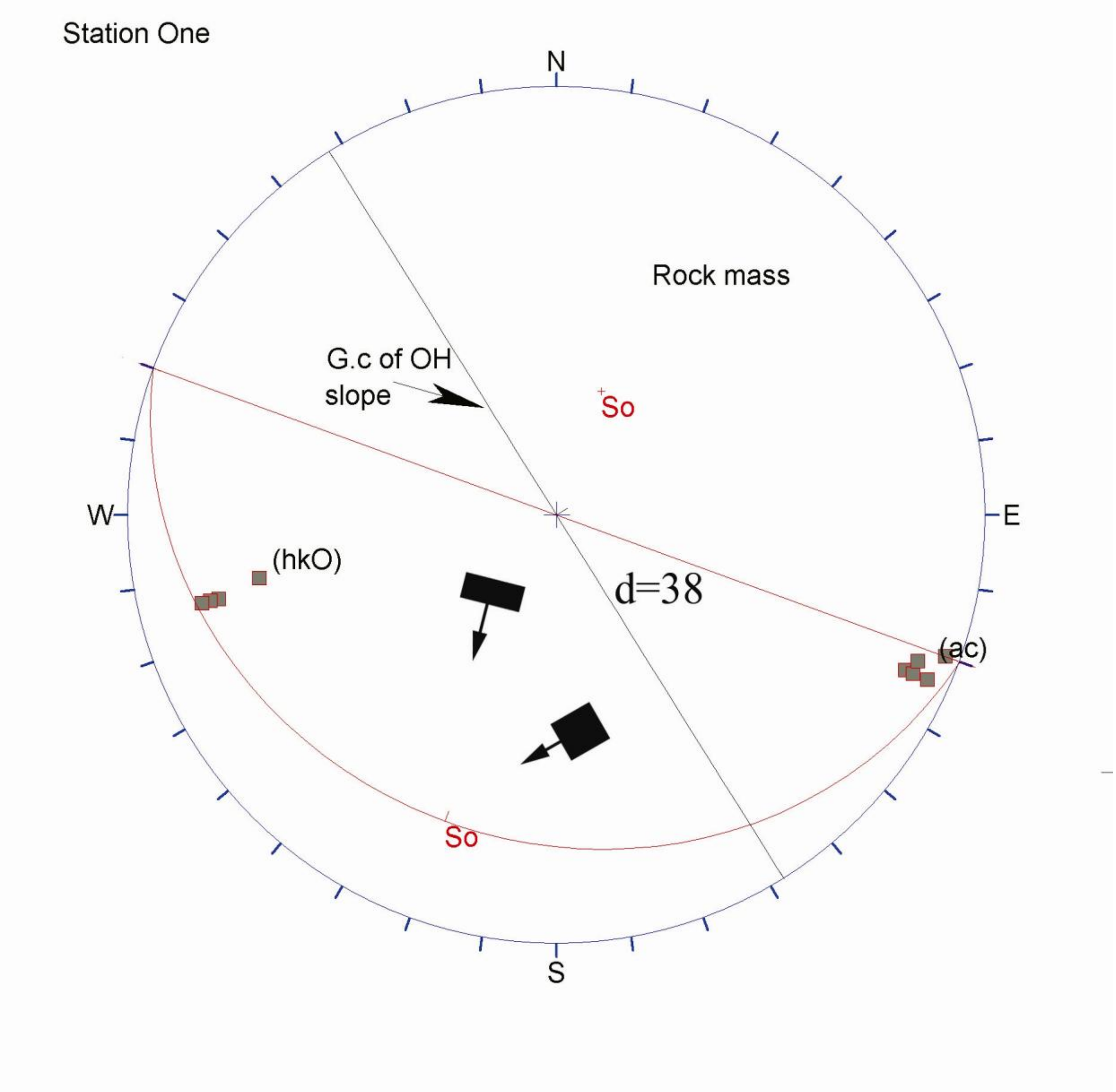


Figure 4.12: Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.1 in Dokan area

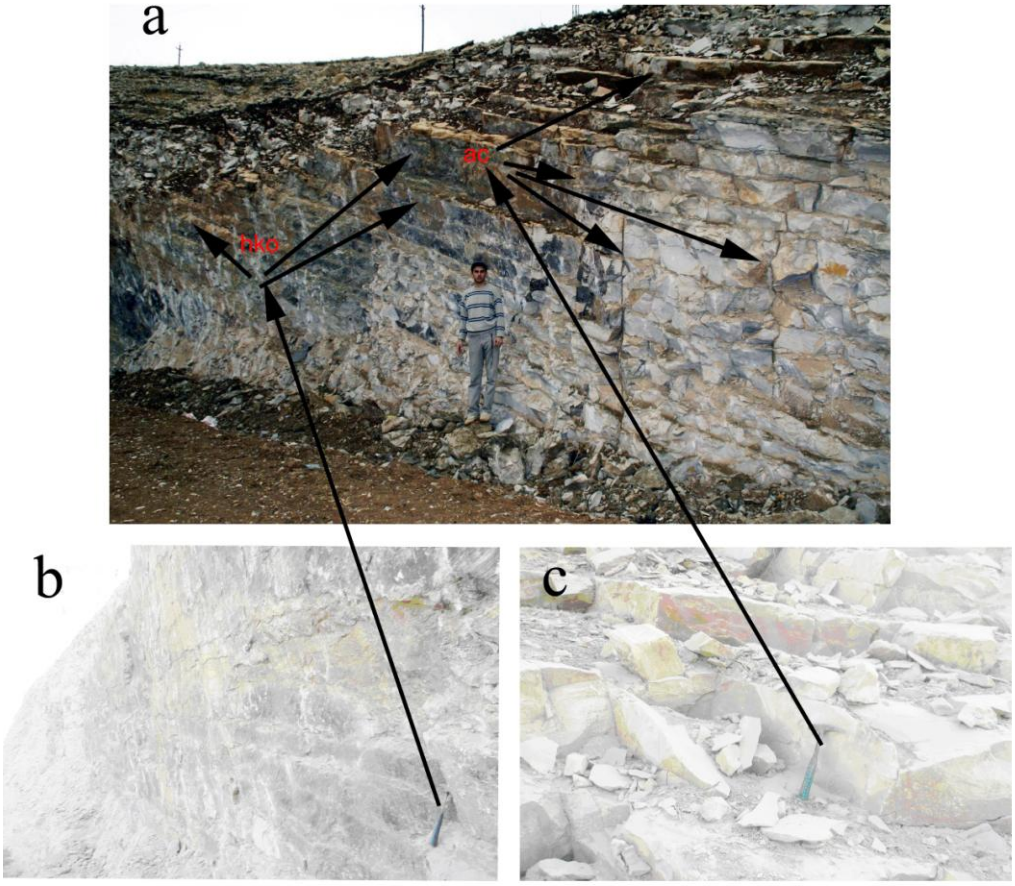


Plate (4-2): a) Frontal view of station No.1 (b) Joint set hkO (c) Joint set of ac

4.8.2 Station No.2:

The station is located on the SW limb of Kosrat anticline along the main road of Dokan to Khalakan at latitude $35^{\circ} 56' 33''$ N and longitude $44^{\circ} 57' 27''$ E (Fig.4-11). It lies within Kometan Formation. The station is man-made slope, where inclined layers of limestone are exposed, it is about 8m high and 10m long parallel to the trend of the slope. It can be divided into two parts. The lower part is daylighting and inclined at (229/90°) while the upper part is inclined (229/42°), the upper part of slope is covered by weathered soil about 1m thick that is liable to Debris slide plate (4-3).

The average bedding plane attitude is 229/34° Figure (4-13) plate (4-3). The slope is Parallel Slope (d=0) concordant depending on (Al-Saadi, 1981) classification.

The rock in this site is composed of white to grayish white, fine grained, thinly bedded to medium bedded, very closely to moderately widely spaced, moderately weathered ,very strong(σc=125.84MPa) LIMESTONE.

These layers are cut mainly by three sets of joints, two sets are in (hkO) and one set is (hkl) plate (4-4 a). They have different persistence and spacing, J_1 represents closed joint, with persistence of 2m and frequency 1-3/m, Joint in J_2 have persistence of 4m and frequency 1-2/m and J_3 set has 5m persistence and frequency of 5/m (plate 4-4b).

Mode of failure: the lower part of slope is daylighting slope because the angle of bedding plane is less than slope angle therefore sliding is likely to occur along bedding planes while joints in J1(hkO_1) and J2(hkO_2) act as back composite release surfaces(plate4-4 c). Rockfall has occurred and likely to occur more in the upper steep meters of the slope.

Plate (4-3): Frontal view of slope at station No.2

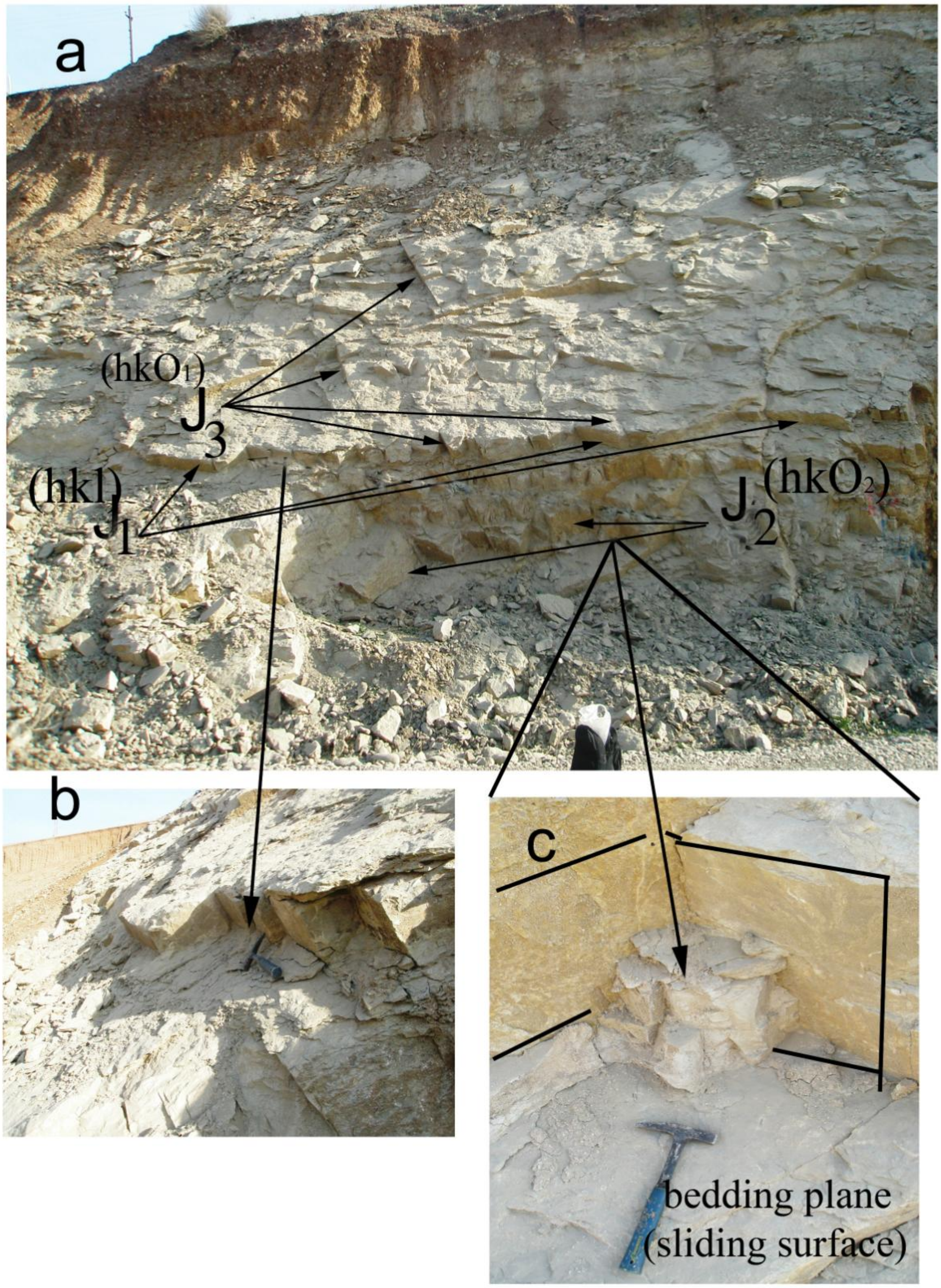


Plate 4-4 :(a) Frontal view shows three types of joint sets at station No.2 (b) Shows joint set (J_3) (c) Composite back release surfaces between J_2 and J_1.

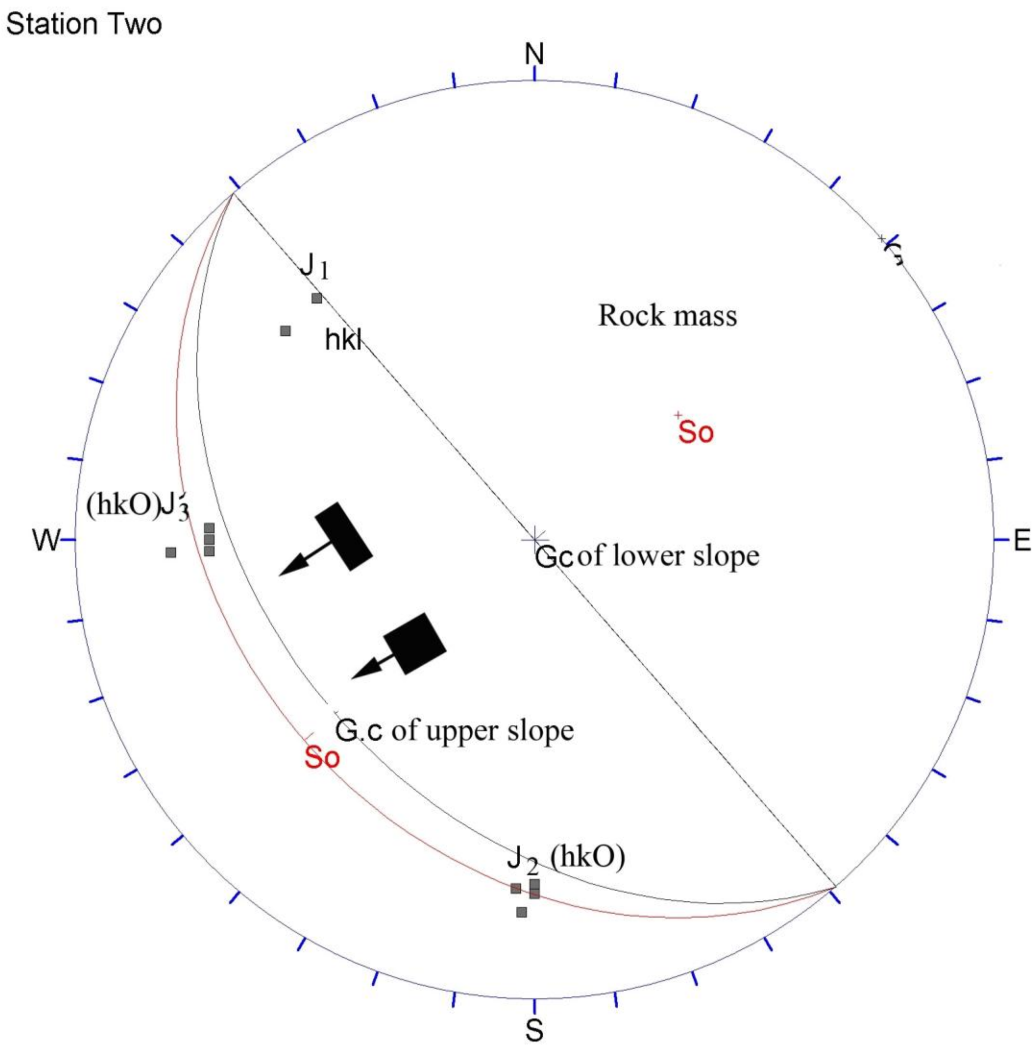


Figure (4-13) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.2

4.8.3 <u>Station No. 3:</u>

The station is located on the SW limb of Kosrat anticline along the main road of Dokan to Khalakan at latitude 35° 56′ 36″ N and longitude 44° 57′ 21″ E (Fig.4-11). It lies within Shiranish Formation, the slope is man-made formed due to excavation of its toe plate (4-5), the slope is composed of layered rocks of marly limestone and it is 4m high and 40m long parallel to its strike. It is divided into two parts, the lower part is a cut toe inclined (208/ 90°) plate (4-5) and upper slope (208/42°).

The average bedding plane attitude is 209/29° plate (4-5). The slope is Parallel Slope (d=1°) right emergent and concordant depending on (Al-Saadi, 1981) classification.

The rock in this site is composed of light grey to grayish white, fine grained, very thinly bedded to medium bedded, closely spaced to moderately widely spaced, Fresh at (toe) to highly weathered at (top), strong (σc =54.89MPa) MARLY LIMESTONE.

The rock is cut by two sets of joints hkO and hkl the persistence of hkO joints ranges between 2 -3m and for hkl is between 3.5-4m.

Mode of failure: The slope is unstable because it is daylighting (plate4-5 and plate 4-6 a,b,c) and plane sliding along bedding planes is geometrically possible. The hkl joints dip is vertical and they act as lateral release surfaces and hkO joint acts as back release surfaces. The rockfall is possible along the slope toe and rock rolling is common type of failure in the upper slope of this station (plate 4-5).

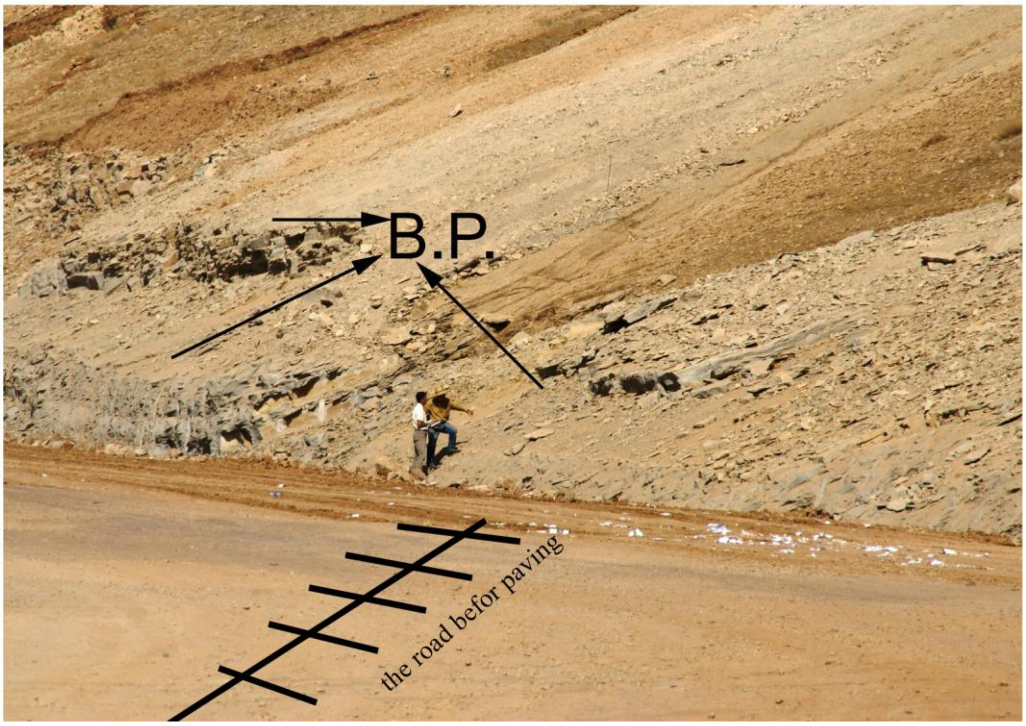


Plate (4-5) Lateral view of the slope at station No.3 along Dokan-Khalakan Road

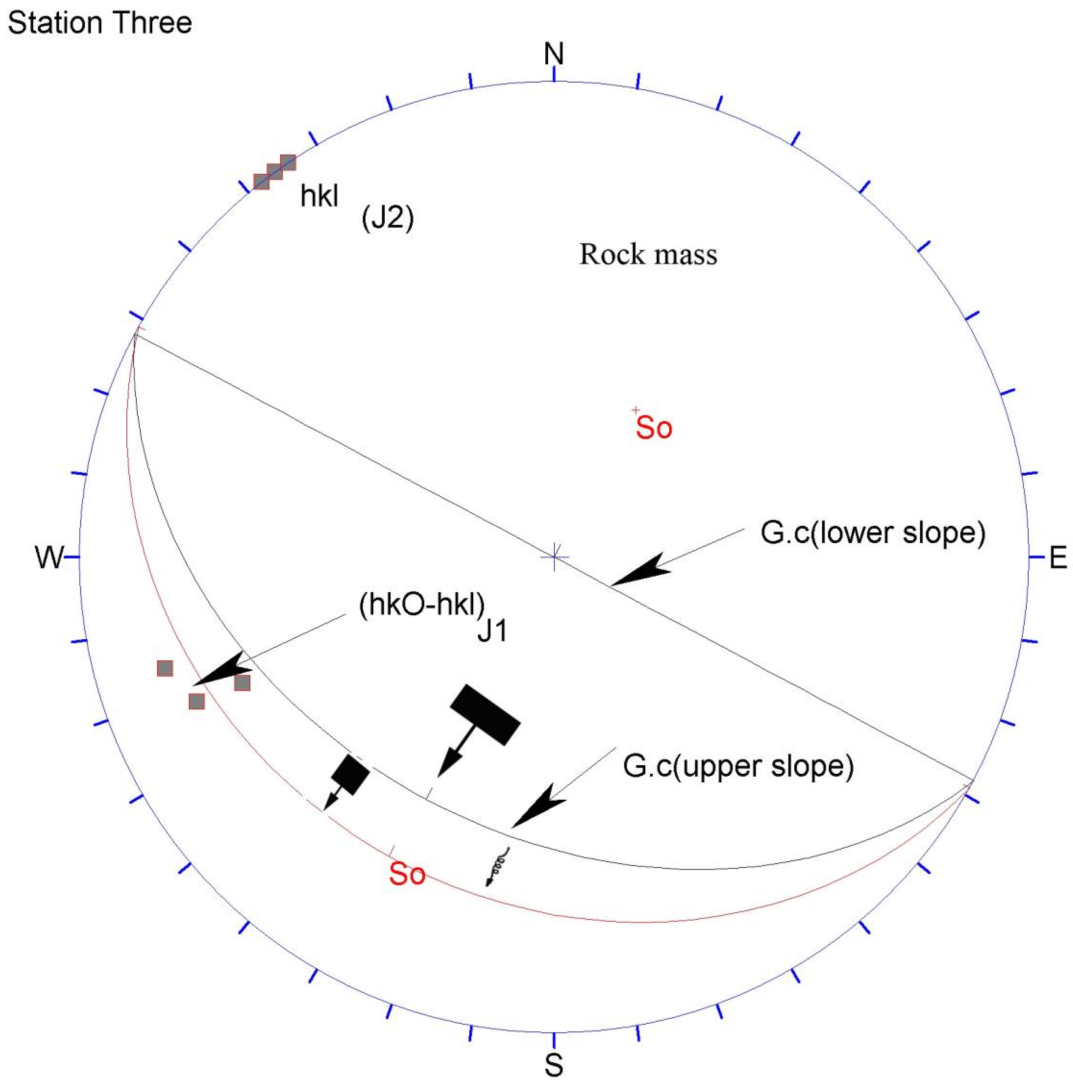


Figure (4-14) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.3

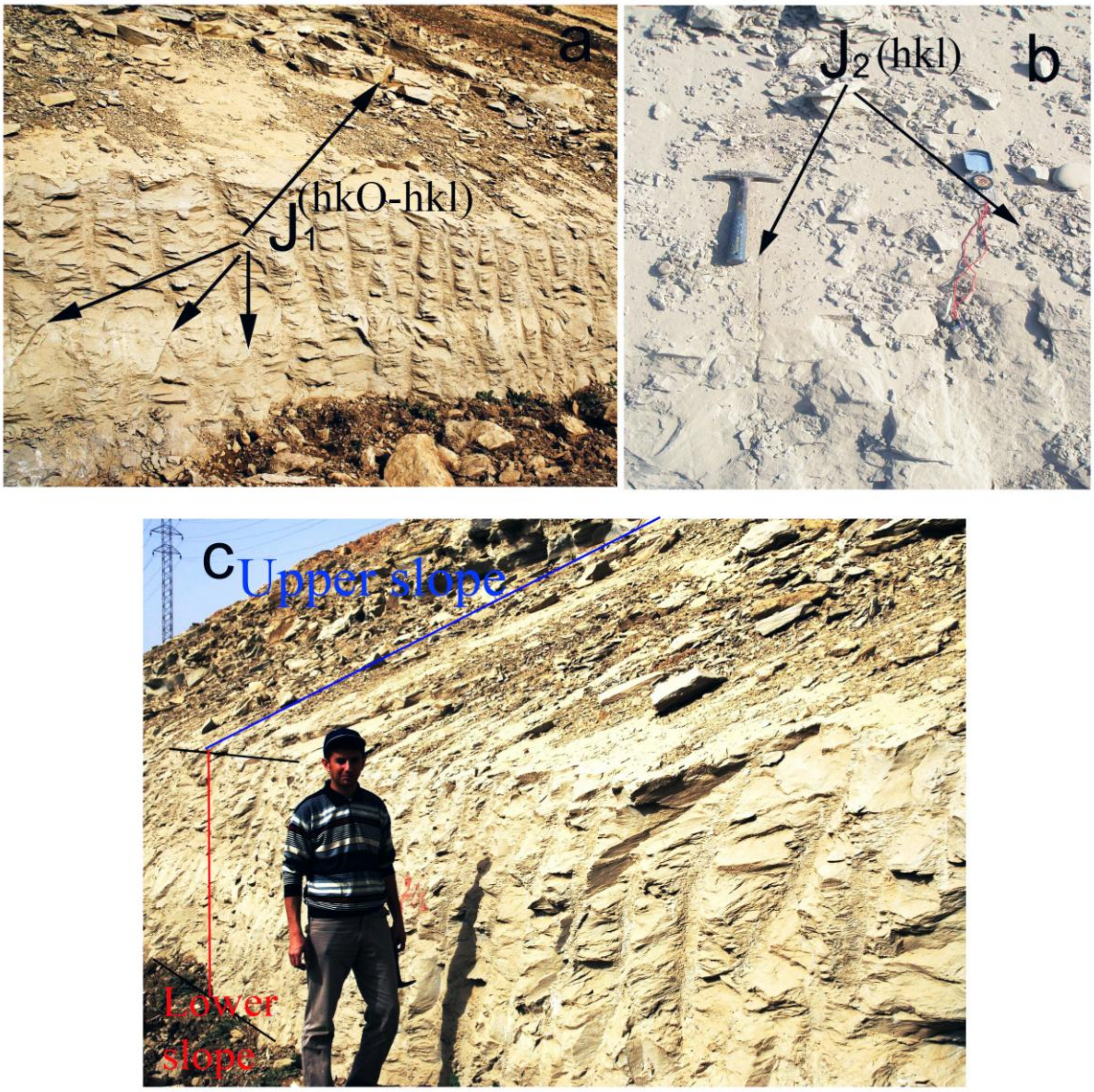


Plate 4-6: (a) Frontal view of the slope at station No.3 showing the vertical toe slope and joint set J_1 (b) Shows joint set J_2 (c) Lateral view of the slope at station No.3 shows the cut toe

4.8.4 <u>Station No.4:</u>

The station is located on the SW limb of Kosrat anticline; along the main road of Dokan to Khalakan at latitude $35^{\circ} 56' 39''$ N and longitude $44^{\circ} 57' 18''$ E (Fig.4-11). It lies within Shiranish Formation. The station is a man-made slope plate(4-7a), it has become unstable since of May 2008 due to widening of the old road and cutting the toe of the slope plate (4-7d). The slope toe is composed of marly limestone, layered it is about 3.5m high and 15m long parallel to strike of slope, having attitude $206/90^{\circ}$-OH.

The average bedding plane attitude is 208/28° plate (4-7b) (Fig.4-16) the slope is Parallel Slope (d=2°) right emergent and concordant depending on (Al-Saadi, 1981) classification.

The rock in this site is composed of light grey to grayish white, fine grained, very thinly bedded to medium bedded, very closely to moderately spaced, fresh to highly weathered from bottom to top due to natural weathering in the upper slope and new cutting of the toe plate(4-7a), strong (σc =54.89MPa) MARLY LIMESTONE.

The joints in the rock have two structural orientations that lie in two main sets hkO_1 and (hkO_2-hkl).

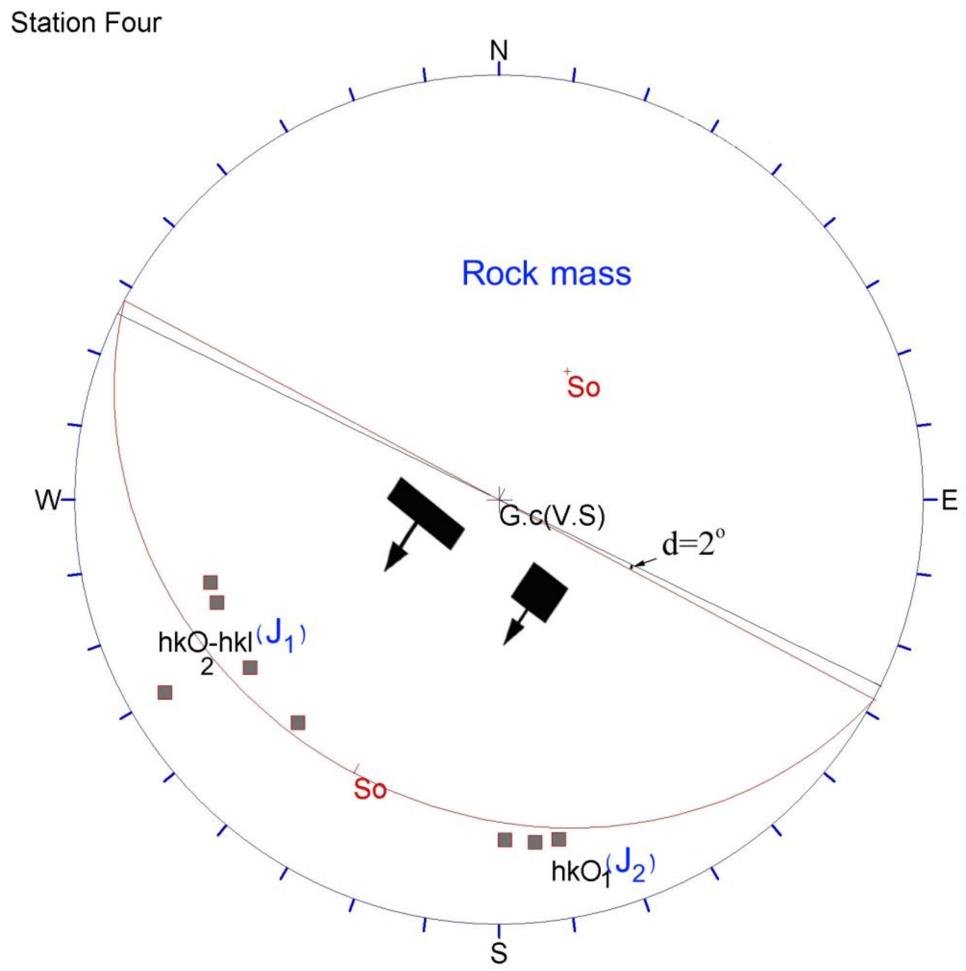


Figure (4-15) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No. 4

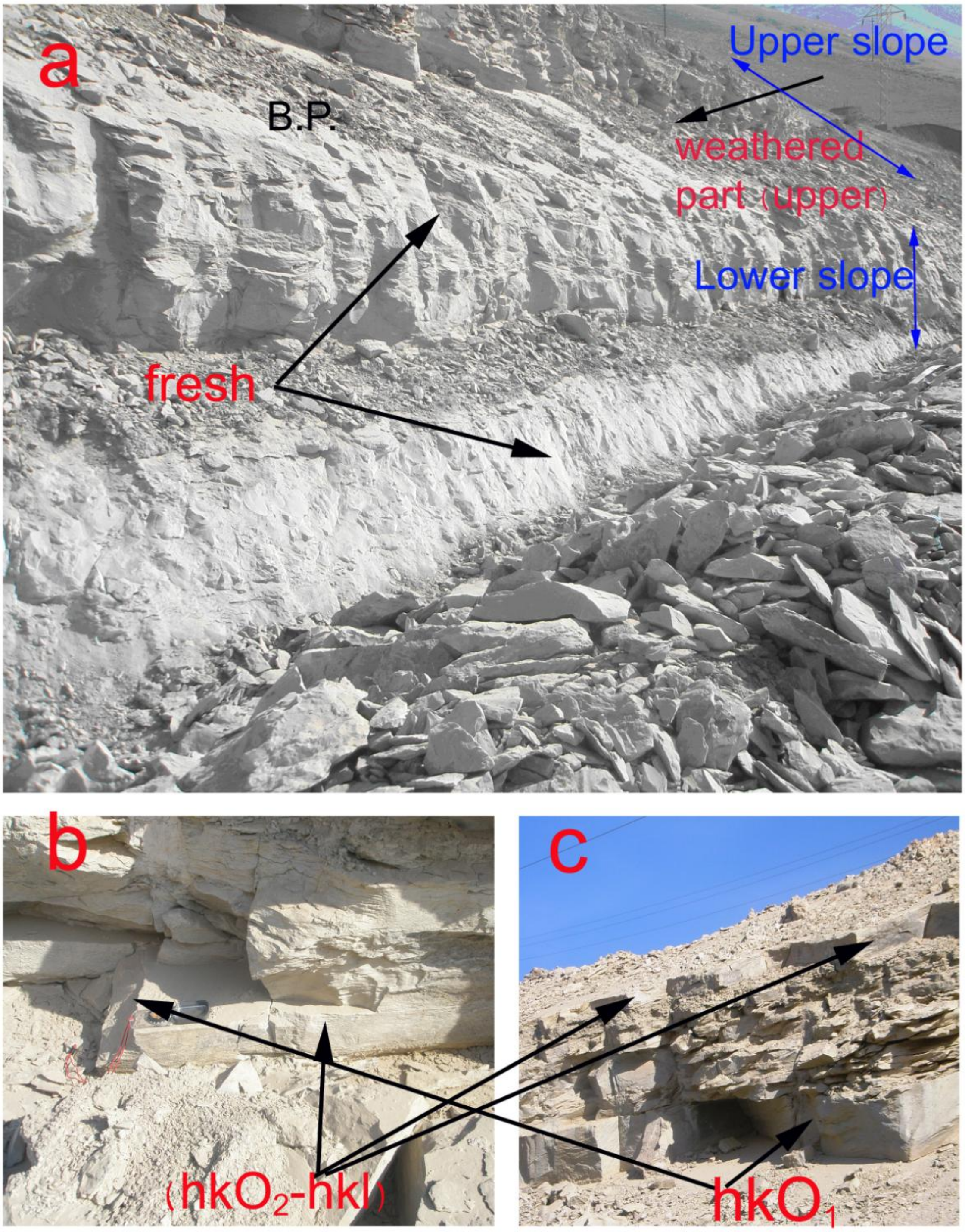


Plate 4-7 :(a) Lateral view shows the cut toe, fresh and weathered rock at station No. 4 (b and c) Frontal view show two sets of joint

Mode of failure: Two main types of rock failures have occurred and are probable to occur in the future, large and small rockfall occurred because the slope is vertical to overhanging. Small plane slide occurred because the slope is daylighting so that bedding planes act as sliding surfaces, while both sets of joint act as composite back release surfaces plate (4-7c).

plate (4-7d): The processes of widening of the road between Dokan to Khalakan at station No.4

4.8.5 <u>Station No.5:</u>

The station is located in the SW limb of Kosrat anticline; along the main road of Dokan to Khalakan at latitude 35° 56′ 41″ N and longitude 44° 57′ 15″ E (Fig.4-11). It lies within Kometan Formation. The station is man-made, the slope exposes highly fractured layered rocks of limestone, about 40m long and7m high, it is divided into two parts, the lower slope (cut toe) with attitude (220/90°-OH) and upper slope inclined at(220/32°)Figure(4-16) and (plate 4-8a).The upper slope is covered by soil which is about 40cm to 1m thick, also there are clay seams of 5cm thick between the bedding planes in the upper part of rock slope plate (4-8b).

The bedding planes have attitude (208/32°). The slope is Parallel Slope (d=12°) left emergent and concordant type depending on (Al-Saadi, 1981) classification.

The shear strength parameters (Ø and c) for clay layers were carried out by shear box test, the frication angle (Ø=10°) and cohesion (c=32kPa).

The outcrop rock is composed of white to reddish white, fine grained, thinly bedded to medium bedded, stylolitic, closely spaced to widely spaced joints, fresh to highly weathered from bottom to top respectively plate strong (σc=99.30), LIMESTONE.

There are three sets of joints in this rock mass, these are hkO1, hkO_2 and bc-hkl. Joint in J1 (hkO_1) have persistence of 20m, while the persistence of J2 (bc-hkl) = 5 to 10m and J3 are not clear, and they have frequency, 1-4/m,1-3/m for J1(hkO_1) and J2(bc-hkl) respectively.

Mode of failure: There are scars of rockfall which occurred due to the presence of steep-overhanging slope, and plane sliding has also occurred because the slope is daylighting and the bedding planes acted as sliding surfaces and both hkO1 and bc-hkl sets of joints act as composite back release surfaces. Because the slope was daylighting plane sliding has occurred in this station in 21- 22/12/2009 after heavy rainfall and it closed the road for two hours without human casualty plate (4-8c).This happend in the upper part of the slope due to:

1- Heavy rainfall.

2- Removal of toe of the upper slope.

3- Presence of thin layer Of clay whose (Friction angle Ø=10°) and (cohesion =32kPa) is less than the (dip angle Ө=32°) of the bedding plane about 5cm plate (4-8d) along which sliding has occurred.

4-Stylolite surfaces that are parallel to the bedding planes act as stabilizing agents due to interlocking of their peaks.

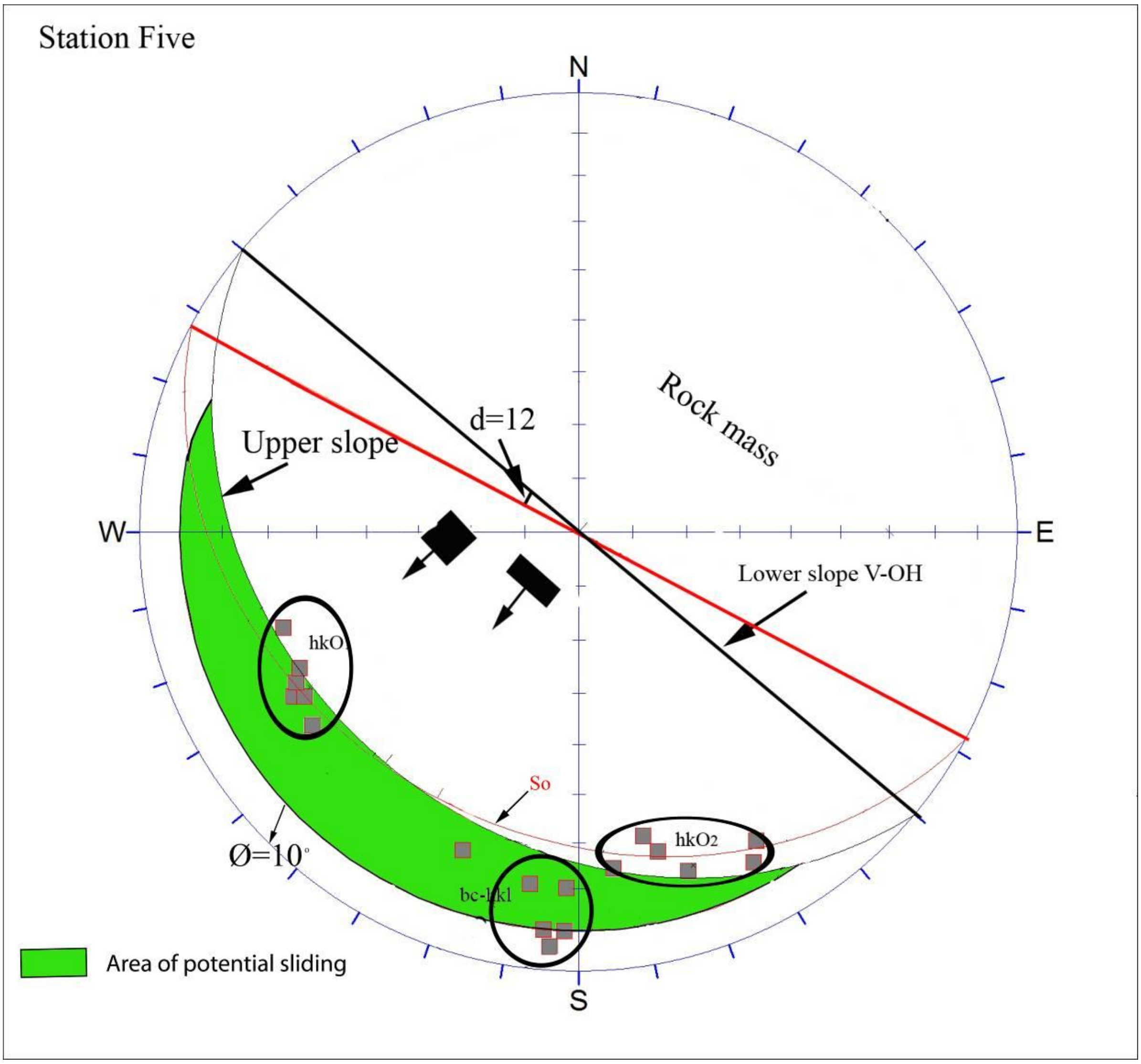
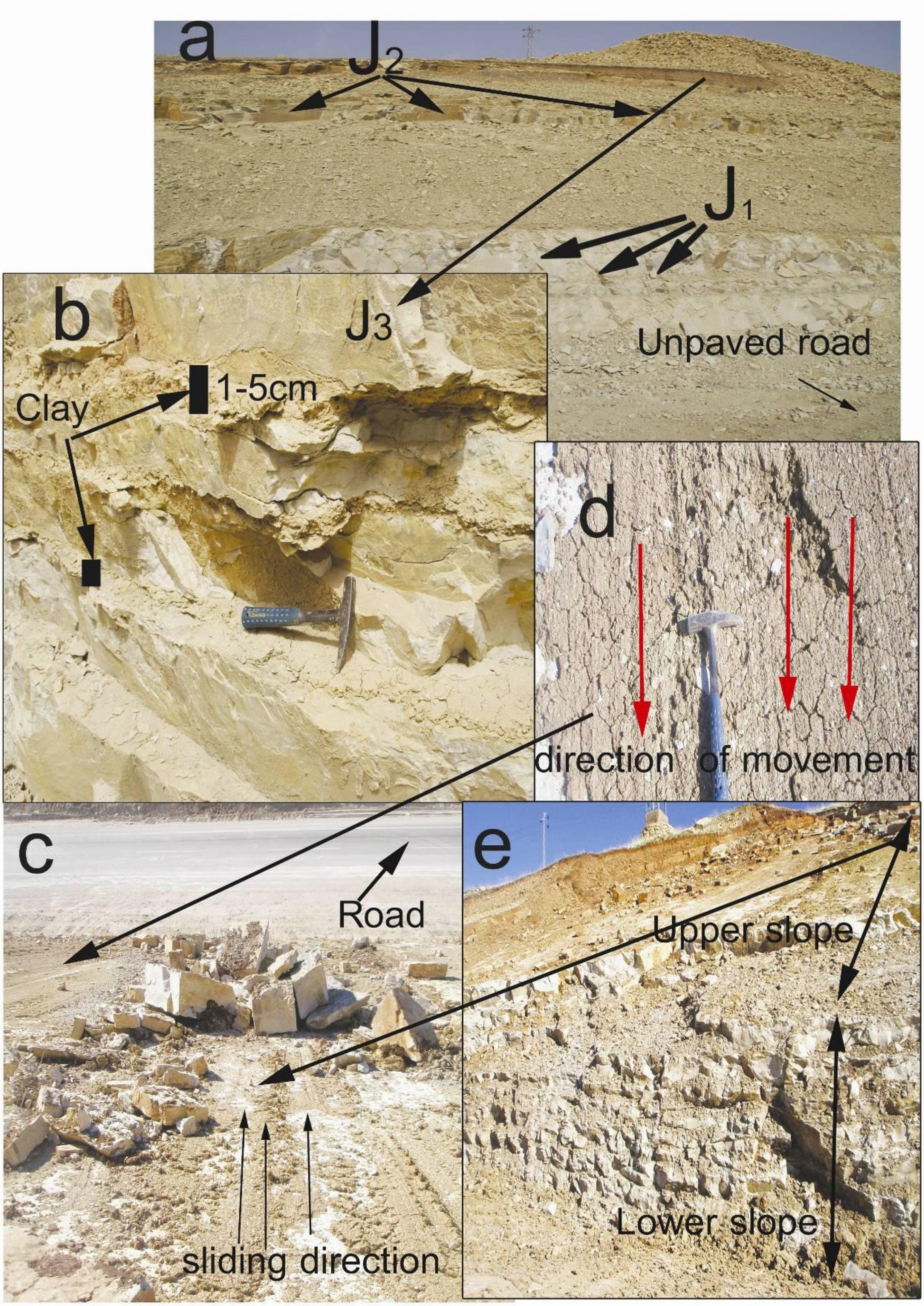


Figure (4-16) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.5



Plate(4-8): **(a)** Frontal view of the slope at station No.5 along Dokan-Khalakan road **(b)** Clay layer between upper bedding plane with stylolitic surface **(c)** Plane sliding after heavy rainfall the slide blocks have moved down slope, photo was taken from the crest of the slope **(d)** Clay layer work as sliding surface **(e)** Lateral view of the daylighting slope at station No.5.

4.8.6 Station No 6:

The station is located on the SW limb of Kosrat anticline, along the main road between Dokan and Khalakan at latitude 35° 56′ 45″ N and longitude 44° 57′ 08″ E (Fig.4-11). It lies within Kometan Formation, The station is formed by man-made excavation. The slope at this station is a vertical slope exposing inclined rock layer (plate 4-9a), it is about 6m high and 40m long parallel to its strike. It is covered by soil in the upper part, its attitude is 210/90° to overhanging Figure(4-17), and it contains many weak zones which are completely fractured, plate (4-10a).

The average bedding plane attitude is 219/28° plate (4-9a). The slope is parallel (d=9°) right emergent and concordant type depending on (Al-Saadi, 1981) classification. The outcrop rock is composed of white to grayish, fine grained, thinly to medium bedded, very closely spaced to widely spaced joints, slightly weathered SW to Highly weathered HW very strong(σc =104.84MPa) LIMESTONE.

Mode of failure: The slope is daylighting because the dip of beds is less than slope inclination therefore plane sliding of small blocks has occurred along bedding plane, while joints in (hkO_1) and (hkO_2) (plate 4-9 b, c and d) acted as composite back release surfaces Fig (4-18). Rockfall of small blocks has also occurred and left many scars in the slope face (4-9a).

The ratio of $\left(\frac{b}{h}\right)$ was measured in some blocks in the slope and was found to be equal to 0.2941, which is less than tan of the basal plane angle (α=28°) of the basal plane (bedding plane) and tan28°=0.5317. Therefore Toppling failure is possible in this slope so that hkO_1 would act as back release surface while hkO_2 would act as lateral releases surface, and the bedding planes as basal surface when cohesion becomes Zero. See plate 4-10b and (Fig 4-18) there are many scars of toppled slabs in the slope face.

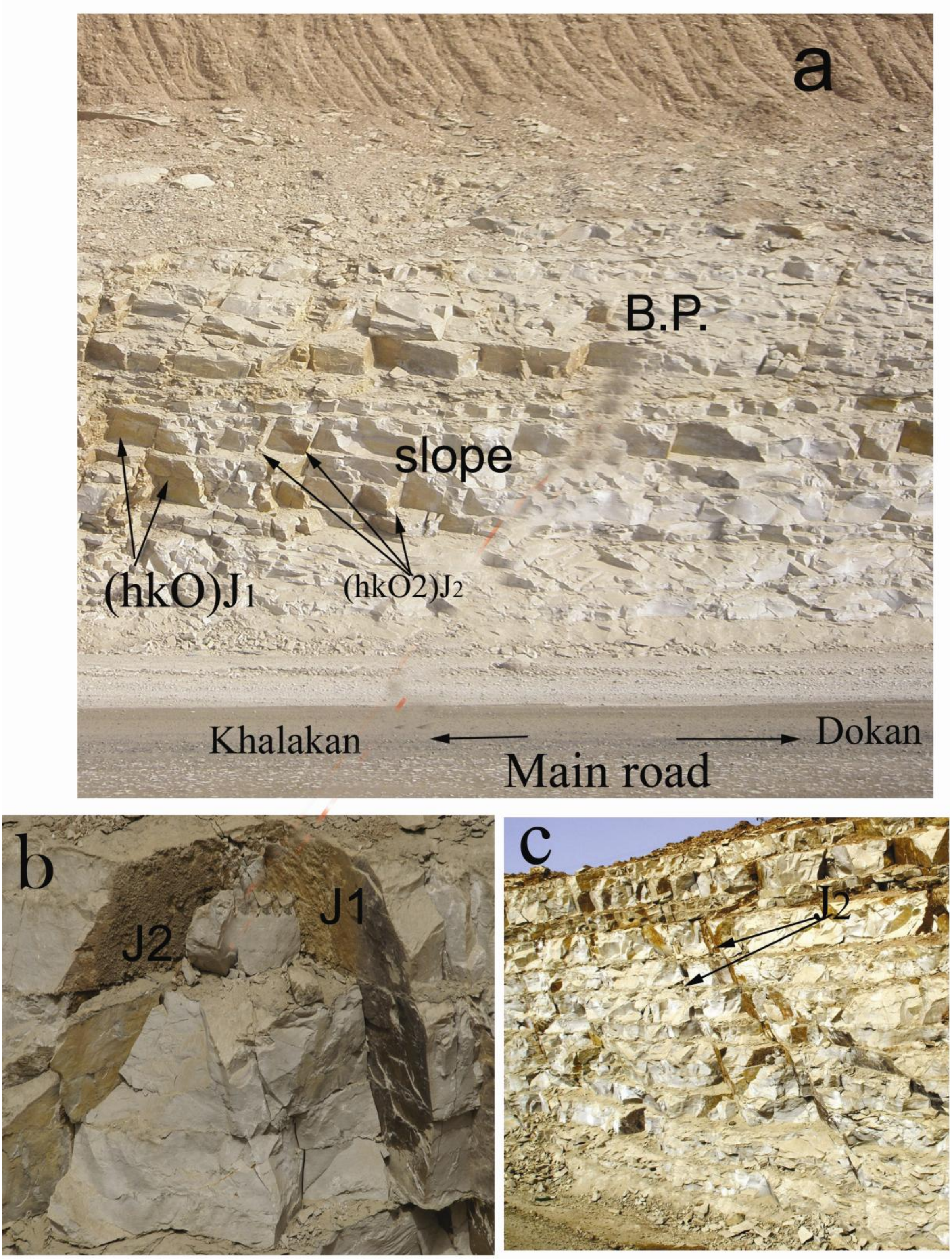


Plate 4-9 (a) Frontal view of the main slope at station No. 6 along Dokan-Khalakan road (b) Joint J_1 in station No. 6 (c) Joint J_2 at station No. two (d) Composite surface between J_1 and J_2 at station No.6.

Plate 4-10a: Shows large weak zone at station No.6


Plate 4-10b: Shows the probability of toppling at station No.6

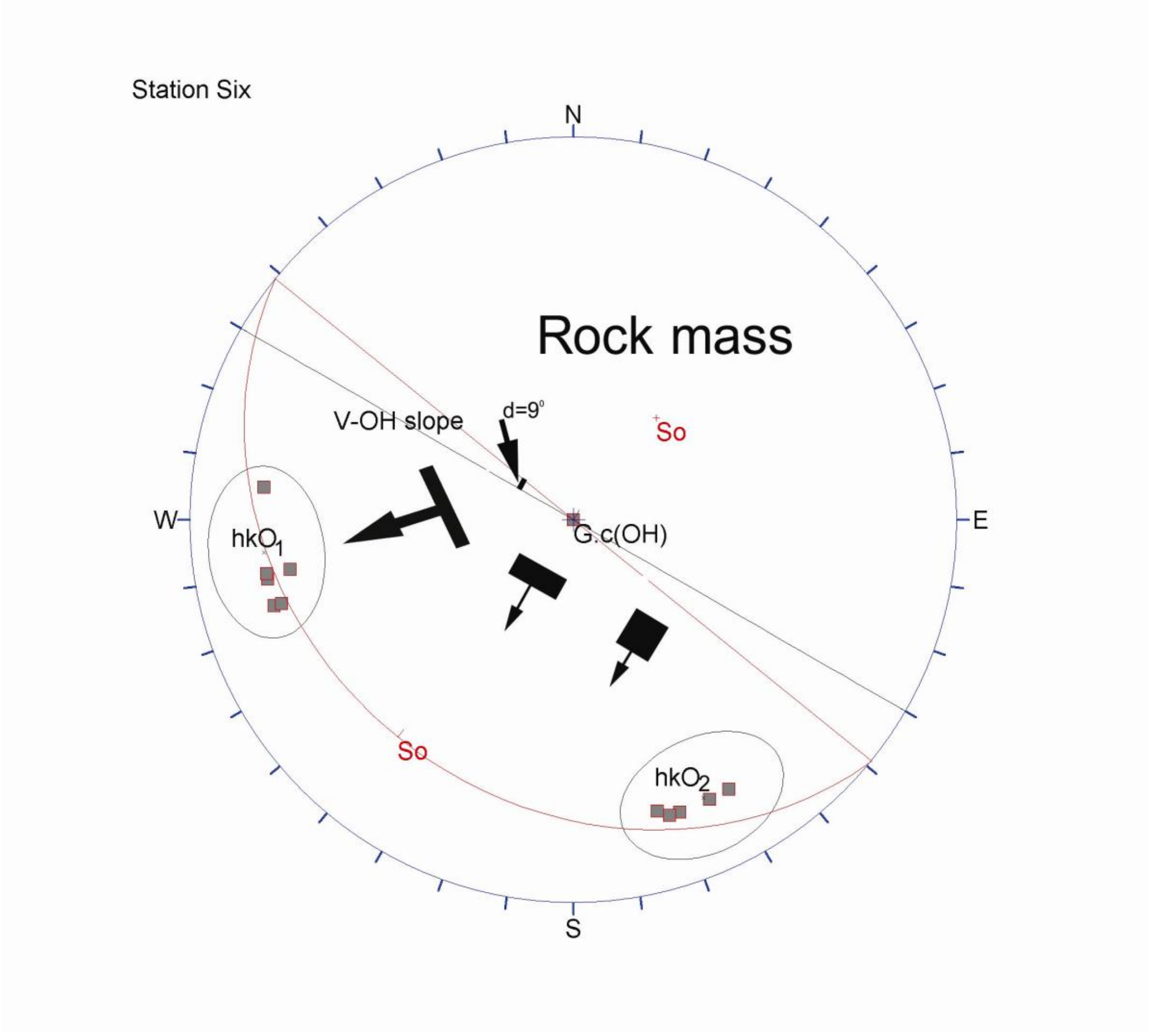


Figure (4-17) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No. 6

4.8.7 <u>Station No.7(A):</u>

The station is located on the SW limb of Kosrat anticline at latitude 35° 56′ 49″N and longitude 44° 57′ 00″E (Fig.4-11). It lies within Shiranish Formation. The station is formed by man-made excavation located in the left (south)side of Dokan to Khalakan road. The slope that exposes highly fractured dark gray marly limestone is about 8m high and 30m long parallel to strike of the slope, its attitude is 030/90°to overhanging (plate 4-11a). It contains large vein(shear zone) that is composed of clay and resulted from shear movement(plate 4-11d).

The average bedding plane attitude is 219/24° plate (4-11a). The slope is parallel slope (d=9°), right emergent and discordant type depending on (Al-Saadi, 1981) classification.

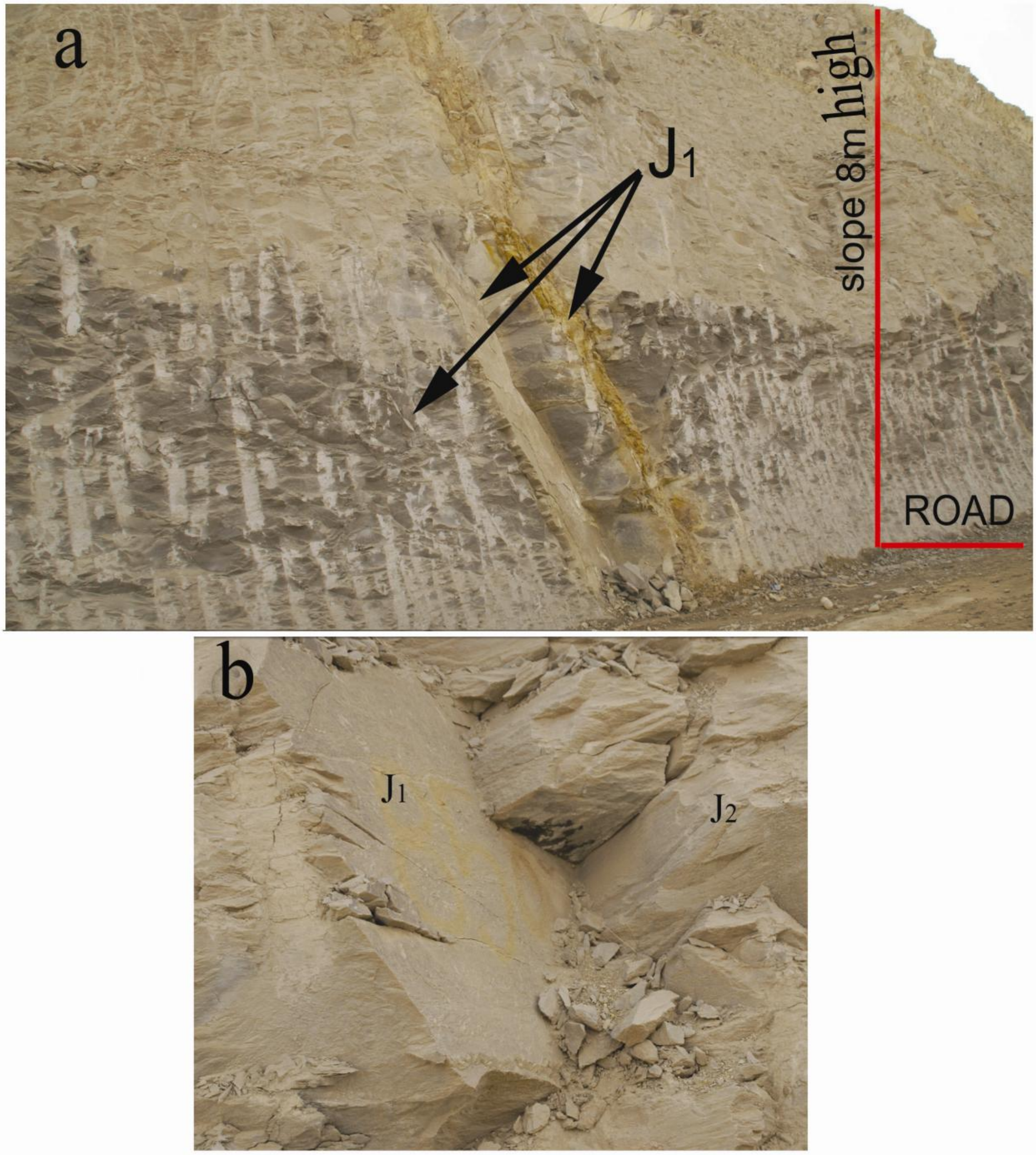


Plate 4-11: (a) Lateral view of the slope at station No.7A on the left (south)side of Dokan to Khalakan road (b) Wedge sliding scar

The rock in this station is composed of dark gray, fine graind, very thinly to thinly bedded, widely to very widely spaced, fresh, moderately strong (σc=49. 8MPa) marly LIMESTONE.

The joints in the rock have various structural directions and their persistency is not clear because the upper part is covered with clay and weathered material. Joints orientation are variable in three main directions so that joint poles in stereogram (Fig.4-19) are dividing into three main areas (J_1) hkl-hkO_1,(J_2) hkl-hkO_2) and hkl.

Mode of failure: The probable types of failure are wedge sliding plate (4-11b) and rockfall. In case of wedge sliding, it occur along the line of intersection J1 and J2 figure (4-18). Rockfall is abundant because of highly fracture rock and very steep to vertical slope. Toppling of slabs of beds which dip into the slope is limited when bedding planes act as back release surface.

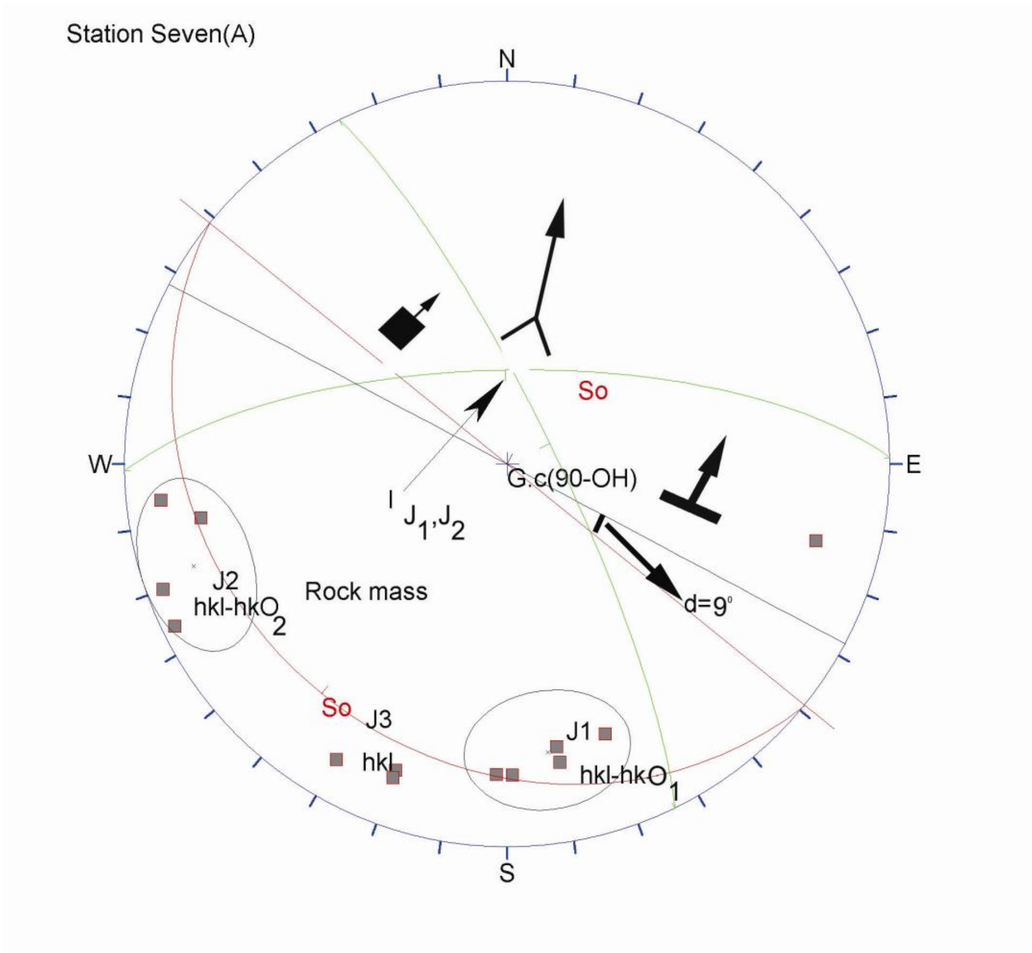


Figure (4-18) Stereogram illustrating the relation among slope, discontinuities and types of failure at station No.7A

4.8.8 Station No. 7B:

The station is located on the SW limb of Kosrat anticline at latitude 35° 56′ 49″ N and longitude 44° 57′ 00″E (Fig.4-11). It lies within Shiranish Formation. The slope at this station is formed by man-made excavation located in the right side of Dokan-Khalakan road. The slope exposes highly fractured dark gray marly limestone covered with clay in the upper part and it is about 30m high and 40m long (plate 4-12a) parallel to the strike of the slope. It has attitude (208/90° to OH) (plate 4-12b).

The average bedding plane attitude is 218/28°. The slope is Parallel (d=10°) right emergent and concordant depending on (Al-Saadi, 1981) classification.

The rock in this station is composed of dark gray, fine grained, very thinly bedded to thinly bedded, widely spaced to very widely spaced, fresh, moderately strong (σc=49. 8MPa) marly LIMESTONE.

The joints in the rock have various structural directions. Joints orientations are variable in three main directions such as joint poles in stereogram (Fig.4-20)

Mode of failure: Many type of rock failures have occurred and are probable to occur in the future. They include Rockfall because of the steep to overhanging slope, and plane sliding along bedding plane (plate 4-12b and d) because the slope is daylighting slope (dip of beds is less than inclination of the slope). During the plane sliding along bedding plane, joints in J_1 and J_2 work as composite back release surfaces while joints in J_3 work as back release surfaces.

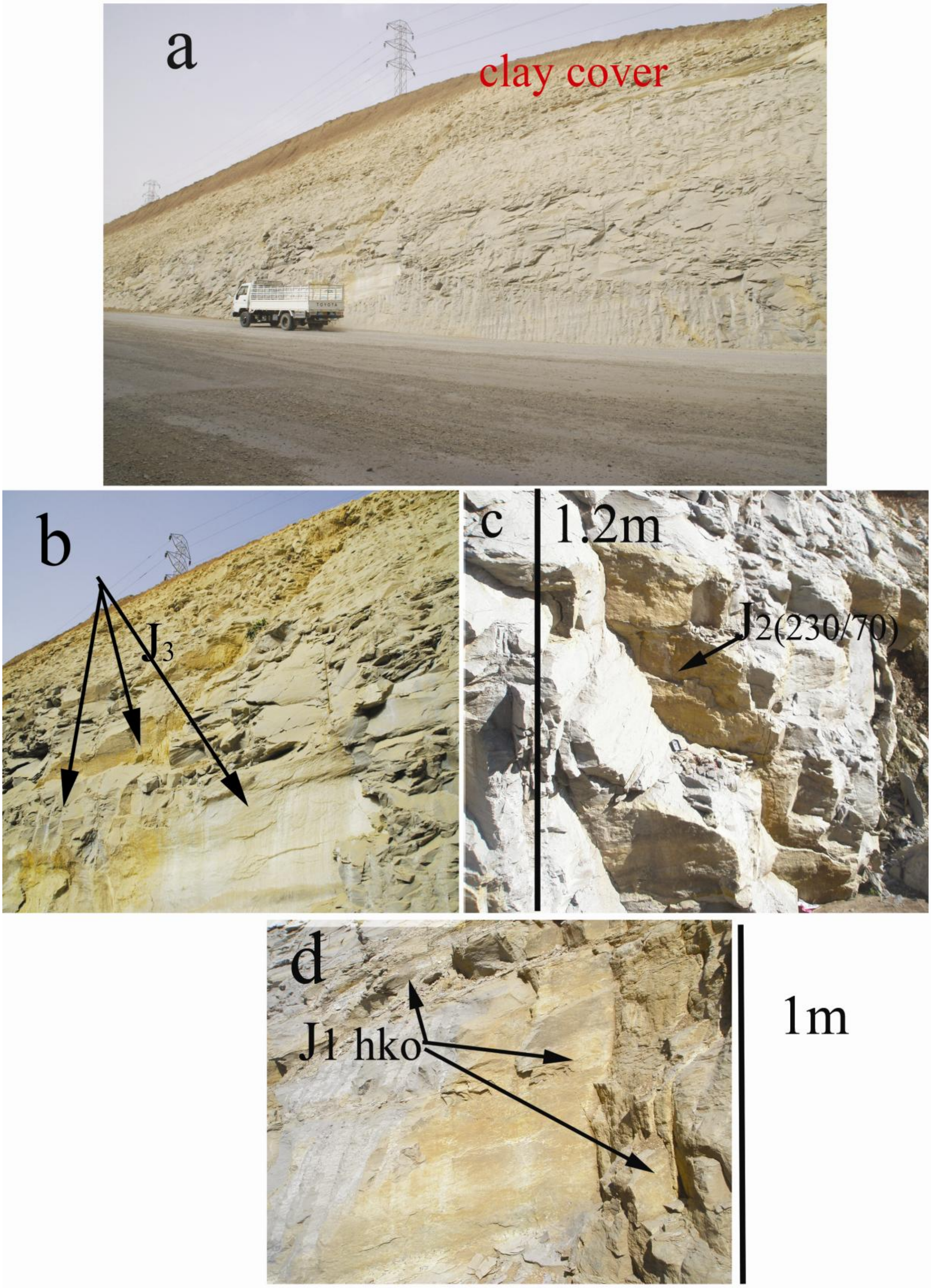


Plate 4-12: a) Lateral view of the slope at sation No.7B on the right side of the road from Dokan to Khalakan . (b, c and d) Shows joints sets of J_1, J_2, and J_3 at station No.7B.

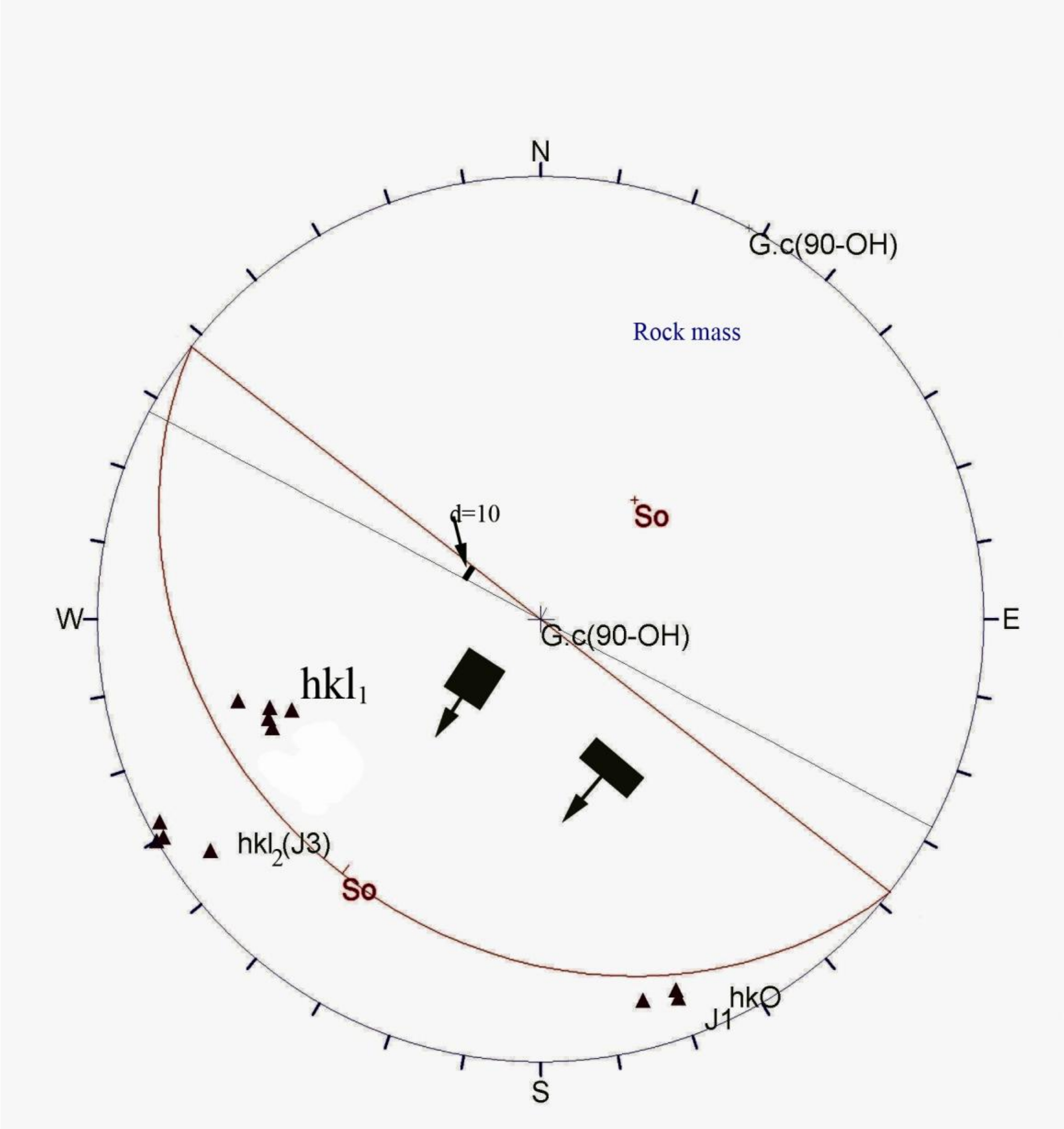


Figure (4-19) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.7b

4.8.9 Station No. 8:

The station is located on the SW limb of Kosrat anticline on the left side of the main road from Dokan to Khalakan at latitude 35° 56′ 33″ N and longitude 44° 57′ 27″ E (Fig.4-11). It lies within Kometan Formation. The slope at the station is a man-made slope, it exposes limestone layers rock. It is 3m high and 5m long parallel to it is strike. It has an attitude of (040/70°) Figure (4-20) and plate (4-13a).

The average bedding plane attitude is 210/22° plate (4-13a)and figure(4-20). The slope is parallel slope (d=10°), left emergent and discordant type depending on (Al-Saadi, 1981) classification.

The rock is composed of light white to grayish white, fine grained, very thinly bedded to medium bedded, very closely spaced to widely spaced joints, moderately weathered (MW), very strong (σc =112.82MPa) LIMESTONE.

Mode of failure: The main types of failure are:

1-Plane sliding along bc tension joints

2-Wedge sliding along the intersection line between hkO1 and hkO2 (I (hkO_1) (hkO_2)) (plate 4-13) and Figure(4-20).

3-Rockfall is also possible because of slope steepness and fracturing of the rock mass.

4- The toppling of layer occurs because bedding plane work as a back release surfaces , J_1 and J_2 work as lateral release surfaces and (J_3) bc joint act as basal surface as shown in Figure (9-20) stereogram projection and plate (4-13b and c).

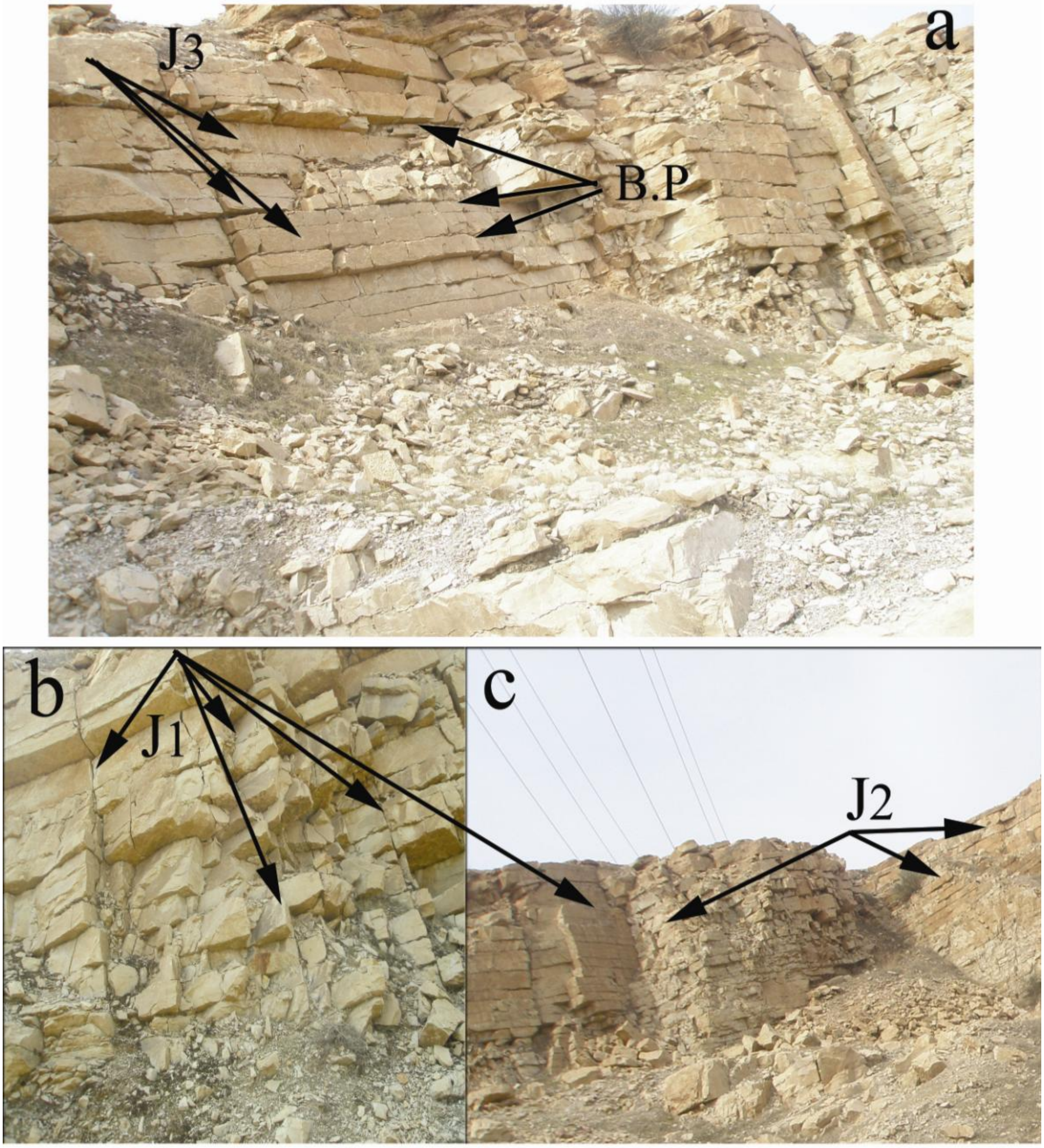


Plate 4-13: a) Lateral view of the main left side of the road from Dokan to Khalakan at stationNo.8 showing wide sliding surfaces of bc set and traces of bedding plane (B.P) that dips into the rock mass. (b) Set (hkO_1) J_1 (c) shows scars of wedge sliding along intersection lines between hkO_1 and hkO_2.

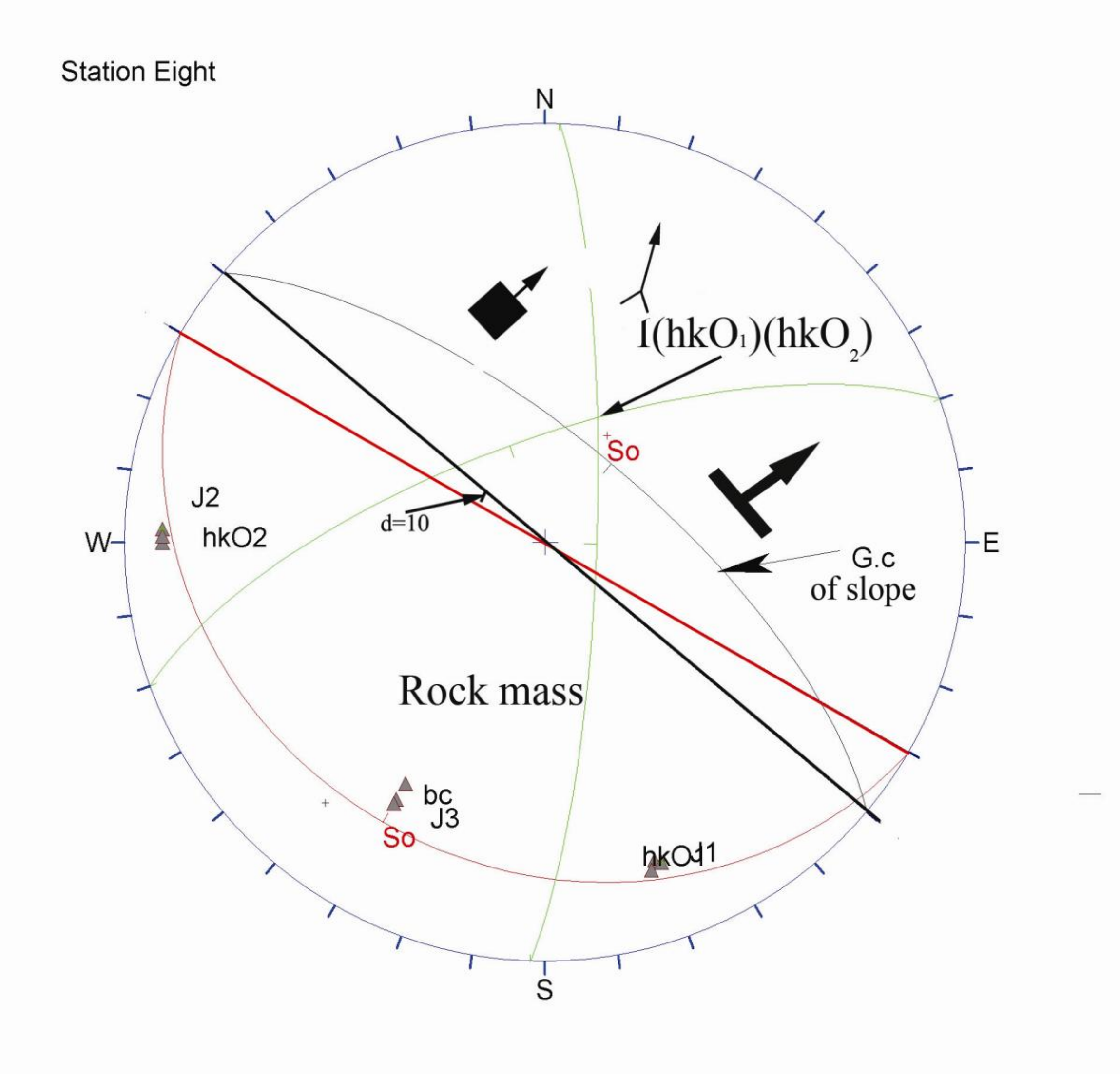


Figure (4-20) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.8

4.8.10 Station No.9:

The station is located on the SW limb of Kosrat anticline along the main road of Dokan to Khalakan at latitude 35° 57′ 16″ N and longitude 44° 56′ 08″ E (Fig.4-11). The station is a man-made slope where Kometan Formation is exposes. The slope at this station is a vertical slope exposing the layered rock mass, it is about 5m high and 10m long having attitude (208/90°).

The average bedding plane attitude is 190/19° (Figure 4-21). The slope is a parallel slope (d=18°), left emergent and concordant type depending on (Al-Saadi, 1981) classification.

The outcrop rock is composed of reddish white, fine grained, thinly bedded to medium bedded, closely spaced to widely spaced joints, moderately weathered and very strong (σc =112.82MPa) LIMESTONE.

Mode of failure: The slope is daylighting slope because the dip of beds is less than inclination of the slope plate (4-14a). Geometrically this is favorable for plane sliding along bedding plane while joints in (hkO_1) or J_1 act as lateral release surface (L.R.S), and joints in (hkO_2) or J_2 act as back release surface (B.R.S) plate (4-14), and the toe is cut due to the widening of the road. Rockfall occurs along the slope face because it is steep to overhanging (OH).

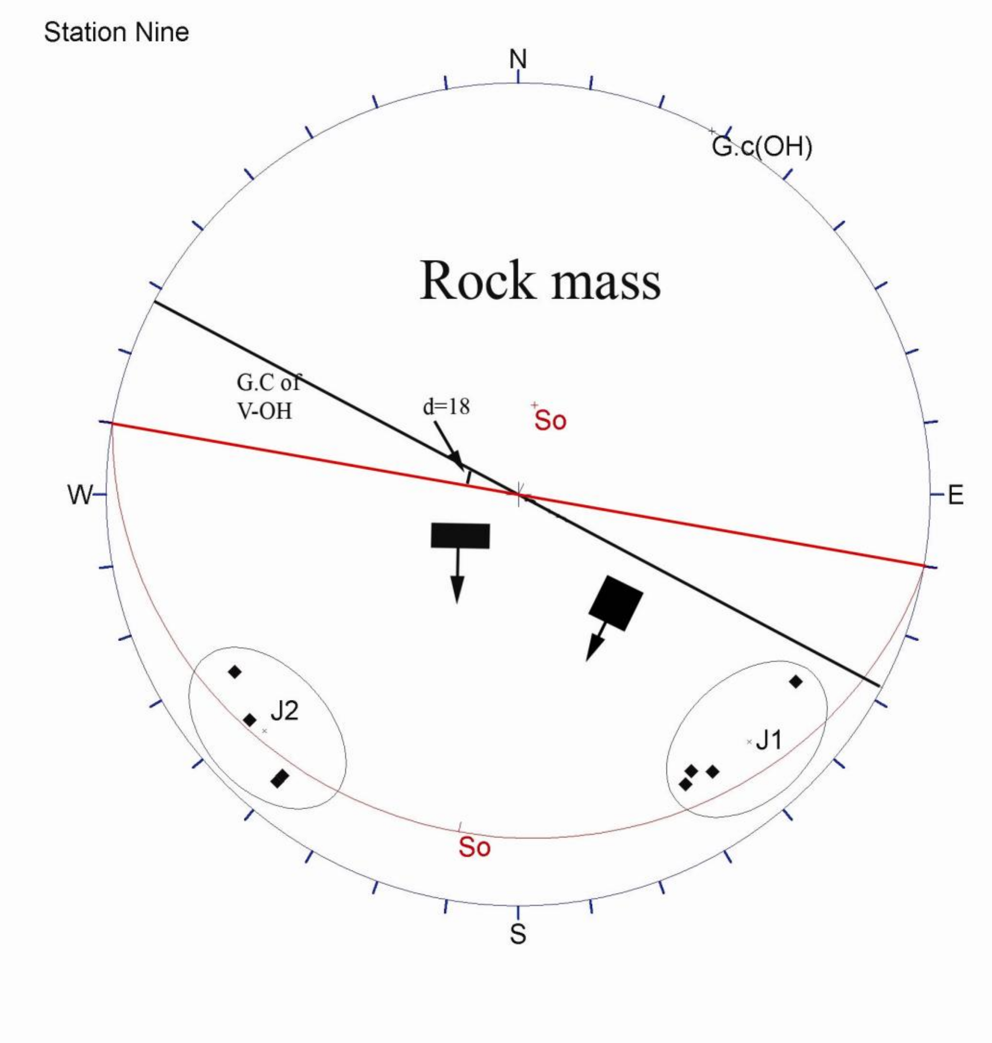


Figure (4-21) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.9

Plate (4-14):a) Lateral view of the slope at station No.9 on the main road shows cut face and fallen rocks b) Shows joints of J_2(hkO2) B.R.S) (c)Shows joints of J_1(L.R.S) (d) Lateral view of the slope at station No.9 shows the main road from Dokan to Khalakan

4.8.11 Station No.10:

The station lies within Kometan Formation and is located on the SW limb of Kosrat anticline at latitude 35° 57′ 17″ N and longitude 44° 56′ 06″ E (Fig.4-11) at the distance of about10m north of station No.9.

Generally, the slope is very close to the road, about 1m away from it (plate 4-15d) with an average inclination of (210/90° to OH) Fig.(4-22). The station lies is a man-made slope that exposes layered rocks of limestone with chert nodules and stylolitic surfaces (plate 4-15b and c). The slope is 5m high and 8m long parallel to its trend.

The average bedding plane attitude is 202/18° Therefore the slope is parallel (d=8°), left emergent and concordant depending on (Al-Saadi, 1981) classification.

There are clay seams between the bedding plane plate(4-15a)which control the engineering properties of bedding planes therefore, the shear strength parameters (Ø and c) for clay layers were carried out by shear box test, the friction angle (Ø=11°) and cohesion (c=64kPa).

Rocks of the slope are reddish white to white, fine grained, thinly to medium bedded, moderately to widely spaced, moderately weathered and very strong (σc =112.82MPa) LIMESTONE.

Mode of failure: Rockfall is the main failure type that occurs in this station. The plane sliding is probable along bedding planes because the clay layer having friction angle Ø=11° which is less than the dip of the daylighting limestone ϴ=18°. The dip of beds is less than the inclination of the slope and both J_1 and J_2 work as composite back release surfaces and J_3 as back release surface. The stylolites that are parallel to the bedding plane act as stabilizing agents due to interlocking of their peaks.

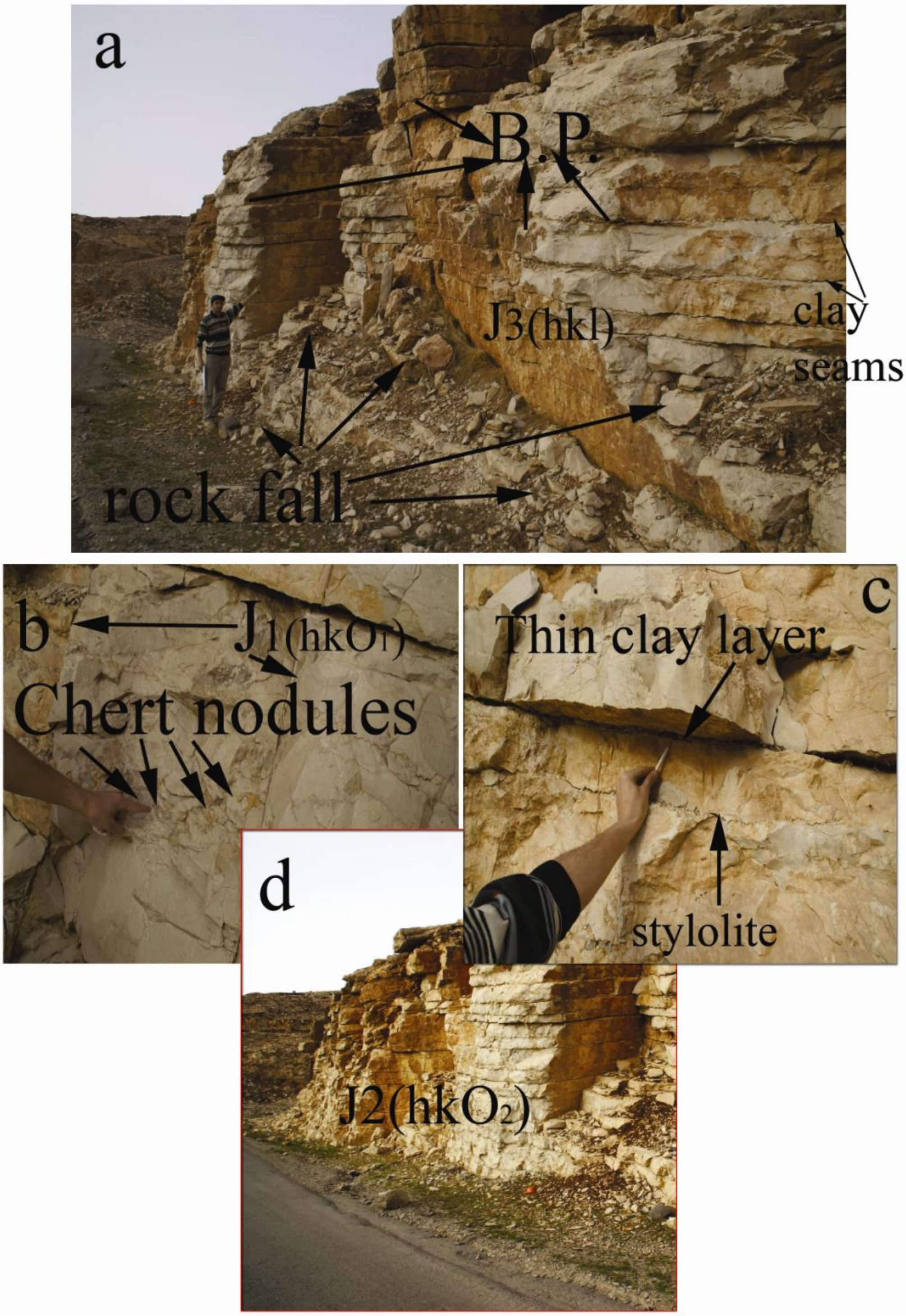


Plate 4-15: a) Lateral view of the main slope on the Dokan to Khalakan road at station No.10 (b) Chert nodules and joint set J_1 (c) Thin clay layer and stylolite (d) Shows the proximity of the slope from the road, and the traces of bedding planes in the daylighting slope

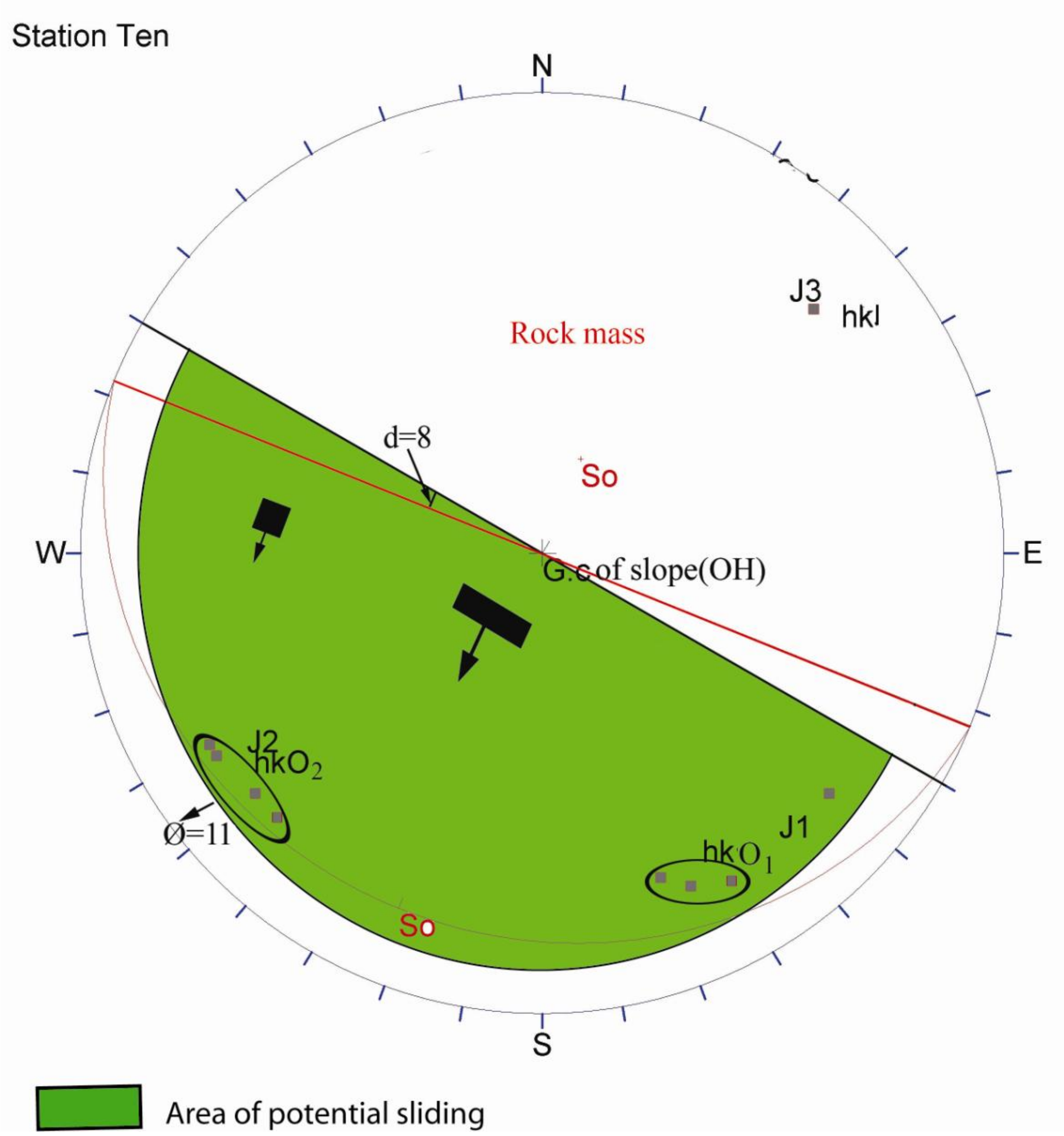


Figure (4-22) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.10

4.8.12 Station No.11:

The station lies within Kometan Formation and is located on the SW limb of Kosrat anticline at latitude 35° 57′ 19″ N and longitude 44° 56′ 02″ E (Fig.4-11). The slope is a man made slope, it is vertical and exposes layered rocks of highly fractured limestone covered by weathered clay layer at the top. It is about 5 to 8m high and 10m long parallel to its trend, having an attitude of (160/90°).

The average bedding plane attitude is (223/20°) Fig (4-23). So the slope is Oblique lateral, (d=63°) right emergent and concordant type depending on (Al-Saadi, 1981) classification.

The outcrop rock is composed of white to grayish white, fine grained, very thinly to medium bedded, moderately widely to widely spaced, moderately weathered (MW) strong (σc =90.44MPa) LIMESTONE. The joints in the rock have various structural directions so they are orientated in two main directions (hkl-hkO) or J_1 and (hkl) or J_2 Figure (4-23).

Mode of failure: The main type of failure is rockfall. The falling scars are clear and can be seen along the slope face (plate 4-16b) and rockfall is aided by slope steepness and high degree of fracturing (plate 4-16)

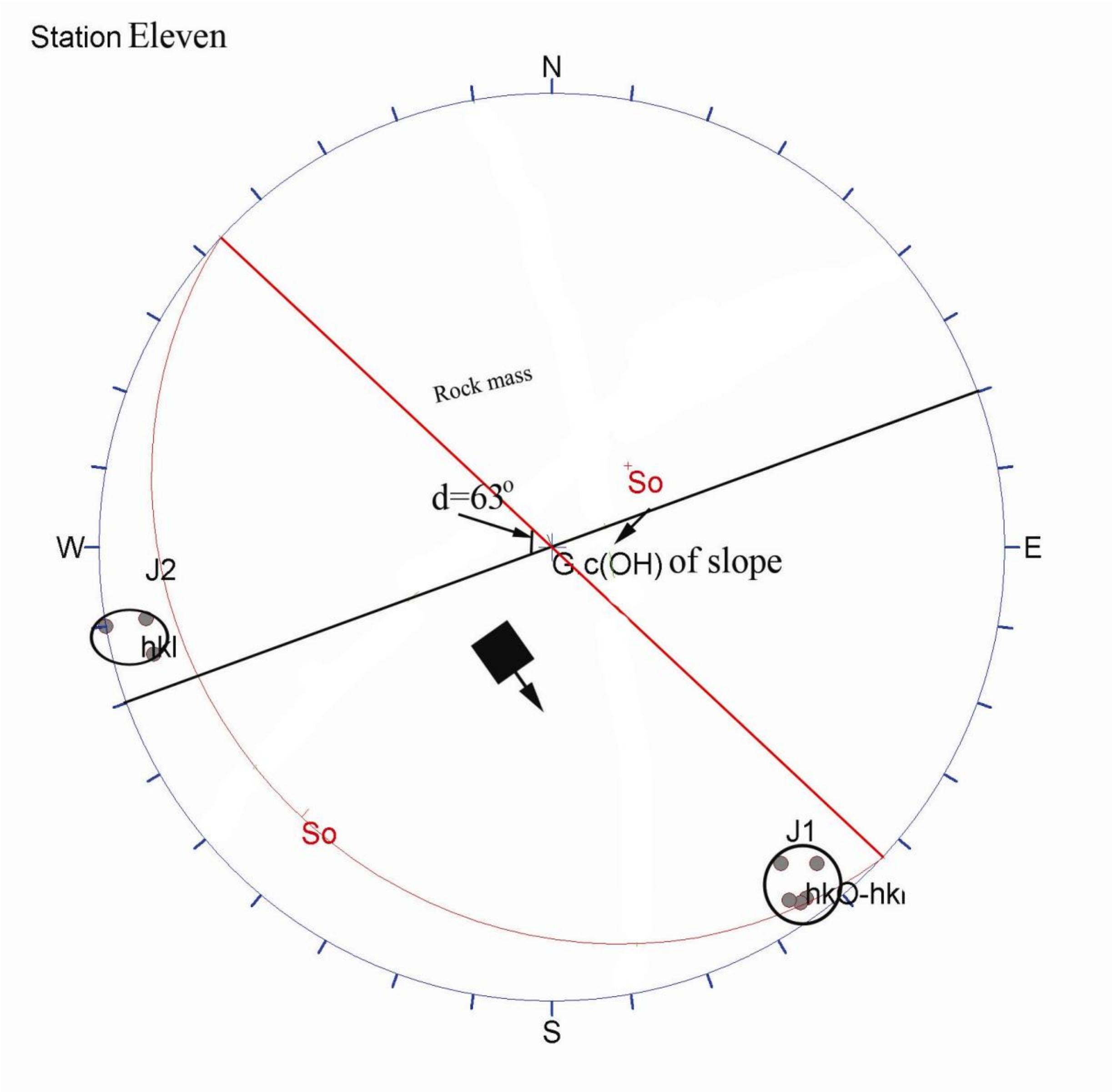


Figure (4-23) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.11

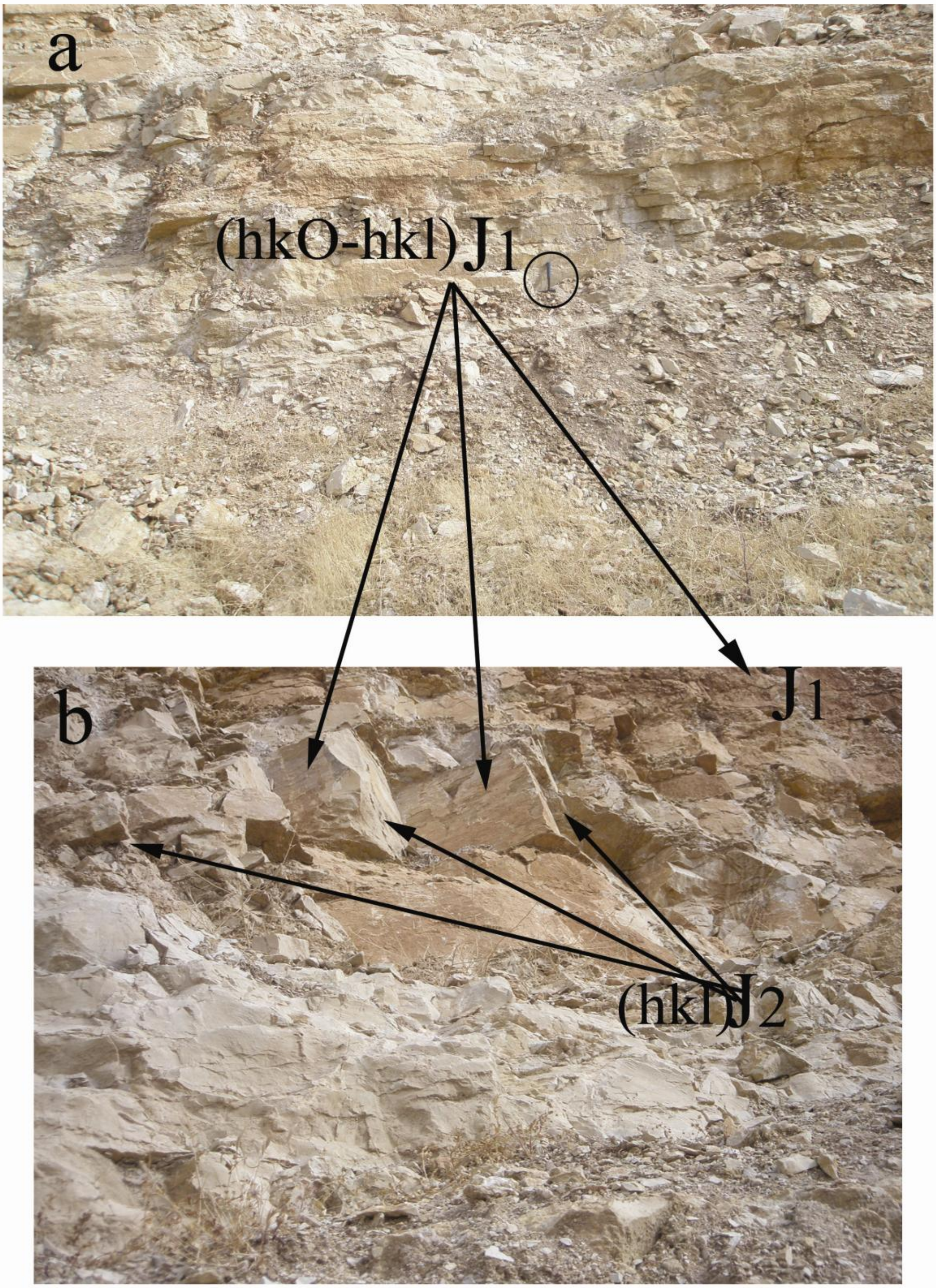


Plate 4-16: a) Frontal views of the slope at station No.11 on the right north side of Dokan to Khalakan road. Fallen rocks cover the slope faces. The 30cm-hammer is in the circle. (b) Shows joint sets J_1 and J_2.

4.8.13 Station No.12:

The station is located on the SW limb of Kosrat anticline at latitude 35° 57′ 20″ N and longitude 44° 56′ 00″ E (Fig.4-11). It lies within Kometan Formation. The slope exposes very highly fractured limestone and it is about 3m high and 12m long parallel to its trend its attitude is (180/80°).The distance between the station and the road is about 2m plate (4-17a).

The average bedding plane attitude is 150/20° plate (4-17a) so the slope is oblique lateral, (d=30°) left emergent and concordant type depending on (Al-Saadi, 1981), classification Fig (4-24).

The outcrop rock is composed of white to grayish white, fine grained, thinly to medium bedded, highly weathered, strong (σc=90.44MPa) LIMESTONE (plate 4-17bandc)

Mode of failure: The rocks are highly fractured and are likely to represent weak zone of crushed rocks by strong tectonic forces so the main slope failures are mechanical disintegration and rockfall of small fragments (plate 4-17)

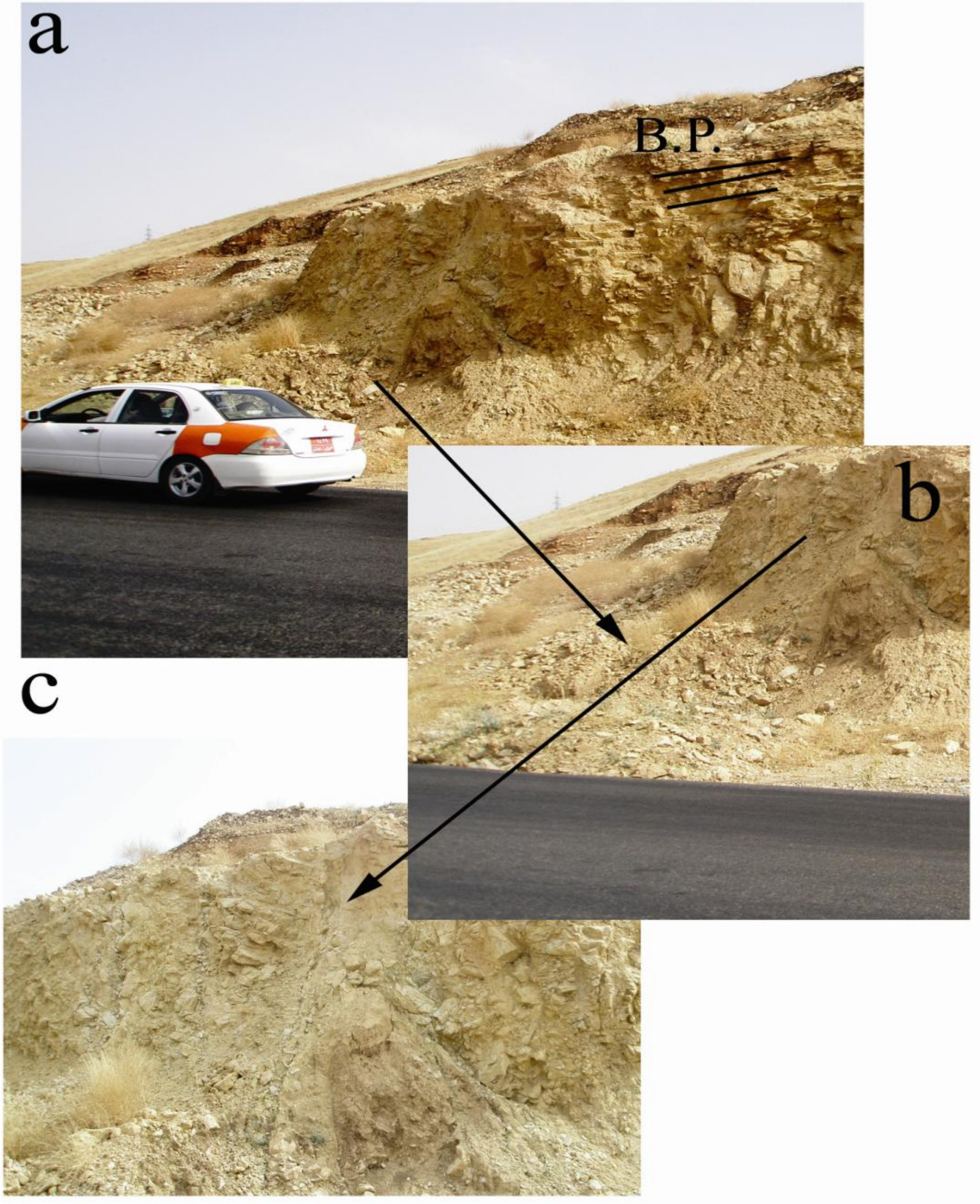


Plate 4-17: a) Lateral view of the slope at station No.12 on the right side of the road from Dokan to Khalakan (b) Weathered rock and fallen rock fragments (c) Closer frontal view of the slope showing rock debris and scars of fallen fragments

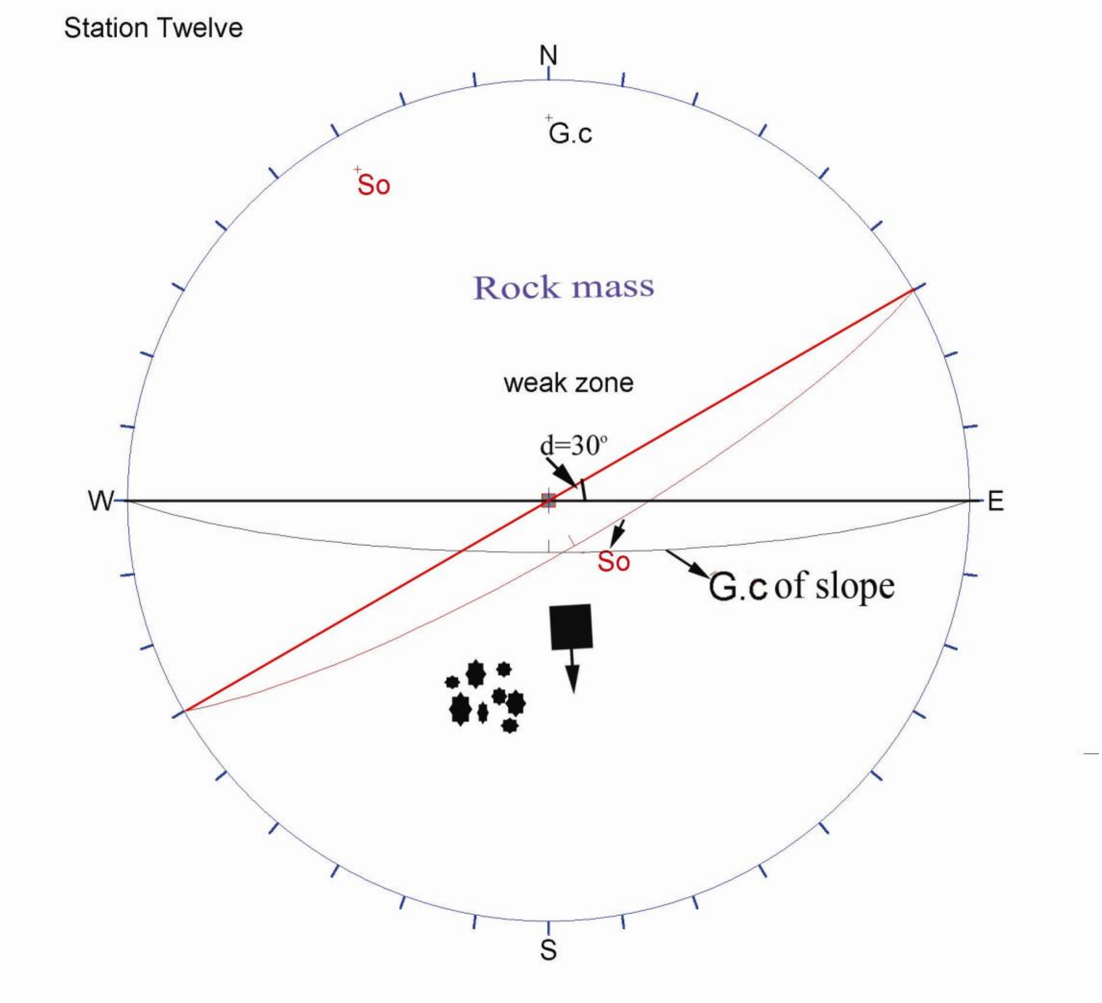


Figure (4-24) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.12.

4.8.14 Station No.13:

The station is located on the SW limb of Kosrat anticline at latitude 35° 57′ 25″ N and longitude 44° 55′ 42″ E (Fig.4-11). It lies within Kometan Formation. The man-made slope, it exposed layered rocks. Its upper part covered by weathered clay. It is about 5m high and 10m long parallel to its trend having attitude (208/70°).

The average bedding plane attitude is (179 /80°) plate (4-18) and Fig (4-25) so the slope is Oblique lateral, (d=29°) left emergent and concordant type depending on (Al-Saadi, 1981) classification.

The outcrop rock is composed of white to reddish white, fine grained, thinly bedded to medium bedded, moderately widely spaced to widely spaced, moderately weathered(MW) very strong(σc =104.95MPa) LIMESTONE.

The joints in the rock have various structural directions so they are orientated in two main directions (hkO) or J_1 and (hkl) or J_2 figure (4-25) and (plate 4-18).

Mode of failure: The main type of failure is rockfall. The fall scars are clear and can be seen along the slope face (plate 4-18). The plane sliding is probable along bedding planes because the dip of bed is less than the inclination of the slope and J_1 acts as back release surface, while joints in J_2 act as lateral release surfaces.

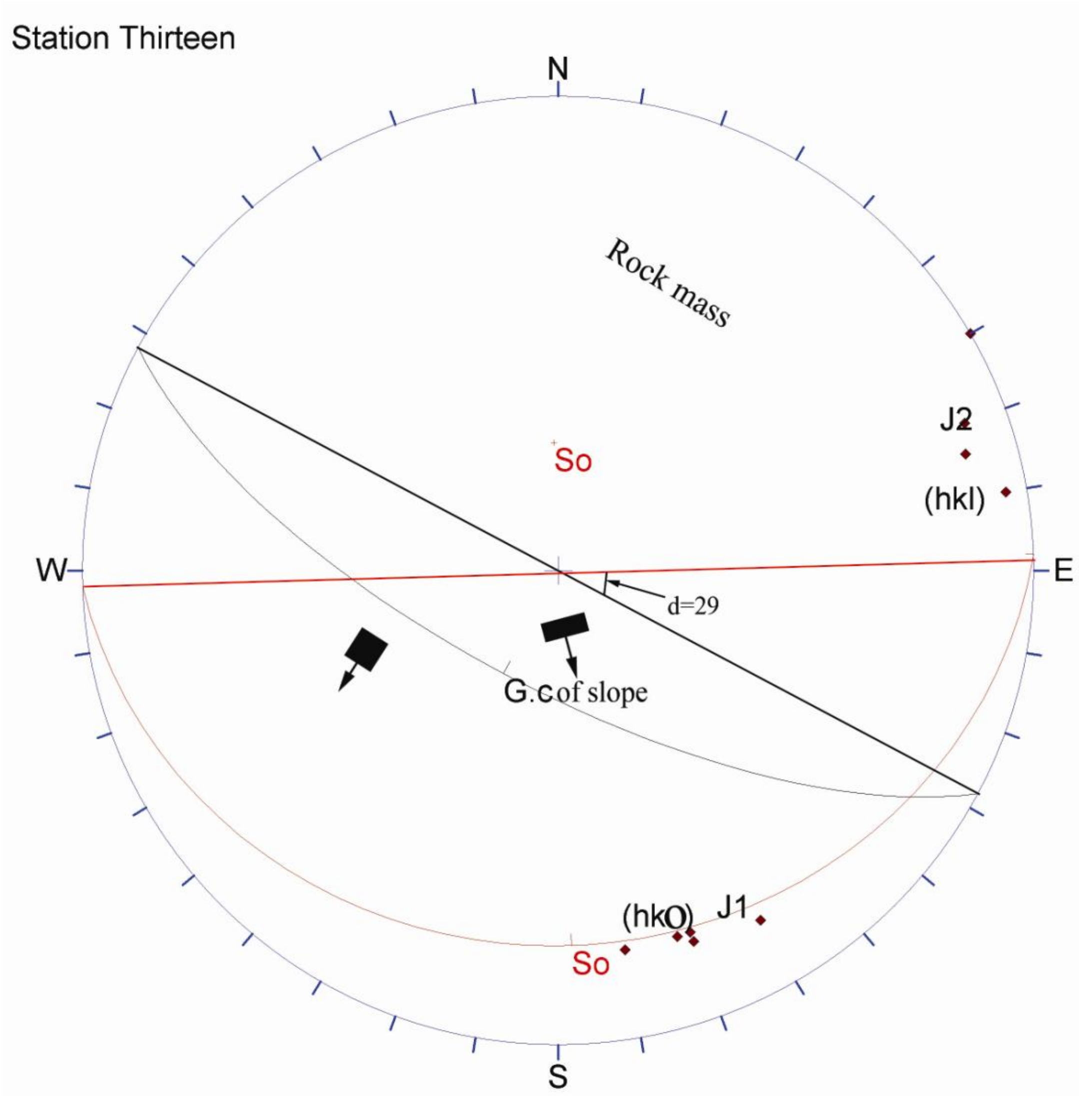


Figure (4-25) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.13.

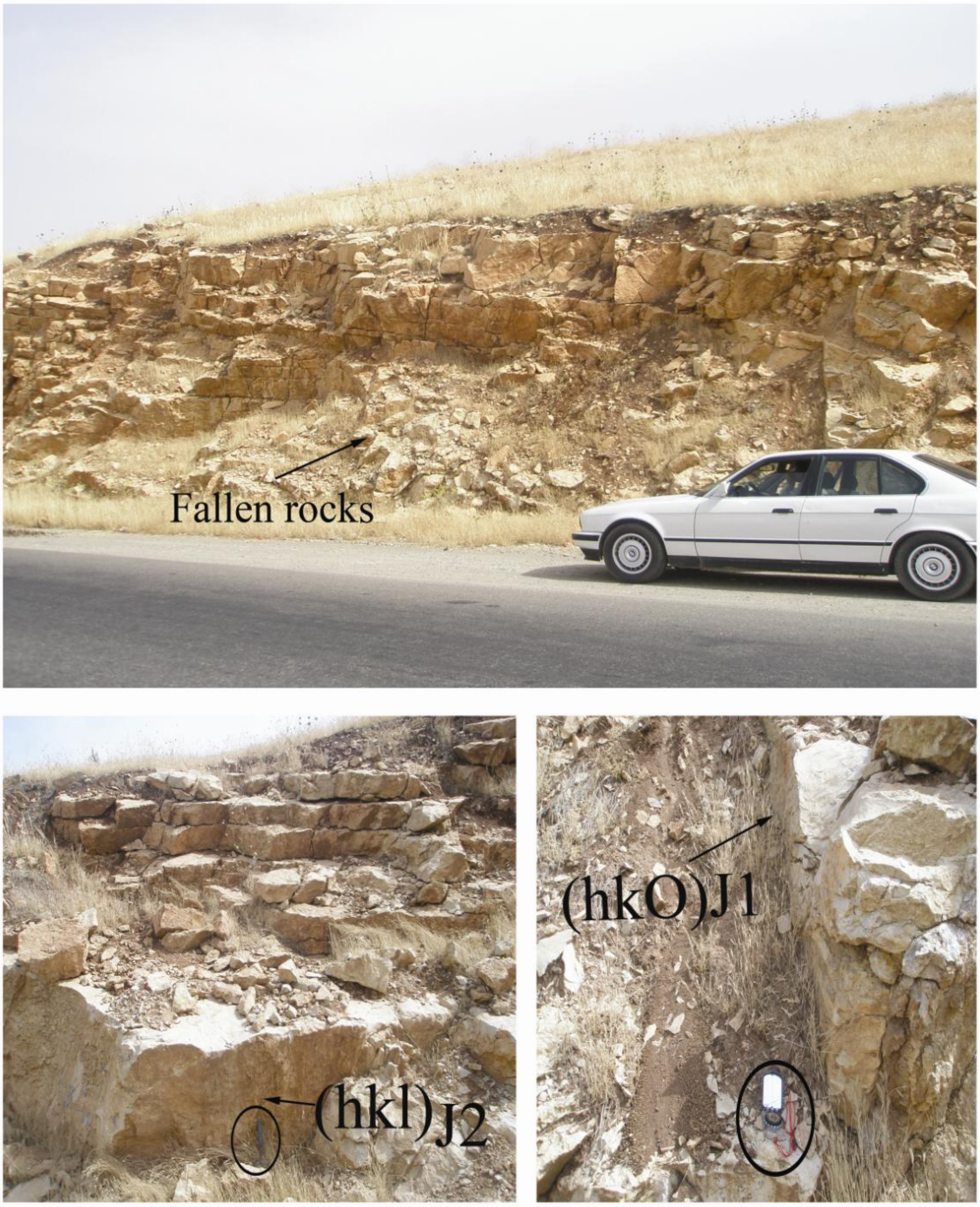


Plate 4-18: a) Frontal view of the slope at the station No.13 along the Dokan to Khalakan road. B and C) Show joint sets (hkl and hkO) at station No.13

4.8.15 <u>Station No.14:</u>

The station is located on the SW limb of Kosrat anticline at latitude 35° 57′ 27″ N and longitude 44 55′ 43″ E (Fig.4-11). It lies within Kometan Formation. Generally the slope is very close to the road and about 2m away from it (plate 4-

19a). It exposes layered rocks of highly fractured limestone. It is about 5 m high and 10m long parallel to its trend, having attitude (240/ 90°-OH).

The average bedding plane attitude is 214/ 20° (plate 4-19)and Fig(4-26) So the slope is Oblique lateral, (d=26°) left emergent and concordant type depending on (Al-Saadi, 1981) classification.

The outcrop rock is composed of white to grayish white, fine grained, very thinly bedded to medium bedded, closely spaced to widely spaced, Stylolitic moderately weathered(MW) very strong(σc =112.25MPa)LIMESTONE.

Mode of failure: The rockfall is the main failure type because of the steep to overhanging slope. Plane sliding is likely to occur along bedding plane because the slope is daylighting (the dip of bedding plane is less than the slope angle at the same general direction) and joints in J_1(hkO) act as back release surfaces while J_2 act as lateral release surfaces plate (4-19b and c) and Fig (4-20).

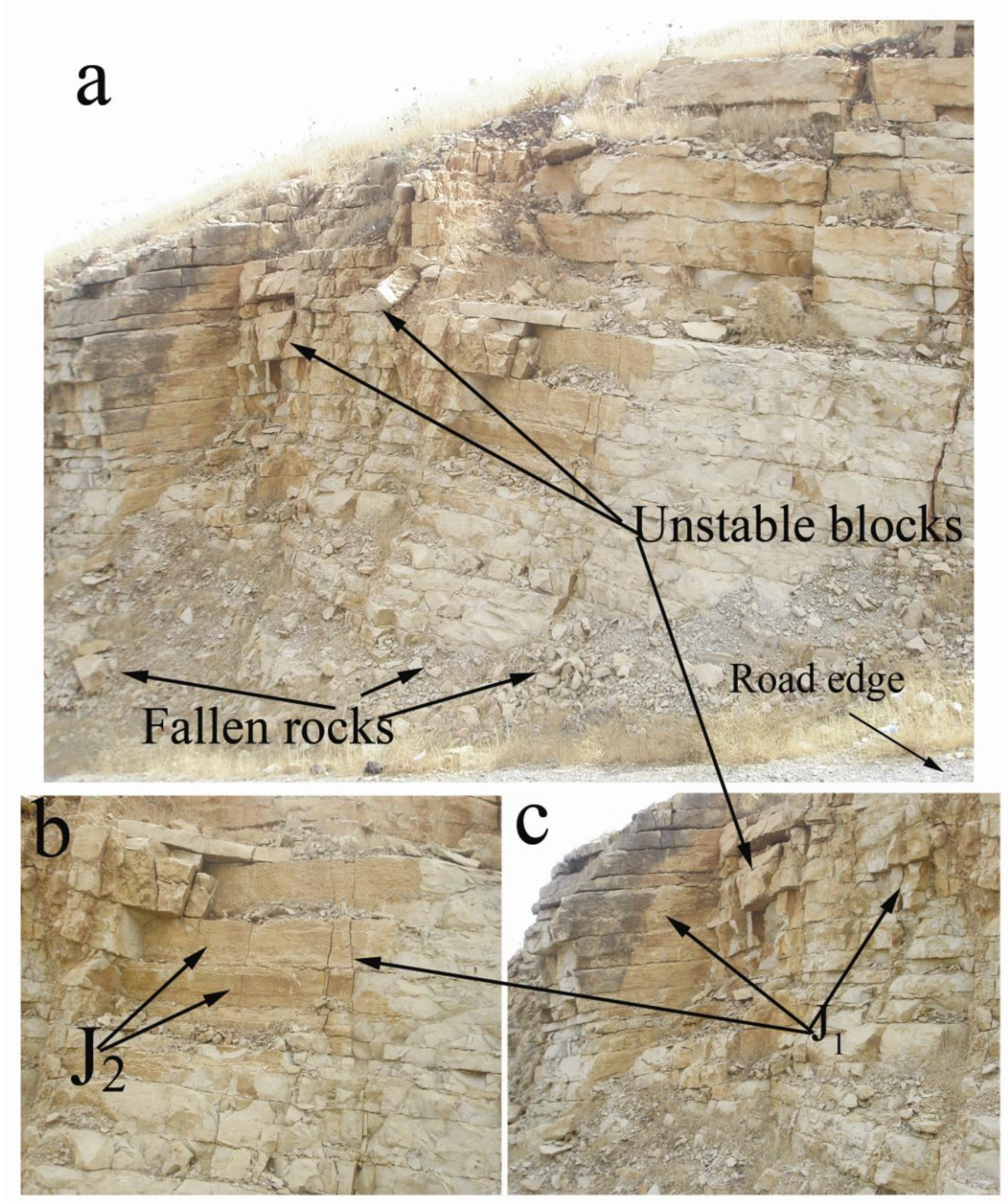


Plate 4-19: a) Frontal view of the slope at station No.14 shows unstable blocks along Dokan to Khalakan road b) Shows joint set of J_2 at station No.14 c) Joint set J_1 at station No.14.

Station Fourteen

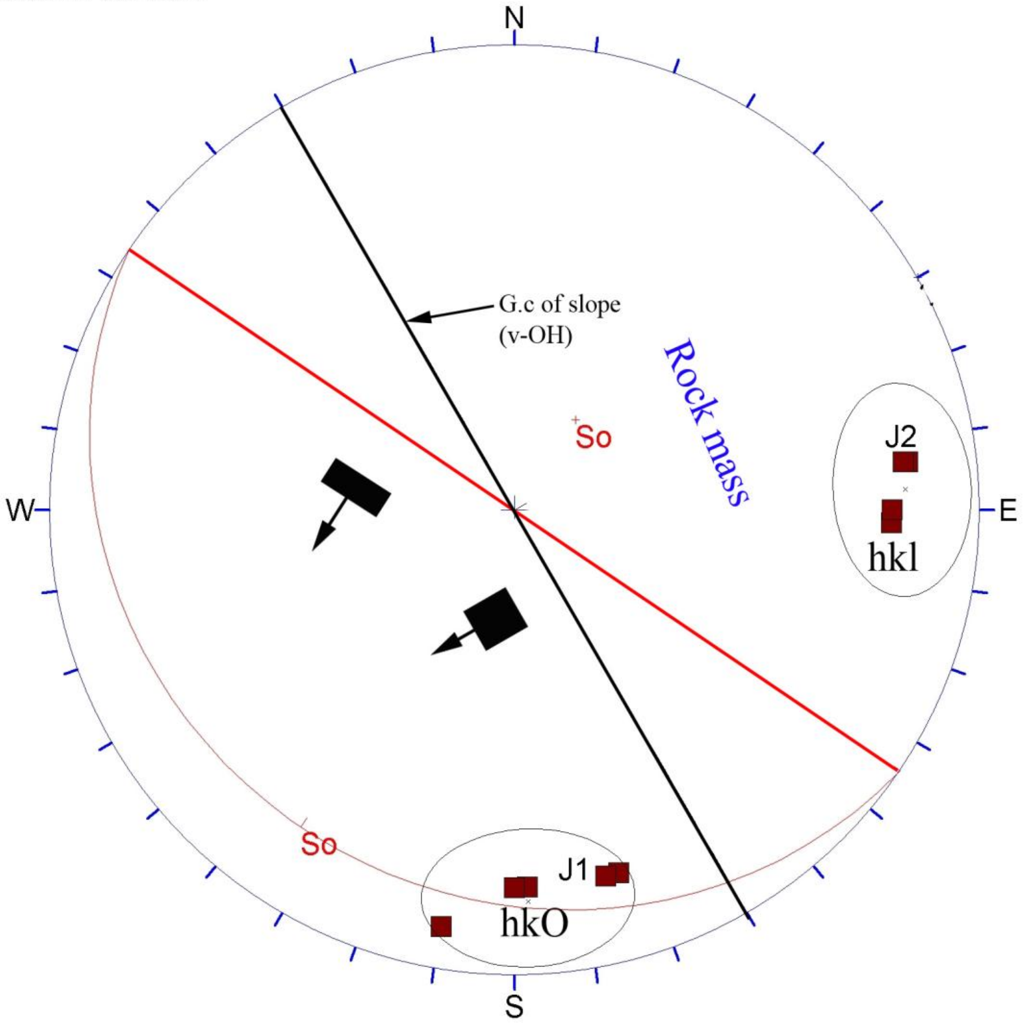


Figure (4-26) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.14.

4.8.16 Station No.15:

The station lies within Kometan Formation and is located on the SW limb of Kosrat anticline at latitude 35° 57′ 28″ N and longitude 44° 55′ 39″ E (Fig.4-11). The slope is a man made, it exposes layered rocks of highly fractured limestone which its upper part is covered by 10 to 50cm weathered clay (plate 4-20a), it is about 5 m high and 20m long parallel to its trend, having attitude (190/70°), Figure (4-27).

The average bedding plane attitude is 200/20° plate (4-20) and Fig (4-28) so the slope is parallel, (d=10°) right emergent and concordant type depending on (Al-Saadi, 1981) classification.

Rocks of the slope are reddish white to white, fine grained, thinly to medium bedded, moderately to widely spaced, moderately weathered, strong (σc=85.51MPa) LIMESTONE.

The joints in the rock have various structural directions so they are orientated in two main directions (hkl-hkO1) or J_1 and (hkO2) or J_2 Fig (4-28).

Mode of failure: The main type of failure is rockfall. The fall scars are clear and can be seen along the slope face (plate 4-20a) because of steep slope. Plane sliding is probable along bedding plane because the dip angle of bedding plane is less than the slope angle at the same direction along bedding plane and J_1 and J_2 act as composite back release surfaces (plate 4-20bandc).

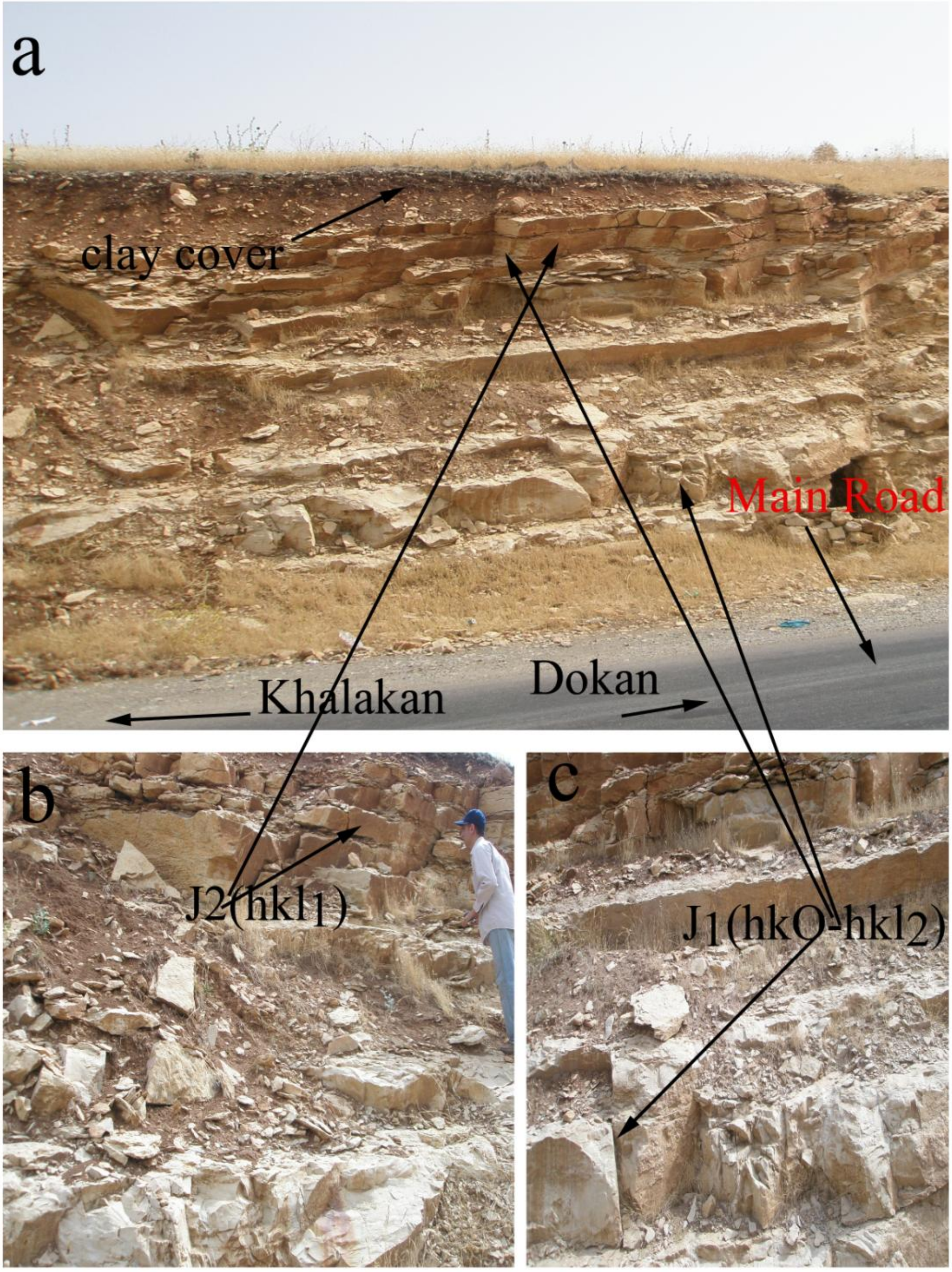


Plate 4-20: a) Frontal view of the slope at station No.15 on the right side of the road from Dokan to Khalakan. b and c) joint sets of J_1 and J_2 at station No.15

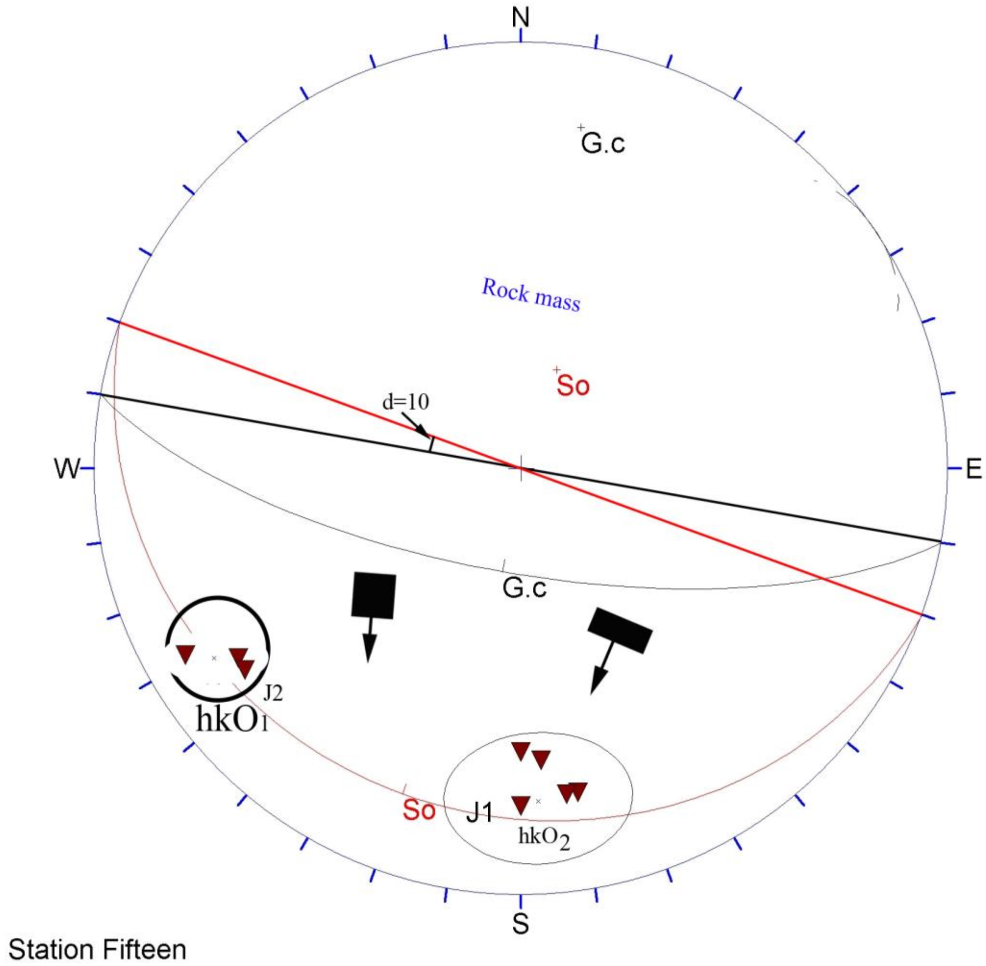


Figure (4-27) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.15

4.8.17 <u>Station No.16:</u>

The station is located on the SW limb of Kosrat anticline at latitude 35° 57′ 29″ N and longitude 44 55′ 47″ E (Fig.4-11). It lies within Kometan Formation. The slope is a man made slope that exposes layered rocks of highly fractured limestone which its upper part is weathered clay. It is 1.5m far from the main road, it is about 6m high and 10m long parallel to its trend, having attitude (210/80°-90°).

The average bedding plane attitude is 200/25° plate (4-21a) so the slope is parallel, (d=10°) left emergent and concordant type depending on (Al-Saadi, 1981) classification.

Rocks of the slope are reddish white to white, fine grained, thinly to medium bedded, closely to widely spaced, strong, (σc=91.40MPa) LIMESTONE.

The joints in the rock have various structural directions so they are orientated in three main directions (ac) or J_1 and (hkl_1) or J_2 and (hkl_2) (plate 4-21c) or J_3 Figure (4-28).

Mode of failure: The probable types of failure are plane sliding, wedge sliding and rockfall plate (4-19b). Plane sliding is likely to occur along the bedding planes which are inclined down slope but at smaller angle so that ac joint would act as lateral release surface, while joints in J_2 and J_3 would act together as composite back releases surfaces. Wedge sliding may occur along the line of intersection J_1 and J_2 plate (4-21). Rockfall is abundant because of highly fractured rock and very steep to vertical slope.

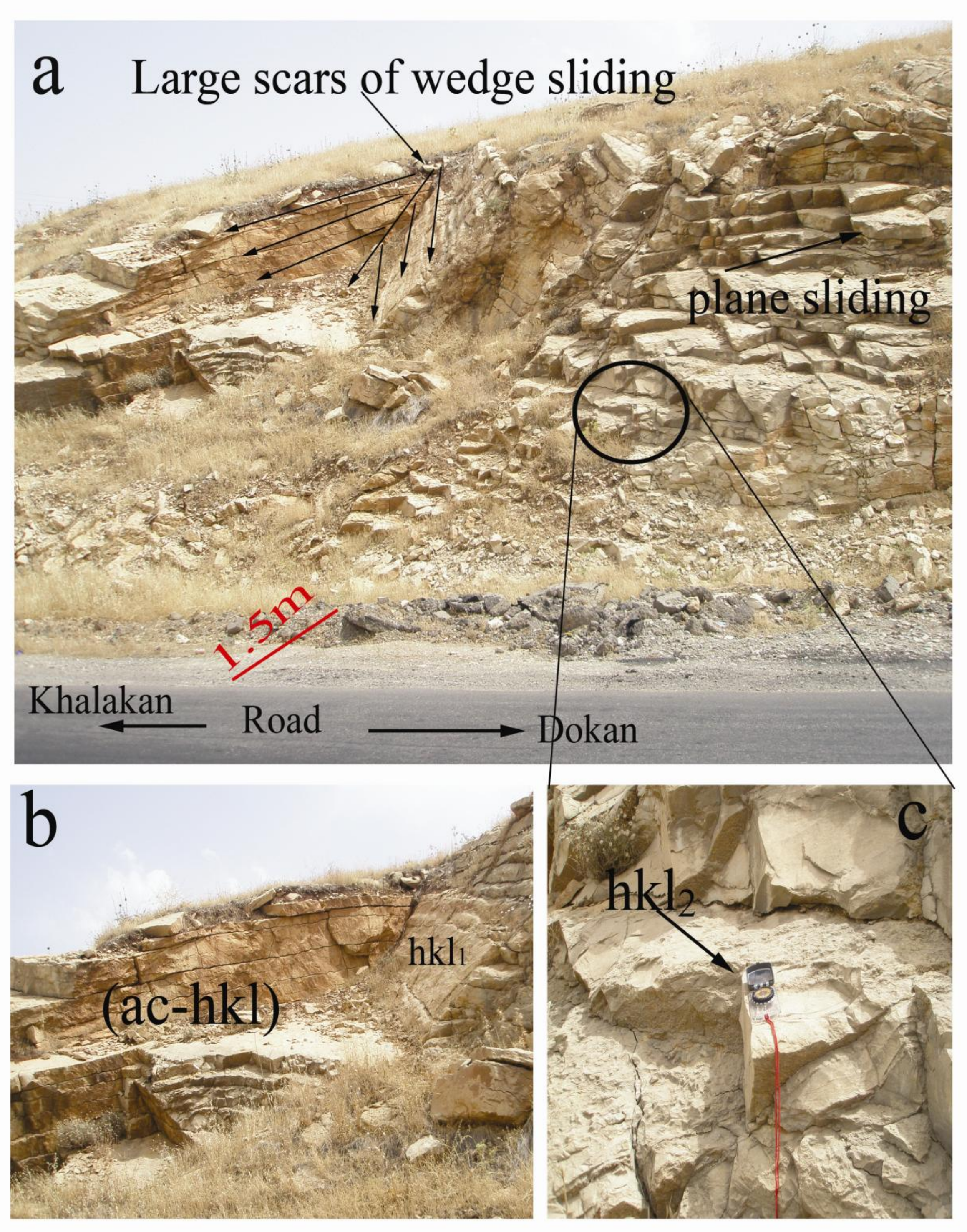


Plate 4-21: a) Frontal view of the slope at station No.16 on Dokan to Khalakan road. b) Wedge sliding scar between set (ac-hkl) and (hkl_1) c) Joints of (hkl_2) at station No.16.

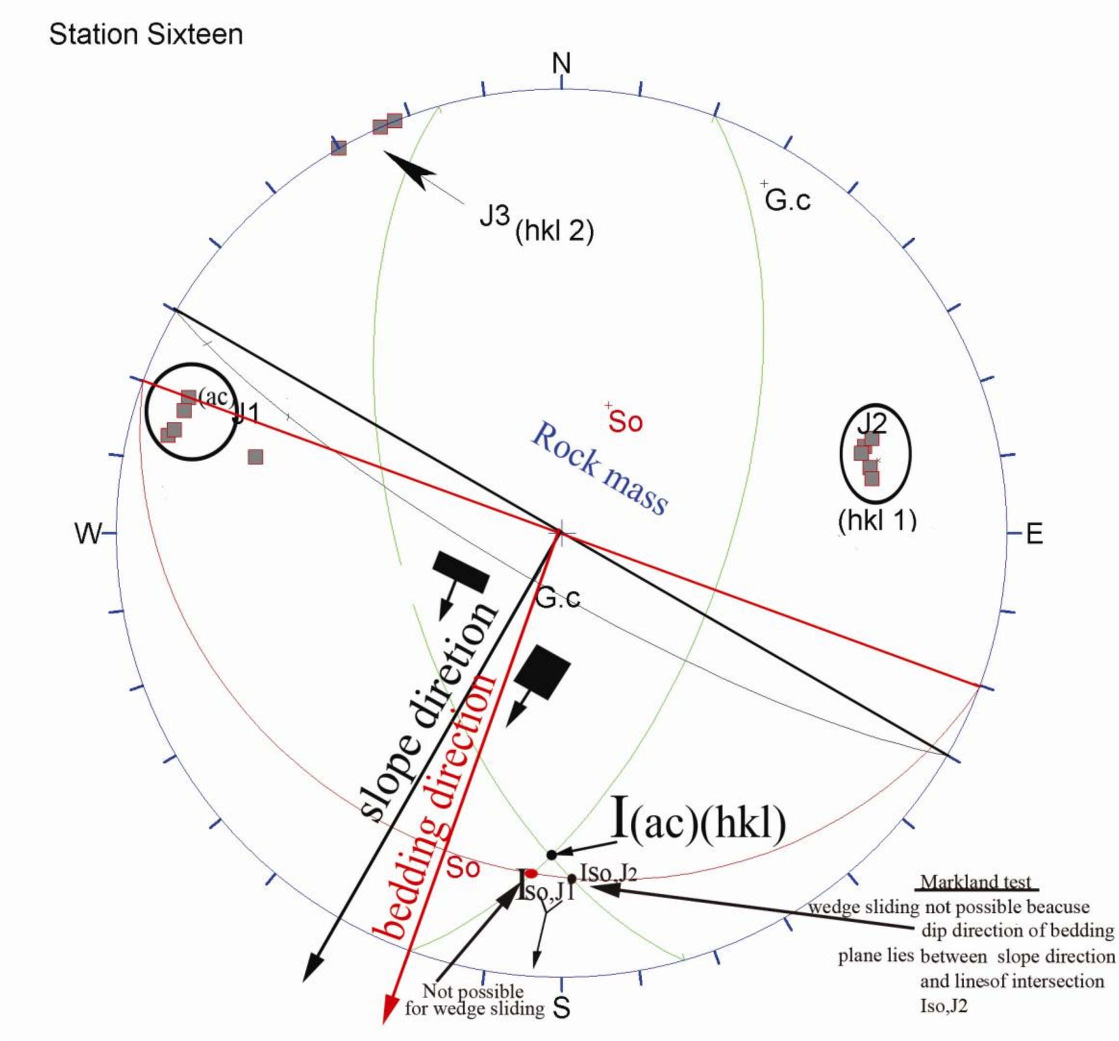


Figure (4-28) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.16.

4.8.18 Station No.17:

The station lies within Kometan Formation and is located on the SW limb of Kosrat anticline at latitude 35° 57′ 30″ N and longitude 44° 55′ 35″ E (Fig.4-11). The slope is man-made. It exposes layered rocks of highly fractured limestone, very close to the main road (plate 4-22a). It is about 4-5m high and 7m long parallel to its trend, having attitude (190°/80).

The average bedding plane attitude is (192/20°), so the slope is parallel, (d=2°) right emergent and concordant type depending on (Al-Saadi, 1981) classification.

The rock in this site is composed of light white to reddish white, fine grained, thinly bedded to medium bedded, closely to widely spaced, stylolitic, highly weathered, strong (σc =91.44MPa) LIMESTONE.

Mode of failure: The slope is daylighting slope because the dip of beds is less than the slope inclination. Therefore, plane sliding of small blocks has occurred along bedding plane, so (bc) joints act as back release surfaces and (hkl) joints acts as lateral release surfaces. Rockfall of small blocks has also occurred and left many scars in the slope face plate (4-22 b and c).The stylolites have small wave length, parallel to bedding planes, they act as stabilization factor due to interlocking of their peaks.

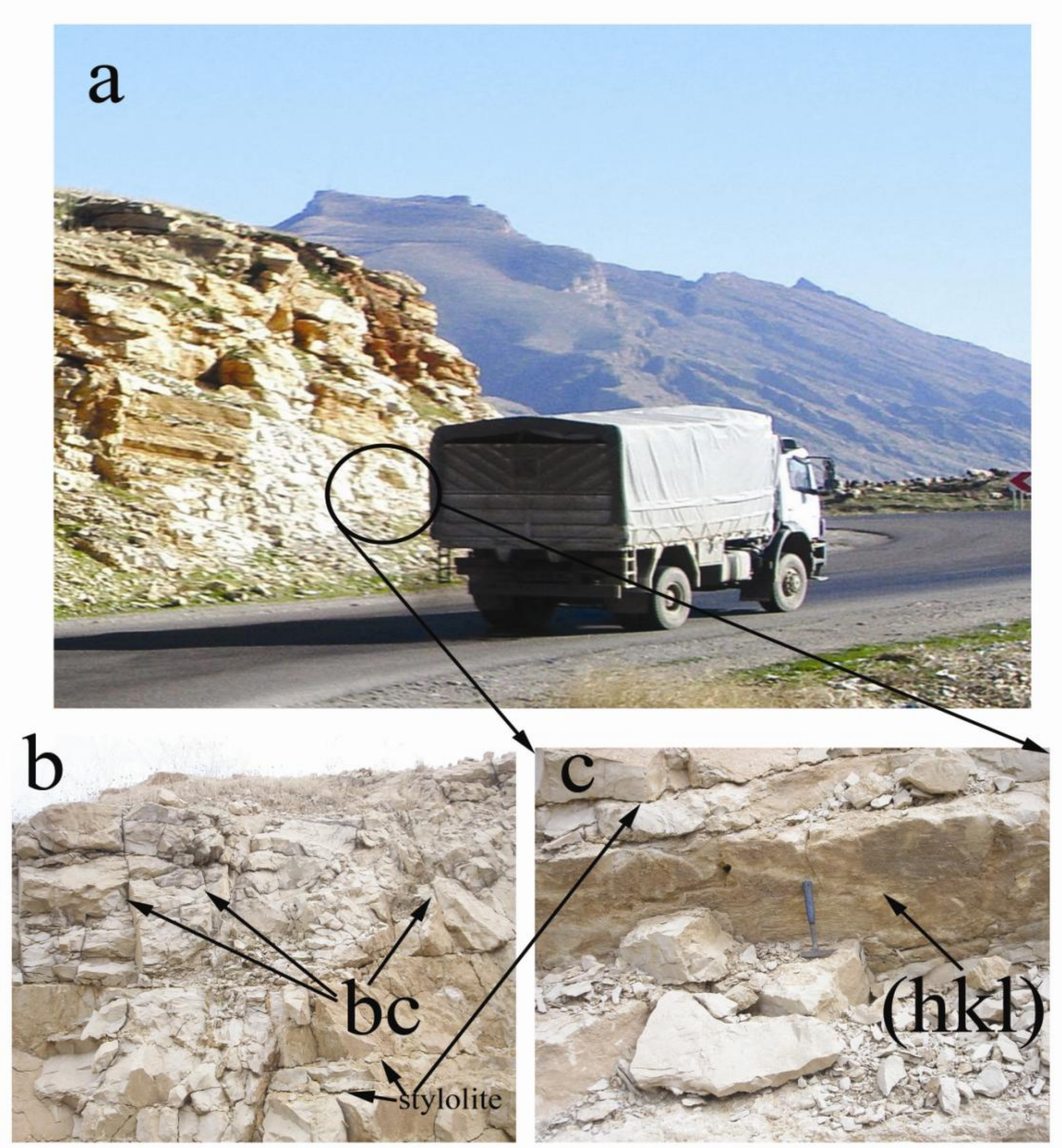


Plate 4-22: a) Lateral view of the slope on the right north side of the road from Dokan to Khalakan. b) Lateral view parallel to slope trend Shows joints of J_1 (bc) and stylolitic surface at station No.17. c) Shows joint set of hkl at station No.17.

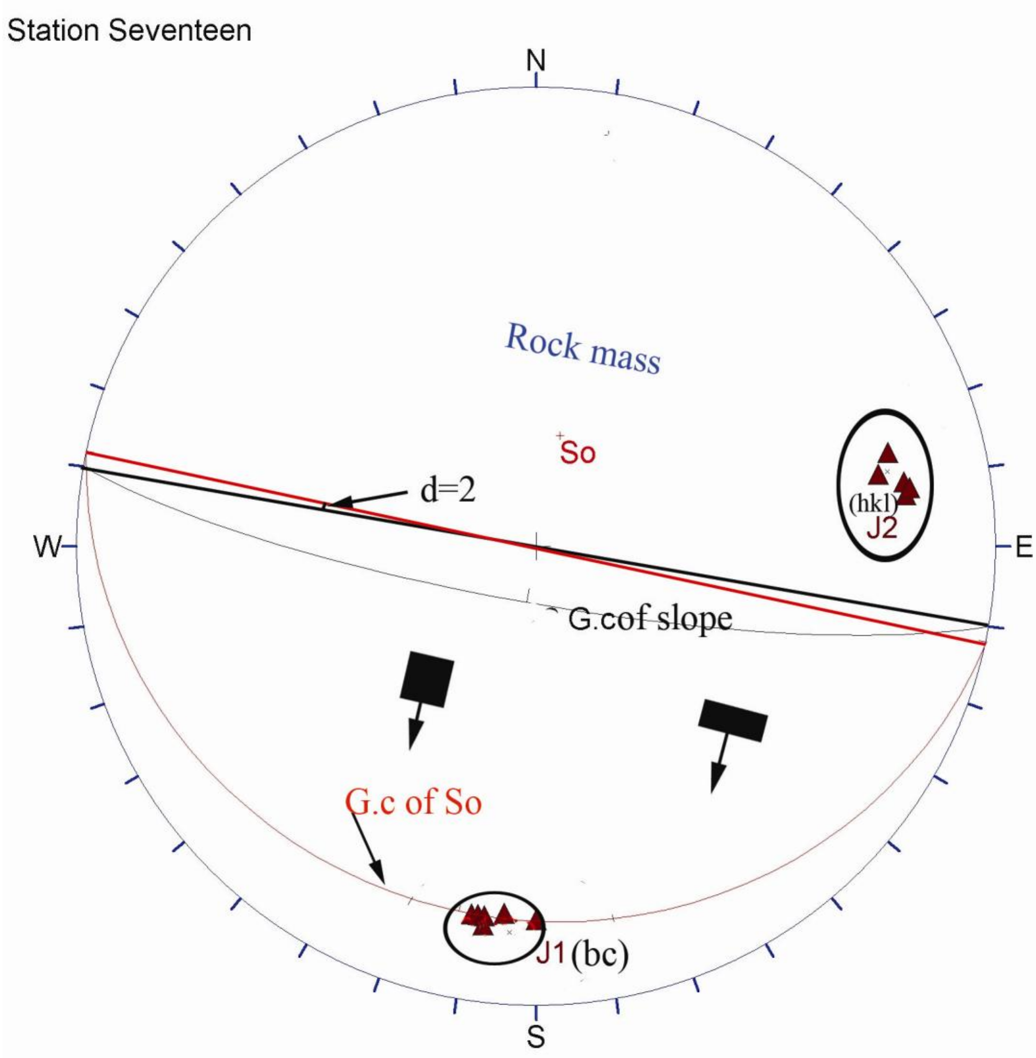


Figure (4-29) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.17

4.8.19 Station No.18:

The station lies within Kometan Formation and is located on the SW limb of Kosrat anticline at latitude 35° 57′ 31″ N and longitude 44° 55′ 25″ E (Fig.4-11). The large part of a slope represents a fault scarp, having attitude (156/70°). This fault scarp works as a stabilizing factor instead of a disturbing factor. It works to stabilize the slope face by making cemented face (plate 4-23a) due to rock displacement along the fault face that built up great friction force which makes the slope face like ironed smooth face, and clear striation and slickenside occur on the slope face (plate 4-23b).

The slope exposes layered rocks of highly fractured limestone outside faults slope at the right side and the left side of slope face, very close to the main road. It is about 7m high and 10m long having attitude (156/70°).

The average bedding plane attitude is (202/30°), so the slope (outside the fault slope) is an oblique lateral slope, (d=46°) right emergent and concordant type depending on (Al-Saadi, 1981) classification.

Rocks of the slope are reddish white to white, fine grained, thinly to medium bedded, closely to widely spaced, strong (σc=92.13MPa) LIMESTONE.

The joints in the rock have various structural directions so they are orientated in two main directions (hkl) or J_3 and (hkO) or J_2 and hkl or J_3 Figure (4-30).

Mode of failure: The main types of failure lie outside the fault slope, they include rockfall where the joint in J1 act as back release surfaces and joints in J2 act as lateral release surface plate (4-23 c and d),plane sliding along the bedding planes where all sets J1,J2,J3 act as composite back release surfaces

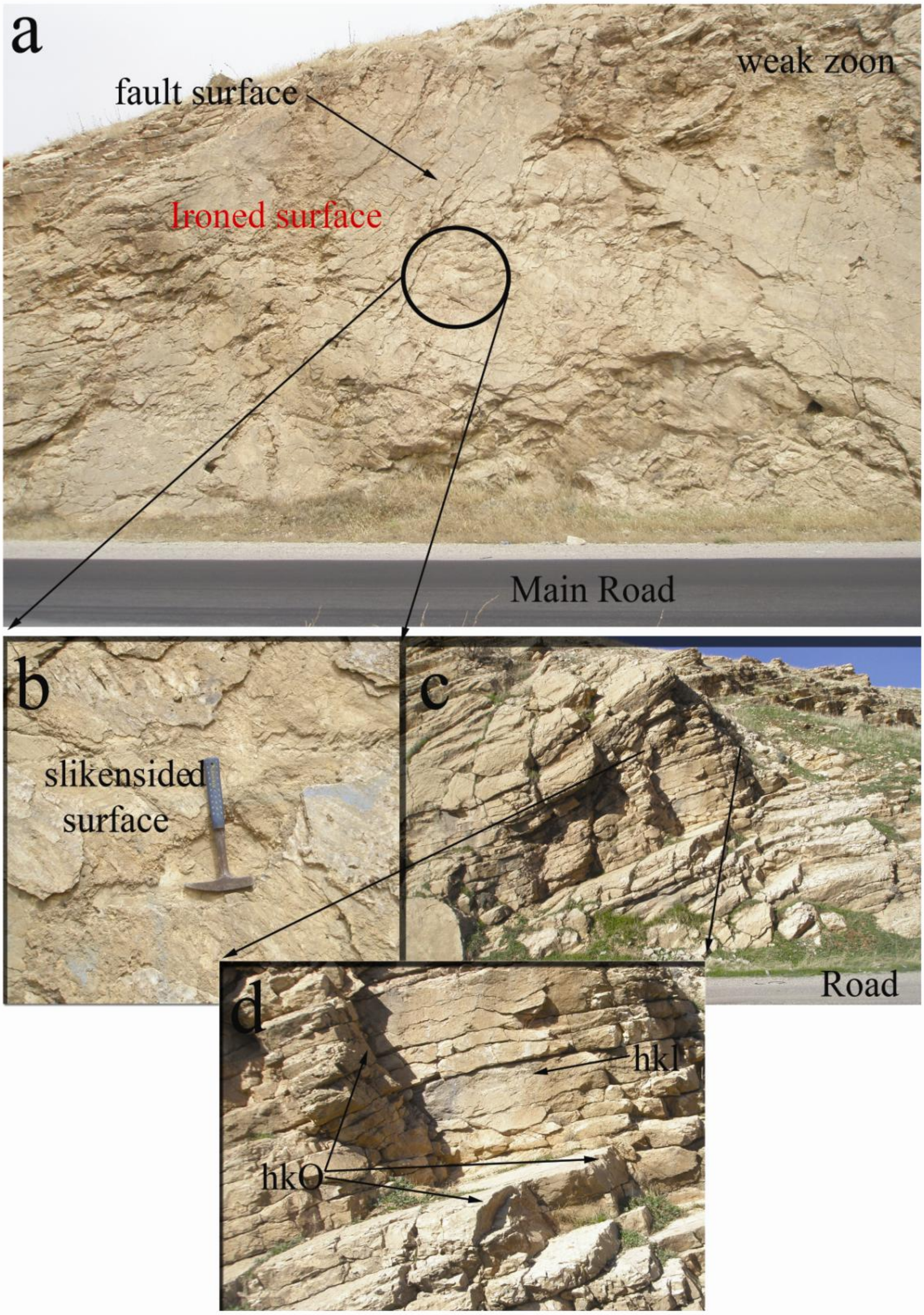


Plate 4-23: a) Frontal view of the slope on the right (north) side of the road from Dokan to Khalakan at station No.18. b) Slickenside along fault surface at station No.18. c and d) Show joint sets of (hkl) and (hkO) at station No.18.

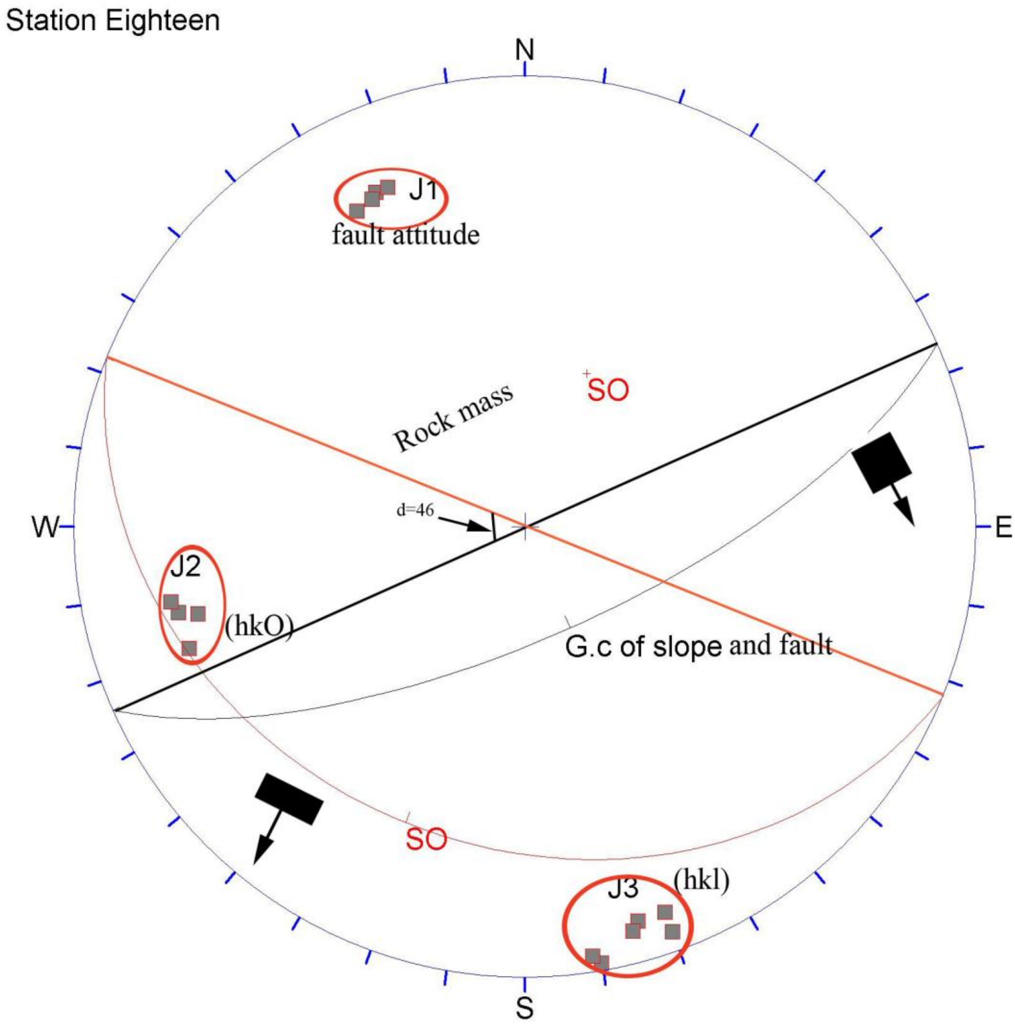


Figure (4-30) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.18

4.8.20 Station No.19:

The station is located on the SW limb of Kosrat anticline on the right side of the main road from Dokan to Khalakan at latitude 35° 57′ 32″ N and longitude 44° 55′ 19″ E (Fig.4-11). The slope is a man-made slope that exposes layered rocks of highly fractured limestone which its upper part is covered weathered clay. It is about 6m high and 10m long parallel to its trend, having an attitude of (190/80°).

The average bedding plane attitude is (200/31°) plate (4-24) and Fig (4-32) so the slope is parallel, (d=10°) right emergent and concordant type depending on (Al-Saadi, 1981) classification.

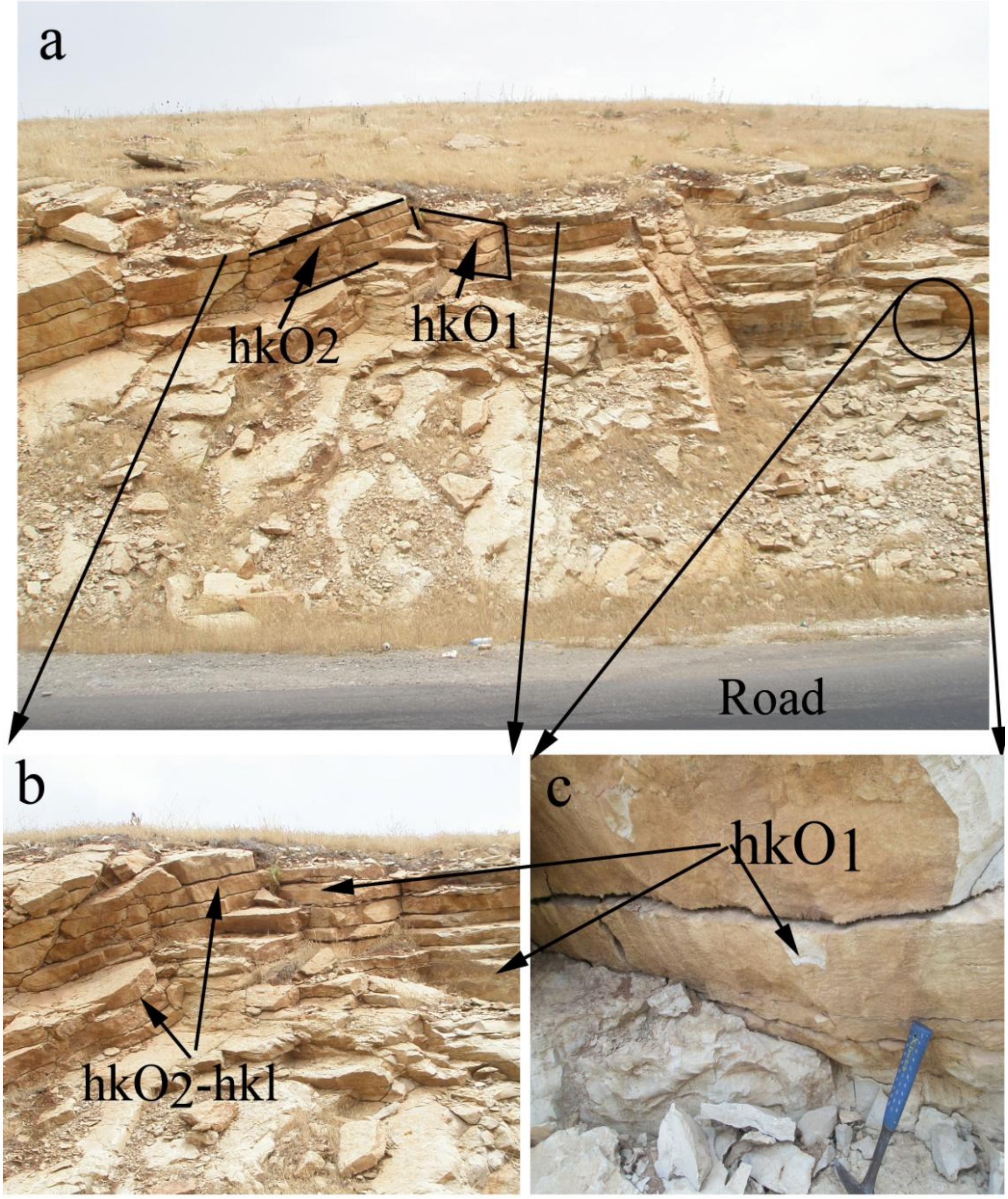


Plate 4-24: a) Frontal view shows the slope on the right side of the road from Dokan to Khalakan at station No.19. b) Shows fallen rock and composite release surface c) Shows joint (hkO1) with colored and open surface at station No.19

The outcrop rock is composed of white to reddish white, fine grained, thinly bedded to medium bedded, moderately widely spaced to widely spaced, moderately weathered (MW) strong (σc =92.13MPa) LIMESTONE.

The joints in the rock have various structural directions and their persistency range from 1m to 2 m. Joints orientations are variable in two main directions so that joint poles in stereogram Fig(4-31) would be divided into two main areas (hkO_1-hkl) or J_1 and (hkO_2) or J_2

Mode of failure: Many types of rock failures have occured or are likely to occur, such as small failures types like plane sliding along bedding planes, and rockfall has already occurred. The slope is daylighting because the dip angle of bedding plane is less than the slope angle and both are inclined in the same direction. Joints in (hkO_1-hkl) and hkO_2 (plate 4-24c) acts as composite back release surface (plate 4-24b).

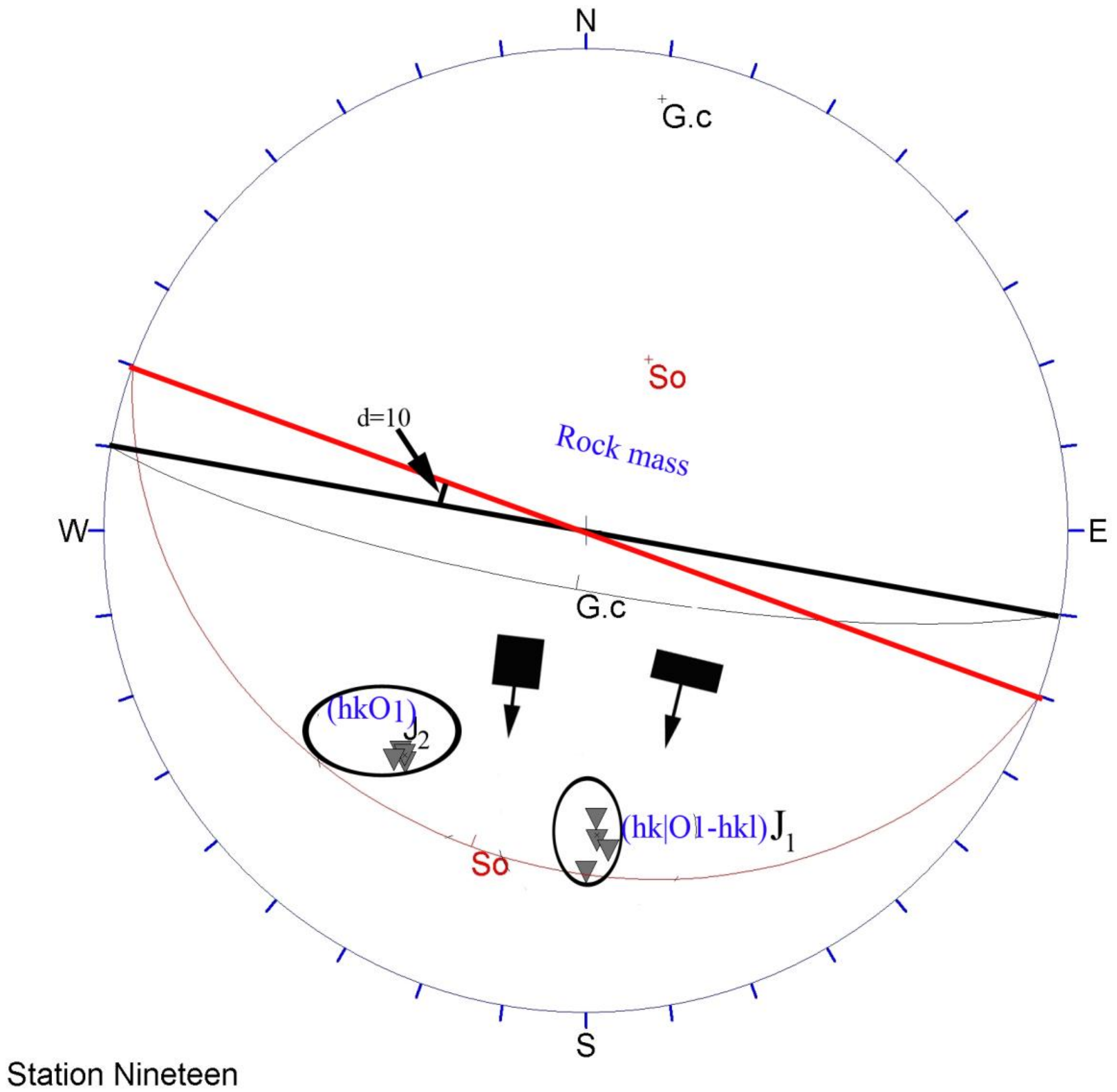


Figure (4-31) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.19

4.8.21 **<u>Station No. 20:</u>**

The station is located on the SW limb of Kosrat anticline on the right side of the main road from Dokan to Khalakan with latitude 35° 57′ 32″ N and longitude 44° 55′ 13″ E (Fig.4-11). It lies within Kometan Formation. The station is formed by man-made excavation. The slope at this station exposes inclined rock layer (plate 4-25a) .It is about 5m high and 9m long parallel to its trend, having an attitude of 230/30°.

The average bedding plane attitude is (202/24°) plate (4-25) and Fig (4-33) so the slope oblique-lateral, (d=28°) left emergent and concordant type depending on (Al-Saadi, 1981) classification.

The outcrop rock is composed of white to reddish white, fine grained, very thinly bedded to medium bedded, moderately widely spaced to widely spaced, moderately weathered (MW) strong (σc =92.13MPa) LIMESTONE.

The joints in the rock have various structural directions and their persistency ranging from 3m for J_1 frequency 1 to 2/m,J_2 has persistence 2m to 3m and frequency 1-3/m, J_3 has persistence 2m and non-clear frequency . Joints orientation is variable in three main directions so that joint poles in stereogram Fig (4-32) are divided into three main areas (hkl_1) or J_1 and (hOl-bc) or J_2,(hkl_2) or J_3.

Mode of failure: Rock roll is abundant because of highly fractured rock and the slope is moderately inclined, small failures types like plane sliding is likely to occur along bedding planes because the slope is daylighting (the dip angle of bedding plane is less than the slope angle and both are inclined at the same direction). Discontinuity in J_1 and J_2 acts as back release surfaces, and joints in J_3 act as lateral release surfaces.

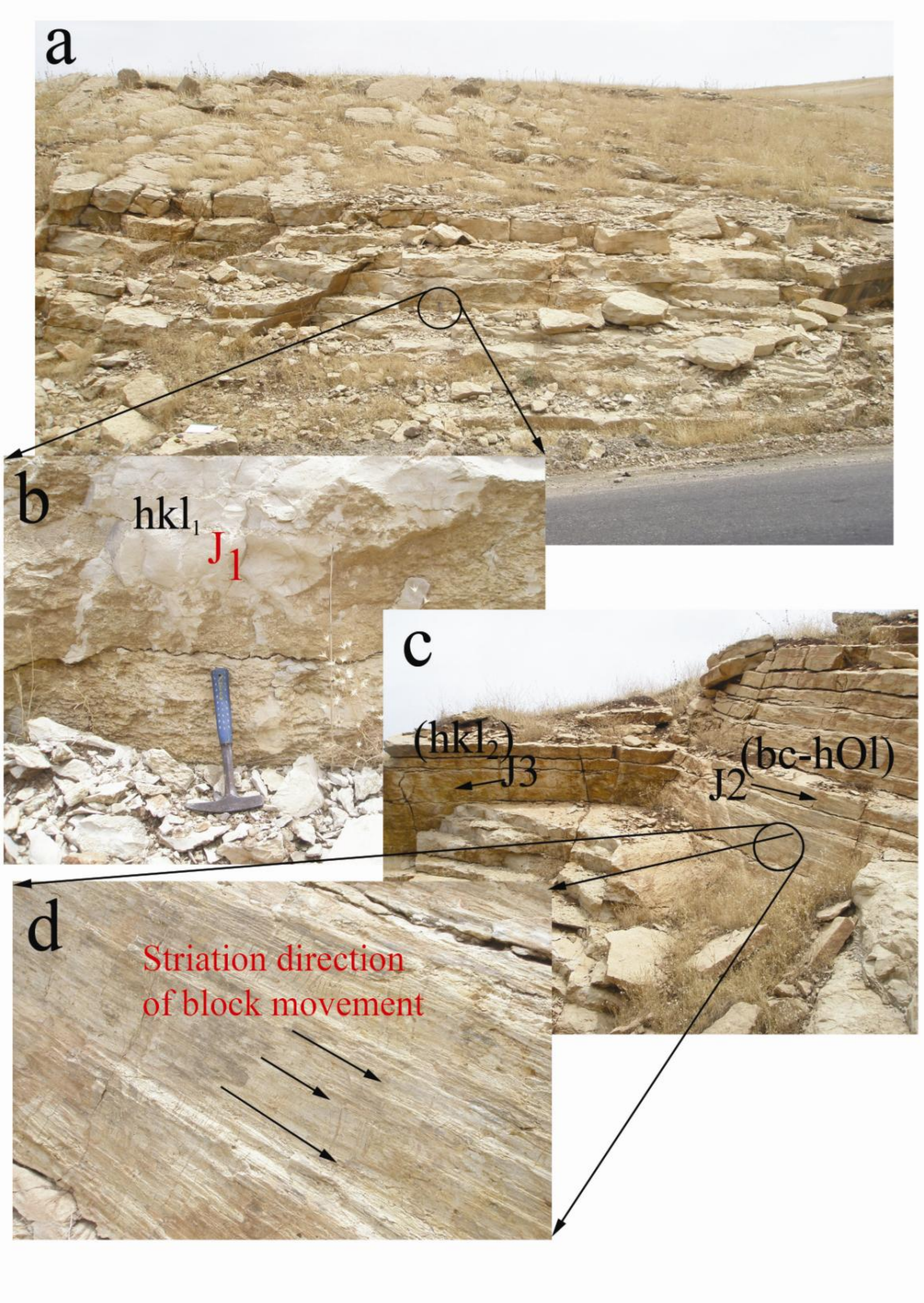


Plate 4-25: a) Frontal view of the slope at the station No.20 shows unstable block along Dokan to Khalakan road. b) Shows joint set of J_1 at station No.20 c) Joint set J_2 and J_3 at station No.20. d) Shows striation direction of the joint face J_2 at station No.20.

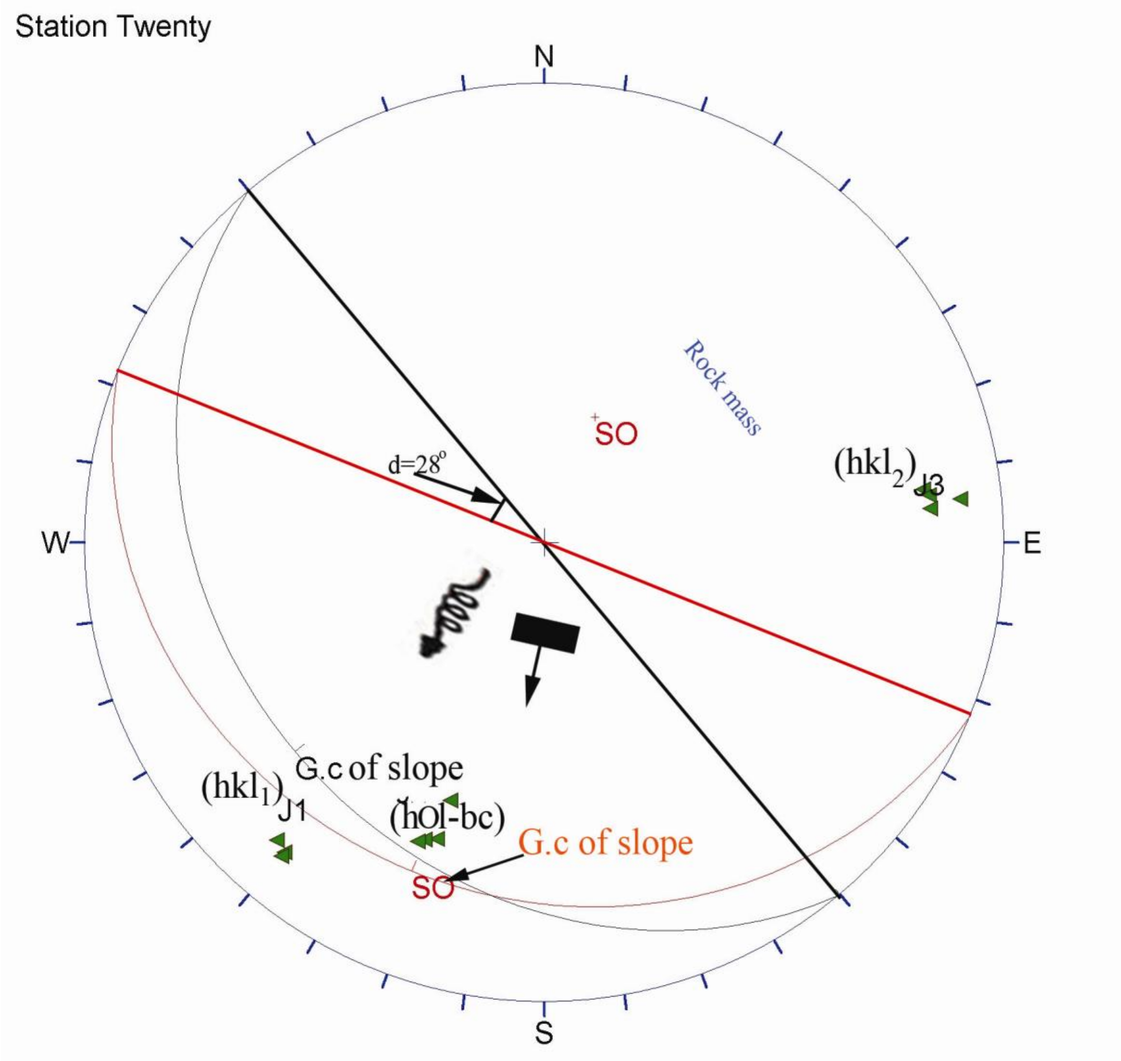


Figure (4-32) Stereogram illustrating the relations among slope, discontinuities and types of failure at station No.20

4-9 Discussions:

The assessment of slope stability in the twenty-one stations reveals the following points:

1- The study is about slope stability in the highly fractured, stylolitic, strong layered limestone and weak marly limestone.

2- Rock slopes in the study area (Dokan-Khalakan) road belong to four types of lithology:

A- Layered rock, highly fractured, weathered, limestone of Kometan Formation.

B-Strong layered rock, , no weathered limestone (fresh) Kometan Formation.

C-Layered highly fractured marly Limestone, weathered and non-weathered Shiranish Formation.

D- Sandstone and Marlstone of Tanjero Formation and Recent deposit

3- In the slopes that are having lithology of type (A), the layered limestone rocks of the upper part of slopes that remain after making road widening are characterized by:

I. Large and small blocks of intact rock bounded by closely to widely spaced discontinuities.

II. Presence of two groups of discontinuities in the strongly fractured rocks:

Group 1 which:

a) Consists of planar and closer in shape to non-systematic joints. They are discontinuities that dip in different directions and they do not form sets of discontinuities and these are common in type and properties within Kometan Formation.

b) The fractures have a variable orientation that lead to form irregularly shaped blocks of various orientations.

c) The highly variable block shapes and orientations with respect to the daylighting slope largely influence the stability of these slopes because various block dimensions and shapes of the rock change the mode of failure from rockfall to sliding to toppling.

Group two:

Consists of more systematic joints that form sets or more precisely subsets because they are sub-parallel with each other.

4- In slopes having lithology of type (B), the layered rocks that belong to Kometan Formation are characterized by greater role of the bedding planes in failure, especially they act as sliding surfaces. The joints in them are more systematic (hkl, hkO. ac, bc), therefore they have smaller blocks of the intact rock bounded by the discontinuities with more preferred orientation. They act as lateral, back or composite back releases surfaces during the failure such as in station(5,6,19,20) .

5- In slopes having lithology of type (c), the layered rocks that belong to Shiranish Formation are characterized by greater role of the bedding planes; especially they act as sliding surfaces. The joints are more systematic (hkl, hkO) and they act as lateral, back or composite back releases surfaces during the failure such as in station (3 and 4).

6- Assessment of the probable modes of failure is primarily based on the geometric relationship between the discontinuities and the slope especially in the cases of plane, or wedge sidings, and toppling. Rockfall existence in all slopes is more related to slope inclination so it is abundant in steep, nearly vertical to overhanging slopes.

7- The occurrence of plane sliding in two stations (4 and 5) is a good proof that the discontinuities (along which sliding has occurred) are inclined at steeper angle than their friction angle. If the dip angle (θ) of a daylighting discontinuity is less than its friction angle (φ), this does not fulfill geometrically the requirements of sliding, but under the effect of water (and from the beer can experiment described in Hoek and Bray, 1981), the friction angle could be reduced and become smaller than the discontinuity dip angle and this in turn verifies one of the basic conditions of sliding.

The presence of thin clay layers between rock layers in station 5 act as lubricant material that decreases factor of safety at the bedding surface by adding water to the joint sets at winter seasons which causes sliding at the beginning of the first winter rain.

8- The fault does not always act as a factor of instability but sometimes acts as a factor of the stability that make slope face stable and forming ironed surface as it is noticed at station (No.18) this condition is not common and it is considered as exceptional condition in which the fault surface acts as stabilizing factor to slope surfaces.

9- Table 4-12 summarizes the results of slope stability studies in twenty one stations in the study area.

Table (4-12) Summary of data about slope stability assessment in twenty one stations along Dokan-Khalakan (road) area.

Station No.	**Formation**	**Types of rock**	**Layered Or highly fracture**	**Discontinuities**	**Mode of Failure That occurred**	**Mode of Failure likely to Occur due to widening**
1	Kometan	Limestone	Layered	2 Set	Rockfall	Plane sliding
2	Kometan	Limestone	Layered	3Set	Roc fall	Plane sliding
3	Shiranish	Marly limestone	Layered	2Set	Rockfall, Rockroll	Plane sliding
4	Shiranish	Marly limestone	Layered	2Set	Rockfall, Plane sliding	Plane sliding
5	Kometan	Limestone	Layered	3Set	Rockfall, Plane sliding	Plane sliding
6	Kometan	Limestone	Layered	2Set	Rockfall, Plane sliding ,Toppling	Plane sliding
7A	Shiranish	Marly limestone	Layered	3Set	Rockfall, Plane sliding, Wedge sliding	Plane sliding
7B	Shiranish	Marly limestone	Layered	3Set	Rockfall, Plane sliding	Wedge sliding
8	Kometan	Limestone	Layered	3Set	Rockfall,Toppling, Wedge sliding	
9	Kometan	Limestone	Layered	2Set	Rockfall, Plane sliding	Plane sliding
10	Kometan	Limestone	Layered	3Set	Rockfall, Plane sliding	Plane sliding
11	Kometan	Limestone	Layered	2Set	Rockfall	
12	Kometan	Limestone	Highly fractured	-	Mechanical disintegrating, Rockfall	
13	Kometan	Limestone	Layered	2Set	Rockfall, Plane sliding	Plane sliding
14	Kometan	Limestone	Layered	2Set	Rockfall, Plane sliding	Plane sliding
15	Kometan	Limestone	Layered	2Set	Rockfall, Plane sliding	Plane sliding
16	Kometan	Limestone	Layered	3Set	Rockfall, Wedge sliding, Plane sliding	Plane sliding
17	Kometan	Limestone	Layered	2Set	Rockfall, Plane sliding	Plane sliding
18	Kometan	Limestone	Layered	2Set	Rockfall	Plane sliding
19	Kometan	Limestone	Layered	2Set	Rockfall, Plane sliding	Plane sliding
20	Kometan	Limestone	Layered	3Set	Rockroll, Plane sliding	

CHAPTER FIVE

FAILURE HAZARD MAP AND STABILZATION

PART 1-FAILURE HAZARD MAP

5-1 Landslide Mapping and Monitoring

The identification and map portrayal of areas highly susceptible to damaging landslides are first and necessary steps towards loss-reduction (Zeizel, 1988). Landslide hazard zonation is commonly portrayed on maps. Preparation of these maps requires a detailed knowledge of the landslide processes that are or have been active in an area and an understanding of the factors that may lead to an occurrence of potentially damaging landslides. Accordingly, this is a task that should be undertaken by geoscientists. In contrast, vulnerability analysis, which assesses the degree of loss, requires detailed knowledge of population density, infrastructure, economic activities, ecological, water quality values, and the effects that a specific landslide would have on these elements. Specialists in urban planning and social geography, economists, and engineers should perform these analyses (Gilbert et al., 2004). Landslide hazards and associated concepts are reflected the following definitions, based on Varnes (1984), the Australian Geomechanics Society (AGS, 2000), and the more general terminology presented in the International Strategy for Disaster Reduction (ISDR) draft report (UN, 2002) in (Gilbert., et al 2004)

• **Landslide hazard** refers to the potential for occurrence of a damaging landslide within a given area; such damages could include loss of life or injury, property damage, social and economic disruption, or environmental degradation.

• **Landslide risk:** Refers to the probability of harmful consequences—the expected number of lives lost, persons injured, extent of damage to property or ecologic systems, or disruption of economic activity—within a landslide-prone area. The risk may be individual or societal in scope, resulting from the interaction between the hazard and individual or societal vulnerability.

• **Landslide hazard zonation:** Refers to divisions of the land into homogeneous areas or domains and the ranking of these areas according to their degrees of actual or potential hazard or susceptibility to landslides.

5-2 Landslide hazard map types:

In the absence of accepted national standards for landslide hazard maps, a variety of mapping styles have been employed for each type of map:

- **Landslide susceptibility map:** ranks slope stability of an area into categories that range from stable to unstable. Susceptibility maps show where landslides may form. Many susceptibility maps use a color scheme that relates warm colors (red, orange, and yellow) to unstable and marginally unstable areas and cool colors (blue and green) to more stable areas.

- **Landslide hazard map:** indicates the annual probability (likelihood) of landslides occurring throughout an area. An ideal landslide hazard map shows not only the chances that a landslide may form at a particular place, but also the chances that a landslide from farther upslope may strike that place.

- **Landslide risk map:** shows the expected annual cost of landslide damage throughout an area. Risk maps combine the probability information from a landslide hazard map with an analysis of all possible consequences (property damage, casualties, and loss of service).

- **Failure hazard map:** Failure hazard is commonly shown on maps that display the division of land in domains and the ranking of these areas according to their degrees of hazard caused by rock failure. There are several methods for risk assessment and rockfall risk along roads such as Rockfall Hazard Rating System (RHRS) developed by (Pierson et al., 1990), Slope Mass Rating by (Romana 2003), Colorado's RHRS (Andrew, 1994), (MORH RS) Missouri Rockfall Hazard Rating System (Maerz ea al., 2003; Youssef et al., 2005), (Bejerman 1994,1998) and (Barison & Conteduca, 1998) which are used in the present study.

Failure Hazard Map of study area:

In this study failure Hazard maps are drawn to divide the study region into areas according to their failure hazard level or degree. They range from No hazard areas to High hazard areas. This zonation has been done according to the landslide possibility index (LPI) of Bejerman (1994, 1998)which is based on ten parameters.

5-2-1 Failure Hazard Zonation according to LPI (Bejerman, 1994)

According to this method the hazard degree of slopes is determined by the value of Landslide Possibility Index (LPI). This value depends on 10 parameters as listed in table (5-1). There are some estimations for each parameter which is determined for each slope according to the geological , structural, hydrological and geomorphological conditions at the site. The sum of estimations represents the LPI value (Table 5-1) and eventually the hazard degree of slopes classified into three categories according to this value (Table 5-2). These parameters are:

1- Slope height: represents vertical height of the slope.

2- Slope angle: represents the amount of the slope inclination.

3- Grade of fracturing: represents numbers of discontinuity traces in the slope and depends on the intensity of tectonic stresses, thickness and lithology of the beds in the slope.

4- Grade of weathering: this parameter depends on the climate, lithology of the rocks and intensity of fracturing. It could be estimated by the description given by Hawkins (1986) (Table, 4-9).

5- Gradient of the discontinuities: represents the average dip angle of the discontinuities in the slope.

6- Spacing of the discontinuities: represents the average distance between discontinuities measured perpendicular to the discontinuities in the slope.

7- Orientation of the discontinuities: this parameter depends on the attitude (dip direction and dip amount) of the discontinuities with respect to the slope inclination (amount and direction of the slope inclination). Therefore, if the configuration induces instability it will be unfavorable and if not, it will be favorable.

8- Vegetation cover: represents the area of the slope which is covered by vegetation and is expressed as a percentage. So that the instability (sliding) will increase by increasing the percentage area of the slope covered by vegetation because the vegetation is regarded as one of the biological weathering factors so that their roots may move within discontinuities and increase their apertures. This movement also induces an extra shear force to the slope.

9- Water infiltration: amount of the water infiltration in the slope depends on the slope angle, grade of fracturing, and permeability of materials in the slope. Infiltration of water results in the water pressure within the fractures, and hence the shearing force will increase.

10- Previous landslides: this parameter depends on the occurrence of landslides and their volumes at the past times, and is related to the probability concepts therefore, if there were previous landslides at the site, there will be the possibility of more landslides in the future.

The assessment of the LPI category neither establishes the quantity and time for the block to slide nor identifies the stabilization method. The main objective is to evaluate the possibility and to indicate the need for a detailed study, regarding the stability of certain rock slopes with respect to others that present fewer tendencies to the slide (Bejerman, 1998).

In this study some modifications of Bejerman (1994) method for LPI and failure hazard map is introduced and proposed, this includes the use of new category IB of LPI where its value is zero and it represents No hazard area, so that the rating of category I (small) becomes (1-5).

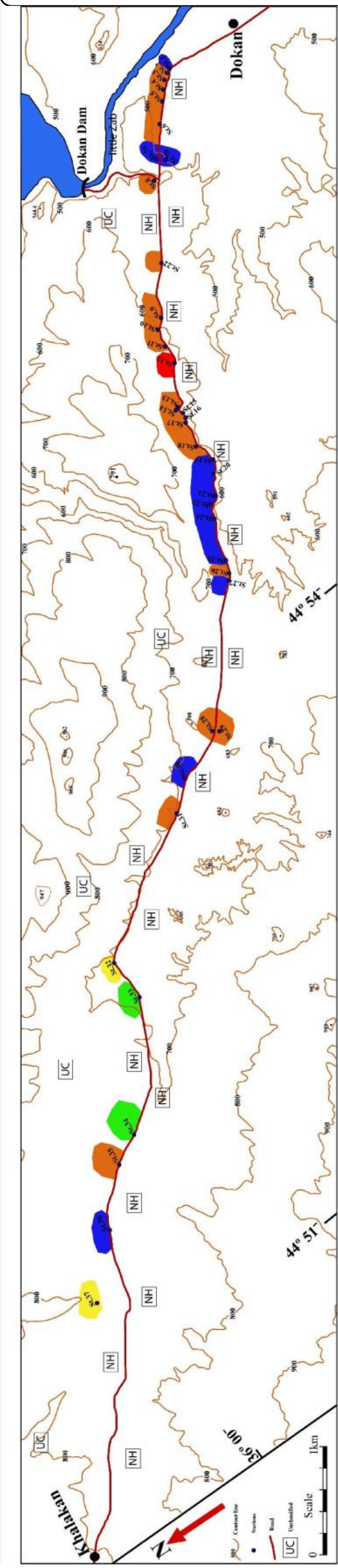
Table 5-1: Parameters and corresponding estimations for the determination of LPI modified after Bejerman (1994).

LANDSLIDE POSSIBILITY INDEX					
1- Slope Height	**Esti.**	**2- Slope Angle**	**Esti.**	**3- Grade of Fracture**	**Esti.**
1-8 m 9-15 m 16-25 m 26-35 m >35 m	**1 2 3 4 5**	**<15 15-30 30-45 45-60 >60**	**0 1 2 3 4**	**Sound Moderately Frd. Highly Frd. Completely Frd**	**0 1 2 3**
4- Grade of Weathering	**Esti.**	**5- Gradient of the Discontinuities**	**Esti.**	**6- Spacing of the Discontinuities**	**Esti.**
Fresh Slightly Moderately Highly Completely Residual soil	**0 1 2 3 4 5**	**<15 15-30 30-45 45-60 >60**	**0 1 2 3 4**	**>3 m 1-3 m 0.3-1 m 0.05-0.3 m <0.05 m**	**0 1 2 3 4**
7- Orientation of the Discontinuities	**Esti.**		**8- Vegetation Cover**		**Esti.**
Favorable Unfavorable	**0 4**		**Void <20% Scarce 20-60% Abundant >60%**		**0 1 2**
9-Water Infiltration	**Esti.**		**10- Previous Landslides**		**Esti.**
Inexistent Scarce Abundant: Permanent Seasonal	**0 1 2 3**		**Not Registered Registered (small volume) Registered (high volume)**		**0 1 2**
1 + 2 + 3 + 4 ± 5 + 6 + 7 + 8 + 9 + 10 = □					
0 (No hazard) (0) III (low) (11-15) I (small) (1-5) V (high) (21-25) II (very low) (6-10) IV (moderate) (16-20) VI (very high) (>25)					
The LPI value is obtained by adding the estimations of attributes 1-10. If the orientation of the discontinuities is Favorable, the estimation of gradient subtract.					

Table 5-2: Classification of hazard category depending on the LPI value modified after Bejerman (1998).

LPI		
Value	**Category**	**Hazard Category**
0	**0**	**No hazard**
10 ≥	**I - II** **Small very low**	**Low**
11-20	**III - IV** **Low Moderate**	**Moderate**
21 ≤	**V - VI** **High very high**	**High**

Calculated values of LPI for slopes at the study area (Appendix Table1).Show that there are slopes of very high LPI (>25) value which are limestone beds of Kometan Formation at Station (12) which is due to the daylighting slope and highly fractured rocks. The slopes of High LPI (21-25) value are represented by limestone of Kometan Formation at the stations (2,5,6,8,9.10,11,13,14,15,16,17,18and31) Fig (5-1),marly limestone of Shiranish Formation at the stations (3,4,26,28and29), sandstone beds and marlstone beds of Tanjero Formation in the station(35) due to the large height and steep faces of the slopes that extend and are adjacent to the station on both sides of the cut toes at Dokan to Khalakan road along SW cut limb of Kosrat anticline (Fig. 5-1). The slopes of Moderate value of LPI (16-20) are represented by limestone beds of Kometan Formation at stations (1, 19, 20, 21, 22,23,24 and 30), marly limestone of Shiranish Formation at stations (7A, 7B,25 and 27), sandstone and marl of Tanjero Formations in station (36). The slope of low LPI value (11-15) represented by recent deposit are belonging to stations(33 and 34).The slopes of very low values(6-10) of LPI are represented by Tanjero Formation belong to stations (32 and 37).Classification of these slopes according to LPI by using table (5-2) is illustrated in (Appendex table 1)which shows that same slopes of High and Very



LPI	Category	Estimation		Hazard Zone
VI	Very High	> 25		High Hazard
V	High	21-25		
IV	Moderate	16-20		Moderate Hazard
III	Low	11-15		
II	Very Low	6-10		Low Hazard
I	Small	1-5		
0	No hazard	0	NH	No Hazard

Fig. 5-1: Failure hazard map of the study area according to LPI

High LPI value are of High Hazard category. The slope of Moderate Hazard category includes the slopes of Moderate LPI value and Low LPI value. The slopes of Low hazard category include the slopes of very low and small LPI value.

5-2-2 Failure Hazard Zonation according to Their Influence on Road:

Transportation corridors in many regions are often susceptible to failures, and failures can result in enormous casualties and huge economic losses in mountainous regions. In order to mitigate failure hazard effectively recent advances in risk analysis and risk assessment are beginning to provide systematic and rigorous processes to enhance slope management. In recent years, risk analysis and assessment have become an important tool in addressing uncertainty inherent in landslide hazards (Dai, et al., 2001). The hazard zonation of slopes according to LPI only indicates the possibility of the rock failure at the slope without indicating the effect of failure on the human life, rockfall risk and road construction. So many methods for the analysis of rockfall risk along roads and motorways provided like (Barison & Conteduca, 1998)table (5-3) and (Budetta,2004).In this study the method of (Barison & Conteduca, 1998)was prepared and used in this research. Rockfall Hazard Rating System (RHRS) developed by (Pierson et al. 1990) can also be used but it is not used, due to limitation of time and it requires modification to be usable for this study area.

In this method (Barison & Conteduca, 1998), the slope hazard classification is based on the influence of the detached blocks on the road without any reference to the geometry of the slope and discontinuities. This method is used and modified here to assess and cover the influence of failure hazards on roads . The table (5-3) is modified to cover No Hazard areas (N.H.) with zero rating value, the category I of very low hazard has rating (1-2).

Table 5-3: Parameters that influence the determination of the rock slope failure hazards on the roads (Barison and Conteduca, 1998 in Al-Obaidi, 2005)

Contributory Factor	Category			Rating
Rockfall reaching the road (> $3m^3$/year)	**Don't reaching the road**			0
	Reaching the road	**Seasonal**	**Small blocks (D<0.05 m)**	1
			Large blocks (D≥0,05 m)	2
		Permanent	**Small blocks (D<0.05 m)**	3
			Large blocks (D≥0,05 m)	4
The distance from the road to the nearest slope toe (m)	**> 10.0 m**			0
	0.5 - 10.0 m			2
	< 0.5 m			4
Protection works	**Present**	**More useful**		0
		Less useful		1
	Absent	**Not required**		0
		Required		2
		Extremely		3
1 + 2 + 3 = ☐ ☐ ☐	**I- Very low (1-2) IV- High (7-8)** **II- Low (3-4) V- Very high (>8)** **III- Moderate (5-6)**			

1- The size of individual detached blocks that reach the road

2- The distance between the road and the nearest slopes toe

3- Protection works availability in the site

The procedure is similar to previous method and the hazard degree is determined by summation of rating values of parameters, which are listed in the table (5-3). Calculation of field data depends on this method, as it is illustrate in Appendix Table2. The hazard degree data in Appendix table 2 were used in preparing failure hazard map, Fig (5-2) which shows that High Hazard Zone

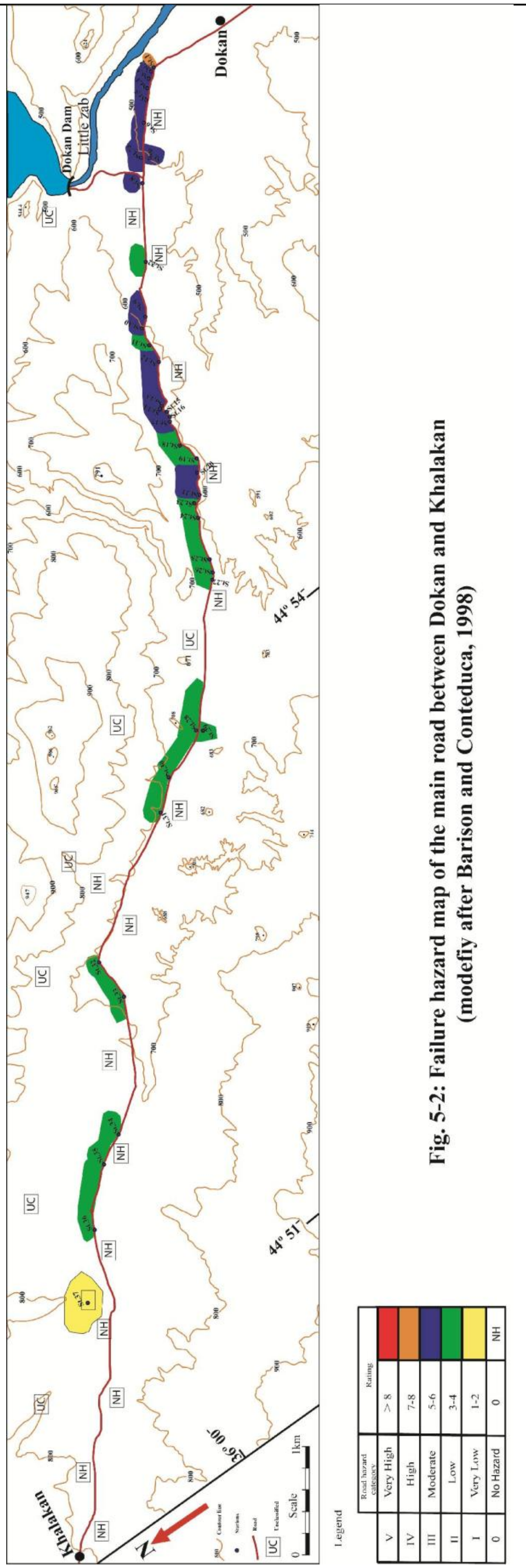


Fig. 5-2: Failure hazard map of the main road between Dokan and Khalakan (modefiy after Barison and Conteduca, 1998)

(Orange) is located at station (1) that was destabilized due to widening of the road in the year 2009-2010. This made the slope daylighting in turn which made it easier for large blocks to reach the road.

The Moderate Hazard Zone (Blue) is represented by relatively steep slopes of Kometan Formation and Shiranish Formation, also it is due to cutting of the toe of slope during widening processes of the road which make unstable blocks derived from upper parts of slope at SW limb of Kosrat anticline and reach to the road. The Low Hazard (Green) and very Low Hazard zones (Yellow) belong to those stations where the road was not widened in 2008.

PART TWO- STABILATATION OF FAILURES:

5-3 Stabilization of rock slope:

In mountainous terrain, the operation of highways, road and railways, power generation and transmission facilities, and the safety of residential and commercial developments often require stable slopes and control of rockfalls. In the study area the main road connects Dokan town to Khalakan town, and due to its proximity to Dokan dam it contains large number of electric power generator lines located along the unstable slopes of SW limb of Kosrat anticline and above the cut toe of the new road construction. This needs quick and appropriate stabilization and protection treatments.

5-3-1 Stabilization measures

The most common stabilization measures are divided into two main categories: (Wyllie and Mah, 2004) as in Figure (5-3)

(a) Reinforcement

(b) Rock removal

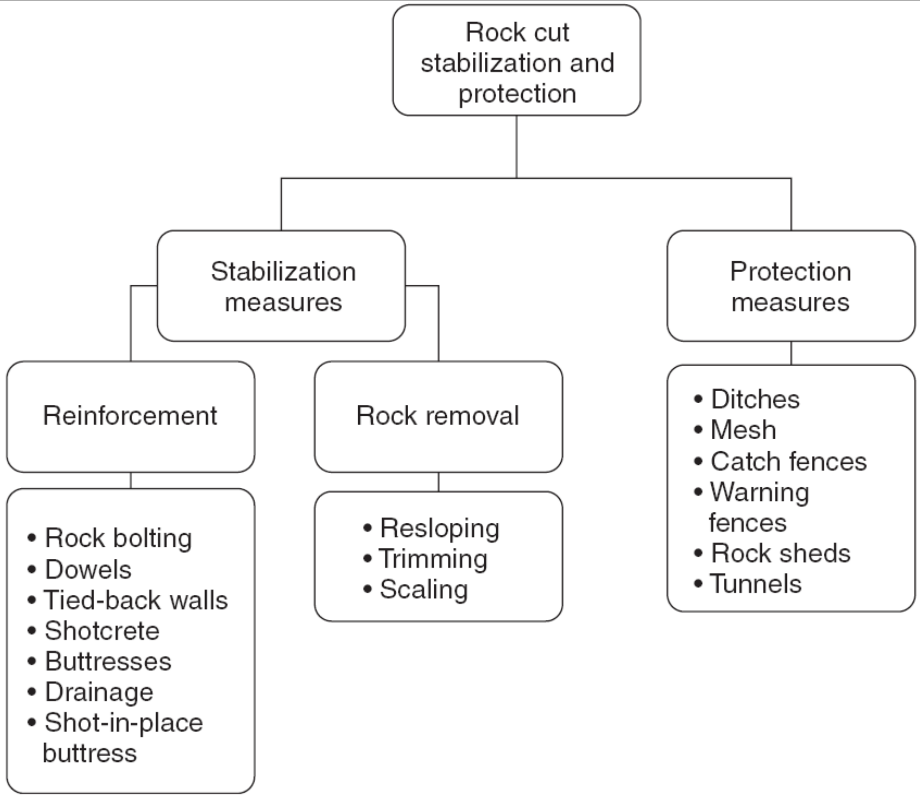


Figure (5-3) Categories or rock slope stabilization measures (Wyllie and Mah, 2004).

(a)Reinforcement:

The common feature of all these techniques is that they minimize relaxation and loosening of the rock mass that may take place as a result of excavation. Once relaxation has been allowed to take place, there is a loss of interlock between the blocks of rock and a significant decrease in the shear strength Fig (5-4).

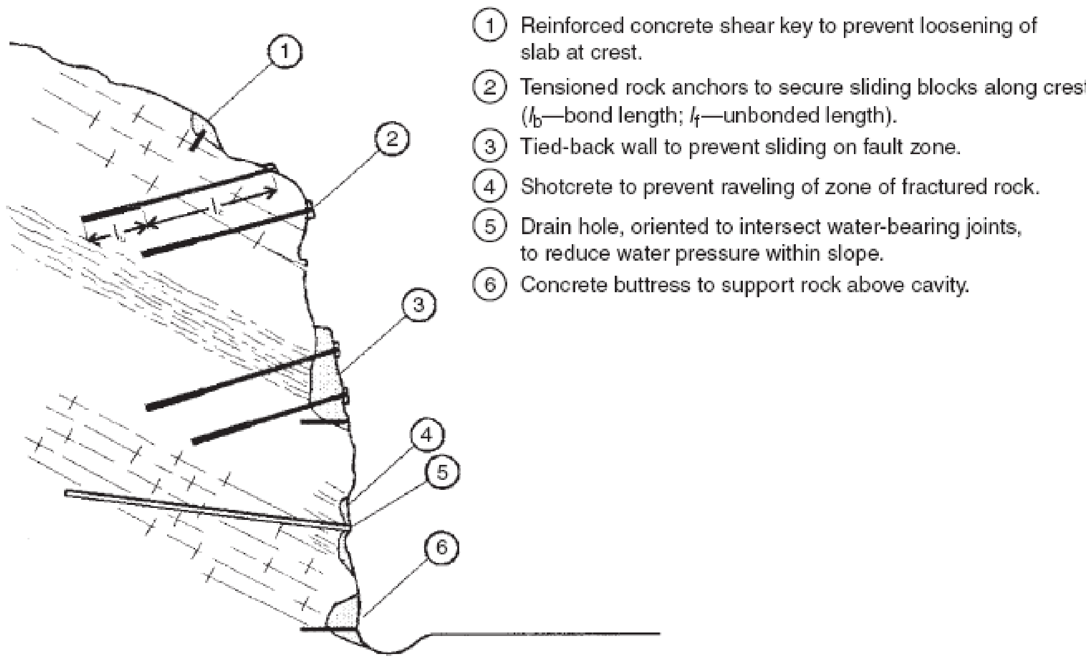


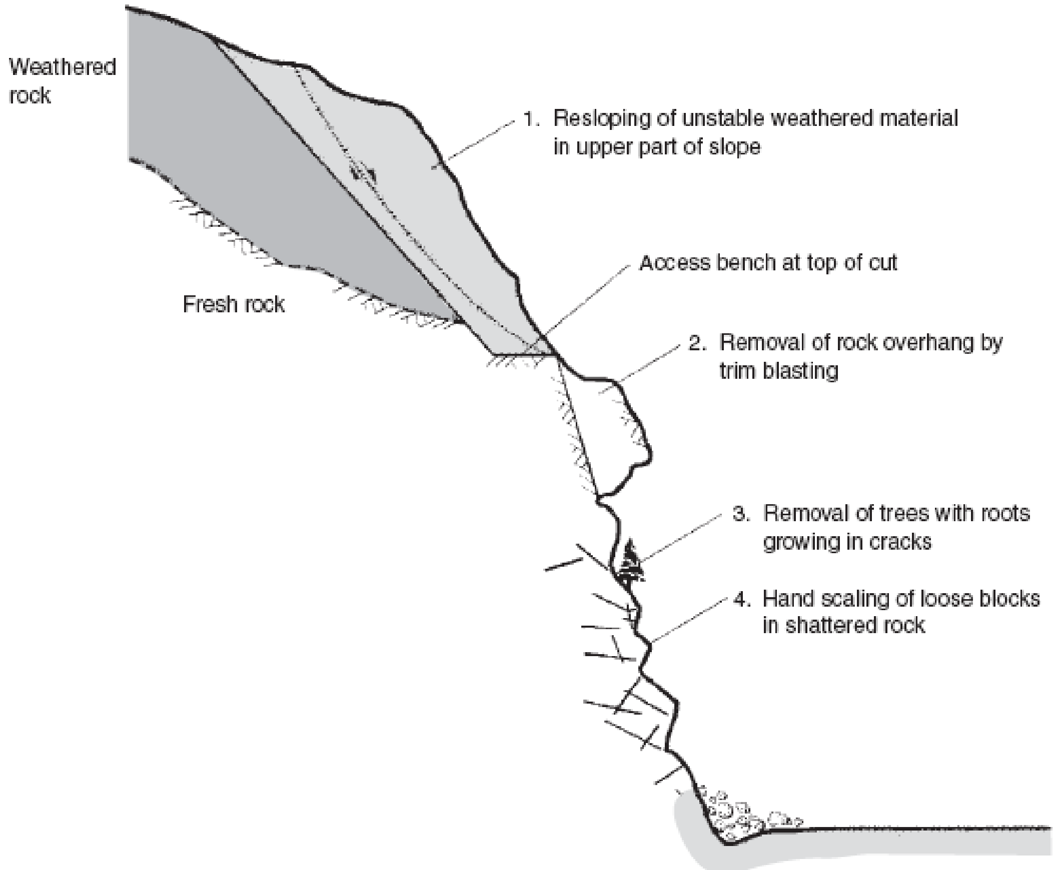
Figure (5-4) Rock slope reinforcement methods ((Wyllie and Mah, 2004)

(b) Rock removal:

Stabilization of rock slopes can be accomplished by the removal of potentially unstable rock; including

- resloping zones of unstable rock;
- trim blasting of overhangs;
- scaling of individual blocks of rock.

In general, rock removal is a preferred method of stabilization because the work eliminates the hazard, and no future maintenance will be required. However, removal should only be used where it is certain that the new face will be stable, and there is no risk of undermining the upper part of the slope (Wyllie and Mah, 2004) figure (5-5).



Figure(5-5) Rock removal methods for slope stabilization (Wyllie and Mah, 2004)

5-3-2 Protection measures:

An effective method of minimizing the hazard of rockfalls is to let the falls occur and control the distance and direction in which they travel. Methods of rockfall control and protection of facilities at the toe of the slope include catchment ditches and barriers, wire mesh fences, mesh hung on the face of the slope and rock sheds (Wyllie and Mah, 2004). A common feature of all these protection structures is their energy-absorbing characteristics in which the rockfall is either stopped over some distance, or is deflected away from the facility that is being protected, The common type is ditches.

➢ Ditches:

Catch ditches at the toe of slopes are often a cost effective means of stopping rockfall, provided there is adequate space at the toe of the slope. The required dimensions of the ditch, as defined by the depth and width, are related to the height and face angle of the slope; a ditch design chart developed from field tests is shown in Figure (5-6) (Ritchie, 1963). The figure shows the effect of slope angle on the path that rockfall tend to follow, and how this influences ditch design. For slopes steeper than 75°, the rocks tend to stay close to the face and land near the toe of the slope. For slope angles between 55° and 75°, falling rocks tend to bounce and spin with the result that they can land a considerable distance from the base; consequently, a wide ditch is required. For slope angles between 40° and 55°, rocks will tend to roll down the face and into the ditch.

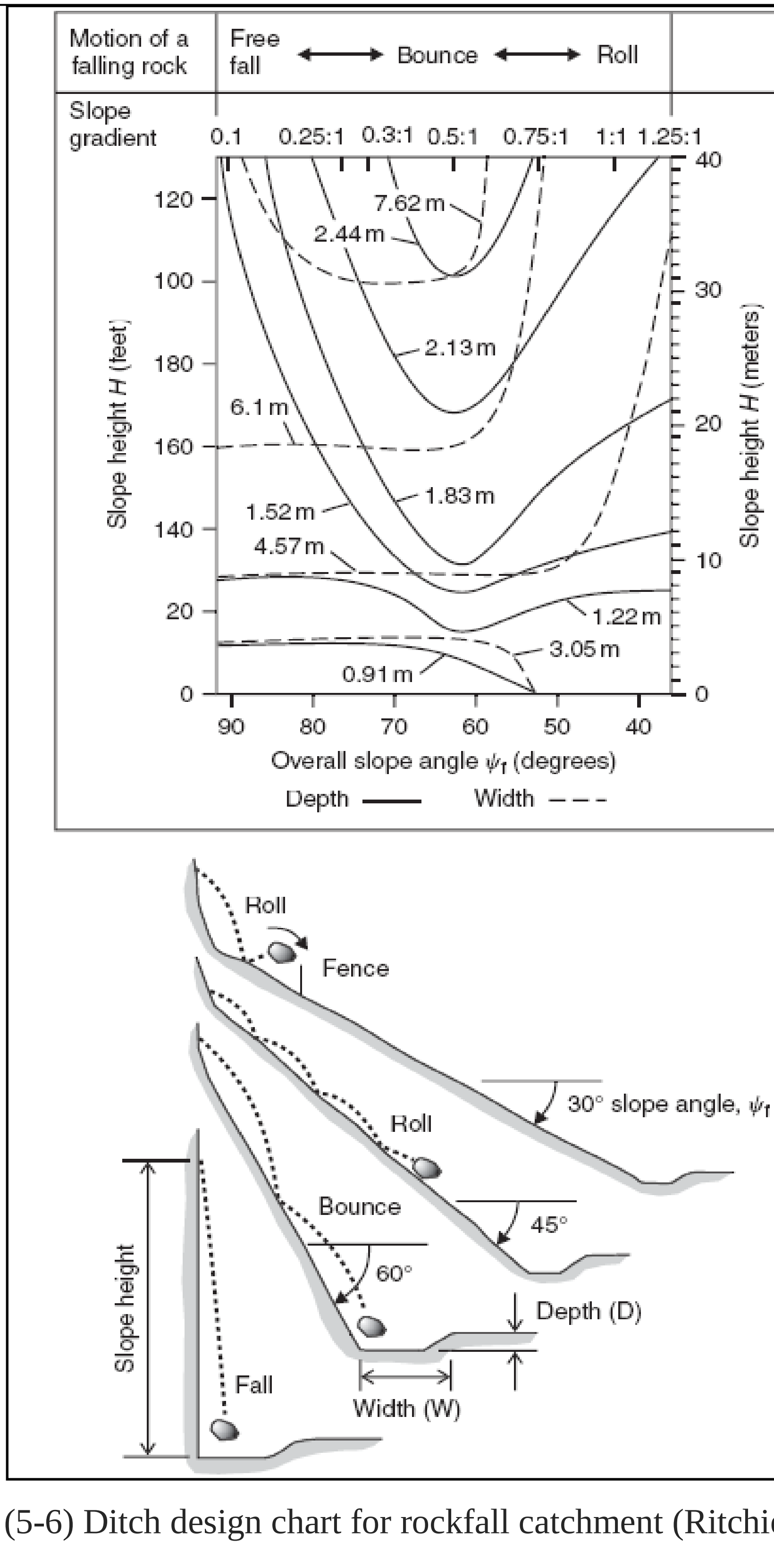


Figure (5-6) Ditch design chart for rockfall catchment (Ritchie, 1963)

5-3-3 The stabilization method for Shiranish Formation:

The Shiranish Formation slope faces require protection measures like wire mesh or Gabion and ditches because they contains much unstable rock fragments, and detached rocks. They are so close to the road especially at stations (7A and 7B). They need quick protection and stabilization measures for unstable blocks.

5-3-4 The stabilization method for Kometan Formation:

The Kometan Formation requires two main procedures:

1-Stabilization measures for the slope faces that have vertical slope and cut toe (daylighting slope) by reinforcement of the slope face (dip-slope face) especially in the slopes (1, 2, 4, 5 and6). These stations located in the area that contains 4 towers especially at station (5) one tower has moved 1cm as seen before landsliding that was happened in the station (5) in this winter (2010) .Tower located above station (1), where the slope is daylighting slope contains weak zone, make the toe of tower completely unstable. Rock removal for all unstable blocks must be made. These stations need quick stabilization because if the tower falls it would caused death to many people that pass through this area.

2-Protection measures like reforcement retaining wall with using dowels and ditches for all of the stations in Kometan Formation are required because this area especially Kometan Formation which is highly fractured and there are non-systematic fractures in all directions and all stations contain rock fragments and unstable blocks that can reach the road on both sides.

5-3-4The stabilization method for Tanjero Formation:

The best way for stabilization is rock removal because its slopes have low height in all stations with highly fractured rocks and can be removed easily and ditches required after the process of removal.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6-1 Conclusions:

After detailed study and assessment of rock slopes and their hazard along Dokan-Khalakan road, this study has come up with the following conclusions:

1-The highly fractured (Systematic and non-systematic joints) nature of limestone in Kometan Formation has largely influenced the slope stability along the Dokan -Khalakan road by providing blocks when detach from the slope to reach the road.

2-The water is considered as basic factor that causes failure along the main road from Dokan to khalakan especially during the wet season.

3- Road widening process largely influenced slope stability along Dokan-Khalakan road by removing toe of slopes that act as support for rock layers and make slopes at most stations as daylighting slope and unstable. For example, the road widening that was made in the year 2009 made the road hazard level risky and failure increased by 100%.

4-Many types of failure occurred in the slopes of Kometan Fn. adjacent to road sides from Dokan to khalakan especially in the upper part of the slope that contains thin layer of weathered clay between limestone beds that act as sliding surfaces and led to the decrease the shear strength parameters (Φ & c) causing sliding of rock masses along bedding planes.

5-Mechanical weathering has great role in all slopes which leads to disintegrating and fracturing of layered rock and opening joint surfaces which help water to circulate easily through the joints when rain fall during winter. This helps water accumulation in cracks and between layers and makes thin clay layer between the limestone layers as lubricant material.

6- The structural and geomorphological situation of the study area make the bedding surfaces act almost as failure surfaces(sliding surface) and (unfavorable) depending on LPI, especially where they are dipping down slope toward the road.

7- The presence of systematic joins and fractures in Kometan and Shiranish Formation leads to the occurrence of plane sliding and wedge sliding. The joint surfaces act as release surface in all stations including back release surfaces (B.R.S), lateral release surfaces (L.R.S) and back composite release surface which lead to occurrence of many types of failures like rock fall, plane sliding, wedge sliding, and toppling.

8. Depending on (Al-Saadi, 1981) classification most of stations are parallel (few are oblique lateral), right or left emergent and concordant/ (few are discordant). This makes the surfaces of bedding planes act as sliding surfaces especially where they dip down slopes but at smaller angle.

9-Field observations revealed the presence of major fault plane (fault scarp)forming steep stable slope in contrary to the well-known role of faults as factor of instability. This fault slope is stable due to the high cohesion of the fault surface, that occurred because of intense friction along fault walls during fault displacement. This is a new case recorded in this study.

10-Direct shear tests on some inter layers clay indicates that the friction angle (Ø) values range between ($10\text{-}11^{\circ}$) and the cohesion values (c) range between (32-64)kPa which help largely in sliding along clay filled bedding planes.

11-Failure hazard map based on landslide possibility index (LPI) shows wide range of failure hazard categories from very high to No hazard area.

12-Road failure hazard map shows wide range of hazard categories from No hazard to High.

13-Stylolite surfaces that are parallel to the bedding planes act as stabilizing agents due to the interlocking of their peaks.

6-2 Recommendations:

1-Prevention of cutting slopes at the toe during road widening from Dokan to khalakan along the SW limb of Kosrat anticline because this leads to increase of the road hazard, road failure risk and failure probability. Widening of the road must include only the left (SW) side where the slope is discordant and the layers are dipping into the slope .

2-Changing the position of towers of electric generator above station (1, 2,3,4,5,6 and 7) and installing them on more stable areas because their present position are unstable, or quick stabilization and protection measures for these stations must be made.

3- Construction of retaining walls and using dowels for most of stations considered as daylighting slopes especially the cut toe slopes.

4-Constructions of ditches along both sides of the road to collect the detached and fallen rock fragments and draining water during the rainfall.

5-Using wire mesh or gabion on the slope faces for all stations especially in the upper part of the slopes because they restrain detached rock piece, fragments and preventing them from reaching the road.

6-Removing unstable blocks along the road and re-sloping the slope face especially in Tanjero Formation.

7-Making rockfall hazard rating system (RHRS) database for Kurdistan region, because it is a mountainous area, by using new systems of satellite images and remote sensing and GIS bases.

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Appendix Table (1): Estimations of the parameters used for determination LPI and construction of hazard map at the study area

	Bejerman (1994, 1998)												
Parameters / Station No.	1	2	3	4	5	6	7	8	9	10	LPI	LPI Category	Failure hazard Category
1 Kometan Fn.	1	4	1	1	4	1	4	0	1	1	18	Moderate	Moderate
2 Kometan Fn	2	4	2	2	4	2	4	0	1	1	22	High	High
3 Shiranish Fn.	1	4	1	3	4	2	4	0	1	1	21	High	High
4 Shiranish Fn.	1	4	1	3	4	2	4	0	1	2	22	High	High
5 Kometan Fn.	1	4	1	3	4	3	4	0	1	1	22	High	High
6 Kometan Fn.	1	4	2	3	4	3	4	0	1	0	22	High	High
7A Shiranish Fn	1	4	1	2	4	1	4	0	1	0	18	Moderate	Moderate
7B Shiranish Fn	1	4	1	2	4	1	4	0	1	0	18	Moderate	Moderate
8 Kometan Fn	1	4	1	2	4	4	4	0	1	0	21	High	High
9 Kometan Fn.	1	4	1	3	4	3	4	0	1	1	22	High	High
10 Kometan Fn.	1	4	1	3	4	3	4	0	1	0	21	High	High
11 Kometan Fn.	1	4	2	3	4	3	4	0	1	1	23	High	High
12 Kometan Fn.	1	4	3	4	4	4	4	0	1	1	26	Very high	High
13 Kometan Fn.	1	4	2	2	4	3	4	0	1	1	22	High	High
14 Kometan Fn	1	4	2	2	4	3	4	0	1	1	22	High	High
15 Kometan Fn.	1	4	1	2	4	3	4	0	1	1	21	High	High
16 Kometan Fn.	1	4	1	2	4	3	4	0	1	1	21	High	High
17 Kometan Fn.	1	4	2	2	4	3	4	0	1	1	22	High	High
18 Kometan Fn.	1	4	1	2	4	3	4	0	1	1	21	High	High

Parameters / Station No.	1	2	3	4	5	6	7	8	9	10	LPI	LPI Category	Failure hazard Category
19 Kometan Fn.	1	2	1	2	3	3	4	0	1	1	18	Moderate	Moderate
20 Kometan Fn.	1	1	1	2	3	3	4	0	1	1	17	Moderate	Moderate
21 Kometan Fn.	1	2	1	2	4	2	4	0	1	1	18	Moderate	Moderate
22 Kometan Fn.	1	3	1	2	3	1	4	0	1	1	17	Moderate	Moderate
23 Kometan Fn.	1	1	1	2	4	2	4	0	1	1	17	Moderate	Moderate
24 Kometan Fn.	1	4	2	2	3	2	4	0	1	1	20	Moderate	Moderate
25 Shiranish Fn.	1	4	2	2	3	2	4	0	1	1	20	Moderate	Moderate
26 Shiranish Fn.	1	4	2	2	4	2	4	0	1	1	21	High	High
27 Shiranish Fn.	1	3	2	2	3	1	4	0	1	1	18	Moderate	Moderate
28 Shiranish Fn.	1	4	2	2	4	2	4	0	1	1	21	High	High
29 Shiranish Fn.	1	4	2	2	4	2	4	0	1	1	21	High	High
30 Kometan Fn.	1	3	2	2	4	2	4	0	1	1	20	Moderate	Moderate
31 Kometan Fn.	1	4	2	2	4	2	4	0	1	1	21	High	High
32 Tanjero Fn.	1	4	1	2	-3	2	0	0	1	1	9	very low	Low
33 Recent deposit	1	4	3	5	0	0	0	0	1	0	14	Low	Moderate
34 Recent deposit	1	4	3	5	0	0	0	0	1	0	14	Low	Moderate
35 Tanjero Fn.	1	4	2	2	4	2	4	0	1	1	21	High	High
36 Tanjero Fn.	1	4	1	2	4	1	4	0	1	1	19	Moderate	Moderate
37 Tanjero Fn.	4	3	1	2	-4	1	0	0	1	0	8	Very low	Low

Appendix Table 2: Estimation of parameters used to determine hazard degree of slopes on roads and residential areas at the study area

According to Barison and conteducae (1998)					
Parameter / Station No.	Block size	Distance to road	Available protection work	Sum	Road hazard class
1 Kometan Fn.	2	2	3	7	High
2 Kometan Fn	1	2	3	6	Moderate
3 Shiranish Fn.	1	2	3	6	Moderate
4 Shiranish Fn.	1	2	3	6	Moderate
5 Kometan Fn.	1	2	3	6	Moderate
6 Kometan Fn.	1	2	3	6	Moderate
7A Shiranish Fn	1	2	3	6	Moderate
7B Shiranish Fn	1	2	3	6	Moderate
8 Kometan Fn	0	2	2	4	Moderate
9 Kometan Fn.	1	2	2	5	Moderate
10 Kometan Fn.	1	2	2	5	Moderate
11 Kometan Fn.	0	2	2	4	Low
12 Kometan Fn.	1	2	2	5	Moderate
13 Kometan Fn.	1	2	2	5	Moderate
14 Kometan Fn	1	2	2	5	Moderate
15 Kometan Fn.	1	2	2	5	Moderate
16 Kometan Fn.	1	2	2	5	Moderate
17 Kometan Fn.	1	2	2	5	Moderate
18 Kometan Fn.	0	2	2	4	Low

Parameters / Station No.	Block size	Distance to road	Available protection work	Sum	Road hazard class
19 Kometan Fn.	0	2	2	4	Low
20 Kometan Fn.	1	2	2	5	Moderate
21 Kometan Fn.	0	2	2	5	Moderate
22 Kometan Fn.	0	2	2	4	Low
23 Kometan Fn.	0	2	2	4	Low
24 Kometan Fn.	0	2	2	4	Low
25 Shiranish Fn.	0	2	2	4	Low
26 Shiranish Fn.	0	2	2	4	Low
27 Shiranish Fn.	0	2	2	4	Low
28 Shiranish Fn.	0	2	2	4	Low
29 Shiranish Fn.	0	2	2	4	Low
30 Kometan Fn.	0	2	2	4	Low
31 Kometan Fn.	0	2	2	4	Low
32 Tanjero fn	0	2	2	4	Low
33 Recent deposit	0	2	2	4	Low
34 Recent deposit	0	2	2	4	Low
35 Tanjero fn	0	2	2	4	Low
36 Tanjero fn	0	2	2	4	Low
37 Tanjero fn	0	0	0	0	Very low

المستخلص

تم اجراء دراسة جيولوجية هندسية للمنحدارات الصخرية على طريق دوكان–خلكان في محافظة السليمانية لتقيم استقرارية المنحدارات في المنطقة. شملت الدراسة اربع مراحل وهي :(١) المرحلة تمهيدية لجمع المعلومات (خرائط و مصادر عن المنطقة الدراسة)،(٢)مرحلة العمل الحقلي و شملت اجراء و قياسات و جمع نمازج ،(٣) مرحلة الفحوصات المختبرية ،(٤)مرحلة العمل المكتبي لتمثيل و تفسير المعلومات وكتابة الرسالة.

جرى تقيم الستقرارية المنحدارات في واحد و عشرون محطة على طريق دوكان-خلكان حيث تم اجراء مسح واسع للمنحدارات و الانفصالات.ثم تمثيل المعلومات و تحليلها بواسطة برنامج(DIPS) لاول مرة و الاسقاط الجسم على شبكة شمت المتساوية المساحة.

اظهرت الملاحظات الحقلية على وجود انواع مختلفة(حاصلة و محتملة)من الانهيارات في المنطقة:انواع الانهيارات في الحجر الجيري القوي لتكوين الكوميتان جيد التطبق (من الاكثر الي الاقل تواجداً)هي سقوط الصخري ،الانزلاق المستوي ،الانقلاب و الانزلاق الاسفيني.المنحدارات الصخرية في طبقات الحجرالصلصالي و الصلصل الاضعف في تكويت شيرانيش تتميز بالانزلاق المستوي والسقوط الصخري. تم ملاحضة فالق كبير شديد الميل له سطح ذو مادة رابطة قوية و محزز بسب الاحتكاك الشديد على جدران الفالق مكوناً منحدراً شديداً.هذا المنحدر مستقر بسب التماسك العالي لسطح الفالق بعكس الدور المعروف جيداً للفوالق كعناصر عدم الستقرارية في المنحدارات و هذه حالة جديدة.

الفواصل بانواعها المختلفة عملت كسطوح انطلاق جانبية و خلفيةو خلفية المركبة خلال انهيار المنحدارات بينما عملت سطوح التطبق كسطوح انزلاق (باستثناء المنحدرات غير متوافقة حيث عملت سطوح التطبق فيها كسطوح انطلاق خلفية).

اضهرت فحوصات القص المباشر على بعض طبقات الطين ان زاوية الاحتكاك(Ø) تتراوح بين (١٠-١١°) وان قيم تماسك (c)تتراوح بين (٣٢-٦٤) كيلوبسكال مما يساعد كثيرا على انزلاق على طين الذي يملاء سطوح التطبق.

قيم المقاومة النضغاطية غير محصور (والمحسوبة بطريقة غير مباشرة من فحص حمل النقطة)تتراوح بين(٦١-١٠٤)ميكابسكال للحجر الجيري لتكوين الكوميتان و تتراوح بين(٤١-٤٢) ميكابسكال للحجر الجيري الصالصالي لتكون شيرانيش.

للتقيم مخاطر الانهيارات تم جمع المعلومات من ٣٧ محطة و تم رسم خارطة مخاطر لانهيارات لمنطقة الدراسة لاول مرة و بمقياس (١:٢٠٠٠٠)بموجب دليل احتمالية الانزلاق (LPI)و المستند الي عشرة عوامل.هذا الخريطة تُضهر مجاميع مخاطر مختلفة تتراوح بين قليلة جداً الي عالية جداً.

خارطة مخاطر الانهيار للطرق رسمت و بنفس المقياس اعلاهً و لاول مرة و هي تعتمد على ثلاثة عوامل وهي:(١)حجم الكتل المنفصل (٢)المسافة بيت الطريق و اقرب قدم المنحدر ،(٣)توفير العمال حماية للمنحدرات. يتراوح مدى مخاطر في منطقة دراسة بين واطئة جداً الى عالية.

كانت عملية توسيع طريق دوكان-خلكان نشطة جداًصيف عام ٢٠٠٩ و ادت الى تكوين منحدرات بارزة و غير مستقرة تركَت بدون حماية و معالجة.لذلك تم اقتراح بعض اجراءات في هذه الدراسة لحميات المنحدارات الطبيعية و ما صنع الانسان من الانهيارت المستقبلة.

دراسة جيولوجية-هندسيةلاستقرارية المنحدرات الصخرية على طريق دوكان – خلكان، اقليم كردستان،شمال شرق العراق

رسالة مقدمة إلى مجلس كلية العلوم-جامعة السليمانية
كجزء من متطلبات نيل درجة ماجستيرعلوم
في علوم الأرض

من قبل:

فهمي عثمان محمد مامليسي

بكالوريوس علوم/جيولوجي-جامعة السلمانية /٢٠٠٥

بأشراف:
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رمضان-١٤٣١هـ أب-٢٠١٠مـ

پوختەی توێژینەوە

توێژینەوەیەکی جیۆلۆجیای ئەندازیاری لەسەر سەقامگیری بەدرێژای لێژاییەکانی ڕێگەی نێوان دوکان-خەلەکان لە پارێزگای سلێمانی بە ئەنجام گەیەندرا، توێژینەوەکە لە چوار قۆناغی کارکردن پێکهاتبوو: قۆناغی سەرەتایی کە بریتی بوو لە کۆکردنەوەی داتا لەسەر ناوچەی توێژینەوەکە، وەکو نەخشەو سەرچاوەی زانستی پەیوەندیدار بە شوێنی توێژینەوەکە. قۆناغی دووەم لێکۆڵینەوەی کێڵگەیو کۆکردنەوەی نموونە. قۆناغی شیکردنەوەو پێوانی تاقیگەیی. قۆناغی چوارەم نوسینەوە و لێکدانەوە کەدوا قۆناغ بوو.

بۆئەم توێژینەوەیە بیست ویەك خاڵ بۆ نرخاندنی سەقامگیری لێژاییەکانی نێوان دوکان-خەلەکان هەڵبژێردران و ڕووپێوی تەواو لەسەر لێژایی و درزو قڵیشەکانیان کرا،وە بۆ نرخاندن و لێکۆڵینەوە و خستنەڕوویان بۆ یەکەم جار سوود لە پرۆگرام (DIPS) وەرگیرا ، لەگەڵ (Stereographic projection) ندا داتاکان خرانەڕوو و شیکردنەوەیان بۆکرا. شیکردنەوەی سەقامگیری و تێبینییە کێڵگەییەکان بونە هۆی دەرخستنی جۆرە جیاوازەکانی ڕوخانی بەرد کە لەئێستادا ڕویانداوەو، یان پێشبینی ڕوودانیان دەکرێت. جۆری ڕوخانە بردیەکان لەو بەردانەی بەهێزن و پێکهاتوون لە چینە بەردەکانی پێکهاتەی کۆمیتان لەزۆرەوە بۆ کەم بریتین لە کەوتنی بەرد(rockfall)، خلیسکانی بەرد(Plane Sliding)، هەڵگەڕانەوە(Toppling)، خلیسکانی ئسفینی(Wedge Sliding)، خولانەوەی بەرد(Rock Roll). بەڵام ڕوخانی بەردینی لەلێژاییە بەردینییەکانی کەڤرە لاوازەکانی پێکهاتەی شیرانش بریتی بوون لە خلیسکانی بەردو و کەوتنە خوارەوەی بەرد.

یەکێك لە لێژیەکان کە پێکهاتبوو لە شکاویەکی گەورە و ڕوویەکی شێوە کۆکنکریتی زۆر لێژی دروستکردبوو، بەهۆی ئەو لێکخشانە توندەی کە لەسەر ڕووەکە ڕویداوە و نیشانەی خلیسکانەکەی لەسەر دەرکەوتووە، ببووە هۆی سەقامگیری ئەو ڕووە بە پێچەوانەی ئەو شێوە باوەی کەشکاوی ڕۆڵی هەیە لە دروستکردنی ناسەقامگیری.

ئەنجامی تاقی کردنەوەکانی (shear box test)کە لەسەر چینەکانی خۆڵی نێوان بەردەکان ئەنجامدرا دریان خست کە گۆشەی لێکخشان لە نێوان (١٠-١١) و بەیکانووسانی نێوانیان لە نێوان (٣٢-٦٤)kpa دایە وە بوونەتە هۆکاری یاریدەدەر بۆ ڕوودانی داخزان لەسەر چینە خۆلەنە کەلە نێوان و لەسەر رووی چینەکان بەردەکان.

بەهاکانی پەستانی تاك تەوەری(Uniaxil compressive streangth)کە مەودایەکی فراوانیان هەبوو بۆ پێکهاتی کومیتان لەنێوان(٦١ -١٠٤)MPa بوون و بۆ پێکهاتەی شیرانش لەنیوان(٤١ - ٤٢)MPaدا بوو.

بۆ نرخاندنی مەترسی رووخان داتا لە (٣٧) خالْ وەرگیرا و نەخشەی مەترسی روخان بۆیەکەم جار بۆ ئەو ناوچەیە دروست کرا بە پێواری(١:٢٠٠٠٠)بە پێی پێوەری شیاوی رۆچوونی زەوی(LPI)کە پشت دەبەستێتە(١٠) فاکتۆر.ئەم نەخشەیە پۆلینی زۆر جۆری جیاوازی مەترسی ڕوخانی پیشاندا کە لەنێوان ناوچەی زۆر مەترسی بەرز بۆ زۆر مەترسی نزمدا بوو کەئەمەش مەودایەکی فراوان بوو.هەروەها بەهەمان پێواری پێشوو و بۆ یەکەم جار نەخشەیەك لەسەر بنەمای مەترسی داڕوخان بۆ ڕێگاوبان کە پشت دەبەستێ بە سێ فاکتۆر(١)قەباری پارچە ڕووخاوەکان (٢)ماوەی نێوان لێژی و ڕێگاوبان(٣)بوونی هۆکاری پارستن لەکەوتنە خوارە بەرد، دروست کرا کە پولینی جیاواز و مودای جیاوازی لەنێوان بەرز بۆ زۆر نزم نیشاندا.

شەقەکان جۆری جیاوازیان هەبوو کاریان وەکو رووی ئاسانکەر لە شێوەی جیاوازی وەکو ڕووی لا تەنیشت و پشتەوەو ڕووی یەکتربڕەکان کە لەکاتی ڕوودانی ڕووخانی بەردەکان یامەتی کەوتنە خوارەوەیان دەدەن، هەرچی ڕووی نێوان چینە بەردەکانە(Bedding plane) کاریان وەکو ڕووی خلیسکان لەسەر دەکرد.

پرۆسەی فراوانکردنی ڕێگای نێوان دوکان-خەلەکان کە لە هاوینی ساڵی ٢٠٠٩ دا دەستی پێکرد بووە هۆی دروستکردنی ڕووی لێژی هەڵواستراوی بێ پایەی بەردینی و بەبێ هیچ جۆرە هۆکارێکی سەقامگیرکردن یان پاراستن لە کەوتنە خوارەوە بۆیە لەم توێژینەوەیەدا هۆکاری سەقامگیرکردن و پاراستن لە کەوتنە خوارەوە باسکراوە بۆ پاراستنی ئەو لێژاییانەی کە سروشتین یا دەستکردن.

توێژینەوەیەکی جیۆلۆجیای ئەندازەیی بۆ سەقامگیری لێژایی یە بەردی یەکان بەدرێژایی ڕێگەی نێوان دوکان-خەلەکان، هەرێمی کوردستان ، باکووری ڕۆژهەلاَتی عێراق

نامەیەکە

پێشکەشە بە ئە نجومەنی کۆلێجی زانست لەزانکۆی سلێمانی وەك بەشێك لە پێویستیەکانی بەدەست هێنانی پلەی ماستەر لە زانستی جیۆلۆجی دا

لەلایەن

فەهمی عوسمان محمد مامڵێسی

بەکالۆریۆس لە جیۆلۆجی دا / ٢٠٠٥

(زانکۆی سلێمانی)

بەسەرپەرشتی

پرۆفیسۆر.د سعد نعمان السعدی

خەرمانان-٢٧١٠ کوردی　　　　ئابی- ٢٠١٠ زاینی