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Slope Stability of theMiddle Eocene Rocks

of Gebel Mokattam

Mahmoud S.M. Yousif Department of Geology,
Faculty of Science, Ain Shams University

Abstract- The middle plateau of G. Mokattam is made up of hard limestone rocks of Middle Eocene age. The slopes of these rocks, however, show the effect of man-made activities, especially past-quarrying. For this reason, these slopes are very steep and form sheer scarps in several places. In addition, large natural caves also exist near the top of the Middle Eocene rocks of G. Mokattam as well as the area south of G. Mokattam to the east ofMaadi and Helwan.

In spite of their persistant nature, the slopes of the Middle Eocene rocks of G. Mokattam are, at present, generally unstable. A tragic slope failure occurred in Manshiet Naser area in 1993 and caused many casualties and property damage. This anthropogenically induced instability is basically being related to the presence of some vertical quarry faces dissected by inclined joints dipping toward the free side of the slope, the presence of steep undercut slopes in old quarries, random housing on top of the middle plateau close to the edge, increased pore-water pressure due to domestic water (both sewage and drinking water)leakage from the top of the middle plateau , earth vibrations resulting from large explosions in the limestone quarries of the cement factories of Tura and Helwan, instability of protruding (side) ridges between old crescent-shaped quarries, and unstable roofs of the natural caves lying close to the top of the Middle Eocene rocks. Several precautionary measures and slope treatments are recommended in order to decrease the potentiality of slope failure in this area and its adverse impact on escalating encroachment of human settlements and activities in the general vicinity.

Introduction

Gebel Mokattam is located east of Cairo and is bounded on the north by Gebel Ahmer, on the east by a gently sloping desert area leading to the New Cairo city, on the south by the Greater Cairo ring road, and on the west by the autostrade and Salah Salem road. Gebel Mokattam is a topographically high area that has a relief equal to about 160 meters. It includes two main flat-topped areas locally referred to as the middle and upper plateaus. Mokattam city was built on tto upper plateau whereas the middle plateau is the site of a large housing project that started in the 1980's and has not been completed so far. The topographically low areas surrounding G. Mokattam, especially on the west and south are areas of large urban expansion in a relatively very short period of time (Fig. 1). Manshiet Naser and El Doweiqa are two of these highly populated areas with randomly built houses (urban sprawl) on the topographically low area abutting G. Mokattam on the west and north respectively (Fig. 2). Old cemetery as well as the Abajia houses are located on the southern side of G. Mokattam.

The slopes bounding the upper plateau of G. Mokattam are affected by several engineering problems represented mainly by slope failure posing a real threat to life and property in the Mokattam city. Such problems were dealt with by Abdel Tawab (1989) and Moustafa et al. (1991). The slopes bounding the middle plateau of G. Mokattam are mostly steep and also pose similar threat on inhabited areas surrounding G. Mokattam (Fig. 2). The main objectives of this work are: 1) studying the stability of the slopes of the middle plateau of G. Mokattam, 2) indicating the areas of potential slope failure, and 3) making recommendations for avoiding slope failure in the study area.

Geology of Gebel Mokattam

The exposed rocks of G. Mokattam have a total thickness of 166 meters (Moustafa et al., 1985), Fig. 3. These rocks are Middle and Late Eocene in age. The stratigraphy of these rocks were studied by several workers; e.g. Awad et al. (1953), Shukri (1953), Said (1962 and 1971), and Strougo (1985). The exposed Middle Eocene rocks of G. Mokattam are 77 meters thick and are composed mainly of white, hard, micritic, fossiliferous limestone with some marly limestone beds. These Middle Eocene rocks are divided into three formations which are, from base to top, the Gebel Hof Formation, the Observatory Formation, and the lower part of the El Qurn Formation. The overlying Upper Eocene rocks have brown to yellowish brown color and are 89 meters thick. They include the following formations, from base to top, the Upper part of El Qurn Formation, the Wadi Garawi Formation, the Wadi Hof Formation, and the Anqabia Formation.

The Middle Eocene rocks of G. Mokattam form the middle plateau and its bounding scarps (Fig. 4). The latter are characterized by their overall white to grayish white color and their resistance to erosion. On the other hand, the Upper Eocene rocks form the slope and upper surface of the upper plateau and are generally less resistant to erosion and form recessive slopes.

The exposed rocks of G. Mokattam have a gentle northeastward dip equal to about 3°. Moustafa and Abdel Tawab (1985) indicated that the eastern side of G. Mokattam is controlled by NW-SE oriented faults that have downthrows toward the northeast. They also indicated that the southern side of the Gebel is controlled by a WNW-ESE oriented normal fault that has a downthrow toward the SSW. This fault lies at some distance (about 1 km) from the southern scarp of G. Mokattam. The western sheer scarps of G. Mokattam that overlook the Citadel and Salah Salem road are also believed to be controlled by normal faults which are concealed under the urban area west of the Gebel. The northern part of G. Mokattam plunges underneath the Oligocene sands of G. Ahmer area. This northern part of G. Mokattam has relatively steep (about 13°) northeastward dip and is inferred to be underlain by a WNW-ESE oriented fault (Moustafa and Abdel Tawab, 1985).

From a geotechnical point of view, the Middle Eocene rocks of the middle plateau of G. Mokattam have a low-medium compressive strength equal to 40 MPa and a Young's modulus equal to 5600 MPa (Moustafa et al., 1991).

Slopes of Gebel Mokattam

The slopes of G. Mokattam are more prominent on the southern and western sides than on the northern and eastern sides (Fig. 5). Some of these slopes bound the exposed Upper Eocene rocks and others bound the Middle Eocene outcrops. The slopes of the Upper Eocene and Middle Eocene rocks differ in their shapes and angles (Fig. 6). The slopes of the Upper Eocene rocks are concave upward and are relatively gentler than those of the Middle Eocene rocks. The latter are steep to very steep, form sheer scarps, and have stair-case geometry in some places. Field work shows that the slopes of the Middle Eocene rocks of G. Mokattam are not natural and show the effect of stone quarrying. The slopes of the Middle Eocene rocks of G. Mokattam characterize the southwestern and western sides of the middle plateau as well as the northwestern part of G. Mokattam (Fig. 5). The slopes of the southwestern and western parts of G. Mokattam are marked by a single high cliff. Further north, at the latitude of the Citadel, the Middle Eocene outcrops have several slopes forming a stair-case geometry at Manshiet Naser area.

Almost all the slopes of the Middle Eocene rocks of G. Mokattam are man-made slopes formed due to the past quarrying activities. Vertical smooth slopes characterize the area east of the Citadel reflecting saw-type quarrying. At Manshiet Naser, some of the stair-case slopes are also formed by saw-type quarrying (Fig. 7). On the other hand, nearly vertical and rough slopes characterize the ^Middle Eocene outcrops extending from Abajia to the southern side of G. Mokattam and seem to have been formed by mild explosion-type quarrying.

Factors Affecting the Stability of the Middle Eocene Slopes of Gebel Mokattam

Detailed field work at G. Mokattam points to the effect of two different factors on the stability of slopes of the Middle Eocene exposures. These are past quarrying activities and caves. These two factors make some of the slopes highly dangerous and potential sites for slope failure such as the famous slope failure of 1993 leading to the collapse of a huge block of Middle Eocene rocks that fell down on some of the houses ofManshiet Naser causing a large number of casualties and property damage.

A- <u>Past Quarrying Activities:</u>

Past quarrying activities in the western and southern parts of G. Mokattam affect the stability of slopes of Middle Eocene rocks in three different ways. These are:

1. Vertical quarry walls.
2. Undercutting of the quarry walls.
3. Protruding ridges between adjacent quarries (side ridges).

1- <u>Vertical Quarry Walls:</u>

Vertical quarry walls represent potential sites of slope failure where they are affected by inclined joints dipping toward the free face of the quarry. In such cases, failure takes place only when the shear resistance (r) along the joint surface is less than the downslope driving force (D) of the block overlying the joint (Mathewson, 1981), Fig. 8. Several factors can contribute to slope failure in such cases. These are factors increasing the value of (D) and/or factors decreasing the value of (r).

According to Mathewson(1981), factors leading to the decrease in the shearing resistance along a joint surface (r) as well as the increase in the downslope driving force (D) include:

a-Removal of lateral support of rocks which is the case in the vertical quarry walls of G. Mokattam area.

b-Increased loading above the rocks which is partly taking place in G. Mokattam where some construction work has started on top of the Middle Eocene rocks in the area east ofManshiet Naser.

c-Transitory earth stresses which include the effect of lateral stresses on the rocks which takes place in case of natural earthquakes as well as in the case of relatively large, man-made earth vibrations during quarry explosions. The latter factor is actually happening in vicinity of G. Mokattam area in the limestone quarries of the cement factories of Tura and Helwan.

d-Increase in pore water pressure of rocks which happens when the rocks are continuously soaked with water in vicinity of joint surfaces. This phenomenon is common in G. Mokattam area such as the slopes north of the Abajia cemetery east of where surface water is leaking from the top of the middle plateau through the jointed Middle Eocene rocks (Fig. 9). The same phenomenon is also taking place at the Samaan church at Manshiet Naser where the church was built on top of a terrace in the western scarp of G. Mokattam. Activities in the church include cultivation and gardening work which leak some water through the limestone beds underlying the church and forming the lower scarp of this area.

2- <u>Undercutting of Quarry Walls</u>:

Undercutting of the base of the quarry walls is also another factor leading to the instability of the slopes of the Middle Eocene rocks ofG. Mokattam. Field work indicates that undercutting of these slopes could be natural or man-made. Natural undercutting of quarry walls is mostly due to the effect of jointing where an inclined joint dipping toward the quarry wall affects the basal part of the slope. Removal of the footwall blocks of this joint during quarrying leads to the development of the undercutting at the base of the slope. Man-made undercutting of quarry walls is either due to the uneven quarrying operations where more rocks are excavated from the basal part of the quarry face (Fig. 10) or due to human activities in close vicinity of the quarry walls. The latter factor includes storing and/or burning trash in vicinity of the walls of abandoned quarries. The stored trash is fermented in a short period of time leading to the formation of organic acids which react with the limestone beds underneath. Continued storage of trash leads to increased dissolution of the underlying rocks and thereby undercutting starts to develop in the quarry walls. Burning trash, on the other hand, increases the danger in the lower part of the quarry walls because the heat changes the calcium carbonates of the limestone into calcium oxide which is weaker than the limestone beds themselves and is easily removed leading to the formation of undercutting in the quarry walls.

3- Protruding Ridges Between Adjacent Quarries:

Protruding ridges between adjacent quarries represent one of the most dangerous features in the slopes of the Middle Eocene rocks of G. Mokattam. Field work indicates that old limestone quarries at Manshiet Naser had crescent shapes (Fig. 11). In each quarry the excavated area represents the inner part of the crescent. In this way, adjacent quarries are separated by a ridge of limestone left between each two adjacent quarries (Fig. 12). Figure 13 shows two ridges between three crescent-shaped quarries at Manshiet Naser area. Figure 14 shows another crescent-shaped quarry with two ridges on both sides. The inner part of the quarry was used later as a construction site and many houses were built in contact with the quarry walls and the protruding ridges.

Protruding ridges at the sides of the crescent-shaped quarries are potential areas of slope failure especially when natural or man-made causes decrease the slope stability as mentioned in a previous section. One such ridges collapsed in Manshiet Naser area in 1993 where the middle part of the ridge collapsed leaving its distal part as well as the part attached to the middle plateau (proximal part) in place (Fig. 15). The collapsed part is at least 30m long by 7 m wide by 20 m high and fell down on the nearby houses. Several quarries in the western and southern scarps of G. Mokattam have protruding ridges which represent potential failure areas like that of Manshiet Naser.

B- Caves:

The Middle Eocene rocks ofG. Mokattam and the area east ofMaadi and Helwan are characterized by the presence of large natural caves which are several tens to a few hundreds of meters in length and width and about 20-40 meters high. These caves were probably formed in past pluvial periods by dissolution although no karst deposits or karst features have been found within the visited caves probably due to later modifications for anthropogenic uses.

Five main caves are found in the Middle Eocene rocks on both sides of the Mokattam city road (Fig. 16). These caves occupy the uppermost part of the Middle Eocene section (Fig. 17). The walls of these caves seem to have been trimmed by humans likely when these caves were used for military purposes during the British occupation of the country. The walls were trimmed to attain convex upward profiles in order to distribute the stress resulting from the overburden and also to allow larger area in the lower part of each cave. The floors of these caves are covered by soft dusty material resulting from the erosion of the limestone rocks of the cave walls and ceiling.

Water was leaking from the ceiling of cave number 2 forming a continuous, shower-like flow. Detailed inspection of the area overlying this cave indicated that the leaking water comes from a sewage pipe that passes above the cave and leaks most of its water in this area. Running sewage water is obvious on the slopes of the Upper Eocene rocks above the cave (Fig. 18). Large salt deposits are located on the same slopes due to evaporation of some of the leaking water. Also, abundant flourishing of brown, green, and orange algae characterize this wet area. Leaking sewage water infiltrates through the joint surfaces into the cave and forms shower-like drainage at the intersection of the joint surfaces with the ceiling of the cave. Most of the joint surfaces dissecting the walls of this cave also have calcareous sinter deposits due to recrystallization of the calcium carbonates dissolved by the leaking water in open joint spaces (Fig. 19).

Field work during another field season (six months later) indicated that leaking water stopped in the cave due to the abandonment of the old sewage pipe. It was also obvious that a very large block collapsed from the ceiling of the cave between the two field seasons. The collapsed block is about 25 meters long, 6 meters wide, and 1-2 meters thick. It was separated from the rest of the ceiling along joint surfaces and bedding planes. The collapsed block probably fell down under the effect of increased weight due to saturation of the limestone by water as well as due to the decrease in shear resistance of the rock due to increased pore water pressure during water leakage.

The ceiling of cave number 3 on the western side of the Mokattam city road is formed by the bedding planes of limestone beds. Joints dissecting the overlying rocks are potential surfaces of failure along which the ceiling is cracked and may lead to the collapse of the overlying rocks (Fig. 20). Any triggering mechanism may lead to the collapse of the overlying rocks along these joint surfaces. Triggering mechanisms are the same like those mentioned in a previous section which lead to increase in the weight of the overburden and/or decrease in the shear strength of the rocks.

Decreasing the Potentiality of Slope Failure in G. Mokattam

Several precautionary measures and slope treatment should be undertaken in order to decrease the potentiality of slope failure of the Middle Eocene rocks of G. Mokattam. These include:

1. Avoiding any leakage of water (sewage water, drinking water from water pipes, gardening water,... etc.) from the top of the plateaus ofG. Mokattam into the Middle Eocene rocks. In severe cases of highly water-saturated Middle Eocene rocks, some shallow wells may be drilled from the top of the middle plateau through these areas in order to drain such water and decrease the pore-water pressure.

2. Terminating all proposed housing and construction works in vicinity of old quarry walls.

3. Prohibiting building on the edge of the middle plateau if the slope at this edge is steep. A minimum distance of 100 meters should be left between the edge of this plateau and the area of allowed building.

4. Trimming the undercut slopes of old quarry faces by removing some rocks from the middle and upper sections of these slopes. Such removal is done until the slope becomes inclined toward the free side of the slope, i.e. opposite to the direction of slope in the undercut section.

5. Decreasing the magnitude of earth vibrations due to quarry explosions in the limestone quarries of the cement factories of Tura and Helwan by allowing several smaller explosions instead of a single large explosion.

6. Using rock bolts to fasten blocks of the Middle Eocene rocks lying on top of inclined joint surfaces dipping toward the free side of the scarps of the middle plateau.

7. Avoiding storage and burning of trash close to vertical quarry walls in order to decrease the erosion of limestone rocks at the base of slopes of the middle plateau.

8. Trimming the protruding (side) ridges lying between adjacent crescent-shaped quarries. Trimming includes decreasing the elevation of these ridges as well as decreasing their slope angles.

9. Periodic check of the stability of ceilings and walls of the caves in the Middle Eocene rocks.

10. Controlling the entrance of these caves in order to prevent any human use without advance testing of the stability of their walls and ceilings.

Conclusions

The slopes of the Middle Eocene rocks which form the boundaries of the middle plateau of G. Mokattam are unstable and represent potential areas of rock failure in many places. The proposed precautionary measures and slope trimming must be taken into consideration in order to decrease the potentiality of such failures. Similar danger can be avoided in other similar areas and in new cities by preventing random sprawl housing, avoiding random use of the land, and careful urban planning.

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Figure Captions

Fig. 1: Russian Satellite image of the northwestern part of G. Mokattam showing heavily populated areas (dark) surrounding G. Mokattam. Image date is May, 1995.

Fig. 2: Field panorama (looking due east) showing random urban expansion of Manshiet Naser area where houses are built both on top of the middle plateau and close to the scarps of old quarries on the sides of G. Mokattam.

Fig. 3: Composite stratigraphic section of G. Mokattam (after Moustafa et al., 1985).
Fig. 4: Simplified geologic map and cross sections ofG. Mokattam (after Moustafa and Abdel Tawab, 1985).

Fig. 5: Distribution of slopes in G. Mokattam. Slopes on Upper Eocene rocks are represented by thin barbed lines whereas those on Middle Eocene rocks are represented by thick barbed lines. Dashed straight lines show the locations of slope profiles shown in Fig. 6.

Fig. 6: Slope profiles of the northern, western, and southern parts of G. Mokattam. Asterisk defines scarps on Upper Eocene rocks.

Fig. 7: Field photograph of quarry walls in Manshiet Naser. Notice the smooth vertical slopes in the lower part of the photograph due to saw-type quarrying activities and the rough slope at the top of the exposure due to normal or explosion-type quarrying.

Fig. 8: A- Planar slope failure on a joint surface cutting rocks exposed in a vertical scarp. B- Parameters affecting slope stability after Mathewson (1981). Block marked by vertical ruling is a block overlying a discontinuity in the rocks (e.g. joint surface). T is shearing resistance along the failure surface, D is the downslope driving force, and W is the weight of the block.

Fig. 9: Leaking water through the limestone beds on the southern scarp of G. Mokattam at the cemetery east of Abajia. Water leaks through the fractures in the limestone beds and comes from water discharged due to human activities on top of the middle plateau.

Fig. 10: Undercutting (shown by arrows) at the base of a quarry face in the southern scarp of G. Mokattam west of El Rifai quarry. This undercutting was formed due to more excavation in the lower part of the quarry.

Fig. 11: Vertical aerial photographs of Manshiet Naser area taken in 1967 (a) and 1994 (b) showing the effect of quarrying (elliptical form) where three quarries had crescent shapes at the end of quarrying operations leaving side ridges between the quarries. The middle segment of the southernmost one of these ridges collapsed in 1993 (surrounded by small circle) leaving an isolated mesa to the north (indicated by the arrow). The floors of these abandoned quarries have dark tone in photo (b) due to storage and burning of trash until 1993.

Fig. 12: Topographic cross section through the three side ridges separating the **three** crescent-shaped quarries shown in Fig. 11-b. Star designates the ridge that collapsed in 1993.

Fig. 13: Two limestone ridges (R) left between three crescent-shaped quarries at Manshiet Naser. Notice undercutting (U) in the lower part of the closer ridge due to an inclined joint surface dipping toward the right.

Fig. 14: Old crescent-shaped limestone quarry at Manshiet Naser. This quarry was used later as a construction site and houses are built close to the side ridges of the quarry. Any slope failure that may happen in this area (especially in the side ridges) may lead to serious loss of life and property.

Fig. 15: Remnant of a collapsed side ridge of an old quarry at Manshiet Naser area. This ridge collapsed in 1993 and the part shown is the proximal part of the ridge. Another part left at the tip of this ridge now forms an isolated mesa and lies outside the photograph (behind the observer). Notice smoke in the right-hand side of the photo due to burning of trash.

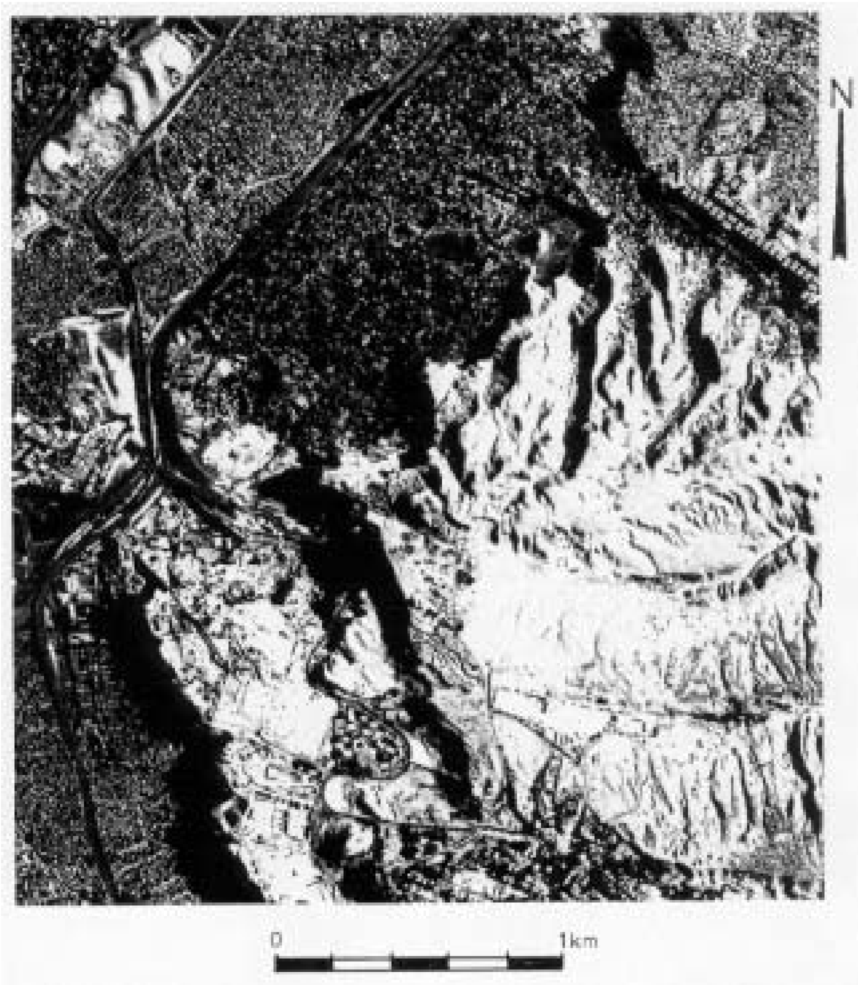
Fig. 16: Location map of the five main caves in the Middle Eocene rocks of G. Mokattam (numbered 1 through 5) located on both sides of the Mokattam city road.

Fig. 17: Field photograph of caves number 1 and 2 shown in Fig. 16. These caves are located in the uppermost part of the Middle Eocene section.

Fig. 18: Leaking sewage water on the slopes of the Upper Eocene rocks overlying caves number 1 and 2 of G. Mokattam.

Fig. 19: Field photograph of white calcareous sinter deposits in the joints dissecting the walls of cave number 2 of G. Mokattam.

Fig. 20: Close-up view of cave number 3 in the Middle Eocene rocks on the western side of the road to Mokattam city. Notice that bedding planes form the ceiling of this cave and joints cutting the overlying rocks are potential failure surfaces along which the overlying rocks may collapse.



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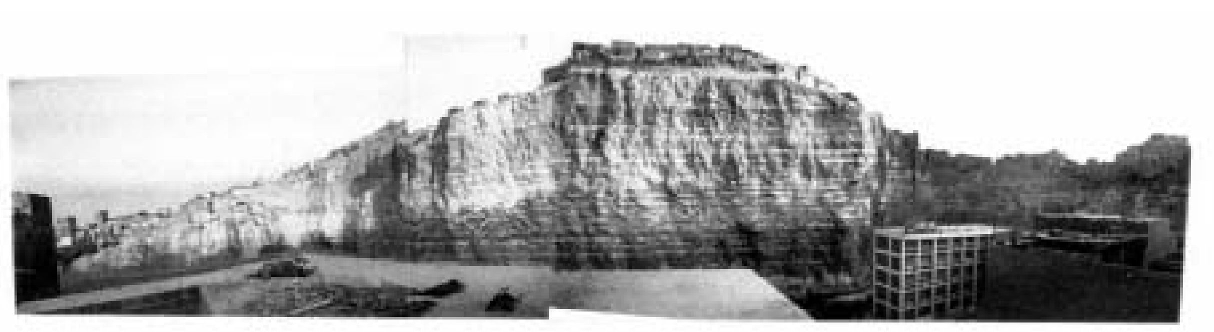

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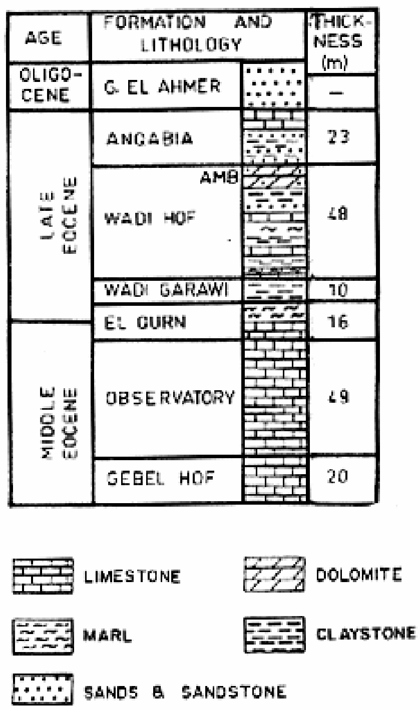
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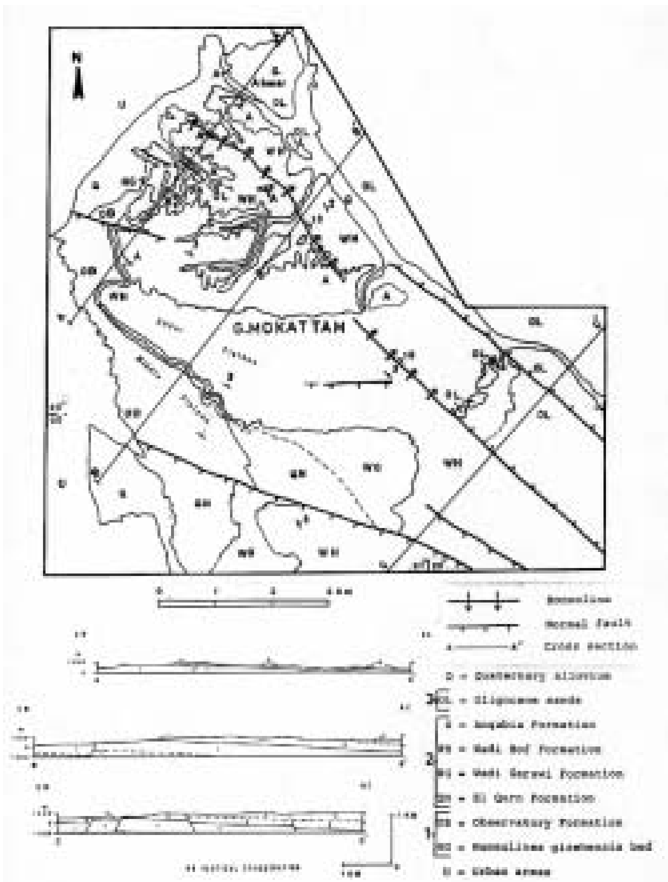
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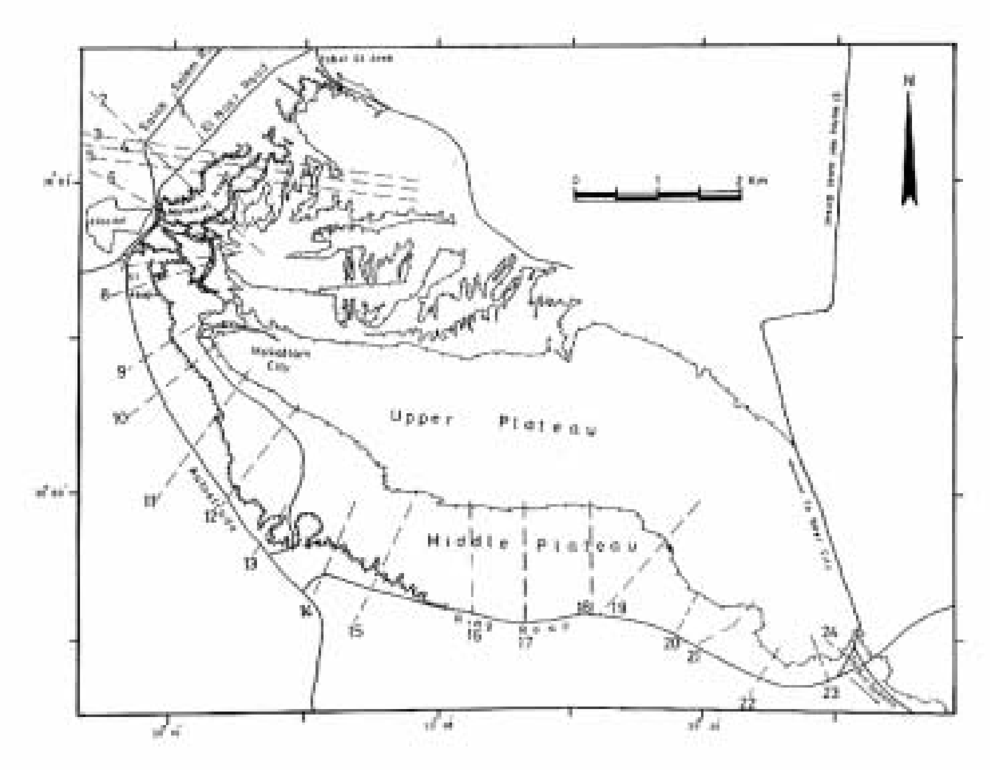
Fig. 4



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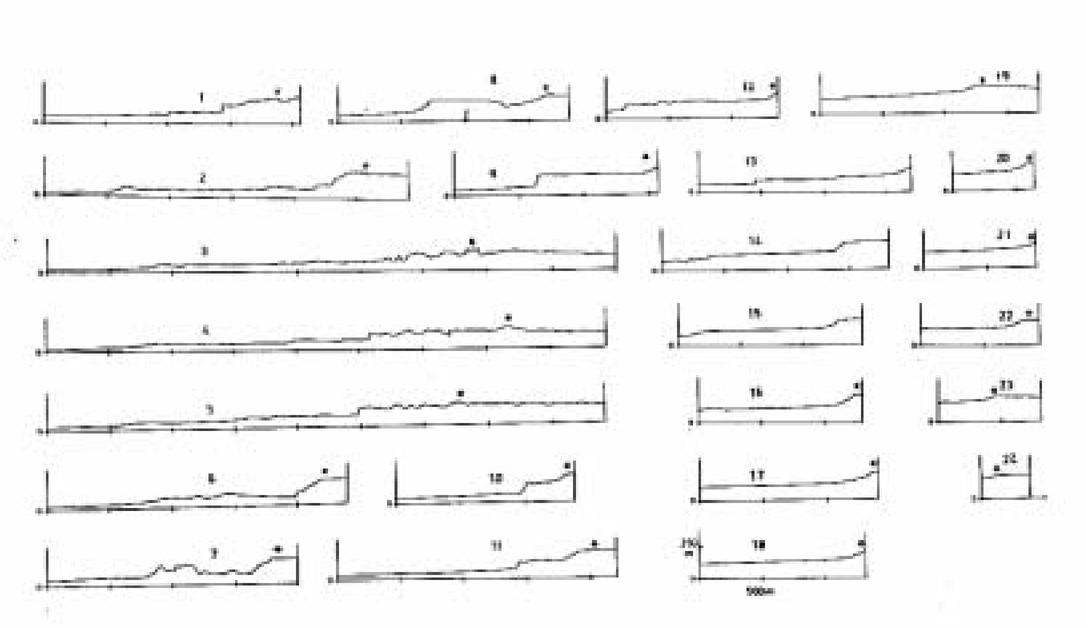

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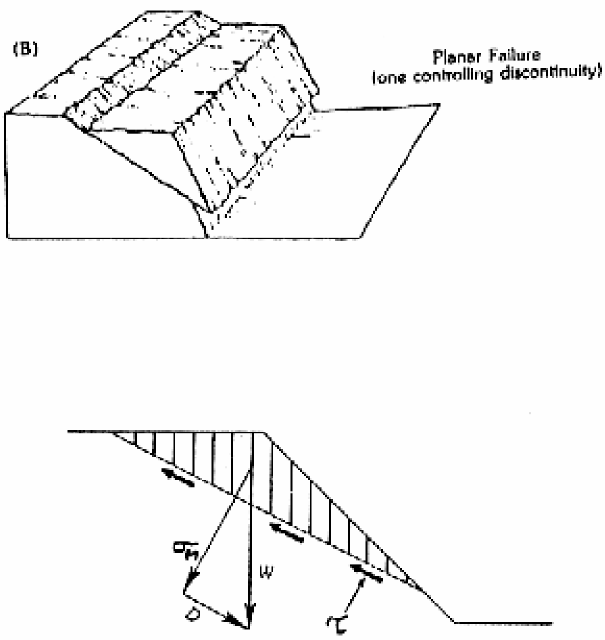

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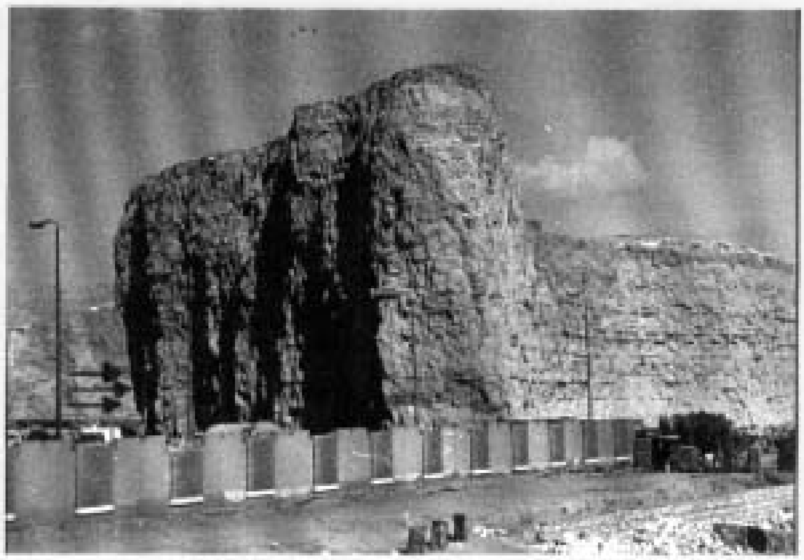

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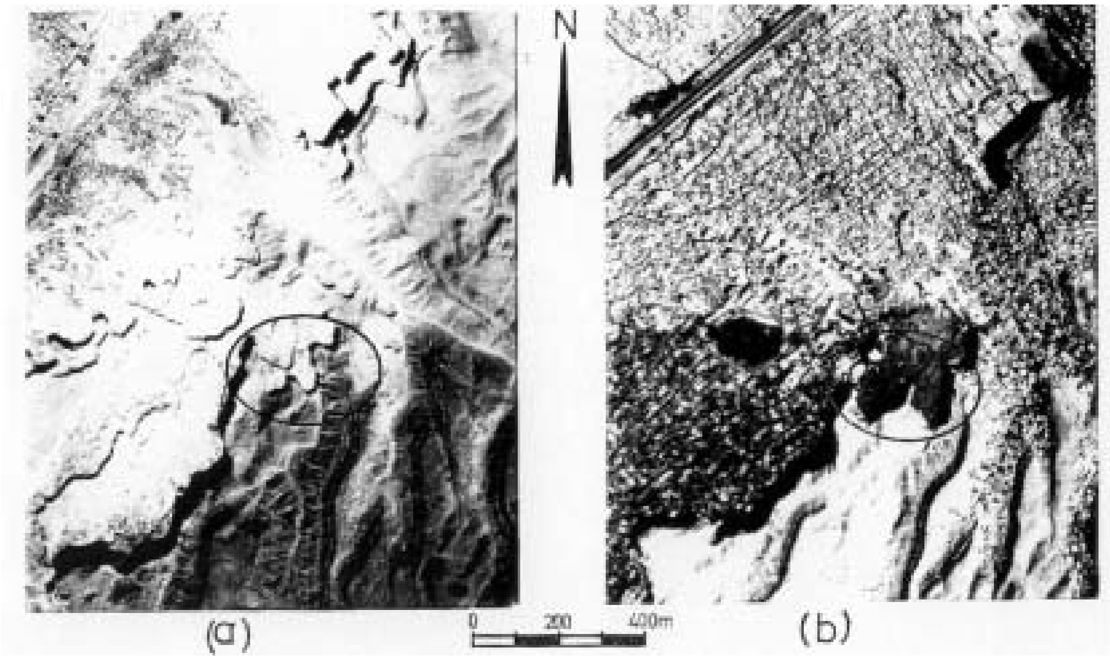

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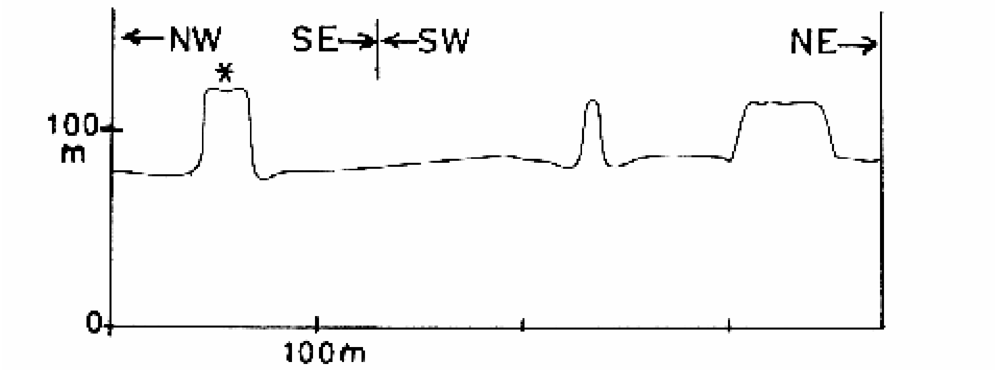

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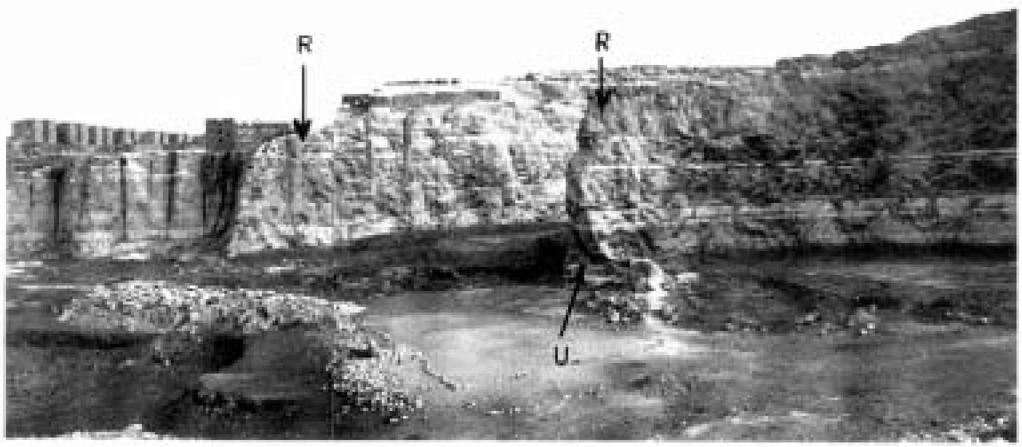

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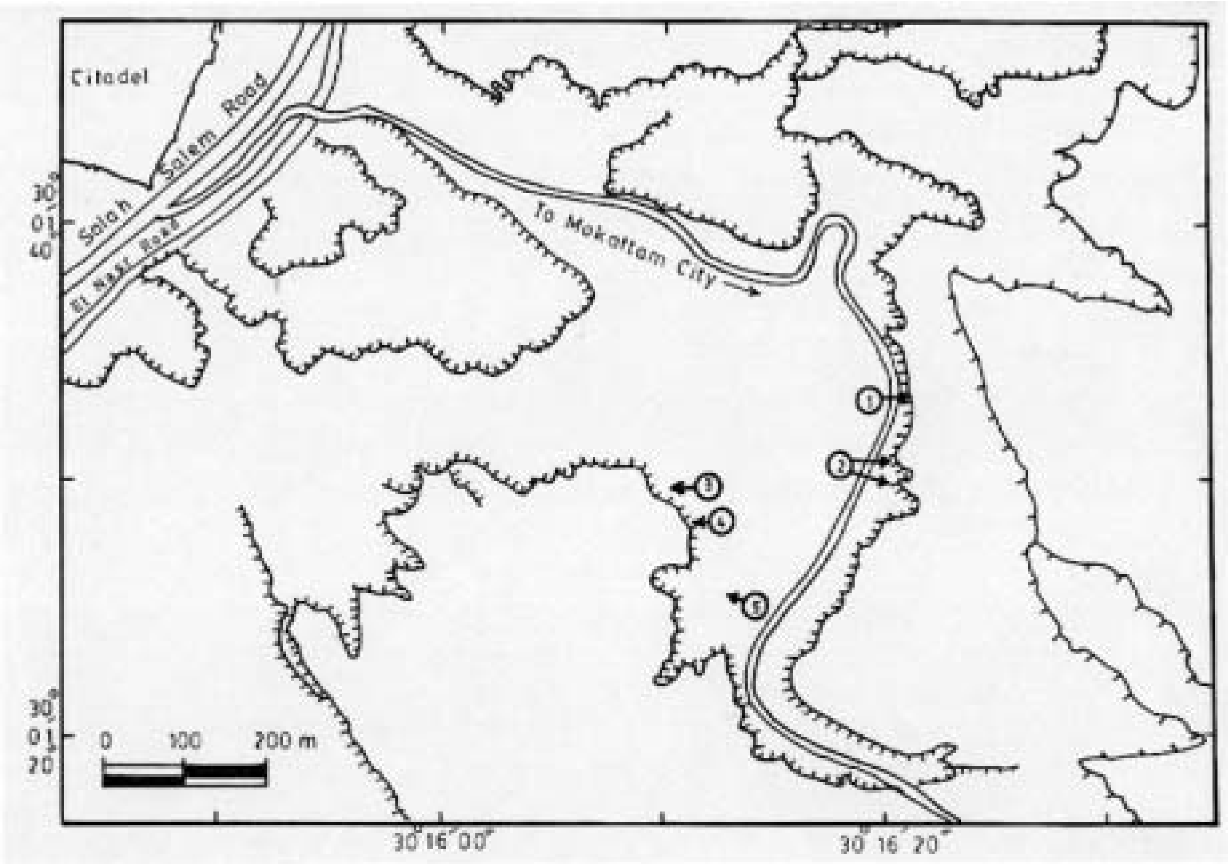
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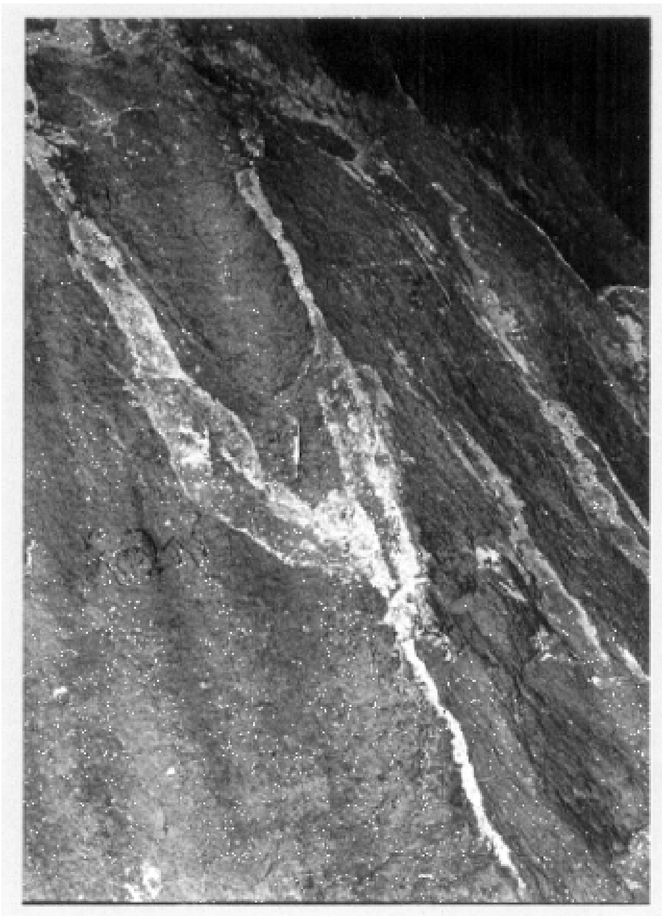

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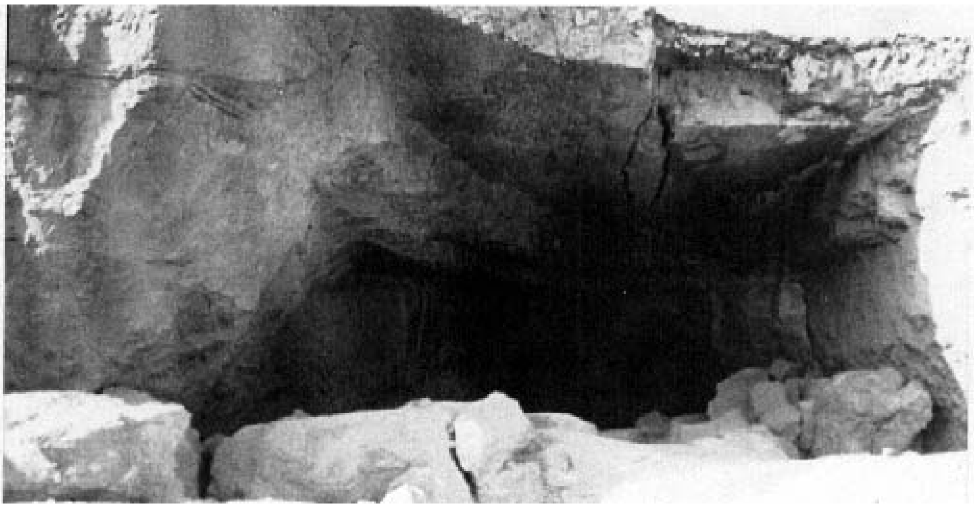

Fig.20