

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 ₂ O ₃	SiO ₂	MnO ₂	CaO	P	V*	Al ₂ O 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

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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 interfluvial 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 wind-swept 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

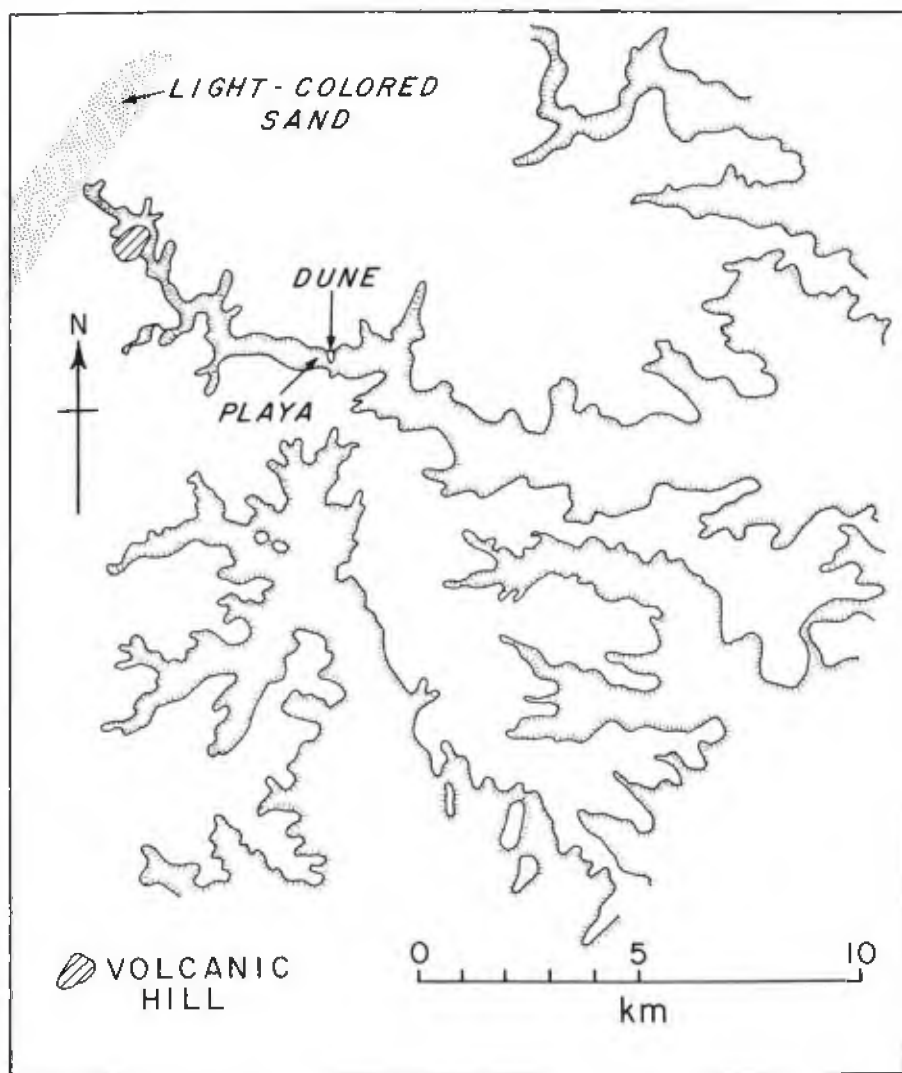


Fig. 4. Map of Wadi Bakht on the southeastern margin of the Gilf Kebir (based on LANDSAT images)

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.

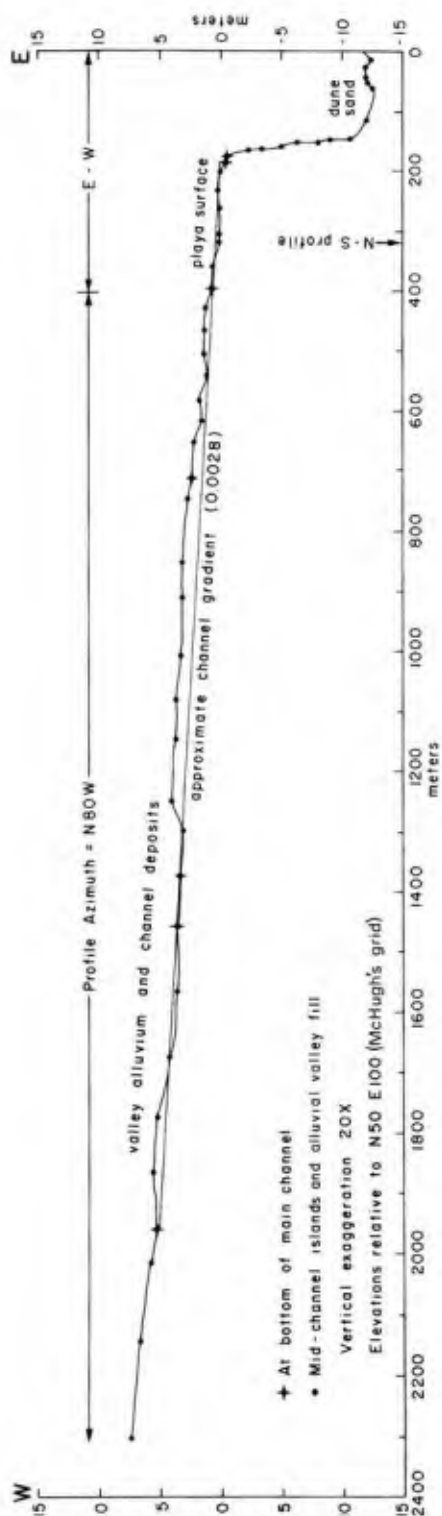


Fig. 5. Longitudinal profile of Wadi Bakht

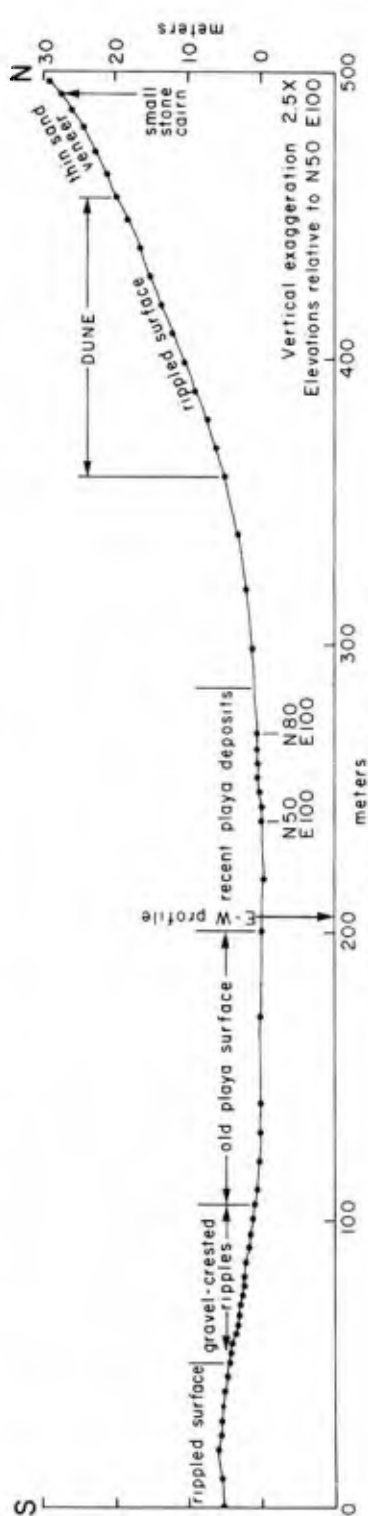


Fig. 6. Transverse profile of Wadi Bakht

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-

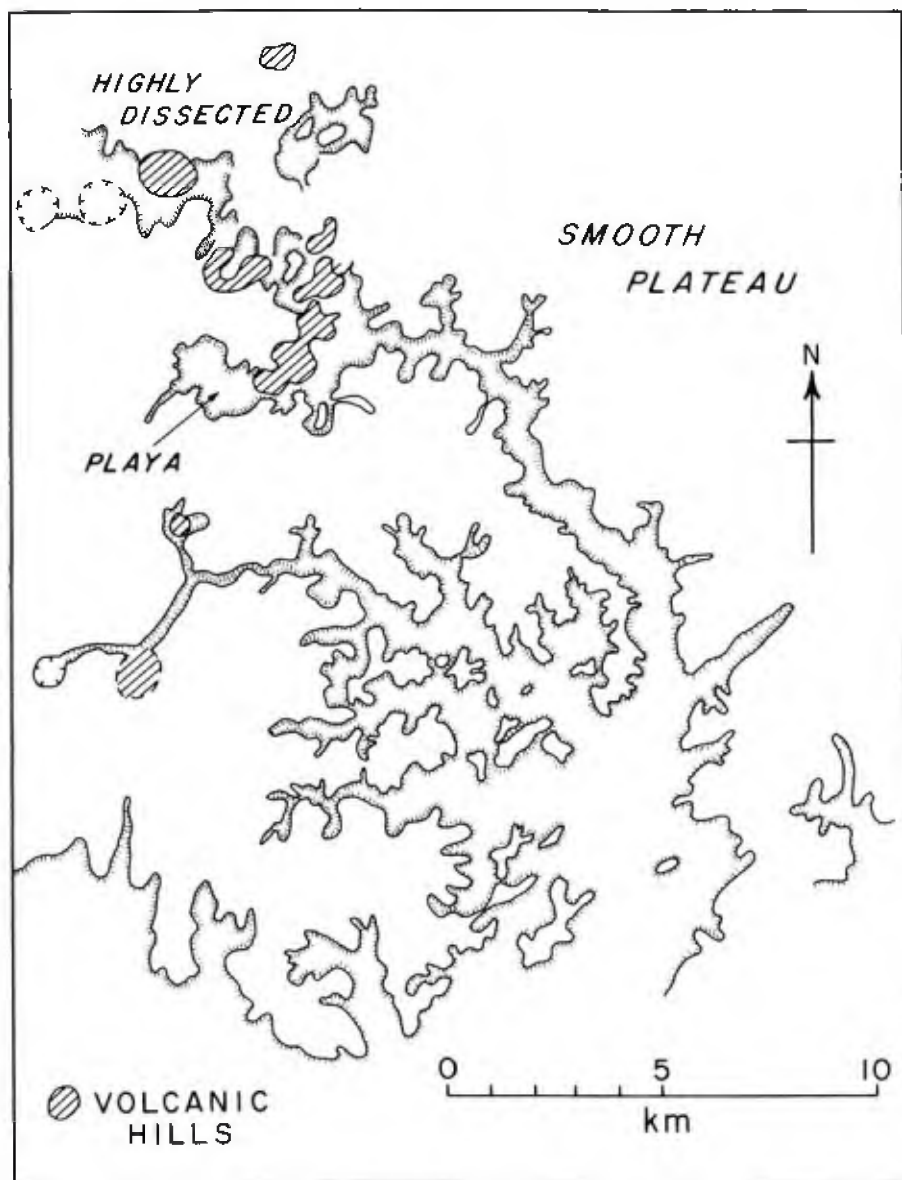


Fig. 7. Map of Wadi Ard el Akhdar on the southeastern margin of the Gilf Kebir (based on LANDSAT images)

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

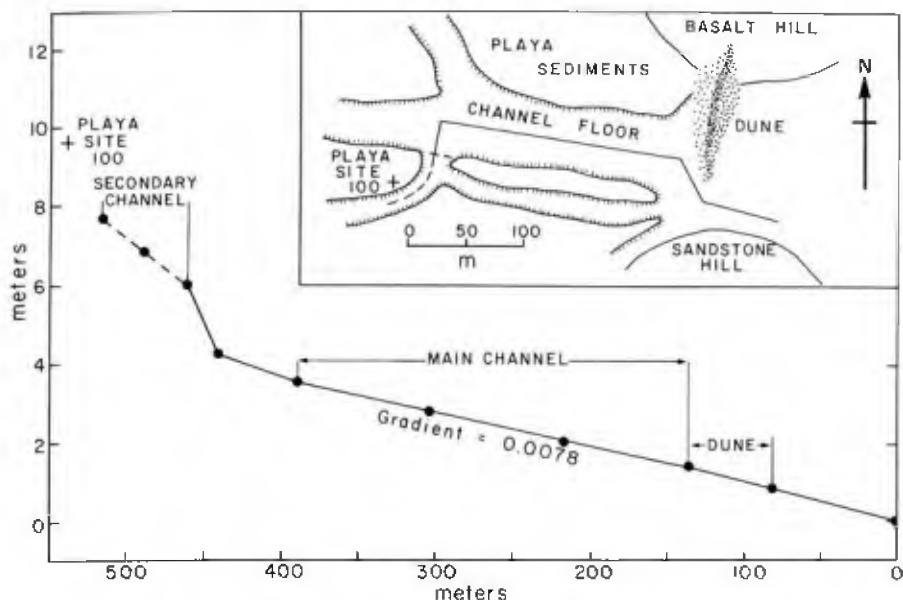


Fig. 8. Sketch map and profile of the mouth of Wadi Ard el Akhdar

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.

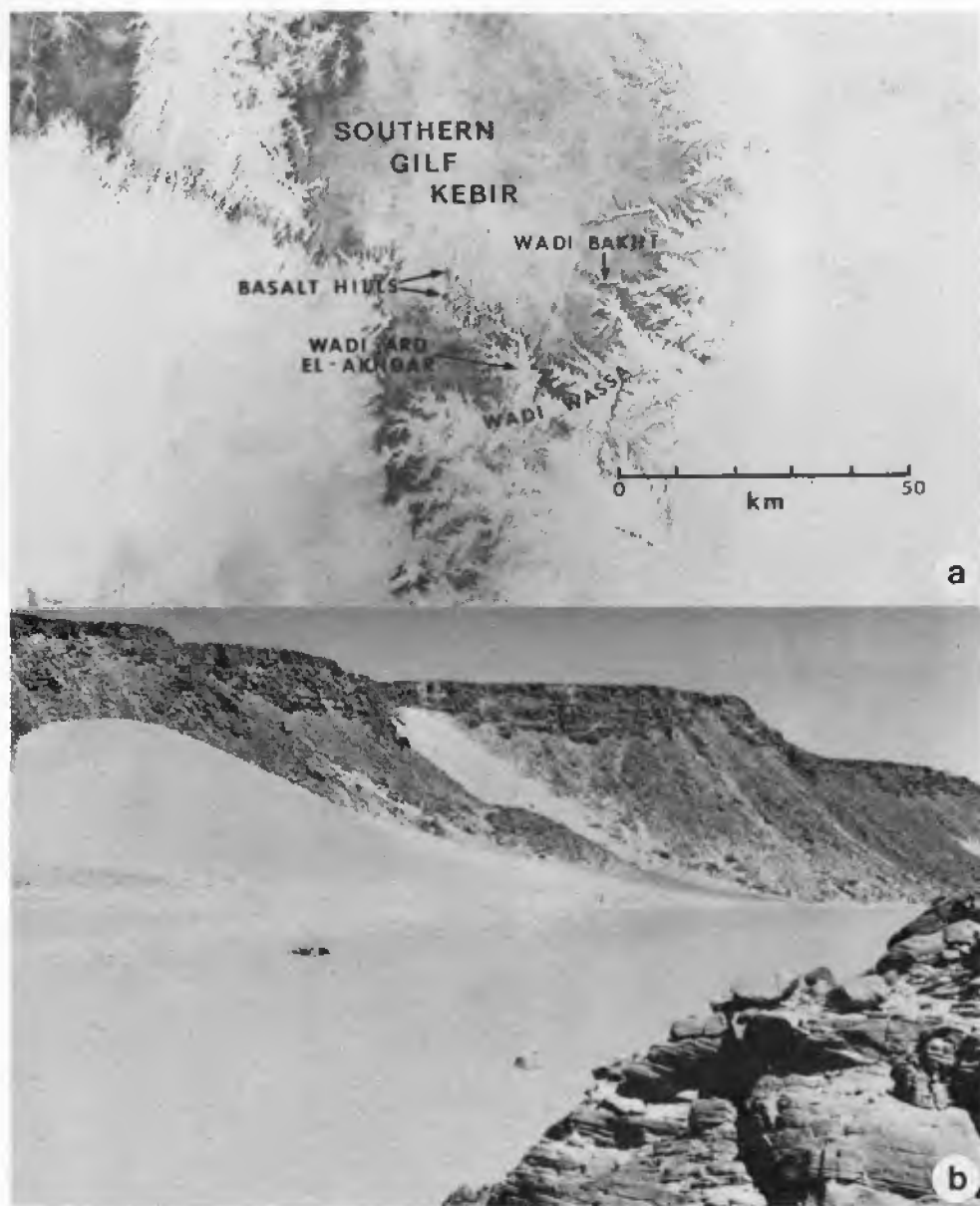
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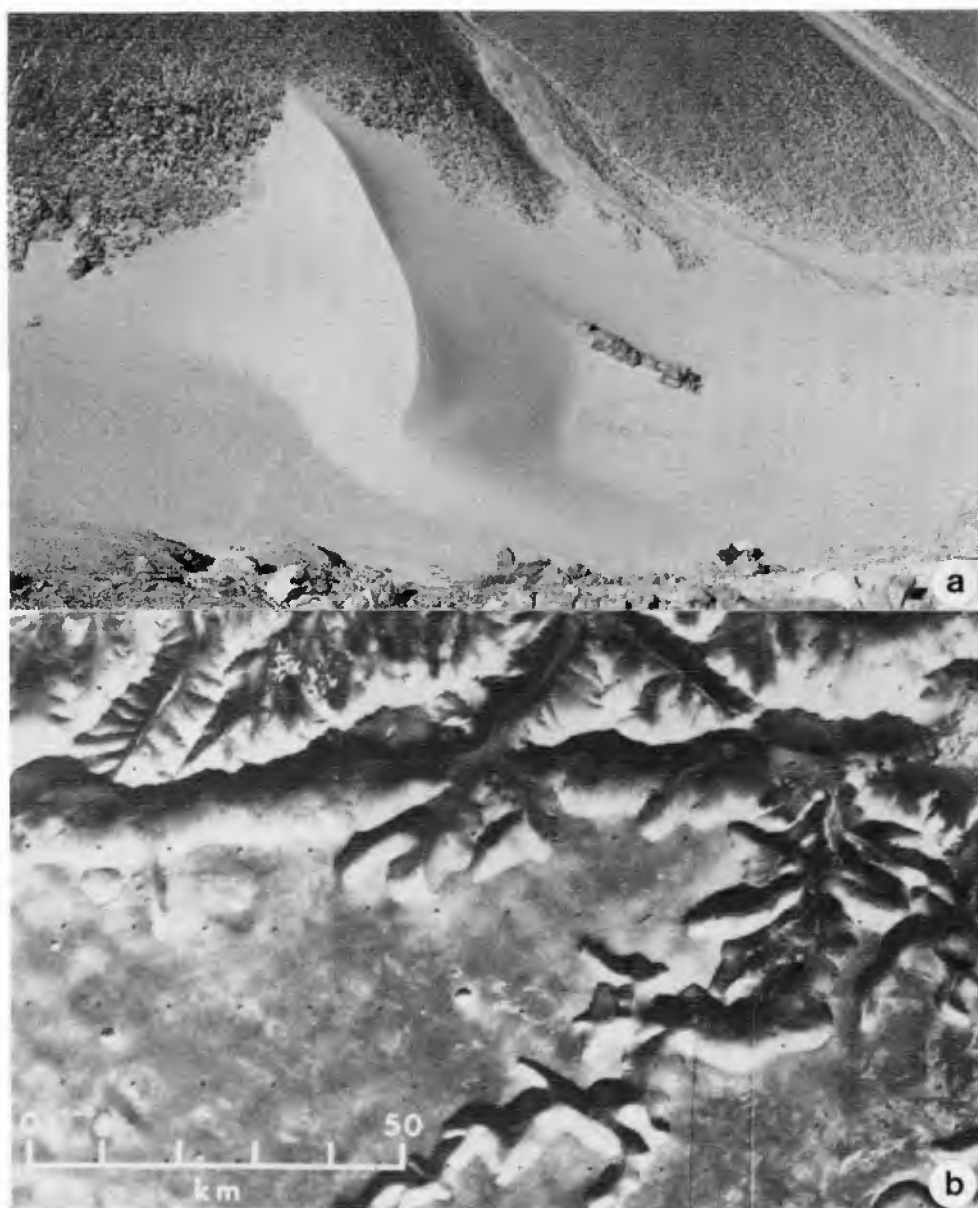
PLATE V



The southern Gilf Kebir, upper right, and Gebel Urweinat, lower left of centre, as seen in a four-image mosaic from LANDSAT satellite (see also Plate XVII(a))



(a) Enlargement of a LANDSAT mosaic showing the southern Gulf Kebir; (b) playa deposits exposed at breached natural dam in Wadi Bakht



(a) Basalt hill and climbing dam-dune in Wadi Ard el Akhdar of the Gilf Kebir; (b) Viking image of wadis in Ius Chasma on Mars