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Geomorphology of Slope Talus on both sides of Sharm El-Sheikh-Dahab Road in the Southeast of Sinai Using Geomatics Techniques

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Abstract: Manifestations of rock weakness contribute to creating favorable conditions for the activity of erosion factors and weathering processes with their various characteristics, the results of which were the disintegration and fragmentation of rocks to form one of the geomorphological phenomena, which is slope talus. The research aims to shed light on the effect of rock weaknesses on the origin and development of slope talus. Therefore, the aim is not to explain the spatial variation, as it is limited in the study area, for all the rocks in the belong to the Precambrian era. Hence, the main aim is to monitor the weaknesses within the rocks and link their degrees with the most important and first phenomenon that may arise from this weakness, which is the slope talus. The application is carried out on the slopes of both sides of Sharm El-Sheikh-Dahab Road, southeast Sinai, due to the spread of this phenomenon in multiple locations, with its diverse morphological characteristics, which helped in identifying how it originated and developed. This is done by making morphometric measurements and terrain profiles of talus covers and cones, and studying the various rock units, in addition to conducting physical, chemical, and microscopic analyzes of selected samples from each rock unit.

Keywords: Talus, slopes, weathering, geomorphology, geomatics.

1. Introduction

Slope talus is one of the most important geomorphological phenomena resulting from rock weakness. It consists of sedimentary fragments and rock masses that settle over the middle and lower parts of the slopes in the form of sedimentary covers or talus cones. This is mainly due to the processes of rock creep, landslides, gravity and rainwater, and with the help of both joints and cracks in addition to the predominance of drought and scarcity of vegetation.

The research aims to shed light on the origin and evolution of the slope talus, monitoring the weaknesses within the rocks and linking their degrees with the morphological and morphometric characteristics of the covers and cones of the slope talus. The application is carried out on the slopes of bothsides of the Sharm El-Sheikh-Dahab road, particularly in the part located in Wadi Malhij, one of the tributaries of Wadi Kid in southeast Sinai (Figure 1). The length of the road in the study area is 31.44 km, and the study area covers an area of 60.898 km2. This location is chosen due to the spread of this phenomenon in multiple places, with the diversity of its morphological characteristics, which helped in identifying how the slope talus originated and evolved.

The levels of the study area range between 140 and 1108m above sea level. The predominant category is less than 250m, representing 25.4%, followed by the category 550m or more, with a percentage of 25.3%. The eastern directions (east, southeast, and northeast) and western directions (west, southwest, and northwest) cover the vast majority of the study area, representing 85.6% of the total area of the study area.

2. The Inputs

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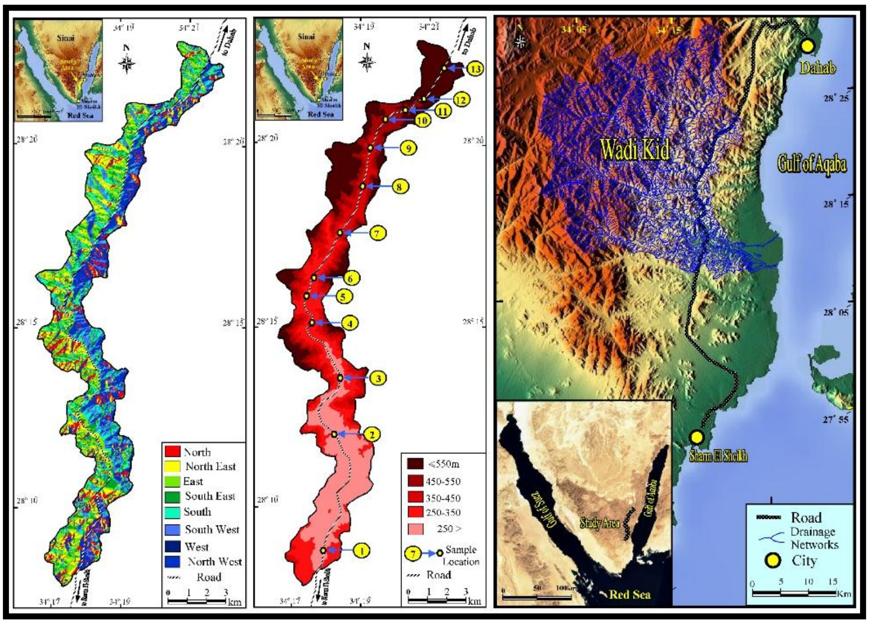
2.1. Geological Formations

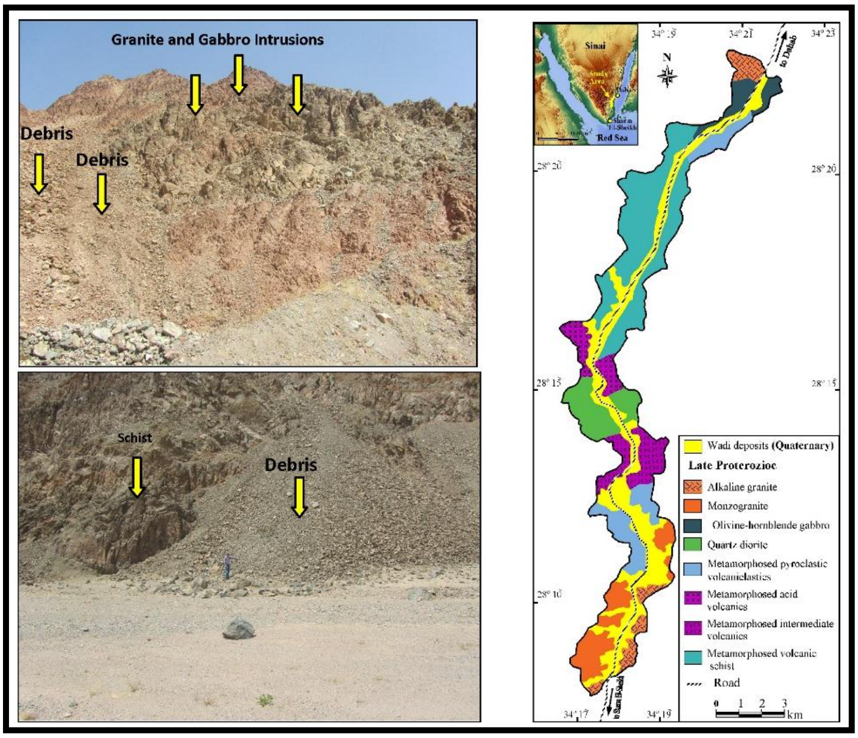
The analysis of Figures 2 and 3 indicates the following:

- The oldest rocks in the study area date back to the Precambrian, and they cover approximately 70% of the total area of geological formations, with the predominance of metamorphosed rocks of volcanic origin, by 45.2%. This is owing to the fact that Egypt was distinguished in the Precambrian era in the stage of metamorphism, as it was characterized by a metamorphism of a low pressure of 4.4 kilobars and a high temperature of 5566°C (Shallaly, 2006). This, in turn, led to a clear dominance of schist rocks, pyroclastics and volcaniclastics, and monzogranites, which are rocks that are weakly resistant to weathering processes, particularly mechanical ones. As a result, this helped to disintegrate and fragment them to form the sediment of the covers of the slope talus in the study area (Figure 2).



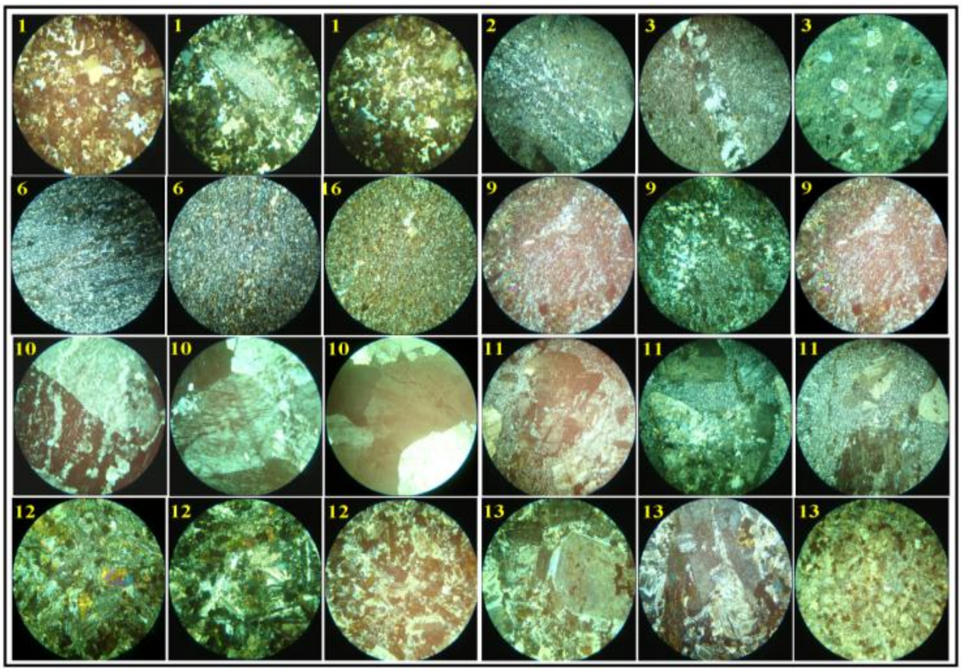
Source: It is based on SAS.Planet and topographic maps, scale 1:50,000, 1987.

Figure 1: The General Features and Locations of the Study Area Samples



Source: Geological map of Sinai, scale 1: 250,000, Egyptian General Authority for Geological Survey and Mineral Resources, 1994, and field study.

Figure 2: Surface Geological Formations in the Study Area



Source: The analysis is conducted in the central laboratories of the Faculty of Science, Kafr El-Sheikh and Al-Azhar Universities, 2017

Figure 3: Mineral Composition of Rock Samples in the Study Area Using a Thin-section Polarizing Microscope

- There is a large variation in the minerals that make up the rocks, as they consist of quartz, biotite, microcline, olivine, plagioclase, muscovite, and feldspar. Quartz is the most common mineral in the rocks of the study area, with a variation in the size of its crystals, and its distribution in the form of veins in some locations.
- The minerals that make up the rocks were affected by tectonic factors and weathering processes, particularly mechanical ones, which led to compression in the texture of the minerals, resulting in deformation of the crystals of the minerals that make up the rocks, particularly quartz. This had a major impact on the weakening of the rock and the spread of cracks and gaps, which in turn helped increase the porosity of the rock and thus created paths for weathering, leading to the spread of many phenomena such as fragmentation and exfoliation.

2.2. Petrophysical Characteristics of Rocks:

The analysis of Table 1 and Figures 4 and 5 indicates the following:

- The porosity of igneous and metamorphosed rocks ranged between 4.09 and 7.14%, due to deformation of mineral crystals, such as quartz, biotite, microcline, mica, and plagioclase, as a result of compression resulting from tectonic factors and mechanical weathering processes. In consequence, there was a spread of cracks and gaps (Figure 4). In this case, porosity is called secondary porosity that was not formed with the formation of the rock itself.
- There is a slight discrepancy in the speed of ultrasonic waves, which ranged between 2.08 km/sec and 2.64 km/sec. The existence of this discrepancy is due to two reasons: namely the degree of homogeneity, ranging between 1.0 and 1.13, and the degree of internal friction. The lowest value was 4.1 and the highest value was 6.6, and the lower the speed of the ultrasonic waves, the more it indicates that the samples are weathered and vice versa.
- The rocks respond to weathering processes, as the general average reached 7.53, and this is due to the increase in the degree of porosity. It was observed that the total porosity was equal in some rock samples, but they differed in the degree of their response to weathering. The explanation for this is related to the diameters of the pores within the rock compound itself. Figure 5 shows that rocks with porosity ranging between 0.1 and 5.0 microns have a high response to weathering.
- The rocks have an ability to absorb water, which ranged between 3.33 and 5.04. Moreover, the highest degree of absorption, which was more than 5.0, was recorded in 6 samples, representing 50% of the total number of rock samples in the study area.
- The general density of less than 3.0 was recorded in 6 samples, which are represented by monzogranite rocks in the south, schist in the
- center, and olivine in the north. Accordingly, these rocks respond to weathering processes more than the other samples.

2.3. Joints, Fractures and Cracks:

Joints are widespread in all rocks without exception. They take a horizontal, vertical, or inclined form, and they may extend a few millimeters or hundreds of meters (Holmes, 1992). Besides, joints and fractures affect the way rocks disintegrate and fragment, which leads to the formation of slope talus. The characteristics of the joints and fractures vary in the study area (Table 2) and (Figure 6).

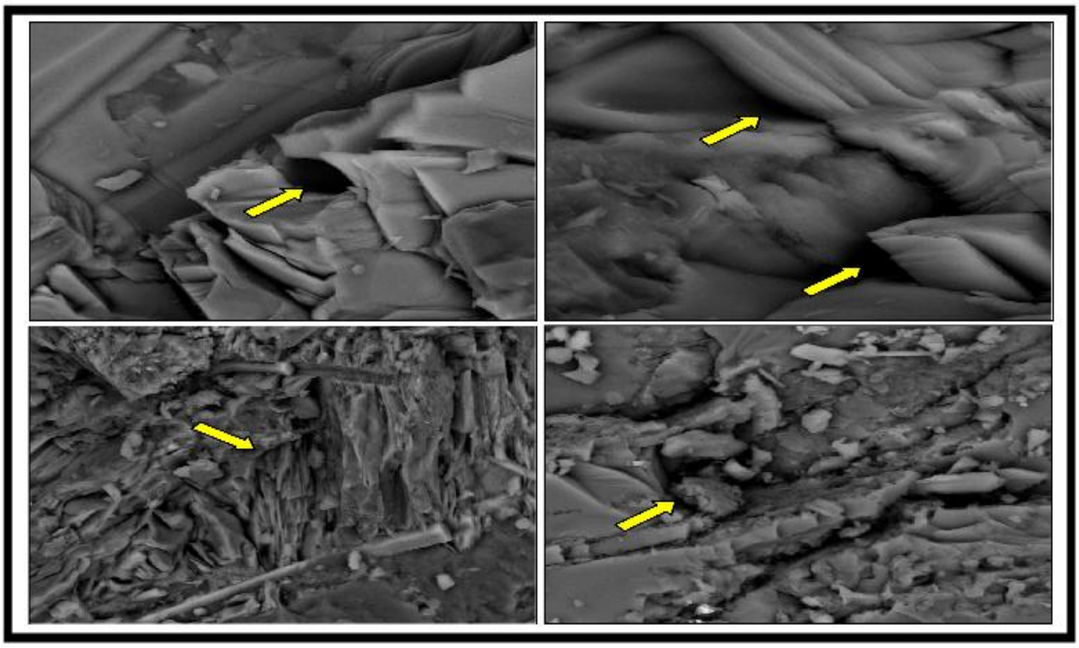
The analysis of Table 2 and Figure 6 indicates the following:

Table 1: Petrophysical Characteristics of Rocks in the Study Area

Sample	Location	Porosity Rate (%)	CP km/sec.(1)	Homogeneity Degree	Homogeneity Description (2)	Internal Friction with the Rock	Response Degree to Weathering (3)	Response Criterion to Weathering	Specific Density	Degree of Water Absorption
1	West	7.04	2.08	1.13	Low	6.60	14.18	Highly Responsive	2.94	5.02
2	East	5.12	2.58	1.00	High	4.17	3.91	Resistant	3.53	3.51
3	East	5.23	2.53	1.01	High	4.51	5.37	Resistant	3.49	3.69
6	West	6.12	2.09	1.13	Low	6.70	6.50	Responsive	2.96	5.02
8	East	6.09	2.35	1.03	Average	6.11	8.48	Responsive	2.98	5.04
9	East	5.18	2.49	1.01	High	4.53	3.42	Resistant	3.52	3.33
	West	4.09	2.51	1.01	High	4.41	4.40	Resistant	3.52	3.42
10	East	7.11	2.18	1.06	Low	6.43	12.79	Highly Responsive	2.98	5.02
12	East	7.14	2.11	1.10	Low	6.60	12.29	Highly Responsive	2.96	5.03
	West	5.33	2.53	1.02	Average	4.50	6.55	Responsive	3.53	3.71
13	East	7.12	2.27	1.04	Average	6.50	7.51	Responsive	2.98	5.01

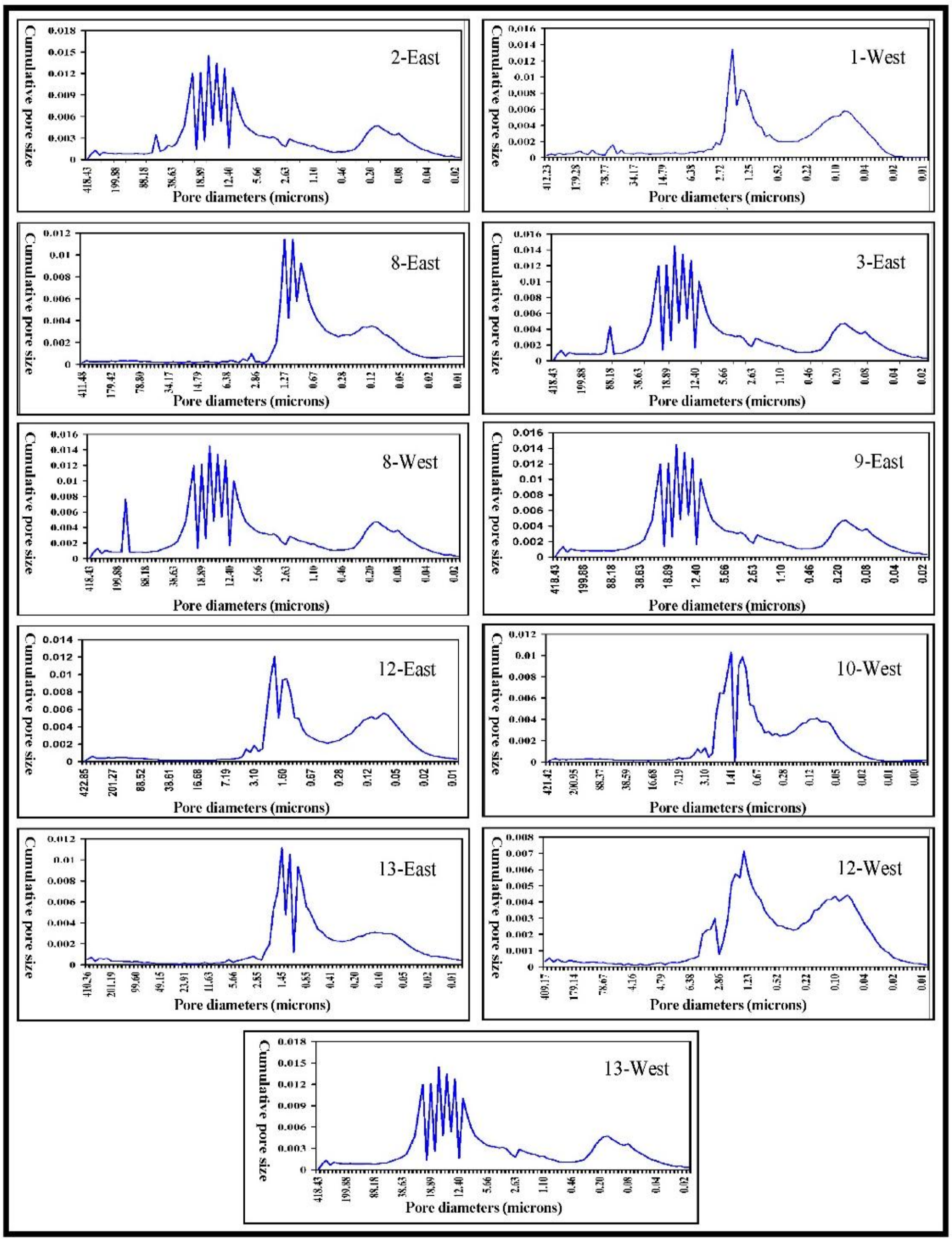
(1) CP: Ultrasound speed measurement.
(2) Description of homogeneity: less than 1.02 high, 1.02 – 1.05 average, 1.05 or more low homogeneity.
(3) It was classified based on the criterion developed by Yu and Oguchi (2010).

Source: The analysis is conducted at the Faculty of Engineering laboratories, Kafr El-Sheikh University.



Source: The analysis is conducted in the Central Geological Survey Laboratories, 2017.

Figure 4: The Spread of Secondary Porosity in the Rocks of the Study Area (Using Electron Microscope)



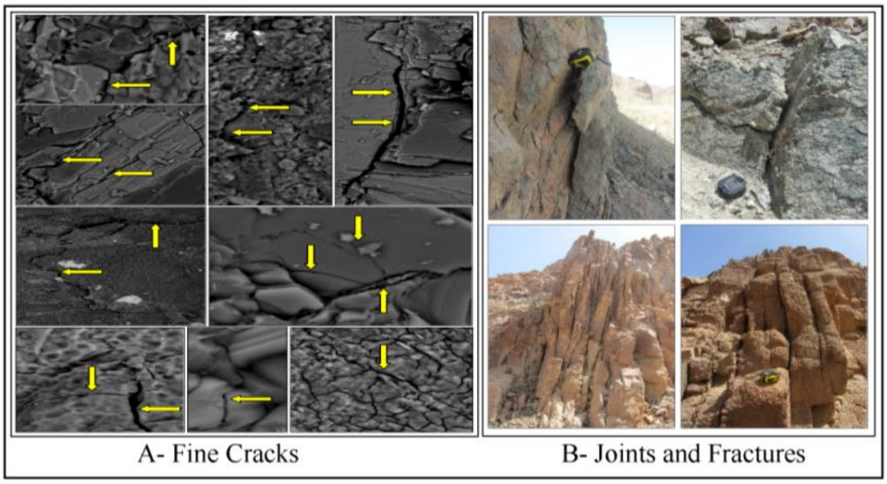
Source: The analysis is conducted in the General Petroleum Company laboratories, 2017.

Figure 5: The Rate of Rock Pore Diameters in the Study Area

Table 2: General Characteristics of Joints and Fractures in the Study Area

Location	Density	Directions	Degree of Intersection	Location	Density	Directions	Degree of Intersection
1	High	Multiple	Medium	8	High	Multiple	High
2	Medium	Multiple	Medium	9	Medium	Multiple	Medium
3	Medium	Multiple	High	10	High	Multiple	High
4	Medium	Multiple	High	11	High	Multiple	High
5	Medium	Multiple	Medium	12	Medium	Vertical and Horizontal	Medium
6	High	Multiple	High	13	Medium	Vertical and Horizontal	Limited
7	High	Multiple	High				

Source: Field study, 2017.



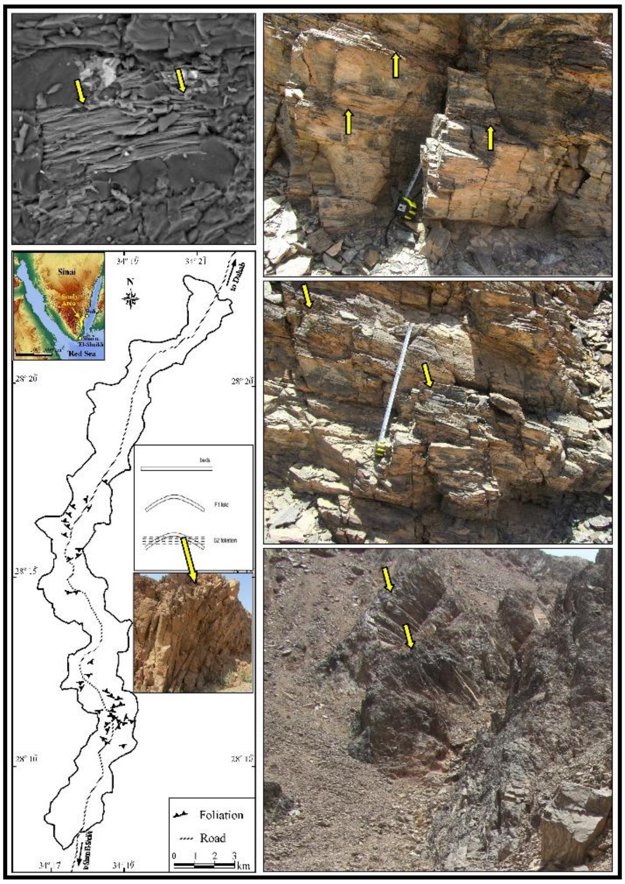
Source: The researcher's photography, and the analysis is conducted in the General Petroleum Company laboratories, 2017.

Figure 6: The Spread of Fine Joints, Fractures and Cracks in the Rocks of the Study Area

There are many joints and fractures, particularly in granite and schist rocks. The joints take two directions, both vertically and horizontally, north of the study area, and the degree of intersection is limited to moderate. Accordingly, the phenomenon of granular disintegration spreads. Concerning the south of the region, the directions are multiple, but the degree of intersection is moderate. This led to the presence of some large-sized debris with fine debris, due to the spread of the phenomena of block disintegration and separation together. As for the center of the study area, it is characterized by the presence of multiple directions and high density, resulting in the formation of medium and small-sized debris. As Figure 6 indicates, there is a spread of many cracks resulting from mechanical weathering, ranging from fine to medium, in biotite minerals, and across crystals of quartz, mica, and kaolin. Cracks are also characterized by taking either a longitudinal or zigzag shape, and intersecting with each other randomly or perpendicularly, particularly in schist rocks. Some cracks are deep and wide across the edges of rock crystals, and across weak levels of mica, forming large secondary pores and weathering paths that help fragment the rock in subsequent stages.

2.4. Foliation

Figure 7 shows that the degree of rock foliation is very high, with parallel foliation spreading, which usually occurs in fine-grained rock units when they are twisted. This is observed in schist rocks, and the foliation in these rocks is known as schist fabric (Mibei, 2014). This phenomenon was observed in many places, especially east of the Sharm El-Sheikh-Dahab road. The density of foliated rocks decreases until it is almost non-existent far north of the study area. There is also widespread internal foliation in many rock samples, resulting in the spread of separate slices of schist rocks in the form of rectangles. With the spread of the phenomenon of granular disintegration, the rocks of the study area are among the ones that have a high response to tectonic movements and weathering processes, which helped in their fragmentation to eventually form the slope talus.



Source: The researcher's photography, the electron microscope, and Fowler *et al.* (2010).

Figure 7: Foliated Rocks in the Study Area

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2.5. Climatic Factors:

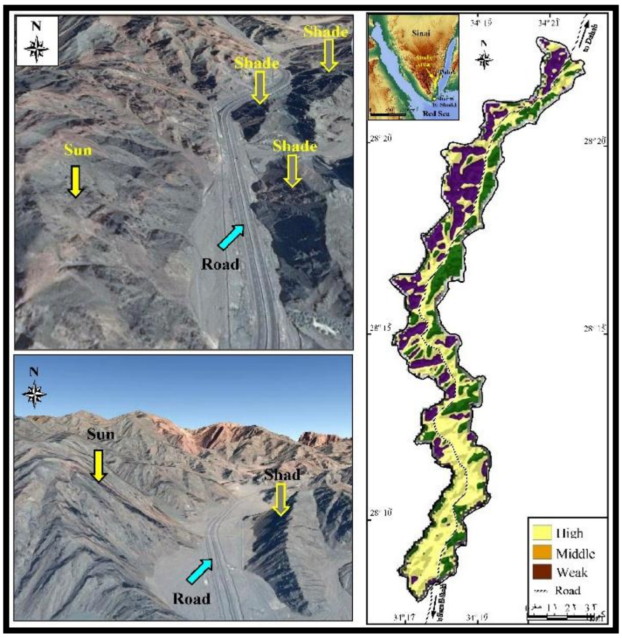
The analysis of Table 3 indicates the following:

- The temperature range was high, not less than 8.5° in the winter, while the highest range reached 10.3° in the summer. It is worth noting that the highest temperature recorded in the study area was 46.8 on 6/22/2010, while the lowest minimum temperature was 6.7° on 1/3/1992 during the period from 1976 to 2010 (Salama, 2016).
- The seasonal rate of solar brightness was high, not less than 8.5 hours/day in the winter, and the highest rate was 12.3 hours/day in the summer, noting that this high rate of sunshine is not completely received by the rocks (Figure 8). Table 4 shows that more than 75% of the area of the study area is exposed to moderate to intense solar radiation, and this process leads to intense heating of the rock during the day, whereas during the night the rocks quickly lose their heat. There is no doubt that this change affected the activity of the process of mechanical weathering: As this process continues, the rock weakens and fragments to form debris of different sizes, particularly in granite and schist rocks, which cover the vast majority of the study area.
- The low relative humidity in the summer (35%) and high temperature caused an increase in the activity of rock disintegration processes as a result of mechanical weathering. However, in the winter (44%), the availability of a certain amount of humidity and low temperature led to the activity of the chemical weathering process. Figure 9 indicates that the feldspar mineral in granite rocks transformed into clay and illite minerals, mica and biotite minerals transformed into clay illite minerals, and mica minerals transformed into clay. This transformation of basic minerals into other minerals helped to make their resistance very weak to weathering processes, and to fragment the rocks and turn them into fine grains.
- The role of rain in the study area at the present time is limited, as the total amount of rain per year does not exceed 16.16 mm, and most of it falls in the winter (13.1 mm). However, heavy rain may fall sometimes, as the largest amount of rain that fell during one day was recorded at Sharm El-Sheikh station 59 mm on 1/17/2010 during the period from 1976 to 2012 (Salama, 2016), carrying with it slope talus to deposit it in the lower parts. In spite of the lack of rain in the study area, it has a significant impact on weakening and fragmenting the rock. This little water helped plants grow in the rocks (Figure 10), and this growth has a mechanical impact that helps widen the joints and fractures and then disintegrate and fragment the rock. Furthermore, this growth has a chemical impact in terms of the formation of organic acids from rotting plants. These acids have a significant impact on the possibility of dissolving some elements, which leads to an increase in porosity. As a result, the joints and fractures widen more and more, and the rock becomes weaker and eventually fragments, forming slope talus.

Table 3: Some Climatic Characteristics at Sharm El-Sheikh Station (1982-2010)

Characteristics / Seasons	Temperature Range (°C)	Solar Brightness (hours/days)	Relative Humidity (%)	Rain (mm)
Winter	8.5	8.5	44	13.1
Spring	9.8	10.3	38	1.4
Summer	10.3	12.3	35	0
Autumn	8.6	10.6	45	1.6

Source: General Authority of Meteorology, Climate Department (unpublished data).



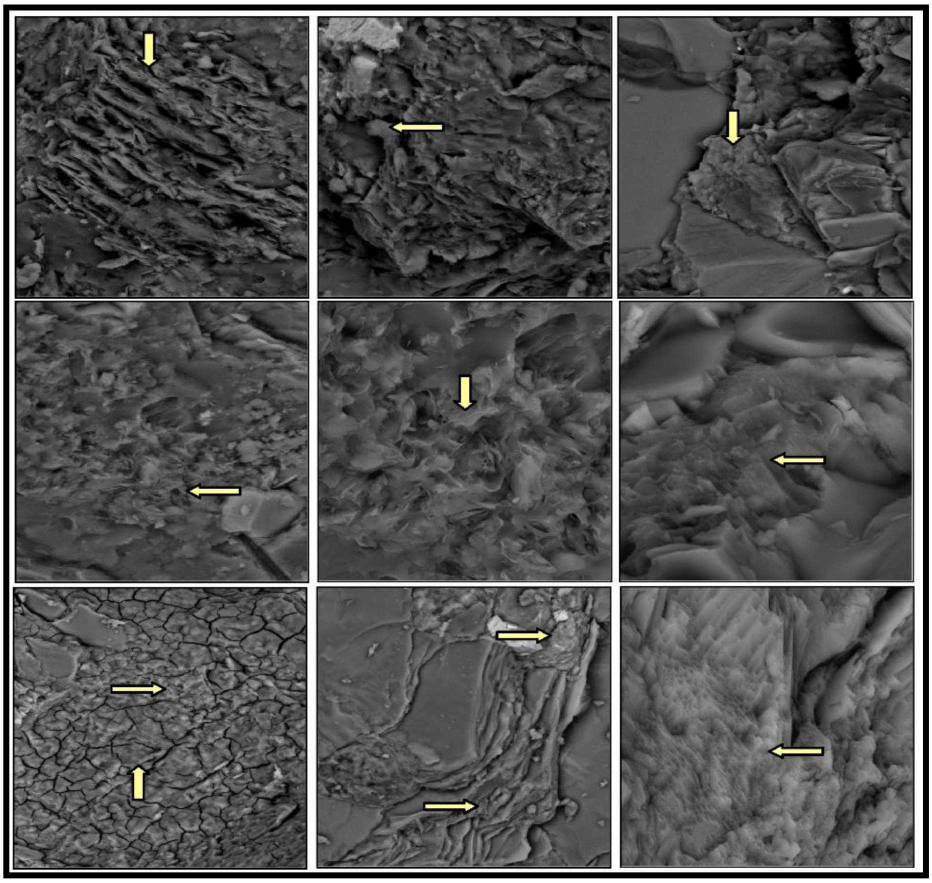
Source: Using Arc GIS and Google Earth.

Figure 8: Degrees of Exposure to Solar Radiation in the Study Area

Table 4: Solar Brightness in the Study Area

Categories (Degrees)	Area (km^2)	Area (%)
Weak	14.798	24.3
Middle	6.760	11.1
High	39.340	64.6
Total	60.898	100

Source: It is based on Figure 8.



Source: The analysis is conducted in the General Petroleum Company laboratories, 2017.

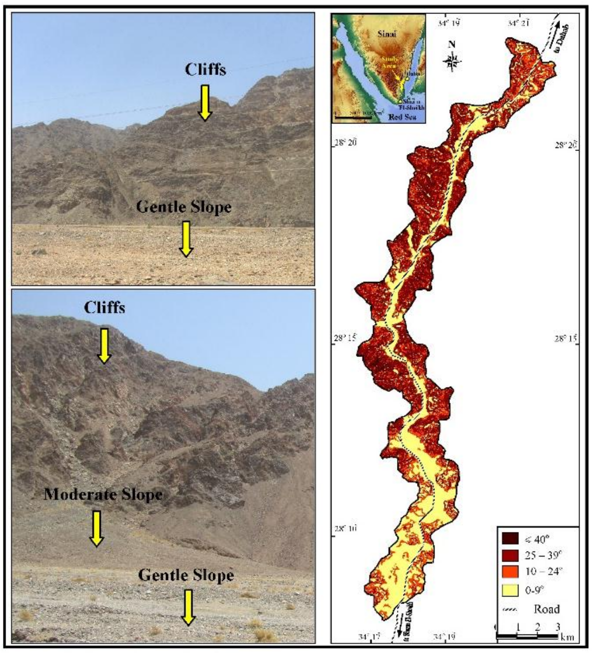
Figure 9: The Impact of Chemical Weathering Activity on the Rocks of the Study Area

Source: The researcher's photography, 2017.

Figure 10: Plant Growth within Joints and Fractures in Rocks of the Study Area

2.6. Degree of Slope

The degree of slope is one of the most significant factors influencing the movement of slope talus, as the process of formation of talus depends on its different angles of repose and the size of the debris. Figure 11 and Table 5 indicate that the gentle and moderate slopes represent 55.7% of the total study area. Most of them are located south of the study area, particularly east of the road, and are topped by blocks and rock debris forming talus covers. These slopes do not allow the movement of large blocks. Concerning the steep slopes, they represent one-third of the study area, and the phenomena of block shattering and separation are widespread. As for the cliffs, which have a slope of more than 40 degrees, they cover 11.6%, and the movement here is a block and granular precipitation, and it is completely free of sediment. However, the sediment accumulates below it in the form of talus cones.



Source: It is based on topographic maps, scale 1:50,000, 2006.

Figure 11: Slope Degree in the Study Area

Table 5: Slope Categories in the Study Area

Categories (Degrees)	Slope Nature	Area (km^2)	Area (%)
0-9	Gentle Slopes	22.252	36.5
10-24	Moderate Slopes	11.714	19.2
25-39	Extremely steep Slopes	19.884	32.7
40 or more	Cliffs	7.048	11.6
Total		60.898	100

Source: It is based on Figure 11.

3. Discussion

3.1. The Origin of Slope Talus

Slope talus is formed through basic processes: block disintegration and separation, exfoliation, and granular disintegration. These processes have resulted in a largevariation in the sizes of sediments that make up the slope talus. What follows is a study of these processes:

3.1.1. Block Disintegration and Separation

It was observed in all locations, particulalry in the middle of the study area in schist rocks, some gneiss, granite, and gabbro; and in the south of the study area in schist and granite rocks, due to the spread of vertical and horizontal joints intersecting with the activity of weathering processes that separate schist and granite rocks into large blocks of different sizes. The collision of the falling blocks with the surface of the slope led to their cracking and shattering, particularly with relatively large rock blocks, whose length ranged between 1.5 and 2.7 meters, and their height between 0.5 and 1.6 meters. In addition, the weathering of Katrina volcanic rocks resulted in another form of fine block disintegration, which takes on the fine schist appearance in the form of small-sized blocks that take the form of medium-sized cubes, with their maximum length not exceeding 75 cm, and their maximum height 10 cm (Figure 12).

3.1.2. Exfoliation

Exfoliation in the study area can be classified as follows (Figure 13):

- **Large sections:** The thickness of these sections ranges between 3 and 12 cm, and they are spread across granite rocks. This phenomenon is associated with cliffs and free faces. The most important thing to note about these materials is that their edges are sharp-angled, as they are local deposits that have not been subjected to transport processes.
- **Small sections:** They appear in granite and schist rocks, as the upper parts of the surface of the rock blocks show exfoliation into layers no more than 3 cm thick.
- **Very fine sections:** There is fine exfoliation in quartz and feldspar minerals, as well as in the lamellar structure of mica. These sections were separated to eventually form fine sediments of slope talus.

3.1.3. Granular Disintegration

- **The** phenomenon of granular disintegration arises as a result of the variation in the types of minerals that make up the rocks, and this results in the presence of varying rates of expansion within the rock. Accordingly, many pressures exist within the rock that result in disintegrating grains (Ollier, 1984). Granular disintegration can be classified as follows:
- **Large-sized grains:** This phenomenon was observed in all study sites, and the diameter of the grains did not exceed 4.0 cm. They represent the coarse sediments in talus cones, and their shape ranges from sharp to semi-sharp, due to their transport over small distances (Figure 14).
- **Medium-sized to small-sized grains:** Quartz crystals spread across the fabric of many minerals, particularly feldspar and biotite (Figure 15). As a result, in the event of weathering of these minerals, the cohesion process will weaken, and the quartz crystals will separate and fall, forming medium and fine sediments in the slope talus (sand) in the study area (Figure 16).

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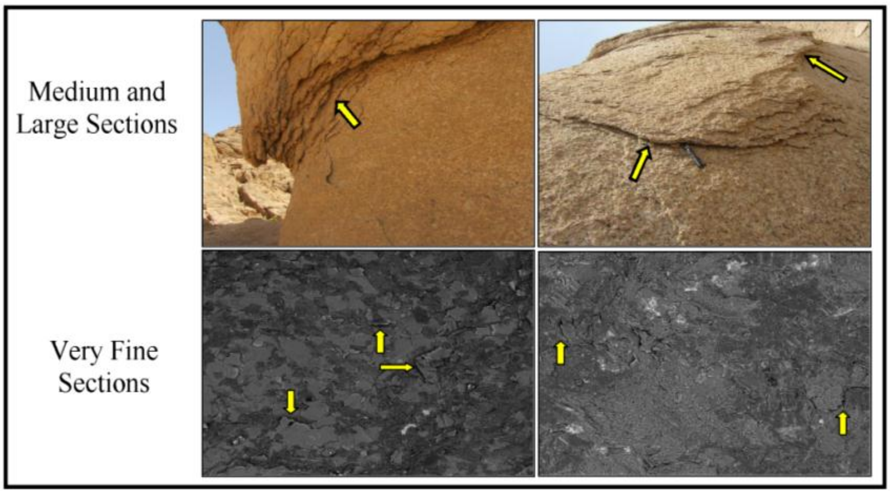
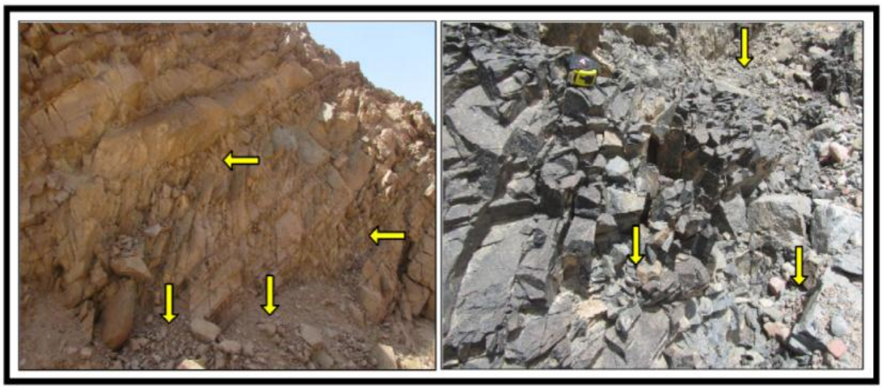
Source: The researcher's photography, 2017.

Figure 12: The Impact of Block Disintegration and Fractures in the Rocks of the Study Area



Source: The researcher's photography, 2017.

Figure 13: The Impact of Exfoliation in the Rocks of the Study Area



Source: The researcher's photography, 2017.

Figure 14: Granular Disintegration (Large-sized Grains) in the Study Area

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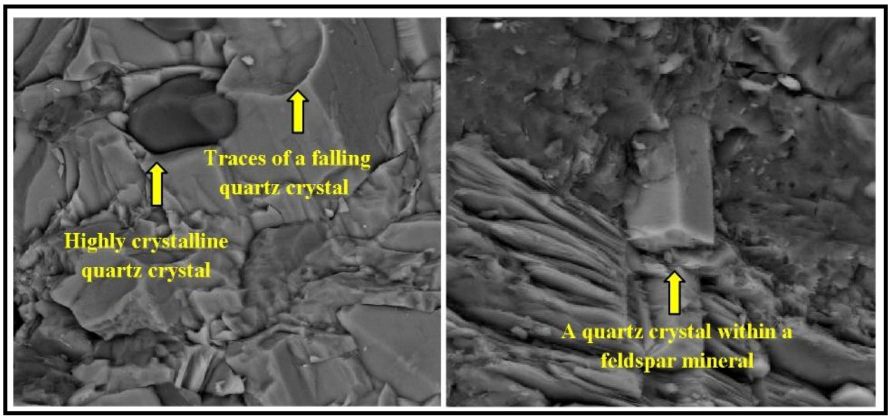
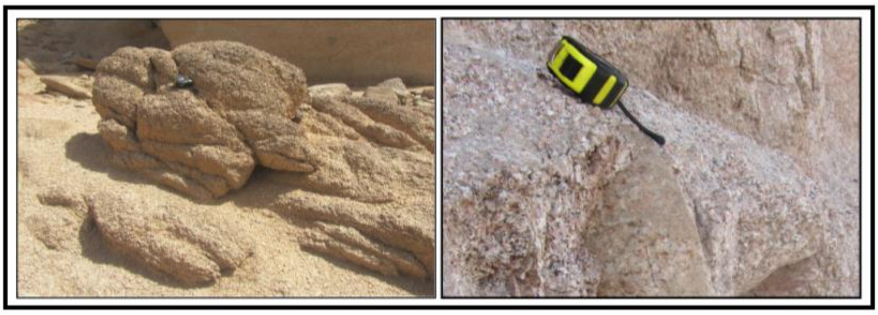


Source: The analysis is conducted in the General Petroleum Company laboratories, 2017.

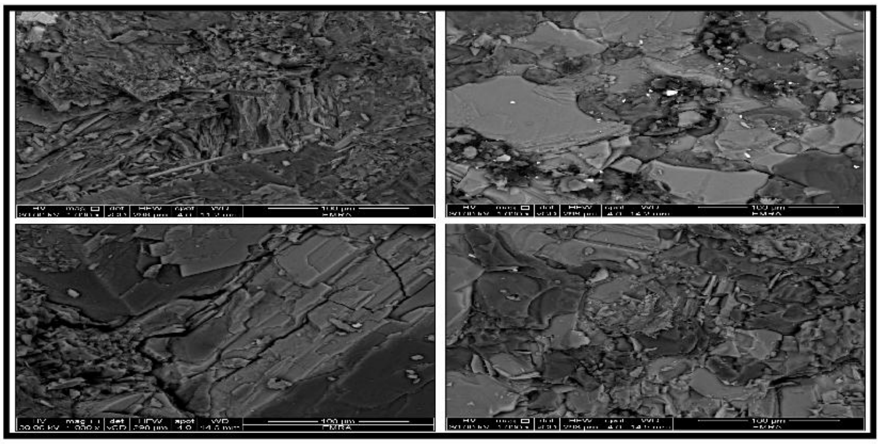
Figure 15: Granular Disintegration (Medium to Small) in the Study Area



Source: The researcher's photography, 2017.

Figure 16: Granular Disintegration (Medium-sized to Small-sized Grains) in the Study Area

- **Fine-sized grains:** Figure 17 shows the spread of fine disintegration in the fabric of highly crystalline mica rich in potassium, feldspar and biotite, as a result of the activity of weathering processes, and the transformation of many of the original rocks into other minerals as previously mentioned. These new minerals have weak resistance to weathering processes. Figure 15 shows that there are some traces of separation of quartz crystals, in addition to an increase in the density of cracks that take multiple directions and many of them are intersecting, which helped weaken the rock until it ends up disintegrating, forming very fine sediments in the slope talus.



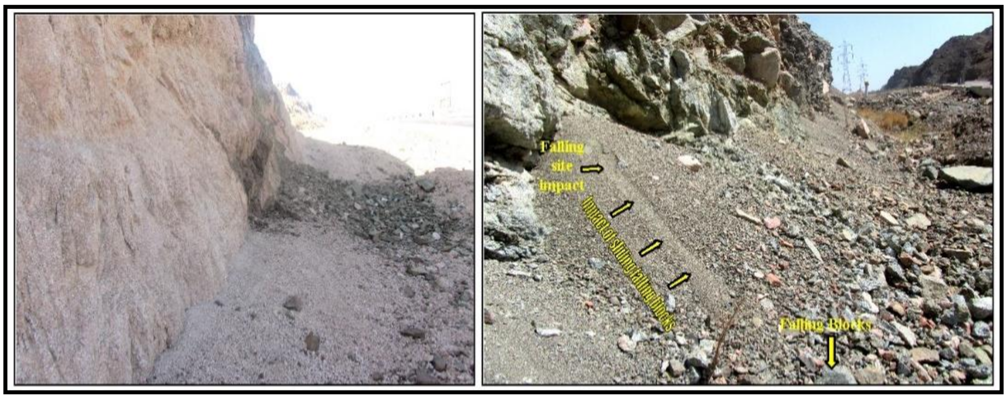
Source: The analysis is conducted in the General Petroleum Company laboratories, 2017.

Figure 17: The Spread of Fine Disintegration in the Minerals Forming the Rocks of the Study Area

3.2. Material Movement Patterns

The movement of materials varies in the study area, as there are all patterns, which are as follows:

- Fall is not only limited to large rock blocks, but also includes small-sized debris. It refers to any free fall that transports material from the top of the slope towards the bottom, without the material contacting its surface, in a sudden and very rapid movement, settling at the bottom of the slope and forming slope talus (Goudie *et al*., 2005). Fall has been observed in all locations, where the phenomena of falling large blocks and the process of granular disintegration are widespread. The explanation for this is that block fall occurs on slopes whose slopes exceed 70 degrees (Norris *et al*., 2008), which in turn made the sediments of talus cones in the study area mostly heterogeneous (Figure 18). This is mainly due to the shattering of the rock blocks when they collide with the surface of the earth, transforming into parts smaller than the original size of the falling blocks. These blocks are characterized by being sharp-angled.
- Block slide on slopes is characterized by a high degree of slope, while debris slide is the sliding of large quantities of debris from the top of the slope towards the bottom, and it occurs on slopes whose degree of slope ranges between 15 and 40 degrees (Ashour *et al*., 2016). The field study reveals that there are some traces that show the presence of rockfall at the top of a talus cone, then a process of slide with the help of fine sediments, until the rock blocks settle at the bottom of the cones (Figure 18).
- Talus creep is a form of slow movement that is able to repose on slopes if their slope is less than 35° (Al-Husseini, 1998). As the accumulation of debris increases, they push each other towards the feet of the slopes. The quantities of these clastic materials and the sizes of their sediments vary. They were observed in all slopes of the study area covered by talus, with more than 50% of the slope area, and in large quantities of medium sizes interspersed with fine sediments.



Source: The researcher's photography, 2017.

Figure 18: The Impact of the Fall Process and the Movement of Materials on the Sizes of Slope Talus in the Study Area

3.3. Area

The analysis of Table 6 and Figure 19 shows the following:

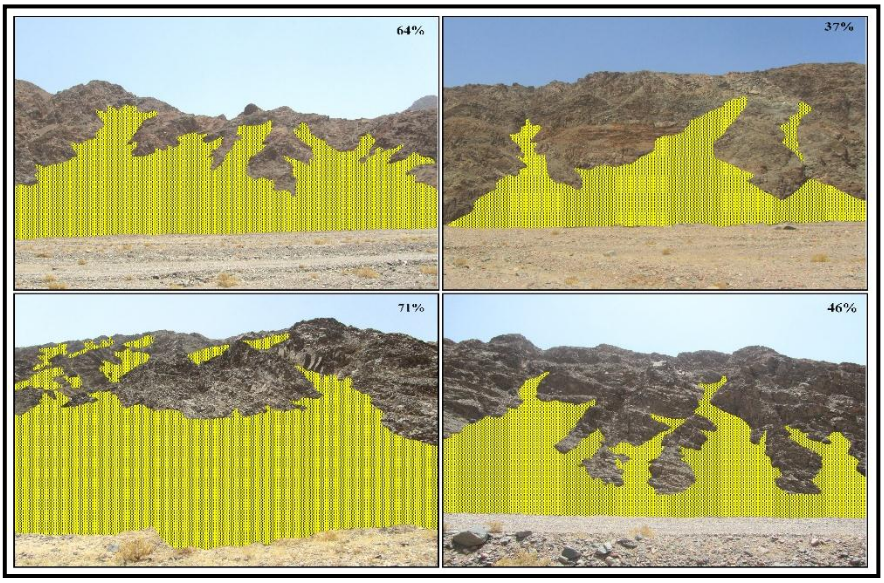
- Slopes with talus covers exceeding 60% of the slope area were observed in 9 areas. One of the southernmost slopes of the study area observed was almost completely covered with talus covers, as they reached 95% of the total slope area.
- Slopes with talus covers ranging between 30 and 60% of the slope area appeared in 9 areas as well, particularly in the north of the study area.
- Slopes with talus cover less than 30% of the slope area were observed in all areas except the first area, which is located in the far south of the study area.
- Slopes devoid of talus covers were also observed, but this does not mean that they are devoid of talus cones underneath. They appeared in some areas characterized by a high degree of slope and were found in 6 areas, particularly in the north of the study area.

It is evident from the previous analysis that the areas covered by talus covers on their slopes dominate at a percentage of less than 30% of the slope area, followed by areas that exceed 60%, then areas that range between 30 and 60% of the total slope area. They appeared in all areas with their percentage varying between one area to another.

Table 6: Percentage of Areas Covered by Talus Covers on the Slopes of the Study Area

Area	Location	Less than 30%	30%-60%	60% or more	Zero
1	4	0	1	1	2
2	6	1	2	3	0
3	7	4	0	1	2
4	3	2	0	0	1
5	3	1	1	1	0
6	7	3	1	3	0
7	5	2	1	2	0
8	5	2	0	3	0
9	9	2	3	4	0
10	5	2	2	1	0
11	15	3	5	3	4
12	5	2	1	0	2
13	4	2	0	0	2
Total	78	26	17	22	13

Source: It is based on the field study.



Source: The researcher's photography, 2017.

Figure 19: Models of Slopes Covered by Talus in the Study Area

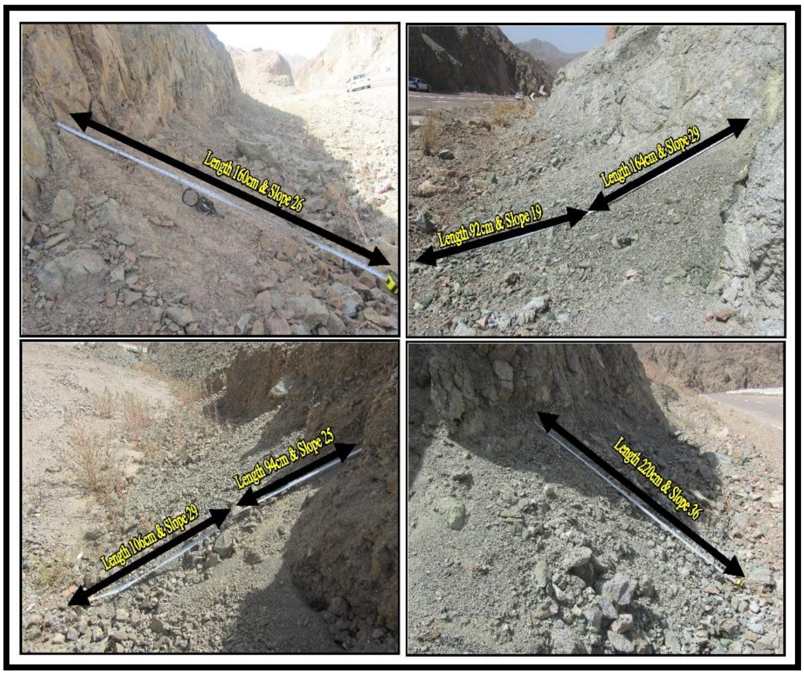
3.4. The Slope Degree of Talus

Talus covers are an integral part of the slope, and therefore the degrees of slope that were previously calculated express the degree of slope of the talus covers. Accordingly, the focus in this part is on studying the degree of slope of only the talus cones that are not connected to the talus covers (Figure 20). The following is indicated:

- Most talus cones consist of one slope unit, and the rest consist of two units. Often there are a long unit, represented by the upper part of the cone; and a short unit, represented by the lower part.
- The dominant pattern is the spread of straight sections, due to the fineness of the debris and the continuous fall processes.
- Degrees of slope fall into only three categories: moderate, extremely steep, and cliffs.
- The percentage of extremely steep slopes is high, reaching 48.5% of the total lengths, and its characteristic angle is 25°.
- The percentage of moderate slopes is 34.0% of the total lengths, and its characteristic angle is 23°.
- Cliffs cover 40° or more of the remaining percentage of the degrees of the talus cones, as their percentage does not exceed 17.5% of the total lengths, and their distinctive angle is 40°.

3.5. Volumetric Characteristics of Sediments

Sediments are characterized by certain characteristics in terms of size and shape, whether along their horizontal or vertical extension (Figure 21). These characteristics can be studied as follows:



Source: **Source:** The researcher's photography, 2017.

Figure 20: Variation in the Degree of Slope of Talus Cones in the Study Area

3.5.1. Degree of Homogeneity:

Based on the degree of homogeneity of the sizes of the talus sediments, it was found that there are three types of homogeneity of the phenomenon grains in the study area as follows:

- **Talus of homogeneous sediments**: It is limited in the study area and spreads in the center of the study area, particularly the eastern edge, where a slight variation in sediment sizes is noted. It is associated with fine sediments and spreads on the slope, forming talus covers and cones as a single block.
- **Talus of semi-homogeneous sediments:** It is prevalent in talus covers. It has been shown that there is a difference in the sizes of the sediments, but with a certain predominant size. Moreover, the majority here are the large sizes, which take a cylindrical shape whose length does not exceed 15 cm, and their average width is 5 cm. The reason for this shape is the spread of perpendicular cracks, so some large blocks appeared on the talus covers.
- **Talus of heterogeneous sediments:** It is spread only in talus cones. It has been observed in many locations, particularly in the north of the study area. The size of the sediments ranges from very fine to blocks.

3.5.2. Degree of Classification:

The classification process appears in talus cones more than in talus covers. Comparing the sizes of sediments at the tops of the cones with those in the lower parts, a gradation in the size of the sediments was observed. This is mainly due to the fact that boulders and large blocks descend quickly towards the feet of the edges, topped by medium blocks, pebbles and grits, while sand sediments and fine dust cover the tops of the cone (Figure 22).

3.5.3. Form of Sediments:

Most talus cover sediments tend to have a sharp or semi-sharp shape, due to the short distance they are exposed to during transport operations. Besides, the fall process plays an effective role in the spread of this type due to the shattering of rock blocks when they collide with the surface of the earth, transforming into parts smaller than the original size of the falling blocks, which in turn turns them into fragments. These blocks are characterized by being sharp-angled

3.5.4. Thickness of Sediments:

Talus spreads over slopes in large quantities, which has increased its vertical extent. The greatest thickness of sediment in the measured locations ranged between 1.0m and 2.40m, noting that this thickness gradually decreases until it disappears completely towards the top. It is inferred from the succession of these layers that the deposition of the sediments of these cones was not uniform. Sometimes it is somewhat homogeneous, ranging from fine to medium, as is the case in the center of the study area. Other times, it is heterogeneous, with a certain dominant size, particularly medium-sized sediments of sharp angles.

Source: The researcher's photography, 2017.

Figure 21: Variation in the Size of the Sediments of Slope Talus (Covers and Cones) in the Study Area

Source: The researcher's photography, 2017.

Figure 22: Thickness of Sediments of Talus Cones in the Study Area

4. Results

The most important results can be summarized as follows:

- There is a clear predominance of schist rocks, igneous clastics, monzogranite, and granite, with great variation in the minerals that make up them, and their influence by tectonic factors and weathering processes, particularly mechanical ones. This has led to the presence of compression in the texture of the minerals, and an increase in secondary porosity that did not form with the formation of the rock itself, but as a result of weathering processes, particularly since the specific density of the rocks is medium. This, in turn, helped in their fragmentation and disintegration to form sediments of talus covers and cones.
- Joints and fractures spread with high density and in multiple directions, particularly in granite and schist rocks, with a very high degree of foliation. Therefore, they are considered weak points in the rocks, resulting in the formation of debris of different sizes.

- The impact of climate is evident in weakening rocks. There is no doubt that the change in temperature and solar brightness has directly affected the activity of the mechanical weathering process, particularly with the decrease in relative humidity. It is worthy of notice that the presence of humidity in the winter helps the activity of the chemical weathering process, transforming the basic minerals that make up the rocks into other minerals whose resistance is very weak to erosion and weathering factors and disintegrating rocks and turning them into fine grains. Despite its small amount, rain has an impact on weakening the rocks, as it helps plants grow in the rocks, particularly since the rocks of the study area have the ability to absorb water. This growth has a mechanical impact that helps widen the joints and fractures and then disintegrate and fragment the rock. Moreover, heavy rain may fall sometimes, bringing with it the talus to be deposited at the feet of the slopes.
- Slope talus is formed through basic processes, namely disintegration, block separation, exfoliation, and granular disintegration, which is observed in almost all locations. The phenomenon of talus prevails in all areas, with its percentage varying from one area to another. It is indicated that there is a predominance of areas covered by talus covers on their slopes with less than 30%, followed by areas with more than 60% of the total slope area. Most talus cones consist of one slope unit, and the rest are composed of two slope units. The prevailing pattern is the spread of straight sections, and the degree of slope falls into three categories: moderate, severe, and cliffs.
- The degree of homogeneity of the talus sediments varies. Some sediments are homogeneous, which are limited to the study area; some are semi-homogeneous, which are prevalent in talus covers; and some are heterogeneous, which are spread only in talus cones. The slope talus consists of a different group of sediment sizes, ranging from very fine to rock blocks. In addition, the classification process appears more in talus cones than in talus covers. It is observed that the sediments range from very fine sediments at the top to pebbles and boulders at the edges, and most sediments tend to have a sharp and semi-sharp shape. Furthermore, the slope talus is spread in large quantities, which has led to an increase in its vertical extent, noting that this thickness gradually decreases until it disappears completely towards the top in the study area.

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