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Age Estimation of Qara Chattan Landslide, Using Exposure Dating Method, Sulaimaniyah, Northeast Iraq

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Abstract

The northeastern part of Iraq; the Kurdistan Region is a mountainous area with rough topography that increases in relief differences and roughness towards north and northeast. Among those mountains is Pera Magroon with highest peak at elevation of 2773 m (a.s.l.) and relief difference with the southern plain of about 1000 m.

Pera Magroon Mountain represents a double plunging anticline trending NW – SE; with many minor complications on both limbs. The oldest exposed rocks in the anticline belong to Late Jurassic, whereas the rocks of the Qamchuqa Formation form the carapace of the mountain. The southwestern limb is steeper than the northeastern one; almost being vertical.

A very old and large landslide had occurred along the southwestern limb of Pera Magroon anticline ended near Qara Chattan village; therefore, it is called "Qara Chattan Landslide". The landslide is a rock slide type with rectangular tongue-shaped and crescent-like toe area. The slid blocks belong to Qamchuqa Formation, range in size up to 3 m3; but the average size is about 1 m3.

The Qara Chattan Slide had happened; most probably above an area that was originally an old alluvial fan. The slid mass has swiped the alluvial fan sediments as the large blocks were moving in very high speed down the slope during the sliding. However, on both sides of the landslide the remnant of the alluvial fan sediments can be seen in form of longitudinal and narrow masses; like embankments.

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To estimate the age of Qara Cahttan Landslide, the exposure dating method is used depending on the size, depth and length of the existing valleys, the age of the nearby landslide and alluvial fans, and historical data acquired from archaeological site.   Accordingly, the age of the landslide is estimated to be few thousand years; during the Holocene.
Keywords: Landslide, Alluvial fan, Pera Magroon anticline, Kurdistan, Iraq

1 Introduction

1.1. General

The northeastern part of Iraq; the Kurdistan Region is a mountainous area with rough topography that increases in relief differences and roughness towards north and northeast. Among those mountains is Pera Magroon, which is located northwest of Sulaimaniyah city; with length of about 25 Km; width of 3. 5 Km and highest peak of 2773 m (a.s.l.), the relief difference with the southern plain is about 1000 m.

A very old and large landslide had occurred along the southwestern limb of Pera Magroon anticline ended near Qara Chattan village; therefore, it is called "Qara Chattan Landslide".

The study area is located in Sulaimaniyah Governorate, about 29 Km northwest of Sulaimaniyah town, north of the main Sulaimaniyah – Dukan road, near Zaiwi gorge (Fig.1).

Fig.1: Flash Earth image of the study area

The main aim of this study is to estimate the age of Qara Chattan Landslide using the Exposure Dating Method [1], besides revealing the reason of the sliding, origin of the existing embankments on both sides of the slid mass and type of the mass movement.

1.2. Previous Studies

Studies concerning the concerned landslide are very rare; however, as general mass movements' studies are concerned in the area; few are present. Hereinafter, are some of those studies that deal with Qara Chattan Landslide.

[2] studied the Qara Chattan Landslide and presented detailed data about the landslide including the type, reasons, geometry and morphological data.

[3] presented a detailed study about Qara Chattan Landslide; it is well documented. They described the mass movement as "the failure is rockslide; near Qara Chattan village and therefore, they called it "Qara Chattan Landslide". The slid rock debris now rested on a gently sloping plain near the village and forming tongue like hill about 50 m high". They also gave a detailed description of the landslide with a geological map of the site. The estimated weight of the slid mass is about 200 million tons with coverage area of about 2 Km2. They also gave stratigraphical, geomorphological, hydrogeological and structural evidences for the landslide, which they describe it as a planar slide.

[4] conducted a geological hazards study of the whole Iraqi territory and considered the area of Qara Chattan Landslide as Active Mass Movement zone.

[5] compiled the Geological Hazards Map of Iraq and considered the area of Qara Chattan Landslide as Unstable Mass Movements Zone.

[6] compiled the Geological Hazards Map of Sulaimaniyah Quadrangle at scale of 1:250000 and presented Qara Chattan Landslide on the map, but without mentioning the details, due to the scale limitations of the map.

[7] conducted detailed geological mapping of Pera Magroon area and northwards, they mapped the landslide but without giving the details.

1.3. Materials and Methods

In order to achieve the main aim of this study, which is to estimate the age of Qara Chattan Landslide and main causes, the following materials were used:

- Topographic and geological maps of different scales of the studied area.
- Google Earth and FLASH Earth images.
- Historical data about the archeological site in the crown area of the slide.
- Field observation data.

Using the available topographical and geological maps of different scales with the help of FLASH Earth and Google Earth images, the parameters of the landslide were measured. Field work was carried out during September 2016 to check and map the exact limits of the landslide, to record significant parameters of the landslide, crown area, shear plan and other interested data.

Because the landslide is very old; therefore people from Qara Chattan village were not asked about the landslide age and/ or the age of the grown trees surrounding the slid mass and its top. The age of the village is about 150 years.

2. Geological Setting

The geomorphology, structural geology and tectonics, and stratigraphy of the study area are given briefly; hereinafter, depending mainly on best available data [8,9,10,11].

2.1. Geomorphology

The main geomorphological units in the studied area are:

- **Anticlinal Ridges:** The well bedded massive carbonates of the Qamchuqa Formation have formed obvious anticlinal ridges along the southwestern limb of Pera Magroon anticline. They exhibit different mass movements' phenomena.
- **Alluvial Fans:** Many large alluvial fans are developed in the study area and near surroundings among them are a very large alluvial fan called "Zaiwi Alluival Fan" (Fig.1).
- **Flat Irons:** These are well developed due to the thickly well bedded and massive carbonates of the Qamchuqa Formation (Fig.1). Their height and widths range from (150 – 550) m and (100 – 500) m, respectively (Fig.2).
- **Mass Movements:** Many small phenomena occur in the study area, like toppling and rock fall, beside the main landslide (Figs.3, 4 and 5), which is concerned in this study.

Figure 2: Giant flat irons along Pera Magroon anticline

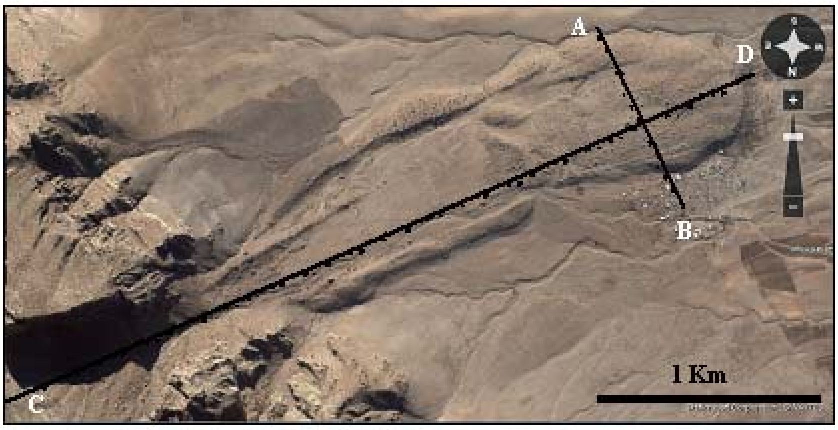

Figure 3: Flash Earth image, facing south showing the Qara Chattan Landslide.
(A – B is a cross section to show the curvature of the slid mass,
and C – D is longitudinal cross section

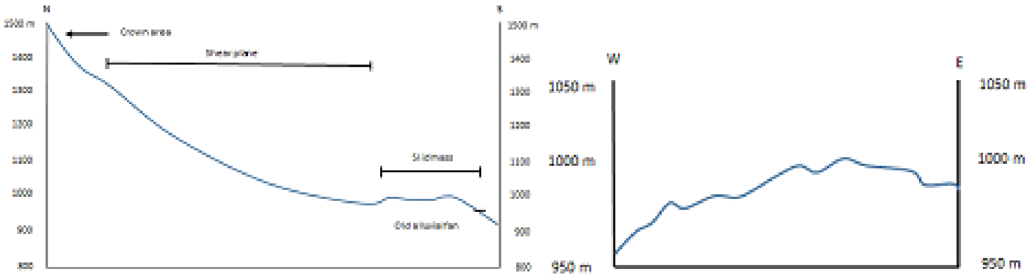

Figure 4: Qara Chattan Landslide, **Left)** Longitudinal cross section (1.9 cm = 1 Km),
Right) Cross section in the slid mass (3.8 cm = 1 Km)

2.2. Structural Geology and Tectonics

The study area is located on the southwestern limb of Pera Magroon anticline, which is a NW – SE trending double plunging anticline. The length is 25 Km, whereas the width ranges from (2 – 5.5) Km. The southern limb is very steep; up to 85°, whereas the northeastern limb is very gentle; not more than 20°;

therefore, the the anticline shows acute asymmetry (Figs.1 and 5). This acute asymmetry has formed many wine glasses; like Zaiwi Wine Glass (Fig.5) in the anticline with very steep valleys; some of them are canyon like; such as Zawiw Gorge (Fig,5); consequently, giving the possibilities of different mass movement phenomena.

Tectonically, the studied area is located within the High Folded Zone of the Outer Platform (Unstable Shelf) of the Arabian Plate [10]. The zone is characterized by narrow and long anticlines with wide and shallow synclines. Some of the anticlines exhibit thrust faulting; where the northeastern limb is thrusted over the southwestern one or the northern limb is thrusted over the southern one.

Fig.5: Google Earth image facing south showing the acute asymmetry of Pera Magroon anticline. QCL = Qara Chattan Landslide, ZG = Zaiwi Gorge, ZWG = Zaiwi Wine Glass, ZAF = Zaiwi Aluuvial Fan. Formations: S = Sarmord, Q = Qamchuqa, K = Kometan. = Limits of water basin of the Qara Cahttan Alluvial Fan

2.3. Stratigraphy

The following formations are exposed in the study area (Fig.6); the main lithology is quoted from [7,11]. Other formations; however, are exposed too, but have no significant importance on the concerned landslide.

- **Sarmord Formation** (Lower Cretaceous)**:** The formation consists of alternation of well bedded limestone, dolostone and marl, it forms gentle – steep slopes; on the anti-dip side (Fig.5).

- **Qamchuqa Formation** (Lower Cretaceous)**:** The formation consists of thickly well bedded, massive dolostone, dolomitic limestone and limestone, it forms steep – very steep slopes; towards the dip direction (Figs. 3 and 5).
- **Kometan Formation** (Lower Cretaceous)**:** The formation consists of thinly well bedded white marly limestone, and rare marl, it forms gentle – steep slopes towards dip direction (Fig.5).

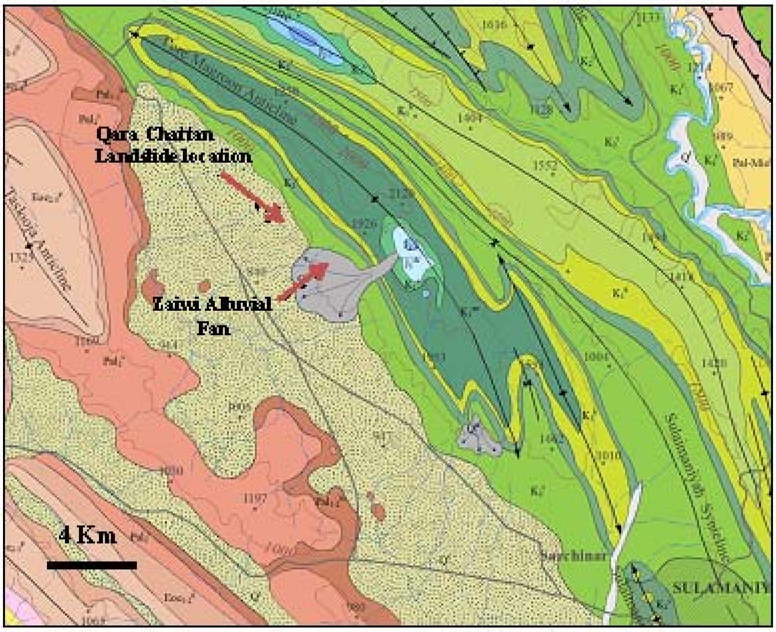

Figure 6: Geological map showing the location of the studied section (After Sissakian and Fouad, 2012). Geological formations: K_1^q = Sarmord and Qamchuqa, K_1^k = Kometan, K_2^s = Shiranis and K_s^t = Tanjero

3. Characters of Qara Chattan Landslide

Qara Chattan Landslide was well documented and described by [2] and [3]; they all gave detailed description for the geometry of the landslide, its type and causes. The present authors; however, presented their own acquired data about the geometry of the landslide and its causes. Since more detailed satellite images are used in the current study, which were not available to [2] and [3]; therefore, the current authors have studied the landslide in different perspectives.

3.1. Geometry of Qara Cahttan Landslide

The Qara Chattan Landslide has occurred along the southwestern limb of Pera Magroon anticline (Figs. 1, 3 and 5). The landslide is a rock slide type with rectangular tongue-shaped and crescent-like toe area; the length is about 1190 m; the width is about 474 m and the coverage area of the slid mass is about 564060 m^2. If an average thickness of 3 m is considered for the slid mass; then the estimated volume of the slid mass will be 1692180 m^3. The moved distance; up to the toe area is about 2610 m (Fig.2). The height of the scar's bottom is 1260 m (a.s.l.); whereas, the height at the bottom of the toe area is 927 m (a.s.l.), which means the gradient of the landslide is 12.75 %. The height at the top of the slid mass is 1063 m (a.s.l.); therefore, the gradient of the slid mass is 11.43 %. The length of the crown area is 877 m; the heights of its eastern and western sides are 1755 m and 2007 m, respectively; whereas the middle part is at height of 1762 m. The downslope length of the crown is 1185 m; therefore, the gradient of the crown is 69. 78 %.

3.2. The Crown Area

The crown area of Qara Chattan Landslide is large; since its length is 877 m, with two side cliffs (Fig.7). The indications for sliding on the crown area are almost vanished because it is very old landslide; however, the eastern cliff is still clear and active area for toppling and rock fall of small blocks (Fig.7, Left). When comparing the shape of the remained main cliff and side cliffs, and the developed hallow below the cliffs with other neighbouring cliffs; then it is very clear that a very large mass had slid downslope (Fig.7).

In the lower part of the crown area, coarse grained well cemented clastics occur (Fig.8, Left); most probably they belong to an old alluvial fan that was radiating from a valley through which the landslide had occurred. Moreover, some solution caves occur too indicating the presence of accumulated water in the site (Fig.8, Right). This was also recognized and confirmed by [3].

Fig.7: **Left)** Google Earth image facing south showing the crown area and side cliff of Qara Cahttan Landslide, **Right)** Photo from the crown area [3]

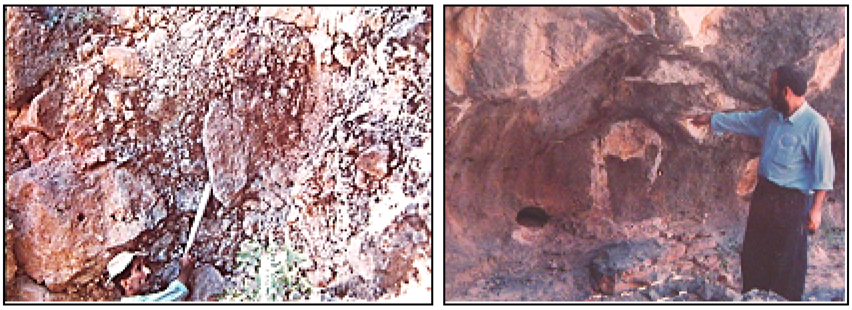

Fig.8: **Left)** Coarse grained sediments; most probably of an old alluvial fan, in the outlet of the fan, **Right)** Solution cave in the crown area (Both photos are after [3].

3.3. The Slid Mass

The slid mass of Qara Chattan Landslide is a longitudinal mass; tongue shaped with crescent shaped toe area. The length is about 1190 m; the width is about 474 m and the coverage area of the slid mass is about 564060 m^2 (Figs.9 and 10). The slid blocks belong totally to Qamchuqa Formation, of dolomite, limestone and dolomitic limestone. The blocks range in size up to 3 m^3; very rarely more, but the average size is about (< 1 – 1) m^3, usually without any cement; with subrounded forms. However, some smoothening can be seen on the blocks due to weathering and erosional processes that have been acting on the blocks for long period of time. They are randomly distributed on the top of the slid mass; but, are more concentrated at the beginning of the slid mass and on its last third part; before the end of the mass, especially the large blocks (Fig.9). The maximum height on the top of the slid mass is 1063 m (a.s.l.) (Point 1, Fig.3), the height at the end of the slid mass is 951 m, (Point 2, Fig.3). The height difference in the toe area with the surrounding plain is 17 m.

The eastern side of the slid mass is partly limited by a valley (E V in Fig.9) that runs from Pera Magroon Mountain and merges into Zaiwi valley, which flows out of Pera Magroon Mountain through Zaiwi Gorge (Fig.3). This valley is older than the landslide, since it started to erode the eastern limits of the slid mass. Along the western side of the slid mass, a small valley is developed (W V in Fig.9); it started eroding the shear plane and part of the slid mass. This means the valley is younger than the landslide.

Along the slid mass (Fig.9), some clean flat areas can be seen, these are area cleaned by the local people of Qara Chattan village and used for agricultural purposes.

3.4. The Shear Plane

The shear plane of Qara Chattan Landslide is very clear (Figs. 3, 5 and 9). The slid mass has left a distinct shear plane, especially out of Pera Magroon

Mountain along the slope. The plane is clear from rock blocks; except recently fallen blocks that can be seen in the beginning of the plane (Figs. 7, 9 and 11). This is a good indication that the slid mass had swept during sliding all existing rock blocks leaving a bare soil. The upper part of the shear plane, which is along Sarmord and Qamchuqa formations is also clear one; without remaining of the original slid mass. However, recently fallen blocks from the crown and side cliffs can be seen.

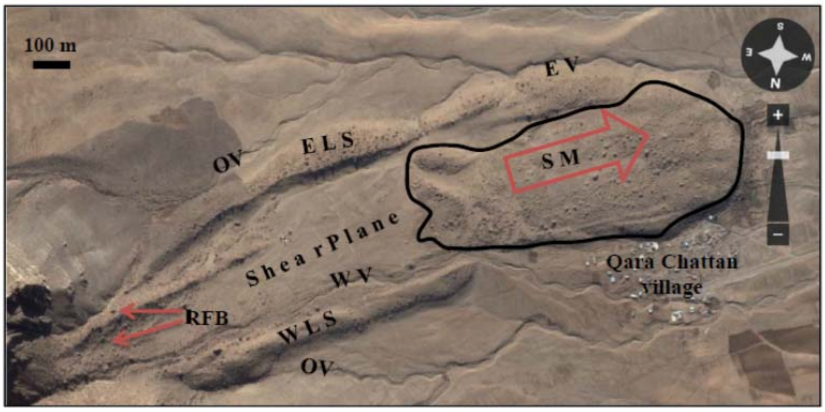

Fig.9: Flash Earth image facing south showing the slid mass (**SM**), the Eastern longitudinal strip (**ELS**), Western Longitudinal Strip (**WLS**), eastern valley (**EV**), western valley (**WV**), recently fallen blocks (**RFB**).
Note the concentration of the large blocks on the top of the slid mass

Figure 10: Top view of the slid mass. Note the status of the weathering of the blocks

3.5. The Longitudinal Strips

The Qara Chattan Landslide has happened; most probably above an area that was originally an old alluvial fan. The slid mass has swiped the alluvial fan sediments (Fig.12) as the large blocks were moving in very high speed down the slope during the sliding. On both sides of the landslide; however, the remnant of the alluvial fan sediments can be seen in form of longitudinal and narrow strips; like embankments (Figs. 3, 9 and 13). The length of the eastern strip is 1365 m, whereas the western one is 1002 m, the width of both strips ranges from (30 – 100) m. The height of the two longitudinal strips ranges from (3 – 7) m.

Figure 11: A recently fallen block, in the back ground the crown area and the eastern cliff can be seen

To show the height of both longitudinal strips, which are developed on both sides of the slid mass (Figs.3 and 9), the height of different points are measured along a cross section (A – B, in Fig.3), and another longitudinal cross section is drawn to show the morphology of the scar area, shear plane and the slid mass (Fig.3) The height of both longitudinal strips decreases towards the slope. The maximum height difference towards the slid mass is on the eastern strip; it is 7 m, whereas on the western strip is 3 m. The maximum height difference towards out of the slid mass is on the eastern strip; it is 17 m, whereas on the western strip is 15 m.

Figure 12: Alluvial fan sediments. **Left)** Coarse grained sediments along the longitudinal strips, Right) Fine sediments on the top of the fan (below the slid mass)

Figure 13: Part of the eastern longitudinal strip (ELS)

3.6. The Toe Area

The toe areas of both the old alluvial fan and that of the slid mass almost coincide to each other (Fig.14). The blocks of the toe area of the old alluvial fan consist of coarse breccia; the fragments are either small in size of angular form or are large in size of subrounded limestone of the Qamchuqa Formation (Fig.15).

Figure 14: The toe area of the old alluvial fan (TAF) and that of the slid mass (TSM)

Figure 15: Toe area of the old alluvial fan, **Left)** The fine fragments (FF). **Right)** The coarse fragments (CF)

4. CAUSES OF QARA CHATTAN LANDSLIDE

In Qara Chattan Landslide, multiple causes had developed the landslides; these are explained hereinafter.

4.1. Geological Causes

Among these causes are the presences of thickly well bedded carbonates of the Qamchuqa Formation (Fig. 16) underlain by limestone and marl beds of the Sarmord Formation that have played as slippery materials for sliding after being saturated by rain water and after ice melting. Moreover, the presence of joints and bedding planes and fractures, all have acted as weakness zones, besides being good passage for the rain water in between the weakness zones. During wet climate, the presence of open cracks, fishers and joints; all were filled with weathered materials, which formed slippery plains and have triggered and accelerated the sliding.

The carbonates of the Qamchuqa Formation are highly deformed (Fig.16); locally, fractured and faulted; consequently, weakness planes are developed that have been accelerated the sliding due to breaking of the massive beds into small blocks that have lost their equilibrium due to increasing of the pore water pressure, which can happen due to decreasing of the internal friction angle [12].

4.2. Morphological Causes

Among morphological causes, the main one is the fluvial erosion by the rain water, besides the freeze-and-thaw weathering (Fig. 8, Right) and shrink-and-swell weathering. All these factors have played significant role in triggering of the sliding. Moreover, the steep slopes (Fig.7), which are higher than the dip angle of the beds, have developed day light slopes (Fig.17) that were easily triggered and accelerated the sliding.

Figure 16: Qamchuqa Formation in Zaiwi gorge.
Note the intense bedding and highly deformed beds

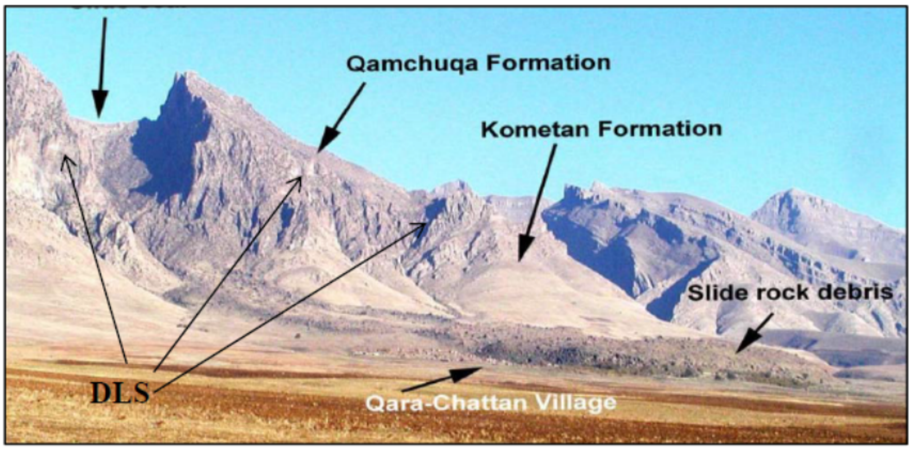

Figure 17: Qara Chattan Landslide after Ahmed et al., 2000). DLS = daylight slopes

Among other morphological causes that have contributed in the sliding is the drainage basin of the previously existing alluvial fan in the area (Fig.5), in which 3 main valleys were draining (1, 2 and 3, in Fig.5). Most probably the amount of the collected water in the water basin was more than that can be drained out through the outlet of Qara Chattan Alluvial Fan; therefore, weight of the collected water was acted on the rocks of both sides of the outlet that was acting as a natural barrier and couldn't hold the force; consequently, the sliding might had happened in the already deformed and bedded rocks of the Qamchuqa Formation.

4.3. Climatical Causes

From the presence of many alluvial fans near surroundings of the landslide area and most probably even in the place of the landslide, it is obvious that the climate was wet with heavy rainfall that have developed all those alluvial fans (Figs. 1, 2, 3, 5, 6, 8 and 9), even forming Bajada in particular areas (Fig.1); along the limbs of Pera Magroon anticline. The outlet of the alluvial fan was narrow (Fig.7); carved in the massive carbonate rocks of the Qamchuqa Formation; underlain by soft marl beds alternated with hard carbonate beds of the Sarmord Formation. The presence of: **1)** ice formed caves in the outlet area, which was replaced as the crown area of the landslide (Fig.7, Right), **2)** curved U-shaped form below the crown area (Fig.8, Right), and **3)** presence of coarse clastic alluvial fan sediments in the crown area (Fig.8 Left), all these aspects are good indication that the outlet of the alluvial fan was blocked by water and ice. Consequently, the internal friction angle was decreased by increasing of the pore water pressure[12]; therefore, the whole mass of the uppermost part of the alluvial fan with the carbonate rocks of the Qamchuqa Formation were slid down, sweeping the already existing alluvial fan down the slope. However, on both sides of the slid mass; longitudinal strips (Figs. 9 and 13) still exist.

5. PRECAUTIONS and LANDSLIDE CONTROL

As in each mass movement phenomenon, Qara Chattan Landslide area is a prone area for different types of mass movements, especially landslide, toppling and rock fall (Fig. 9). It is worth mentioning that in each old landslide area, new mass movements are expected [13,14,15,16].

For each type of mass movement, there are certain types of precautions to control the movement [13]. In Qara Chattan Landslide, the most reliable process to control and stabilize the unstable slopes is digging a ditch surrounding the upper part of the landslide and near surroundings. This assumption is attributed to the fact that Qara Cahattan Landslide is of block-slide type with the presence of daylight slopes; due to deformed beds and intensely jointed, fractured and well bedded carbonates (Figs. 16 and 17). However, since the area is not habituated, apart from Qara Chattan village; therefore, the mentioned step is not necessary to be performed urgently.

6. DATE ESTIMATION

To estimate the age of Qara Cahttan Landslide, the exposure dating method [1] is used depending on: **1)** the size, depth and length of the existing valley, **2)** the age of the nearby landslide, **3)** the age of the present alluvial fans, and **4)** the weathering status of the slid blocks within the slid mass, and **5)** historical data.

6.1. Drainage system

In reviewing thoroughly the slid mass of the Qara Chattan Landslide (Figs. 9 and 18), it is clearly seen that a new valleys started to be developed on the shear plane as well on the top of the slid mass. The shear plane as well the top of the slid mass should be free from drainage system, because in the former case all existing valleys were cleared and/ or filled during the sliding. Whereas the top of slid mass also should be clear or free from the drainage. This is attributed to the fact that the top cover of the slid mass is a recently developed mass; therefore, no drainage would be on the top. However, in both cases; the shear plane and the top of the slid mass are not free from drainage and started to exhibit fine rills (Fig. 12, example at points 1, 2, 3, 4 and 5) indicating the effect of the water erosion on both surfaces. Certainly, development such rills will need thousands of years.

When comparing the size and the depth of the old valleys along both sides of the slid mass (OV in Fig. 9) with those developed on the shear plane (EV and WV in Fig.9), it can be seen that clear differences exist. This means that the valleys developed on the shear plane of the landslide are younger than those valleys that exist on both sides of the slid mass, which are almost early Holocene in age.

Figure 18: Google Earth image facing south showing the details of the slid mass

6.2. Shape and Type of the Sediments of the Alluvial Fan

The shape of the old alluvial fan is still clear, especially on both sides of the slid mass (ELS and WLS in Fig. 9and 13). The weathering status of the longitudinal strips when compared with the weathering status of the slid mass;

clear difference can be recognized between them. This means that the landslide has happened after the development of the alluvial fan, which is usually during upper Late Pleistocene up to early Holocene [17,18]. Moreover, the type of the sediments within the alluvial fan differs also. Along the outer rims of the alluvial fan which are left as longitudinal strips (Figs. 9 and 13). The sediments are highly cemented in form of calcrete (Fig. 12, Left), due to long time of exposure to weathering and climatic changes. In contrary, those sediments which were covered by the slid mass are still not well cemented (Fig.12, Right). This is attributed to being covered and protected from weathering and climatic changes.

6.3. Shape of the Slid Blocks

The rock blocks in the slid mass show clear surfaces that indicate very old departing from the original outcrops; up in the mountain. This can be seen in form of growth of small rock fragments on their lower parts due to being attached to the ground surface and the effect of capillary action on the fallen blocks (Fig.19).

Fig.19: A block within the slid mass. Note the growth of small parts in its lower part.

Another feature that indicates that the sliding has occurred very long time ago is the shape and opening size of the fractures (Fig.20). If those fractures were originally present in the rocks before sliding, then they will be parted to different blocks and not being exists within the slid mass as a one block.

Figure: 20: A large block showing the size of the fractures

6.3. Historical Data

An archeological site occurs just west of the slide area. It is dated as the first millennium B.C., which means it is more than 3000 years in age (Fig.21). According to one of the local people of Qara Chattan village many archeological indications exist even in the landslide area; like thick defence walls. This means that the site is younger than the landslide; otherwise it shouldn't exist there; it should slide down with the slid mass.

Figure 21: The shield of the archeological site that indicates the estimated age of the site

7. DISCUSSION

The main reasons of the Qara Chattan Landslide are the water, dip angle, slope angle and internal friction angle. [3] have constructed stereoscopic projection to show the relation between discontinuities, slope and type of failure in the Qara Chattan Landslide (Fig. 13). From the great circle (Fig. 22), the critical slope angles can be known; any slope face having slope angle within the critical slope angle presented in Figure (22) will slide down or will be in very critical equilibrium.

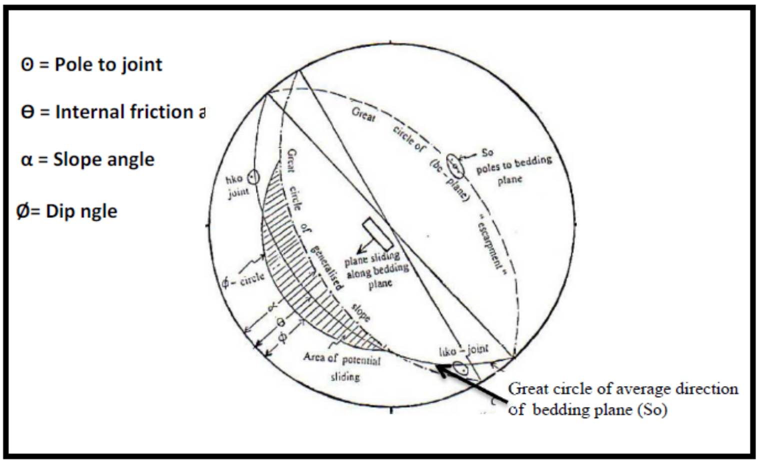

Figure 22: Stereoscopic projection showing the relation between discontinuities, slope and type of failure in the Qara Chattan Landslide (After[3])

The decrease of the internal friction angle due to increase of the pore water pressure [12], is one of the main reasons for the sliding. This is attributed to the high rainwater fall and accumulation of high amount of water in the basin of Qara Chattan Alluvial Fan. The flow rate of the accumulated water was more than the ability of the outlet of the alluvial fan's to drain the accumulated water (Fig.5). Moreover, the presence of karst forms (Fig.23); mainly sinkholes have increased the amount of the infiltrated water in the beds of the Qamchuqa Formation. The infiltrated water will contribute in decreasing the internal friction angle due to increase of the pore water pressure (Terzaghi and Peck, 1948).

The exerted forces by the accumulated water in the water basin of Qara Chattan Alluvial Fan had contributed in the sliding. This is attributed to: **1)** Short and narrow outlet of Qara Chattan Alluvial Fan as compared to that of Zaiwi Alluvial Fan (Figs. 5 and 7) and was unable to drain out the accumulated water in the basin, **2)** The presence of marl beds of the Sarmord Formation bellow the massive and thickly bedded carbonates of the Qamchuqa Formation. The former was acted as lubricant for the latter to trigger and accelerate the sliding, and **3)** The freezing of the water and presence of ice in the uppermost part of the cliff (Fig.8, Right) have contributed in the blockage of the outlet. The curved slopes of the present caves in the uppermost part of the crown area (Fig. 8, Right), the steep, straight sides and a flat bottom U-shaped form of the existing valley; after the sliding (Fig.7 Right), all are good indication that the sliding had occurred contemporaneously with ice movement, since U-shaped valleys are characteristic for ice movements [19,20].

Figure 23: Google Earth image facing south. Note the karst forms on the Qamchuqa Formation; some are encircled in red colour

As the age estimation is concerened, the most relevant estimated age is few thousands years, which means Holocene. This estimation is based on: **1)** Shape and depth of the developed valleys on the shear plane area (Fig.9) and the top of slid mass (Fig.18), **2)** The weathering status of the exsiting blocks on the top cover of the slid mass (Fig. 20), **3)** The weathering status of the longitudinal remains on both sides of the Qara Chattan Alluvial Fan (Figs. 3, 9 and 12), **4)** The differenec in the weathering status of the blocks of the toe area of the alluvial fan and those of the slid mass (Figs. 14, 15 and 24), and **5)** The existing historical data in the uppermost part of the crown area that referes to more than 3000 years.

Figurw 25: Brecciated sediments of the old alluvial fan; to the right and a normal fallen block from the slid mass; to the left.

8. CONCLUSIONS

The following can be concluded from this article:

The Qara Chattan Landslide is a block rock slide type, has happened in the massive carbonate beds of the Qamchuqa Formation. Before the sliding, there was a large alluvial fan; called in this article as Qara Chattan Alluvial Fan in the same area, their toe areas coincide to each other. The main causes of the landside are the increase of the pore water pressure and decrease of the internal friction angle, presence of marl beds within the Sarmord Formation that underlies the Qamchuqa Formation, which have played as lubricating agent, besides the blockage of the outlet of the alluvial fan. The outlet of the alluvial fan was blocked due to freezing of the water as witnessed by the ice caves, which exist below the crown area, beside the increase of the water amount behind the outlet from where the alluvial fan was radiating.

The landslide has rectangular tongue-shaped and crescent-like toe area; the length is 1190 m; the width is 474 m and the coverage area of the slid mass is about 564060 m^2, with estimated volume of the slid mass of 1692180 m^3. The gradient of the landslide is 12.75 % and the moved distance; up to the toe area is about 2610 m. The length of the crown area is 877 m; the heights of its eastern and western side cliffs are 1755 m and 2007 m, respectively; whereas the middle part is at height of 1762 m. The downslope length of the crown is 1185 m; with gradient of 69.78 %.

The age of the landslide is late Holocene; estimated to be few thousand years (more than 3000 years). This assumption is based on many aspects among them is the presence of archeological site from the first millennium B.C., the presence of old alluvial fan sediments below the slid mass, the size and depth of the developed valleys and the status of the weather blocks within the slid mass as compared to those present in the sediments of the alluvial fan.

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