DESERT LANDFORMS AT THE KURKUR OASIS, EGYPT

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ABSTRACT. The Libyan Desert of the Kurkur area, west of Aswan, was primarily modeled by running water in late Tertiary and early Pleistocene times, and has been subsequently remodeled by wind. Analysis of the desert landforms thus sculptured under semiarid to hyperarid conditions shows that drainage characteristics, slope forms, and surficial materials are distinctive from those commonly associated with humid environments. Areas of smooth slopes and limited relief are dominant, and stream dissection is limited, with very coarse texture a characteristic. Steep, parallel rectilinear mid-slopes offset by sharp, angular breaks in gradient provide a bimodal slope distribution in gentle and steep categories. Lag, talus, and water-transported scree essentially replace the concept of the soil mantle. Alluvial and colluvial deposits are extensive even though thin and rarely activated. This example from Kurkur suggests that systematic studies of landform differences between arid and humid environments are both possible and desirable.

DURING the course of a 7-month field season in southern Egypt during 1962–1963, opportunity was given for a detailed local study of the Pleistocene geomorphology and surficial deposits of the Kurkur area.[1] Wadi Kurkur, a defunct west bank tributary of the Nile, intersects a modest aquifer as it descends through one of the great cuestas of the Libyan Desert. Water emerges in seepage lines that maintain a little moisture in some surficial sands. This wadi gorge with palms, halfa grass, and thorn shrub is known as the Kurkur Oasis. Once providing shallow water holes for travelers on the caravan routes through the Libyan Desert, it is situated 55 km west of the Nile at approximately the latitude of the new High Dam above Aswan.

Modern rainfall has sufficed for occasional, localized wadi floods in recent centuries. But the long-term rainfall statistics for Aswan (less than three millimeters mean annual precipitation) and the Kharga Oasis (less than one millimeter) emphasize that the hydrography is essentially "fossil" today. Nonetheless, the Kurkur landscape has been primarily carved by running water, a fact attested to by massive Pleistocene spring sediments. Yet, despite their fluvial character, the landforms of the Kurkur area are "desert" in aspect.

The purpose of this paper is to present an analytical description of the salient landform features at Kurkur. From most perspectives, Kurkur is a completely insignificant location. But the variability of lithology and topography, the almost complete lack of any vegetation, and a hyperarid environment, all combine to make the area a suitable testing ground for arid-zone geomorphology. It is a well-known fact that distinctive geomorphic forces may be underway in arid lands today or may have been so in the recent geological past: eolian sculpture and certain types of fluvial activity and mass-movements.[2] But, are the resulting arid zone landforms objectively different and distinctive?

It is here aimed to show that the varied landforms evident in the southeastern Libyan Desert near Kurkur are indeed significantly different from those found in humid environments. The role of Pleistocene climatic

[1] K. W. Butzer, "Pleistocene Palaeoclimates of the Kurkur Oasis, Egypt," *Canadian Geographer*, Vol. 8 (1964), pp. 125–41. The study was supported in part by NSF grant G-23777 and U.S. State Dept. grant SCC-29629 to Yale University, and by NSF grant GS-678 to the University of Wisconsin. The fieldwork was carried out in collaboration with Carl L. Hansen while the writer was senior geologist to the Yale Prehistoric Nubia Expedition. M. Gordon Wolman made useful suggestions on the manuscript.

[2] J. Büdel, "Das System der Klimatischen Morphologie," *Abhandlungen deutschen Geographentags, München, 1948* (Munich: 1950), p. 65–100; P. Birot, "*Le cycle d'erosion sous les differents climats,*" *Curso de altos estudos geograficos*, Universidade do Brazil, Vol. 1, pp. 97–118; W. Meckelein, *Forschungen in der zentralen Sahara* (Brunswick: Westermann, 1959); J. Tricart & A. Cailleux, *Le modelé des régions sèches* (Paris: Centre de Documentation Universitaire, 1960–61), 2 Fasc.; K. W. Butzer, *Environment and Archeology: an Introduction to Pleistocene Geography* (Chicago: Aldine, 1964), pp. 125–30, 135, 188–96.

changes will be considered briefly where relevant, but it would serve no purpose to reiterate the physical evidence for Pleistocene paleoclimates.[3] Furthermore, this paper is not intended to be a regional geomorphology of the Kurkur area. A detailed study of the geomorphic evolution of Kurkur and Lower Nubia is planned for a later monograph.

LITHOLOGY AND STRUCTURE

The bedrock of the area consists of broadly horizontal sedimentaries of Upper Cretaceous to Middle Eocene age. The regional dip of less than one percent is towards the west (WNW), although local slumping has reversed this dip along the margins of the great cuesta. There has been no major tectonic deformation, although north–south fractures are conspicuous a little west of the Nile and at the foot of the Kurkur-Gebel Gharra escarpment (Figs. 1 and 2).

The lithological units (Fig. 1) are pertinent to an understanding of the landforms and can be summarized as follows:

a) *Plateau Tufa* (40 m). Buff to brownish gray, semicemented freshwater limestones, consisting of cryptocrystalline calcite with an admixture of quartz sand, silt, and occasional conglomerates. The dominant travertine facies is moderately impermeable. Late Pliocene or early Pleistocene.[4]

b) *Nummulitic Limestone* (local thickness 6 m, but attaining over 100 m further north and west). Massive, indurated, light brownish gray limestone of Lower or Middle Eocene age.[5]

[3] Butzer, *op. cit.*, footnote 1.

[4] Butzer, *op. cit.*, footnote 1.

[5] The Lower Tertiary of Egypt is currently being subjected to sweeping stratigraphic revisions on microfaunal grounds. At Luxor, the Esna Shale, which underlies the lowermost Nummulitic Limestone (Lower Libyan or Theban formation), is now thought to occupy the total of the Lower Eocene. See W. A. Berggren, "Biostratigraphy of the Paleocene—Lower Eocene of Luxor and nearby Western Desert," *in* F. A. Reilly, (Ed.), *Guidebook to the Geology and Archaeology of Egypt* (Tripoli: Petroleum Exploration Society of Libya, 6th. Annual Field Conference, 1964), pp. 149–76. Lateral variations of facies during the regressive Lower Tertiary suggest, however, that identical lithofacies will be of greater age further south.

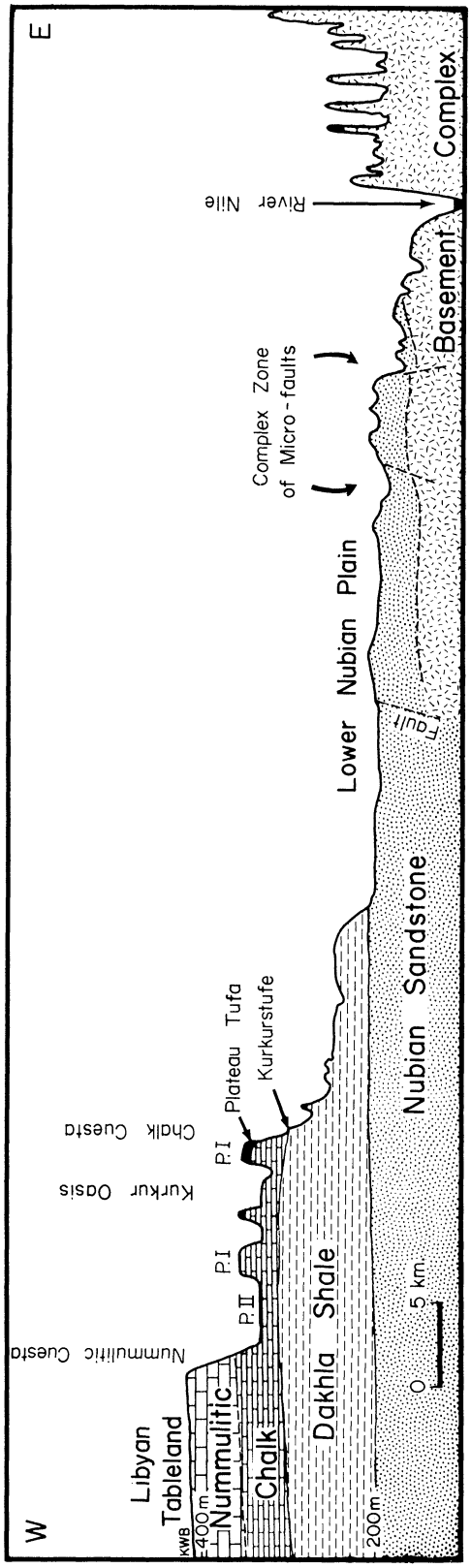

FIG. 1. General cross section from the Kurkur Oasis to the Nile Valley. Topography based on 1:100,000 Survey of Egypt sheets 12/72 (Kurkur) and 12/78 (Aswan), geology by K. W. Butzer and C. L. Hansen.

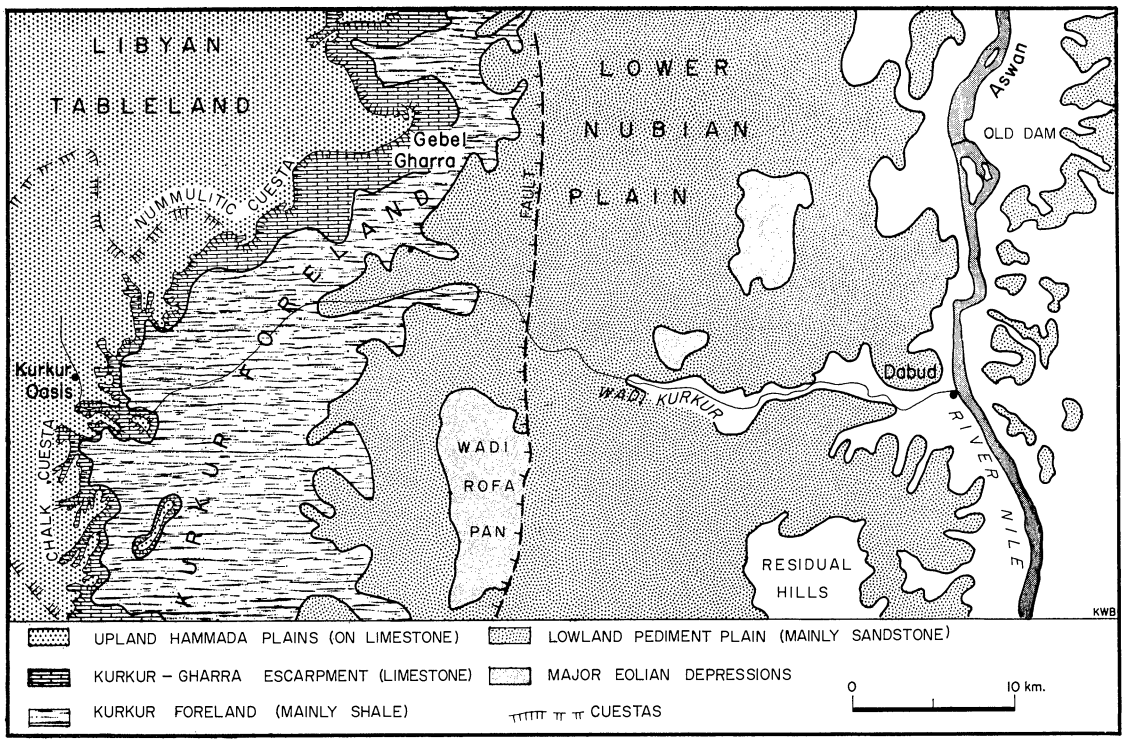

FIG. 2. Geomorphologic Units of the Kurkur-Aswan Area.

c) *Chalk* (70 m). White to buff chalky limestone, thin-bedded except for intercalated beds of tough, massive limestone. Generally rather porous and containing sodium and magnesium sulfates as well as halite. This major aquifer can, in the main part, probably be attributed to the Paleocene.

d) *Kurkurstufe* (4–5 m). Massive, indurated, impermeable, brownish yellow, siliceous limestone. Upper Cretaceous (Danian).[6]

e) *Dakhla Shale* (90 m). Light gray, generally oxidized, fissile clayey siltstone with some lenses of gypsum. Upper Cretaceous (Maastrichtian to Danian).

f) *Nubian Sandstone* (over 50 m, resting disconformably at depth on a Precambrian basement). White to buff, coarse-grained sandstones of moderate consolidation, and both high porosity and permeability. Upper Cretaceous.

[6] J. Cuvillier, "Les Kurkurstufe." *Bulletin*, Institut d'Egypte, Vol. 17 (1935), pp. 117–22.

The five major topographic features of the wider Kurkur area include:

1) a lowland sandstone plain in the east, reaching to the banks of the Nile,
2) the irregular shale foreland between the sandstone plain and the limestone escarpment,
3) a complex cuesta escarpment formed by various limestone units,
4) a series of pediments cut into the limestone uplands, and
5) the limestone plateau to the west.

The distinctive terrain of these regions (Fig. 2) will be described in turn.

THE LOWER NUBIAN PLAIN

The lowland sandstone surfaces to the east of Kurkur are part of a thirty- to fifty-kilometer wide pediplain[7] that fingers its way up the Nubian Nile valley from 100 km downstream

[7] The designation "pediplain" is here used only as a matter of convenience to describe a plain formed by coalescing pediments.

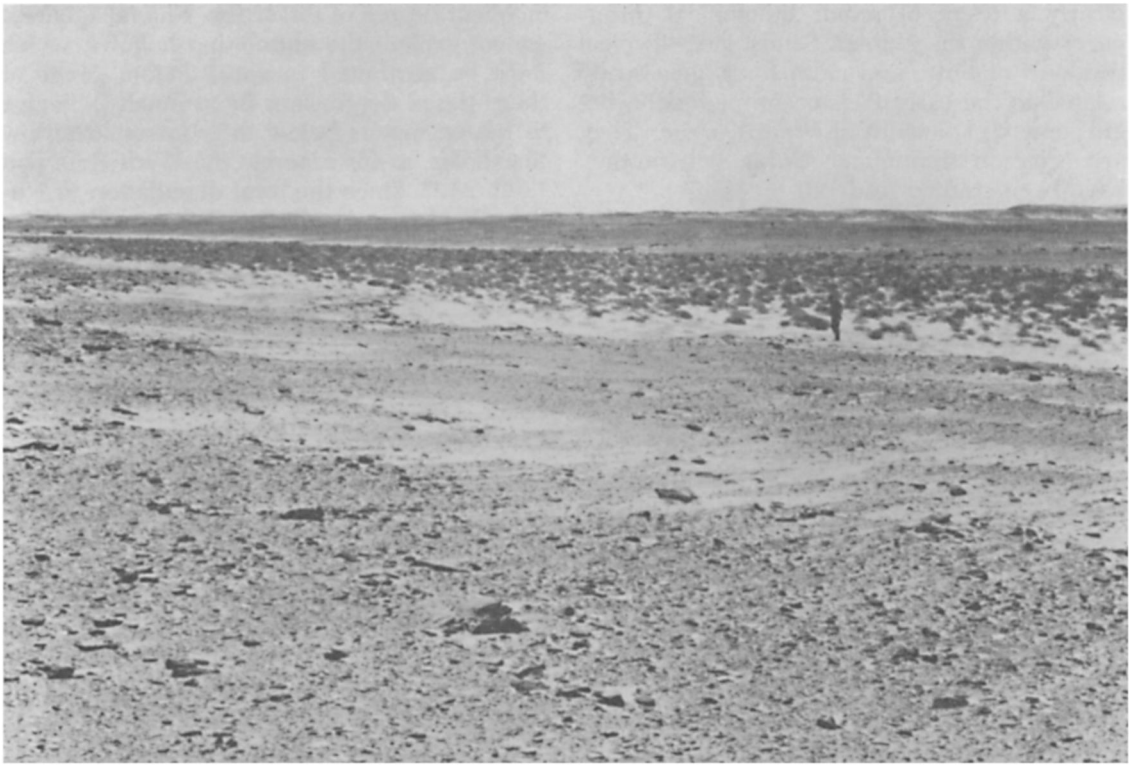

FIG. 3. Wadi Kurkur and the Lower Nubian Plain. Looking southeast about 14 km west of Nile. Low, irregular hillocks mark the horizon, while drifting sand accumulates among the shrub vegetation of the wadi bed. Detrital lag in foreground.

of Aswan to beyond the Sudan border. It was developed in relation to a fluvial base level approximately eighty to ninety meters above modern Nile floodplain, apparently in very early Pleistocene times.[8] The overall eastward dip of less than one percent is obscured by minor topographic irregularities of tectonic or erosional origin. This pediplain crosses both the Nubian Sandstone and the igneous and metamorphic Basement Complex without gross differences in terrain.

Between Kurkur and Aswan the Lower Nubian plain forms a bleak, undulating and almost featureless surface in 180–210 m. Local relief in five-kilometer squares varies from ten to thirty meters, and perhaps ninety-five percent of the slopes are smoother than one or two percent.

Reflecting both the climatic aridity and the lithology, drainage is poorly developed. Except along the dissected fringes of the Nile Valley, drainage lines consist of broad, shallow swales cut a few meters into bedrock or shallow, braided washes in areas of thin alluvium. Many shallow basins have interior drainage, some of these fed by higher order wadis descending from the scarp. Other extensive areas show no recognizable drainage lines at all. In fact Wadi Kurkur (Fig. 3) is the only wadi that crosses the Lower Nubian plain from the limestone scarp to the Nile within a longitudinal stretch of some 80 km.

The sandstone surface is locally studded with conical or elongate irregularities without distinctive forms and a relief of less than ten to fifteen meters. Most of these irregularities have been either formed or accentuated subsequent to the original pedimentation. Some show large-scale patterns and probably reflect minor *en échelon* block faults or extended fracture lines of limited displacement (Fig. 1). The more common dispersed hillocks and some of the concentrated irregularities are

[8] K. W. Butzer and C. L. Hansen, "On Pleistocene Evolution of the Nile Valley in Southern Egypt." *Canadian Geographer*, Vol. 9 (1965), pp. 74–83.

clearly a result of minor lithological differences within the Nubian Sandstone.[9] Typical residuals of butte and mesa form, genetically related to the early Pleistocene pediplain, begin some 10 km south of Wadi Kurkur. They are common throughout Nubia, where they have been studied in detail by Hansen.[10]

Alluvial or colluvial deposits floor the many shallow basins of the Lower Nubian Plain. These are mainly reddish yellow, silty coarse sands with subrounded blocky structure. Coarse sandy wash extends along the courses of the larger wadis. Eolian sand is restricted to veneers or small drifts in the lower elevation range of irregular terrain, or in the lee of desert shrubs studding some wadi beds. However, the most characteristic surface material is a lag of coarse sand and ferruginous sandstone rubble, resting on fresh or patinated bedrock. Only in rougher areas are low, free faces of bedrock exposed. These are usually patinated with ferromanganese precipitates[11] which, in Nubia, have not yet fully discolored prehistoric rock drawings dating from the third and second millenia B.C. This preservation of patinated free faces suggests that weathering and backwearing are virtually inactive today.

Seen in perspective, the Lower Nubian Plain owes its origin to fluvial processes working during a moister phase in the Lower Pleistocene. In conjunction with our Nile Valley work, it may be attributed to wide, coalescing pediment plains cutting their way backwards from the Nile.[12] As a result of prevailing aridity during the later Pleistocene, combined with minimal wadi gradients, subsequent activity by running water has led only to an incipient degree of dissection. Fluvial agencies cannot explain the undulating hollows, which must be attributed to wind action. Some of these closed depressions lie as much as twelve to fifteen meters below their lowest overflow thresholds, as for example the Wadi Rofa pan (Fig. 2).[13] Since the total denudation in Nubian Sandstone locally has been in the order of thirty to forty meters, a crude estimate of the relative importance of deflation is given. In short, eolian activity has remodeled a fluvial landscape in a superficial but conspicuous fashion.

THE KURKUR FORELAND

At distances of five to fifteen kilometers east of the cuesta rim, the Nubian Sandstone gives way to the Dakhla Shales and the topography changes gradually. Average slopes are still less than one percent but persistently dip eastwards. Local relief of five-kilometer squares is somewhat higher but more uniform with twenty-five to thirty-five meters. At the foot of the escarpment, cuesta outliers abruptly increase the local relief to over 100 m. Drainage lines, although shallow, are well developed in coherent dendritic patterns, presumably as a result of both the impermeable subsurface and concentrated drainage from the scarp. The undulating sandstone topography is replaced by a rough, hummocky surface formed by ruiniform masses of shale. The irregularities may have a relief of ten to fifteen meters and are a result of dissection and local slumping of the shales.

The jagged shale hummocks and ridges generally maintain angular shapes with extensive free faces. Instead of the conserving patinae of exposed sandstone bedrock, the shales appear fresh, and small talus aprons of splices and small slabs indicate that mechanical weathering is effective at the present time.

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[9] See A. Shata, "Remarks on the Geomorphology, Pedology and Ground Water Potentialities of the Southern Entrance to the New Valley. The Lower Nuba Area," *Bulletin*, Société de Géographie d'Egypte, Vol. 35 (1962), pp. 273–99.

[10] "Comparative Pediment Landforms in Nubia and the Red Sea Hills." Paper read at Annual Meetings, AAG, Columbus, Ohio, April, 1965.

[11] Ferromanganese rinds and surficial ferruginous cements are common on the Nubian Sandstone of Egypt, locally attaining considerable thicknesses in certain parts of Nubia where the sandstone is rich in primary iron. Little patination is developing under contemporary hyperarid conditions, but ferromanganese patinae appear to be actively forming with a subarid or semiarid climate on the southern margins of the Sahara today; see Tricart & Cailleux, *op. cit.*, footnote 2, Fasc. 1, pp. 79–82.

[12] Butzer and Hansen, *op. cit.*, footnote 8.

[13] Obviously the Wadi Rofa pan is also related to a minor N-S fault. The fact that Pleistocene sedimentation has been unable to fill this depression can be explained only by continued deflation. The preeminently eolian origin of the Libyan Desert oasis depressions has been outlined by M. Pfannenstiel, *Die Entstehung der ägyptischen Oasendepressionen, Abhandlungen,* Akademie der Wissenschaften und der Literatur (Mainz), Math.-Naturw. Kl., 1953, No. 7, although Pfannenstiel erroneously ascribes the Kurkur Oasis to deflation, basing himself on an early, obsolete topographic mission.

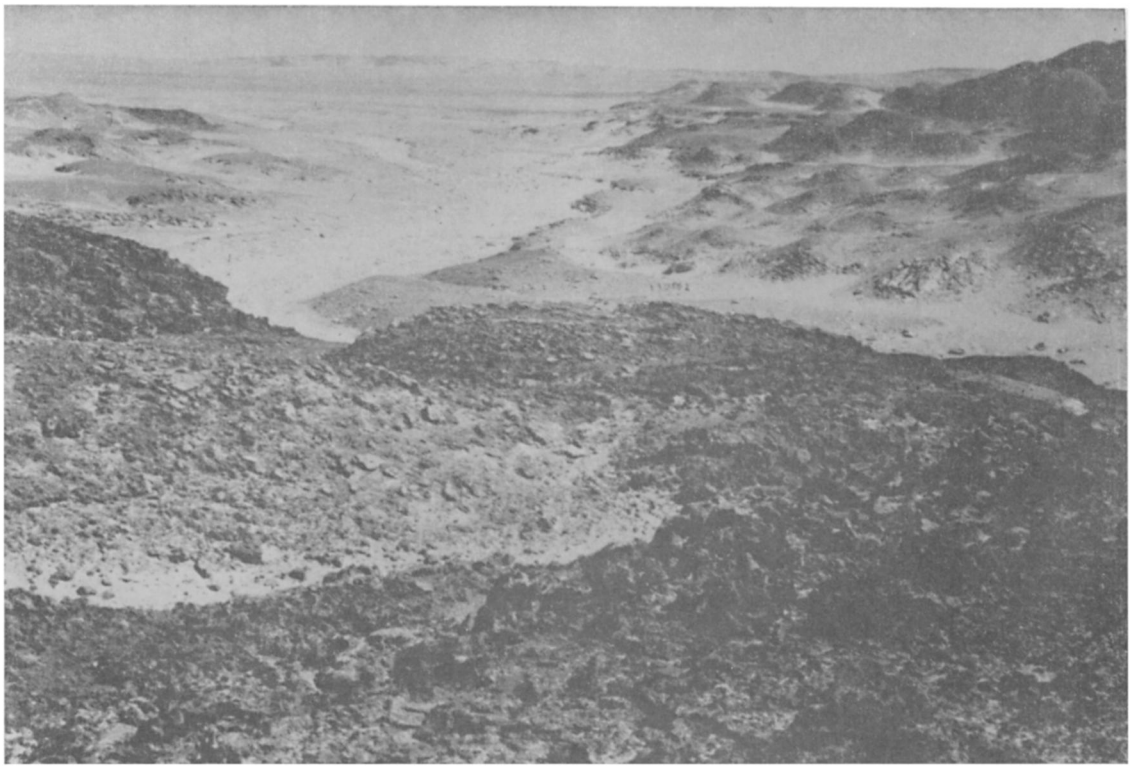

FIG. 4. Wadi Abu Gorma, looking eastwards from the cuesta rim. Plateau Tufa lag surface in foreground, irregular escarpment ridges in Chalk and Kurkurstufe in background. Slumped Chalk masses visible at right, center. Kurkurstufe outlier on horizon.

Gypsum and halite efflorescences, derived from within these sediments, suggest that physical hydration may be the primary agent. The products of mass-wasting are conspicuous in this bedrock area, a fact as unique as the subordinate role of wind in landscape sculpture.

Other surficial deposits include coarse sands with dispersed granule-size materials in the modern wadi beds, as well as older, well-rounded coarse to cobble conglomerates of limestone lithology derived from the scarp and the Libyan Tableland. These gravels rest on the shales, whether slumped or in place, and form shallow piedmont alluvial fans that overlap onto the older Lower Nubian Plain. These attain relative elevations of +16, +7, and +3 m above the wadi floor and can be traced to as much as 20 km east of the escarpment, where relative levels gradually fall off. Dissection followed each interval of alluviation, the oldest of which is Middle Pleistocene in age.[14]

[14] Butzer, *op. cit.*, footnote 1.

THE LIMESTONE CUESTA

The cuesta rim itself is formed by massive, indurated Plateau Tufas, Nummulitic Limestone, or the occasional massive Chalk strata (Figs. 4, 5, and 6). Weathering of these beds is primarily a result of undermining of the poorly consolidated Chalk, with cliff collapse and slow disintegration of the blocks and debris on the slopes. The Chalk weathers through granular disintegration as a result of salt weathering, and produces little or no talus. Slumping is apparent on some oversteepened slopes. In general the smooth, steep limestone faces maintain minimum angles of twenty-five to fifty percent. At the base of the Chalk, the tough siliceous limestone of the Kurkurstufe forms a minor step or low outliers in the foreland (Figs. 7 and 8). Structural instability of the shales at the foot of the scarp has induced sliding and sagging of the overlying strata. As a result, local bedrock along the cuesta peripheries dips eastwards at one to three per-

FIG. 5. The Chalk Cuesta, looking westwards in upper Wadi Abu Gorma (False Wadi). Talus is largely absent, except around the Plateau Tufa cap in center background.

cent, in contrast to the overall westward dip.

The local relief of the Chalk escarpment averages 100–150 m at Kurkur, increasing to a maximum of 300 m to the north at Gebel Gharra, where the Chalk and Nummulitic cuestas converge (Fig. 2). The wadis have cut fifty- to seventy-meter deep, steep-sided valleys into bedrock. Average longitudinal bed gradients attain two to three percent on alluvial reaches, but abrupt steps mark the bedrock contacts. Incision into the shales seems to have been quite rapid since even the Chalk

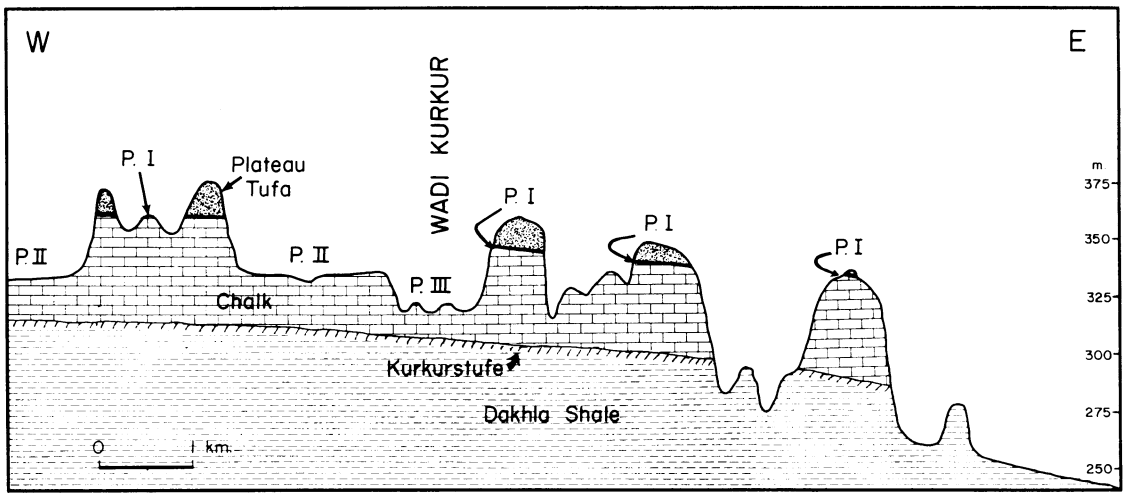

FIG. 6. Bedrock and gradational features of the Kurkur Oasis.

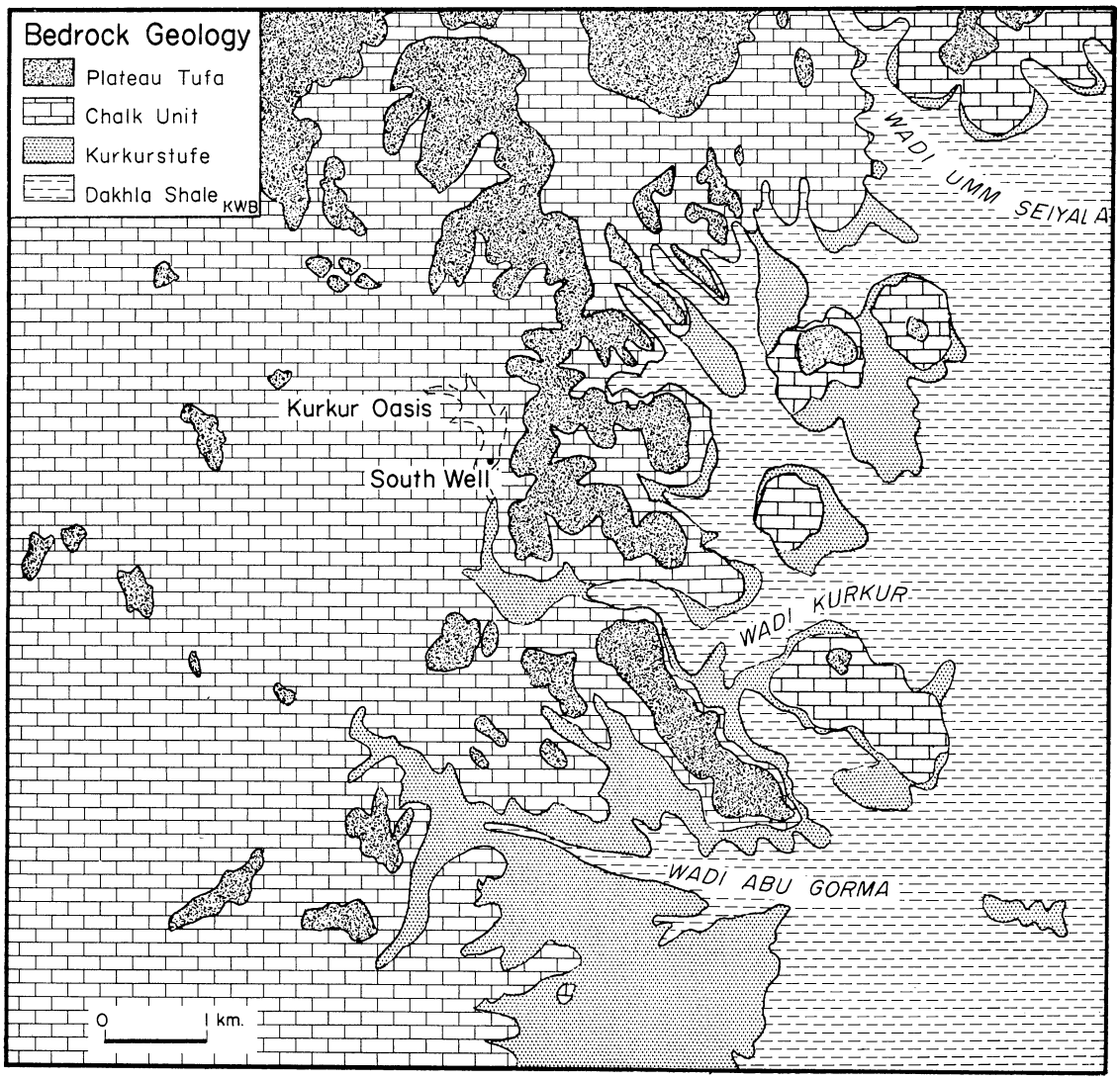

FIG. 7. Bedrock geology of the Kurkur Oasis. Mapped by Butzer and Hansen, 1963.

seems to wear back by weathering or undermining rather than direct stream abrasion. Where not undercut or steepened by dissection, shale slopes average somewhat less than five percent. All in all, the scarp exhibits what may be called a "youthful" fluvial topography.

The basically dendritic drainage pattern is often subparallel near the cuesta (Fig. 9), with many second to fourth order wadis oriented at right angles to the escarpment. Occasional rectangular intersections at the cuesta and on the dip slope may also reflect the NW and NE jointing systems in the limestone. Texture is finest in this region of maximal dissection, but the average drainage density is only 2.3.[15] This rather coarse texture is not apparent in the field, probably as a result of the rough and angular scenery.

[15] The topographic maps at 1:100,000, with a 30 m contour interval, improved and corrected in the field, are not ideal for any systematic quantitative analysis. However, bifurcation ratios determined for 1st through 4th order streams follow the normal progression, suggesting that the drainage density analysis is fairly accurate. Running water is absent in the area today, so that the drainage density computation was made on the basis of topography and contour crenulations; see K. G. Smith, "Standards for Grading Texture of Erosional Topography," *American Journal of Science*, Vol.

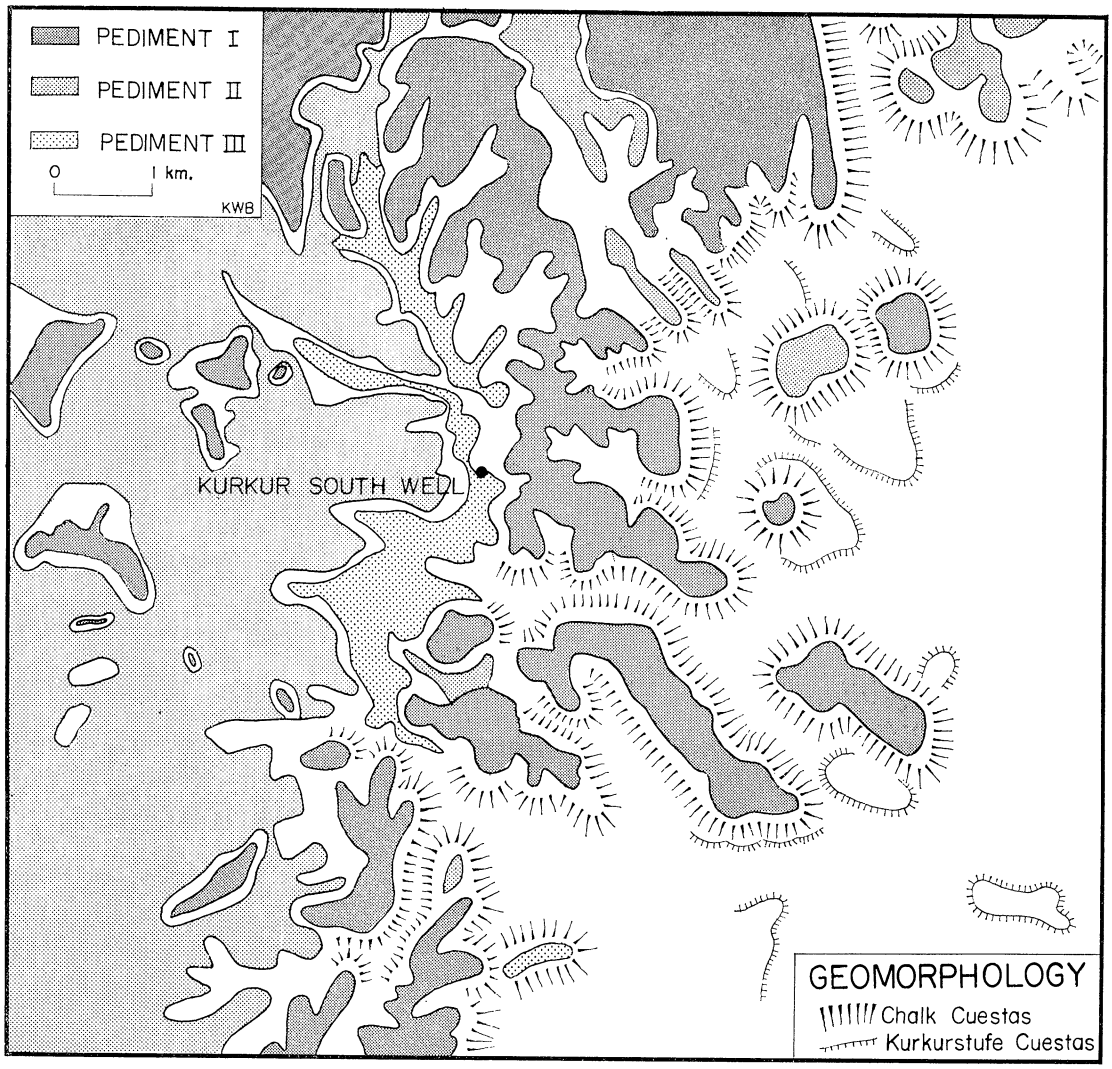

FIG. 8. Geomorphology of the Kurkur Oasis. Mapped by Butzer and Hansen, 1963.

Surficial deposits consist of lag, talus, and alluvium. The lag constitutes a coarse, slate-like detritus, patinated a light bluish gray in the case of the Chalk, brownish gray in the case of the Plateau Tufa. Talus is most evident where massive tufas or limestones have been undermined. Although blocks of talus do occur on the cliff bases or on mid-slope segments, well-developed talus aprons and cones are very rare. Most of the talus debris is discolored on all faces by weathering. This, together with the limited amount of scree overlying Upper Pleistocene alluvial beds, suggests that slope retreat is very slow. The fine, granular products of Chalk disintegration are removed by washing and deflation. In general the limestone slopes are fairly clean and strikingly well defined (Fig. 10) in contrast to the ragged, talus-laden shale slopes. A veneer of water-laid scree, commonly fifty meters or more wide, mantles the foot slopes and forms a transitional facies between the slope talus and the immobile lag of the smooth surfaces.

Alluvial deposits of coarse sands are limited to the wadi floors. Ancient alluvia are inter-

63 (1952), pp. 655–68. Since the flat plains are essentially featureless, and normal criteria can hardly be applied to pediment rills or anastomose sandy washes, drainage density cannot be computed meaningfully for other geomorphic units or the Kurkur area.

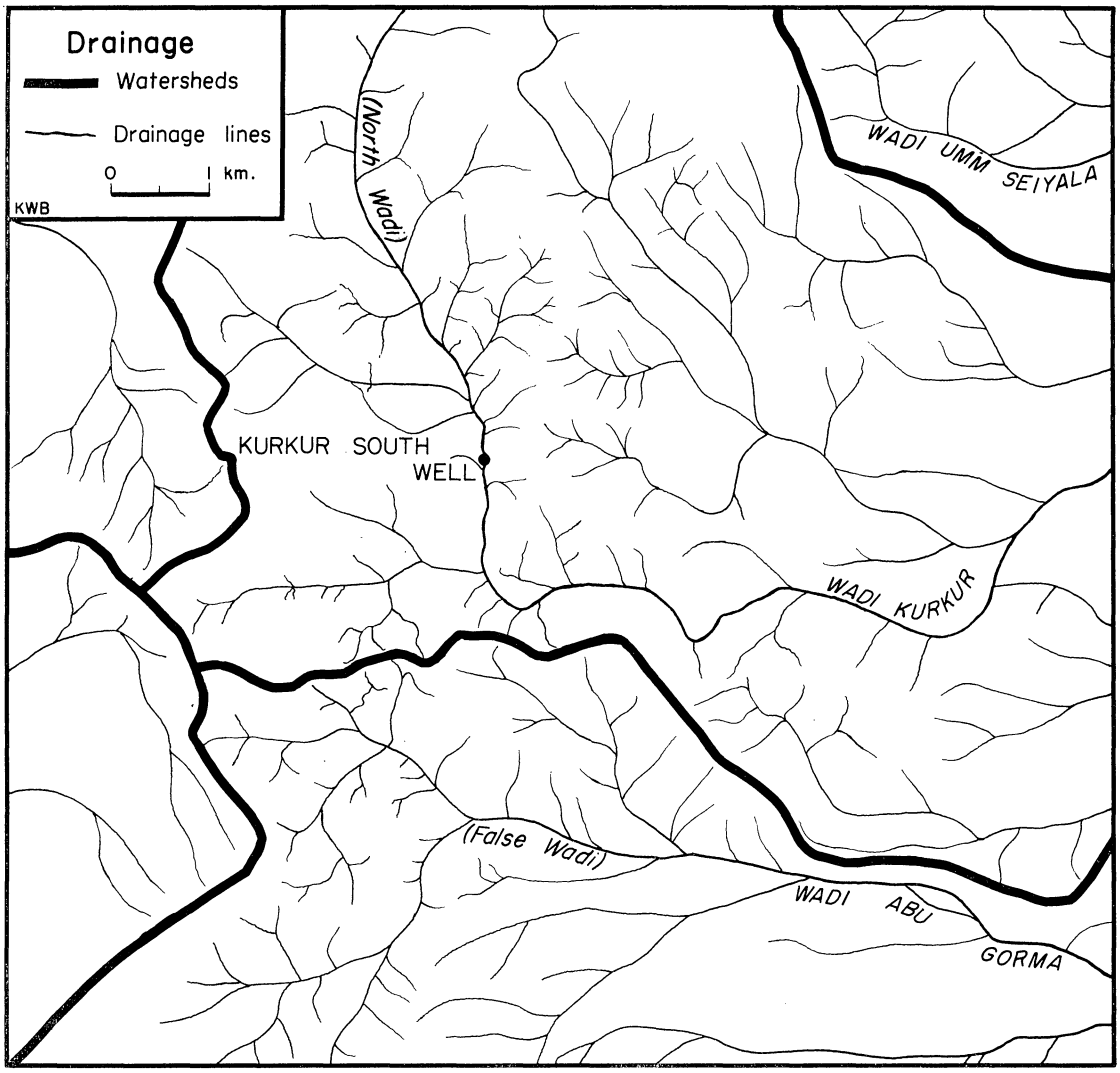

FIG. 9. Drainage lines of the Kurkur Oasis. Modified from the Survey of Egypt map at 1:100,000.

rupted in the wadi gorges of the scarp but are well developed in the shallower wadis upstream, in the area of the Kurkur pediments and the oasis proper.

In the low relief areas of the sandstone plain and the shale foreland, it has not been meaningful to speak of slope forms. In the cuesta wadis such features are striking (Figs. 5, 10). The crest slopes, independent of lithology, are angular, while mid-slopes are rectilinear, maintaining fairly constant angles in homogeneous bedrock, regardless of degree of dissection. Foot slopes are also angular, but less characteristic since they often coincide with abrupt changes in lithology.

The evolution of the limestone escarpment can be interpreted on the basis of the erosional topography as well as the six alluvial terraces of Middle to Upper Pleistocene age found in the uppermost wadis.[16] Bedrock dissection by running water appears to have taken place during moister periods of the early Pleistocene. Fluvial erosion went hand in hand with slope retreat through weathering, washing, deflation, undermining, and mass movement. Major slump blocks of Chalk in Wadi Abu Gorma were cemented by horizontal spring deposits pertaining to the +16 to 20 m Tufa

[16] Butzer, *op. cit.*, footnote 1.

FIG. 10. Rectilinear slopes with angular foot and crest slopes developed in Chalk (whitish) and Plateau Tufa (dark gray). Note limited talus development with localized rock slide at left. Looking northwestwards into upper Wadi Kurkur (North Wadi).

Terrace II, of Middle Pleistocene age. This particular example shows that backweathering of the wadi walls has been minimal during the later Pleistocene. No useful estimates can be made on the rate of scarp retreat during any part of the Pleistocene.

THE KURKUR PEDIMENTS

At Kurkur Oasis the Nummulitic Limestone has been largely eroded by two well-developed pediments cut into the Chalk at 360–365 m and at 340 m (Figs. 8 and 11). These pediments are older than the Plateau Tufa, erosional remnants of which rest on both surfaces and their residuals. Both pediments may have counterparts elsewhere in Lower Nubia and at the Kharga Oasis. This may suggest development prior to the excavation of the Nile Valley in late Miocene or early Pliocene times. An incipient lower pediment level at 320–325 m is considerably younger, probably early Pleistocene in age.

The morphology of these exhumed pediments and their numerous residual hills is analogous to that studied by Carl Hansen in the sandstone of Nubia.[17] The pediments are almost horizontal, dipping by less than one percent to the west.[18] A certain amount of convergence with massive Chalk banks was noted. The flat-topped residuals rise from the pediment plain with steep rectilinear slopes, sharp, angular knickpoints and crest slopes, and moderate talus development. The gentle concave rise of the pediment to the foot of residuals is barely measurable. This all gives the area a bimodal slope distribution (Fig. 8), with gentle slopes, mainly under one percent, and steep slopes, well over twenty-five percent. Intermediate slopes account for less than two percent of the surface. Local relief is in the order of 50 m.

Few if any distinct drainage lines, pertaining to the original pediments, are preserved. Instead, the cuesta wadis have cut their way

[17] Butzer, *op. cit.*, footnote 1.

[18] Since these pediments are almost certainly Tertiary in age, the present slight but consistent westward dip may not have pertained at the time of their development. Today internal drainage characterizes all but the eastern fringe of the Kurkur pediments.

FIG. 11. Exhumed pediment in 340 m with remnants of 360–365 m pediment, capped by Plateau Tufa, in background and on horizon. Looking southwestwards across North Wadi, 2 km north of South Well. Corroded, patinated Plateau Tufa in foreground.

back into the pediments, often terminating abruptly as V-shaped gashes in the landscape. The westward-trending drainage lines (see Fig. 9), on the other hand, are more shallow and seldom incised more than 5 m below the general level of the 340 m pediment. They maintain convex slope forms in cross section. Texture west of the watershed is ultra-coarse, with a partial analysis suggesting a drainage density as low as 1.5.

Surficial deposits include talus, scree, lag, and modern wadi wash comparable in development and type to those of the cuesta. Of particular interest, however, are moderately sorted, rounded limestone gravels, and intercalated spring tufas of Pleistocene age.[19] The gravel tends to be flattened, implying a dominance of sliding rather than rolling motions in stream transport.[20] Terrestrial and freshwater snails, as well as *Ficus* leaf impressions and abundant organic tufas corroborate the physical evidence for more abundant rainfall during Pleistocene pluvial periods.

An appreciable amount of eolian sand has accumulated around the Kurkur wells, choking the local wadi. Factors favoring accumulation include a depression oriented in the direction of the prevailing wind (north by west) and the presence of vegetation to retain and stabilize the drifting sands. Dune forms are parabolic, reflecting deflation rather than primary accumulation of this sand. The material consists of coarse-grained, foreign quartz. Similar sands, at least partly derived from older eolian beds, occur within Pleistocene gravels and tufas.

THE LIBYAN TABLELAND

The Libyan Tableland, the final geomorphic unit of the Kurkur area, resembles the Lower Nubian Plain in relief and slope characteristics. But there are significant differences in form and origin. These upland plains of the Libyan Desert in 400 to 500 m have been de-

[19] Butzer, *op. cit.*, footnote 1.

[20] See Butzer, *op. cit.*, footnote 2, pp. 160–64.

scribed by Leuchs and Uhden,[21] and little can be added to the discussion here.

Over the hammada that stretches almost 200 km west of Kurkur, there is an almost total lack of coherent drainage patterns. A flat but gently undulating, wind-swept lag surface stretches as far as the eye can see, although the amplitude of these smooth ridges and closed depressions may restrict vision considerably. The exposed Nummulitic bedrock of the rolling swells is badly fretted, often polished and generally patinated a light grayish brown. The micro-scour often develops into irregular or geometric grooving suggesting ancient chemical weathering, partly along jointlines, rather than modern wind scour. In fact, true micro-karstic forms are developed in some of the younger, less consolidated Pleistocene tufas. Similarly, solution is at least partly responsible for some of the shallow swales of the hammada: these may be conspicuously corroded under a shallow colluvial fill, and at Kurkur are sometimes related to deep fissures extending to the plateau edge, where they may once have functioned as spring feeders. Away from the plateau edges the only relief is provided by low smooth residual mounds of conical or elongate shape, often masked by sand accumulations in the lee.

Apart from the ubiquitous lag, the only surficial depost of interest is the colluvial or alluvial wash that lines the floors of the wind-carved swales, often under a younger veneer of eolian sand. These reddish yellow, medium to coarse-grained sandy (quartz and calcite) silts commonly show a subrounded blocky structure and moderate stratification. Terrestrial snails may be common. Depths range from twenty to forty centimeters, often underlying coarse lag that is not found within the deposit and must be a product of sheetflood activity. The colluvial wash itself is derived from eroded soils of terra rossa type,[22] with an admixture of quartz sand ultimately of eolian origin. Similar colluviation was last contemporary with the aggradation of the Upper Pleistocene tufa terraces at Kurkur, whereas significant soil development is even older.[23]

It would seem then that solution, physical hydration, and other weathering processes prepare the surface for deflation, with local runoff on rare occasions limited to colluvial deposition in the hollows. Eolian activity, although slow, may in fact attain far greater significance here than any other gradational agent. Periods of more significant chemical weathering and colluviation have alternated with phases of eolian denudation in the wake of Pleistocene climatic changes. Such cyclical alternations, as clearly recorded in the sedimentary record at Kurkur, may well provide optimum denudation rates under these restricted circumstances.

In overview, the Libyan Tableland is a hammada of structural origin. Eolian forces, particularly deflation, are responsible for much or most of the surface sculpture. But the results of cyclical changes of climate, leading to soil development and solution during more humid paleoclimates, must be emphasized as a possible prerequisite to effective denudation by occasional sheetflooding and perennial deflation.

RETROSPECT AND CONCLUSIONS

In a general way the landforms of the Kurkur area can be primarily attributed to the activity of running water during the late Tertiary and early Pleistocene, with subsequent remodeling by wind. Many of the landforms are, in effect, paleoforms. The origin of the Lower Nubian Plain, the dissection and, in part, the retreat of the Chalk and Nummulitic cuestas, and finally the Kurkur pediments cannot be explained by contemporary processes. This dichotomy of past fluvial and modern eolian activity does not distract from the Kurkur area presenting a type case of "desert" landforms. The Pleistocene record at the Kurkur Oasis and in the adjacent Nile Valley[24] leaves no doubt that southern Egypt has enjoyed arid conditions of variable intensity throughout the Pleistocene. The pluvials may have been "subarid" or "semiarid," compared

[21] K. Leuchs, "Eine Reise in der südlichen Libyschen Wüste: Gebel Garra, Oase Kurkur, Gebel Borga," *Petermann's Mitteilungen*, Vol. 59 (1913), pp. 190–91; R. Uhden, "Reise von Debod in Unternubien nach den Oasen von Kurkur und Dungul." *Ibid.*, Vol. 76 (1930), pp. 184–88.

[22] Butzer, *op. cit.*, footnote 1. Similar "pan-silts" have been described by E. W. Gardner from the Libyan Tableland at Kharga, *in* G. Caton-Thompson, *The Kharga Oasis in Prehistory* (London: Athlone Press, 1952), pp. 4, 128–32, and are considered a typical hammada phenomenon by Tricart & Cailleux, *op. cit.*, footnote 2, pp. 15–16.

[23] Butzer, *op. cit.*, footnote 1.

[24] Butzer & Hansen, *op. cit.*, footnote 8.

with an "arid" or "hyperarid" climate today. In short, the climatic variations of the Pleistocene have been changes of degree rather than kind.

The individual features described from the different physiographic units vary considerably according to lithology and topographic location. But there are many similarities as well, and many of the differences are but lithologically or relief-conditioned facies of one and the same phenomenon. The contemporary activity of wind may be taken as examples. Kurkur, unlike other oases of the Libyan Desert, is not a wind-excavated hollow. But eolian activity is everywhere apparent from small features such as lag winnowing, bedrock fretting, and sand accumulation to large-scale deflation of extensive but shallow depressions. Direct sand blast or polish of bedrock surfaces is rare, and deflation[25] almost inevitably proceeds via the intermediate agency of weathering. But the net effects are impressive and fundamental in all but the shale zone (as a result of unfavorable lithology) and the cuesta (as a result of locally concentrated fluvial activity).

What else can then be generalized about the terrain? Many of the large-scale features described, in particular the pediments, pediplains, and piedmont alluvial fans, are widely considered characteristic of arid or semiarid environments. But the distinction of arid and humid landforms is more fundamental. Some of the differences are a result of concurrent or subsequent remodeling by wind. Often they appear to reflect the hydrographic regime and the distinctive processes of fluvial sculpture; however, the almost complete absence of a soil mantle may be the single most significant geomorphic phenomenon. Quantitative expression of the desert landforms at Kurkur is largely precluded by the nature of the fieldwork and the inavailability of air photos or adequate maps. But even so, it appears possible to characterize the surface features qualitatively and, to some degree, by semiquantitative parameters:

1) Areas of remarkably smooth slopes and limited relief are dominant.
2) Limited stream dissection and, to some extent, disorganized drainage are associated with such desert plains.
3) Even where dissection is appreciable in virtue of topographic location, texture is very coarse.
4) Steep, rectilinear slopes characterize any areas of accentuated relief, and midslopes are commonly offset from higher and lower-lying gentle slopes by sharp breaks in gradient.
5) In all stages of dissection there is a persistence of fairly constant slope angles.
6) Throughout the area a bimodal distribution of generalized slope classes in "gentle" and "steep" categories is evident, with very limited intermediate surfaces of five to twenty-five percent slope.
7) Differential weathering and erosion are conspicuous.
8) The concept of a soil mantle is replaced by that of a lag veneer.
9) Lag, talus, and water-transported scree are rather widespread, even in zones of limited relief and constitute a peculiar surficial material. Nowhere do they attain any appreciable depth, however.
10) Alluvial and colluvial materials, although seldom thick and rarely activated, are nevertheless remarkably extensive.

In conclusion there seem to be distinctive arid zone landforms, some or many of which are exemplified in the Kurkur area, and which differ from those generally found in humid environments. These are evidently differences of degree rather than kind, probably conditioned primarily by the absence of a soil mantle and a vegetative cover. Systematic study of landform differences between arid and humid environments appears to be both possible and desirable, preferably making use of more and better quantitative techniques. Then it may be possible to arrive at more general conclusions concerning objective contrasts between landforms of different morphoclimatic environments.

[25] Lag, hammada surfaces, and sand dunes are sufficiently appreciated in the literature. The role of wind in bedrock denudation may require a little reemphasis. The term *blow-out* is loosely used for deflation phenomena in anything from loose sand to consolidated rock. It may be appropriate, therefore, to substitute a more specific designation for closed bedrock depressions resulting in major part from deflation. Possibly the French Saharan term *daya* could be introduced for the purpose; see Tricart & Cailleux, *op. cit.*, footnote 2, pp. 17–18.