A GEOMORPHOLOGY OF THE KARAK PLATEAU OF JORDAN

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Introduction

The Karak Plateau, a small portion of the Jordanian land surface, has well defined natural boundaries, which are not easily altered by cultural forces (**Fig. 1**). The plateau, while somewhat of a continuum, represents an interesting phenomenon, which seems to follow the multiplicity of the region's biophysical attributes as well as its culture (**Fig. 2**). A study of the plateau's geomorphologic process tends to show how the landscape is altered as it relates to the interaction of energy and earth materials.

The Karak Plateau has been the subject of a comprehensive research effort by the Karak Resources Project (KRP) since its inception in 1995. The project's long term goal is to document the manner in which its inhabitants have utilized the environmental resources of the plateau (Mattingly 1997). It intends to attain its goal by: (1) surface reconnaissance; (2) multidisciplinary research in the physical and social sciences, and (3) excavation of significant sites which were occupied over a number of periods (Mattingly 1996). Each year, increased information and understanding is achieved by the KRP team (**Fig. 3**). In 1995, the KRP team examined 18 sites, which had originally been examined as part of the Pinkerton-Miller surveys between 1978 and 1982, and earlier described by Glueck in the 1930's (Miller 1991). In addition to regional studies, it was decided to consider one site for intensive archaeological research (**Fig. 4**); the site of Khirbat al-Muḍaybī', an Iron Age II fortress, was chosen. In situ and regional work was accomplished in 1997, 1999, 2001, 2009, 2011 and 2014; the hiatus of on-site research since then has been utilized for analyses of

1. Map of the Karak Plateau.

2. East Gate at Khirbat al-Muḍaybī'.

3. KRP 2009 Research Team at Mudaybi.

4. Fort of Muḍaybi' from the East.

findings (Wineland, J.D., 2009; Mattingly, 2014).

Multidisciplinary efforts in archaeological research have gathered momentum during the past several decades. As archaeological research becomes more sophisticated with its use of technological advancements, a team approach is now a requirement for surveying as well as for analyses and interpretation. There is little doubt that the study of archaeology is not without environmental considerations, such as geomorphology (Butzer 1974 and 1987 and Rapp and Gifford 1975). More recently, Hill (2001) added to the regional research endeavor with his study of environmental degradation in Wādī al-Ḥasā. This is also the case for the archaeological research currently being conducted by the KRP team on the Karak Plateau of Jordan.

Jordan, as observed today, can be spatially divided into several geophysical areas: (1) the Ghor, which includes three parts from north to south, the Jordan Valley, the Dead Sea and the Wādī 'Arabah; (2) the Northern Highlands east of the Ghor, which are upthrown blocks of upland plains and highlands, including the Karak Plataeau; (3) the Central Jordanian Limestone Area, including the El Jafr Depression; (4) the Southern Basement Complex and Paleozoic Sandstone Area; (5) the Azraq-Wadi Sirhan Depression; (6) the Basalt Plateau, and (7) the Northeast Jordanian Limestone Area (Abu-Ajamieh 1988). The Karak Plateau is commonly defined by the Wādī al-Mūjib to the north, the Wādī al-Ḥasā to the south, the Ghor to the west, and a transitional area, which becomes the Central Jordanian Limestone Area, to the east toward the desert. The plateau is a unique area, in that no other such landform exists in the Transjordan region.

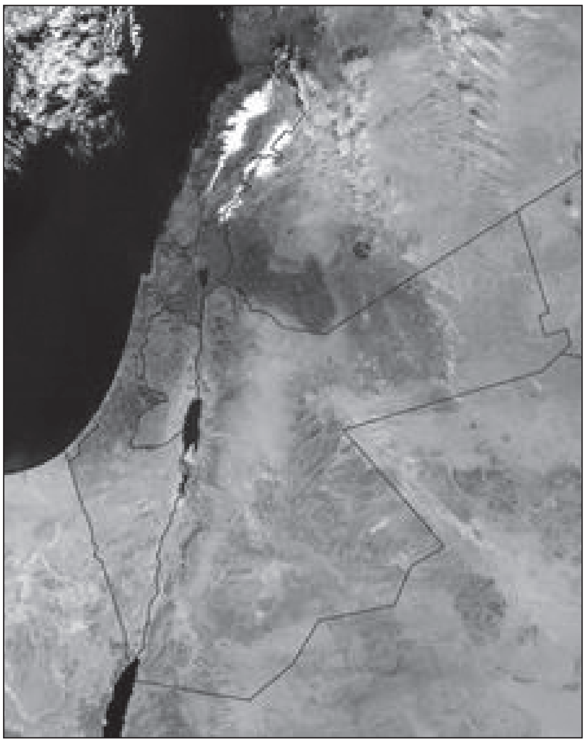
The Location of the Karak Plateau

To understand the Karak Plateau, its place in time is of utmost importance. Geologically, the plateau varies from very old to recent earth materials, as geologic processes never end. Spatially, the plateau is located with respect to adjacent landforms and other spatially distributed phenomena, which defines the uniqueness of the Karak region (**Fig. 5**). Of particular interest is the route east of the Dead Sea Rift known as the King's Highway, which runs through the ancient Kingdom of Moab, including the Karak Plateau, between ancient Babylonia and Egypt.

The Karak Plateau is an area of about 750 square kilometers, with the highest elevation of the upland surface approximately 1,200 meters above sea level in its southwestern quadrant, and its lowest elevation approximately 900 meters above sea level toward the east and the desert. Interestingly, the ancient town of Nakhl (*cf.* **Fig.1**) marks the apex of the drainage divide between the two major wadis mentioned above; this hilltop was well known to the first inhabitants of the plateau (Mattingly *et al.* 1998).

To the north, the Karak Plateau is separated from the Madaba Plain by the Wādī al-Mūjib (**Fig. 6**). To the south, the upland ends with the Wādī al-Ḥasā. To the west is the Dead Sea Rift, also known as the Ghor or Araba, and to the east is the vast Syrian Desert. Another wadi, the Wādī Karak, tends to drain northwesterly into the Ghor from the middle portion of the plateau. The site of the town of Karak is well positioned on a promontory at the confluence of this major wadi and a minor wadi near the top of the plateau surface, not very far from the northern end of the Fajj, which is a graben stretching toward the southeast (**Fig. 7**). The first inhabitants apparently knew of the importance of this very defensible position on the landscape, making Karak a major settlement on the plateau (**Fig. 8**).

The Karak Plateau was a major part of the ancient Kingdom of Moab, dating back to Biblical times. Of particular importance here is how the ancient inhabitants encountered the environment on the one hand, and how modern development is responding to the plateau on the other. Consequently, we are concerned with the surface features, and how they appear to be related to the habitation through time.



5. Satellite Image of Jordan, with the Karak Plateau east of the Southern Half of the Dead Sea (NASA).

6. Wādī al Mūjib, with the Karak Plateau to the South (on the left).

7. Fajj al-'Usaykir, to the east of Muḍaybi'.

8. Karak Castle.

The Karak Plateau can trace human occupation and settlement back to at least Iron Age I (1,200-925 B.C). In all probability, humankind in the earliest periods of occupation witnessed periodic crustal movements and volcanism. During the wet winter months, significant headward erosion from streams occurs, which begin from the base of the major wadis; this tends to incise the fractures or areas of structural weakness. In other words, humankind saw a relatively broad upland landscape, with narrow and sharp separations together with some sharply edged valleys, develop into what exists at the present time. The plateau is now a rolling upland surface interrupted by small wadis, and other surface features such as grabens. Most of the inhabitants appear to be concentrated in relatively small settlements, which are spread along major transportation routes. These routes generally mark the ease of human movement. At certain strategic locations on the plateau, fortresses and settlements have occurred at promontories and junctions of streams or transportation routes. A description of the plateau's surface should reveal how inhabitants have responded to their biophysical environment. Specifically, how did the landforms or the surface features of the Karak landscape develop? This is a major geomorphological question. Insofar as habitation is concerned, what was the response of those who have settled on the plateau? And what are the expectations for the future?

Previously, only a few scientific studies were undertaken in the Karak region, but this has changed in recent years. Burdon (1959) contributed a great deal to the understanding of the geology of Jordan, including the Karak Plateau. Later, Bender (1968) added his learning of the Jordanian geology as well. Both these studies are primarily concerned with stratigraphic references, as related to the general geology of the region. Baly (1985) contributed his environmental approach to the literature of Jordan, adding that the region requires more scientific investigations. In answer to his plea, the Jordanian Geology Directorate has been making progress by mapping the geology of the area (Powell 1988; Shawabkeh 1991; and Khalil 1992). Additionally, Salameh (1997) has added to our understanding of the geomorphology along the eastern side of the Dead Sea.

For general purposes, the studies of Koucky (1987), Frumkin and Elitzer (2001), and Niemi and Smith (1999) on the environment around the Karak area are worth noting. Lastly, Green (2002) summarized the plateau's environment in rather definitive terms. Nonetheless, with so little information available, it is difficult to interpret past environmentally significant events which have contributed to today's environment. It follows that it is even more difficult to estimate, with any degree of certainty, what may take place in the future. Speculation, even misinterpretation, is common. Generalities run wild without an adequate scientific base. More scientific research, with all the zeal that can be mustered, is definitely required for this region. Furthermore, it is possible to improve the decision-making processes which will be necessary, both to plan for orderly development and simultaneously preserve the rich heritage of the Karak region.

A Theoretical Geomorphologic Construct

A literal translation from the Greek roots for defining geomorphology would mean "a discourse on earth forms". Today, the meaning is closer to "a study on how the earth's surface responds to energy processes". This response is one of a variety of resulting features called landforms. What are the surface forms of the Karak Plateau that make it so unique and so special? Landforms have been studied by many scholars since antiquity. Herodotus, for example, recognized the importance of the annual flood cycle of the River Nile, by depositing silts and clays on the delta. In addition, Aristotle recognized that streams removed material from the land and deposited it as alluvium. Strabo thought that a river delta varied in size according to the nature of the region drained by the river. Seneca held the idea that rainfall was insufficient to account for rivers, but that the power of streams made their valleys. Later, in Arabia, Ibn-Sina (Avicenna) held views that mountains were either produced by an uplifting of the ground or were the result of sculpturing by streams (Thornbury 1954). While the relationship between earth materials and energy is rather common knowledge today, it was obviously not so in ancient times. Even so, the mystery about all of this is still present today.

Geomorphology is a branch of the earth sciences dealing with the forms of the earth's surface. It is commonly divided into several areas of study, depending upon the nature of the energy, such as: (1) fluvial or streams; (2) eolian or wind; (3) glacial or moving ice; and (4) waves and currents along the coastline. Since the Karak Plateau is rather dry, one might think, but mistakenly so, that wind is the major sculptor of the land, when running water is actually the most prevalent source of energy, with the resultant alteration of the landscape.

From a genetic point of view, the study of geomorphology should reveal answers about the past, like "the present is the key to the past", as stated by Hutton several hundred years ago. The questions being, for example, what is a plateau? Or what is a caprock? Or what are concordant summits? Or what is a horizontal rock strata? Or what is a gently undulating upland surface? These and many more questions might legitimately be asked with respect to describing a landform such as the Karak Plateau in an historical context, but what about the generic context? About a hundred years ago, William Morris Davis, who many consider the "father" of geomorphology, described the geographical cycle, and this began the generic approach to the study of landforms (Davis 1899).

The geographical cycle, or geological cycle if one prefers, begins with the erosion of the land surface, followed by the transport of the eroded materials, and then their subsequent deposition. Following Professor Davis, from across the Atlantic Ocean in Germany, Walther Penck conveyed a similar construct (Thornbury 1954). However, while Davis advocated a decreasing slope as erosion, with transport occurring, Penck believed a slope retreated parallel to itself; both geomorphologists assumed all forces were equal. But in the late 1930's, the genetic approach used to describe landforms was replaced by a generic approach. Taking this to another level with respect to a fluvial landscape, Horton (1945) suggested the Laws of Stream Order be used to organize and understand the relationships between the earth's surface and energy. Subsequent research has been undertaken by numerous scholars using Horton's construct, including this author (Stephenson 1967), in the analysis of flood frequencies and magnitudes: And the generic research continues. With respect to the Karak Plateau, this endeavor tends to seek an understanding of the land surface as a functional relationship between energy and earth materials, where intermittent streams dominate the landscape.

In the process response model, the primary objective is to explain or account for slope, which is the most dominant feature on the land surface, with the function of landscape variables, all of which are related to energy. An undefined model for defining land surface or slope response is

$S = f(cl, s, v, r, t)$ (1)

Where S (ground slope), cl (climate), s (soils), v (vegetation), r (rocks and sediments), t (time). How does ground slope respond to the elements of climate, namely precipitation, temperature, and wind characteristics, to mention only a few? Also difficult, but no less important, is the role of soils and vegetation as they relate to slope variation. Finally, defining the hydraulic characteristics of water flowing on the slope is extremely difficult to quantify in a process response model. Nevertheless, researchers attempt to explain the process by understanding these relationships in an organized fashion, or by using the dimensions proposed by Horton's stream laws.

Climate on the Karak Plateau

The Karak Plateau is characteristically dry. In contrast to humid regions, arid conditions favor infrequent occurrence of precipitation, but with rather intense periods at times, particularly during the winter months. The Mediterranean climate near the sea to the west has wet winters and dry summers, with a minimum precipitation of 762mm, according to the Koeppen classification of world climates. The occurrence of precipitation on the Karak Plateau is approximately 344mm, which includes an occasional snowfall, and is much less than what is required to be designated as a Mediterranean climate. The plateau's precipitation in winter is similar to the west, with an average January temperature range of 3.5º to 11.6º C., with minimal evaporation, and replenishment of groundwater (Bender 1974).

The "rational equation" commonly used in hydrology research suggests that

$SRO = P + (E - I)$ (2)

Where SRO (surface runoff), P (precipitation, the water supply factor), E (evaportransporation), I (infiltration).

Both losses are modified by the occurrence of soils and vegetation. This relationship should always be kept in mind when dealing with water and its uses, particularly its energy to erode, transport and deposit earth materials.

There is very little, if any, precipitation in the summer, since cooling air is required for condensation to occur. (For example, winter rainfall is only 73.3 mm in the Ghor, which indicates that higher elevations are more favorably located for the occurrence of precipitation [Bender 1975]). With high evaporation because of summer temperatures and a steady breeze, it is exceedingly hot and dry, with an average daily temperature range of 20.7º to 40.1º C in July (Bender 1975). These summer conditions cause the water table to descend to its lowest level, and humankind is required to be very resourceful with respect to water use. At best, the Karak Plateau can be considered a semi-arid or steppe climate, with cool winters and hot summers, and perhaps a limited area to the west with a near-Mediterranean type climate, graduating to a desert climate to the east.

Soils and Vegetation on the Karak Plateau

The soils are moderately thick, but become thinner toward the east, the result of spatial variation in soil formation processes, with

$S = f(cl, o, r, p, t)$ (3)

Where S (soil), cl (climate), o (organic matter), r (relief or topography), p (parent material), t (time).

It is known that soils vary with respect to slope, forming a soil catena. Such is the case with the semi-arid soils of the Karak Plateau, where precipitation is seasonal. Haploxeralfs are the dominant soils, with Zerorthents subordinate (Abu-Ajamieh *et al*. 1988). These soils grade into Chromozerests and some Haploxerfalfs toward the east, and then into Calciothids and Camborthids as aridity becomes a dominant factor in the desert. The upland soils are sufficiently moist to support a grassland type of vegetation in most areas. Foss (2003) however, presents a more practical view of soils on the Karak Plateau, and estimates that only thirty percent of the soils have good agricultural potential, which is not surprising.

Karak vegetation varies, with climate and soils the controlling factors. Much of the plateau was formerly covered by a natural vegetation of grass, which has since been replaced with vast cultivated fields of grain, particularly wheat. In the wadis, where water is available for most of the year, trees and scrub vegetation dominate the winding thalwegs of the wadis. Some trees, usually pine, can be found near the upper elevations of the plateau, where water occasionally seeps out from the rock strata. Limited irrigation on the plateau allows a variety of crops and trees to be grown, such as watermelons and olives. Toward the east the steppe-like grasses, such as wheat, transcend into a desert type of vegetation.

Some scholars believe that past climates had more moisture than today (Burdon 1959). There appears to be several climatologic cycles involved, ranging up to a hundred years or more, when a higher rainfall occurred several thousand years ago (Cordova 2007). If this were the case, it would also mean that the fluvial process would have been different as well (Cordova 2000). The disappearance of the forest vegetation can be attributed to cutting most of the trees for a variety of uses, including logs for building roof supports and as fuel for smelting copper ore in the Araba. As a result, the climate became drier. At the present time, there is a trend for climate change as part of a warmer interglacial stage. This imparts a related drying trend, with the prediction that the existing deserts will have a larger areal extent in the future. Will this mean a warmer and drier climate on the Karak Plateau, resulting in even less water for vegetation, streams, groundwater recharge and humankind? And the many cycles continue as they have before, with the movement of settlements to more advantageous locations. In any case, with respect to the geomorphological process on the plateau, scant soils and vegetation will allow weathering and erosion to be maximized, but in a somewhat different manner than before, as we tend to improve the utilization of present and future technologies.

Rocks and Sediments on the Karak Plateau

At the base of the plateau are Pre-Cambrian plutonic materials. These rocks can only be found at the lowest elevations on the eastern side of the Ghor, which is known as the Southern Basement Complex and Paleozoic Sandstone Area (Abu-Ajamieh *et al*. 1988). The age of these rocks is estimated to be more than 570 million years, and structurally complex. In the Karak area, the only known outcrop of the basement is near Safi in the Ghor, well below the upland surface. Cambrian age sandstones and conglomerates sit unconformably above the late Proterozoic basement complex, which also has volcanic dikes.

The plateau area, for the most part, was inundated by the ancient Tethys Ocean during the Cretaceous Period (Powell 1988; Tarawneh 1988; and Khalil 1992). This means an unconformity exists from the Cambrian to the Cretaceous period. From the Cretaceous period and since, vast marine deposition has occurred. Sedimentation of the plateau was the result of organisms dying in the shallow ocean, which tended to vary its shoreline location as sea levels changed. Thus, limestones, chalks, marls, conglomerates and phosphorites were layered upon one another depending on the ocean depth, the velocity and direction of the currents and tides, and the location of the shoreline. All these items had a bearing on the type of organisms spatially distributed in the seas. Changes in transgression and recession levels of the seas dominated most of the area, with a number of lithological facies being formed, until a major uplift occurred in the Quaternary period. This sedimentary material was deposited for approximately 180 million years, almost without interruption. The stratigraphy can be observed easily throughout the plateau, particularly along the steep slopes of the major wadis. However, there have been volcanic intrusions from Jabal Shihan, as well as other volcanic eruptions that have occurred, forming partial basaltic covers of the land.

Orogenic activities after the Pre-Cambrian were practically non-existent until the Tertiary period, when uplift and faulting occurred. The major geologic fault in the area is, of course, the Ghor or Araba. This rift is part of a system extending from north of the Dead Sea through Lebanon and Syria to Turkey, and southwards toward the Gulf of Aqaba, the Red Sea and beyond to the East African Rift; a distance of more than 6,000 km. (Atallah 1991). The Ghor is related to the compression of two tectonic plates moving toward one another at an angle. In addition, compression resulted in the plates moving vertically upward on either side of the rift, and in between, blocks were moved outward as well as downward (Quennell 1983; Sneh 1996; and Wdowinski and Zilbermann 1996). The upthrown blocks on either side were raised to a maximum elevation of more than

1,100 meters, while the downthrown blocks were lowered to approximately 400 meters below the present sea level; a displacement of more than 1,500 meters. Due to the tremendous pressure created by this tectonic movement, transverse faults also occurred in the rift, as well as on either side of it.

Movement of the earth's crust creates sound waves known as earthquakes. This tectonic activity has been continuous since the rift was formed. The rift area has had numerous movements and resulting earthquakes, with a magnitude of six or more on the Richter scale. A recurrence interval of 20 years has been estimated (El-Isa 1991). This means, as in the past, more tectonic activity can be expected in the future (Husein *et al*. 1995).

Volcanism was active during the development of this gigantic structural zone of weakness, or geosuture, during the Pre-Cambrian period (Bender 1975). During the Oligocene, uplift began on the east side of the Araba. These orogenic activities continued through the Pliocene, with lithographic facies development. In the middle and upper Pleistocene, volcanism complicated the faulting and folding**.** During the Pleistocene and continuing today, there has been weathering, mass wasting, and erosion of the plateau surface, primarily by the drainage of the three major wadis already mentioned, which are in most cases, the surface expression of underlying tectonic structures (Powell 1988; Tarawneh 1991; and Khalil 1992). The nature of the Karak Plateau has responded, and will continue to respond, to the characteristics of climate, soils, vegetation, rocks, sediments and the geomorphic processes.

The Karak Land Surface Response

A classic plateau surface is a positive land form, in that there is considerably more upland surface than lowland or steeply sloping surfaces. The dominant sculptor of the land surface is running water. Further, there is commonly a resistant horizontal, or nearly so, strata of rock near the surface with less resistant rock below. Earth materials loosened from exposed bedrock by the weathering processes are ready to be removed downslope by mass wasting or the force of gravity, and then by flowing water. However, the plateau exists for many hundreds of millions of years before it becomes a negative land form, or one that is primarily a lowland surface with very little upland area.

The major element of the land surface is slope, or ground slope, which is measured as the relationship between the vertical and horizontal dimensions. Ground slope is commonly represented in percentage or degrees. A slope map is usually derived from a topographic map, illustrating slope areas of varying degrees. It can be observed that steep slopes occur on three sides of the plateau, in addition to the Wadi Karak near the middle, which drains in a westerly direction. Relatively steep slopes also appear along the Fajj. The majority of the remaining areas are of moderate or insignificant slope. Many of the moderate sloping areas are related to faults. The insignificant slope areas occur mainly to the east, as the plateau merges with the Syrian Desert. The topography of the plateau tends to show the changes in ground slope very well, rising from the north to the south and from west to east. The topography reveals how the land surface is responding to the independent variables of climate, soils, vegetation, rocks and sediments, and time. The ground slope is largely controlled by the cap rock, which dips from its highest point in the southwestward corner of the plateau, descending toward the north as well as toward the east, as a result of the uplifting of the formation of the Araba.

The flow of water, or surface runoff, on the plateau varies, according to the precipitation regime and slope characteristics. As indicated previously, precipitation occurs in the winter months, sometimes intensely, when evaporation is low and the water table is high. The consequence of such a regime is overland flow, such as sheet flow, then small rivulets or streams. Trails or pathways, as well as ruts made by vehicles and furrows, also contribute to flow direction and magnitude. This tends to erode the land surface from one place and deposit the material at another, lower level. Patterns of erosion and deposition are largely geologically controlled. Again, the Karak Plateau itself is defined north and south by two major wadis, with a third draining its interior. Within this defined area, there are additional geologic structures that tend to control the drainage pattern as well, although they may be difficult to see or perceive. The pattern, nevertheless, results because the fluvial processes are the major sculptor of the land surface.

Plateaus are commonly defined as having a resistant caprock. The Karak has several, particularly near the major wadis. The Amman Limestone formation, consisting mostly of siliceous limestone, dominates the plateau as a caprock. Other formations below this include, but are not limited to, the Dana Conglomerate, the al-Hisa Phosphorite, and the Wadi as-Sir Limestone. These formations, due to their dip and the differential erosion of strata, tend to exhibit a step-like appearance. The basalt formations in the northern part of the plateau, toward the east from Wādī Balū‘, and southward to Khirbat al-Muḍaybī‘, also show a step-like surface.

The subsequent surface runoff on the plateau surface tends to follow the tilted and faulted bedrock formations, generally toward the northeast. The highest point on the plateau is about three or so kilometers south-southwest of al-Mazar near the rim of the Wādī al-Ḥasā, with an elevation of more than 1,297 meters. This location forms the southern end of a ridge which continues northward to Karak, and divides the drainage basins entering the Ghor and Dead Sea from the Wādī al Mūjib drainage area. This point is also located on the drainage divide between several tributary wadis of the Wādī al-Ḥasā and the Wādī Numayrī, which drain directly in to the Dead Sea toward the northwest and the Wādī al Mūjib. Directly and immediately to the east of the highest point, the Wādī ash-Sharma drains eastward to the southern portion of the Fajj al-‘Usaykir, and then in to the Wādī al-Ḥasā.

To the north and east of the highest area on the plateau, the majority of the faults on the plateau tend to lie in a similar direction; that is, northwest and southeast in alignment with the Fajj. In the northwest, Jabal Shihan dominates the plateau surface at 1,054 meters. Basaltic dolerite outcrops occur at approximately 800 meters in elevation, forming an additional rim for the plateau in some locations. The Wādī ash-Shuqayq drainage basin has its headwaters at Jabal Shihan, draining directly westward into the Dead Sea.

There should be little doubt that the interaction of climate, soils, vegetation, rocks and sediments have a functional relationship with how the Karak land surface responds. Of course, the time factor tends to suggest change. Recently, because of dam construction in the adjacent wadis, changes in the base level of streams will tend to alter the characteristics of the former erosion and deposition process. Thus, it is extremely important to substantiate baseline information under the most natural land surface conditions as possible.

A Comparison of Selected Fourth Order Drainage Basins in the Karak Plateau Region

In keeping with the generic Laws of Stream Order as suggested by Horton (1945), observations of six fourth order stream basins were made for the purpose of learning about the spatial variation of stream characteristics (**Table 1**). A fourth order stream is defined as having at least two third order streams, both of which have at least two second order streams, with each second order stream having at least two first order streams, which constitute the headwaters of the drainage area. The geometric progression of these stream parameters is obvious, and shows how streams vary spatially, as related to geologic and energy characteristics. The Wādī Numayrī and the Wādī ash-Shuqayq drain directly in the Dead Sea, the Wādī ash-Sharma and the Wādī Salaha drain into the Wādī al-Ḥasā, and the Wādī al-Ghuwaylah and Wādī al-Batra drain into the Wādī al-Mūjib. All waters eventually enter the Dead Sea. Except for the major wadis, all are intermittent streams in the region. Generally, drainage basin analysis is based on perennial streams, or those that flow all year long. However, the intermittent streams are definitely incised, making channels quite obvious, and can be observed and measured for comparative purposes. It should be kept in mind that a whole year's worth of fluvial energy takes place only during the winter months.

The fourth order drainage basins vary in size from 25.25 km^2 to 106.19 km^2, with an average size of 55.79 km^2. The largest fourth order basins drain directly into the Dead Sea from the eastern slope of the plateau, while the basins draining into the Wādī al-Ḥasā are intermediate in size, and located in the southern area of the plateau. The smallest of the sample basins, the Wādī al-Batra, is located on the eastern flank of the Fajj al-'Usaykir, draining into the Wādī ad-Dabba towards the Wādī al-Mūjib, while Wādī al-Ghuwaylah is located in the northeastern area of the plateau. The variation in drainage basin size for the fourth order streams appears to be related to geologic controls such as rock type and rock structure, but basin orientation and relative location are also important, as is distance to the stream's base level. The variation in stream numbers for the first and second order streams indicate an interesting grouping, with the highest occurrence draining into the Wādī al-Mūjib, and the lowest occurrence draining into the Dead Sea.

The Wādī an-Numayrī

This wadi is located on the western slope of the Karak Plateau, between the Wādī al-Karak and the Wādī al Ḥasā (refer to the Karak 1:50,000 topographic quadrangle). Wādī an-Numayrī's southern interfluve is in the Wādī al Ḥasā drainage area, but the stream drains into the Dead Sea. The highest elevation is 1,297 meters above sea level, while the lowest point, where distributaries from an alluvial fan are located, is 140 meters below sea level. The relative relief is therefore 1,437 meters, the highest of the basins examined. This wadi is also the largest of those examined, but has the lowest drainage density, at 0.89. This means that for every square kilometer of drainage area, there is only 0.89 kilometers of stream length. The orientation of the basin toward the west, steepness of slope and the nature of the earth materials, are contributing factors for this relatively low density of streams.

Settlement in the Wādī an-Numayrī drainage basin is related to the King's Highway on the plateau, with the small villages of el-Iraq at approximately 900 meters, and Khanzīra at approximately 1,000 meters, both being several hundred meters below the plateau upland. Located near the headwaters are the important towns of al-Mazar and Mu'tah, with drainage oriented toward the east. Several small hamlets are scattered within this drainage basin, above the crenulating rim of the plateau,which tend to have a functional relationship with the farming activities in the area. The steepness of the slope below the 900 meter elevation tends to inhibit settlement and economic activities.

The Wādī ash-Shuqayq

The headwaters of this wadi are at Jabal Shihan, located in the northwestern portion of the Karak Plateau, with the wadi draining into the Dead Sea (refer to the 1:50,000 Er-Rabba topographic quadrangle). Jabal Shihan, an extinct volcano with its peak at 1054 meters, has a ground slope of less than 40 degrees. The basin's drainage characteristics are very different on the slope of the volcano, compared to the steepness below the rim of the plateau. Wādī ash-Shuqeiq is the second largest of the drainage basins studied (**Table 1**). Its drainage density is the second highest of the six basins at 1.12, indicating a relatively high total stream length compared to the drainage area.

The headwaters of Wādī ash-Shuqayq reach the plateau rim; the small settlements of Faqū' 'Amra and Ṣirfā are located there at elevations of more than 900 meters. While there is an excellent view to the west of the Dead Sea, the settlements are oriented to farming and other activities on the plateau to the east.

The Wādī ash-Sharma

This drainage basin is located in the southeastern portion of the plateau (refer to the 1:50,000 Adir topographic quadrangle). Dhāt Rās near the headwaters of the basin has an elevation of 1,163 meters above sea level, and drains in an easterly direction toward the Fajj al-'Usaykir and then southerly to the Wādī 'Abyad. Of interest in this area are the ancient ruins of Nakhl. The southern slope of the ruins drains into the Wādī Asmar, which is the northern-most tributary of the Wādī ash-Sharmal however, Nakhl's northern slopes drain toward the Wādī al-Mūjib. Most interesting here are the headwaters of the Wādī Kikhil, which are a fine example of an ancient water catchment system (Mattingly *et al.* 1998). This is the only such catchment system found in the Karak Plateau, reminiscent of those located to the west of the Ghor.

Wādī ash-Sharma is of moderate size, with a drainage density of 1.78, the highest of the six basins examined, and has a dendritic drainage pattern as compared to the rectangular pattern of the Wādī al-Batrā, indicating that it is less structurally controlled by rock type and structure.

As well as Dhāt Rās and Nakhl, Hamat

is also located within this basin, all three at approximately the same elevation. The last vestiges of land suitable for growing grains are found immediately to the east of these settlements. It is here, beyond the Fajj, where the land transcends into a desert landscape, with elevations close to 900 meters above sea level. Located nearby, in a small drainage basin adjacent to the Fajj al-'Usaykir, is Khirbat al-Muḍaybī', an Iron Age II fortress of interest to the Karak Resources Project (Mattingly 1997).

The most prevalent geological structure here is a volcanic flow of basalt, which protrudes at an elevation of approximately 980 meters above sea level at the site of al-Muḍaybī'. Its walls consist almost entirely of local basalt, handcrafted with extreme difficulty into rectangular blocks. It is assumed that this basalt is from Jabal Shihan, located in the northwestern portion of the plateau. Also at al-Muḍeibi' is a very small outcrop, directly below the basalt, consisting of Amman Silicified Limestone, which was also used for building material. The three settlements on the west of the wadi are situated on the Bahiya Coquina, an al-Ḥasā Phosphorite formation of Upper Cretaceous age. Below this formation and over the basalt is a mix of fluviatile and lacustrine gravels and calcrete, all contributing to a soil which is used primarily for agriculture.

The Wādī Salaha

Located in the southeastern portion of the plateau, but very little of the drainage area is on the upland surface (refer to the 1:50,000 Aina topographic quadrangle). The plateau surface in this area tends to drain northerly, then easterly. The wadi is oriented in a southerly direction, draining its steep, rocky slopes directly into the Wādī al Ḥasā, although its basin axis is longer in an east-west direction. The entire basin has intermittent drainage, with elevations between 1,079 and 560 meters above sea level, giving it a relative relief of 519 meters. The drainage density of the wadi is 0.50, similar to Wadis el-Ghuwaylah and al-Batrā.

There are no permanent settlements in the basin area apart from a very small hamlet called Shuqeira, which is located on the plateau rim along the northwest basin interfluve. This area is also known as the Arab al-Mannain.

The Wādī al-Batrā

The Wādī al-Batrā is located in the Fajj al 'Usaykir (refer to the 1:50,000 Adir topographic quadrangle). The Fajj is a small and quite spectacular graben, with the streams structurally controlled, forming a rectangular stream drainage pattern. The geologic structure in the vicinity of the Fajj is obvious from its topography. The graben floor is covered with alluvial sediments underlain with Muwaqqar Chalk, which is a marl of Tertiary age. High on the flanks of the graben are the Amman Silicified Limestone formation topped with the Sultani Phosphorite, both of older Upper Cretaceous age. Below this rock, on the upper slopes of the valley side walls, are the more moderate sloping pediments of fluvial sands and gravels.

The drainage density of this basin is 0.54. Of the basins examined, this is one of the smallest, with the shortest total of stream lengths. The headwaters of the first order streams are high on the flanks on either side of the valley, followed by second order streams at lower elevations. This basin has one of the highest number of first order streams, as well as the most second order streams, largely due to the rock type and structure. The basin is elongated and oriented from southeast to northeast, while the stream pattern is similar on both sides of the valley sidewalls.

There are no settlements in the area, but the immense valley bottom is extensively farmed. This was a major connecting link from the Arabian Peninsula to the Dead Sea and the Araba in earlier times, and evidence of nomadic activities still prevails today. Several small ruined Roman watch towers or fortresses are on either side of the graben, including Khirbat al-Batra at the northern end. Khirbat al-Muḍaybī', a major fortress from Iron Age II farther to the southwest attests to the importance of this ancient highway.

The Wādī al-Ghuwaylah

Located in the northeastern portion of the Karak Plateau, it is oriented in a northerly direction (refer to the 1:50,000 Ariha topographic quadrangle). The Wādī al-Mūjib is located immediately to the east while the Wādī al-Balū' is located immediately to the west. The Wādī al-Ghuwaylah drains directly into the Wādī al-Mūjib at an elevation of 440 meters above sea level. Only a small portion of the wadi at the confluence has a perennial flow. This drainage basin has a relative relief of 524 meters, with only the small upper reaches of the wadi on the plateau surface; the highest point is 964 meters above sea level. The drainage density of Wādī al-Ghuwaylah is 0.50, indicating there is only c. 0.50 kilometers of intermittent streams for every one square kilometer of drainage area. For the most part, earth materials tend to control drainage density and the dendritic drainage pattern, rather than rock type or structure.

Only the two small villages of Smākiyyah and Ḥumūd, at the edge of the plateau and approximately 850 meters above sea level are within the drainage area. At this elevation, the slope is quite steep as it descends into the wadi, while the plateau surface above is gently undulating. Agricultural activities tend to be above the 850 meter contour, with steep slopes below.

Summary

This analysis of selected drainage basins of the Karak Plateau is very brief, with only a few statistics; it is intended to be an invitation for further research in fluvial geomorphology. A more detailed analysis is required for an increased number of fourth order basins, with comparisons of both basic and more complex dimensional characteristics. The six drainage basins described here are merely a small sample of the wide variation of fluvial situations, which have existed on the plateau for thousands of years.

The land surface of the Karak Plateau has responded to varying energy forces, related to both earth materials and structure, and will continue to do so. The land surface is in a state of quasi-equilibrium, and will naturally adjust to varying climatic factors and geologic disturbances. With the change in base level of the major wadis brought about by recent dam construction in the Karak region, upstream dynamics will be altered, and humankind will have to adjust to these changes, as it has in the past.

Some Final Thoughts

This geomorphic study of the Karak Plateau has laid the foundation for additional research endeavors. All sciences play a role in understanding the environment more thoroughly, and how humankind responds to it. Ancient peoples had to make difficult choices, with no knowledge of the outcome. This is not so today. It is now possible to estimate the future of geomorphic phenomena with reasonable accuracy, using the generic approach. Such is the case even though the Dead Sea base level fluctuates, while streams are dammed, changing their base level.

The Karak Plateau has not changed significantly for thousands of years, apart from an increasing population growth in recent years, along with related infrastructure and technological advances. Urban settlements are becoming larger, more roads are paved, and there is more diversity in human activities; not to mention the archeological disturbances. Agriculture, the major economic activity on the

Table 1: Comparison of Selected 4th Order Drainage Basin Data.

	Wādī an-Numayr*ī*	**Wādī al-Shuqayq**	**Wādī ash-Sharma**	**Wādī salaha**	**Wādī al-Batrā**	**Wādī al-Ghuwaylah**
Area (in sq. km.)	106.19	67.34	47.91	25.90	25.25	62.16
Number of 1st order streams	55	50	62	69	118	118
Number of 2nd order streams	12	12	19	13	33	27
Number of 3rd order streams	3	3	3	2	3	5
Number of 4th order streams	1	1	1	1	1	1
Total stream length (in km.)	94.5	75.5	85.5	52.0	46.5	62.2
Drainage Density	0.89	1.12	1.78	0.50	0.54	0.50

Karak Plateau, will continue into the foreseeable future. Nevertheless, an increasing percentage of the land will be used for non-agricultural purposes, due to the growing population and related settlement.

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