

**GEOMORPHOLOGY OF WADI AL AQL  
TERRACES IN THE NORTH EAST OF  
AL MADINAH AL MUNAWWARAH,  
Kingdom of Saudi Arabia**

**Dr. Hamdenoh Abdel - Kader El - Sayed (\*)**

---

**Abstract:**

*Wadi Al Aql terraces were surveyed and investigated by the use of topographic, geologic maps and intensive fieldwork. Some bases such a genetic distinction, topographic relationship between terrace levels, and bedrock lithology has been used to classify the Wadi Al Aql terraces.*

*The results obtained from mapped cross-section and the longitudinal profiles of both Wadi sides and Wadi bed indicated that the Wadi Al Aql terraces could basically be divided into two types of terraces. The first type is a depositional terrace (two levels), and the second type is an erosional one. On the other hand, depositional terraces are classified into paired and unpaired ones.*

*An attempt was made to differentiate between the two populations of sorting occurred in depositional terraces. The differentiation depends upon grain size distribution curves and statistical parameteres. The old terrace formations are coarser, poorly sorted, slinghtly positive skewed and has higher kurtosis value than the recent one. The morphometric analysis of the terrace gravels indicates that the gravels of the recent terrace are rounded, as compared to the gravels of the old terrace.*

**Introduction:**

Wadi al Aql basin is situated in the northeastern part of al

---

(\*) Department of Geography, Faculty of Arts, Alexandria University, Egypt, and College of Education for Girls, Al Madinah Al Munawwarah, Kingdom of Saudi Arabia. P.O.B. 3193.



Madinah al Munawwarah, Kingdom of Saudi Arabia. It lies just northern of Harrat Rahat, and it is located between latitudes  $24^{\circ}20'$  -  $24^{\circ}40'$  N and longitudes  $39^{\circ}39'$  -  $40^{\circ}05'$  E. (Fig. No. 1).

The basin perimeter measures about 137.50 km, while its width varies from about 8.75 km to 25 km, with an average of 17 km. A watershed separating it from Wadi al Qana in the north, and the Wadis of Harrat Hermah and Harrat Rahat in the south. And, it drains an area of about 581.25 sq.km.

The main valley of Wadi al Aql stretches from the western flanks of Harrat Hermah (at the northeast) and follows a southwestward course in a linear structure depression through the basement and volcanic rocks for nearly 47.50 km. Then, it connects with Wadi al Qana at the eastern side of Jabel Uhud before connecting with Al Madinah basin (Panorama. No. 3).

Wadi al Aql receives numerous tributary valleys, the most important of which, particularly in the lower section, are Wadi al Khanaq, Wadi al Bitan on the eastern side, and Wadi Tawrah on the western side.

***Objectives of the study:***

The present study is intended to achieve the following objectives:

1. Surveying of the terrace belt of Wadi al Aql to determine terrace distribution and their levels.
2. Studing the geomorphologic characteristics of these terraces and their deposits in order to assess the rates, conditions and dynamics of the processes operating in the valley at the time of aggradation.
3. Examining the effects of the paleoclimatic conditions, and the recent geomorphic controlling factors.

### ***Materials and methods:***

Data of the present study were derived from the following main sources:

1. Data obtained from the interpretation of topographic and geologic maps of Al Madinah Quadrangle, at scales : 1 : 10,000 , 1 : 250,000.
2. Data obtained from the field measurement as the following steps:
  - Surveying of the terrace belt within three years from 1998 to 2000.
  - To study the terraces morphology and their levels, six cross sections were measured at a different distances.
  - To describe the materials of Wadi terraces, three samples were carefully collected, (one from the old terrace, and the other two from the recent terrace and the Wadi - bed); for laboratory analysis. Mechanical analysis was carried out by the conventional sieving method<sup>(\*)</sup>. Then, the cumulative percentages were plotted on probability paper and graphical method was used. The grain size statistical parameters were calculated by computer, using the formulae of Folk and Ward (1957).
  - To achieve the best results on the roundness ratio of terrace pebbles, 300 pebbles were collected : 150 pebbles from each terrace. In addition, two dimensions were measured for each pebble according to the standard methods.

### ***Geologic and climatic setting:***

The study of the basin geology is important for the type of rock

---

(\*) Mechanical analysis was carried out by Geological Department, Faculty of Science, Alexandria University in 10/8/1999.

underlying the basin determines the nature of material, which is available for erosion and transportation within the drainage basin (Gregory & Walling, 1973).

Precambrian metasedimentary, extensive Tertiary and Quaternary basalt flows and Quaternary surficial deposits underlie Wadi al Aqul basin (Fig. No. 2).

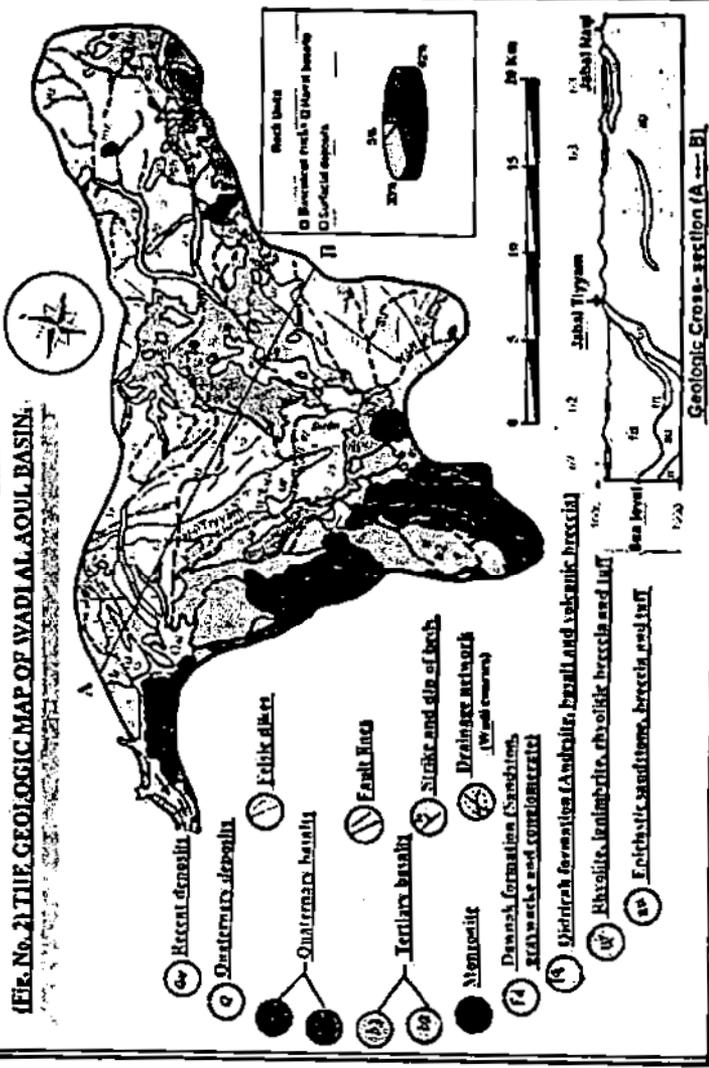
The Precambrian is represented by Upper Proterozoic rocks, which is subdivided into three formations:

1. Urayfi formation, which consists of several thousand meters of Epiclastic <sup>(1)</sup> rocks and is interbedded by volcanic breccia and tuff. These formations form the majority of the basin rocks. Rhyolite, ignimbrite, rhyolitic breccia and tuff are prominent in Jabal Tiyyam at the lower section of Wadi al Aqul (Fig. No. 2). The top of this formation is marked by slight angular unconformity with the Qidirah formation (Pellaton, 1981).
2. Qidirah formation, that is essentially composed of andesite, basalt and volcanic breccia with fragments as much as 30 cm in size. The main outcrop of the Qidirah formation is located in the southern upper section of Wadi Khanaq (A major tributary of Wadi Al Aqul).
3. Dawnak formation, is constituted of sandstone, graywackes and conglomerates and outcrop mainly in the lower section of the basin, east of al Madinah air port (Matar). This formation is restricted to the north of Harrat Rahat basalt. The Dawnak formation is represented by a thick accumulation of various detrital rocks (Panorama. No. 2).

---

(1) The term "Epiclastic" is used to describe immature, heterogeneous and poorly sorted sedimentary rock with subangular fragments and abrupt facies changes which is formed by reworking of volcanic material mostly Pyroclastic in origin.

(Fig. No. 2) THE GEOLOGIC MAP OF VADI AL-AOUL BASIN.



Tertiary and Quaternary basalt cover an area **about 33%** of the basin area (Fig. No. 2). It is possible to distinguish **two** groups of basalt. **Firstly, the oldest basalt** which is gray, and comprises rounded blocks scattered over flat surfaces where the **prismatic** nature of the lava can be distinguished in places, and have **flattened** edges. **Secondly, the youngest basalt** which is blocky display **flow** structures, and has thick edges. These characteristics, **are** progressively disappeared with time due to erosion. Both types of basalt are mainly composed of olivine and zeolite phenocrysts in a matrix of augite (Baubron, 1976).

The Pleistocene and Holocene formations are surficial deposits of varied fluvial, eolian and lacustrine origin, and are commonly closely intermixed. Three types of these deposits have been identified:

1. Wadi alluvium of gravel, sand and clay that particularly follows the main Wadi beds.
2. Sabkha or khabrah deposits of sand and clay, with or without saline deposits, in closed or semi closed depressions (Panorama. No. 2).
3. Terraces of poorly consolidated pebbles and gravel at the lower section of Wadi al Aql and alluvial fans dissected by recent erosion (Panorama. No. 9, as an example).

Most faults in the Wadi Al Aql basin appear to belong to the Najd fault system. They generally strike NE.  $40^{\circ}$  -  $50^{\circ}$  SW. The clearest syncline belonging to this major phase is that at the lower section of Wadi al Aql constituting the Furayh basin at the east of al Madinah airport. It has a north south axis, but is complicated by numerous secondary folds.

Abdel- Aziz Ali (1996) used the factor analysis techniques to study and classify the climate of the Kingdom of Saudi Arabia. He points out that the climate of al Madinah al Munawwarah is of the arid type, which is characterized by a warm and dry winter and very hot and dry summer. Mean annual precipitation reaches about 57.9 mm. The average maximum temperature ranges from 21.5°C to 42°C, and the average minimum temperature ranges from 13.2°C to 29.4°C, with annual average that ranges from 17.3°C to 35.3°C (Said, 1995, in Arabic).

***Distribution and evolution of Wadi Al Aqul terraces :***

The field investigation, illustrated maps (Fig. No. 4) and cross - sections (Fig. No. 5 & 6) indicate that, the Wadi Al Aqul terraces are well distributed at the lower section of the valley, with dissimilar shapes and types. They are extended for more than 5 km from the Wadi dam to the junction point of Wadi al Aqul and Wadi Al Qana (two kilometers at the south west of Al Madinah Airport), with varying width between 50 - 320 m.

The al Madinah basin represents base level (Local base level)<sup>(\*)</sup> of Wadi al Aqul, which is draining into this basin at 600 m above the present sea level. This means that, when the Pleistocene pluvial periods happened, the stream was active, and the terraces were produced by surges erosion, and hence reflected periods of rejuvenation, which have affected stream. In other words, when the

---

(\*) Davis (1902) classified three types of base levels of river erosion : Ultimate (sea level), local (where the level of the major stream channel limits reduction) and temporary (knickpoints). A local base level may persist for very long periods of time. Garner (1974) points out that local base levels can be identified by a depositional datum such as a bar at river junction or fans in arid regions (Morisawa, M., 1985, p. 70).

stream tried to approach an equilibrium state between its old bed and a new one developed; the valley floor had been lowered by vertical and lateral erosion at the same time. Remnants of the old floor were developed and lifted on opposing valley sides at different altitudes.

To conclude, the formation of Wadi Al Aqul terraces is basically attributed to the climatic conditions in Pleistocene and Recent era, and to the lowering of the local base level due to the consequently tectonic events.

Longitudinal profiles of both the old and present courses (Fig. No. 3) indicate that the magnitude of deepening is exceeded 28 m at some locations (Table. No. 1).

Height differences between the old and the recent Wadi - bed are attributed to vertical erosion, which has been predominated especially during the pluvial periods. A height difference of 8 m was measured just before the junction point of Wadi Al Aqul and Wadi al Qana, which marked the beginning of the study terraces. On the other hand, the height difference increased to 28 m immediately after the Wadi dam, for a distance of 5.4 km (Fig. No. 4).

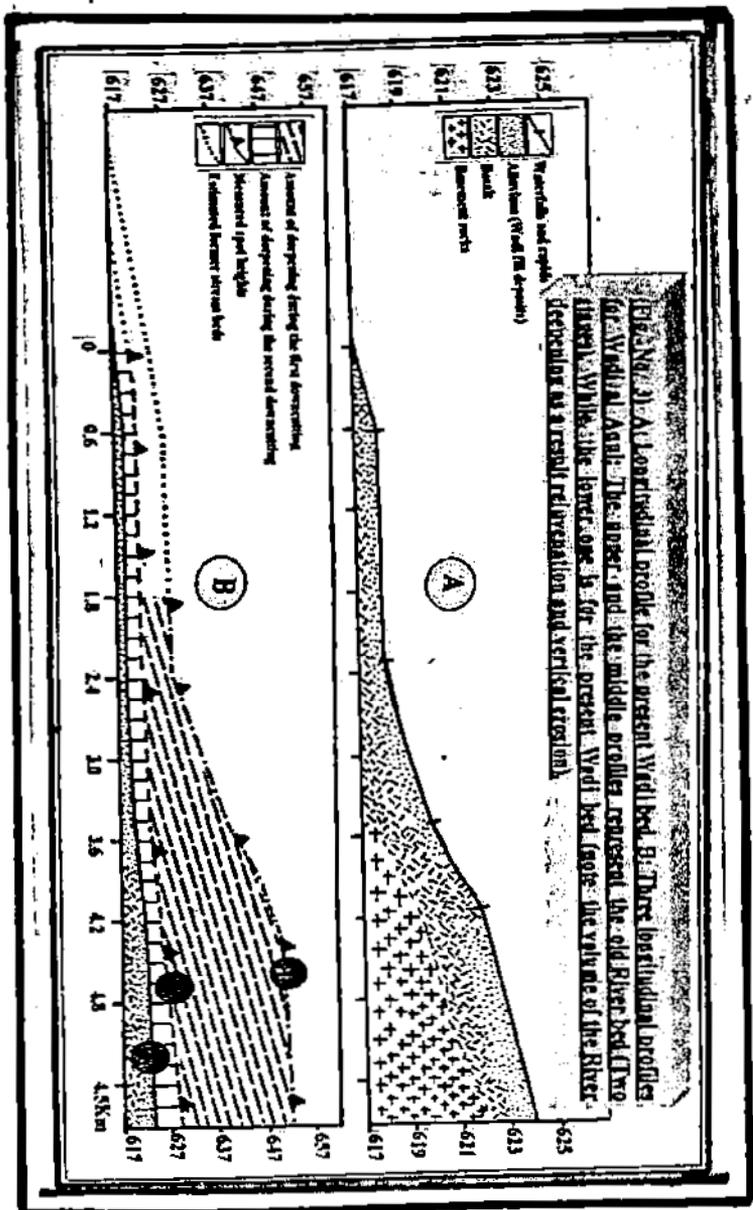
According to the survey of the terrace remnants, limits of the old river bed were traced and mapped (Fig. No. 4). The width of this bed varied between 160 - 350m, with an average of 256 m respecting the first width of the river - bed.

**(Table. No. 1) Vertical and horizontal dimensions of the old Valley floors and the present Wadi bed along the longitudinal profile of Wadi al Aqul (Only at the terrace belt).**

A	B (km)	C (m)			C1 - C2 (m)	C2 - C3 (m)	C1 - C2 (m)
		C1	C2	C3			
1	0.0	625	620	617	8	3	5
2	0.6	626	622	619	7	3	4
3	1.2	627	622	619	8	3	5
4	1.8	627	622	619	8	3	5
5	2.4	628	622	619	8	3	6
6	3.0	635	623	620	15	3	12
7	3.6	641	624	620	21	4	17
8	4.2	650	625	622	28	3	25
9	4.8	651	627	623	28	4	24
10	5.4	652	629	624	28	5	23
The average		636.	623.6	620.2	15.9	3.4	12.6

A : Station number, B : Horizontal distance, C : Levels of the old river - bed and the present Wadi bed (Above the present sea level), C1 : The first level of river-bed, C2 : The second level of river-bed, C3 : The present level of Wadi - bed.

The large bed width, which ranges between 100 - 240 m, with an average of 185 m, at the second or middle River bed, is due to the next incision and rejuvenation which has affected the stream. Clearly, the present Wadi bed formed about 16.4% of the first Wadi bed, and 37.7% of the second one (Fig. 3). This result reflects high magnitudes of downcutting and lateral planation accomplished by the old river under Pleistocenic pluvial / wet periods during the



first stages of erosion cycle. While, by the end of cycle, the magnitudes of erosion decreased as a response to climatic change, and achieved only 16.4% of such magnitude.

***Types of Wadi al Aqul terraces :***

The classification of Wadi al Aqul terraces could be based on several criteria, including a genetic distinction topographic relationship between terrace levels, and bedrock lithology. For this purpose, six cross - sections were surveyed in the field and illustrated in figures (No. 5 & 6).

According to a genetic distinction, terraces of Wadi al Aqul were classified into depositional and erosional terraces :

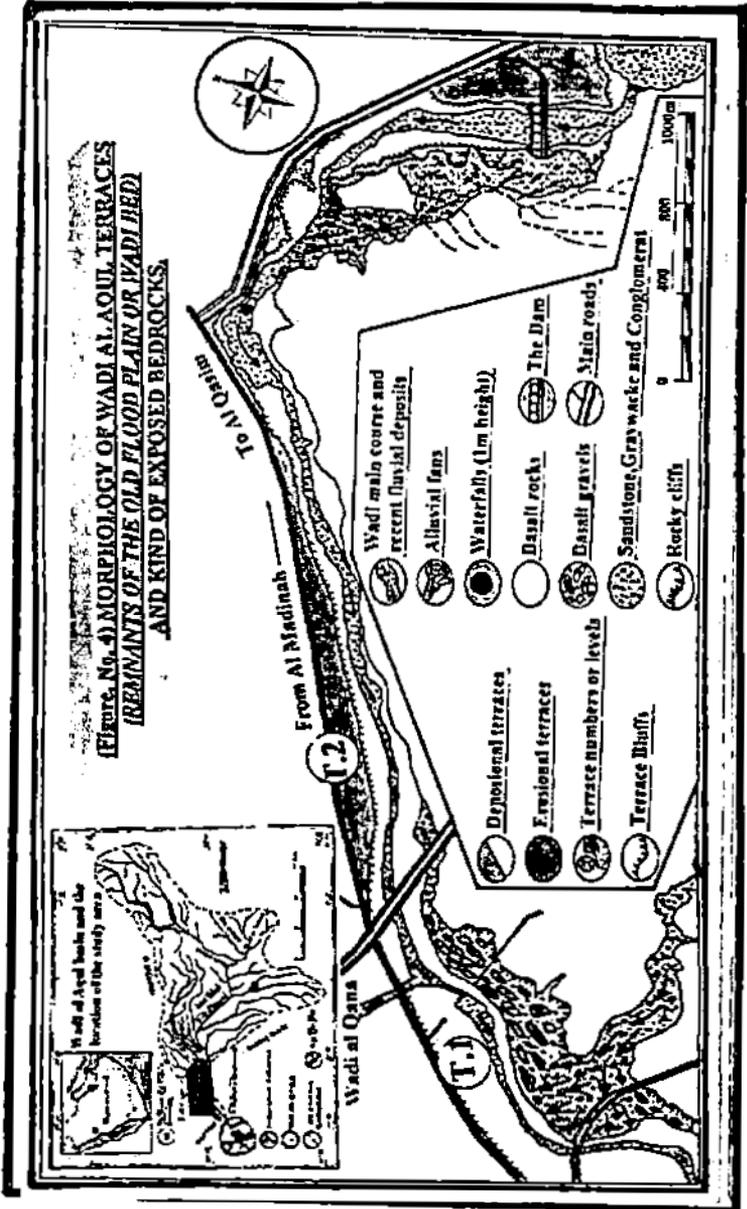
***1. Depositional terraces :***

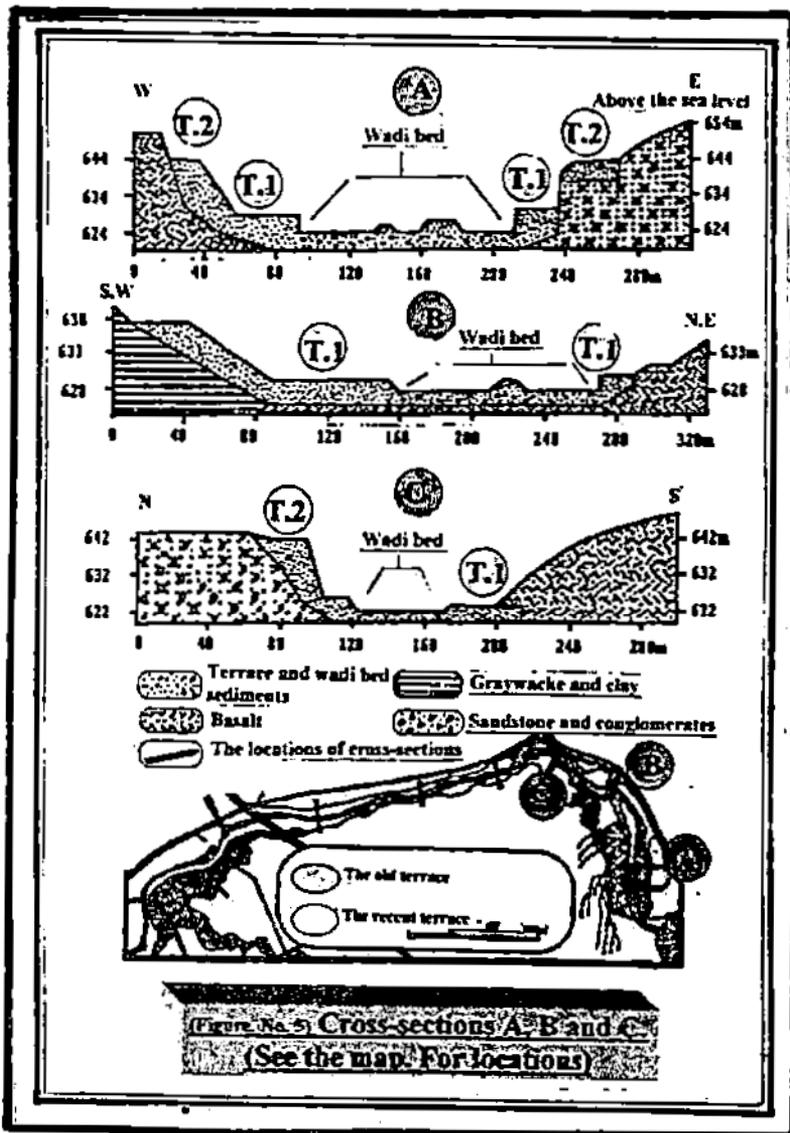
The development of depositional terraces always requires a period for valley filling and for subsequent entrenchment into or adjacent to the fill. Ritter, Kochel, and Miller (1995) mentioned that the tread of depositional terrace represents the highest level attained by the valley floor as it rose during aggradation. The initial entrenchment that forms the terrace scarp is primarily vertical, and so the tread was subsequent to the lateral erosion at a lower level.

The field surveys and the study of the cross - sections (Figures. No. 5 & 6) indicate that, there were two levels of depositional terraces on both sides of Wadi al Aqul.

***A - the old terrace (10 - 28 m) :***

This terrace occupied an area of 26% from the total area of terraces developed along the lower section of al Aqul valley (Fig. No. 4). It is dissected on the northern side of al Aqul valley, while it disappeared entirely underneath basalt flow except for some remnants that took place beyond Wadi dam, at the southern side





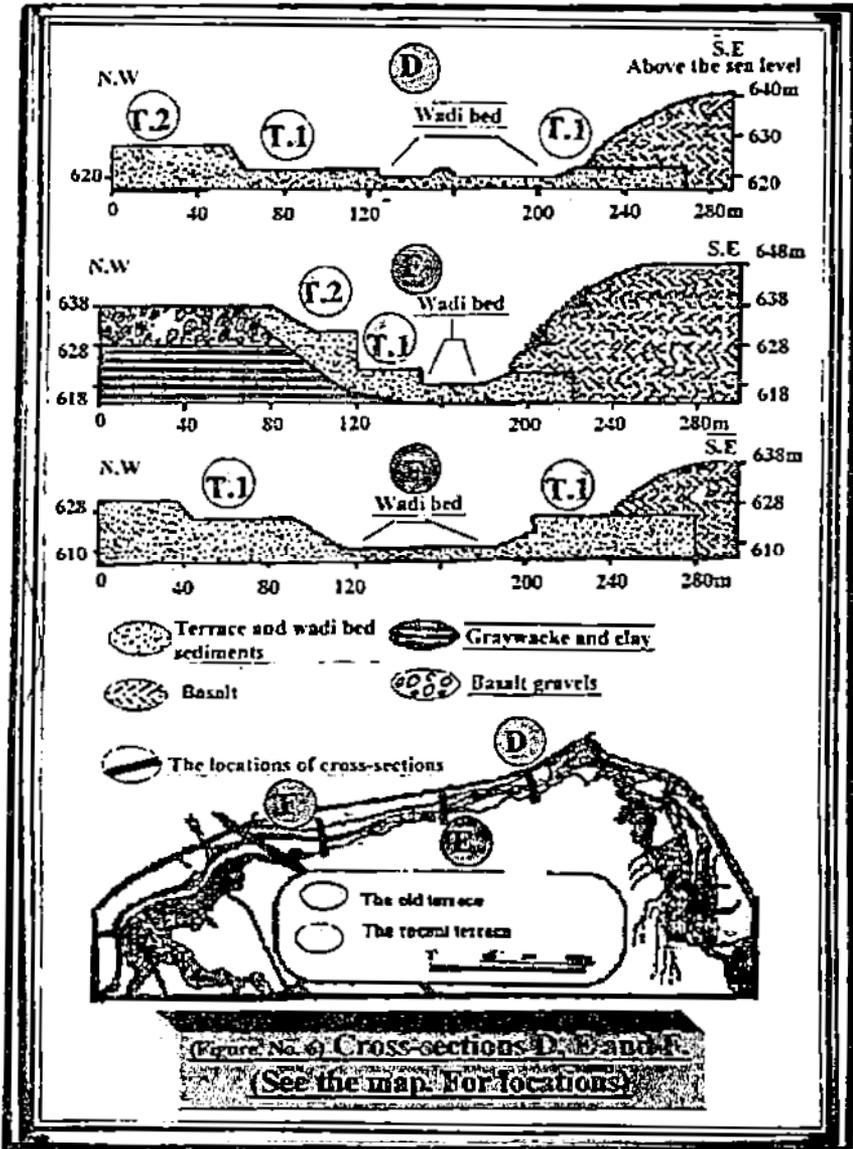


Figure No. 6. Cross-sections D, E and F  
(See the map for locations)

(Cross - sections, A & B). In the same way, this terrace seemed unpaired and asymmetric in all cross - sections.

The height of the old terrace varies between 10 - 28 m above the present Wadi bed (Panorama. No. 4), and its width ranges between 15 - 50 m, with an average of 28 m. Similarly, the thickness of this terrace differs from one place to another. While the apparent thickness was measured at 15, 12, and 18 m in cross - sections namely A, B and C (Fig. No. 5) it was measured at 7, 15 and 12 m in cross - sections D, E and F respectively (Fig. No. 6). Variations in terrace thickness may be attributed to the deposition and erosion effects.

***B. The recent terrace (3 - 5 m):***

Geomorphologic map of the terraces under investigation (Fig. No. 4) indicates that the recent terrace extended on both the northern and the southern banks of the Al Aqul valley. It occupies an area of 68% from the total terrace area, and it was developed just above the recent Wadi bed, with a height ranging between 3 - 5m. This terrace seems to be in paired and is symmetric in all cross - sections (Panorama. No. 3, 5 & 6).

Most of recent terrace mapped in the study cross - sections, namely C, D, E and F is disappeared underneath the recent basalt flows of Harrat Rahat at the southern side of Wadi Al Aqul (Panorama. No. 4).

***2. Fill - cut terraces :***

These terraces are erosional ones. Howard (1959) proposed the use of fill - strath for terraces underlain by alluvium, while, Mackin (1937) has characterized an erosional terrace as a one with a layer of alluvium of fairly uniform thickness deposited on an eroded

surface which is essentially flat and parallel to the overlying alluvium, all of which implies lateral planation. According to the former definitions, the field survey indicates that, there is only one erosional terrace in which bedrock (mainly Tertiary basalt of Harrat Rahat) is partially exposed and developed in some locations at the southern side of Wadi Al Aqul (Fig. No. 4, and cross - sections, A & B). It is capped by a uniformly thin layer of coarse angular gravel and alluvium (Panorama. No. 9).

Fill strath terrace in the study area extended more than 850 m, and its height ranges between 10 - 28 m above the present Wadi bed. The tread of this terrace has been formed primarily by lateral erosion, then the terrace material was deposited, lateral planation practiced by Al Aqul stream is of a very low rate and is decreased by volcanic rock resistance. Lateral erosion occurs where a river swings to one side, thus causing bank erosion (Small, 1989).

Fill strath terrace had undergone sever dissection and trenching by gully erosion in the study area. Ritter, Kochel and Miller (1995) point out that, these types of terraces are related to climatically controlled aggradation.

Finally and most important, the difference between depositional and erosional terraces is that the scarp of an erosional terrace is formed by lateral cutting, while that of a depositional terrace is essentially due to the down cutting. Cotton (1948) mentioned that fluvial terraces are cut, not built, by river (Thornbury, 1954).

According to topographic relationship between terrace level, two types of terraces were distinguished :

**1. Paired terraces (Matched or Poly - cyclic) :**

Alluvial recent terrance was paired in all cross - sections (Figures. No. 5 & 6) whereas, the upper surface of this terrace at the same level on opposite sides of a valley, but differed in area (Panorama. No. 4).

Morisawa (1985, p. 124) points out, uplift and climatic change cause a new cycle of downcutting and then lateral planation to remove part of the old floodplain material, leaving a terrace set. Several such events may result in more incision and lateral cutting to produce a multistoried valley representing several erosion cycles. Paired terraces represent a significant evidence that a river has cut downward in an intermittent fashion (Bloom, 1982).

**2. Unpaired terraces (Unmatched or non - cyclic):**

Alluvial old terrace on opposite sides of Wadi Al Aqul and also erosional one are asymmetric unpaired and can be distinguished along a dissected belt of 3 km length (Fig. No. 4, and cross - sections, A & B).

Unpaired terraces indicate a slower continuous environment change, e. g. non - cyclic erosion. When cycles of aggradation and incision occur repeatedly a cut - and fill terrace is formed. Unpaired terraces like paired ones, may be represented by remnants of alluvium or of the former valley flat cut into rock.

## **Grain size analysis for the formations of terraces**

### **Under investigation**

Grain size analysis is used to differentiate between various environments and facies as well as to predict the paleoenvironmental conditions. It also may be used in the interpretation of the conditions prevailing during depositional processes (Middelton, 1976).

For Grain size analysis, three samples were collected. One from old terrace sediments and the other two samples from recent terrace and Wadi bed sediments. This system of sampling easily permits comparison and shows a sort of relationship between terraces and Wadi bed.

Generally, the terraces and Wadi bed formations are composed of gravel, sand and mud, whereas the gravel ( $> 2 \text{ mm}$  or  $< - 1\phi$ ) ratio ranged from 77.96% (At the old terrace) to 0.25% (At the Wadi bed), with an average of 44.18%. In comparison, the ratio of sand ( $2 - 1 / 16 \text{ mm}$  or  $- 1 : 4\phi$ ) ranges from 15.67% (At the recent terrace) to 9.74% (At the Wadi bed), with an average of 12.79%. While the ratio of mud fractions ( $< 1 / 16 \text{ mm}$  or  $> 4\phi$ ) ranges from 90.01% (At the Wadi bed) to 9.07% (At the old terrace), with an average of 43.03% (Table. No. 2 and Fig. No. 7).

On the whole, the general results of grain size analysis indicate that the old terrace formations are particularly rich in gravel and very coarse sand, while the recent terrace sediments are rich in gravel and mud fractions. The Wadi bed sediments are rich in fine sand and mud fractions. All sample sediments were subjected to dry sieving (Plates. No. 7 & 8). In some locations, channel materials range from coarse sand to very large cabbles and a few boulders with medium diameters of 9.5 m or greater.

**Statistical parameters of grain - size distribution :**

Results of grain size analysis were plotted on Phi - curves; then nine percentiles were recorded graphically from curves for each sample. Percentiles are  $\phi 5$ ,  $\phi 10$ ,  $\phi 16$ ,  $\phi 25$ ,  $\phi 50$ ,  $\phi 75$ ,  $\phi 84$ ,  $\phi 90$ , and  $\phi 95$  (Fig. NO. 10). Four statistical parameters were calculated from these percentiles using the formulae of Folk and Ward (1957), as follows :

1. The graphic mean size ( $Mz$ ) =  $\phi 16 + \phi 50 + \phi 84 / 3$
2. The inclusive graphic sorting (standard deviation  $\sigma 1$ ) =  $\phi 16 - \phi 84 / 4 + \phi 5 - \phi 95 / 6.6$
3. The inclusive graphic skewness ( $Sk1$ ) =  $[\phi 16 + \phi 84 - 2\phi 50 / 2 (\phi 16 - \phi 84)] + [\phi 5 + \phi 95 - 2\phi 50 / 2 (\phi 5 - \phi 95)]$
4. The graphic kurtosis ( $KG$ ) =  $\phi 5 - \phi 95 / 2.44 (\phi 25 - \phi 75)$

Also Griffiths's diagram (1967) was introduced to clarify the relationship between the mean diameter ( $Md$ ) and sorting ( $PD\phi$ ) to elucidate the characteristics and the medium of transportation of the sediments, i. e., traction, suspension, saltation, gravity, eolian, .... etc. These statistical parameters were calculated from the cumulative curves as follows :

1. Medium diameter ( $Md$ ) =  $Md \phi 50$
2. Sorting percentile deviation ( $PD\phi$ ) =  $\phi 90 - \phi 10 / 2$

Accordingly, the study of statistical parameter values indicates that :

1. The collected samples of two terraces and Wadi bed have mean grain size values range between - 4 25 $\phi$  (pebbles and gravels) at the old terraces and 3.25 $\phi$  (very fine sand) at the Wadi bed sediments, with an average of - 0.76 $\phi$  (coarse materials) (Table. No. 3 and Fig. No. 8). Therefore, this result indicates that the formations of the old terrace and that of the recent one are

particularly rich in coarse materials (pebbles, gravel and coarse sand) this probably suggests a similar or identical source, while the Wadi bed sediments are rich in very fine sands. Clearly, the mean size decreases gradually from the old terrace down through the recent one to the Wadi bed, where the very fine sand and silt fraction are concentrated. It is expected to find increasing proportions of finer materials in the down Wadi and towards the direction of transport.

2. The sorting values of the analyzed terraces and Wadi bed samples range between  $0.66\phi$  (moderately well sorted) at the Wadi bed, and  $4.11\phi$  (extremely poorly sorted) at the recent terrace, with an average of  $2.60\phi$  (very poorly sorted). This result indicates that the fine sediments tend to better sorted than coarser ones. Likewise, Folk (1974) suggested that, the main factors controlling the sorting are : The size range of material supplied to the environment, and the type of depositional processes.
3. Inclusive graphic skewness ranges between  $-0.54\phi$  (strongly coarse or negative skewed) at the Wadi bed sediments, and  $0.92\phi$  (strongly fine or positive skewed) at the old terrace sample, with an average of  $0.19\phi$  (slight skewed). The recent terrace sample recorded  $0.21\phi$  (fine or positive skewed). This means that the terrace formations tend to be positively skewed indicating that the fine admixture exceeds the coarse one. (Duane, 1964 and Martins, 1965). The coarse materials (Pebbles and gravel) constitute 77.96% and 54.33% of the old terrace and recent one samples respectively (Fig. No. 8). These anomalies fit well with the fluvial sediments.
4. Kurtosis values of the analyzed terraces and Wadi bed samples range between  $0.46\phi$  (very platykurtic) at the recent terrace and

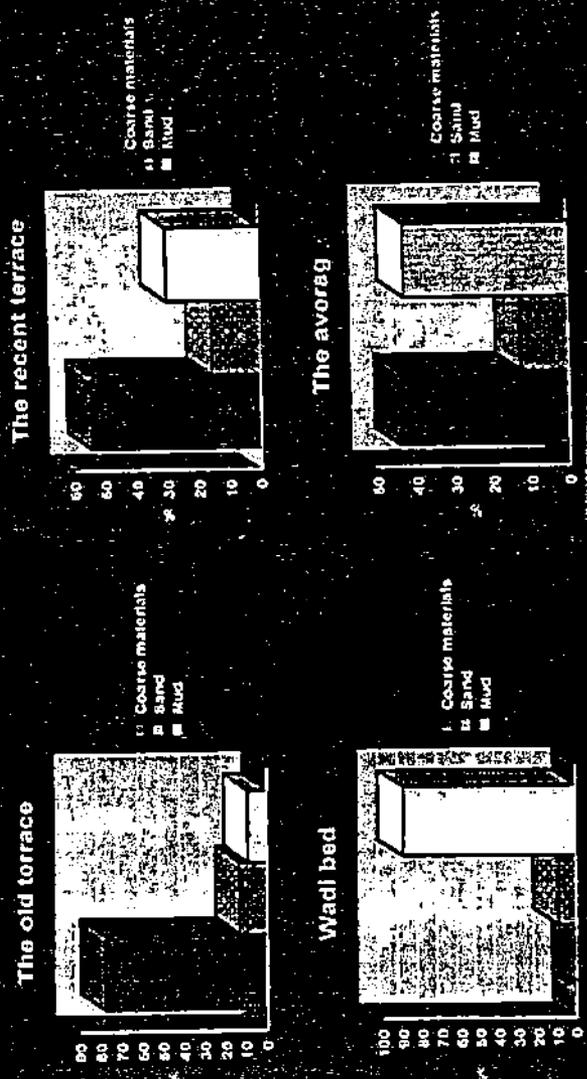
**(Table No. 2) Results of grain size analysis for the studied terraces and Wadi bed samples.**

Fractions	Weight % of fraction											
	Pebbles	Granules	V. C. S	C. S	M. S	F. S	V. F. S	Silt	Clay			
mm	> 4	4-2	2-1	1-1/2	1/2-1/4	1/4-1/8	1/8-1/16	1/16-1/256	<1/265			
Phi (Ø)	< -2Ø	-2.-1	-1.0	0.1	1.2	2.3	3.4	4.5	> 5Ø			
The old terrace	73.77	4.19	3.76	2.84	2.79	2.15	1.43	6.35	2.72			
The recent terrace	40.51	13.82	6.87	1.97	1.96	2.53	2.34	17.43	12.57			
The Wadi bed	-	0.25	0.31	0.67	1.97	2.34	4.45	40.50	49.51			

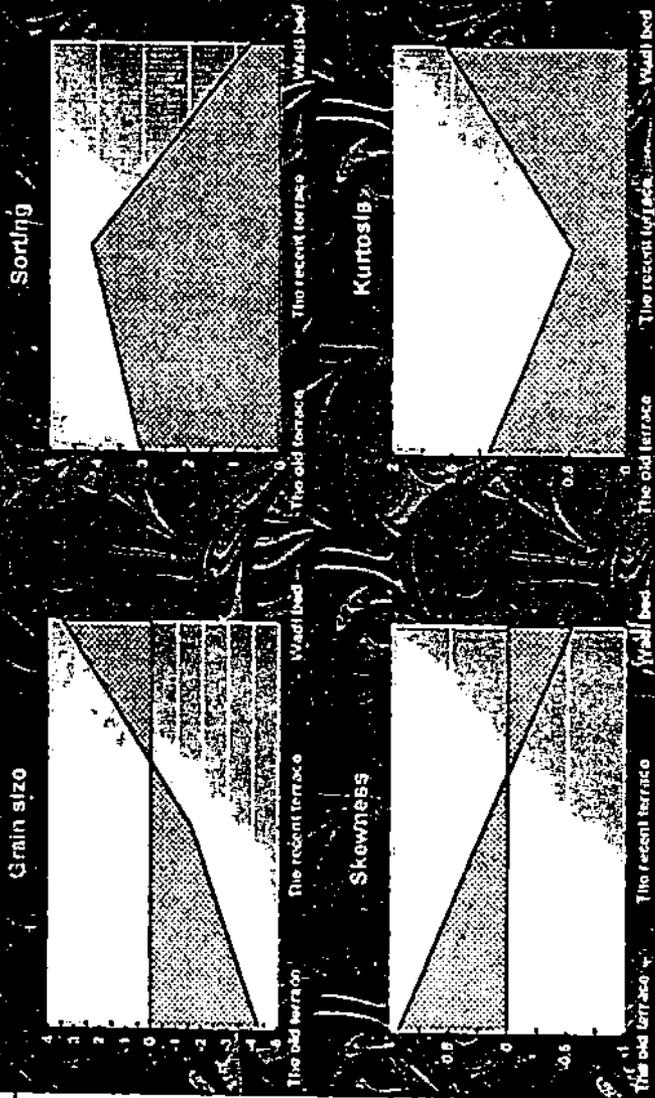
**(Table No. 3) Phi units at different percentiles and calculated parameters according to Folk & Ward (1957), for the studied terraces and Wadi bed samples.**

Phi values (Ø)	Percentiles										Statistical Parameters					
	P5	P10	P16	P25	P50	P75	P84	P90	P95	Mz	σ1	SK1	KG	PDØ	Md Ø50	
The old terrace	-6.50	-6.40	-6.35	-6.29	-6.10	-2.60	-0.30	2.40	3.55	-4.25	3.04	0.92	1.18	4.40	-6.10	
The recent terrace	-6.40	-6.30	-6.20	-6.10	-2.25	3.30	3.80	4.10	4.25	-1.55	4.11	0.21	0.46	5.20	-2.25	
The Wadi bed	1.80	3.00	3.25	3.50	4.00	4.20	4.30	4.36	4.45	3.52	0.66	-0.54	1.55	0.68	4.00	
The average										-0.76	2.60	0.19	1.06	3.43	-1.45	

**(Fig. No.7) Results of grain size analysis for the studied terraces and wadi bed samples**



(Fig. No. 8) Statistical parameters according to FOLK and WARD (1957) for the studied terraces and wadi bed samples.

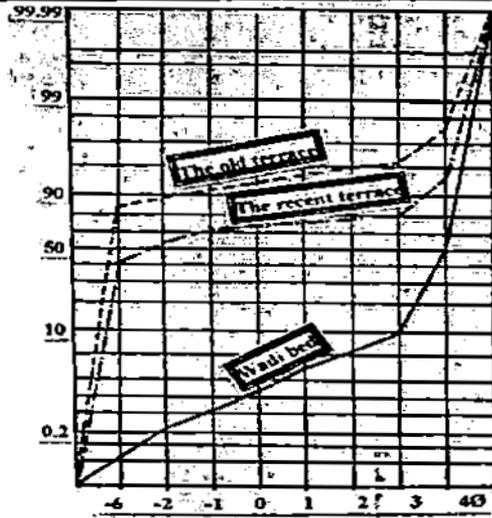


1.55 $\phi$  (very leptokurtic) at the Wadi bed, with an average of 1.60 $\phi$  (Mesokurtic). The old terrace and Wadi bed sediments have nearly the same kurtosis values, as show in table. No. 3 & Fig. No. 8. This lead to the conclusion that, kurtosis does not provide any environmental differences. The difference between kurtosis values of the old terrace and the recent one may only reflects a different degree of mean size and sorting.

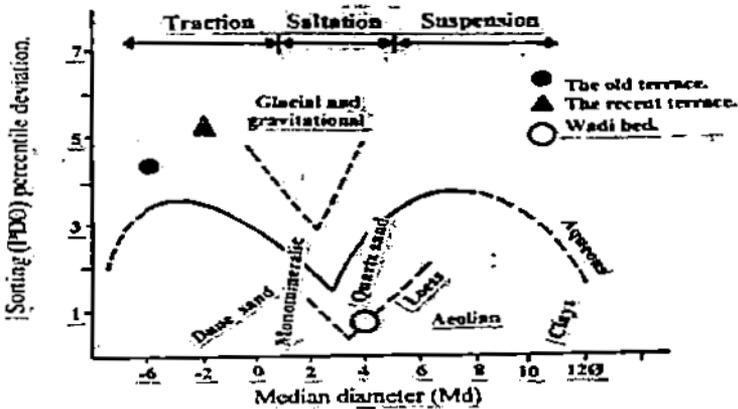
Finally and most important, that the old terrace formations are coarser, poorly sorted, strongly positive skewed, and have higher kurtosis value than the recent one. While the Wadi bed sediments are of very fine sand, moderately well sorted, strongly coarse skewed and have mesokurtic.

Applying the relationship between median diameter ( $Md\phi$ ) and the percentile deviation ( $PD\phi$ ), as outlined by Griffiths (16967), elucidates the characteristics and transportation media of the sediments. Data presented in table (3) and illustrated in figure (10), reveal that most terrace formations are transported by traction process, as  $Md\phi$  valued are - 6.10 $\phi$  and - 2.25 $\phi$ , while the  $PD\phi$  values were 4.40 $\phi$  and 5.20 $\phi$  for the old terrace and the recent one respectively. The most sediments of Wadi bed are transported by saltation and suspension processes as  $Md\phi = 4.00\phi$ , while the  $PD\phi$  value was 0.68 $\phi$ .

In conclusion, based on Fig. No. 10, the terrace and Wadi bed formations are mainly formed under fluvial environment which weathered and eroded from igneous and volcanic rocks. Where the water and weathering are the two mains factors responsible for their formation.



(Fig. No. 9) Cumulative curves of the terraces and wadi bed sediments.



(Fig. No. 10) Size M(d) and size sorting PDG of the studied terraces and Wadi bed samples (Griffiths, 1967).

### *Morphometric analysis of the terrace gravels*

To achieve this study, 300 pebbles and gravels were collected from the two terraces, i. e., 150 pebbles and gravel from each one. As much as possible, basaltic gravels were analyzed. Miller (1966) pointed out that at least 300 pebbles with lengths of 2 - 20 cm should be used to achieve the best results in morphometric studies of pebbles. The work of Nossin (1959) in the Pisuerga drainage basin of the Canlabrian mountains of Spain has also noted that up to 100 pebbles at each site (confining measurement where possible to pebbles of the same lithology) can produce very informative results.

Gravel sites were carefully selected with cuttings or quarries on two terraces. Krumbein and Pettijohn (1938) believe that this removes up to 50% of sampling error; where the pebbles had been shattered by weathering processes after their deposition, they were not included in the count. For this matter, mixture gravels were excluded from the samples to achieve the best result and minimum error of sampling.

Two dimensions were measured for each gravel : The longest axis (L). And  $1/2$  diameter of smallest convexity (DS)<sup>(\*)</sup>.

The results are showed in Table. No. 4, and also are illustrated graphically in Figure. No. 11.

The gravel analysis has provided a very illuminating result, which is discussed, blew:

---

(\*) Roundness ratio is  $2 (DS) / L \times 1000$  (Gouda, 1970). And also roundness ratio =  $I / L$

Where I = the intermediate axis, and L = the longest axis (Glover, 1971 & 1975)

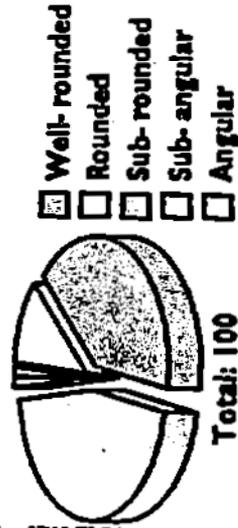
(Table. No. 4) Roundness ratios of terrace gravels

Gravel shapes	The old terrace		The recent terrace		average
	Total	%	Total	%	%
Well - rounded (800 - 1000)	-	-	2	1.3	1.3
Rounded (600 - 800)	7	4.7	16	10.7	7.7
Sub - rounded (400 - 600)	63	42	61	40.7	41.4
Sub - angular (200 - 400)	78	52	69	46	49
Angular (100 - 200)	2	1.3	2	1.3	1.3
The total	150	100%	150	100%	

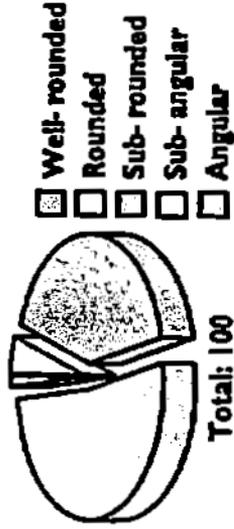
1. Roundness ratio has revealed significant differences between two terrace gravels. Whereas the general results of roundness ratios of both terraces gravel are : Sub - angular (49%), sub-roundness (41.4%), rounded (7.7%), well - rounded (1.3%) and angular gravel (1.3%) consequently, indicating varied energy conditions of deposition.
2. Most recent terrace gravels measured show higher roundness than the old terrace gravels. Whereas, the ratio of well rounded gravels (> 800) and rounded gravels (600 - 800) attained of 12% at the recent terrace, this ratio was not exceeded of 4.7% at the old one gravels. This means that the recent terrace sediments were deposited in climatic conditions characterized by heavy rains and strongly runoff, as compared to the conditions in which the old terrace was formed.
3. The ratio of sub - rounded (400 - 600) and sub - angular gravels (200 - 400) reached 94% at the old terrace, while it reached 86.7% at the recent one. this means that, the weathering processes had been active and effected the rock disintegration,

**(Fig. No. 11) Roundness ratio of terrace gravels  
of Wadi al Aqul**

**The recent terrace.**



**The old terrace.**



then the gravels have been rounded by hydrodynamic transportation.

4. There is a relationship between the roundness and the gravel size. However, the roundness values increase with the increase of the gravel size at the old terrace. In contrast the roundness values decrease with the increase of the gravels size at the recent one.
5. Some of gravels especially basaltic gravels are not deposited by the Al Aqul River (at the time of aggregation). These gravels have a ratio of roundness less than 200, as compared to with fluvial gravels overlying them, which reflects that the valley sides are the source of these gravels.
6. There are significant differences in the gravel roundness ratio of the terrace themselves. This may also be explained in terms of differences in energy conditions under which they were deposited.
7. Visual comparison for terrace gravels along the terrace belt indicates that the gravel roundness tends to increase towards the lower section of the Wadi. This confirms earlier findings by a number of fluvial geomorphologists that gravel roundness increases with distance of transport in streams.

***Summary and conclusions :***

The present study reveals that, the Wadi Al Aqul alluvial terraces could be classified according to their age and level into two type : The lower terrace is recent in origin. It was developed just above the Wadi floor, and extends parallel to the Wadi coarse on both northern and southern banks of the Al Aqul valley. The other terrace is older, higher and occurs as isolated remnants at the northern side of Wadi Al Aqul valley, but it disappeared entirely

underneath basaltic flow of Harrat Rahat at the southern side of the valley.

Determining terrace origins is not easy. Although we postulate guidelines for recognizing terraces of different origins, whereas, the terrace origins and development associated with complex response. According to the discussion of terrace distribution, morphology and grain size analysis are applied to their sediments. The study emphasized that Wadi Al Aqul terraces are basically attributed to changes in the climatic conditions during the recent geological periods (Pleistocene and Recent), or they may be a reflection of environmental changes of local base - level (Al Madinah basin), or they may be a result of both reasons. Furthermore, terrace sizes, morphology and distribution controlled by another different factors as follows :

1. The gradient and complicated topography of Wadi coarse due to the occurrence of high and low and also meander configurations are controlled and affected.

2. Hardness and resistance of rocks are main factors affected in decreasing of terrace sizes.

3. The complex stream current regime created by the complicated channel topography also played a leading role in distribution of terrace materials.

4. The shape and density of the terrace materials are affected. Usually, the variety of sediment shapes causes variations of the setting velocities for particles with the same intermediate diameters.

Grain size analysis indicates that Wadi Al Aqul terraces are mainly composed of pebbles, gravels and finer alluvium, while the sand is rare. For this matter, Griffiths's diagram reveals that most terrace sediments are transported by traction process. Moreover, the

old terrace formations are coarser, poorly sorted, slightly positively skewed and have higher kurtosis value than the recent one as the statistical parameters indicated. The differences in terrace formations may be explained in terms of differences in energy conditions under which they were deposited.

### *Acknowledgments*

I am deeply indebted to **Professor G. H. Gouda**, Prof. of Physical Geography, Department of Geography, Faculty of Arts, Alexandria University, for his continuous guidance, valuable advice during the preparation of this study and critically reviewing the manuscript. And also, I wish to express my gratitude to **Professor F. A. Abou - Raddy**, Prof. of Physical Geography, Department of Geography, Faculty of Arts, Alexandria University, and **Professor M. M. Khogali**, Prof. of Economic Geography, Khartoum University, and the Faculty of Education for Girls, Al Madinah Al Munawwarh, K. S. A., for reading the manuscript.

### *References*

1. Ali, A. A. (1996) : **Climatic Classification of Saudi Arabia Using Factor Analysis Techniques**, Bull. Soc. Géogr. d'Egypt, Vol. 69, pp. 80 - 96.
2. Baubron, J. C. (1976) : **Geomorphological Studies (1976), Mission (Part, 11) : K / Ar Measurements on "Recent" Volcanic Rocks from the Arabian Plate** : French Bureau de Recherché Géologiques. Open - files Report, Orleans, pp. 1 - 22.
3. Bloom, A. L. (1968) : **Geomorphology, Systematic Analysis of Late Cenozoic Landforms**. New Jersey, p. 284.

4. Duane, D. B. (1964) : **Significance of Skewness in Recent Sediments, West Pamlico Sound, North Carolina.** Jour. Sed. Petrol. 34, (4), pp. 864 - 874.
5. Folk, R. L. (1974) : **Petrology of Sedimentary Rocks** Hemphill. Co., Austin. Texas, p. 170.
6. Folk, R. L. and Ward, W. C. (1957) : **Brazos River bar - a Study in the Significance of Grain Size Parameters,** Jour. Sed. Petrol. Vol. 27 (1), pp. 3 - 26.
7. Friedman, G. M. (1961) : **Distribution between Dune Beach and Sands from their Textural Characteristic.** Jour. Sed. Petrol. 31., pp. 514 - 520.
8. Gilbert, G. K. (1977) : **Report on the Geology of the Henry Mountains, US. Geol. Survey, Rock. MT. Region, Washington.**
9. Glover, B. K. (1971) : **A morphometric Analysis of Terrace Gravels in Santa Ynez Basin, Santa Barbara Country, California,** Sedi. Geol., 13, pp. 109 - 124.
10. Gouda, G. H. (1970) : **Methods of Petrography Research for Geomorphologic Study,** Bull. Soc. Géogr. d'Egypt. Vol. (3), pp. 1 - 41 (in Arabic).
11. Gregory, K. J. and Walling, D. E. (1973) : **Drainage Basin Form and Process - A Geomorphological Approach.** New York, p. 59.
12. Griffiths, J. C. (1967) : **Scientific Method in Analysis of Sediments.** Mc Graw - Hill. Book Comp. New York.

13. Howard, A. D. (1959) : **Numerical Systems of Terrace Nomenclature : A Critique.** Jour. Geol., 67 (2), pp. 43 - 239.
14. Howard, A. D. (1967) : **Drainage Analysis in Geologic Interpretation : A Summation the American Association of Petroleum Geologists, Bull, Vol. (5), No. 11, pp. 2246 - 2259.**
15. Krumbein, W. C. and Pettijohn, F. J. (1938) : **Manual of Sedimentary Petrography,** Appleton, Inc., N. Y.
16. Martins, L. R. (1965) : **Significance of Skewness and Kurtosis in Environmental Interpretation.** Jour. Sed. Petrol. 35. pp. 760 - 770.
17. Middleton, G. V. (1976) : **Hydraulic Interpretations of Sand Size Distribution.** Jour. Geol., 84, pp. 1405 - 1422.
18. Miller, V. C. (1966) : **A Quantitative Study of Drainage basin Characteristics in Clinch Mountains Area, Virginia and Tennessee.** New York, pp. 1 - 48.
19. Morisawa, M. (1985) : **Rivers : Form and Process.** New York, pp. 123 - 125.
20. Nossin, J. J. (1959) : **Geomorphological Aspects of the Pisuerga Drainage Area in Cantabrian Mountains.** Leidsche, Geol. Meded. 24., pp. 283 - 406.
21. Odeh, S. A. and Salameh, H. R. (1996) : **Geomorphology of Wala - Hidan Valley Terraces in Jordan.** Bull. Soc. Géogr. d'Egypt, Vol. 69, pp. 16 - 46.

22. Pellaton, C (1981) **Explanatory to the Geologic Map of the Al Madinah Quadrangla, Sheet, 24 D Kingdom of Saudi Arabia**, pp. 1 - 19.
23. Ritter, D F., Kochel, R. C. and Miller, J. R. (1995) : **Process Geomorphology**. Third edit. London. pp. 240 - 246.
24. Said, A M. (1990) : **Physical Geography of Kingdom of Saudi Arabia, Jeddah**, pp. 82 - 99 (in Arabic).
25. Small, R. J. (1989) : **Geomorphology and Hydrology**. Long. London. New York, p. 28.
26. Thornbury, W. D. (1969) : **Principles of Geomorphology**, Wiley, New York, p. 157.

\* \* \*



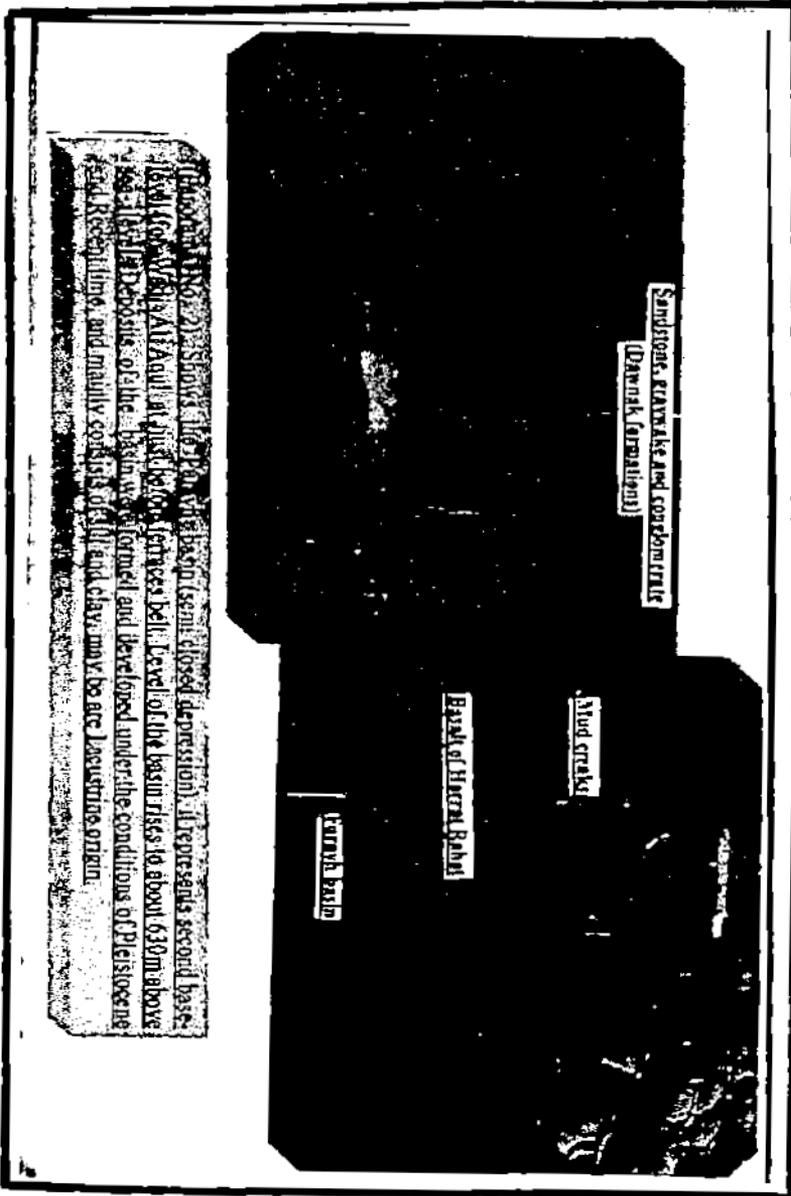
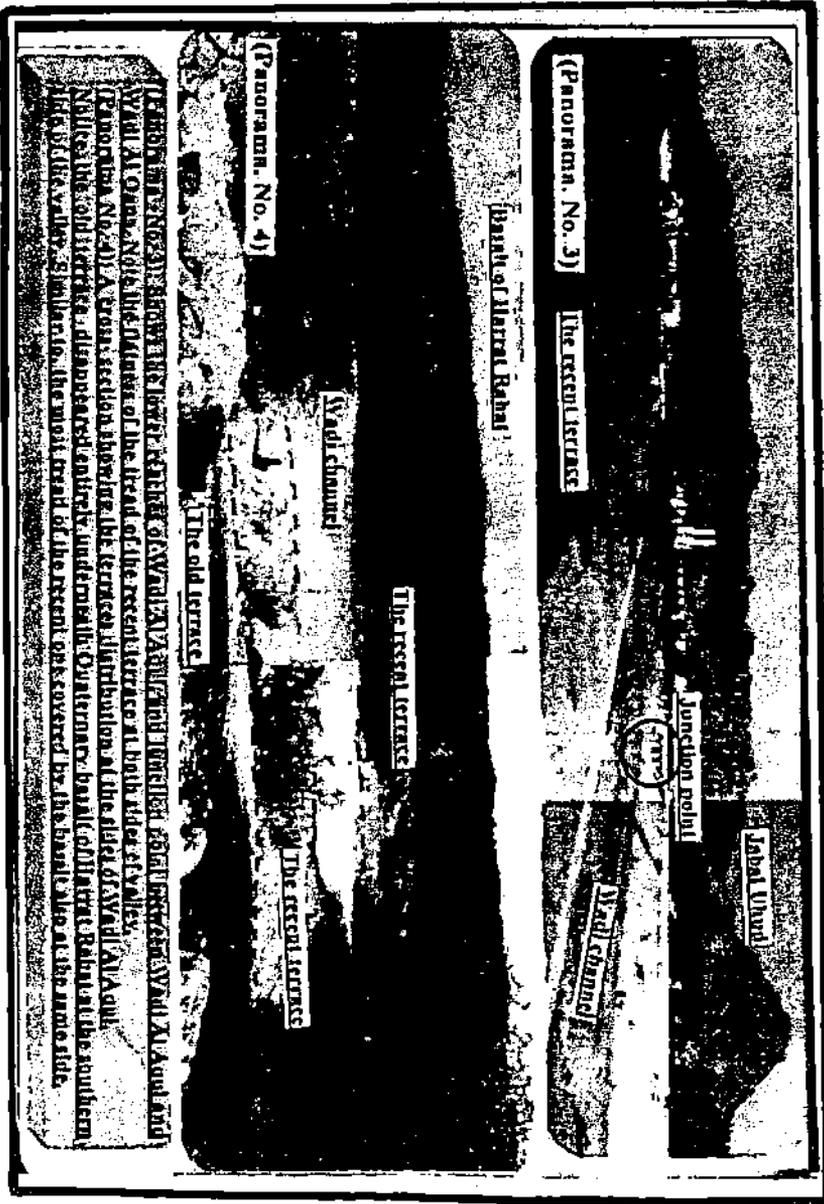


Figure 2 shows the basin (semi closed depression). It represents second base level of the Hazrat Rahat at the level of the terrace belt. Level of the basin rises to about 630m above sea level. Deposits of the basin are formed and developed under the conditions of Pleistocene and Recent time and mainly consists of fill and clay may be of lacustrine origin.



(Panorama, No. 3)

The recent terrace

Bank of Harat Bahat

Junction point

Wadi Uhorat

Wadi channel

(Panorama, No. 4)

Wadi channel

The recent terrace

The recent terrace

The old terrace

TERACE AND WAD CHANNELS IN THE TERRACE FIELD OF WADI AL ORAH. A WAD CHANNEL CUT THROUGH THE TERRACE FIELD OF WADI AL ORAH. WADI AL ORAH, NEAR THE MOUTH OF THE FLOOD OF THE RECENT TERRACE AT BOTH SIDES OF WADI AL ORAH. (Panorama No. 3) A CROSS SECTION THROUGH THE TERRACE DISTRIBUTION OF THE FIELD OF WADI AL ORAH. NOTICE THE OLD TERRACE, DISAPPEARING UNDER THE QUATERNARY BANK OF WADI AL ORAH. RAHAT AT THE SOUTHERN END OF THE VALLEY. SIMILARLY, THE MOST TREAD OF THE RECENT ONE COVERED BY THE BANK OF WADI AL ORAH AT THE NORTHERN END.

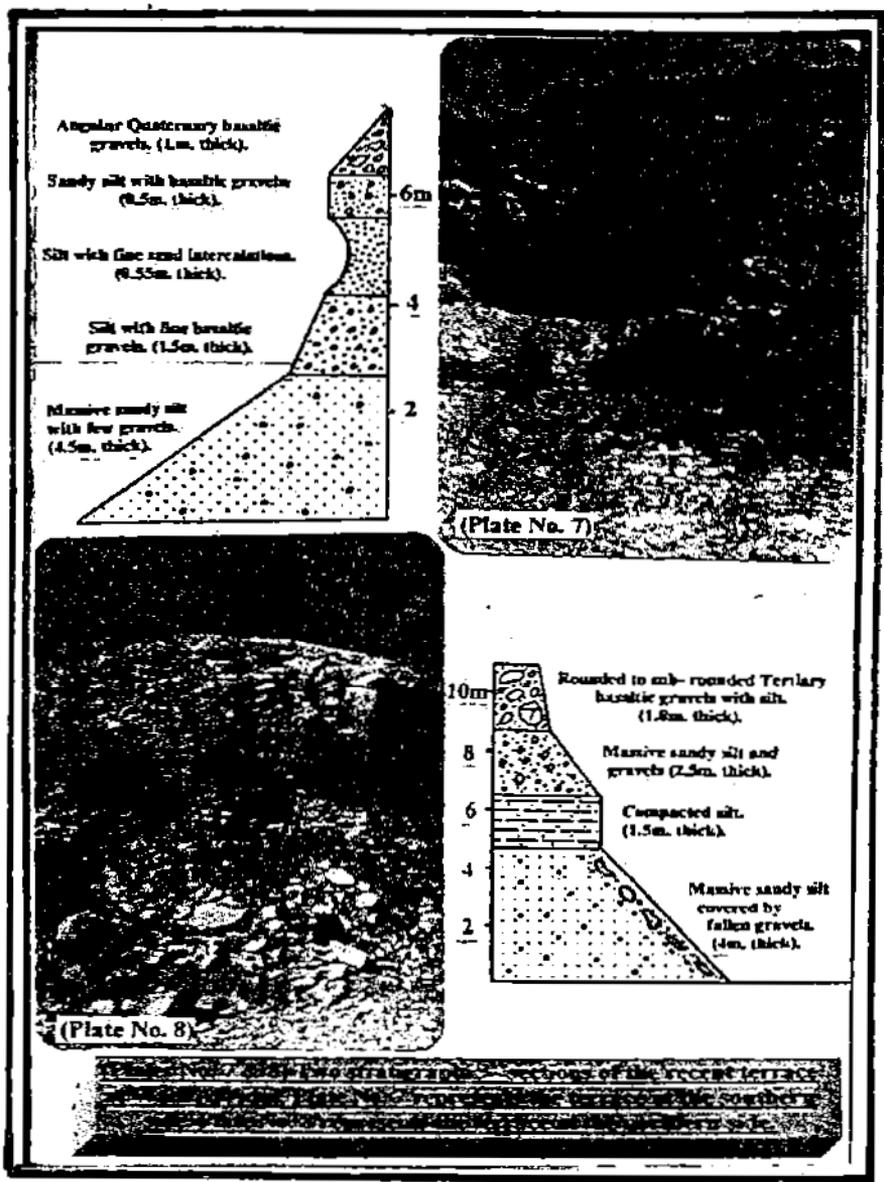


(Panorama No. 5)

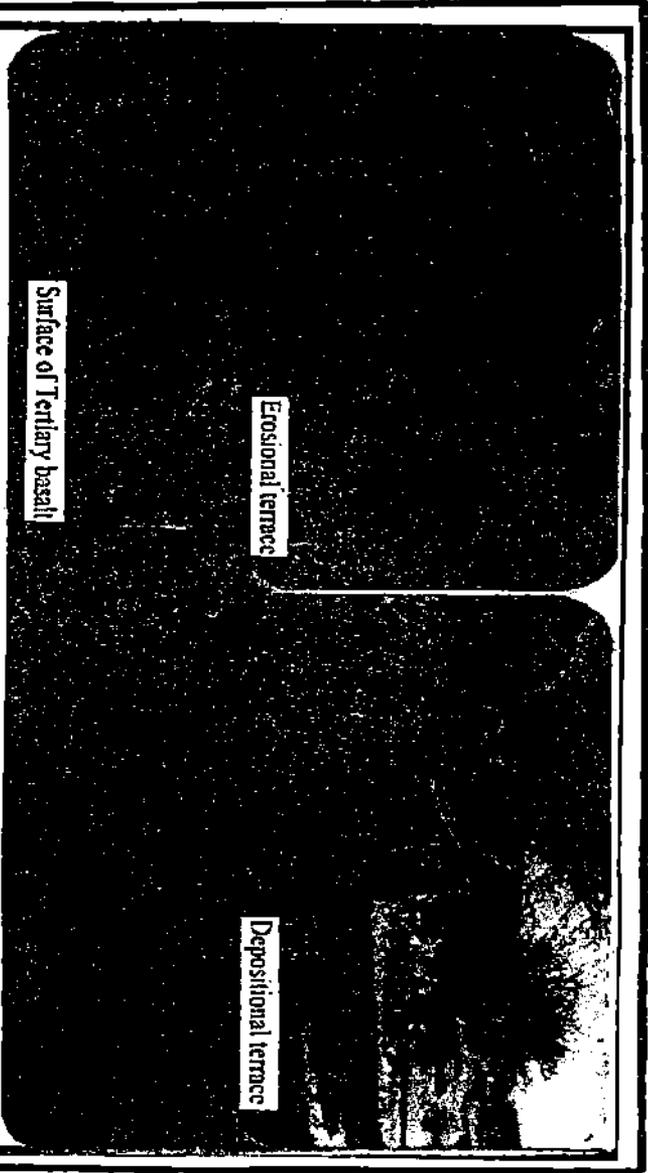


(Panorama No. 6)

(Panorama No. 5 & 6) Show the true thickness of the recent terrace on the northern and the southern sides of Wadi Al Aqab. Notice the recent terrace has been at same level on both sides of the valley (paired terraces).



1  
1  
1  
1  
1  
1  
1



Erosional terrace

Depositional terrace

Surface of Tertiary basalt

(Photogram No. 91) Aerial section shows two types of terraces in the southern side of Middle Atlantic Plateau. Erosional terrace (left) alluvial cover. With truncation of underlying Tertiary basalt of Harrell, Rains, (Osborne) and Depositional terrace (right) underlain by alluvium. It is the highest level of fill deposited in valley.