Origin and Evolution of the Desert

DR FAROUK EL-BAZ
Director, Center for Remote Sensing, Boston University, Boston, Massachusetts, USA

Desert landscapes are the least understood among terrain types of the Earth. The dearth of basic information on arid landforms has resulted in the misconception that the desert is man-made and that, therefore, we can 'fix it'. Scientific evidence indicates that deserts are part of the natural features of both Earth and Mars. They form as a result of the lack or scarcity of rain, which may be cyclical. The basic layout of today's arid terrain appears to have formed during humid periods in the geological past. Understanding of such features and those caused by wind erosion and deposition is essential to the development of deserts and semiarid lands for the benefit of mankind. Images obtained by spacecraft provide a new tool that is very useful in this regard, particularly in the location of groundwater resources to be used at times of cyclical droughts.

The purpose of this review is to exemplify the utility of space photographs in establishing the origin and evolution of arid landscapes. Thus, it is necessary first to define the term 'desert' and to establish how deserts form and how they evolve in space and time.

The word 'desert' originated as an ancient Egyptian hieroglyph pronounced 'desert', which means a place that was forsaken, or left behind. From this came the Latin verb deserere, to abandon. From the latter came desertum, a waste place or wilderness, and desertus meaning abandoned or relinquished. This in itself implies that the desert had been a better place. In it, there was life - in some places teeming life. There was much vegetation, grasses and trees, many animals and human beings. Then something happened, and the place became a wasteland; it was deserted.

Geology and the desert

Arid and semiarid lands make up over one-third of the land masses of the Earth where rainfall is scarce to nonexistent (Figure 1). It is my opinion that we do not understand these dry tracts of the Earth as well as we do other land types. That bothered me as a geologist from Egypt, a country that is 96% desert.

As a science student at Ain Shams University in Cairo, I was taught by very fine, Western-educated teachers. I learned about the geology of the Alps and the Himalayas, all the major river basins, the Grand Canyon, the Paris Basin, and the like. In the meantime, little was uttered about what existed 10 km from the classrooms.

I travelled to the United States for graduate work and was taught by the finest of professors. Later in Germany I worked at the University of Heidelberg and the Max-Planck-Institut für Kernphysik, where I came in contact with some of the best geologists in Europe. All of them knew little about the desert.

Why do we not know as much about arid landforms as we do about processes in humid terrain? The more I thought about it, the more I realised that the reasons must be deep-rooted, and indeed they are. The first reason is that the science that deals with the study of the Earth started in England, France, and Germany, and Europe is the only continent that does not have a desert. Thus, the pioneers that started thinking about the Earth, and the formation of its features, did not have an example of arid landforms to ponder. Those who came after them picked up from where they left off, and those who followed did the same. To this day, we find textbooks in the Earth sciences that do not have a single chapter on arid landforms.

The second reason is that deserts are vast and require an enormous effort to study. For example, the Sahara is 4500 km by 2000 km; that is, 9,000,000 square km. In it one cannot study such a small part and ignore the rest, because whatever happens in one part affects some other place. The dunes that are now at the shores of Lake Chad began their journey in the Western Desert of Egypt (Figure 2). To study such dunes fully one must traverse 2000 km in an exceedingly harsh environment.

The third reason is that geologists prefer to seek samples of solid rock picked up in situ, in place. When one travels in a desert, very rarely does one encounter rocks in place. Everything is a mixture of sand and rock rubble. So there is nothing there for a conventional geologist to do. Furthermore, one cannot underestimate the prevalent sand dunes in which vehicles get stuck, and the field parties lose much time in getting them unstuck. This in itself limits desert exploration.

All three reasons resulting in a limited amount of information about the desert compared to what has been accumulated on other land types.

The ills of 'desertification'

In view of the scarcity of information on the desert, many misconceptions find fertile ground. The basic
misconception results from the use of the ill-defined term ‘desertification’. The term originally came from the French when Aubrèville (1949) published results of his work on the African rain forest. He reported that part of the forest was rather deteriorated, and that if the trend continued, the area would become a desert. For that hypothetical process he coined the term ‘désertification’, which has recently been much overused.

With its use came the misconception that the desert was a bountiful place that became dry due to the activities of man, followed by the camel and the goat. The camels ate everything high in sight, then the goats nibbled at the roots of plants. Thus, the place became a desert. (See also J. Scheerter, Desertification, Interdisciplinary Science Reviews 2, 36, 1977.)

Two connotations of this scenario are very dangerous. The first is that the people that live in arid terrain do not understand it, and through misusing it, they ruin it. With that connotation goes an implication that our ‘planners’ in Washington, New York, Paris, or London, actually know better than those nomads and Bedouin about the desert environment.

The second connotation is that because ignorant natives made the desert, then by putting our advanced space-age technologies to work, we can fix it. This is also very dangerous because if one does not fully understand the environment, then one cannot institute development programmes that are meant to improve it. Therefore, before we move into any area in the desert to ‘fix it’ we should first realize that we cannot radically change it. Just as in any other terrain, we must understand it well to learn how to live with it. Thus, it is not a matter of application of advanced or new technology that can perform the fix. It is, however, a matter of learning about the environment and how it evolved in space and time, and therefore, what will happen next and under what conditions.

This is a significant issue because it affects aid projects and policies of the United Nations Environment Programme (UNEP), the United States of America’s Agency for International Development.

DR FAROUK EL-BAZ is founding director of the Center for Remote Sensing at Boston University. From 1982 to 1986 he was vice president for international development and for science and technology at Ikik Optical Systems, Lexington, Massachusetts. He studied at Ain Shams University in Egypt, the University of Missouri at Rolla, and the Massachusetts Institute of Technology. He taught geology at Assiut University, Egypt, and the University of Heidelberg, Germany. He participated in the Apollo program from 1967 to 1972 as supervisor of lunar science planning and lunar exploration at Bellcomm and Bell Telephone Laboratories, Washington, D.C. During these six years he was secretary of the site selection committee for the Apollo lunar landings, chairman of the astronaut training group, and principal investigator for visual observations and photography. Beginning in 1973 and for the next ten years, he established and directed the Center for Earth and Planetary Studies at the National Air and Space Museum, Smithsonian Institution, Washington, D.C. In 1975 he was selected by NASA as principal investigator for Earth observations and photography on the Apollo-Soyuz Test Project, the joint American-Soviet space mission. Between 1978 and 1981 he served as science advisor to the late President Anwar Sadat of Egypt. He is known for pioneering work in the application of space photography to the understanding of arid terrain, particularly the location of groundwater resources. During the past fifteen years he has contributed to interdisciplinary field investigations in all the major deserts of the world. At present, his research objectives include applications of remote sensing technology to the fields of archaeology, geography and geology.

Address: Center for Remote Sensing, 725 Commonwealth Avenue, Boston University, Boston, MA 02215, USA.
(AID), and other agencies of European, Asian and Arab countries.

Consider the case where 'experts' recommend drilling a series of wells in a given region using advanced technology and operating them by powerful pumps. This may result in gathering the nomads and Bedouin and forcing them to settle in order to receive help.

Such solutions turn out to be counterproductive. Nomads and Bedouin have not developed their way of life because they are a restless lot. Theirs is the only way of utilising the most important natural resource in arid and semi-arid lands: rainwater. In these thirsty lands rainfall is erratic; it rains in one place but not the other, and when the rain returns it does so in another place. That is why the nomads move with patterns of movement of rain clouds based on thousands of years of experience.

When the nomads are settled, as most countries have done (today, for example, there is not a single nomadic tribe in Egypt), people gather from all directions and, with their animals, densely populate an area. The land cover can no longer be sustained and becomes incapable of supporting their large numbers, and so begins the degradation of the terrain. Thus, in the apparent solution to the problem lie the roots of long-term degradation of the environment.

With the continuation of pumping of water in enormous quantities from the same place, and because it usually comes from a limited reservoir, water often runs out. It might take a century or more to replenish a depleted aquifer. Furthermore, pumping from one area may deplete nearby locations. This forces people to limit their movement, and in so doing they no longer can take advantage of the natural environment, where rainfall is erratic in space and time.

Although the aforementioned principles are basic, they are rarely taken into consideration, if at all. This is unfortunately true, particularly throughout the Sahel region of North Africa, of well-intentioned international aid organisations. Many of the programmes of most international agencies in the African Sahel that were instituted since the drought of 1968–1974 have indeed resulted in much degradation of the terrain. (See also G. T. Nankani, The Sahelian Problem, Interdisciplinary Science Reviews 5, 320, 1980.)

Another type of unintentional land degradation occurs in desert reclamation projects. A case in point is the program in Egypt just west of the Nile Delta (Figure 3), in an area called the 'Liberation Province'. Here, the Egyptian Government started a desert reclamation program in the late 1950s. The area is covered with reasonably fertile soil capping an undulating terrain. The profile of the land did not appeal to the agricultural engineers. To them, the land surface must be absolutely level; agriculture along the banks of the Nile has been like that for 7000 years. Furthermore, the level surface must be divided into feddans, by straight lines, and a feddan is divided into 24 kires. When this is accomplished, an irrigation
Figure 3. Increase of vegetation through reclamation of land from the desert west of the Nile Delta. Drawn on a 1968 Gemini photograph are the vegetation boundaries shown on another photograph taken 10 years later by the Apollo-Soyuz astronauts (after Slezak and El-Baz). A mottled zone; B smooth-textured active sand, C darker desert pavement zone.

The canal is dug that brings in water along one side, and along the other a drainage ditch is dug to carry used water downstream. In the process of levelling the undulating terrain and its top layer of the reasonably fertile soil, less desirable layers were exposed on the formerly high areas, measurably degrading the soil. This appears to have been responsible for making the Liberation Province desert reclamation programme not as successful as it could have been.

A further example of unintentional land degradation in Egypt results from the over-irrigation of reclaimed land in desert oases, for example, the Kharga Oasis (Figure 4). Along the banks of the Nile, irrigation channels and drainage ditches work easily because of the natural lay of the land; from Aswan to Alexandria it is all downhill, and the water follows a course that is parallel to the Nile. However, in desert depressions, there is no northward downhill gradient. Water that is used for irrigation by desert reclamation projects is not carried very far by drainage ditches. It stays within basins like the Kharga depression (Figure 4) and clogs the soil.

Such land degradation happens basically because of the lack of a deep understanding of the desert environment. Agriculture in the desert has to be different from agriculture in other places, and it requires a set of practices that vary from the norm. We cannot establish the rules for such practices in a given arid area unless we fully understand the physical parameters that control its environment. Only through such understanding can we utilise parts of the desert for our benefit without degrading the terrain.

The aridity index

In terms of aridity, there are major differences between deserts. No single place typifies all of the desert environment. Every desert is unique, and even in the same desert some places are different from others.

Henning and Flohn established an 'aridity index', to relate the amount of energy that is received from the Sun in a given place to the amount of rain that falls in the same place. In their aridity map, vast areas, including the Western Desert of Egypt and parts of Libya and Sudan, are characterised by a contour line of 200. This means that the received solar radiation in this part of the world is capable of evaporating 200 times the amount of rainfall. That is the largest driest place on Earth.

The aridity index of other deserts is between 20 and 50. Such is the case for the Rub Al-Khali in the southeastern part of the Arabian Peninsula. The
Utility of space photographs

If we view the Earth with the eyes of astronauts, we realise that the deserts are the first recognisable feature from space. Thus, the space programme has provided a new perspective to study the desert.\textsuperscript{10-12} For nearly the same reasons that we cannot fully investigate the desert by conventional ground surveys, the space vista provides a new tool.

First, the desert is the way it is because of the lack or scarcity of rain. Thus, deserts are usually cloud-free and may be photographed from above nearly all the time. The second reason is that deserts are vast, and one needs to consider large areas, such as those covered by a single photograph from space. The third reason is that because of the lack or scarcity of rain, there is little or no vegetation on the surface. This means that whatever is photographed from above represents the natural rock, soil, and sand. Because these materials are usually colourful and the colours are meaningful, we are able to decipher more about the chemistry of the desert from space than about more humid, vegetation-covered terrain.

Thus, attempts were made to study the nature of the desert terrain using space photographs, which were taken by the astronauts of the Gemini and Apollo missions, by the unmanned satellites Landsat and Spot, and by the more recent Space Shuttle missions.

Meaning of colour in photographs

Two cases illustrate the use of colour in space photographs and how they may be considered as soil maps. The first case is just west of the Nile Delta (Figure 3), the first space photograph of the area was taken by the Gemini 5 astronauts in August of 1965. Three different zones of colour were noticed, one close to the Mediterranean that looks spotted or mottled; one
next to it that is smooth-textured; and one in the lower part that is much darker. Geological maps of the area did not explain the reason for the three zones. I asked the Apollo–Soyuz Test Project astronauts to take photographs of the same area, which they did in July of 1975.

The same zoning was noticed in the Apollo–Soyuz photographs. This related to the aforementioned Liberation Province, which lay in the area of the middle colour zone. It was interesting to see how much vegetation expanded at the border of this zone, where most of the effort was spent. The line of agriculture had changed very little.

However, a little further to the north, in the mottled zone that is closer to the Mediterranean, the vegetation line moved much more. The reason for this is that the middle zone is sandy and its sand is very active; it does not form dunes, but shifts about. The area closer to the Mediterranean is made of fertile soil, a mixture of clays and carbonates. Hence, if we had these space photographs in the 1950s they could have been used as soil maps before the initiation of the desert reclamation project.

The second case relates to the red colour in desert sand, which has been ascribed to the oxidation of iron that is mixed with the sand.13–16 Such is the case for the Namib Desert of Southwest Africa.17 The wind in this part of the world blows west to east. It comes over the Atlantic Ocean and collects moisture in the form of clouds. A mountain range east of the coastline holds the clouds, causing rain. The rainwater breaks up the rock components and carries the particles into wadis and deposits the sand at the coast of the Atlantic. But the wind still comes from west to east and redirects the grains of sand back inland. This is how the sand dunes of the Namib are formed and continue to move, and as they move inland they get redder.

A similar case exists in Australia near Lake Blanche at the foot of the North Flinders Ranges. The dry lake is the source of the sand, and the wind direction in this case is from the southwest to the northeast. Here again there is zoning: closer to the source, the sand is lighter, and as it travels farther it gets darker in colour.

Study of such sand grains under the microscope indicates that the red colour is not due to iron oxides but to coatings on individual grains. Sand grains from the Western Desert of Egypt are composed mainly of clear quartz. However, almost all grains have a yellowish-red, frosted appearance due to coating.

The nature of such a coating is revealed by a scanning electron microscope. By enlarging 1500 times, the coating starts appearing, and at >60,000, the nature of the coating becomes clear. It is composed of tiny crystals of a clay mineral, kaolinite, with a submicroscopic iron oxide powder.18 This coating increases in thickness as the transport distance increases – that is, as the sand grains move away from the source. This helps to identify the source area of the sand and to reveal which part of a sand field is more active than others.

The red colour is not restricted to sands in the deserts of the Earth, but is also common on the surface of Mars. In the first views from the Viking Lander in 1976, the colours of Mars appeared reddish-orange. As seen in photographs from orbit, this colour is very close to that of the hyper-arid deserts on Earth, particularly the eastern Sahara.

**Aeolian processes**

**Wind erosion**

Figure 2A illustrates a mosaic of Landsat images of Egypt, particularly showing the major characteristics of the hyper-arid Western Desert. In this type of parched terrain wind action results in parallel features (erosional grooves and/or depositional dunes) which can be clearly seen from space. Erosional grooves appear as striations in the ground. On a smaller scale, one observes finer grooves in the exposed rocks, and when these are closely examined, they reveal finer striations still. Furthermore, when studied under a microscope, they display much finer striations. This means that the striations which are carved by wind erosion vary in scale from microscopic lineations to huge grooves that are visible from space.

Field observations of the process of wind erosion indicate that the wind acts without having to be loaded with dust. Even though it is commonly believed that the erosion is caused by the dust or sand carried by the wind, it seems now that the blasting may be caused by the air itself. I came to this realisation while examining a hill of solid marble in Siwa Oasis in the Western Desert of Egypt. Dune sand climbed up the hill. A moist, or sand-free zone, separated the sand from the rock face at its base. As the wind gusted, sand grains bounced and rolled, stopping about half a metre short of the rock surface. At the same time, minute grains of rock were separating from the marble without a single grain of sand reaching the rock.

It appears that as the wind comes up towards a rock surface, which represents a physical impediment, it loops around. As the velocity increases, the wind behaves as an air drill, which works on individual grains, plucking them one at a time. As grains are plucked from the base of the rock, where the whirring action of the wind is strongest, a piece of rock no longer has support and it breaks off. Thus, solid rock is dismantled a piece at a time and this creates the unique shapes that one encounters in arid environments.

As the wind erosion process continues, the ultimate result may be a surface that is absolutely flat, a ‘desert pavement’. Such is a desert driver’s dream. One can drive on this terrain, after the usual rough going at 5 or 20 km per hour, at 60 or 80 km per hour. Some desert pavements are made of rock fragments or pebbles which cover a soft layer of sand, as if arranged by a master craftsman. These rock fragments are usually one grain thick.19 They act as an armour
Wind deposition

Dunes are the product of sand transportation, accumulation, and deposition by the wind. The Western Desert of Egypt includes some of the largest sand dunes in the world. Some are 70 km long and five km wide, particularly in the Great Sand Sea (Figure 5) near the border between Egypt and Libya.²⁰²¹ The dunes occur in this pattern as bundles or as individual (linear) dune-forms. Some of the latter form as a result of topographic impediments.

As the wind moves across the surface it forks at a topographic high and breaks into two components. As the two components meet again in the lee of the hill, the two winds collide with each other and start unloading the sand. This continues to happen, and the dune grows to several kilometres in length.

The other common type of dune, which affects most desert areas, is the crescent-shaped or barchan dunes. In the presence of these dunes, one always knows the direction of the wind, because it is always in the direction of the two arms, which is the direction of dune movement. Some of these dunes move very fast. For example, in the Western Desert of Egypt, the rate varies between 20 and 100 m per year.²²

The movement of these dunes has far reaching effects. For example, Figure 6 shows the arms of some of these crescent dunes crossing the road that connects the Dakhla Oasis with the Nile Valley; this road is the oasis's only link to civilisation. I visited the same site six months later and observed that the dunes had moved further out. In another six months, the road was no longer passable.

In such situations one cannot do much. One has to figure out a way around the dunes until the sand moves enough to allow the same stretch of road to be used again. We can figure out exactly when this...
will happen because the rate of dune motion is steady and is easily measured. This can be done from photographs taken at different times. It can also be accomplished by field measurements - by labelling markers every metre or so and measuring the movement relative to the markers at different seasons.

In the same manner, the wind can engulf telephone lines, date palm groves, and most dangerously, agricultural land (Figure 7) and whole villages. The case of the village of Ginah in the Kharga depression provides a good lesson. In 1971 all of the inhabitants of that village had to be moved because sand had engulfed their houses. Engineers were sent from Cairo to build a new village, which they did a few kilometres away. In eight years, the new village, called New Port Said, was being covered by another dune mass!

This did not happen because that is the way of the desert, but because the engineers who selected the site for the new village did not take into account the presence of marching dunes upwind. No one gave much thought to the environment or asked the question: where are the sand dunes coming from and what is the rate and direction of their movement? Why? Because there are no dunes in the engineers’ environment in the Nile Valley. Furthermore, none of them was taught about sand movement in or out of college. This case exemplifies the dangers of not understanding the desert environment when planning its development.

My research team studied space photographs of this particular area, mapped the sand dunes, and measured in the field how fast they were moving. This resulted in the identification of areas that will be covered by sand in 10 to 25 years, and those areas that will never receive any sand because of the peculiarities of the terrain.

Figure 8 shows the result of this work in the Kharga depression, where the sand dunes usually occur in long chains. Dotted areas are all covered by sand. The areas in between are sand-free, because in the northern escarpment, where the sand comes from, there are topographic highs. The sand goes on either side around such impediments, leaving corridors that always remain sand-free. If we need to move people from a village from one area that is covered by sand, then we should move them to a zone where the sand will go by on either side, bypassing them.

I found that the only way to ensure that officials took this into consideration was to explain it to the local inhabitants. Copies of the space photographs and maps were distributed to show them the exact setting. They knew the desert very well, and all they needed was the knowledge gained from the new space perspective.

**Sand dune stabilisation**

Sand dune encroachment on human habitation sites is not unique to Egypt. Dunes move in all the deserts of the Earth. For example, this occurs in the Rajasthan Desert of northwest India and the adjacent
The Thar Desert of Pakistan, both part of the Great Indian Desert. There, sand movement also affects human habitation. Thus, Indian scientists at the Central Arid Zone Research Institute (CAZRI) in Jodhpur have tried to work out methods of stabilising the sand. They have experimented for many years with parallel lines of hay fences that could not hold the sand from moving, but did slow it down.

The only highly successful sand stabilisation programme that I have observed is in the Chinese deserts: the Tengger, the Alanshan, and the Taklimakan. The local Uyghur inhabitants are nomadic people who have figured out a way to make hay fences unlike those tested by the scientists in India. The Uyghur have created checkerboard hay fences one-metre square.

The Uyghur make these fences in the typical Chinese labour-intensive way, in groups of people. Using a stick of wood, the first person marks a straight line in the sand. The next carries the hay, and lays it down along the straight line. The third person pushes the hay to about one-third of its height into the sand. So the hay protrudes, to two-thirds of its height of about 30 cm. The last person in the group piles up sand about the hay fence to give it additional strength. As one group does this in one direction, another group will be doing the same thing at right angles. Thus, the area is crisscrossed, and a checkerboard pattern results. As I observed the wind gust in such an area in the Tengger Desert, I noticed the sand moving all the time, within the hay squares. The method did not inhibit the motion of sand, but succeeded in confining the motion of the sand within the one-metre squares.
What appears to happen in this case is that the wind is distributed at or near the surface. It is broken into several components that push the sand back and forth within the one-metre squares. For this reason, the Uygurs do not level the sand, but follow the natural contours. It is unquestionably a case of triumph of the nomads' ingenuity gained by thousands of years of knowledge of how to live with the desert.

**Confirming space observations**

Dunes are only one of the many features that are visible in space photographs. Recognition of other features requires field checking to ascertain their nature. An example is located in the border area between Egypt, Libya and the Sudan, where there is a group of mountains, the largest called Uweinat. There are spindle-shaped dark zones behind these mountains (Figure 9). The mountains occupy the northern part of the dark areas, and the rest of the spindle shape is marked by light-coloured material on either side.

The same kind of feature was observed in images of Mars, and no one could say how it formed. I planned a field visit to the Uweinat area so as to better understand the features on Mars. The plan included taking of samples from specific areas and locating them on Landsat images. However, the best maps of the southern part of the Western Desert of Egypt are at the scale of 1:500,000. This illustrates how little we know about such a place. At this scale, we could not take a sample and try to locate it on a Landsat image. We relied upon space technology to solve the problem, particularly the Nimbus 6 satellite. Knowing the signal frequencies of Nimbus 6, we took a transponder to send signals to the satellite at prescribed times during each day. Two or three times during the day our auto caravan stopped and
waited until each transmission to the satellite was completed.

The Nimbus 6 satellite picked up the transmissions, and sent them over to the NASA Goddard Space Flight Center in Greenbelt, Maryland. There, engineers marked the coordinates of the places from which the transmissions originated. Unfortunately, we did not have a receiver to help us locate ourselves at the time. We had to wait until we went back to the United States to establish where the sampling sites were in the Egyptian desert.

Later, as the Space Shuttle missions began, we tried another way of confirming the location of sampling sites in the desert. This was done during Columbia's second flight in November 1981. One of its orbits crossed the Western Desert of Egypt northwest to southeast. At the time of the mission we were in the desert marking with Mylar strips the places from which we took samples (Figure 10). This was done so that we could correlate the mineral composition of the ground with what showed up in the Shuttle data.

Comparisons with Mars

The aforementioned field checks allow the comparison of features in the Western Desert of Egypt with those on the surface of Mars. For example, in the upper left quadrant of Figure 9 there is a hill, Hagar El-Garda (Figure 11A). Like the Uweinat Mountain, it has a spindle-shaped sand-free zone in its lee. Sand forms the light-colored pattern on either side. In the lee of the hill, where there is no sand, the exposed ground is dark. Figure 11B shows an almost identical situation on Mars. The dark area in the lee of the crater is the original surface; around it are light-colored dusty deposits.

Another case is illustrated in Figure 11C, which shows part of the desert in Sudan southeast of the Uweinat Mountain. As the wind moves between the numerous knobs, it leaves sand-free lanes behind them and a streaked pattern is developed. Figure 11D shows an area in the Cerberus region of Mars, which displays the same kind of pattern.

There are other similar similarities. In photographs of Mars, mixtures of rock sizes were believed to be the result of catastrophic events such as a flood or an impact of a meteor. However, in the Western Desert of Egypt we find a similar condition that results from the natural decomposition of the rocks in the hyper-arid environment (Figure 12A and B). A fourth example of similarities between the hyper-arid environment of the Western Desert of Egypt and the surface of Mars is even more instructive. When we first saw vesicles in the Martian rocks as revealed by the Viking Lander camera (Figure 12CD), we immediately thought of vesicular basalt. This is a specific type of volcanic rock which covers large tracts in many places such as the Deccan region of southern India, and the northwestern United States. It is vesicular because as the lava is chilled very quickly, its gases have no time to escape, and they become trapped in pockets. Thus, the rock acquires a spongy appearance. A similar rock fabric that has nothing to do with volcanic activity occurs in the Western Desert of Egypt (Figure 12C). Here, the pits were formed by persistent wind erosion. Thus, the rocks on Mars were not necessarily volcanic, but could have been any type of rock that had been pitted by the wind.

These comparisons between the features of the hyper-arid Western Desert of Egypt and the surface of Mars suggest that aeolian processes such as wind erosion and deposition are as common on Earth as they are on Mars. The geologic history of Mars included wet periods, which resulted in the formation of riverlike features. Furthermore, today's conditions indicate that nearly all the processes that act upon the surface of Mars are very similar to those that shape the deserts of the Earth.

Evolution of the desert

Topographically high areas in arid lands are usually rimmed by wadis, or dry valleys. These could not
form except in the presence of vast amounts of running surface water. Flat areas in the Western Desert of Egypt also appear to have deeply incised valleys that have long since been covered by sand. This was revealed by the Shuttle Imaging Radar (SIR) instrument on board the Space Shuttle Columbia on the aforementioned second flight in November 1981.

The SIR transmitted radar waves towards the Earth. As the instrument received the reflected echoes, these were optically recorded to produce an image of the surface. The planned radar images in this part of the desert were expected to reveal very small features, which we could not see in other photographs. What resulted was totally unexpected.

We had studied a Landsat image of the area (Figure 13A), which covers 185 × 185 km. It showed only two slightly raised hills; the rest of the image was occupied by a flat sand cover. Not so in the radar image. Because of the extreme dryness (the heart of the region characterised by the 200 aridity index) the sand was not radar reflective. Thus, the waves penetrated through all the sand cover, and were reflected by the solid layer of rock beneath the sand (Figure 13B).

The radar image instantly explained the two raised hills. The dark, sinuous zones that appeared in the radar image were courses of ancient rivers. A large valley bordered each side of the two hills - islands that were left by the water that once flowed and eroded the surface.

There must have been a great deal of water to form valleys as wide as the Nile Valley, 20 km across. If there were rivers as large as the Nile, then there was much rain and a great deal of surface water. Some of that water would have evaporated, some of it would have been lost to lakes at the mouths of the rivers, and some would have seeped through the porous rock beneath and stored in aquifers.

At the time that this became known, I learned about the interest of the Egyptian Government in locating sources of groundwater in the Western Desert for reclamation projects. An area was selected for test drilling near the confluence of several of the buried valleys, where the likelihood of finding groundwater would be greater. Indeed, a few years later, nine wells were drilled and all brought sweet water. A desert reclamation project was started near Bir Tarfawi and is called Uweinat, after the mountain to the west. The present experimental farm of about 5000 feddans (1 feddan = 0.42 ha) may be expanded to 150 000 feddans when the project reaches maturity.
Prehistoric human habitation

Numerous valleys in the Gilf Kebir Plateau, northeast of Uweinat Mountain, are blocked by volcanoes, rock rubble, or accumulations of sand. Wherever this occurs, there is evidence of dry lakes upstream. This evidence may be in the form of lake deposits, some of which are up to seven metres thick. Indications of prehistoric human habitation abound in such places and near the edges of former lakes in lowlands. Remains of houses are in the form of circles marked by rock slabs, never in squares or other forms; square architecture must have been originated by the ancient Egyptians on the banks of the Nile.

By association, archaeologists have determined that the youngest dwellings in this particular area are over 5000 years old. Core rocks from which the ancient human inhabitants chipped pieces to form their tools in the Western Desert of Egypt vary in age from 5000 to nearly 200,000 years old.

As stated earlier, one can drive in this desert for 500 km and not see a blade of grass. Thus, it appears very odd to encounter a milling stone with its own grinding stone – indications of grain made into flour. This could not have happened unless there was much water that supported large numbers of living beings.

In the Western Desert it is also common to find ostrich egg shell fragments. Ostriches require grasses; these are therefore have enjoyed a savannah-like environment. Some shell fragments appear to have been carved into round pieces with holes in the middle. The holes were fashioned by human hands to make a necklace out of ostrich egg shells!

The most interesting of all indications of habitation in the desert are the petroglyphs – the drawings on walls of caves on high ground. One particular site in Uweinat depicts numerous giraffes and baboons. The artist who made these could not have drawn them from descriptions; they had to have these creatures around to be able to draw them so well. One petroglyph in Uweinat shows a revealing stratification in animal life (Figure 14). The oldest, or most faded, drawing is of a giraffe. Next are illustrations of a baboon, which is almost covered by another animal depiction, and an ostrich. The newest petroglyphs are of an animal resembling present-day cows. The upper one is perhaps an ancestor of the cow without horns.

This gives us an idea of the evolution of the life forms in the area. First, there was a forest, where giraffes could eat leaves off high trees. Then, came baboons and ostriches that could live in a savannah-like environment, with some trees. Then, the grasses
became rather scarce, and only the cow, capable of grazing, could roam the land. The change appears to have happened gradually, due to a natural degradation of the vegetation cover reflecting a decline in the amount of rainfall, which reached near zero about 5000 years ago.

**Environmental changes**

As a student in Egypt, I was taught that the Western Desert had been the ‘granary of the Roman Empire’. It had been a fertile land in which the Romans raised wheat and other crops. Then it was ruined by mismanagement and bad land-use practices after the Romans. However, observations in this desert uncovered not a single organic remain of any sort that is younger than 5000 years, long before the Romans. The Romans may have utilised the localised rainfall along the Mediterranean Sea coast, but nothing could have grown in the open desert farther south. The ‘granary’ may have been the Nile Delta and the Nile Valley.

The desert was not always as dry as it is today. Wet periods alternated with dry episodes throughout the Quaternary. The last wet period prevailed between about 10000 years ago to about 5000 years ago. Before that there was a dry period, which was preceded by a wet period. The cyclicity of wet and dry resembles that of the Ice Ages. Both cycles are part of a natural change, which depends on the global circulation of the atmosphere and on how much energy is received by the Earth from the Sun. It is the fluctuations of the amount of energy from the Sun that fuel major changes in our environment.

Thus when we consider the desert and the way it changes in space and time, we must take into account the whole environment of the Earth. It is in this light that we must now endeavour to understand the desert and its setting better, so that we can utilize more of it for the benefit of mankind.

**Conclusions**

- The desert is not as well known as other types of terrain on Earth. Geologists have generally
neglected arid land processes, compared to those of humid regions. The need exists for accelerated collection of basic data on the terrain of deserts and semiarid lands worldwide.

- The term ‘desertification’ has resulted in the proliferation of the misconception that the desert is man-made, and that new technology can ‘fix it’. These unfounded concepts unfortunately form the basis of numerous aid projects aimed at economic development of areas affected by cyclical droughts; such projects may unintentionally cause degradation of the environment.

- Deserts and semiarid lands vary greatly depending on their ‘aridity index’. Therefore, it is dangerous to make generalisations about conditions of soil moisture, and other factors. Each area must be considered separately and dealt with as a microcosm.

- Photographs obtained from spacecraft provide a new tool to study the arid lands of the Earth. Emphasis should be placed on the use of these data in future investigations of deserts, particularly because they allow the study of regional patterns.

- Natural colours of desert surfaces in space photographs are meaningful and could be used to distinguish formations and areas of active erosion. In desert sands, the darker the red colour, the older the deposit and/or the farther away from its source.

- The basic features of the terrain in deserts and semiarid lands were formed by water erosion in the geological past. These features are often overlooked in the study of what is now an arid, wind-sculptured environment.

- Wind is the major agent of erosion and deposition in today’s deserts. Features of wind erosion and deposition must be fully understood in order to avoid the menace of moving sand dunes.

- Stabilisation of sand dunes is possible by means that were learned by inhabitants of desert regions from thousands of years of experience. Each region may require a unique solution to the prob-
lem of dune motion; in some cases it is best to live in inter-dune corridors.

- Field observations are essential to the proper interpretation of features seen in space photographs and other data. Correlations of the two sets of data usually result in a better understanding of the terrain and its characteristics.

- Many of the features of the deserts of the Earth are also common on Mars, which appears to have hosted much surface water in its geological past. However, today it is controlled by wind action, which is also true of Earth's arid lands.

- The eastern Sahara, the driest large area on the face of the Earth, has enjoyed milder climate in the past. The present dry conditions began some 5000 years ago. Between then and about 10000 years ago there was much water, and many plants and animals. Human habitation sites abounded. Prior to 10000 years ago there was another dry period, but before that and going back to 20000 years ago, there were at least three other wet periods. These changes depended on the global circulation of the atmosphere and the amount of energy that was received by the Earth from the Sun.

- The layout of the land and how it evolved in space and time should be considered in all development projects in deserts and semiarid lands. This will ensure that such projects benefit the local inhabitants and do not unintentionally degrade the environment.

**Literature cited**


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