JOURNEY TO THE GILF KEBIR AND UWEINAT, SOUTHWEST EGYPT, 1978

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A multidisciplinary group of sixteen scientists visited the southwestern desert of Egypt to verify interpretations of Earth-orbital photographs. The two-week journey started at Kharga Oasis and proceeded south-southwest to Bir Tarfawi, west to the Gilf Kebir plateau, and then to Gebel Uweinat, on the border between Egypt, Libya and Sudan. Members of the expedition discovered sites of prehistoric human settlements ranging in age from approximately 3000 to perhaps 200 000 years ago. The condition of plant remains in the Gilf Kebir area indicated a prolonged period of dryness of up to 20 years. However, a cloud mass observed on a weather satellite image in mid-December 1977 may have provided rainwater for numerous plants in the Uweinat region. The geological findings, including prospects for economic mineral deposits, were valuable. Fluvial and aeolian erosional patterns were studied at Gilf Kebir and also at Uweinat. Many of the desert landforms display similarities to those recently identified on Mars. Correlations of features in the Egyptian desert with those on the Martian surface will help us to a better understanding of surface processes on both Earth and Mars.

I. NARRATIVE OF THE JOURNEY

FAROUK EL-BAZ

THE MAIN purpose of this two-week expedition was to verify in the field interpretations of tonal variations and surface patterns observed on Earth-orbital photographs. On Gemini and Apollo–Soyuz photographs and LANDSAT images, the Gilf Kebir plateau displays many interesting fluvial landforms (Plate V), which must have been formed during wetter periods in the past. Furthermore, patterns of light- and dark-coloured wind-formed features in the Uweinat region (Plate V) appear very similar to those shown on Mariner and Viking photographs of Mars (El-Baz, 1977: 77–80). The investigation of these features was included in a research project conducted jointly by Cairo's Ain Shams University and the Smithsonian Institution. In addition, as scientific adviser to President Anwar Sadat of Egypt, I needed to complete the investigation of the development potential of the Western Desert by the reconnaissance of its southwestern part. In preparing this report on the expedition, we follow the scheme of the paper that reported results of a similar expedition made 40 years ago (Bagnold *et al.*, 1939).

This part of the Libyan Desert is a desolate wasteland. Gebel Uweinat is 670 km as the crow flies from Kharga Oasis (Fig. 1), the nearest point where supplies may be purchased. Dependable desert vehicles are therefore essential for

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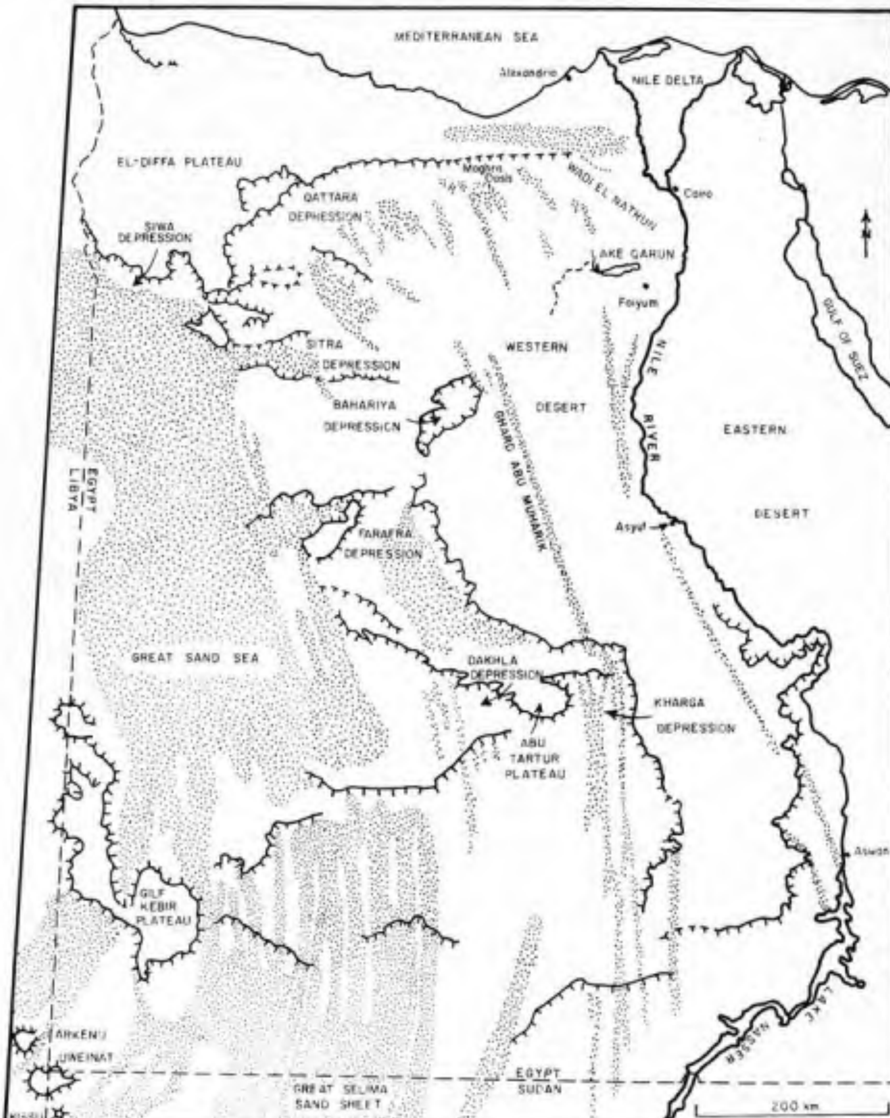

Fig. 1. Map of Egypt west of the Nile showing major oases and scarps and the distribution of dune fields and other sand deposits (modified from Gifford et al., *1979)*

the transport of personnel, water, petrol, food and camp equipment, and these were provided by the Geological Survey of Egypt. The convoy consisted of six Soviet Gaz jeeps, two 4·5-ton tanker trucks for water and petrol, and a 12-ton lorry loaded with food, oil barrels and camp equipment. In addition we used two Volkswagen Type-181 vehicles from research projects sponsored by the National Geographic Society. This fleet of vehicles was necessary because of the considerable number of scientists involved in the interdisciplinary expedition. The scientific group consisted of seven American and nine Egyptian specialists in the fields of geology, geography, Quaternary geology, archaeology and botany.

Those from America were: myself; Carol Breed, Maurice Grolier and Jack McCauley, from the US Geological Survey; Vance Haynes, from the University of Arizona; Ted Maxwell, from the Smithsonian Institution; and William McHugh, from the University of Nebraska and GAI Consultants, Inc. The Egyptian group comprised: Bahay Issawi, Atef Dardir, and Mohamed Ibrahim, of the Geological Survey of Egypt; Hassan El-Etr, Nabil Embabi, Hamed Dowidar, Adel Moustafa, and Mahmoud Yousif, from Ain Shams University; and Loutfy Boulos, from the National Research Centre. In addition Hatim Farid, science editor of Cairo's *October Magazine*, joined the party. Sixteen employees of the Geological Survey of Egypt supported the expedition as drivers, mechanics, cooks, etc., making a total of 33 people in all.

Our expedition benefited greatly from the knowledge gained by 13 previous journeys to Uweinat from various localities in Egypt. We were especially fortunate to have Bahay Issawi, who was the last to map the region (in 1971) as our field guide. By the use of maps, conventional navigation, and Earth-orbital photographs, we endeavoured to establish accurately our locations throughout the trip. In addition, we performed an experiment of navigation by NASA satellite tracking. On one of the Volkswagen vehicles, we carried a transmitter that sent signals to the Nimbus 6 satellite as often as three times daily (Plate VIa). The signals were retransmitted by the satellite to the Goddard Space Flight Center at Greenbelt, Maryland, where the location of the transmitter was calculated and plotted.

On the morning of 24 September 1978, the American contingent assembled in Cairo, and proceeded to the offices of the Geological Survey of Egypt to meet with our Egyptian colleagues. The group spent much of the day studying maps and photographs of the route and sites to be visited. The following paragraphs summarize the activities of subsequent days in the desert.

25 September: We left Cairo at 9.15 a.m. by air and, during the flight to Kharga, we observed and photographed many interesting features, particularly the danger to fertile land from encroaching dunes (El-Baz, 1978) which is very evident between Faiyum and Asyut (Plate VIb). At Kharga we met the jeeps which had arrived a day earlier, and along the road caught our first glimpse of the Kharga yardangs, or what Bagnold (1939) and other British explorers called 'mud lions': wind-sculpted lacustrine deposits with blunt fronts and aerodynamically-shaped bodies. While at Kharga, we visited the Hebis Temple, northeast of the town (Plate VIc).

26 September: Leaving Kharga, we drove west to Dakhla along the asphalt road built in 1963 (avoiding various barchan dunes marching across it), and at the 60-km mark turned south-southwest into the open desert, aiming for Tarfawi West, a locality east of Bir Sahara (Fig. 2). Scattered conical and pyramidal hills reminded me of an earlier speculation on whether the ancient Egyptian engineers designed the pyramids after these wind-resistant forms. About 70 km from the asphalt road, we stopped to study a large petrified tree, noting the sand grains deeply lodged in grooves in its surface—an early instance of the power of the sand-moving winds (Plate VId).

27 September: Proceeding towards Bir Tarfawi, we visited what Vance Haynes referred to as 'Site 1', where a patch of oxidized peat outcropped along an ancient dry lake-shore (Plate VIIa). The determined age of gastropods and snails embedded in the dry lake bed, and the abundant associated artefacts in these strata, indicated that this site supported human settlements at least 30 000 years ago. At Bir Tarfawi the water at the well dug by the General Petroleum

Company of Egypt was reached at a depth of 2 m (Plate VIIb). In this area, narrow and closely-spaced tyre tracks, identified by our Egyptian colleagues as those made by the vehicles used by Prince Kemal el Din Hussein in 1925, were still visible in the moderately coarse lag gravel, although not in fine sand. In the Bir Tarfawi sand sheets, coarse grains overlie finer particles. The sand colour was closest to A17 on the Apollo–Soyuz colour wheel (equivalent to Munsell colour 7·5YR 6/6; see El-Baz, 1977: 49–55). Southwest of camp, we sampled a barchan dune that appeared redder than the surface lag, and here we found implements estimated by both Haynes and McHugh to be about 8000 years old. A few inches in the soil below, Vance Haynes found pieces of ostrich eggshell. That evening and for a few nights we feasted on ducks brought from Kharga, which provided a pleasant change from the more usual desert fare.

28 September: From the Tarfawi West camp, we headed east to Qaret el Maiyit (Arabic for 'hill of the dead', because of a human skeleton discovered there). Here the exposed granitic rock displayed a long down-wind tail of dark material surrounded by light-coloured sand on either side. Weathered orthoclase from intervening pegmatite veins in the granite gave this tail a reddish tone. Here again, the effects of wind erosion were evident in the abundance of vortex pits on exposed rock surfaces. Near Qaret el Maiyit were large sandstone and granitic blocks arranged in crude circles which we assumed to mark an ancient human settlement (Plate VIIc). Continuing east, we crossed the old Darb el Arba'in caravan route, which was nearly 20 km wide where we intersected it, and nearby we examined the mineralized products (mostly silica and iron) of what may once have been a hot spring or geyser. A Geiger counter check for radioactive minerals was negative. Driving on, we were surprised by the sight of a camel caravan emerging from the distant mirage about 10 km southwest of Bir Kiseiba. The five camel drivers were just as astonished to see us. Their 60 camels were loaded with *atrun* (Plate VIIIa) which they had carried from Ma'atin in the Sudan, and they told us that this evaporite, mostly trona (sodium sesquicarbonate), was used to tenderize chewing tobacco packed at Esna on the Nile. Continuing south towards El Shab, we encountered at Bir Kurayim a 'ghost settlement' established there by the Egyptian Desert Development Organization in 1964. Badly placed along shifting sands, the settlement contained buildings of galvanized metal and glass now half filled with sand, structures ill-adapted to the desert (Plate VIIIb).

29 September: Turning now towards the Gilf Kebir, we first drove north for 32 km to a block of conglomerate protruding from the featureless plain and erected on it a 2 m high cairn to guide other drivers (Plate VIIIc). In this section, the heavy vehicles stuck frequently in patches of soft sand, and to free them we used metal channels similar to the sand tracks used by Bagnold and later by the British Army during World War II. Close to Black Hill, one of the major landmarks along our route, we noticed that the tracks made by the Bahay Issawi expedition seven years earlier were now covered by a barchan dune. We camped that night near the hill.

30 September: With the morning light we studied a field of small yardangs near our camp, several being 2 m high and exhibiting a straight windward face (Plate IXa). At a distance of 244 km from Tarfawi West, the car tyres started to expose very red soil a few centimetres below the surface sand or lag deposit, and here and there we encountered iron and manganese concentrations in the form of strata or nodular masses. These again exhibited vortex pits and hollows drilled by the wind. As we approached the southeastern scarps of the Gilf Kebir, we headed towards Bagnold's 1938 camp and observed that his tracks around the end of the

1-km longitudinal dune were now covered by that dune's extension. The western side of the dune had also partly submerged the 1938 camp site (Plate IXb), while wooden boxes at the site showed the effects of wind erosion: a piece of wood 13 cm thick on the nailed side was only 2 mm thick at the exposed surface. After sampling the dune sand and remembering the pioneers who erected the camp, we took photographs of each other at this historic site.

1 October: From a base camp established at the entrance to Wadi Wassa near the southeast tip of the Gilf Kebir (Fig. 2; Plate XVIIa) we headed northward to Wadi Mashi. To navigate we used enlargements of LANDSAT and Apollo–Soyuz photographs and the map drawn by Ronald F. Peel in 1938 (pers. comm.). We were all very impressed by the accuracy of that map. On the top of the Gilf Kebir, William McHugh discovered a new archaeological site where implements were strewn near core blocks of quartzite from which they had been chipped (Plate IXc). Geologists studied the fluvial landforms and the erosional effects of wind action as the archaeologists studied the site and excavated to 30 cm below the surface. At Wadi Mashi we noticed a smooth dome of basalt; the columnar rock was dense and fine-grained inside, but pitted by wind action on outer surfaces. Back at camp it was obvious that more time was needed for further investigation of wadis of the Gilf Kebir, and we agreed to divide the expedition into two groups. The larger, of 21 people, stayed at the Gilf to investigate Wadis Bakht and Ard el Akhdar, while ten scientists and two drivers proceeded to Uweinat.

2 October: The Uweinat party headed west within Wadi Wassa, noting that the floor of this wadi showed evidence of an alternation of wet and dry cycles. In places, four generations of mud had accumulated in brief wet periods, but from the condition of the scanty vegetation, Loutfy Boulos, the team's botanist, estimated that it had not rained for approximately 20 years. Giant sand ripples, 10–30 m long, and with truncated flat tops, covered the wadi floor. We left the Gilf Kebir through a pass 10 km north of Wadi Firaq, where kaolinized material was exposed at the base of the cliffs. Running south towards the Peter and Paul Hills, we suddenly found ourselves traversing dark volcanic rocks (basalts and trachytes), with aprons of alluvium and colluvium. Maars (explosion craters) appeared, with quartzitic layers standing on edge and marked crater rims, but no volcanic rock exposed within (Plate Xa). By nightfall we had arrived at the north entrance of a small unnamed valley just west of Karkur Talh in the Uweinat complex, 243 km from the Gilf Kebir camp site.

Meanwhile the Gilf Kebir party spent this day at Wadi Bakht (Plate XVIIa). McHugh, Embabi and Maxwell began work at Oliver Myers's neolithic site in upper Wadi Bakht, while McCauley and Breed spent the morning examining the relative effects of wind and water erosion in the lower part of the wadi. Pebbles and cobbles of friable sandstone on the floodplain showed abundant evidence of wind erosion in the form of delicate, etched projections along bedding planes aligned with the wind. In the afternoon, studies were made in the upper wadi of the archaeological site; the relationships of falling and rising dunes, yardangs and ripples; and the structure of a very large granule ripple, together with surveys of the local topography.

3 October: Exploring the northern slopes of Gebel Uweinat, we were again much impressed by the evidences of wind erosion. The predominantly north wind had sculptured the rock into eerie shapes resembling frozen dinosaurs and other giant animals. Exposed rock surfaces were all pitted, and where sand grains are trapped in these pits, they swirl round in wind gusts, enlarging the cavities.

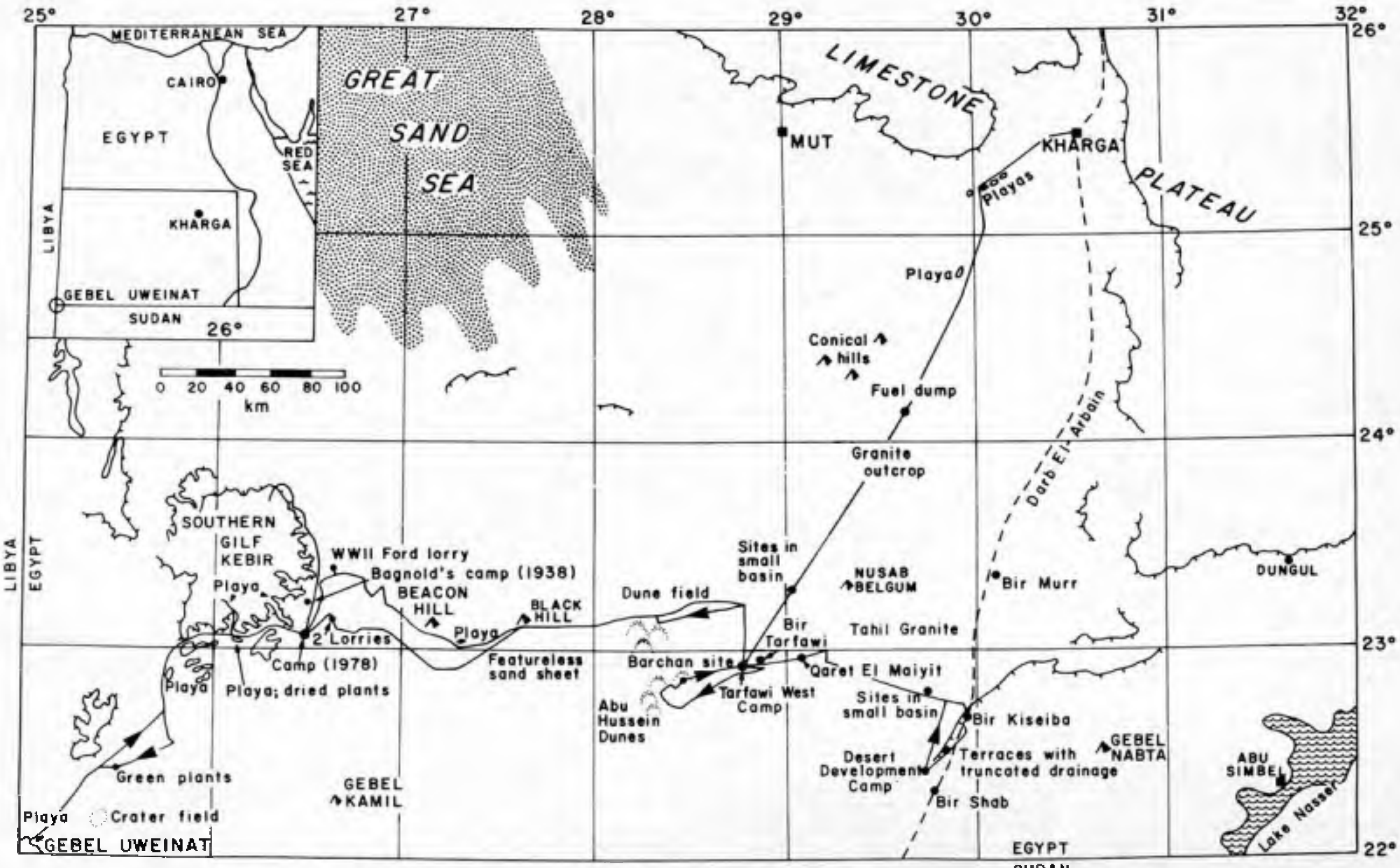

Fig. 2. Route map of the 1978 journey to the Gilf Kebir and Uweinat, southwestern Egypt

Pits, often aligned in rows, graded into fluted surfaces. As Maurice Grolier and I studied these effects, petrologists sampled the Uweinat granites, structural geologists examined the fracture patterns, Loutfy Boulos collected plants, and Vance Haynes photographed rock engravings. Haynes also found a camel saddle perched on an *Acacia* tree. We later drove south into Sudan and examined the dark apron about Ras el Abd (Arabic for 'head of the slave'). This apron, like others studied on Earth-orbital photographs, was much darker than the surrounding materials. Around the hill we noted a well-preserved alluvial fan formed by a rainfall in the not too distant past.

Meanwhile at the Gilf Kebir, Maxwell completed the topographic profiles while McHugh and others continued excavation and collection at the archaeological site in Wadi Bakht. McCauley, Embabi and Breed drove westward through Wadi Wassa to the route marked by Bagnold's petrol cans, and turned south, re-marking some very old tracks. Some 7·4 km south, they built a boulder pile marked with the name and date of the expedition, and a request to future explorers to note the condition of their tracks relative to the much older tracks in terms of wind erosion and gullying. A little further south they collected pitted quartzite from the top of a conical hill.

4 October: Before loading the cars at sunrise at Uweinat, I examined the two *Acacia* trees at the northwestern ridge of Karkur Talh. The stem of one had been partly removed by termites (Plate Xb). On the other, the leaves on the top two branches appeared much drier than those on lower ones, suggesting a fall in the level of the watertable and some consequent water starvation in those upper parts of the tree needing a higher osmotic pressure for water to reach them. On quartzitic surfaces we noticed numerous *magals*, natural cavities in this impervious rock which preserve collected rainwater, sometimes for a whole season. Leaving Uweinat for the Gilf Kebir, we sampled an exposure of grey granite and conglomerate around it, a natural setting for radioactive element concentration. The last objective of the day before rejoining the Gilf party was the broad sand streak just east of Gebel Babein, samples of which I required for comparison with samples from other parts of the Great Sand Sea collected earlier, to study sand-reddening with time (El-Baz, 1978). The sand had here accumulated into a giant whaleback dune with gentle slopes and no slip faces.

On this day, the entire Gilf party was occupied in Wadi Ard el Akhdar (Plate XVIIa), where McHugh excavated sites while Maxwell conducted topographic surveys. McCauley, Breed and Embabi investigated the relationships of a fanglomerate wedge to the eroded lake beds at the narrow constricted neck of the wadi, now occupied by the so-called 'blocking dune'. Later they were joined by Vance Haynes and Loutfy Boulos, who had returned from Uweinat.

5 October: At the Gilf Kebir, camp was broken and we headed back eastward towards Bir Tarfawi, passing relics of World War II on the way: a dismantled British army truck, with pieces strewn in the sand. The engine hood had created a micro wind-flow producing an 8-m sand tail in its lee. Making a stop to cool the jeep engines, we found ourselves on a ferruginous sandstone layer in which hematite was exposed as a thinly-laminated red layer of unknown depth (we dug to over 40 cm without reaching its base). This red layer contained dark brownish-black nodules of iron and manganese oxides. We drove for 11 km over this iron ore, which we estimated to lie some 150 km west of Bir Tarfawi. Collecting petrol at Bir Tarfawi, we turned north for Kharga.

6 October: On arrival at Kharga around midday, a group assembled to study the barchan dunes and their invasion of roads, telephone lines, cultivated fields, houses, wells and even whole settlements. It was apparent that the great efforts of the local villagers to combat their advance, by planting *Tamarix* and *Acacia* trees, for example, slowed down but did not halt the advance of the dunes. At an evening meeting with local geologists, hydrologists, engineers and agricultural experts, we discussed the findings of the expedition, and the pros and cons of large-scale agricultural development in the New Valley province. Underground water supplies appear still to be plentiful, but the irrigation schemes are wasteful of the water. Available data did not allow a resolution of the much argued question of whether or not the underground water supply is being replenished from the south and west, but the preponderance of igneous and volcanic intrusions at the southern and southwestern borders of the Western Desert indicates, if inconclusively, that the water supply is not now being effectively replenished.

7 October: The scientists again split into two groups, one heading for the plateau north of the Kharga Depression, the other south to Baris Oasis (Fig. 9). On the plateau, further wind-sculptured forms were studied, for here the wind had carved yardangs in extremely hard crystalline limestone. Below, within the depression, we observed the alignments of mounds marking ancient springs set along north–south trending faults. Fault boundaries are marked by *Tamarix* trees and growths of reeds in the salty soil, while the remains of irrigation canals built in Roman times and lined with palm-tree trunks were clearly apparent. Evidence of active soil erosion by wind was pronounced everywhere. At Ain el Shurafa, Vance Haynes estimated that nearly 24 m of soil had been removed by the wind during the last 3000 years, a mean rate of 8 mm per annum, and the resultant sand accumulations were ubiquitous. Little remains, for example, of Dakhakhin, across from Ain Gaga, which was a major oasis when photographed by Beadnell in 1909. After studying the stratigraphy of the scarps around the Kharga Depression, we visited the 'Bagawat' complex, a desert market place with numerous facilities built by the Egyptian architect Hassan Fathy (Plate Xc); in the evening a seminar was held to discuss the findings of the expedition and their implications.

8 October: The morning was spent in sorting samples and separating those to be left at Kharga, for one of the results of the expedition was to interest the local unit of the Geological Survey in keeping samples from all expeditions at the newly-established Kharga Museum. On the afternoon flight back to Cairo, the lighting was perfect for a view of the enormous field of yardangs north of Kharga, possibly the largest such field in the world. We reached Cairo at sunset, ending a most interesting and highly successful journey.

Acknowledgements

Numerous organizations and individuals contributed significantly to the success of this expedition. We should like to acknowledge the financial support of the following institutions: Ain Shams University, Cairo, for providing food, photomosaics and some camping needs; the Egyptian Air Force, for providing an aircraft to transport the scientists from Cairo to Kharga and back; the Geological Survey of Egypt, for making available the necessary vehicles, petrol, support personnel and camp equipment; Goddard Space Flight Center, for providing the transmitting apparatus and the satellite tracking data; and the New Valley Government, for providing the space for lodging, meals, and lectures and seminars at Kharga. International travel was also financially assisted by several organizations including: the National Air and Space Museum (for T. Maxwell); the University of Arizona (for V. Haynes); the National Science Foundation (for F. El-Baz); the Smithsonian Foreign Currency Program (for C. Breed and J. McCauley); and the US Geological Survey (for M. Grolier). The NASA Planetology Program Office covered salary costs for C. Breed and J. McCauley during the expedition.

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II. QUATERNARY GEOLOGY AND ARCHAEOLOGICAL OBSERVATIONS

VANCE HAYNES

IN RECENT years, new and important Palaeolithic and Neolithic discoveries have been made in the southern part of the Western Desert of Egypt. Of particular significance are the sites at Tarfawi West, Bir Tarfawi, Gebel Nabta, and in Wadi Bakht in the Gilf Kebir (Myers, 1939; Wendorf *et al.*, 1976, 1977). New discoveries made on this trip (see following section by McHugh) can be interpreted in the light of the previous work and will add valuable data about this little-known area. While in the field, archaeological sites and playa deposits were recorded in our dead reckoning log along with any observations pertinent to Quaternary geology. A number of sites and deposits were examined in more detail, as time permitted.

Bir Tarfawi region

Playa deposits were first encountered along the Kharga–Dakhla road between 50 and 60 km from Kharga. These occur in deflational basins around the base of the Abu Tartur plateau. Larger playas to the west, in an area known as El Zayat, are being considered for agricultural development with groundwater irrigation. A small playa was recorded along our route 40 km south–southwest of the Kharga–Dakhla road, and 130 km further to the southwest is the 'dike area' where Schild and Wendorf (1977) excavated Mousterian artefacts associated with ancient dune deposits. The archaeology and geochronology of Bir Sahara and Bir Tarfawi have been reported by Wendorf and others (1976; 1977).

A small basin about 50 km northeast of Bir Tarfawi contains several concentrations of Neolithic hearth stones and artefacts scattered over the floor of

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what may have been a playa. Terminal Palaeolithic and Neolithic artefacts are essentially absent from the basins at Tarfawi West and Bir Tarfawi. This may be an indication that playas were not present during these times as at other places in the desert (Haynes *et al.*, 1977). The absence of playa deposits at the Tarfawi basins may be due to the high permeability of the dune sand exposed in the floors of the depressions by deflation of overlying lacustrine deposits of Mousterian–Aterian Age. These earlier lacustrine deposits probably formed in groundwater-supported lakes in which marls and peat deposits developed instead of the slope-washed, fine-grained sediment so typical of playa deposits. The main watering place at Bir Tarfawi lies at the foot of a small cluster of date palms at the centre of the elongated miniature oasis. Comparison of photographs taken 53 years apart shows essentially no change in dune morphology and only minor changes in the vegetation, the greatest being the loss of one or two date palms (Plate XI).

The Tarfawi West–Bir Tarfawi basins are surrounded by a sand sheet which is a northward extension of the Great Selima Sand Sheet described by Bagnold (1933). The age of this remarkably flat deposit of aeolian sand is unknown but, in 1973, I found non-diagnostic stone artefacts in association with a fire hearth buried 15 cm deep in a sand sheet approximately 20 km east of Bir Misaha. On the present trip, a surface concentration of lithic implements was discovered in the Abu Hussein dunes 35 km west–southwest of Bir Sahara (see following section by McHugh). An ostrich eggshell sample from this site has a radiocarbon date of 8170 BP ± 120 (A–1966), consistent with the degree of pedogenic development in the sand sheet compared with that observed in the Gebel Nabta area (Wendorf *et al.*, 1977).

At the granite hill of Qaret el Maiyit, 20 km east–northeast of Bir Tarfawi (Fig. 2), two stone structures were found on the southwest flank near a smaller outcrop of granite. These structures, one several times as large as the other, consisted of simple upright slabs of sandstone arranged in crude squares. Presumably they formed parts of a dwelling and a detached storage bin. A thin scattering of artefacts occurs all around the flanks of the hill, and human bone fragments were observed in crevices within the rock. Mousterian or Late Acheulean blade fragments and flakes, highly sand-blasted, occur along the northwest foot of the hill, but there is practically no hope of finding this material *in situ*. On top of the hill, stream-rounded, fine to medium pebbles were noticed in cracks and small depressions suggesting a lag from lowering of the desert floor, probably before Late Acheulean time. We found a small basin with playa deposits, a strand line, and numerous Neolithic sites with hearths 120 km east of Bir Tarfawi.

The Gilf Kebir region

On our way to the Gilf Kebir, another playa deposit with Neolithic artefacts was found, 15 km southwest of Black Hill (Fig. 2). However, the playa sediments had been severely deflated and all of the artefacts appeared to have been let down. Several pebbles, especially of quartz, on the playa floor display a high degree of natural polish. Similar polish on quartzite, quartz pebbles, and chert artefacts occurs around the southern flanks of Black Hill. Here also was found a human skeleton in a sheltered space under a large rock. The skeleton, without associated artefacts, might be that of one of the refugees from the Italian occupation of Kufra Oasis in Libya who tried to reach Dakhla from Uweinat in

1931 (Clayton, 1936), for desiccated bodies were occasionally found in remote desert places a decade or two thereafter.

At the eastern edge of the southern Gilf Kebir while looking for Bagnold's 1938 camp, we found a World War II Ford cab-over-engine lorry made in Canada in 1942. According to W. B. K. Shaw (pers. comm.), vehicles of this type were used by the Long Range Desert Group to supplement their Chevrolet trucks. The abundance of heavy gauge, 4-gallon petrol tins scattered about indicated that this one was a fuel lorry. Two other World War II abandoned vehicles, a Ford lorry and a GMI (General Motors Incorporated?) stake-bed lorry, were found 10 km southeast of the southern Gilf on our return trip. The Ford bore painted-over insignia of crossed wrenches on one bumper and a camel in a circle on the other, probably indicating use by the Sudan Defence Force (Wright, 1945).

Approximately 10 km south of Aqab el Gadim is the location of the 1938 base camp (Bagnold, 1939) and the Acheulean site investigated by Myers (1939). With photographs from original negatives provided by Ronald F. Peel, I was able to rephotograph some of the exact locations of the 1938 expedition. Comparison of the 1978 and 1938 photographs shows that very little change has occurred to the desert floor in 40 years (Plate XII). Views of the base camp show minor changes in the seif dune, as expected (Plate XIII). Tracks to the 1938 camp, still clearly recognizable, pass under the seif dune which extends approximately 40 m farther south than it did in 1938.

Close inspection of the ridge north of the base camp revealed a channel filled with red, cross-bedded, medium sand inset into the sandstone ridge. This appears to be aeolian sand reworked by water and deposited into a channel that may have been dammed by dune sand as at Wadi Bakht or Wadi Ard el Akhdar (Peel, 1939). The bedrock ridge and inset sand deposit are overlain by 1–2 m of pebble- to cobble-sized gravel composed of subrounded to rounded sandstone of varying degrees of cementation. In 1975, I found the Acheulean artefacts at Myers's site to be in the uppermost part of alluvial fan gravels that make up an inactive surface at least 10 m below the top of the gravel-capped ridge. It is likely, therefore, that the upper gravel represents a mid-Pleistocene or earlier episode of alluviation of a fan or pediment cap. The buried channel sands are, of course, even older. Thus, the evidence of cycles of contrasting Pleistocene climates documented by Caton-Thompson and Gardner (1931–1932) is further strengthened. No artefacts were noticed in the upper gravel, but time did not permit a thorough search. The occurrence of fine-grained channel sediments below the upper gravels opens up the possibility of finding pre-Late Acheulean archaeological sites around the edges of the Gilf Kebir.

Being one of the group that went to Uweinat, I was able to spend less than two hours at the Wadi Ard el Akhdar perched playa deposit, and most of this time was spent in locating some of Peel's photographic sites. While new photographs of these show remarkably little change in 40 years, small changes in the centre of the wadi floor indicate that there has been at least one episode of discharge during which vegetation was either blown or swept away (Plate XIV), and a small cut terrace formed in a westerly branch of the main wadi, but not in the easterly branch (Plate XV). Bank remnants appear to have been washed from the right bank of the main channel (Plate XVI) but I cannot be certain that my photographic station was as far up the wadi as Peel's. The evidence of discharge since 1938 and the absence of similar vegetation today indicate that the dried plants observed at the mouth of the wadi are less than 30 years old, as suggested by Boulos in Section IV.

The playa sediments have a few lenses of interbedded gravel washed from the surrounding slopes, but these gravels are minor compared with the several decimetres of slope-washed gravels over the outer edges of the playa deposits on the northeast side. They may correlate with similar gravels in the El Nabta area and suggest more torrential rains than those under which the finer-grained playa deposits formed. High deposits were noticed along the north side (Plate XV), and a strand line appears on the hillside above these.

Uweinat region

En route to Uweinat, we followed the westward extension of Wadi Wassa and left the Gilf Kebir through a pass approximately 10 km north of the traditional pass of Wadi Firaq (Bagnold, 1939). However, from the number of old tracks and World War II petrol tins, it appeared to have been well used. Three-metre-high terraces of clayey sand and silt alluvium were observed in parts of the wadi. The relief on the western side of the Gilf Kebir is 200 to 300 m greater than on the eastern side; the black, nearly vertical, cliffs were quite impressive as we headed south. Two playas were exposed in an area of nearly flat but gently undulating sand sheets, 25 and 40 km south of Wadi Firaq. Numerous archaeological sites, with Neolithic milling stones, were observed. In one of the craters related to igneous intrusions (Sandford, 1933), we noticed partly indurated playa sediments.

At Gebel Uweinat, an unnamed wadi just west of Karkur Talh and connected to it by a northeast–southwest-trending valley contained playa sediments with recent mud-pan deposits set into the deflated floor. Low dunes separated this playa from the floor of what I shall call 'Wadi Handal' because of the abundant green gourd plants (*Citrullus colocynthis*). From the cliffs above the wadi, their distribution clearly defined the meandering thalweg in spite of a cover of sand. This and other greenery was a most pleasant surprise, especially in view of the fact that other colleagues and I had observed a few green plants east of Bir Kiseiba seven months earlier where they had not been observed before. Subsequent examination of NOAA satellite images revealed a strong cloud cover extending over both areas on 16 and 17 December 1977. As suggested by Boulos (Section IV), the green plants may have grown because of rain on those days.

At two places along Wadi Handal, dunes, probably covering alluvial terraces, occur 6 m or more above the present floor. Both of these terrace remnants, one on each side, have archaeological sites in the covering dunes and probably in association with the terrace surface as well. A radiometric date of 3670 ± 80 BP (A–1972) was determined from ostrich eggshell. Cursory examinations of potsherds and lithic artefacts indicate occupations ranging in age from historic to Neolithic, an interpretation supported by the degree of soil development observed in the older dunes on the terrace. The potsherds have been studied by Kim Banks at Southern Methodist University, who confirms the mixed age of the assemblage (pers. comm.).

At the head of Wadi Handal, we observed excellent examples of petroglyphs pecked through the dark-brown desert varnish on boulder-size sandstone blocks. In addition to the often reported giraffe figures, there is a figure that appears to be a baboon. Strand lines, presumably from the December 1977 rain, occurred on the boulders and indicated water depths of approximately 1 m in some of the plunge pools.

In Karkur Talh proper, the evidence of recent habitation is shown by recently used milling stones, fire hearths, cordage, woven mats, wooden hut frames, camel saddles, a sooty teapot, World War II jerricans patched with gum, and a thorn-bush corral. This inventory is not unlike that of Guraan or Tibu people in pre-war years (Peel, 1942). The recent occupants could have come from either Sudan or Libya to take advantage of the grazing provided by the recent rains, but the numerous vehicle tracks, a large petrol drum, and pieces of cardboard cartons with Libyan brand names and addresses suggest at least some connection with the Libyan garrison reported to be at Ain Doua on the southwestern corner of Gebel Uweinat. We also observed six wild (? feral) asses and a gazelle in a grassy reach with *Acacia* trees. These have not been reported at Uweinat in modern time and the only reference to them is from local information, obtained by King (1925, p. 303).

The return trip was for the most part by our outbound route except from Gilf Kebir to Black Hill. In this stretch we passed 10 km to the south of Beacon Hill (Fig. 2), and on the rest of the way to Black Hill, for nearly 30 km, we passed numerous archaeological sites on a fine-pebble sheet and just southward of its border with a dark brown alluvial hamada extending from the highlands to the north. Examination of these sites will have to await future expeditions.

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III. ARCHAEOLOGICAL SITES OF THE GILF KEBIR

WILLIAM P. McHUGH

MY INTEREST in the Gilf Kebir–Uweinat area began in the middle 1960s when research on arid lands' geomorphology led me to this area and its archaeological potential. In 1966, I was able to study the artefacts Oliver Myers had collected in the Gilf Kebir and Uweinat. By combining the information contained in the rock art with the geomorphic and other observations of Peel (1939) and Bagnold *et al.* (1939), I developed a model of palaeogeographic conditions and human adaptation in the Gilf Kebir–Uweinat area for the late prehistoric period (McHugh, 1974a, b; 1975). This model is based on data gathered largely for other purposes and is without any solid geochronological basis; it is clearly a provisional one and needs to be tested and refined. The invitation to participate in the joint expedition to the Gilf Kebir and Gebel Uweinat, organized by Farouk El-Baz and directed by Bahay Issawi, was an opportunity to appraise the potential of the southern Gilf for further research along the lines initiated by Oliver Myers (1937; 1939).

Before we arrived at the Gilf Kebir, several days were spent visiting locales between Kharga Oasis and the Gilf. On an excursion from Bir Sahara to Abu Hussein dune field, some 35 km west (Fig. 2), Vance Haynes located a concentration of lithic artefacts on the flat, sandy plain within the horns of a large barchan dune. A second, smaller concentration was noted some 75 km southwest of the first. Each assemblage consisted of quartzite blades and flakes, mainly unretouched, and small chunks of conglomerate and sandstone. I had some subsurface test pits excavated to determine the vertical extent of the artefacts and to examine the soil structure. A moderately developed soil profile exists, which Haynes estimates to be of Neolithic age; but the implements were here confined to the surface (see note 1. at end).

The presence of these two artefact concentrations in this particular area is surprising. Apart from the giant-size barchan dunes, there is no relief in the area and no drainage channels were observed. The dunes are marching across the sandy plain to the south and these sites will be covered some time in the future, as they may have been in the past. The degree of soil development beneath the two sites and their mere presence in this, now, incredibly inhospitable environment demonstrate that very different conditions must have existed in the past. Yet, the simple assemblage suggests no more than temporary encampments of hunter-gatherers en route, perhaps, to a distant well or playa where a main camp may have been located. The absence of milling stones and ceramics reinforces this view. An important lesson learned from the discovery of this site is that no part of the Western Desert can be assumed to be barren of evidence of prehistoric occupation. Our experience has been that, wherever one travels in the eastern Sahara, prehistoric groups have been there before and have left signs of their presence.

En route to the Gilf Kebir, we stopped briefly at Black Hill, where I located a widely-distributed Middle Palaeolithic assemblage dominated by Levalloisian debitage on highly-varnished quartzite. Nothing like this assemblage was noted in the Gilf, although Myers (1937; 1939) reported the presence of Mousterian

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materials. On the afternoon of our arrival at the Gilf Kebir, Haynes, I, and a few others proceeded to the base camp used by the Bagnold expedition of 1938. We examined the site of Myers's investigations and found clear evidence of his systematic efforts (e.g. a 25×30 m area which he had completely cleared, trenches he had excavated, etc.). Examination of this area and the maps and sections Myers produced impressed us with his energy and skill as a field archaeologist. Because strata in this area contain both Acheulean and Neolithic settlements, they deserve further investigation.

We were able to get to the top surface of the Gilf plateau only briefly. At the crest of a cliff above a branch wadi of the Wadi Dayiq, in the northeast corner of the southern Gilf, we found a small, almost flat spur literally covered by chipped stone artefacts over an area of about 12×20 m (Plate IX). Bordering one corner was an outcrop of dark-stained quartzite blocks, many of which bore detachment scars where raw material had been removed for reduction nearby. Among the mantle of macro-size blades and flakes were still larger cores and in its centre was a 1 m-diameter concentration of small-scale lithic debris, the product of flaking on the spot. The macro-size lithic specimens continued to a depth of at least 30 cm and were incorporated into a reddish-brown, clayey silt, which was penetrated by desiccation cracks filled with a fine, buff-coloured sand.

The reduction station was apparently used over a fairly long period, long enough for at least 0·3 m of cultural materials to accumulate and for pedogenesis to occur. This soil indicates the existence of climatic and other conditions conducive to its development, e.g., moisture, vegetation, stability. The sediments may have been deposited by slope wash, as Haynes suggested, but they remained in place long enough for the soil to develop on top of them. In addition, the small circle of small-scale lithic debitage indicated the undisturbed, non-transported nature of these artefacts. The palaeoclimatic implications of the reduction site and associated soil lend support to the evidence for prehistoric mesic conditions in Wadis Bakht and Ard el Akhdar which we subsequently examined.

Myers (1939) investigated the Wadi Bakht (Fig. 4; Plate XVII) and collected artefacts from the blocking dune and from the eroded surface of the lake deposits which had accumulated behind the dune (McHugh, 1975). This locale has outstanding potential for contributing to the study of the late prehistoric palaeoenvironments and cultural adaptation in the area. The dune has been breached in the centre by water pouring out of a narrow gorge in the eastern edge of the lake deposits, here about 10 m thick. Abundant artefacts (stone implements, potsherds) and rock fragments cover both dune shoulders of the central depression. Similarly, abundant artefacts cover higher parts of the dune and disappear under the sharply-defined crest. While these artefact materials may have been 'let down', they were carried to the dune surfaces by humans, who certainly dwelt on it at a time when it must have been stabilized by moisture and vegetation. Scattered and concentrated artefacts exist on the eroded surface of the lake deposits along with deflated hearths. Ostrich eggshell fragments and fragmentary mammalian skeletal remains are also present on the surface of the lake sediments (see note 2. at end).

On the basis of our examination, prehistoric occupation of Wadi Bakht began late in the history of the lake, at first on the dune surfaces, and later on the dried-out lake deposits. The 10-m thickness of the lake sediments implies a relatively long period for their formation and, of course, for climatic conditions with considerable local precipitation during this period. The adjacent plateau surface and the outlying plains must also have received rainfall. There would have been a large area available for exploitation by the inhabitants of Wadi Bakht, an area supporting extensive vegetation and wildlife.

The faunal remains we collected from the playa surface, not yet identified, are indicative of the exploitation of ostriches and some species of herbivores. These remains and the milling stones used for grinding some kind of plant seeds suggest a diversified economic base for the wadi inhabitants. The presence of pottery, both on the dune surfaces and on the eroded lake deposits, reveals a degree of persistence in the occupations although not necessarily continuity. In fact, the differences between the ceramics from the dune and those from the playa both in technique and in style may denote separate occupations by different groups. Settlement activities on the playa surface include the making of fires; we found deflated hearths embedded in the upper zone. Carbon-14 dates from hearth charcoal may eventually provide dates for this phase of settlement. A single C14 determination on an ostrich eggshell collected from the northeastern corner of the playa by Vance Haynes (pers. comm.) gives a date of 7280 BP $\pm$ 90 years (SMU-273; Wendorf *et al.*, 1977, p. 230). This is a reasonable estimate for the age of the playa settlement.

If this single radiometric age determination faithfully reflects the median age for the playa settlement, it would appear that the wadi lake had already disappeared by about 5200 BC. We cannot now tell whether this was due to the breaching of the dune dam or to a decrease in the inflow of water into the wadi. The wadi playa would have continued to attract human groups whenever local precipitation drained into and collected among the old deposits. Finally, Wadi Bakht was abandoned completely, not to be visited again for thousands of years. Thus, the opportunity exists for natural scientists and archaeologists to investigate jointly this unusual record of human adaptation during the last major moist phase in the southwestern desert of Egypt.

It is unlikely that investigations in the Wadi Bakht can, by themselves, define the parameters of the Early and Middle Holocene environmental changes or the changing modes of human cultural adaptation. The plateau surface, the outlying plains and other wadis also need to be studied in a systematic fashion. This point was driven home when we visited the second of the two major wadis studied by Myers in the southern Gilf, Wadi Ard el Akhdar (Fig. 7). From its opening on to the broad, east–west trending Wadi Wassa, Wadi Ard el Akhdar runs north and then curves progressively to the southwest, terminating some 35 km from its mouth. Located approximately 5 km from the head of Wadi Ard el Akhdar is a 2 km broad, amphitheatre-like basin which is filled with dissected lake sediments, 5 to 6 m thick in places. These sediments were deposited behind a barrier (possibly a combination of talus scree and sand) in a manner similar to that of Wadi Bakht, but in Wadi Ard el Akhdar the original blocking sand dune has been completely removed.

There are dozens of loci of human settlement and activity on the surface of the dissected lake sediments. In the short time we were there, I was able to examine only two of these loci. There is clear evidence of fire-making on the playa surface; we found several deflated hearths in the two areas examined. Flaked stone artefacts are common, although not many are fully-finished tools. Several circular groupings of large rocks, sometimes including milling basins, surround slight rises on the surface. Scatters of potsherds were present although apparently with less frequency than at Wadi Bakht. Some animal bone and teeth and ostrich eggshell fragments were collected from the surface (see note 3. at end). The deflated hearths and some of the animal bone were slightly embedded in the sediments, but few of the artefacts were so placed. We found no evidence that the artefact materials were located anywhere but on the surface of the eroded lake sediments. Subsequent to the last human occupation of Wadi Ard el Akhdar lake deposits, there had been considerable erosion by both water and wind. Lithic artefacts often rest in the shallow gullies and on rather steeply sloping surfaces. Deflated hearths sometimes mark local high points in the topography as do the circular groupings of large rocks.

Initial human settlement of the upper part of Wadi Ard el Akhdar seems to have taken place only after the lake had begun to dry up. A much larger area was available for settlement than at Wadi Bakht (of the order of ten times). On the plateau surface in the immediate vicinity of the wadi, another reduction station was discovered by Ted Maxwell (pers. comm.), above the point of wadi constriction. The economic mode of the Wadi Ard el Akhdar occupants cannot be specified but there is a reasonable probability that, in addition to collecting some kind of seeds (cereals?) and hunting indigenous wild species, they were raising domestic cattle and goats. The latter are well known from the rock art at Uweinat, and cattle are depicted in the rock art of the Gilf Kebir. One shelter with paintings of cattle is located near Wadi Wassa, about 15 km southwest of the mouth of Wadi Ard el Akhdar (site 83 of Winkler, 1939: p. 11; Plates 22–2 and 28–2) (see note 4. at end).

If domestic cattle were raised by the late prehistoric inhabitants of the southern Gilf Kebir, there must have existed broad areas of grassy pastures, a savannah-type biome. Water must have been available throughout the year to meet the needs of the cattle. The lakes in Wadis Bakht and Ard el Akhdar may have been the dry season refuges of the cattle pastoralists, perhaps the only sources of water during this critical period of the year. Settlement on the outlying plains and on the plateau surface would, presumably, have been possible during the rainy seasons and for some time thereafter. This may be, in part, the significance of the abundant sites on the surface of the Gilf Kebir plateau found by Peel and Bagnold (1939). We noted other sites at the edges of the southern Gilf (for example, the extensive one where we camped at the eastern end of Wadi Wassa), but did not have time to examine them. Relict geomorphic features are similarly widespread in the region. The investigative problem becomes not how to find evidence for constructing models of palaeoenvironmental and cultural change, but how to sample adequately the abundance of evidence present in the area.

Dr McHugh has sent the following supplementary information which was too late for inclusion within his paper:

1. The vertebrate remains collected from the sites in the Abu Hussein dunefield and the Gilf Kebir were submitted to Dr A. Gautier, of the Geologisch Instituut, Ghent, Belgium, for identification. He has tentatively identified the single, truncated skull from the Big Barchan site as that of a calf (*Bos* sp.), probably domesticated. The hunters-gatherers responsible for the debitage left at the site may also have been cattle pastoralists. Ostrich eggshell collected from the site by C. Vance Haynes has been C14-dated to 8170 BP ± 120 (A. 1966) (Haynes, pers. comm.). This date corroborates Haynes's estimate of the antiquity of the soil development at the Big Barchan sites and agrees well with those from neolithic sites at Nabta Playa (Wendorf *et al.*, 1977) where domestic cattle have also been recovered.

2. Gautier has identified both domestic *Bos* and caprovid remains among the samples collected from Wadi Bakht. These specimens come mainly from the surface of the lake bed in the northeast corner of the playa; some were slightly embedded in the hard silt. This is the approximate location where the C14-dated ostrich eggshell fragments were collected.

3. Gautier positively identified caprovid remains in the Wadi Ard el Akhdar specimens and tentatively suggests that some specimens derive from cattle. As Gautier (1979) points out, the conjunction of *Bos* and caprovid remains in the Gilf wadis is repeated in the Uweinat rock paintings where shorthorn cattle and goats are depicted (cf. Van Noten, 1978).
4. In 1938, Ronald F. Peel discovered paintings of domesticated cattle in the upper part of Wadi Abd el Malik in the northern Gilf Kebir (*Geogrl J.* **93**, 4: 287).

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IV. BOTANICAL RESULTS OF THE EXPEDITION

LOUTFY BOULOS

THE EARLIEST available modern botanical information about Uweinat and the Gilf Kebir was provided by Shaw and Hutchinson (1931; 1934) from the collections made by Shaw who joined Major R. A. Bagnold's two expeditions to this desert in 1929–30 and 1932. A short account of the botanical results of the first expedition was given by Hutchinson (1933). Little attention was given to

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botanical exploration until the 1964–65 Belgian Trans-Saharan Expedition passed by Uweinat. Some 25 different flowering plants were collected by Léonard (1966), who stated that the wadis radiating from the base of Uweinat were then dry. A few years later, the expedition of the United States Naval Medical Research Unit Number Three (NAMRU-3, Cairo) visited Uweinat in April 1967. Osborn and Krombein (1969) gave an account of its habitats, flora, mammals, and wasps.

During the winter of 1968–69, a Belgian–Libyan expedition visited Uweinat and the Gilf Kebir. The University of Libya group was restricted to Uweinat and camped near Ain Zuwia. It included two Egyptian scientists: Rashid Hamdy (zoologist) and the present author (botanist) and one Libyan mycologist, Mohammed Mokahel. Two more Libyan groups joined the expedition, one of them military, and the other, police. The Belgian camp was in Karkur Talh with a small camp near the Gilf Kebir. The results of the Belgian Expedition were published, including a chapter on the flora (Léonard, 1969) and a chapter on the fauna (Misonne, 1969). Unfortunately, the botanical material which I collected was not published.

Ten years later, I had the opportunity to join this 1978 expedition to visit the Gilf Kebir and to revisit Uweinat across the southwestern desert of Egypt (Figs. 1 and 2). This desert is extremely arid, a 'sterile country' with few scattered spots of vegetation; one may have to travel hundreds of kilometres to reach one of the green, living plants. Periods without rain may extend for several years, but when it recurs, it causes the resurrection of plant life. The recurrence of rain cannot be accurately predicted, because it is so erratic, both in terms of interval and quantity. Thus, we are left with no means for predicting what will happen in the future. What happened in the past is not recorded because of the lack of weather stations, and we have no simple means for reconstructing how the vegetation looked in earlier years.

The vegetation types which I observed in the area covered by the 1978 expedition fall into four categories: ephemeral, ephemeral and perennial, perennial near wells, and perennial in gorges.

Ephemeral vegetation

Ephemeral vegetation appears after occasional showers, continues to grow for a few weeks to several months, then dries up; but in this period, the plants produce fruits and leave their seeds in the ground to await the next rain. In the Gilf Kebir region, the dry remains of plants suggest that some perennials may produce fruits in a shorter time (behaving as ephemerals), e.g. *Zilla spinosa* (Turra) Prantl, *Trichodesma africanum* (L.) R.Br. and *Citrullus colocynthis* (L.) Schrader. It appeared that the Gilf Kebir area had not received any appreciable rain for some 20 years prior to our visit, a rough estimate based on the condition of the dry plants subjected to the wind and the heat of the sun. We may cite here a few words from the notes given by Shaw describing his 1932 trip: 'The great mountain mass of J[ebel] 'Uweinat presented a very dried-up appearance, even more so than on the previous visit [he means that of 1930] as the last rains seem to have been in 1927.' (Shaw and Hutchinson, 1934, p. 281).

As discussed by Haynes in Section II, it was cloudy on 16–17 December 1977 over an area 5 km southeast of Peter and Paul mountains (50 km northeast of Uweinat). In this area, some plants were still growing as we passed, on 20 October 1978, in a small wadi with sandy soil and trachyte boulders. The only species which was still in good living condition, though with some signs of senility, was

Fagonia arabica L. The grass *Stipagrostis plumosa* (L.) Munro ex T. Anders. was almost dry. Already two species were quite dry: *Farsetia ramosissima* Hochst. and *Trichodesma africanum*. The seeds of the above four species, which were well-kept in the soil, must have germinated shortly after the rain that may have fallen ten months earlier. Considering that these plants were about to die out before 12 months had passed, we can conclude that the four species behaved as annuals (ephemerals) and not as perennials; or, *Fagonia arabica* and *Trichodesma africanum*, which are known to be perennial species, changed their growth form into annuals to meet the difficult environmental conditions of this habitat. On the other hand, *Stipagrostis plumosa* and *Farsetia ramosissima*, which are known to grow either as annual or perennial species, successfully acquired the annual habit and produced seeds before they dried out.

Ephemeral and perennial vegetation

A mixture of ephemeral and perennial vegetation, entirely dependent on rain, occurs in wadis and water catchments where no perennial groundwater is available. The difference between this and the previous category (where only annuals could survive) is a matter of availability of more rain and runoff which form a layer of temporary underground moisture available to the root systems of perennials during their lifetime, which may not exceed three or four years. This temporary moisture would have a limited persistence under the infrequency of rainfall and rapid evaporation. Examples of this type of vegetation are the dry perennial grasses and shrubs (difficult to identify) in some wadis of the Gilf Kebir, e.g. Wadi Bakht and Wadi Ard el Akhdar.

Perennial vegetation near wells

The perennial vegetation that abounds around the wells comprises trees, shrubs and perennial herbaceous species. Several species were recorded in the vicinity of five wells (Tarfawi West, Bir Tarfawi, Bir Kiseiba, Bir El Shab and Bir Kurayim) visited by our expedition. These included two palm species: *Hyphaene thebaica* (L.) Mart. (dom palm) and *Phoenix dactylifera* L. (date palm) as well as *Tamarix nilotica* (Ehrenb.) Bunge. Some huge dead trunks of *Tamarix nilotica* trees were found lying on the ground at Bir Tarfawi, suggesting that these trees flourished in the not too distant past. However, the living individuals of the same species are either smaller trees or shrubs. This may suggest that the groundwater has become depleted and may no longer support large trees as it used to do some hundred years ago. Around the other wells, *Tamarix nilotica* grows as a shrub forming hummocks, which sometimes unite (e.g. at Tarfawi West) forming enormous crescent-shaped hills of pure stands, i.e. in the complete absence of any other species. Another shrub, *Acacia ehrenbergiana* Hayne, was recorded 25 km northwest of Bir Kiseiba, on a hummocky sand dune.

The herbaceous perennials are mainly grasses; *Sporobolus spicatus* (Vahl) Kunth, which grows around the wells very close to the water or in areas where the water level is very high and almost approaching the ground surface. This species grows in saline soils. Other grasses are: *Imperata cylindrica* (L.) Beauv. and *Phragmites australis* (Cav.) Trin ex Steud., which grow near and around the wells in Bir Kiseiba and Bir Kurayim. Another perennial grass, *Stipagrostis vulnerans* (Trin and Rupr.) de Winter, with stiff sharp spiny leaves, formed a pure stand over 1 km on the sand dunes at El Shab. This was recorded on 28 September 1978, probably for the first time from this area.

A very characteristic leguminous perennial shrublet with spiny-tipped twigs, *Alhagi mannifera* Desv. (a good fodder for camels), was recorded from Bir Tarfawi and Bir Kurayim where it covered extensive parts of the ground in the drier areas near the wells.

Perennial vegetation in gorges

Perennial vegetation in the gorges (*karkur*) of Uweinat depends on groundwater. Occasional showers may feed the groundwater and allow ephemeral growth. An example of this type of vegetation is that found on the floor of Karkur Talh (*Talh* is the local vernacular name of *Acacia raddiana* Savi) and one of its tributaries which we visited. The conspicuous element of the vegetation is the luxuriant growth of *Acacia raddiana* which forms, together with the less common *Acacia ehrenbergiana*, an open thorny forest with dense tufts of the perennial grass *Panicum turgidum* Forssk. covering a large proportion of the Karkur bed. The grass is grazed by camels, goats and gazelles. Three (probably) feral donkeys, black and white in colour, were observed in this area. Other plants observed and collected include: *Crotalaria thebaica* (Del.) DC., *Morettia phileana* (Del.) DC., *Fagonia indica* Burm fil., *Citrullus colocynthis*, *Pulicaria undulata* (L.) Kostel, *Aerva javanica* (Burm. fil.) Juss. ex J. A. Schultes, *Cleome chrysantha* Decne.

The paucity of annual species observed during our visit may have been due to a rather long interval of drought; dry annuals were also not observed. However, the shower that brought into existence the green vegetation near Peter and Paul mountains might have reached other parts of Uweinat which we did not visit.

Finally, as the only botanist on this expedition I am reminded of the delightful note by Shaw (1931, p. 35) in which he stated:

> It is called high-speed botany. The process is this: When you are passing through bad sandy country, and soft going, you see a plant you wish to collect. You know if you stop the car it may take about half an hour to push it out and also that you will receive the extremely candid opinions of the rest of the party on botany in general and on yourself as a botanist in particular. What happens is that the eager collector leaps out of the car while it is still going, and uproots the unfortunate plant; meanwhile the driver drives round in small circles until the show is over and the collector has jumped in again.

Acknowledgement

I wish to thank Professor M. Kassas, President of IUCN, for reading this manuscript.

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V. GEOLOGY, STRATIGRAPHY AND STRUCTURE OF SOUTHWEST EGYPT

BAHAY ISSAWI

GEOLOGIC knowledge of the Uweinat–Gilf Kebir area is confined to certain routes or passes connecting it to the oases in the Western Desert. Previous work has been summarized by Sandford (1935) and Hume (1962). The known succession of strata from bottom to top is as follows: Precambrian basement of schists, granites, etc.; Lower Palaeozoic sandstone; rhyolites; Lower Carboniferous, plant-bearing sandstones; and the 'Nubian' Series of buff and brown false-bedded sandstone.

In the Uweinat area and at Karkur Talh, the upper surface of the rhyolite is smoothed and worn, and the overlying sandstones are similar in appearance to the Carboniferous bed at Karkur Murr. No sandstone was seen below the Karkur Talh rhyolite. If the rocks are the same, a definite interval must be allowed between the period of rhyolitic extrusions and the formation of Lower Carboniferous beds. This is the first indication of Palaeozoic volcanism in the area, which implies the presence of contemporary hypabyssal and deep-seated acid rocks.

Burollet (1963) and Mahrholz (1965) worked on the nearby Libyan outcrops where they were able to establish Cambro-Ordovician and Devonian clastic sections, both unconformably resting on Precambrian gneisses. The present author made a provisional geological map of the area in 1971. In this map, a Devonian age is given to the clastics west of the Gilf Kebir, while the thick sandstone section forming the Gilf itself is believed to be of Jurassic–Cretaceous age. The Upper Cretaceous marine boundary was shifted several hundred km further south of Abu Ballas twin hills (see Fig. 9) where marine fossils were collected. As a result of this work, the Geological Survey of Egypt published a regional map of the outcropping basement rocks in the southern Western Desert (El Ramly, 1972).

Stratigraphic sequence

The oldest rock outcrops in the Uweinat–Gilf Kebir area are the Precambrian granites, granite gneisses and diorites, which form a northward-projecting outcrop of the main African Shield. During the Palaeozoic several intracratonic basins were formed within the shield, and sediments of this era fill those basins. One example of the intracratonic basins is the Uweinat–Gilf Kebir area. The stratigraphic sequence of the area is illustrated in Figure 3.

The Palaeozoic rocks.—In the Uweinat–Gilf Kebir area, three Palaeozoic units were recognized which have considerable areal extent. The basal unit is made of hard quartzitic sandstone beds interbedded with highly consolidated conglomerate and syenite porphyry sheets. This unit assumes a thickness of approximately 20 m and fills concavities and undulations in the Precambrian granite–granodiorite-complex surface between Gebel Uweinat and the Gilf Kebir. A similar unit was recorded by Burollet (1963) on the west side of Gebel Uweinat, the Hassaouna Formation, which he assigned to the Cambro-Ordovician. In the absence of any reliable evidence which would help in dating the Egyptian unit, it seems logical to equate it with Burollet's Cambro-Ordovician Hassaouna Formation.

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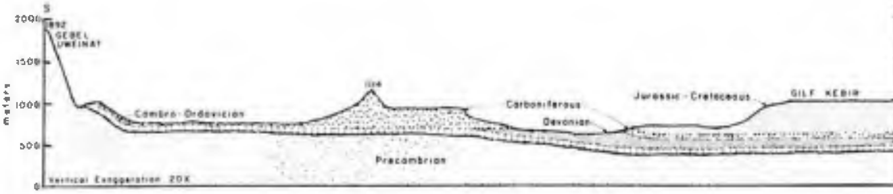

Fig. 3. Geologic cross section of the Gebel Uweinat-Gilf Kebir area; horizontal distance is 200 km

As to the middle and upper units, the lower contact with the basement complex is highly kaolinized and contains angular quartz grains. The top is an erosional surface, which stretches northward for almost 130 km. It forms benches or rock-cut pediments, which, in the Uweinat area, are capped by approximately 20 m of interbedded sandstone, phonolite, trachyte and microsyenite sills and dikes. Northward, and west of the Gilf Kebir, the section loses it volcanic components and another unit of sandstone thickens gradually between the Cambro-Ordovician unit and the upper sandstone section. This middle unit is approximately 120 m in thickness and forms the surface of the desert west of the Gilf Kebir and the hills of Umm Ras and Abu Ras near the Libyan border, at latitude 23° 50′ north. Here, the middle unit is partly clayey and the clay bands yield *Granualtisporites* and *Verrucosisporites*, which relegate the section to the Devonian. On the other hand, fossil plants from the upper unit in the Uweinat area assign it to the Carboniferous.

After the deformation and plutonism of the Precambrian, the entire shield was uplifted and warped into broad intracratonic basins in which the sequence of Palaeozoic and volcanic rocks was accumulated. Although unstable for some periods during the Palaeozoic, as witnessed by the immense volcanic sheets and flows of that era and the uplift of the Uweinat high trending northeast–southwest, no serious deformation has occurred since then.

The Mesozoic rocks.—The Gilf Kebir is made of a thick sandstone unit which unconformably overlies the Palaeozoic section. The lower contact is kaolinized while the top of the Gilf is characterized by a very hard quartzitic wall-like bed 3 m thick. The sandstone is varicoloured showing wide textural and lithological variations. To this stratum the name 'Gilf Sandstone' is here given. At the northeast corner of the Gilf Plateau, clays intercalate the upper part of the sandstone section, which yields Upper Cretaceous fossils comparable to the Dakhla and Duwi Formations in the Kharga–Dakhla oases stretch. It is evident that the Gilf Sandstone is comparable to the Nubian and the subsurface sandstone section in the area of the oases. This subsurface section is considered Jurassic by Helal (1966), Kedves (1971) and Saad and Ghazaly (1976). It thus seems feasible to assign the Gilf Sandstone to the Jurassic at the base and to the Upper Cretaceous at the top.

The Upper Cretaceous Nubian Sandstone covers a great tract of the country south of the Kharga depression. It abuts southwards of Bir Tarfawi and Bir Sahara against either basement rocks or Palaeozoic sandstone to the west. In the field, the differentiation between the two sandstones is made possible by the abundance of fossil wood; huge tree trunks are found everywhere in the Nubian Sandstone, strewn over its surface and interbedded in the strata, while the Palaeozoic and also the Gilf sandstones totally lack petrified wood.

Volcanic basalts and dolerite sheets, flows, sills, dikes, and volcanic cones are well represented in the southern part of Egypt. Recent age determinations (Meneisy and Kreuzer, 1974) using K/Ar total rock method for some samples collected from Darb el Arba'in area give ages ranging from about 80 m.y. (Upper Cretaceous) to 33 m.y. (Lower Oligocene).

The Quaternary.—A huge patch of Quaternary deposits has been recently mapped from the Bir Sahara–Bir Tarfawi area and further south encompassing nearly 10 000 km^2. Lacustrine diatomite, limestone, carbonaceous silt and old sand dunes are the main types of sediments associated with cultural remains of Upper Acheulean to Final Acheulean, Mousterian, Aterian and Historic ages; 44 700 BP and older, to 4510 $\pm$ 70 years ago (Wendorf, 1977).

Structural setting

The general flatness of the southwestern desert of Egypt is its most striking feature. Rock beds are nearly horizontal, and only in rare cases did our party encounter significant angles of dip, e.g., at Karkur Talh (Uweinat), where several short east–west faults were noticed. The main faults in this part of the desert are normal gravity faults, including the Gilf fault, which extends about 150 km in a north–northeast direction on the west side of the Gilf Kebir; the Kemal fault, which is also 150 km long and trends in a northwest direction along the western Gilf; and the Tarfawi fault, which skirts the western side of the Tarfawi igneous mass and runs over 220 km in a north–northeast direction.

The distribution of the basement rocks, and the type and thickness of sediments, reflect several phases of structural development. Of importance are the two main igneous bodies at Uweinat in the west and Tarfawi in the east. Between these two main masses lies the thick clastic section of the Gilf Sandstone indicating a basin of significant depth and continuation.

The Lower Palaeozoic sediments are poorly represented in the Uweinat area while the Devonian–Carboniferous are better developed and show evidences of being slightly folded. This folding and the igneous intrusions may indicate post-Carboniferous orogenic movements that resulted in the Uweinat high. The configuration of the Gilf basin is bounded eastward by the Tarfawi high. Because the sediments within the Tarfawi high are mostly Cretaceous and younger, it appears that the rise of the basement was initiated during a much later date than that of the Uweinat high. The only igneous rocks associated with this later movement are basalts of Cretaceous–Oligocene age.

Northward extrapolation of these highs and lows makes it obvious that the Tarfawi high trends north–northeast to join the Kharga swell. The Gilf basin, which assumes nearly the same trend, is believed to be a southern extension of the Dakhla basin, while the Uweinat high, also of the same trend, is mantled by the thick cover of the Great Sand Sea to the north.

The fact that the western part of the area had been very active during the Late Palaeozoic–Early Mesozoic whereas the eastern part shows signs of being unstable during the Cretaceous and Early Tertiary points to an eastward shift of tectonism with time. Any reference to terms such as stable, unstable, or mobile shelves, must take the time factor into account.

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VI. IGNEOUS ROCKS AND MINERAL DEPOSITS

A. A. DARDIR

DURING THE 1978 Gilf Kebir–Uweinat expedition, many crystalline basement outcrops were investigated. These can be classified into three distinct groups:

1. *Precambrian basement complex*: This group is made of diorite gneiss, diorite, microdiorite and granite. Rocks of this complex form extensive plains and patches lying between Uweinat and the Gilf Kebir and to the east of Bir Tarfawi. The Precambrian masses, particularly the granites of Qaret el Maiyit, east of Tarfawi, are cut by pegmatite, aplite, and felsite dikes of variable thicknesses and orientations. The Precambrian outcrops rarely form mountains of significant relief. In most cases they are covered either by thin Palaeozoic and/or Mesozoic sandstones or wind-blown sands.

2. *Alkaline rocks*: Phonolites and trachytes are the main rock types of this group. They form massive isolated hills with steep sides especially northeast of Gebel Uweinat and south and southwest of the Gilf Kebir, e.g., Peter and Paul, Gebel 1114 and Ras el Abd. The investigated part of Gebel Uweinat was found to be composed of a huge phonolite mass intruded in Palaeozoic sandstones. The latter dip steeply northward. The trachytes in the area form sheets, dikes or sills usually of small thicknesses and extensions. They are clearly observed intruded in the sandstones at Karkur Talh and its tributaries.

3. *Dolerites, doleritic basalts, and basalts*: These rocks are found in the form of cinder cones, sheets and dikes cutting either the Precambrian basement rocks or the Palaeozoic and Mesozoic sediments. The basement outcrops within the Uweinat–Gilf Kebir area form the eastern extremity of a series of highs within the North African 'old platform' or shield. They are lower in elevation than the Tibesti and Hoggar mountains, which lie in Libya and Algeria respectively, and are separated from the Uweinat high by the Kufra basin. The eastward extension of this old platform gives way to the Arabo–Nubian Shield outcropping on both sides of the Red Sea in Egypt, Sudan and Saudi Arabia.

Mineral deposits

In 1971, Bahay Issawi recorded the presence of iron ore 420 km southwest of Kharga and 20 km west and southwest of Black Hill. The area of the deposit is a

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wide plain of approximately 50 km². Two iron ore types were recognized: (1) goethite-hematite ore in the form of large lenses more than one metre in length of 50–60 per cent Fe; and (2) highly ferruginous, fine-grained sandstones, which represent the major part of the deposit. Four samples collected from the deposit during the 1978 expedition were chemically analysed; the results are shown in Table I.

TABLE I
Chemical analysis of iron ore samples

No.	*Fe/tot.*	*FeO*	Fe_2O_3	SiO_2	MnO_2	*CaO*	*P*	*V**	Al_2O_3
1	24·5	0·75	34·14	36·10	0·15	2·59	1·52	—	14·70
2	25·1	14·51	19·74	55·15	1·00	2·59	1·05	140	1·70
3†	58·3	3·16	79·90	6·57	0·37	2·46	0·82	252	1·20
4	15·1	2·75	18·59	51·10	12·00	1·91	0·96	196	5·00

* Vanadium concentration is given in parts per million, others in percentages
† Sample 3 represents the high-grade goethite–hematite ore, the rest are from the low-grade siliceous hematite ore

In addition to the iron-rich ore, manganese pockets (23 per cent Mn) are commonly associated with the iron deposits. These occur in the sandstone, which forms the main country rock in the form of plains or as exposures in the surrounding scarps. Manganese veinlets were also noticed in many places in the sandstones of Gebel Uweinat. This occurrence requires further detailed investigation. From this, it is concluded that the mineral prospects of the Gilf–Uweinat area in general are promising, both within the basement outcrops, and in the overlying sedimentary cover. The area should be investigated to evaluate more fully its mineral potentials.

VII. GEOMORPHOLOGY OF THE GILF KEBIR

TED A. MAXWELL

THE GEOGRAPHICAL extent of the Gilf Kebir plateau is clearly displayed on Earth-orbital images. However, it is only on the basis of field observations that the detailed character of the terrain can be described. Peel (1939) informally divided the Gilf Kebir plateau into northern and southern parts. The southern part appears as a flat-lying surface at the resolution of LANDSAT images (Plates V and XVIIa), whereas field investigations by Bagnold *et al.* (1939), and results of the present expedition show it to be an extremely rough surface composed of isolated, rounded basalt hills and rough sandstone pavement on the interfluve ridges. The southern Gilf extends 70 km east–west and 100 km north–south. The most extensive wadi systems are developed on the eastern and southeastern edges of the plateau, and extend up to 30 km into the interior.

There is no evidence to rule out either marine or sub-aerial denudation as the cause for the uniformity of the plateau surface. Lithologic control is suggested by the highly silicified layer of resistant sandstone underlain by finer-grained, less cohesive sandstone. However, as Peel (1939) has pointed out, there is some folding

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near the volcanic intrusions which has no topographic expression. Planation may have begun in Cretaceous time with the northward retreat of the sea, but the windswept surface of the plateau indicates that deflation and lithologic control dominate at the present time.

Just as the origin of the plateau surface is uncertain, so is the mode of development of the wadis. The major problems with wadi evolution were summarized by Peel (1939, p. 304) and are still applicable today:

> The wadis present several curious features: their floors are flat; in many cases their width is out of all proportion to their length, and they grade into open bays; many contain alternating narrow gorge-like sections and broad, open basins; they run at peculiar angles, with tributary wadis occasionally pointing upstream; both in transverse profile and at their heads, the wadi beds end in abrupt cliffs; and there is little or no evidence of water flowing over the plateau surfaces to pour into the wadis.

These features must be taken into account for theories involving wadi evolution by runoff versus cliff sapping.

Because of the constraints of time in the field and petrol (rations of 100 km/day), only two wadis were investigated. Of the three days allotted, one and a half days were spent in Wadi Bakht, and one in Wadi Ard el Akhdar. However, even this amount of time was reduced by travel up the wadis, unfamiliarity with the terrain, and difficulty of navigation. The three primary purposes of these investigations were: (1), to resurvey and resample the archaeological sites discovered by Myers (see sections by Haynes and McHugh); (2), to add to the existing data concerning wadi development; and (3), to provide data that will be useful for interpretation of channels on Mars.

Wadi Bakht

The main channel of Wadi Bakht extends 25 km into the Gilf Kebir (Fig. 4). Similar to others, this wadi is dominantly flat-floored, but the lower, wide part consists of gently sloping alluvial fans with braided channel systems. Here the main channel occupies only the northern part of the valley, and is not adjusted to the drainage of the fans whose channels are above the level of the main channel. This lack of adjustment is consistent with localized rainfall and runoff originating in the upper part of the wadi.

The upper reaches of Wadi Bakht are quite different in valley morphology, especially upstream from the dune-dammed reach of the wadi. The flat-floored valley is bounded by steep (100 m) escarpments, with no alluvial fans. Channel incision is sporadic; in places incision reaches 2 m, but is normally no more than several tens of centimetres. Drainage characteristics have been affected by the dune-dam more than any other factor. More than 10 m of interlayered lacustrine and aeolian sediment was deposited upstream from the dune. This dam has been breached, however, and fluvial erosion has exposed a cliff in the playa sediments (Plate XVIIb). Near the cliff, the bedding in the playa deposits dips at low angles to the west (upstream), suggesting that at least during the latest episodes of playa formation, growth of the dune (and consequent damming) kept pace with formation of the intermittent lake. As noted by Peel (1939), the wadi bed below the dune had been much more vigorously eroded, although the sand-choked channel found during the present expedition indicates no recent fluvial erosion.

Longitudinal and transverse topographic profiles were surveyed during our stay in Wadi Bakht. Because of time constraints, it was not possible to extend the longitudinal profile further to the east (downstream) below the dune (Fig. 5). The low accuracy of the pace-and-hand-level profile makes it difficult to interpret the

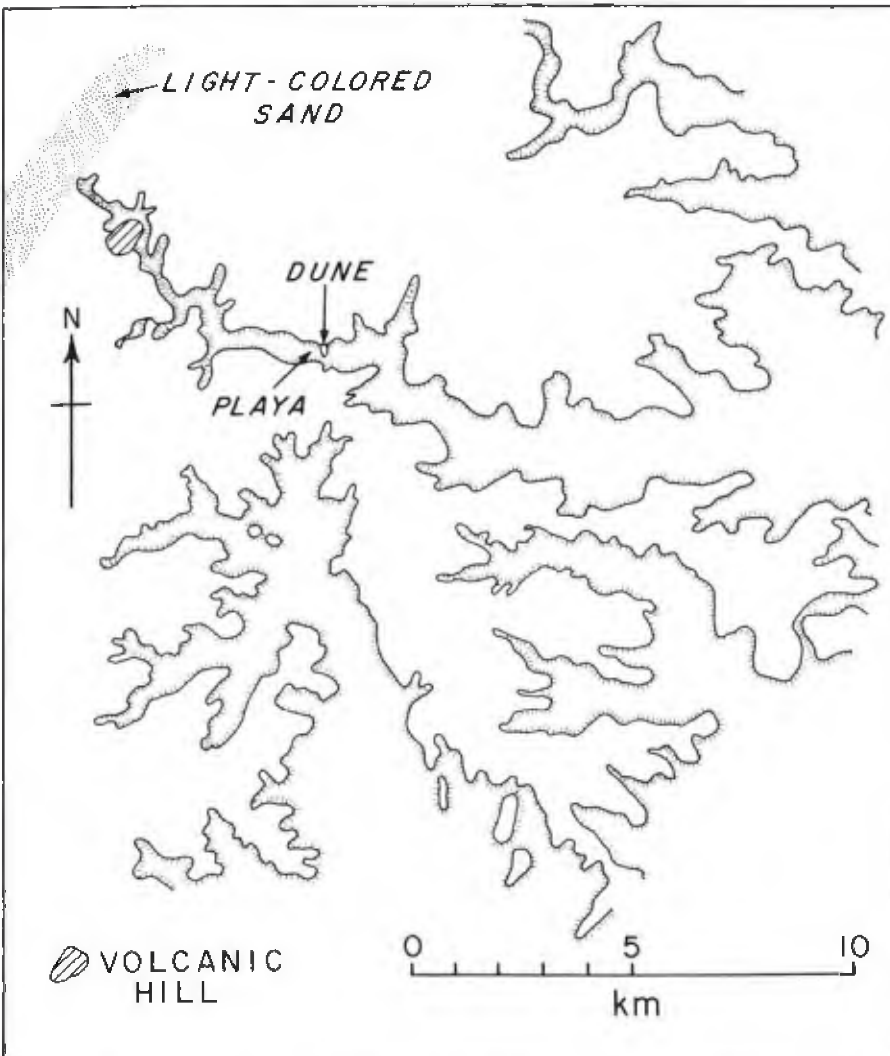

Fig. 4. Map of Wadi Bakht on the southeastern margin of the Gilf Kebir (based on LANDSAT *images)*

change in channel gradient above and below the upstream extent of the playa. However, this relationship may provide the easiest means of estimating the total volume of playa deposits.

The north–south transverse profile of Wadi Bakht was made 120 m upstream from the cliff at a concentration of artefacts (along the E100 section line of McHugh's grid for the archaeological site). Distances for this profile were measured with a steel tape, and a small stone cairn was left at the north wall of the valley to mark the location of the profile (Fig. 6). In addition, two steel survey pins were left at the northernmost and southernmost extent of the archaeological site. It is hoped that any future exploration of this valley will include a resurvey of the section to monitor possible modern changes of valley morphology.

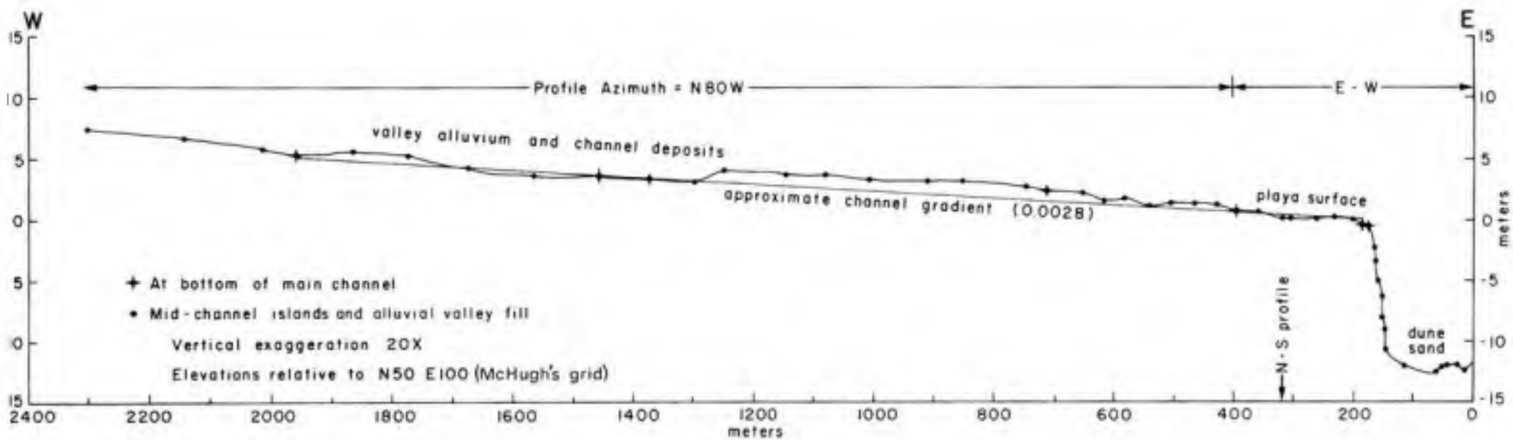

Fig. 5. Longitudinal profile of Wadi Bakht

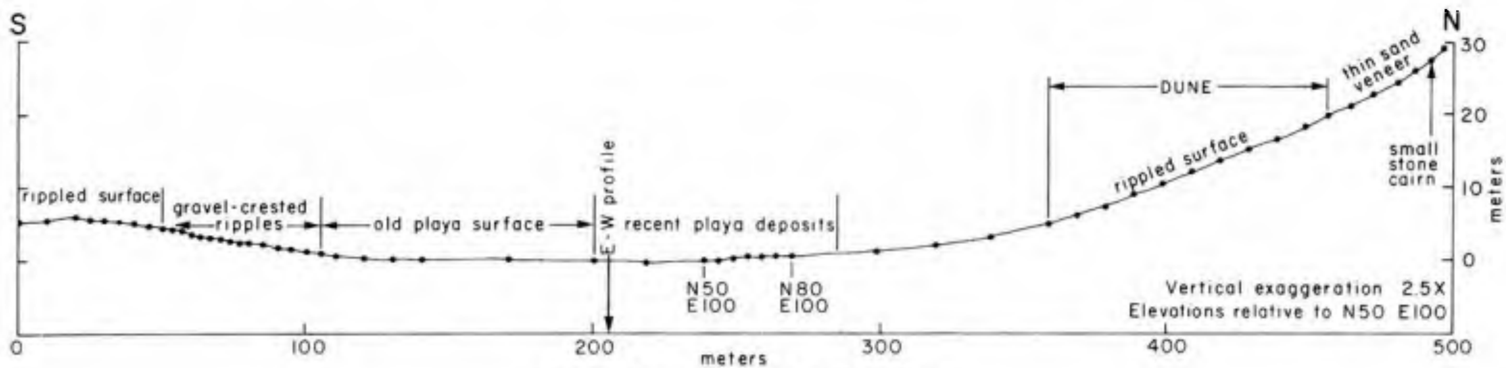

Fig. 6. Transverse profile of Wadi Bakht

In addition to the sharp-crested falling dune on the north cliff of the wadi (the 'dam-dune'), there is an extensive accumulation of aeolian sand along the south wall. Rather than a discrete dune type, however, this sand forms a low (5 m high), gently sloping ridge that is topped by granule-crested sand ripples. The symmetry of the ripples and bedding exposed in a trench dug by Nabil Embabi suggest that both up- and down-valley winds are responsible for redistribution of material on top of this sand body, if not for the entire accumulation.

The detailed topographic section of the archaeological site indicates a minimum of 1 m aeolian deflation from the highest hummocks of lacustrine silts to the level plain represented by the most recent mud-cracked playa surface. Artefacts were found within the playa deposits as well as on the surface of the lake bed, suggesting that habitation took place contemporaneously with deposition of the intermittent lake, and during the final stages of lake formation. The single C14 age of 5330 ± 90 BP of an eggshell in Wadi Bakht (SMU-273; Wendorf *et al.*, 1976) can be used to put this site in the context of others in the Western Desert. However, much more detailed stratigraphic work needs to be done in order to establish both the history of human habitation, and the cycles of dune formation and playa deposition in this area.

Wadi Ard el Akhdar

The single day spent in Wadi Ard el Akhdar proved to be more of a reconnaissance survey. This wadi is oriented north–south, turning northwest towards its source, and extends approximately 20 km into the Gilf Kebir (Fig. 7) starting at Wadi Wassa (Plate XVIIa). The southern part of Wadi Ard el Akhdar is 10 km wide, and like Wadi Bakht, is surfaced with broad alluvial fans sloping down from the base of steep cliffs of the plateau. The narrow part of the wadi, however, is flat-floored and terminates in the 2 km amphitheatre-like depression described by Peel (1939). Although rounded basalt hills are numerous at the head of the wadi, the circular depression is surrounded on the southeastern end by cliffs of highly silicified sandstone.

The narrow gorge through which the upper part of the wadi discharges is bounded on the north by a basalt hill, and on the south by a hill composed of extremely resistant dark-coloured quartzite. As in the case of Wadi Bakht, this gorge is blocked by a sharp-crested dune that abuts the basalt hill (Plate XVIIIa). Along the quartzite hill on the south side, however, channel incision has exposed a 3·4 m vertical section of sediment. The section is primarily composed of poorly sorted pebbles and cobbles set in a matrix of playa silt and mud. However, alternating with these structureless beds are well-sorted red sand lenses with low angle (14°) planar stratification dipping to the west. Consequently, it is most likely that, just as in Wadi Bakht, dune growth kept pace with, and controlled, playa formation.

In contrast to Wadi Bakht, the upper valley floor of Wadi Ard el Akhdar consists of channels incised up to 3 m in the playa sediments. Near the mouth of the amphitheatre, secondary channels incised in the playa deposits are not at grade with the main channel (Fig. 8). Instead, there has been 0·5 to 1·0 m of incision of the main channel below the level of the tributaries. This is consistent with intense local rainfall on the upper parts of the drainage basin and the occurrence of alluvial fans over the playa sediments observed by Haynes (Section II).

Artefacts at the head of Wadi Ard el Akhdar were found only on the uppermost surface of the 3 m thick playa deposits. The total thickness of these deposits may have been much greater, for both sheet flooding and aeolian deflation may have removed a significant amount of material. On the basis of present evidence, there-

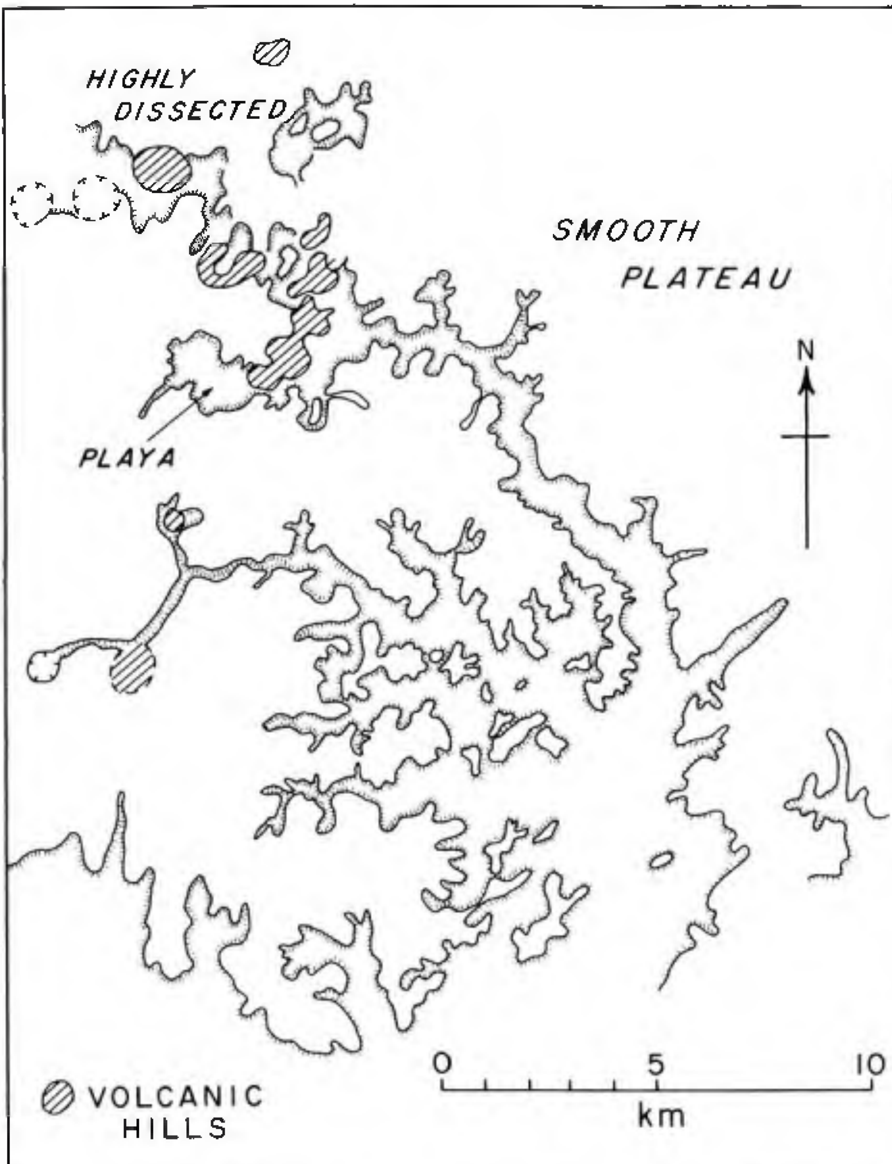

Fig. 7. Map of Wadi Ard el Akhdar on the southeastern margin of the Gilf Kebir (based on LANDSAT *images)*

fore, it is not possible to determine whether human habitation occurred during the latest pluvial episodes, or was confined to a relatively short time during the fluvial period of playa deposition.

In addition to the resurvey of Oliver Myers's site on the wadi floor, a reduction station was discovered on top of the plateau at the southeast corner of the amphitheatre, typical of sites in the Gilf Kebir region. In several instances, reduction and chipping stations are located adjacent to the hardest, most resistant beds of

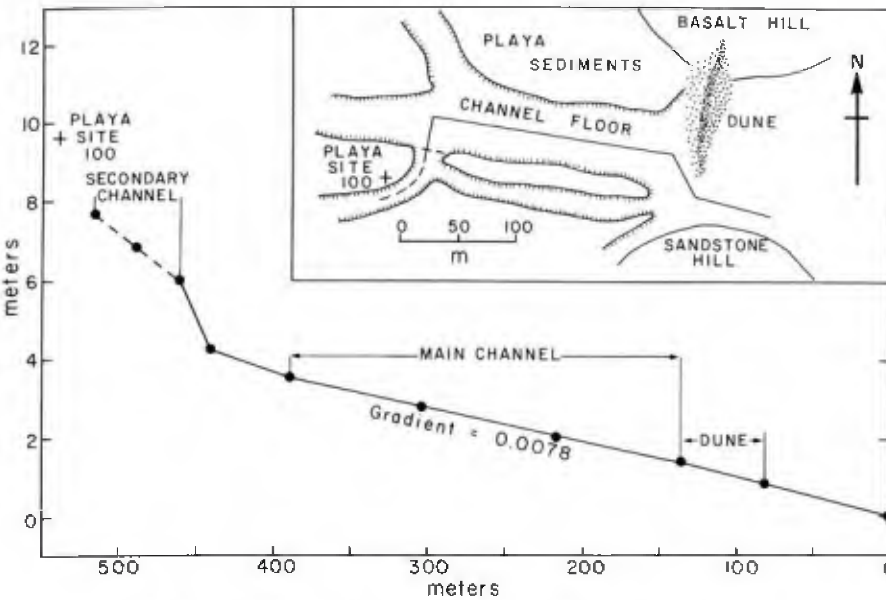

Fig. 8. Sketch map and profile of the mouth of Wadi Ard el Akhdar

quartzite. The station of Wadi Ard el Akhdar provides evidence that these quartzites may be the result of local metamorphism adjacent to the Tertiary intrusive volcanic necks. This provides a geologic basis for preferential human habitation of certain regions. A test of this hypothesis would result from future exploration of the northern part of Wadi Ard el Akhdar, where volcanic hills have been identified on the basis of LANDSAT images.

Comparisons with Mars

Interpretation of the morphology of Martian canyonlands and the immense outflow channels seen in Mariner 9 and Viking Orbiter images is based solely on photogeologic interpretations of these varied landforms. Because several characteristics of the Gilf Kebir are present in the landscape of Mars, field investigation of this region provides some basis for an understanding of Martian erosional features, particularly as the dramatic change in climate from fluvial to aeolian domination is similar to that postulated for several areas on Mars. Interpretation of erosional processes in the Gilf Kebir is applicable to the Martian problems of canyon erosion in stable headlands, cliff retreat by possible subsurface drainage, and aeolian modification of fluvial valleys and channels.

South of Ius Chasma on Mars (Plate XVIIIb), dendritic systems of tributaries extend up to 60 km into the plains of Sinai Planum. Although these Martian canyons do not exhibit the characteristic flat floors of those of the Gilf Kebir, they are similar in that there are no drainage tributaries on the surface of the plain, and several of the canyons terminate in subcircular, amphitheatre-like depressions such as that of Wadi Ard el Akhdar. Both the Martian canyons and those of the Gilf Kebir suggest valley development by subsurface drainage which aids undercutting of cliff faces. This has been suggested for the Gilf wadis by Peel (1939), and for the Martian canyons by Sharp (1973). The intrusive volcanic necks at the heads of several wadis suggest that structural control played a part in the orientation of these canyons. It is possible, therefore, that control of subsurface drainage by fracture patterns may have been important in canyon development in both the Gilf Kebir and Ius Chasma. However, the dendritic drainage pattern of the Gilf may also be inherited from pre-existing drainage basins that once overlaid the plateau (Haynes, 1977).

Except for the major effect of the dunes that dammed Wadi Bakht and Wadi Ard el Akhdar, the present aeolian environment has had little effect on the channels within these wadis. Less than a few tens of centimetres of aeolian sand is present in the channels of both Wadi Bakht and Wadi Ard el Akhdar. It is probable that the greatest impact of the up- and down-valley winds is their ability to maintain the flat-floored valley morphology and aid in erosion of the steep cliff faces. Assuming that similar topographically-controlled wind regimes are present in the Martian canyons, these results provide the rationale for comparison of terrestrial and Martian fluvial regimes based on valley morphology.

In contrast to the wadi interiors, the mouths of the wadis on the southeastern edge of the Gilf Kebir have been highly affected by aeolian activity. As on Mars, no clear zones of deposition are present, and there is no development of coalescing alluvial fans such as exist in slightly more humid climates. Present-day aeolian deposition dominates over the more sporadic fluvial episodes, and fluvial deposits are buried by the sand sheet that grades upward to the edge of the plateau. On the basis of this expedition's investigation of the Gilf Kebir, and in the absence of more detailed topographic data for either the Gilf Kebir or Mars, we feel that this explanation would account for objections made to Martian fluvial erosion based on the apparent absence of debouchment features.

Summary

The remote setting of the Gilf Kebir ensures that many of the questions raised by this and previous expeditions will not be resolved in the near future. Although the erosional patterns of the plateau and the morphology of individual wadis have been investigated over the past 40 years, comparatively little attention has been given to the origin of the plateau itself. The morphologic similarity of the Gilf Kebir to the Colorado plateau in the southwestern United States hints that structural uplift of the Gilf Kebir may have occurred. In the absence of geophysical data, however, this suggestion must remain purely speculative.

On the basis of field observation made on the 1978 expedition, subsurface drainage and cliff sapping appear to have played the dominant role in wadi development. Possible fracture control of the location of major wadis is suggested by the volcanic necks at the wadi heads, but this too must await further detailed study. Within Wadi Bakht and Wadi Ard el Akhdar, however, the interplay of fluvial and aeolian deposition provides a detailed history of the recent evolution of these valleys. The available stratigraphic evidence indicates the periodic desiccation of the wadi floors, which may eventually be correlated with alternating wet and dry periods throughout southern Egypt. In addition, further research in this region will provide valuable insight into several of the major surface processes operating on Mars.

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VIII. PITTED ROCKS AND OTHER VENTIFACTS IN THE WESTERN DESERT

J. F. McCAULEY, C. S. BREED, M. J. GROLIER AND FAROUK EL-BAZ

THE MARINER 9 (1971) and Viking (1976) missions to Mars helped to stimulate a new interest throughout the world in atmospheric processes, particularly the role of wind in shaping terrestrial landforms in arid and semi-arid regions. Mariner 9 images showed that Mars is indeed a desert planet where the wind has been a very important geologic agent (McCauley, 1973). Dune fields comparable in size to the ergs of the Sahara, deflation hollows, fluted cliffs and yardangs are well represented on Mars. Early Viking results, especially those from the Landers, cast doubt on the efficacy of the wind in landscape development on Mars. Because of its extreme aridity and strong winds, the Western Desert of Egypt is surely the best terrestrial desert in which to test the role of wind in sculpturing the surface of Mars.

Common on the aeolian peneplain that lies between Kharga and the Gilf Kebir are small, scattered, severely wind-etched outcrops of the Nubian Series. Most of the Nubian rocks in this region are tough orthoquartzites, rarely with calcium carbonate in the matrix, which are covered with a veneer of dark grey desert varnish. At small scale, these rocks are etched into an array of grooves, projections and irregular shapes that are almost invariably aligned with the prevailing north wind. Even the talus from the many conical hills on the aeolian peneplain is grooved, fluted or etched, mostly along bedding planes.

Particularly resistant rocks in the process of being let down from above by deflation were noted near our campsite of September 29 and 25 km east of Beacon Hill. These forms were given the name 'beheaded sphinxes' because the heads, made up of a thin quartzite layer, have been toppled forward into the wind by undercutting of their prows. These features provide insight into how coarse lag surfaces form in certain desert environments (Plate XIXa).

Just below the notch and the archaeological site in Wadi Bakht (see section III by McHugh), numerous wind-eroded stream cobbles abound, particularly on the surfaces of the older and slightly higher fluvial terraces. The fragile, finely-etched veinlets, bedding planes and windward projections observed could not possibly have been subjected to prior wind erosion; what is now present on their surfaces must postdate the last stages of wadi-cutting. Also of interest is the wide variation in the degree of erosion observed on artefacts at the various archaeological sites visited throughout the desert. As expected, the older artefacts (Acheulean and Mousterian) were the most wind-eroded — frequently fluted and polished by sandblasting. Undisturbed hearthstones of various Nubian lithologies that are Neolithic, or possibly older, show flutes, pits and projections aligned into the prevailing wind.

Comparisons with Mars

In terms of Viking Lander interpretations the most significant small erosional features found in the Western Desert are the pitted and fluted quartzites and basalts. Along the slopes of Black Hill, we encountered wind eroded alluvial fan deposits that were so similar in appearance to the views from the Viking Landers

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as to be startling (Plate XIXb). The sizes and shapes of the rocks were almost identical with those in the Viking scenes. Depositional tails lay in the lee of most rocks; larger sand drifts occurred locally along with patches of sand on the tops of some of the larger rocks. Many rocks were angular as in the Viking pictures but most were pitted and also fluted to a lesser extent.

Controversy has raged in the geologic literature about the origin of pits and flutes on various types of rocks in arid, semi-arid and humid environments. The general consensus among most American geologists is that they are produced by solution processes and possibly enlarged or modified by wind action. Whitney (1978) has shown that small scale wind vorticity can produce pitted rocks with or without entrained sand particles. Solution effects on the basalts and quartzites exposed in the Western Desert of Egypt must be minimal, based on our knowledge of its present and past climatic conditions.

Some of the most interesting pitted and fluted rocks occur on the top of the Gilf Kebir in let down remnants of cap rock and even on the slabbed surfaces of the Neolithic implement reduction station discovered by McHugh during this expedition. These rocks bear a striking resemblance to many of those seen in the Viking Lander pictures (Plate XIXc and d). Since they consist of rock so tough that it was suitable for implement making by early man, it is doubtful whether solution could have played a significant role in the development of the textures seen. Sand blasting, vorticity and deflation of the worn down particles are more logical explanations.

An even more revealing example of pit formation by wind was discovered along the north side of the west end of Wadi Mashi, where remnants of a basaltic intrusive form a large, rounded hill. Talus fragments including blocks of basalt columns are extensively pitted and the surfaces on the tops of the fragments are partly filled with fine yellowish sand. At first glance, one might ascribe these pits to the presence of vesicles in the basalt. However, when broken open, these rocks proved to be massive, with only a small percentage of olivine grains to mar their internal uniformity. In this almost rainless desert, it appears almost certain that these are wind vortex pits. Chemical weathering may have initiated the pitting process — relative humidity in excess of 25 per cent and light dews are known to occur from time to time during the night. Vorticity and the development of small aeolian 'pot holes' is then responsible for the enlargement of the pits and the present surface texture of the rocks.

These preliminary observations in the most arid desert on Earth, where wind erosion has dominated the land for thousands and perhaps millions of years, raise the issue as to whether the terrain seen by the Viking Landers is as little eroded as was at first reported. Dense fine-grained rocks such as basalts and even orthoquartzites can become pitted and fluted in hyperarid environments even without sand — the dust in the air is sufficient. This raises the question as to whether the pits seen by the Viking Landers are vesicles or vortex pits.

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IX. YARDANGS OF THE WESTERN DESERT

M. J. GROLIER, J. F. McCAULEY, C. S. BREED AND N. S. EMBABI

THE FLAT surface of the Western Desert of Egypt is broken here and there by abruptly-rising, isolated hills, which include inselbergs and yardangs. In contrast to inselbergs, which require escarpments of sufficient relief for their formation, yardangs are hills or hillocks which are streamlined by the wind. The critical morphological criterion in distinguishing a yardang from an inselberg is that a yardang's length greatly exceeds its width, by a ratio of 3:1 or more, whereas most inselbergs are irregular and roughly equidimensional. The world-wide distribution of yardangs (McCauley *et al.*, 1977) indicates that they are restricted to the most arid deserts, where wind erosion predominates over water erosion in moulding the landscape. Yardangs are eroded in soft and hard rocks by a combination of wind and blown sand. The most obvious prerequisites for their formation are strong, unidirectional or reversed winds, and great fetch over barren but continuous rock surfaces, or exposures of slightly consolidated sediments. In the southern part of the Western Desert, these conditions are met on the limestone plateau between Asyut and the Kharga depression, on the floor of the same depression, and wherever lacustrine or sabkha deposits occur.

One of the largest fields of small yardangs in easily erodible lacustrine deposits occupies the floor of the Kharga depression between Kharga and Gebel el Ghennima to the east. It is easily accessible along the paved road leading to Asyut, lying a few kilometres north of Kharga. The lacustrine deposits consist of brownish sand and clays that unconformably overlie harder and older rocks. They are furrowed by wind and sand into a multitude of elongated hummocks, which are 4–5 m high, a few metres wide, and tens of metres long (Beadnell, 1909, p. 111). The rate at which the lacustrine deposits are deflated varies from layer to layer according to slight differences in resistance to weathering and erosion. Degree of cementation, bedding and jointing patterns are among the controlling factors of rock resistance to wind erosion. The resulting wind-sculptured landform is known by a variety of highly evocative names such as mud lion, recumbent lion, sitting sphinx, and sphinx hill. The hummocks are separated by long and shallow depressions or *couloirs*, which bear no morphological evidence of fluvial erosion. The long axes of both hummocks and *couloirs* are parallel to the direction of the prevailing northerly wind (Plate XXa). Fields of well-developed mud lions also occur south of Kharga, particularly near el Ramah on the Kharga–Baris road (Embabi, 1972).

In addition to wind-eroded mud lions, yardangs eroded out of the much more resistant Nubian sandstone also occur within the Kharga depression. They were first sighted and photographed during our flight from Cairo, but there was no time to study them on the ground. The plateau which extends between the Kharga depression and the valley of the River Nile is underlain by limestone. This limestone was previously reported to be furrowed by the wind into a very rough surface, that was called 'kharafish' (Beadnell, 1909, p. 35). 'Kharafish' topography, as originally described, consists of innumerable sharp-ridged hillocks separated by troughs which are partly buried with sand. Hillocks and troughs lie parallel to the direction of prevailing winds. This type of terrain was

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considered by Gautier (1935, p. 112–13) to be similar to that in western China, where yardangs were first described by Hedin (1905). However, the general impression left by these early explorers was that the wind-eroded forms were small-scale features. In the flights to and from Kharga, we realized that the 'kharafish' topography represents only a small part of a far more extensive field of yardangs. This field of streamlined hills and intervening furrows (*couloirs*) is approximately 150 km long and tens of kilometres wide. The innumerable hillocks reported by Beadnell (1909) are only the smaller of the yardangs. Countless numbers of larger yardangs occur either as isolated hills or in clusters, hundreds of metres long and tens of metres high (Plate XXb).

We were able to undertake a one-day preliminary study of these features on the ground. The irregular tops of the larger yardangs in this field are mantled by a grey-pink residual material, which resembles the terra-rossa so commonly found on limestone terrain in much of the Mediterranean region. Terra-rossa extends downward into cracks and irregular cavities within the limestone. The upper part of the Thebes Limestone of early Eocene age — that part which is furrowed by the wind — is silicified, and unusually hard and resistant. Siliceous concretions (called melons by British geologists) are common erosional remnants on the wind-swept surface of the 'kharafish' terrain. The chemical weathering implied by terra-rossa, silicification, and solution features such as interconnecting cavities suggest that a humid climate prevailed over the region for a long time during the Cenozoic era.

The smaller streamlined rock exposures typical of the 'kharafish' terrain are intensely fluted into the wind, in the lee of the wind, and also on side slopes. They resemble artichoke heads or the prows of heavy ships, with the stem or the prow pointing into the wind (Plates XXc and XXIa). The wind-fluted and polished crystalline limestone glistens in the sun to a height of several metres above the *couloirs*, which are choked with ripples of sand and granules. Unlike the sharp-crested, keel-shaped yardangs that were observed in other deserts, these are frequently flat-topped and retain some of the original weathered surface. Thus, these yardangs are less mature than the sharp-crested variety, and the tops mark a surface against which the depth of wind erosion can be estimated. A detailed study of this extraordinarily large yardang field will lead to a better understanding of the extensive yardang fields seen on Mars on the recently acquired Viking Orbiter images.

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X. WIND DEPOSITS IN THE WESTERN DESERT

C. S. BREED, N. S. EMBABI, H. A. EL-ETR AND M. J. GROLIER

ENORMOUS quantities of debris (mainly the products of wind erosion) are moving inexorably across the Western Desert of Egypt, driven southward by the prevailing winds. Because running water no longer plays a significant role in the transportation and deposition of sediment in the Western Desert, its landscape, like that of Mars, reflects almost total 'aeolian takeover' (McCauley *et al.*, 1977, p. 131). The landforms produced by wind processes on Mars, despite its 100-times less dense atmosphere, are remarkably similar in shape and distribution pattern to those on Earth. Photographs of the Viking Lander sites suggest a segregation of wind deposits by grain size on Mars, analogous to that which we observed in the Western Desert. If the analogy is valid, some of the questions regarding the general absence of sand and dunefields from certain areas of Mars may be explained.

A striking characteristic of the Western Desert is that its wind deposits are not mixed up and scattered at random throughout the region. Rather, they are discretely zoned in response to the capacity of the wind to sort out and segregate particles by grain size. The finest particles (clay and silt sizes) are winnowed out wherever they are exposed, and whirled away as dust, settling out of suspension beyond the zones of high wind energy characterized by the 'sand' plains. In our journey across the 'sand' plain between Kharga and the Gilf Kebir, we experienced many winds of sand-moving strength (generally 30 kph or more), yet the air was clear of dust. The only dust particles we saw were the plumes that rose from the tracks of our vehicles as they broke through the surface lag gravels (Plate XXIb). Elsewhere the desert floor was eerily still.

The term 'sand' plain is a misnomer, for these vast, essentially flat areas are veneered with a surface of granules or pebbles, commonly well sorted and only one grain thick (Plate XXIc). This lag forms an armour that is apparently in equilibrium with the strongest winds. The maximum winds must blow infrequently, for in places the tracks of vehicles used in expeditions in the 1920s and 1930s have not yet disappeared. The process of surface creep, by which the wind distributes the coarse materials, seems imperceptible except under rare conditions. Conversely, removal of the lag results in immediate deflation of the suddenly unprotected, underlying silty soil, and produces lasting scars. In contrast to the intermittent, slow creep of the coarsest particles, fine-to-medium sand saltates readily in the ubiquitous brisk winds of the Western Desert. By the saltation process, the wind segregates particles of sand size from the clays, silts and gravels and shepherds them into dunes. From the Qattara Depression southward, great belts of dunes march in slow but measurable procession toward Libya and Sudan (Fig. 1).

The long, mostly unobstructed fetch of the dominant north–northwest wind between the River Nile and the Kharga Depression has resulted in the growth of one of the longest, most massive longitudinal dunes on Earth, the Ghard Abu Muharik (Fig. 1). This great compound linear dune, with its numerous companions such as the Ghard Ghorabi, are typical 'sand-passing' dunes that transport sand lengthwise along their axes for great distances. The exact mechanisms by which the sand migrates, and the roles of different types of wind

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regimes in the formation of these dunes, is controversial. One of our objectives, therefore, was to observe dunes of this type in the Western Desert, where wind regimes are better documented than in most African deserts, and where vegetation is absent.

Where the great belts of longitudinal dunes in the Western Desert cross escarpments and spill into depressions, as at Kharga (Fig. 1), they commonly break up into fields of barchan dunes. The Ghard Abu Muharik reaches the escarpment north–northwest of Kharga and, as sand from this dune belt descends into the depression, it is distributed into fields of barchans and barchanoid ridges (Plate XXIIa). The nature and extent of the Kharga barchans were known prior to the expedition, having been studied most recently by Embabi (1970–71). Thus, our attention was directed mainly to exploring areas of future research. The barchans of Kharga are typical of the 'sand-trapping' dunes that form transverse to the prevailing wind in topographically low areas in deserts, both on Earth and on Mars. Where further migration is blocked, such dunes may eventually accumulate sand to great depths, as in the Murzuk Sand Sea of Libya and perhaps in some craters on Mars. The Kharga barchans are distinguished by their fast rate of southward migration; their annual rate of movement varies between 20 and 100 m depending on individual dune size.

At several localities east of the Gilf Kebir we observed longitudinal dunes about a kilometre in size in the lee of hills (Plate XXIIb). Following our return from the Gilf Kebir, we visited the Bahariya depression (Fig. 1) where we examined a small longitudinal dune that is part of Ghard Ghorabi (Plate XXIIc). During this time we were able to dig several trenches to examine the internal bedding patterns of this dune (Plate XXIId) and to obtain sand samples for grain size analyses. These observations will, in combination with wind records and analyses of field relationships, provide evidence of the mechanisms by which this dune, and others like it, have grown. This field study may prove useful in the interpretation of local wind regimes in the north polar region of Mars, where fields of longitudinal dunes occur in certain areas, apparently related to changes of slope and/or local wind regimes.

At the downwind ends of several of the longitudinal dunes east of the Gilf Kebir and at Bahariya, we observed dome dunes, which resemble incipient barchans but are round, with no slipfaces. In the southwestern United States, dome dunes are known to occur in zones of highest wind energy which, in these instances, are located at the upwind ends of barchan dune fields. The presence of dome dunes at the downwind ends of longitudinal dunes in the Western Desert may mark the zones of highest wind energy in which dune forms can be maintained; in other words, the margin beyond which saltating sand does not settle long enough to build dunes, but rather streams out in the form of sand sheets or streaks. In the Black Hill area east of the Gilf Kebir (Fig. 2), surrounded by the gravel plain, we observed longitudinal dunes growing southward in the sheltered lee of the hills. Beyond the longitudinal dunes were a few dome dunes. Tyre tracks showed that one of these domes has migrated 20 m in 8 years — 2·5 times as fast as the longitudinal dune at Bagnold's camp. Elsewhere on the gravel plain, sand capable of saltation occurred only as 'tails' in the lee of boulders. This relationship seemed to illustrate, in microcosm, the selectivity of aeolian deposition in the Western Desert and, perhaps by analogy, on Mars.

Acknowledgements

The study of the longitudinal dune of Ghard Ghorabi was done in cooperation with Ted Maxwell, Adel Moustafa, Mahmoud Yousif, Abdel Halim Abdel Basit, and Abdel Moneim Osman. Trenching of this dune was made possible by the kind cooperation of the Egyptian Iron and Steel Company, especially engineer Sayed Abdel Razik of the El Gedida Iron Mine. We thank the Geological Survey of Egypt for providing the vehicles for transport between Cairo and Bahariya.

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XI. WIND STREAKS IN THE UWEINAT REGION AND MARS

FAROUK EL-BAZ AND TED A. MAXWELL

THE SOUTHWESTERN part of the Western Desert of Egypt is characterized by alternating bands of light- and dark-coloured streaks. Our field observations indicate that some of the light-coloured streaks are composed of sand sheets and highly reflective lag deposits. However, some of the light-coloured streaks appear to be extensions of the longitudinal sand dunes of the Great Sand Sea to the north (Fig. 1). Orientations of these dunes and streaks indicate a prevailing wind direction in this area from the northeast, which supports Bagnold's (1933) suggestion of a clockwise rotation of prevailing wind about a centre near Kufra Oasis, in southeastern Libya.

The Mariner 9 and Viking spacecraft photographed numerous alternating light and dark streaks and streak bundles on Mars, particularly in the Cerberus and Elysium Mons regions. Similar streaks and streak bundles abound to the east of Gebel Uweinat. In both cases the streaks emanate from crater rims and isolated knobs (Plates XXIIIa and b), and the knobby material protrudes through the surrounding terrain on a line that is oblique to the prevailing wind.

This preliminary study of light and dark streaks in the southwestern desert of Egypt indicates that: (1) the light streaks are depositional; sand dunes and/or sand sheets form most of the light streaks; (2) the dark streaks are erosional products of high mountains and hills; they represent virtually sand-free areas; and (3) the morphology of both light and dark streaks is controlled by the flow of the wind around topographic highs. These findings have significant implications for the interpretation of streaks on Mars.

In the Uweinat region, dark-coloured streaks occur in the lee of topographic barriers; the largest streak is southwest of Uweinat itself (Plate XXIIIc). This mountain stands 1900 m above the surrounding sandy plain. Under the prevailing wind from the north-northeast, this mountain ring creates a flow pattern that is similar to those observed on Mars (El-Baz, 1978). This pattern is also similar to those generated by laboratory experiments to simulate the flow of wind around Martian craters (Greeley *et al.*, 1974; and Iverson and Greeley, 1978). The morphological similarities between the terrestrial and Martian dark streaks are clearly illustrated in Plate XXIII.

The importance of local material to dark streaks in southwestern Egypt is demonstrated in the lee of Qaret el Maiyit hill (Plate XXIVa). This streak is composed of 5–7 mm granitic pebbles eroded from the hill itself. This surface is surrounded on either side by a light-coloured sand sheet. Because of their large size, the dark pebbles of the streak are less likely to move under the sand-moving winds. Consequently, the shape of the streak will change mainly in response to the shifting of the light-coloured sand on both sides. A similar setting was encountered by the senior author in the area of Ras el Abd in Sudan (see Section I).

Field investigation of dark streaks in the Uweinat area by the senior author indicates that the surface is also strewn with irregular chips of dark rock. These chips or flakes are usually a few centimetres in diameter. They appear to be fragments from the Gebel Uweinat rocks. Usually the dark-coloured chips cover smaller, lighter-coloured fragments and sand grains (Plate XXIVb). However, the colour of the larger fragments dominates, giving the area a dark colour in the field and in Earth-orbital photographs. These findings may help us better understand both light- and dark-coloured streaks on the surface of Mars.

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XII. FUTURE WORK IN THE SOUTHERN PART OF THE WESTERN DESERT

FAROUK EL-BAZ

SCIENTIFIC interest in the southern part of the Western Desert of Egypt goes beyond the study of the well-developed aeolian landforms. The part of this desert south of 24° north latitude is not well known and its potential has not been fully evaluated. For this reason our remarks will not be limited to the Gilf Kebir and Gebel Uweinat area, but will include the territory that is bordered by Lake Nasser to the east (Fig. 9).

It is clear that the southern segment of the Western Desert of Egypt received more rain in the past. Ancient lake boundaries, underground water close to the surface, and drainage patterns are physical evidence of this. Archaeological evidence indicates that the area was inhabited from 3000 to perhaps 200 000 years ago. Furthermore, during our expedition from Tarfawi West to the Gilf Kebir we encountered many areas where fertile, clayey soil was exposed or buried under a thin sheet of sand.

This indicates that there are some agricultural prospects in this part of Egypt; the prospects of good soil should be investigated along with groundwater resources. Also, there is the question of whether or not the underground water reservoir in the Western Desert oases is being replenished by the flow of water from the south or west. This question will not be resolved until the southern part of the Western Desert is more fully studied. In addition, areas of good soil in the eastern part may be utilized in crop-raising by the transport of fresh water from Lake Nasser via canals or, better, pipelines.

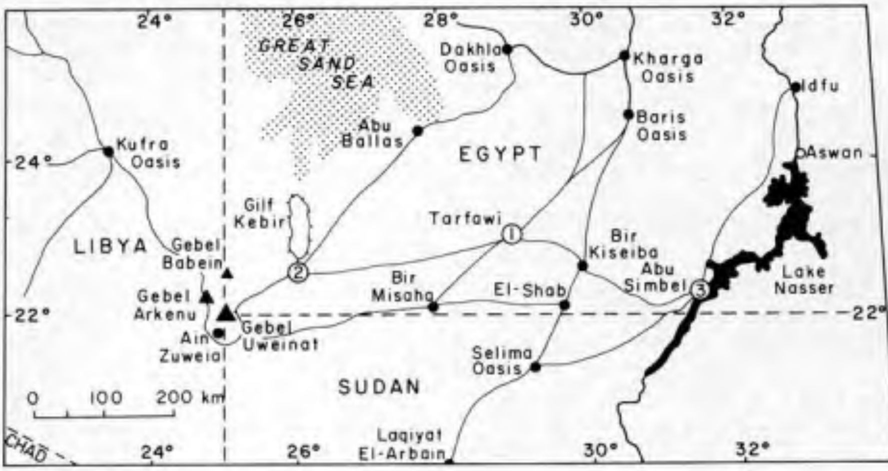

Fig. 9. Map of the southwestern desert of Egypt showing desert routes to neighbouring Libya and Sudan. Indicated are the proposed locations of a permanent camp at Tarfawi West (1), and seasonal camps at Gilf Kebir (2) to the west, and Abu Simbel (3) to the east

In addition to the agricultural potential, the area's mining potentials are encouraging. The iron ore which we sampled on our expedition about 150 km west of Bir Tarfawi turned out to be quite promising; as analysed in the laboratories of the Geological Survey of Egypt, the concentration of iron in the red type is 25 per cent and in the black ore is 58 per cent. Also some black ore is 68 per cent iron oxide and 22 per cent manganese oxide. This ore may be economical when the new railroad from Dakhla to the Nile Valley is built to transport the Abu Tartur phosphate ore.

The phosphate layer of Dakhla extends along the southwest-trending scarps far beyond Abu Ballas (Fig. 9). Although the known layer is thin, measuring less than 60 cm, thick layers may occur. Also, kaolinized material is exposed along the base of cliffs on the western side of the Gilf Kebir plateau. Kaolin may be present there in economic amounts. More importantly, the lithologic setting is suitable for radioactive element concentrations in the Uweinat area; the conglomerate horizon above the Uweinat granite may carry the highest concentrations.

The southern part of the Western Desert of Egypt also has socio-political significance. The Darb el Arba'in is the natural road connection between Egypt and Sudan. Trade between Egypt and Sudan and between these two countries and Libya would be served by paving the desert roads (Fig. 9). Probably the best way to study the area fully would be to assemble a multidisciplinary group from all three nations. It is here proposed to study the Egyptian part first by the establishment of the three desert camps shown in Figure 9.

Surface mapping

The exploration of the southern part of the Western Desert of Egypt is hampered by the lack of adequate maps. The only maps that cover the whole region are at 1:1 000 000 scale. The southwestern corner is covered by 1:500 000 maps, and the Nasser Lake region and the oases are mapped at larger scales. To serve as base maps it would be most desirable to have contoured orthophotomaps at 1:50 000 scale. In the absence of mapping-quality photographs, mosaics should be made from digitally enhanced and colour corrected LANDSAT images at

1:250 000 scale. These LANDSAT base maps are required to compile the surface geology of the region by the Geological Survey of Egypt. Some emphasis should be placed on mapping sand dunes and dune bundles. Boundaries of sand sheets and the motion of sand dunes may be very important factors in considering the development potential of the desert. In addition, both structural and soil maps should be made. The structural maps would emphasize the hydrogeology and petroleum potentials and the soil maps would classify the exposed soils for agricultural utility.

Subsurface mapping

Aeromagnetic and gravity surveys are necessary to establish the depth and shape of the basement rocks beneath the sediments in the southern part of the Western Desert. This knowledge is essential to a full understanding of the underground water reservoir and its future. In addition, surveys of the natural γ-ray radiation should be made to locate areas of high concentrations of radioactive elements. An effort should also be made to compile all the subsurface geological data obtained by drilling wells by various organizations to decipher the near-surface stratigraphy. It may be necessary to pursue a modest drilling programme to fill any gaps and allow extrapolation of existing well data and complete the subsurface picture.

Fluvial history

The fluvial history of the southern part of the Western Desert of Egypt is most interesting; large lakes have given way to sun-scorched rock and sand. The Gilf Kebir plateau presents a special challenge in the study of fluvial landforms. The plateau surface is not dissected by a drainage pattern. However, the scarp of the plateau is deeply incised by valleys, particularly on the southeastern side. Perched high in some of these valleys are also dry lakes. Layers within these lakes have kept a record of past fluvial episodes, which may give clues to climatic change. The lake beds of Wadi Bakht and Wadi Ard el Akhdar are particularly interesting where lakes were formed as a result of natural damming. These localities warrant detailed study by a multidisciplinary group to shed some light on past, wetter conditions and thus on the climatic history of the region. This history would in turn expand our understanding of the changes in climate in all of North Africa.

Aeolian history

Unlike the fluvial history which has to be deciphered by digging in layers of ancient lakes, signs of aeolian history are still exposed on the surface. The southern Western Desert exhibits a great variety of aeolian landforms. In fact, it is believed that this region, because of its extreme aridity, may display more signs of wind erosion than any other part of the Sahara. In addition to the numerous sand sheets and a variety of sand dunes, it displays various wind-carved landforms. Particularly in the Uweinat region, the displayed features help in the interpretation of wind-blown patterns on Mars. Patterns created by the interaction of the wind with the circular mountains in the Uweinat region may be analogous to those formed as the wind bypasses circular craters on the surface of Mars. These features should be studied in more detail to allow more specific comparisons and to help us better to understand the aeolian regimes of both Earth and Mars.

Note: The spelling of place names in this series of papers is that of the authors and not necessarily that of the RGS.