

Geomorphological Evidences of Climatic Changes in Northeastern Badia of Jordan (Research Note)

*Iyad A. Abboud **

ABSTRACT

Wadi Muqat occupies the Central Wadian (The system of Wadis in the study area) Area, and forms the main drainage system of the Hammad Basin in the NE Badia region of Jordan. Its general drainage is towards the north and ultimately into Qaa' Al-Musmma in Syria. The drainage patterns, which cover the area, include dendritic, subdendritic, distributary, anastomatic and multi basinal patterns with a coarse Wadi texture.

Quaternary sediments in Wadi Muqat include a coarse alluvial Wadi deposits, alluvial fan deposits and fine-grained clay-silt Qaa' deposits. Wadi and alluvial fan deposits are formed of locally derived debris of limestone, basalt and chert pebbles and gravels.

A series of Qaa's occur along Wadi Muqat and represent the site of laminated/varved clay-silt deposits indicating that these Qaa's were occupied by lakes probably formed by natural blocking of the Wadi course by alluvial fans or any coarse Wadi deposits. These lakes are indicated not only by the type of Qaa' deposits, but also by remnants of old shorelines in some places. They indicate a wetter climate during the Late Quaternary. Two main shorelines were determined and constructed for the lake of Wadi Muqat system by aerial photographs and field trips.

Keywords: Geomorphology, Jordan, Qaa', Lake Burqu', Fans, Badia.

1. INTRODUCTION

Morphological and geomorphological evidences provide a useful starting point in the investigation of Quaternary environments. There is sufficient morphological and lithological evidence to show that major climatic changes have affected many regions in the world during the Quaternary (Lowe and Walker, 1984).

During the Quaternary period many major changes in the types and rates of operation of morphological and geomorphological processes appear to have taken place in many parts of the world. These include expansion and contraction of lake areas affected by climatic change activity, fundamental changes in the regimes of many of the major rivers and the nature and effectiveness of morphological and geomorphological processes (Lowe and Walker, 1984).

The fundamental morphology evidence used to reconstruct palaeolake chronologies is shoreline evidence (Sack, 1994). Detailed mapping of principal lake levels is crucial in accurately determining the magnitude of changes in palaeolake surface area and elevation (Street-Perrott and Harrison, 1985). In the low latitudes, phases of aridity were interspersed with periods of wetter climatic conditions, so that desert regions were often more extensive during the Quaternary (Lowe and Walker, 1984).

The record of lake-level fluctuations in large lakes can be obtained through several methods of investigations. The first is the study of ancient shoreline, which can help to document past lake-level highs. Such morphological features are sometimes so obvious and extensive across the landscape that they are distinguishable on aerial photographs, especially in extensive lacustrine systems. It must be remembered through that only the regressive phases leave shoreline on the landscape. Transgressive lake phases will tend to rework ancient shoreline (Bowen, 1978).

* Institute of Earth and Environmental Sciences, Al Al-Bayt University, Al-Mafraq, Jordan. Received on 7/3/2005 and Accepted for Publication on 9/4/2007.

Emphasis in this work is placed on reconstruction of the climatic conditions, landform classification and description with respect to structure, deposition and denudation of the Late Quaternary in the northeastern desert part of the Badia region in Jordan.

2. STUDY AREA

2.1. Location

The studied area (Wadi Muqat basin) constitutes a small part of the Hammad Basin, which covers a very large area including the southern part of Syria, westernmost part of Iraq, and northernmost part of Saudi Arabia, in addition to the central part of NE Jordan (Figure 1).

The area is located between latitudes $31^{\circ} 30'$ to $33^{\circ} 20'$ north, and longitudes $36^{\circ} 30'$ to $39^{\circ} 20'$ east. The

study area is divided into two basins; Al Harra basalt plateau constitutes the western part of the basin in Jordan, and the limestone desert plateau constitutes the eastern part and the floodplain area is in the center. Numerous Wadis are distributed over the area of the basin.

Most of the surface of Hammad Basin is relatively flat with numerous hills distributed in the region, and the Eastern Jordan Mountains series in the east. The elevations in the basin range from 500 and 950 m.a.s.l. (Figure 2). The area is drained by the Wadi system, nameless, Wadi Muqat.

Wadi Muqat extended from the southern part of the Hammad Basin to the northern part forming main drainage system in the area with some contribution from small Wadis from surrounding areas, with different amounts of water retained from water rainfall and water runoff.

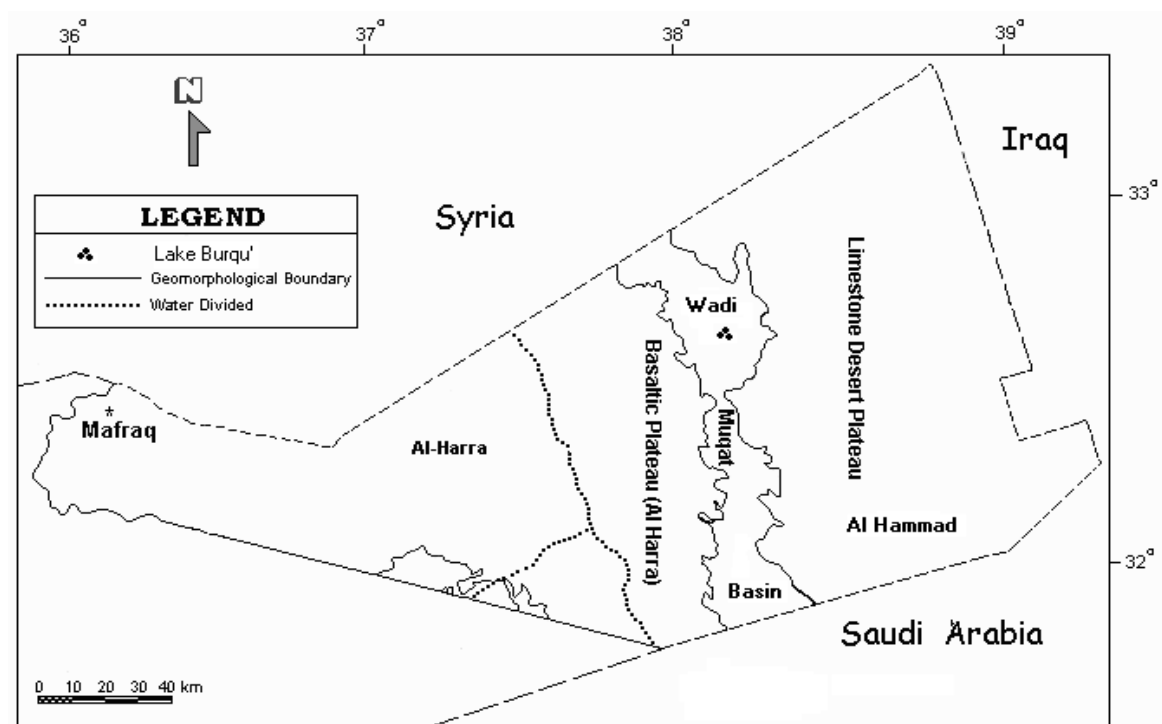


Figure 1. Location and general geomorphological features map of the study area in NE Jordan.

2.2. Geological Setting

Three types of rocks and deposits are exposed within the studied area, namely: volcanic and sedimentary rocks and superficial deposits.

Quaternary continental basalts and volcanic tuffs are predominant in NE Jordan and cover approximately 11200 km². The basalts of NE Jordan show several eruptive forms including widespread flows characterized by fissure eruptions, valley-fill lavas and explosive

volcanic cones (Bender, 1974).

Unconsolidated superficial Quaternary deposits; fans, mudflats, Qaa's and lacustrine deposits cover most of the NE part of Jordan with a maximum thickness of about 15m in the center depression of Qaa's (Abboud, 1999).

The Wadi deposits are coarse-grained consist, dominantly, of black angular fragments of chert and small fragments of basalt and limestone. These fragments represent the erosional products of the regional bedrock.

The basalt fragments are derived from Al Harra basalt flows; the chert and limestone fragments are derived from the formations in the area. Also surrounding Qaa's or

bounding some Wadis are unconsolidated alluvial fans which consist of gravel, sand and some clay in some places (Abboud, 1999).

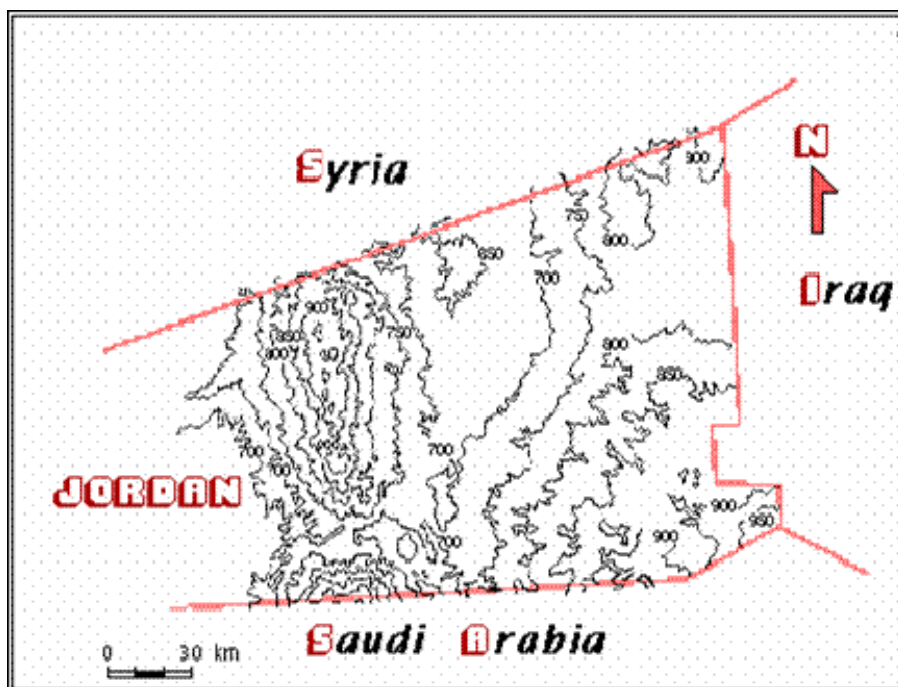


Figure 2. Topographic contour lines of the study area.

In the Qaa's, water may accumulate during winter season. Sediments are mainly soft clay, silt and sand grains which combine to form mudflats or siltflats (Qaa' deposits) (Abboud, 1999). Sometimes, small boulders of basalt, black chert and gravel, which are derived from various lithological units, are found. These forms of deposits occur in open or closed depression regions (Figure 3) (Abboud, 1999).

2.3. Soil and Vegetation

Landform features of Hammad Basin are mainly controlled by soil and vegetation types. Physical and chemical properties of soils, such as salinity, silt and calcium content, organic matter and others, are important in determining the soil structure and type of vegetation.

Parent materials, topography and climatic conditions have controlled the formation, type and properties of the soil in Hammad Basin. Depending on parent materials two types of soil were found. On the basalt plateau soils appear to be essentially composed of silt and medium sands. This type is derived from the lava flows and represents most of the soil in the Badia region. This soil has low organic matter content is often gypsiferous, and

calci with fragments of black angular chert and basalt (WAJ, 1995; Abboud, 1999).

On the East of Jordan limestone plateau, the soils are associated with parent materials including limestone, fragments of black chert, chalk, calcareous sand, gypsum and marls. Soil in the limestone plateau area appears as a solid block of silt and sand with other gravel fragments. Generally, the soil of Hammad Basin is poorly developed as is characteristic of the arid soils of desert areas (Abboud, 1999).

Land vegetation cover in the Badia region is not sufficiently dense and has low production levels. Vegetation is generally found in Wadi beds and in some places, where flood runoff occurs.

2.4. Geomorphological Features

Geomorphological and lithological evidences indicate major climatic changes that were effected in many regions in the world during the Quaternary period. The study area encompasses 19800 km², within the Hammad Basin and the Jordanian Badia. The part of Hammad Basin in Jordan lies east of the Azraq catchment divide covering an area of approximately 18250 km² (Figure 1).

The elevated ground of Tulul Al Ashaqif dominates the Western Hammad, where the Al Harra Basalt crops out. Elevations generally range between 800 to 900m.a.s.l. reaching up to 1000m.a.s.l. In the mudflat area in the center, elevations are about 650m.a.s.l. they raise in the southeast to approximately 900m.a.s.l. and in the northeast to about 800m.a.s.l.

The floodplain areas have many small flat shallow basins that act as water entrapments during the wet seasons. These are locally called Khabary (Singular: Khobra) and are usually inhabited by Bedouins when water is available in them; they normally dry up in the summer. These Khabary occur along the west margin of the central floodplain area, bordering the basalt plateau as Abu Elhussain Khobra.

2.5. Topographical Features

Aerial photographs have formed for decades the basis for geomorphological mapping in deserts. Their perspective, detail and stereoscopic potential provide a valuable basis for field mapping and opportunities for monitoring environmental changes (Cooke *et al.*, 1993).

Conventional black and white aerial photographs, actual scale 1:25,000, taken by Geographical Royal Center in 1961, were used to produce a geomorphological map of the study area with sufficient accuracy to show the relevant features. Fieldwork succeeded and preceded aerial photographic study to verify the interpretations.

The detailed geomorphical map, which was compiled of the study area, is shown in Figure (4).

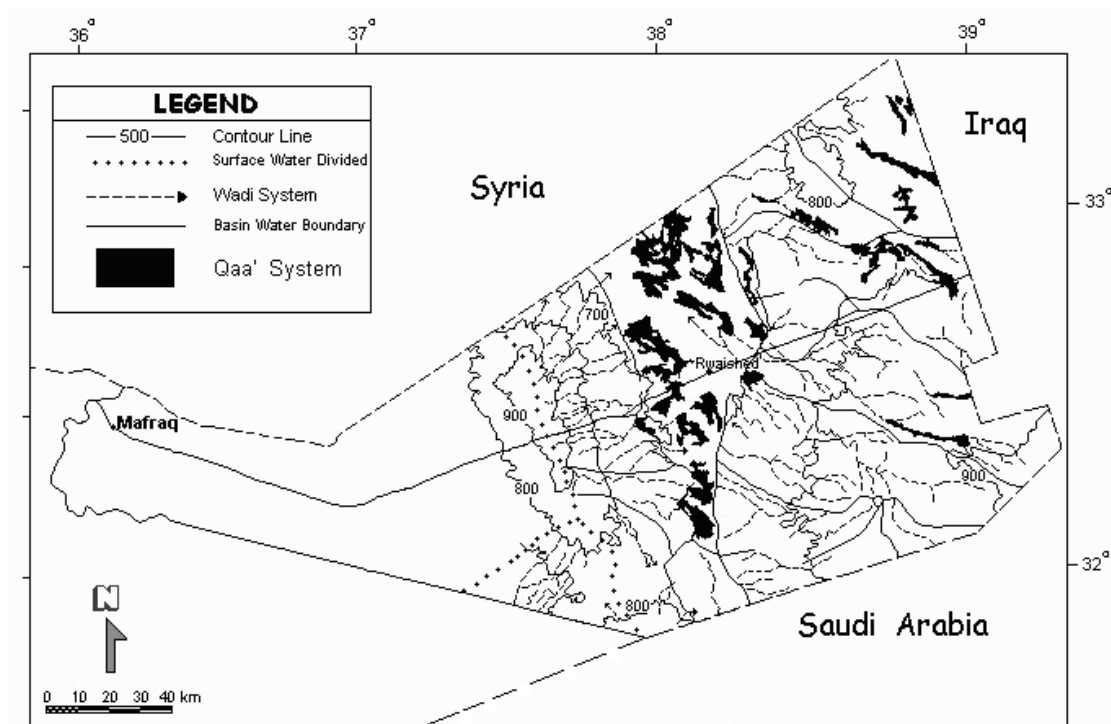


Fig 3. Qaa' and wadi systems distribution in study area, NE Jordan.

3. DISCUSSION

In the following section the identified land systems of the Jordanian Hammad are geomorphologically classified according to a number of important parameters and at a number of scales, as: Basaltic flows, Qaa' system, drainage system, limestone plateau ...etc. At the largest scale of land systems can be divided into three subdivisions (Figure 1), these areas:

Basaltic Plateau (Al-Harra): This plateau consists mainly of basalt lava flows that cover the western

part of the studied basin with an area of 10100 km² (about 27.5% of the total Jordanian Hammad Basin). The maximum elevation in Tulul Al Ashaqif is about 1046 m.a.s.l. and rises to about 1114 m.a.s.l. at Ed Duruze Mountain which gently slopes towards the southwest. Many small Qaa's and Marabs are found in the valleys that cut this plateau. To date little development has taken place in this area.

Central Wadian Area (Wadi Muqat Area): This geomorphological unit consists of wide converging Wadi systems that drain the Basaltic Plateau to the

west and the Limestone Desert Plateau to the east. Numerous Qaa's, Marabs, Khabaries and alluvial fans are found along this Wadi system. It covers an area of about 14290 km² (41.9%). The general slope of this area is in a northward direction, and its lower basal part lies nearer to the Syrian borders with a general elevation of about 650 – 700 m.a.s.l.

Limestone Desert Plateau: The main mountains of the Jordanian Hammad occur in the Limestone Desert Plateau with a maximum elevation at 1011 m.a.s.l. The land surface generally slopes towards the north. These mountains cover about 11220 km² (30.6% of the total Hammad Basin) in Jordan.

At intermediate and small scales individual land systems can be defined based on geological and geomorphological characteristics. These features are shown on the geomorphological map (Figure 3); a few of the more important features are briefly described here:

- **Qaa' and Marab:** The size, location and sedimentary characteristics of the features vary in size and depth from Qaa' to Qaa' across the study area. These features include any flat-bottomed basin and mainly filled with fine sediments.
- **Wadi systems (Drainage system):** The Wadis vary in size and morphology. In some cases the variations can be related to geological subdivisions and structural controls.
- **And some specific ground surface cover characteristics:** The size and spacing of basalt boulders, the presence and lithology of reg deposits and the extent to which ground clearance has been undertaken. Some areas can be seen to have large boulders, whereas others have just small angular fragments. Extensive Wadi systems can be seen to traverse the area and many varieties of water laid sediments, varying in size and character, are also present. Thus it can be seen that the Badia shows variable geomorphological characteristics (WAJ, 1995). Satellite images of the Badia region can distinguish twelve geomorphological subdivisions or zones (Al-Homoud *et al*, 1995; Davies, 1995; Abboud, 1999). Four of these zones (Zones 1,2,3 and 4) constitute an important part of the study area. The main characteristics of the geomorphological zones in the study area are outlined as follows:
- **Zone 1:** Light colored basalt outcrops with a small number of Qaa's, suggesting more porous lava flows and forms, slightly higher topography than the

surrounding area. The zone divides the drainage into east and west.

- **Zone 2:** The main area of basalt outcrops, with numerous Wadi systems and Qaa' deposits. The Wadis are highly interdigitated and frequently incised, particularly as individual channels merge towards the south. Many of the Wadis flow to the east and south.
- **Zone 3:** This zone occurs at the far northeast corner of the study area. It is characterized by predominantly parallel, northwest to southeast trending Wadi systems and Qaa' deposits. Many of the fine, water laid deposits take the form of thin, linear strips, following the line of major Wadis.
- **Zone 4:** A region with a thin cover of aeolian sediments, forming small, linear dunes in some places and with frequent rock outcrops where wind blown sediments are lacking. Some major Qaa' deposits occur in the north, fed by Wadi systems draining from northwest. The Qaa' deposits are absent in the south. Qaa' systems in study area are lies between geomorphological features of zone 1 and zone 2.

3.1. Lake Burqu'

Lake Burqu' is located within Wadi Muqat basin north of Rwaished town, which is about 18 km north of Amman-Baghdad highway and the distance from Amman to the lake is about 283 km (Figure 1). The access to Lake Burqu' is through unpaved roads at undefined Qaa's and Wadis.

Lake Burqu' covers an area of approximately 1.875 km² with an ellipsoid shape, about 2500 m long and 200-500 m wide, and is oriented in a north-south direction. It is located behind a man-made small dam, which block the Wadi. Large Qaa' which represents a playa of a palaeolake that covered an area of about 409 km², surrounded by an arid catchment basin of about 19800 km². Lake Burqu' and surrounding Qaa's may represent the largest of the Late Pleistocene lakes in northeastern Jordan. It is a closed basin connected with ephemeral Wadis that feed the lake with seasonal rainwater. Water input to the lake is the result of surface runoff from Tulul Al Ashaqif to the west and the Saudi Arabian high lands to the south.

Lake Burqu' lies along the main course of Wadi Muqat on the edge of the basalt plateau between two blocks of small dykes, which bounds the basin from west

and south, and the limestone desert plateau which bounds the basin from the east. Alluvial fan deposits cover the area north of the lake.

Qasr Burqu' is a ruin building at the eastern bank of Lake Burqu', and is surrounded by Al Harra basalt flow.

The building exists in a zone that provides water and grazing through the dry season in the Badia region. This suggests that the location of this building is for defensive reasons, a rest point for the travelers in the middle of the desert, and/or a Qasr for recreational reasons.

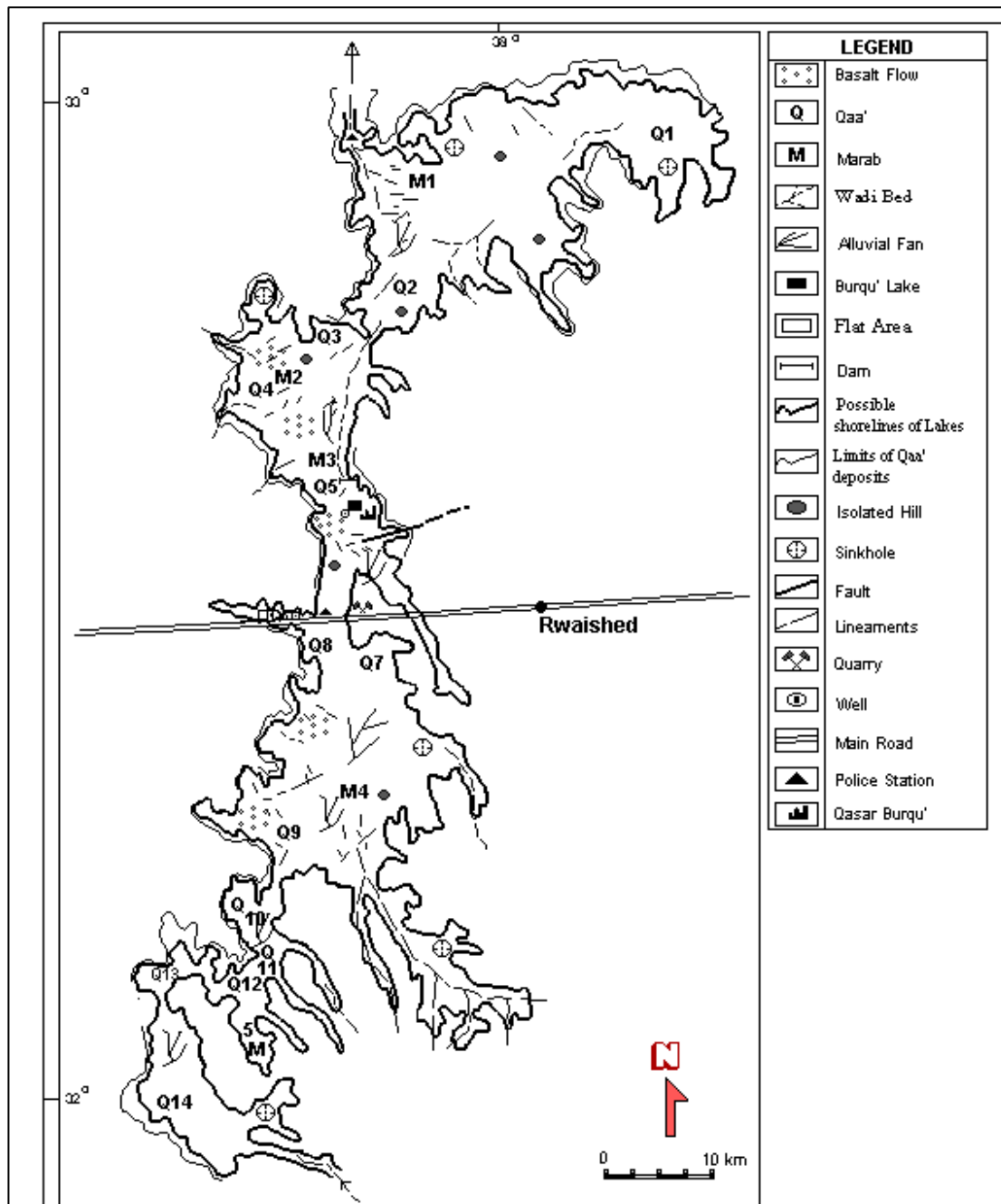


Figure 4. Geomorphological Map of the Wadi Muqat system, NE Jordan.
Prepared from topographic maps, aerial photograph and filed work.

3.2. Qaa' Systems

A distinctive feature of the study area is the presence of large number of basins with surfaces of fine-grained sediments, known locally as Qaa' and Marab (Abboud,

1999). They represent areas of sediment and water accumulation and storage in topographic depressions. In general geological terms, Qaa' is either a dry lake or a playa. The local term Marab is used to indicate a pan in

which abundant natural vegetation occurs. Many Marabs have been tilled by Bedouins and some appear to be low angle fan deposits grading into Qaa' sediments (WAJ, 1995; Abboud, 1999). Playa deposits have received much attention due to their value in determining the nature of climatic and ecological changes in desert basins during the Quaternary (Chivas *et al.*, 1986). Land Systems Mapping and inspection of the 1:25,000 aerial photographs suggest a tentative classification of pans into three broad groups; e.g. WAJ Report 2, (1995):

- **Small closed basin pans.** These occur in the younger ridged lavas and show highly irregular topography. Associated channel networks are usually limited. Watersheds are clearly defined and the Qaa's represent areas of local silt and clay accumulations from the surrounding slopes.
- **Pans with distinct Wadi inlets and outlets.** These features are often locally referred to as Marab, they occur where a basin exists along the axis of a Wadi, and are characterized by very low angle, fine-gravel fans, which extend from the Wadi inlet out into the pan.
- **Large inflow pans with limited outlet drainage.** These tend to be pans with the largest catchment areas. They have limited or no outlet drainage.

Areas lying within Marabs are topographically lower than the outlet Wadi. Pans (Qaa's) are considered important areas to study because appropriate soil and water management techniques may promote rangeland or agricultural production. In order to evaluate the potential of pans it is necessary to examine the variation in their sedimentary characteristics.

Qaa's in the study area are distributed over a large area with different sizes and shapes, while many Wadis connect most of the Qaa's with each other. Although the surface of Qaa's seemed uniformly flat and smooth, hard mud cracks appear on the dry clay surface. Qaa's in the study area were used to examine the palaeoclimatic indicators in the Eastern Jordanian Badia.

The materials of Qaa' consist of calcium carbonates, quartz, kaolinite with low proportions of evaporates (Abboud, 1999). These sediments are often impermeable. In some places the base of Qaa' sediments is basaltic flows which originally flooded the lakes. The quantity and quality of eroded materials reaching the lakes depend on the geological and climatic environment conditions within the large basin. Sheets of silty-clay sediments are present over the entire Qaa' surface, whereas at the

mouths of Wadis, pavements of small fragments of basalt and chert pebbles and gravels are present, which may disappear at the centre of Qaa's.

3.3. Wadi Systems

The Wadi systems which drain the study area are extensive and their flow directions may be classified into three distinct complexes:

- The main Wadi flowing from south to north; their drainage basins are entirely developed within the central Wadian area and limestone desert plateau.
- Wadis flowing from east to northwest; their drainage basins are entirely developed within the limestone desert plateau.
- Wadis flowing from the west to northeast; their drainage basins are entirely developed within the basaltic plateau.

In general, drainage from Tulul (Hill) Al Ashaqif is into the flat areas to the East and northeast towards Syria. In East Jordanian Hammad drainage is to the northwest mainly into the low-lying flats of Rwaished. Drainage is well defined over the hilly area of Tulul Al Ashaqif and to a lesser degree in southeast Hammad, but becomes diffused in the mud flats, north of Rwaished.

Aerial photographs show that the drainage patterns consist of dendritic, subdendritic, distributary, anastomatic and multi basinal patterns with a coarse Wadi texture. Over the basalts there are eight main Wadis. Individual Wadi catchments are small, less than 800 km², whilst the total area of all catchments is 3330 km² (WAJ, 1995; Abboud, 1999). The mudflats to the east are fairly extensive, especially north of Rwaished, and cover an area of 3450 km² (WAJ, 1995). In the limestone desert plateau, catchments are much larger. There are seven main Wadis; these are from south to north (after report 2 of Ministry of Water and Irrigation; Water Authority, 1995): Wadi Ed Dumeitha (480 km²), Wadi Um Tuis (870 km²), Wadi Rwaished Abu Hifna (1960 km²), Wadi Rwaished and Wadi Abu Al Trafi (2230 km²), Wadi Rishaat Umm Rujum (2070 km²), Wadi Sehiliya (1020 km²), Unnamed Wadis in northeast corner (1530 km²) and Other unnamed Wadis (1310 km²).

In the basalt area, Wadi courses are well defined and contain coarse volcanic detritus. Over the limestone areas, Wadi bed sediments tend to consist of fine silty material whilst in the mudflats they are mostly clays (WAJ, 1995; Abboud, 1999).

Within the courses of all of the Wadis in the area, chains of small silty-sandy bars occur as a result of supply at times of high influx. Some Wadis are wide and divided into braided channels whereas some are debauch. This reflects the high amount of runoff, which causes large

erosional channels and sedimentation rates in different phases. Moreover, peak flows in Wadis during wet seasons can be considerable. However, the surface water resource is poorly managed, drains away very rapidly and is not retained or utilized for the benefit of the area.

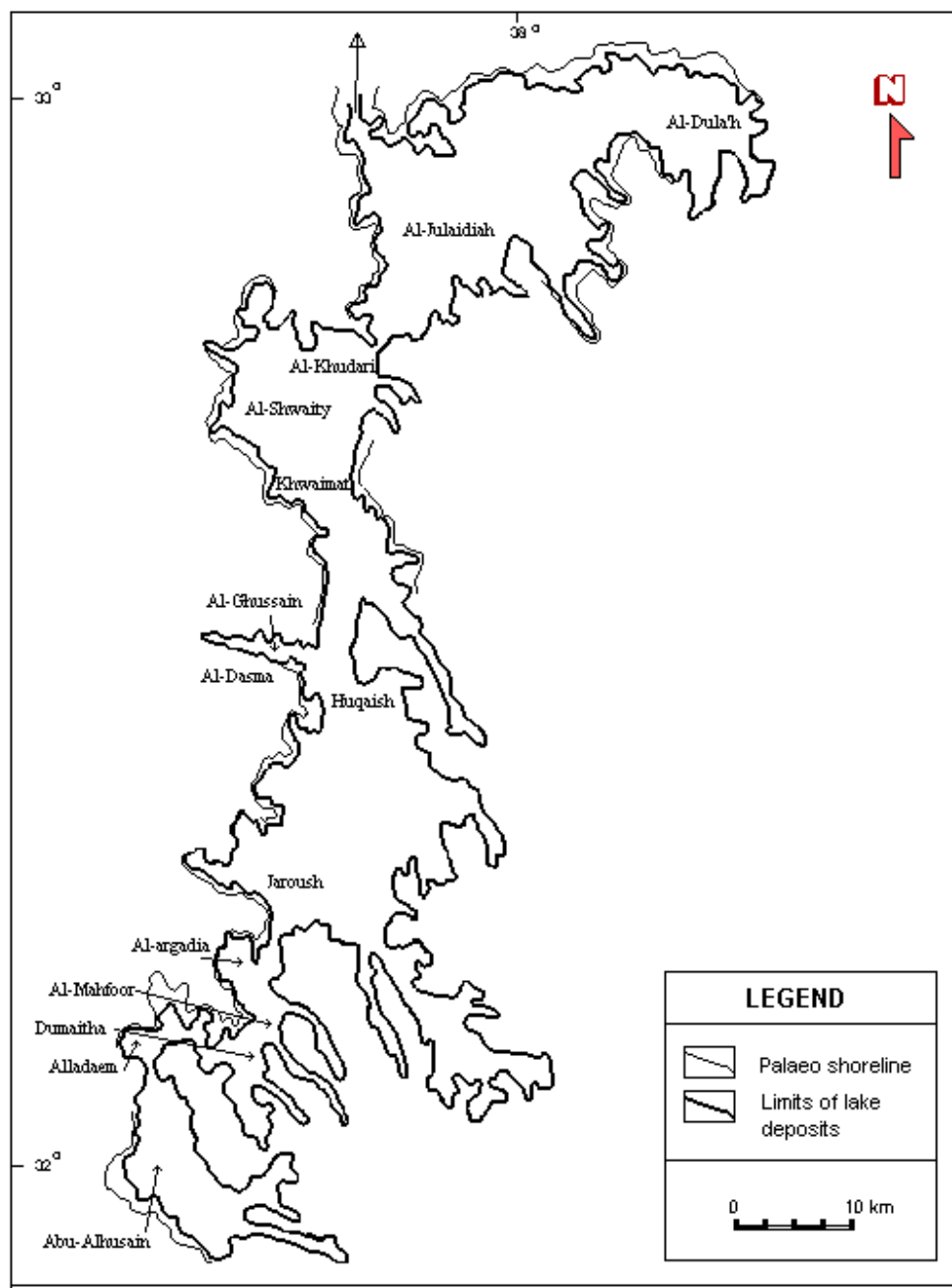


Figure 5. Old shorelines and limits of lake deposits of Muqat palaeolake system.
Prepared from topographic maps, aerial photograph and filed work.

3.4. Alluvial Fans

The other key geomorphological feature in the area is the alluvial fans deposits that encroach on the mouth of Wadis and/or built up along the catchment of Wadis. Alluvial fans are important landforms and sedimentary

environments, as zones of modern sedimentation, as important Quaternary landforms of arid and semi-arid areas and as important sedimentary sequences in the geological record. Fans are developed where sediment generation is high in relation to transport velocity

(Harvey, 1992).

Under arid conditions, mountains, hill slopes and escarpments mainly undergo slope wash and gullying. Talus is very limited, and is the result of collapse, wash and footslope piling of debris. Rugged exposed bedrock, occasionally entrenched by rills, is the typical landscape. These form the debris flow part of alluvial fans formed in high runoff areas with large annual variability in climatic conditions (Gerson, 1982).

There are peripheral contacts with surrounding regions where the larger Wadis have built up large alluvial fans that tend to encroach on the lakes. There are four major fans varying considerably in extent because of the varying characteristics of catchment areas.

Quaternary alluvial fans are built up of two main depositional sequences; a coarser (gravel and sand) sequence close to the mouth of the Wadi and a finer (sand-silt-clay) sequence away from the mouth (Abboud, 1999). These fans occur on both sides of Wadi Muqat; that is on the basaltic plateau margin, and on the limestone desert plateau margin. The fans are evident on the aerial photographs. Two pediment plains are present. Along the limestone desert plateau margin there are very well developed alluvial fans that coalesce into pediment plain. Along the margin of basaltic plateau, alluvial fans are smaller.

In this study, the Quaternary alluvial fans are formed as an accumulation of locally derived debris of basalt and chert pebbles and gravel. Size and extent of pebbles and gravels are related to the intensity of the annual rainfall. The gradient of the fans is very gentle approaching the horizontal surface; the fans are covered with desert plants.

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3.5. Lake Shorelines

Shorelines indicate water body edges and the water level in the lake at any period, which may differ from time to time (Abboud, 1999).

Through field observations discontinuous shorelines were detected for some Qaa's at the study area (Lake Basin) (Figure 5). Unfortunately, these shorelines were not observed on aerial photographs. This is probably due to relatively short duration of water at these levels. The best-preserved shorelines are best defined along the southern part of the study area. Shorelines were not as evident in other locations, because the lakes perhaps did not stand at any level for a sufficient time to clearly make the shoreline. The observed lake shoreline palaeolevels are at approximately 700m.a.s.l. for northern part and at approximately 650m.a.s.l. for southern part of the study area.

4. CONCLUSIONS

The geomorphic features record at Wadi Muqat basin is naturally weak because of the gentle slopes for the present and palaeolakes (Qaa's). In addition, rapid changes in lake levels, reworking by later water-level fluctuations and obliteration by sub-aerial processes with increasing age. Structural alluvial fans, Qaa's and drainage patterns are the main forms that reflect the dominant influence of exogenous structural factors built in by wind and water. The majority of landforms on the rims of the Qaa' depressions are degradational, whereas those on the central part of the Qaa' depressions are mostly degradation, which is deduced by the development of the depression in the central part.

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