ALLUVIAL TERRACES OF THE LOWER VAAL RIVER, SOUTH AFRICA: A REAPPRAISAL AND REINVESTIGATION[1]

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ABSTRACT

The alluvial terraces of the Lower Vaal River, South Africa, are well known for their unique stratigraphic record of the Pleistocene period and as the focus of an apparent Acheulian sequence. Recent field examination indicates that this terrace suite is both more complex and more systematic than previously understood, extending downstream from the classical study area at Windsorton and Barkly West to the Orange-Vaal confluence. An expanded stratigraphic framework for the late Pliocene to early Pleistocene Older Gravels is described, while major subdivisions for the Younger Gravels (with Middle Pleistocene fauna and Acheulian occurrences) are proposed. A new late Pleistocene to Holocene lithostratigraphic entity, the Riverton Formation (with five members), is defined. Finally, problems of paleoenvironmental interpretation are discussed.

INTRODUCTION

In the 1940s southern Africa seemed to offer one of the best-known Pleistocene environmental and cultural successions of the continent. However, in the last three decades conceptual developments and discoveries elsewhere have placed the South African record in a backwater position. The early and mid-Pleistocene time range is now relatively poorly understood from either the stratigraphic/environmental point of view (see, e.g., Flint 1959; Cooke 1967) or the archeological one (see Cole 1961; Mason 1962, 1967). The study of this period in South Africa does not compare well with current information on the Rift Valley in East Africa, where the discoveries at Olduvai, along the eastern shores of Lake Rudolf, and in the lower Omo Basin have proved so rewarding. The South African australopithecine deposits and faunas stand in stratigraphic isolation, with the regional implications of their paleoenvironmental inferences controversial (see Butzer 1971*b;* 1971*c,* p. 427–432; 1973*d*). With the exception of Amanzi Springs (Deacon 1970; Butzer 1973*a*), no excavations of Acheulian sites south of the Zambezi have been fully reported. The earlier work in southern Africa was, for its time, excellent yet intensive reinvestigation of nearly all the early and mid-Pleistocene deposits seems to be needed.

One of the foremost study areas of early and mid-Pleistocene environments and cultures in South Africa has been the lower Vaal River Basin. Here the Vaal and its tributaries have created complex terrace forms that provide an intermittent alluvial history spanning all of the Pleistocene. Since the Interior Plateau of southern Africa has been subject to extensive erosion through most of the Cenozoic, the "Vaal Gravels" comprise one of the few moderately large areas of Pleistocene deposition. In addition, the Vaal Gravels contain mammalian fossils and Acheulian artifacts in several of the younger alluvial units.

The Vaal River gravels were "discovered" in the early 1870s by diamond-diggers, whose relentless search for alluvial diamonds over the succeeding 100 years pitted most of the occurrences of the Vaal Gravels into a cratered landscape. Such gravels can be readily traced at intervals from the Vaal-Orange confluence upstream for 280 km to Windsorton, beyond which

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exposures become few and sporadic. The most productive gravels, between Barkly West and Windsorton, yielded fossils and artifacts in sufficient quantity to attract the attention of Du Toit (1907, 1907–1908) at the turn of the century, leading to closer scientific investigation since the mid-1930s. This work is primarily associated with Söhnge et al. (1937), Cooke (1947, 1949), Breuil et al. (1948), and Van Riet Lowe (1952). Huzayyin (1941) drew attention to the importance of the Vaal Gravels, and Zeuner (1958 [1945], 1959 [1946]) successfully introduced the Vaal sequence into the secondary literature of the northern hemisphere. After this first impetus for study passed, reservations, modifications, and even negative evaluations began to appear for the established terrace sequence (Maarleveld 1960; Partridge and Brink 1967), the paleoclimatic interpretation (Flint 1959; Cooke 1967; Bond 1967; Partridge and Brink 1967; Butzer 1971*a*, 1973*d*), and the archeological record itself (Cole 1961; Mason 1962, 1967).

As a result of these much-needed, primarily negative, reassessments, the Vaal sequence is now widely regarded with equivocation. Meanwhile, ongoing geochronological, paleoenvironmental, and archeological work elsewhere in eastern and southern Africa continues to emphasize the potential importance of the Vaal Gravels for elucidating both environmental history and prehistoric subsistence patterns during the early and mid-Pleistocene time range.

Following brief reconnaissance in 1969 and 1970, a reinvestigation was begun by Butzer in 1971 with further detailed studies (D.M.H.) currently underway. The purpose of this paper is to review critically the available evidence, both from the older literature and particularly as gained in the field since 1969. Whereas our interpretation of the older erosional forms and depositional features remains to be completed, study of the late Pleistocene and Holocene sequence now allows the definition of a new lithostratigraphic entity. The results presented here are based on sedimentological analysis of over 75 samples, involving hydrometer and wet-sieve determinations, Chittick calcium carbonate readings, preliminary quartz-grain micromorphology, pH values, and further, selective chemical tests.

GENERAL GEOMORPHOLOGY OF THE VAAL BASIN

The Vaal River rises on the High Veld Plateau of the southeastern Transvaal and eastern Orange Free State, an area of undulating plains at 1,400–1,800-m elevation and formed primarily by shales and sandstones of the Karroo System. Along the subsequent section of its 1,350-km course to join the Orange River at 957-m elevation near Douglas, the Vaal generally cuts below Karroo shales, tillites, and diabase intrusions ("dolerite") into Precambrian quartzites, dolomites, andesitic lavas ("diabase"), and granite. Beyond the grain of the complex Precambrian structures of the Vaal's superimposed course between Vereeniging and the Vredefort Dome, the valley broadens out onto the lower planation surface of the Middle Veld, an irregular plain studded by hills and mountains of resistant igneous rocks.

The beveled nature of the Veld surfaces, gently cutting across the strata of the Karroo System, was first emphasized by Davis (1906), who interpreted it as a peneplained landscape studded with monadnocks. Dixey (1938) went further and interpreted the High Veld "peneplain" as part of a mid-Tertiary erosional surface claimed to be almost ubiquitous for the African continent. King (1963, p. 226–229; 1968, p. 271–274), on the other hand, considers the High Veld to be part of an "extreme" planation surface, resulting from pedimentation processes whereby subhorizontal plains are cut when extremely broad, coalescent pediments remove upland interfluves. Like Dixey, King (1968, chap. 9) postulates a sequence of universal erosional cycles that deserve consideration in discussing the evolution of the Vaal Valley:

1. "Gondwana" Planation Surface, cut during the Late Triassic and Jurassic across the Stormberg basalts (Karroo System) and now forming residuals along the crests of the Vaal watershed.

2. "Post-Gondwana" dissection, with cutting of incipient surfaces in valley heads below the "Gondwana" Surface. These Early Cretaceous readjustments adjacent to the upwarped Drakensberg were followed by further tectonic disturbances along the Great Escarpment.

3. "African" Landsurface, cut across the High Veld during the time span of the Late Cretaceous to mid-Cenozoic.

4. Two cycles of pediplanation, in response to repeated epeirogenic uplift in Miocene and again in Pliocene times, cutting the broad valley-side and tributary pediments of the Lower Vaal Middle Veld.

5. The Pleistocene stage was set by reelevation of the Great Escarpment while the old interior watersheds were possibly uparched. Deep dissection and headward cutting of the coastal rivers into the escarpment has continued into the present, without significantly affecting the exceptionally low gradients of the river courses (e.g., 6.5:10,000 in the case of the Vaal) of the interior plateaus.

The High Veld surface has been tentatively approximated in figure 1 by attempting to reconcile the 1:250,000 topographic maps with King's small-scale outline map (King 1968, fig. 119). Elevation of this surface rises gradually from 1,200 m in the Kimberley region to nearly 2,000 m at the watershed of the Great Escarpment. In general, the High Veld constitutes an impressive planation surface. Nonetheless, it is disturbing that some sectors, such as the Gaap Plateau on Precambrian dolomites,

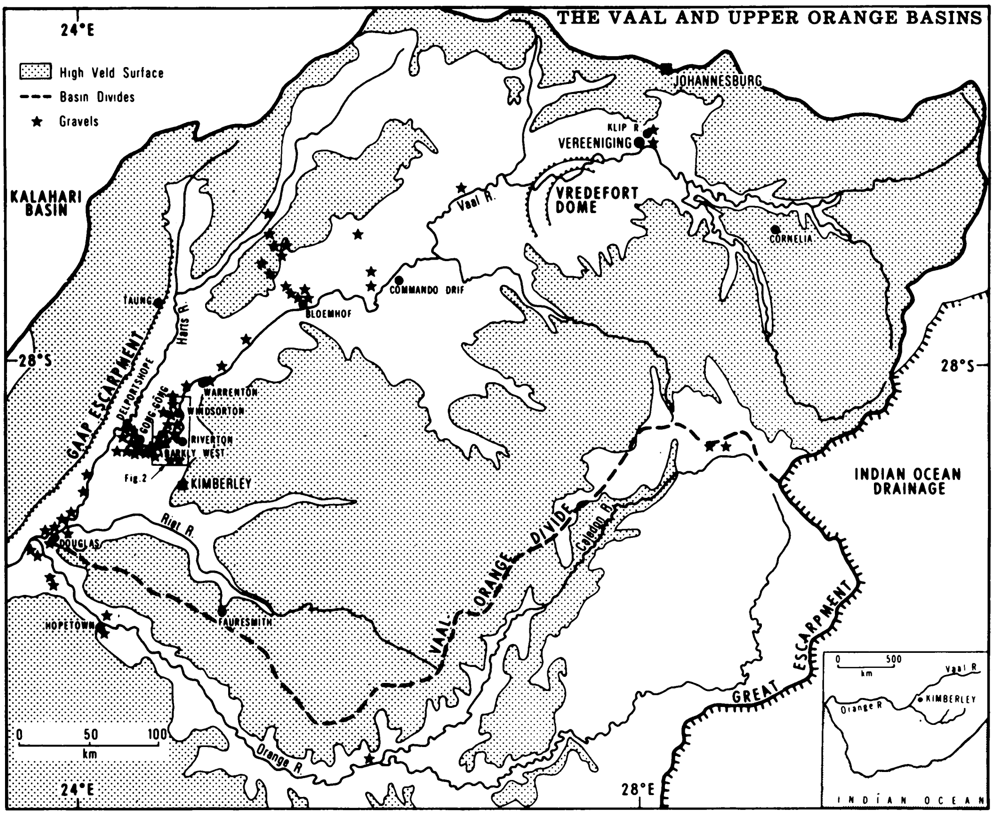

FIG. 1.—The Vaal and upper Orange Drainage, with High Veld planation surface and gravel occurrences. In part modified after DuToit (1907), Söhnge et al. (1937), Cooke (1947), and King (1968).

are developed on highly resistant rocks and represent exhumed pre-Karroo surfaces (see Wellington 1937). Whether this High Veld surface is everywhere contemporaneous and attributable to a single set of geomorphological forces in the Vaal drainage is, therefore, uncertain. Even more debatable is whether it can be correlated beyond the Orange-Vaal watersheds with other, apparently convergent, surfaces, and so established as a morpho-stratigraphic marker for all of Africa. Any such universal surface could only be cut with reference to a single base level, the ocean surface. At this point of the erosional "cycle," pediplanation becomes distinguishable from peneplanation only in terms of processual details and, as Wellington (1955, p. 32–34) has pointed out, it is difficult to conceive of the High Veld peneplain (or pediplain) stretching across the continent from the Atlantic to the Indian Ocean. Instead, it is far more reasonable to postulate a continuous post-Triassic erosional hemicycle, initially rather rapid as the softer Karroo rocks were reduced (Wellington 1955, p. 33). Eventually, the resistant Precambrian units were exposed in the lower Orange valley below the Orange-Vaal confluence. At this point in the erosional history, several stages of partial planation may have occurred, reflecting both the history of cutting through rock barriers downstream and possible, repeated uparching of the Orange-Vaal watersheds. Variable surface gradients of the upland plains, as well as breaks of longitudinal gradient in the Orange and Vaal river systems, can all be adequately explained in this fashion.

In other words, the identification of the High Veld with the postulated "African land surface" of Dixey or King, either in terms of age or functional origin, is far from an established fact. Similarly, the universal dicyclic nature of Late Tertiary erosion remains to be demonstrated. The immediate relevance of this is that the several erosional surface of the Vaal Basin have not been "dated" and their origins can be determined only by detailed field study. Furthermore, the true extent and differentiation of these surfaces is a delicate matter, and will require careful mapping. This is particularly so in the Kimberley region, where the delimitation of the lower margins of the High Veld surface is difficult, and where it is uncertain whether one or more younger surfaces can indeed be recognized. Finally, it remains to be considered whether several extensive erosional surfaces in the watersheds of the lower Vaal and Harts are not after all lateral pediments penecontemporaneous with the highest gravels in these areas.

DISTRIBUTION OF GRAVELS IN THE VAAL BASIN

Compared with the better-known terrace sequences of higher latitudes, the Vaal gravels are thin, of limited areal development, and of small vertical differentiation in relation to a shallow and unimpressive valley.

The uppermost 400 km of the river are weakly incised into the High Veld Karroo rocks. These shales and sandstones provide no durable gravels, and there are no mid-Pleistocene or older stream terraces. The oldest deposits consist of valley-bottom clays fragmentarily preserved under late Pleistocene silt terraces. Included in such erodible strata is the faunal site of Cornelia (Butzer 1973*c*), with its Middle Pleistocene mammalian assemblage (Cooke 1973).

The 100-km stretch of river near Vereeniging traverses Precambrian rocks, and gravel deposits to +30 m are indicated, primarily by well and foundation drillings (A. B. A. Brink, personal communication, 1969; Mason 1962, p. 35–39, 117), and normally found under a complex mantle of late Pleistocene alluvial silts. Some of these older gravels, consisting mainly of quartzite and chert from the Precambrian basement, appear possibly to be reworked in the younger alluvial terraces well exposed by quarries along several north-bank tributaries. These include important mid-Acheulian assemblages excavated from +10 m gravels of the Klip River (Mason 1962, p.

40–42). No gravels at all are exposed along the subsequent erosional stretch of the river 300 km downstream to Commando Drif. Consequently, the first 900 km of the river offer few possibilities of establishing a terrace sequence and the Vereeniging gravels will remain difficult to relate to terraces of the Lower Vaal.

Between Commando Drif and a little upstream of Windsorton, a stretch of 175 km, gravels are sporadically preserved at +15–50 m above a shallow, low-gradient Vaal, along eroded, sloping spurs mantled by sandy wash of eolian origin or partly obscured by late Pleistocene silt terraces. Near Bloemhof these silts mantle crude colluvial detritus in which Mason (1969; see also Cooke 1949) excavated a late Acheulian occupation site and several as yet unpublished faunal sites. Older deposits are absent along the south-bank tributaries of this stretch, probably because of the eolian cover mantle and well-developed late Pleistocene to Holocene silt terraces. To the north, however, there are a number of tributary gravels (see Söhnge et al. 1937, p. 36–38; Cooke 1947), that merit further study.

Optimal terrace development is found between Waterval/Windsorton and the Harts River confluence at Delportshope, a 130-km stretch marked by alternating steep and gentle longitudinal gradients, where there are multiple and systematic terrace levels, with Vaal as well as tributary facies to a maximum relative elevation of almost +100 m. This is the area of the classic studies of Söhnge et al. (1937) and Cooke (1947, 1949).

Finally, the remaining 155 km from the Harts to the Orange confluence has sporadic, but nonetheless significant, gravel exposures recognized in principle by Du Toit (1907, 1907–1908) but ignored or forgotten by later authors.

"OLDER GRAVELS" OF THE LOWER VAAL

The oldest alluvial deposits of the Lower Vaal are found at relative elevations of 20–90 m above modern flood level. These are cobble-grade conglomerates, generally embedded in a matrix of calcreted silty sand. Except for basal units with locally derived rock, gravel rounding is good to excellent, while sorting according to grade is rather poor. In most areas, Ventersdorp diabase (andesite) is the dominant cobble and boulder component, with local significance of indurated shale, dolerite, and silicified wood of Karroo lithology, and a ubiquitous residual component of quartzite, quartz, chalcedony, chert, agate, and jasper pebbles derived from the Precambrian Basement Complex. Gravel thickness is locally seldom greater than 5 m, although a section of 18 m has been reported by Partridge and Brink (1967).

Previous work in the Lower Vaal area led to differentiation of two categories of Older Gravels: primary and derived (see Söhnge et al. 1937; Cooke 1947; Breuil et al. 1948; Van Riet Lowe 1952; Partridge and Brink 1967). The primary gravels ("Basal Older Gravels" of Cooke 1947) are in situ alluvial deposits, with appreciable quantities of diabase and/or dolerite. By contrast, the derived gravels (synonyms include "Redistributed Older Gravels," "Older Red Gravel," and "Potato Gravels") have been reworked by colluvial agencies and weathering has removed all but the resistant silica rocks. As a result, the primary gravels consist mainly of poorly sorted, coarse-pebble to boulder-grade materials whereas derived gravels are well sorted in the coarse-pebble grade. The majority of outcrops of the derived gravels form unconsolidated surface veneers seldom more than 30 cm thick; these are found on flat surfaces as well as slopes. Local thicknesses may exceed 2 m, however, and some occurrences are calcreted—for example, in the Windsorton area, where derived gravels are found cemented in old soil pipes or in surface calcretes over primary gravels (Partridge and Brink 1967; Mason 1967).

Cooke (1947) pointed out that the primary Older Gravels are found at progressively lower elevations nearer the river, spread out laterally over as much as 10 km. Since they were presumed to lie in old hollows of the original river bed, they could hardly be contemporaneous. Consequently, he interpreted them as a discontinuous record of different stages in bedrock dissection as the river encountered ever more resistant hard-rock barriers, requiring increasing adjustments of channel profile, with increased local gradients. In view of the fragmented nature and seemingly random vertical distribution of the Older Gravels, it is understandable that Söhnge et al. (1937) did not explicitly suggest a terrace stratigraphy, even though their longitudinal profile (Söhnge et al. 1937, pl. 4) does show three stages with gradients paralleling those of the modern river bed. Cooke (1947) is even more cautious, recognizing the difficulty of correlating these terrace fragments across the two steep-gradient knickpoints upstream of Windsorton and downstream of Barkly West. To avoid these problems of longitudinal correlation, Partridge and Brink (1967) confined their study to the Windsorton sector, where they identified discrete terrace bodies by airphoto interpretation, field mapping, and establishing representative lithostratigraphic profiles for each. Three units were recognized: 200, 100, and 70 feet above lowwater level or, about 57, 30, and 18 m above flood stage.

The knickpoints found along the Lower Vaal are crucial to any interpretation of the terrace gravels since the former could either be a result of "fixed" bedrock barriers or of successive longitudinal stream adjustments migrating upstream. In the first case, ancient river gradients would have maintained some basic similarity to those of today, even if barrier resistance increased with dissection; in the second instance, former gradients would have had little similarity to those of the modern river. Previous authors have emphasized the notion of successive stream adjustments and Partridge and Brink (1967), following up in part on Cooke (1947), attribute the Older Gravel terraces to: (1) headward advance of knickpoints related to subphases of the post-African "erosion cycle" of King and "produced by splitting of the cycle across lithological barriers," (2) the local effect of the barriers themselves and their subsequent removal through breaching (3) increased longitudinal gradients through axial warping of the watershed, and (4) the development of knickpoints due to rapid lowering and river capture by the Harts (Partridge and Brink 1967, p. 35).

The only way that the knickpoints can be understood and a terrace stratigraphy elucidated is by detailed mapping of *both* gravels *and* fluvial platforms along the length of the Lower Vaal, combined with lithostratigraphic characterization of each outcrop. Figure 2 shows our preliminary map of gravel exposures and platforms of the Barkly West-Windsorton area; detailed fieldwork is currently underway along the entire Lower Vaal with this primary objective in mind. The tentative information now available can be summed up as follows:

a) The highest fluvial platform is cut across diabase at 1,130–1,170-m elevation, south of the Vaal between Riverton and Schmidtsdrif. At about +90 m, this surface may represent remnants of a river-cut platform or, perhaps, an exhumed, Paleozoic, glacially eroded plain. However, there are appreciable gravel deposits on top of this feature near Nooitgedacht (see *Nooitgedacht Platform*, fig. 2), and derived gravels from this major outcrop were subsequently reworked at lower levels by minor tributaries draining towards a Vaal River then at or below +60 m. Similar colluvial "tributary" gravels are found southwest of Gong-Gong.

b) A second platform can be traced continuously west of the river from above Waterval to near Barkly West, at elevations of 1,150–1,170 m cutting across both diabase and Dwyka shale, with a gradient half that of the modern river (see *Holpan Platform*, fig. 2); relative elevation at Windsorton is +60 m, at Barkly West +80 m. Here again, there is some conformity with the exhumed, pre-Karroo topography. Primary deposits are restricted to the Holpan area, where they have already been mapped by Partridge and Brink (1967) as "200-ft" gravels. Derived gravels form veneers over much of the platform.

c) Another, subcontinuous fluvial platform

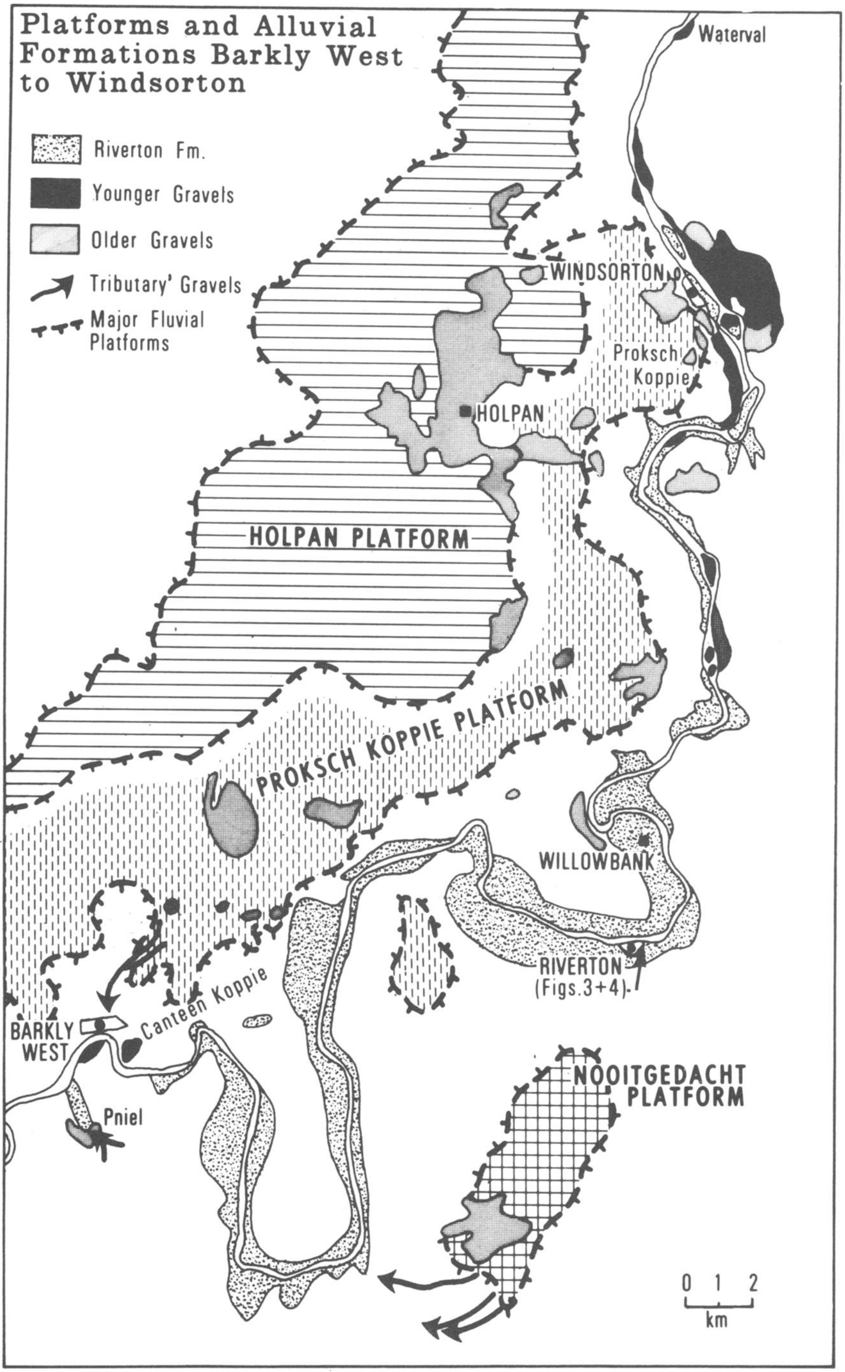

FIG. 2.—Preliminary mapping of platforms, gravels, and Riverton beds in the Barkly West-Windsorton area.

can be identified at 1,105–1,130 m west of the Vaal between Windsorton and Gong-Gong, with a gradient only half that of the modern river (see *Proksch Koppie Platform,* fig. 2). Thus the relative elevation increases from +33 m upstream to +72 m downstream. This is the "100-ft" gravel mapped by Partridge and Brink (1967) at Windsorton (Proksch Koppie). Various other gravel bodies are found on this platform between Windsorton and Gong-Gong—some primary, some weathered to residual products, most reworked, including derived "tributary" gravels north of Barkly West. Studies of gravels and matrices must be completed before a correlation with +45–50 m gravels in the Orange-Vaal confluence area can be confirmed.

d) Lower-lying gravels are preserved sporadically and restricted to the immediate bedrock slopes or bed of the Vaal, where any platforms are narrow. In addition to the Younger Gravels discussed below, these younger deposits include Partridge and Brink's (1967) "70-ft" stage at Windsorton (Little Proksch Koppie, Wedburg, Amandelhoogte)—a key alluvial unit linked with gravel outcrops at Willowbank (+26 m), and at +30–36 m in the Douglas area.

The distinction between primary and derived gravels can be a difficult one to make. In many instances, shallow gravels have been deeply weathered in situ, without reworking on slopes of 1° or less; only the more resistant silica rocks remain. In other instances, such residual pebbles are dominant or exclusive in intact, calcreted gravel terraces. Examples such as this, including the Willowmore exposures, are characteristic wherever there are no local diabase or dolerite bosses liable to erosion. Consequently, each gravel outcrop or veneer must be evaluated separately. In fact, in the majority of cases, apparently derived gravels do carry stratigraphic implications for a particular platform and (implicitly) stage in river evolution.

It is improbable that the major terrace stages were ever represented by uniform gravel bodies over great longitudinal reaches of the Vaal. Preliminary studies show that gravel exposures adjacent to hills or steeper valley margins include both particularly coarse grades and high proportions of local rock, with some evidence of valley margin dips and lateral intercalations of rubble screes. Intervening stretches of lower gradient or softer Karroo bedrock presumably supplied few durable materials; local alluvium here was probably fine grained, so that sandy or silty facies must have once been widely represented. This finds some support in recurrent sandy or loamy interbeds, such as those of the "100-ft" terrace at Windsorton (see Partridge and Brink 1967, profile 4). Contrary to the opinion of Van Riet Lowe (1952), these are fluvial rather than eolian facies. Nonetheless, eolian sands of Kalahari origin have been tapped by the Harts headwaters and thereby introduced to the Vaal sediment complex on one or more occasions (Van Rooyen 1971, chap. 5); such materials were repeatedly reworked by fluvial and eolian agencies on or downwind of the Vaal floodplain.

The pedogenetic alteration of the Older Gravels remains to be studied systematically. The two common patterns are (1) calcreted conglomerates with corroded but intact silicate rocks, and (2) rubefied, unconsolidated gravels of exclusively resistant lithology. The latter would appear to indicate intensive weathering during formation of fersiallitic soil profiles. The former reflect massive calcification. In addition, the calcrete facies is more often than not capped by younger calcretes developed in colluvial rubble or even in superposed, derived gravels (see Partridge and Brink 1967). The mutually exclusive occurrence of both pedogenetic forms remains to be explained, as do their temporal relationships.

PALEONTOLOGY AND ARCHEOLOGY OF THE "OLDER GRAVELS"

The protracted period of bedrock dissection and sporadic gravel aggradation recorded by the successive generations of Older Gravels is poorly dated since there are no materials suitable for radiometric assessment, and faunas appear to be absent.

However, problematic remains of several rather ancient forms of uncertain provenance have been described from the Lower Vaal. These include molars of *Gomphotherium*, *"Archidiskodon" subplanifrons*, and *"Archidiskodon" broomi* (Cooke 1963, table 7; 1967, p. 180). Further in question are the discordant remains of the archaic suine *Notochoerus capensis* and the giraffid *Sivatherium* (?) *cingulatum* (Wells 1964). These fossils may originally relate to one or other of the Older Gravel units and in fact may not have been found in the Younger Gravels. Unfortunately, the field records are wholly inadequate as a result of uncontrolled collecting over many decades, but Helgren's ongoing work has failed to find traces of bone in any of the Older Gravel units.

However, the mastodont is a Pliocene form, and Maglio's (1970) revision of the Elephantidae reclassifies the Vaal elephants as *Mammuthus subplanifrons* and *Loxodonta* sp. nov., respectively, species that date 4.0 m.y. B.P. in the East African potassium-argon chronology. This appears to lend some measure of support to the crude estimate of 4.8 m.y. B.P. derived for the "200-ft." gravels at Windsorton by geomorphologic criteria (Partridge and Brink 1967). Therefore, it is possible that the Older Gravels date from the terminal Pliocene as well as the early Pleistocene.

The primary Older Gravels may or may not contain man-made implements. Fock (1960) and Mason (1967) have recovered possible, but isolated, artifacts from well within the matrix of "200-ft" conglomerates near Windsorton. Evaluation of older reports of possible artifacts from the same sediment body (see Breuil et al. 1948) is rendered impossible by the multiple solution pipes that penetrate the intact terrace alluvia but which are filled with superficially similar materials (Partridge and Brink 1967; Mason 1967).

Some of the derived Older Gravels contain artifacts (Breuil et al. 1948; Van Riet Lowe 1952; Mason 1962, p. 45–46; 1967) although their provenance is generally impossible to assess. However, J. D. Clark, K. P. Oakley, and Van Riet Lowe did recover artifacts in the cemented, reworked top of the "200-ft." gravels at Windsorton (Clark, personal communication, 1972). Mason (1967) subsequently excavated a small collection from this same position, dividing the materials into Later, Middle, and Earlier Stone Age on typological grounds. But, according to Clark (personal communication, 1972), "I saw nothing in the collection he recovered that could not have been E.S.A. in the light of the Olduvai assemblages." Conceivably, therefore, information of value may yet be forthcoming, although any such artifacts are decidedly scarce.

"YOUNGER GRAVELS" OF THE LOWER VAAL

Prior to the next period of aggradation along the Lower Vaal, Cooke (1947) postulates epeirogenic deformation in the Orange-Vaal drainage, with uparching of the interfluves and intensified bedrock downcutting. Whether or not this was the case, accumulation of a complex body of Younger Gravels began along the length of the Vaal. These Younger Gravels are as coarse as or coarser than the Older Gravels, and of similar lithology. Van Riet Lowe (1952), amplifying the interpretation of Söhnge et al. (1937), identified four stages of deposition (I, IIa, IIb, and III), each supposedly resting on freshly cut bedrock platforms. The scheme is roughly as follows, employing raw data from the scale sections of Söhnge et al. (1937, pls. 2–3) and revising the technical terminology:

1. Bedrock dissection followed by lateral planation at 16–18 m ("12 m") above modern river bed.
2. Aggradation of Younger Gravels I (7 m thick) on this rock-cut platform, to 12 m or more above modern flood level.
3. Renewed bedrock dissection, followed by lateral planation at 8–13 m ("6 m") above modern river bed.
4. Aggradation of Younger Gravels IIa and

IIb, separated by lenses of current-bedded sands, with a total thickness of 12–14 m, on this platform, to 12 m or more above modern flood level.

5. Aggradation of silt and sand, with diatomaceous lenses and *Achatina* shells, resting on current-bedded sands that fill the base of swales in an undulating topography formed by gravels I–II. Local thickness of these "Calcified Sands" is almost 12 m, cumulative thickness probably 17 m or more.

6. Calcification of the previous fine alluvium.

7. Renewed bedrock dissection to modern channel floor, seemingly preceded or followed by lateral fill-cutting of terrace spurs at 7.5 m above modern flood level.

8. Aggradation of Younger Gravels III (5 m thick) on floor of modern channel, to 3 m *below* modern flood level.

9. Sheet erosion ("peneplanation") of previous deposits at 12 m above modern flood level, contemporary with aggradation of so-called Youngest Gravels in minor, local tributaries.

10. Wind-blown sands.

In evaluating this sequence, Cooke (1947) argued that the Younger Gravels I are found at a single locality, that the distinction between units IIa and IIb is based solely on the presence of some discontinuous sandy units, and that gravels II and III are conformable at several sites. He consequently regarded gravels I, II, and III as conformable deposits recording "a single and practically continuous cycle of downcutting" (Cooke 1947, p. 256). However, the younger unit of "Calcified Sands" (5) was considered to be distinct. Partridge and Brink (1967) lump all the gravels and alluvial sands of phases (2–5) under the misleading designation "Current Gravels," while not implying that vertical and lateral changes of facies are absent. The total is ascribed to "a single cycle of channel development involving entrenchment over a considerable period of time and culminating in the development of the present floodplain" (Partridge and Brink 1967, p. 25). The "Youngest Gravels" are labeled "Gully Wash Gravels" and given little stratigraphic significance within this overall time range.

Although we do not accept all of the conclusions of Söhnge et al. (1937), we find that the field evidence also negates some of these specific criticisms of Cooke (1947) and Partridge and Brink (1967). Our views and tentative results are as follows:

a) The bedrock base to the Younger Gravel complex (as, e.g., illustrated by the excellent scale sections of Söhnge et al. [1937, pls. 2–3 and figs. 5–6]) shows no demonstrable fluvial platforms of stratigraphic significance. In fact, the discrepancies between the raw observational data and the textual generalizations of Söhnge et al. (1937) are too great to be overlooked. The field evidence shows clearly that the Vaal's bedrock channel had already been cut approximately to its modern depth and morphology *prior to* aggradation of the Younger Gravels at Windsorton.

b) The Younger Gravels can indeed be subdivided into three successive alluvial bodies that are distinct both on facies and stratigraphic criteria. The basal unit ("A") consists of massive, traction bed-load deposits of cobble-grade gravel, with a rubefied matrix (a red cambic soil horizon), and with subsequent formation of a calcrete or silcrete duricrust on top. The intermediate unit ("B") is more typically represented by uncemented coarse sands and pebbles showing complex current-bedding, trough cross-bedding, and gravel "dunes" moving downstream. The top unit ("C") is a thick accumulation of coarse to cobble-grade gravel, deposited as gravel bars splaying across the former channel axis in pool and riffle sequences; a major postdepositional duricrust cements most of the sediment body. This tripartite sequence can be traced downstream from Windsorton to Delportshope, despite minor facies variations within each unit and repeated pinching out of "B." Whereas "B" and "C" may be conformable, "A" is appreciably older, with a long interval of polygenetic weathering intervening. Altogether, the Younger Gravels represent at least two discrete sedimentary intervals, with bed-load sediments deposited on an irregular bedrock floor and derived primarily from "headward" erosion along successive knickpoints. This is difficult to reconcile with the concept of a "single" cycle of "downcutting," since there were at least two hemicycles of net aggradation along most of the lower Vaal.

Our own tripartite subdivision of the Younger Gravels appears to match the IIa and IIb units, with intermediate sandy beds, of Söhnge et al. (1937); their unit I has no apparent validity, and their unit III is either truncated unit "A" or reworked gravel.

c) The Younger Gravel complex rises from at least +12 m (above modern flood level) at Windsorton to +16 m at Canteen Koppie (under a thick mantle of colluvial loam), and even higher elevations of +22–23 m at Gong-Gong, dropping off again toward Delportshope, where in situ unit "C" gravels extend from below the modern river bed to +19 m, but unit "A" gravels are at +27 m. Further downstream, comparable gravels to +15–18 m are found near the Riet confluence and at Douglas. It appears that the major reason for these variations of gradient lies in the flow adjustments of a greatly augmented river discharge to local constrictions of the valley.

d) The "Calcified Sands" are stratigraphically distinct from and disconformably above the Younger Gravels, rendering Partridge and Brink's (1967) characterization of the "Current Gravels" as a one-phase, subcontemporary feature totally invalid. Geochemically too, these units are distinct. The various outcrops of Younger Gravels at Windsorton have 4%–45% calcium carbonate and 5%–15% amorphous silica in their matrix; by contrast, the local "Calcified Sands" have only 1.0%–1.5% amorphous silica with similar carbonate ranges as the Younger Gravels. These "Calcified Sands" are coeval with one of the late Pleistocene units (Member II) of the Riverton Formation, as defined further below.

e) The morphological terrace formed by the Younger Gravels (plus Calcified Sands) was not sculptured by sheet erosion (see Cole 1961, p. 112–113). Instead, it is a bonafide but convergent +12-m floodplain surface, reflecting the final aggradation stages of both the Younger Gravels and the Calcified Sands. Erosional steps subsequently cut on the flanks of this sediment complex presumably reflect on later fluvial episodes.

f) The "Youngest Gravels" are of interest in that they contain large boulders moved by gravity processes. Their stratigraphy is difficult to determine at Windsorton; elsewhere, crude local detritus may underlie or be intercalated with the younger Riverton Formation, whereas similar deposits above Bloemhof contain good Acheulian occurrences and mammalian fauna (see Mason 1969).

g) Although there are wind-blown sands in the Windsorton area, many exposures of "red sands" prove to be colluvial loams that thicken in footslope areas. Such colluvia commonly include a component of reworked eolian sand. The stratigraphy of these reddish loams and sands generally requires a good deal of local fieldwork due to regional facies peculiarities. Some units are equivalent to the Riverton Formation, others are younger, but all distinctly postdate the Younger Gravels complex.

PALEONTOLOGY AND ARCHEOLOGY OF THE "YOUNGER GRAVELS"

The age of the Younger Gravel complex is thought to be late Middle Pleistocene on the basis of disparate and sporadic faunal collections made over the years (Cooke 1949, 1963). These come primarily from Windsorton, from diggings into the gravel body, although some materials appear to come from superposed sands and loams, or even from the base of the "Calcified Sands" (Cooke 1949). The most recent faunal inventory has been provided by Wells (1964). Excluding the five Plio-Pleistocene elements discussed above, it includes 36 species or genera, of which at least 17 (or 48%) are extinct; Wells (1964) considers it probable that further specific determinations will augment the proportion of extinct species.

Since at least some of the Vaal faunal collections substantially postdate the Younger Gravels "C" and another part is of apparent Plio-Pleistocene age, a simple "late Middle Pleistocene" age assignment is becoming increasingly difficult to uphold. Even within the undisputed "younger" assemblage there are at least four species of zebrine and caballine horses, four genera and at least seven species of suines, and three forms of elephant (see Cooke 1963; Wells 1964). This is difficult to reconcile with one, brief faunal span. In addition to the "derived" Plio-Pleistocene forms, there probably are three distinct assemblages relating to Younger Gravels "A," to Younger Gravels "B/C," and to the Calcified Sands and other superficial deposits of late Pleistocene age. There is then reason to believe that the Younger Gravel complex spans a much broader range—and possibly all—of the Middle Pleistocene.

Of potential stratigraphic value are a number of faunal concentrations in situ excavated by Mason (1969) near Bloemhof, in 1968. An analysis of this fauna is awaited.

The Younger Gravels, as well as the overlying, loamy red colluvia, contain what are best described as Acheulian and "Fauresmith" artifacts (Cole 1961). The key collections come from six sites: Homestead, Larsen, Newman's Pont, and Riverview VI at Windsorton, and Canteen Koppie and Pniel at Barkly West. In part as a result of dispersal to museums of many countries, the total number of artifacts preserved in the Witwatersrand University is a mere 614. Each collection was made almost exclusively from mine dumps from several pits dispersed over an area of several acres. Each collection was made selectively by several individuals over a span of several decades, and subsequent "sortings" must be assumed for most or all of the collections. Finally, each collection represents a spectrum from rolled to unworn artifacts. As a result, the collections are inhomogeneous, from neither primary nor semiprimary contexts, as well as heavily biased in favor of bifaces, cleavers, and large flakes. Nonetheless, Cole's typological and metric analyses show significant differences among the collections, although their meaning, as with all other gross measurement typologies, is unclear.

Archeological research in the Younger Gravel complex has been exploratory only, with the volume of discursive and secondary literature out of all proportion to the significance of the limited and inadequate materials in hand. The only systematic excavation was devoted to the (at best) quasisterile Older Gravels (Mason 1967), rather than to a careful survey and testing of suitable deposits within the Younger Gravel complex. Artifacts can still be recovered in quantity at Canteen Koppie and from the tailings of diggings next to the modern river. At the rate at which primary gravels are being worked over, it is consequently urgent that pit sections be examined whereever the related tailings contain little-worn artifacts, and that new in situ sites be located in finer-grained facies that offer some likelihood of at least semiprimary contexts.

SEDIMENTARY UNITS POSTDATING THE "YOUNGER GRAVELS": THE RIVERTON FORMATION

The late Pleistocene and much of the Holocene time range are spanned by a series of deposits that postdate the Younger Gravels. These are well exposed in erosional gullies (Afrikaans: *dongas*) near Riverton-on-Vaal (28°′S, 20°46′E), where we have established a complex stratigraphic sequence. Five units (members) have been recognized and they can be summarized as follows, with reference to figures 3–4:

I. *Over 6 m,* base not exposed. Intensively gleyed, white to light gray or pale yellow (Munsell hues 5Y), generally massive, clayey silt with slickensides. Interdigited with lenses of sandy or gravely detritus, in part well stratified to laminated. A Vaal floodplain deposit, 8.5 m above modern flood water, including local tributary interbeds. Postdepositionally calcified, and followed by erosional disconformity.

II. *7 m.* Weakly to moderately gleyed, white (5Y), massive to well-stratified, silty sands to sandy silts, with dispersed basal pebbles. Followed by development of a 60-cm, light gray, loam *vertisol* with prismatic structure, local slickensides, and secondary calification. A Vaal flood silt to +10.5 m. Followed by at least 5 m dissection by tributary streams.

III. *9 m.* Local alluvia grading into +13-m Vaal terrace. The various facies, both alluvial and colluvial, include basal gravels up to more than 3 m thick, followed by weakly gleyed, white (5Y), calcareous, silty sands with gravelly lenses and horizons of reworked concretions. At the type site, the tributary terrace has a relative elevation of 8.5 m above the donga bed, downstream, falling off to +5 m midstream, ultimately converging with the valley floor upstream (fig. 3). Locally, the tributary facies may preserve a truncated calcareous paleosol, with a profile in excess of 1 m, or a calcrete

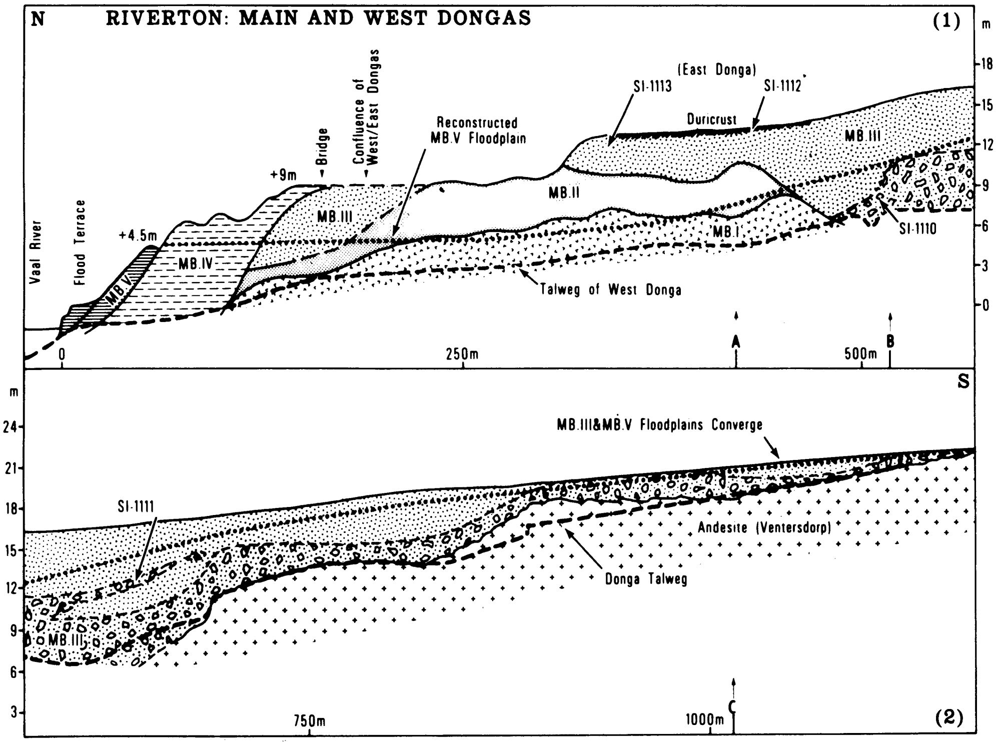

FIG. 3.—Longitudinal scale section of Riverton Boat-House Donga (west branch), exposing type section of Riverton Formation. Vertical exaggeration: 8×.

duricrust with abundant amorphous silica. Followed by at least 15 m of fill dissection by the Vaal River.

IV. *9 m.* Vaal terrace at +8.5 m, embanked against unit III, and consisting of grayish brown (10YR) to light brownish gray (2.5Y), stratified, clayey to sandy silts. These flood deposits extend up the tributary streams, but no local deposits are preserved, although older deposits appear to have been regraded (e.g., erosional shoulders) to conform to the new gradients. Followed by at least 11 m of fill dissection by the Vaal River.

V. *6 m.* Tributary alluvia interdigited with +4.5 m Vaal alluvial terrace. The tributary facies is a massive-bedded, grayish brown (2.5Y), silty sand, forming a terrace that, at the type site, rises from +3 m downstream to +6 m midstream before gradually converging with the donga floor upstream (see figs. 3–4). The Vaal facies is a well-stratified, dark gray brown (10YR), clayey silt embanked against unit IV and spilling into tributary valleys. The tributary terraces show remnants of a deep, relict vertisol with a dark gray (5Y) 180-cm A + Ca horizon of loamy texture and strong prismatic structure. Followed by at least 6 m of fill dissection in the major valleys.

Younger upland sediments are restricted to low dunes of yellow red medium sand and light brown, laminated colluvial sediments of similar or finer texture. The donga floors carry pink to very pale brown sands and silty sands, well stratified, with grit lenses and rare clayey lenticles. Commonly, too, there may be remnants of a +1–1.5 m wash terrace, consisting primarily of well-stratified, derived reddish sands of eolian origin, together with lenses of unit III or V material. Finally, the subrecent Vaal flood silts consist mainly of light brown (10YR), laminated clayey to sandy silts.

The Riverton Formation provides a distinctive and useful lithostratigraphic datum

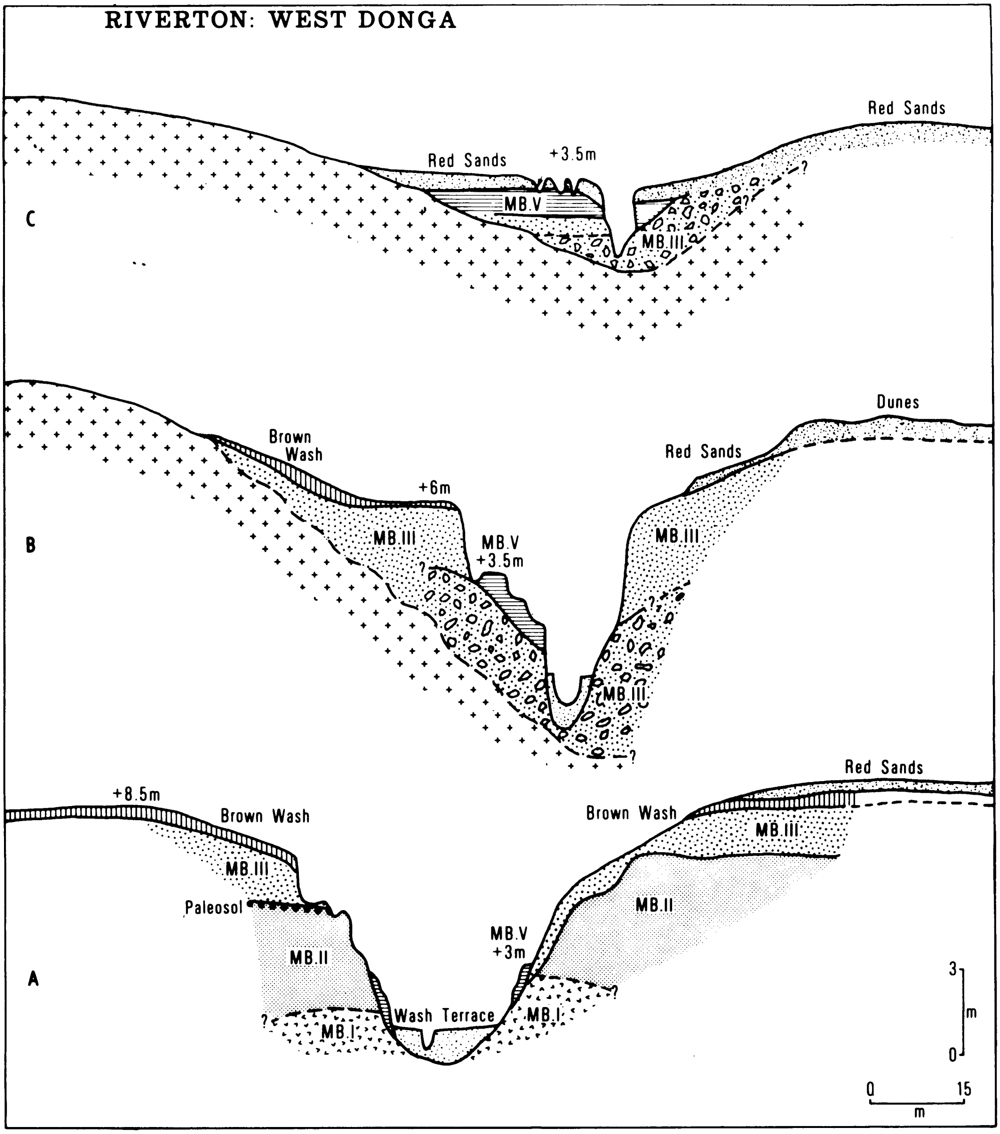

FIG. 4.—Selected scale cross-sections of Riverton Donga (west branch). Locations and patterns as in fig. 3. Vertical exaggeration: 4.5×.

with which to identify and correlate Pleistocene deposits between Windsorton and Delportshope and, to a lesser extent, downstream to the Orange confluence, where facies change progressively. However, detailed correlations of the Riverton Formation with the "Calcified Sands" and other post-Younger Gravels units at Windsorton remain to be completed. Distribution of the Riverton Formation in the Barkly West-Windsorton area is shown by figure 2.

PALEONTOLOGY, ARCHEOLOGY, AND RADIOCARBON DATING OF THE RIVERTON FORMATION

Fossiliferous exposures in the Riverton Formation are restricted to unit III, the upper part of which includes proliferations of *Achatina zebra obesa* (Pfeiffer), identified by J. P. E. Morrison. These are generally shells of uniform size (5.0–6.0 cm in length), referrable to subadult individuals. A fragment of ostrich eggshell was also found in the basal detritus of unit III.

Archeological vestiges are also confined to unit III, where we found derived Acheulian and Middle Stone Age materials, as well as several interesting Middle Stone Age surface collections that appear to have been in semiprimary context before being exposed by recent erosion. The homogeneous Middle Stone age collections include, apart from pieces of quartzite, andesite, and chert, mostly artifacts of indurated shale (lydianite). Dominant tool types are Levallois points (convergently patterned) and true blades, some of Levallois type, generally with minimal retouch. Other components include large side-scrapers, a lanceolate point, cores (among which is a large, high-backed, prepared example), as well as a number of rather poorly standardized small tools. The overall impression is that of a later, as yet undiagnostic variety of Middle Stone Age. At Windsorton, the fine-grained alluvia that we correlate with the Riverton Formation also contain Middle Stone Age artifacts (Söhnge et al. 1937; Breuil et al. 1948; Van Riet Lowe 1952).

Later Stone Age artifacts are definitely absent from units IV and V, although microlithic bladelets of Smithfield type occur both in and under the post-Riverton sands.

Materials suitable for radiocarbon assays are limited to inorganic carbonates and shell. Except for a few outcrops of Pleistocene calcretes, there is no calcareous bedrock anywhere in the Vaal Valley. Instead, carbonates are derived from weathering of soda-lime feldspars, primarily at local diabase and dolerite outcrops, or in association with mineral springs related to doleritic intrusions. *Dead* carbonates are consequently no problem, but carbonate cycles are actively underway and the recrystallization of calcite in even very recent sediments promises that contamination by younger carbonates is a serious liability in all samples. This was borne out by the radiocarbon determinations.

Samples were collected from two localities (see fig. 3) in the eastern and western branches of the Riverton donga. Based on the old half-life, the Riverton dates are as follows:

SI-1110.—Member III, base; 8,640 ± 260 B.P. Fragments of ostrich eggshell within gravel matrix. Very small sample, no pretreatment given, and sample diluted. Since sample is subject to recrystallization, age must be considered as minimum due to contamination by younger $CaCO_3$.

SI-1111.—Member III, middle; 9,610 ± 95 B.P. Massive calcrete matrix of conglomeratic lense related to former land surface or groundwater level. Washed in 0.5N HCl before CO_2 evolution. Must be considered as minimum age.

SI-1112.—Member III, top 30 cm; 17,240 ± 485 B.P. Shell of *Achatina zebra obesa* in terminal, calcrete duricrust. Small sample, diluted. Sample soaked in distilled H_2O to soften matrix, matrix then washed off, and shells washed in 1N HCl before CO_2 in H_3PO_4.

SI-1113.—Member III, top 120 cm; 17,180 ± 215 B.P. Shell of *Achatina zebra obesa* in marly sand. Same pretreatment as SI-1112. Samples agree closely and provide basis for estimating age of top of Riverton Member III. Shell from this same collection was dated 11,400 ± 175 B.P. (UW-167A), with the porous, calcareous matrix giving an apparent age of only 7,360 ± 115 B.P. (UW-167B); these divergencies indicate high levels of contamination by younger carbonates both in the matrix and in the external shell walls, so that adequate pretreatment is essential to realistic dating.

Altogether samples SI-1112/1113 would appear to indicate that alluviation of Member III terminated no later than 17,000 B.P. Samples SI-1110 and 1111 are useless as dates for Member III, but their convergence near 9,000 B.P. may possibly reflect on a younger carbonate cycle active perhaps 6,000–8,000 years ago. Implicitly, therefore, they may be related to the aggradation of Members IV or V. In any event, this sample suite shows that C^{14} dates on calcretes (e.g., Netterberg 1969*a*) and inorganic carbonates in the Lower Vaal region are of limited value. As a final crosscheck we attempted to date the buried Ca-horizon of a paleosol within the Riverton Formation at the supposed "Fauresmith" type-site (28°33′S, 21°20′E), on Groenvallei Farm, Orange Free State:

SI-1114.—2,664 ± 65 B.P. Pedogenetic carbonate horizon with root drip, disconformably under 1.5 m vertisolic alluvium and modern soil. This probably correlates with Riverton Member III as locally developed, forming top of unit 1 of the Older Fill of Butzer (1971*a*). Sample subject to contamination by younger carbonates and age must be considered minimum for formation. $\delta C^{13} = -1.79‰$.

In fact, the carbonates of the Fauresmith/Groenvallei Ca-horizon appear to be primarily related to accumulation of the overlying dark cracking clays and the attendant mobilization of carbonates. Since this vertisol is equivalent to Riverton Member V, the final period of aggradation may have terminated less than 3,000 years ago.

STRATIGRAPHIC INTERPRETATION

The preceding information on the geomorphic evolution of the Lower Vaal is summarized in figure 5. The chart is provisional, since ongoing fieldwork will require corrections and amplification for both the Older and Younger Gravel complexes. However, this attempt does reflect a substantial improvement in our comprehension of the Vaal terraces, and the scheme provides a working hypothesis that emphasizes the true complexity of river evolution through time.

PROBLEMS OF PALEOENVIRONMENTAL INTERPRETATION

Söhnge et al. (1937) interpreted each hemicycle of bedrock cutting, gravel deposition, and sand alluviation as the result of a wetter climate that began to wane as aggradation began. Pedogenetic calcification of the Riverton beds was ascribed to a semiarid climate, and eolian activity and "peneplanation" related to an arid climate, drier than today.

Cooke (1941, 1947) emphasized that since river gradients were less and drainage areas similar to those of today, the coarse Vaal gravels would require a very large river with greater stream competence, and a far more abundant or less seasonally contrasted rainfall. Unlike Söhnge et al. (1937), Cooke (1947) favored nonclimatic, "temporary increases in erosive activity" to explain the successive stages of bedrock dissection that separate the several discrete bodies of gravel alluvium. The "Calcified Sands" (Riverton Formation) are attributed to a "sluggish, much diminished stream flowing over a sandy floodplain" at a time of drier climate, and pedogenetic calcification to upward capillary movement during the low-water season.

Van Riet Lowe (1952), commenting on the "Youngest Gravels," suggests marked sheet erosion and seasonality of rainfall. This point is developed by Maarleveld (1960), who proposes maximum runoff at times when vegetation was sparse, but increasing in response to increasing rainfall; at the height of a wet phase, on the other hand, the vegetative mat would have been too effective for rapid runoff. Flint (1959) expressed strong reservations regarding oversimplified interpretation of phenomena or processes, while Partridge and Brink (1967) and especially Partridge (1969) are reluctant to recognize climatic factors in the vicissitudes of the Vaal River's evolution.

The suggestions put forward below must be considered as preliminary and inconclusive, although we do wish to emphasize that the Vaal sequence is potentially far from uninformative in terms of paleoenvironmental inferences. The evidence marshaled here allows the following commentary:

Ecological zonation of the Vaal Basin.—Any paleoclimatic interpretation of the history of the Vaal River must consider the interplay of local and distant geomorphic balances. The highest parts of the eastern watershed are moist subhumid ($C_2B'_2r$ by the Thornthwaite classification), the broad central parts of the basin dry subhumid

HOLOCENE		Recent Vaal downcutting and gullying Alluviation of Vaal flood terrace and 1.5m sandy tributary terrace. Traces of *Later Stone Age* (Smithfield). Dissection of fill (vertical amplitude >6m). Eolian activity.	
HOLOCENE	RIVERTON FORMATION	Mb V Alluviation: 6m of Vaal flood silts and tributary loams, climaxed by vertisol development. Floodplain +4.5m. Dissection (>11m). Mb IV Alluviation: 9m of Vaal flood silts. Floodplain +8.5m.	
UPPER PLEISTOCENE	RIVERTON FORMATION	Dissection (>15m). Mb III Alluviation: 9m of tributary sands and gravels. Floodplain +13m. Terminated by 17,000 B.P. Partly coeval with *Middle Stone Age* settlement. Dissection (>5m). Mb II Alluviation: 7m of Vaal flood silts. Floodplain +10.5m. Dissection (amplitude ?). Mb I Alluviation: 6m of gleyed floodplain silts. Floodplain +8.5m.	
UPPER PLEISTOCENE		Dissection of fill (vertical amplitude >12m).	
MIDDLE PLEISTOCENE	YOUNGER GRAVELS (+12 to 22m)	Calcareous paleosol Unit C (gravels) Unit B (sands and gravels) Cambic and calcareous paleosols Unit A (gravels)	*Middle to Late Acheulian* settlement. Middle Pleistocene fauna.
MIDDLE PLEISTOCENE		Bedrock dissection (vertical amplitude >18m).	
PLIOCENE TO EARLY PLEISTOCENE	OLDER GRAVELS	(iv) Alluviation: '70ft' gravels. Bedrock dissection (>12m). (iii) Planation of Proksch Koppie Platform (+33/72m) with terminal aggradation of '100ft' gravels. Related tributary gravels (Barkly West). Bedrock dissection (>27m). (ii) Planation of Holpan Platform (+60/80m) with terminal aggradation of '200ft' gravels. Earliest artifacts ? ? Source of derived Pliocene fauna? Related tributary gravels (Nooitgedacht, Gong-Gong). Bedrock dissection. (i) Formation of Nooitgedacht Gravels (+90m) and Platform.	
PLIOCENE TO EARLY PLEISTOCENE		Protracted, alternating bedrock dissection and planation.	

FIG. 5.—Tentative late Cenozoic evolution of the Vaal Valley between Barkly West and Windsorton

($C_1B'_2d$), and the lower basin, below Bloemhof, semiarid (DB'_3d) (Schulze 1958). Correspondingly, rainfall decreases from over 800 mm in the upper basin to 300 mm near the Orange confluence. The spontaneous vegetation of most of the central and upper watershed is grassveld, but the crucial lower basin has thorn savanna (thornveld) with patches of semidesert Karroo shrub (Acocks 1953). In fact almost all of the gravel occurrences below Commando Drif are found within these more xeric vegetation zones. Consequently, any study of the depositional sequence must emphasize the distinction between local and distant pebble components, and between alluvial and colluvial facies.

Bedrock versus fill cutting.—Unlike stream dissection of solid bedrock, downcutting into alluvial fills can be a rapid process, easily initiated and often easily reversed. On the other hand, incision into the shale bedrock and, particularly, diabase or dolerite, requires long periods of suitable mechanical abrasion, preferably in combination with chemical weathering. Partridge and Brink (1967, p. 34) chided Söhnge et al. (1937) for invoking climatic changes to explain (bedrock) incision by the Vaal; however, their counterexamples of rapid (fill) cutting by American streams in recent decades are spurious . Söhnge et al. (1937) did raise a difficult problem, noting that there has been little appreciable bedrock dissection since the Younger Gravels episode. It is not immediately obvious why the Vaal should have cut down 60 m or more into resistant rock between late Pliocene and mid-Pleistocene times, with minimal change thereafter. Surely the extreme stepped gradients of the Delportshope-Warrenton sector, if indeed applicable as the basic explanation, should have continued to provide ample nonclimatic stimulus to "grading" of the longitudinal profile.

Platform cutting and planation.—A problem that had been given little attention is the extensive development of fluvial platforms and marginal pedimentation surfaces, compared with a remarkably discontinuous and shallow veneer of river gravels. Lateral planation by river channels is still a difficult subject, and peripheral pedimentation (see discussion of planation by Rust 1970) can hardly explain the sharply restricted erosional surfaces between Barkly West and Windsorton. There are as yet no specific explanations for these broad surfaces and the long time spans they represent. Only careful fieldwork can provide new insights on the complexity of processes favoring longitudinal versus lateral change.

Gravel aggradation.—The former transport of cobble- to boulder-size gravel by a stream now as incompetent as the modern Vaal can hardly be brushed aside by invoking the 1-in-100-year flood catastrophe (e.g., Partridge 1969). As Wolman and Miller (1960, p. 72) have shown, depositional features owe their origin primarily to "events of moderate magnitude which recur relatively frequently rather than [to] rare events of unusual magnitude." Prior to the construction of regulatory dams and irrigation devices, monthly discharge at Riverton for January (the month with greatest average flow, or 21.6%) varied from as much as $3{,}974 \times 10^6$ m^3 (1917–1918) to as little as 13×10^6 m^3 (1932–1933) over a 26-year period (see Wellington 1955, p. 374). Nonetheless, the Younger Gravels that commonly clog the river bed are seldom disturbed, and all the late Pleistocene and Holocene bed-load deposits of the Vaal channel studied so far contain nothing coarser than granule-size gravel. Thus, the Vaal gravels do require a stream competence that is quite unusual if not outside the range of recent variability.

Relevant to simple tectonoerosional interpretation of the Vaal terraces, there is a gathering body of evidence that a systematic terrace sequence extends from the Orange-Vaal confluence to upstream of Windsorton. This sequence transcends a variety of discontinuities, both in lithology and gradient. Thus, the terrace system implies long periods of general geomorphic stability alternating with phases of dynamism (in the sense of Erhart 1956), ruling out the knickpoint and piracy theories of terrace development. Furthermore, the same terrace sequences now appear to maintain comparable *mean* gradients along a river stretch in excess of 250 km, making epeirogenic deformation increasingly unlikely as a primary factor. Finally, the interdigitation of "tributary gravels," lateral colluvial rubbles, and tributary-channel boulders with the basic Vaal gravels all indicate unusually vigorous slope denudation and local runoff during at least some of the phases of aggradation. Since comparable slope rubbles nowhere overlie the Riverton Formation, a change of environmental parameters must be posited.

The field evidence in the Douglas-Windsorton area further suggests that the Lower Vaal and its tributaries responded to local changes in geomorphic equilibrium and runoff, not to changing discharge of the distant Vaal High Veld drainage. If this is fully verified by the systematic study of facies in the different gravel bodies, then it should be possible to develop reasonable models of (1) vegetation mat, (2) rainfall intensity, duration, and seasonality, (3) runoff factors, and (4) balances between rates of erosion and weathering that could have favored such gravel transport and deposition (see parallel discussion in Butzer and Helgren 1972).

Alluvial silts.—Suspended sediments are characteristic of Vaal alluviation during the present century in particular, and the Holocene (e.g., Members IV and V of the Riverton Formation) in general. The most common facies is a clayey silt deposited within low-velocity channel sectors, embanked against channel berms, and, very locally, flooding into low-lying areas such as tributary mouths. At the Vaal-Orange confluence, there is a prominent contrast of facies; the Orange is rapidly depositing a sandy silt (with a strong maximum in the 20–100 μ grade) that is building up into a prominent spit, behind which the Vaal slowly accumulates clayey silts (almost exclusively under 50 μ). Although this trend to fine sedimentation has been accentuated by the moderating effects of successive dams upstream since the 1930s, the Riverton flood-silt terraces nonetheless seem to fall within the modern range of variation. The facies and distribution of the silty basal units (Members I and II), in particular, imply a much broader floodplain with well-developed backswamps or sloughs in the past, subject to widespread seasonal inundation and accretion of fine, suspended sediments. It would appear that erosion/weathering ratios and runoff on the watershed, as well as discharge and sediment relationships within the river, were quantitatively different from those of today, and qualitatively distinct from those applying to times of gravel aggradation.

Alluvial and eolian sands.—Massive alluvial sands, such as the "Calcified Sands" of Windsorton and those of Member III of the Riverton Formation are difficult to explain. Although detailed facies relationships at Windsorton remain to be established, Riverton exposures indicate that sands was common to Vaal and tributary channels as well as to local colluvia. The last include the terrestrial snails washed into sedimentary contexts after mass deaths of single-age populations, presumably in response to severe (seasonal?) desiccation. Grain-size spectra of these moderately sorted sands peak between 50 and 200 μ, with a trace of coarse sands and granules in most samples. Quartz sands above 100 μ are generally subrounded to rounded in shape and, except for the absence of ferric skins, are indistinguishable from so-called Kalahari-type eolian sands (see Van Rooyen 1971, chap. 5; Piaget 1963). Frosting properties, unduly emphasized by Bond (1954) in an earlier study of eolian components in Zambezi River sands, are inconclusive since surface micropitting varies in part according to the chemical environment of the depositional medium (Kuenen and Perdok 1962; Butzer and Gladfelter 1968). Polygenetic, reddish sands of Kalahari-type are prominent both at Riverton and Windsorton, where they constitute several generations of dune sands or colluvial wash.

Such sands are known to lose their oxide coatings soon after being blown into rivers or seasonal lakes. Altogether we believe that an appreciable part of the sand component in the Riverton Formation was derived either from existing eolian deposits by colluvial action or possibly by direct eolian sedimentation over permanent streams and standing waters. This implies that eolian sands were particularly abundant during or just prior to accumulation of Riverton Member III, although a large, expanded non-outlet lake in the Kimberley area indicates a very moist climate at about the same time (Butzer et al. 1973).

Paleosols.—Buried and relict soil phenomena in the Lower Vaal region include (1) massive calcretes cementing primary or reworked gravels, (2) silcrete duricrusts in some exposures of the Younger Gravels, (3) deep, reddish cambic horizons in primary or reworked eolian deposits as well as many gravel exposures, and (4) localized vertisols, primarily in Riverton sediments. Holocene vertisols are commonly encountered in Riverton floodplain deposits of the western Orange Free State and they presumably indicate slow geomorphic change, reduced proportions of runoff, and more effective moisture (Butzer 1971*a*). Calcrete chemistry has been summarily discussed by Goudie (1972); possible modes of origin of the Windsorton calcretes have been outlined by Netterberg (1969*b*). In particular, the calcification of the primary gravels may well be related to the periodic oscillations of a water-table, falling subsequent to aggradation. The calcreted colluvial mantles, on the other hand, appear to be more strictly pedogenic phenomena. In general, calcretes are found in a wide variety of arid to semiarid South African environments and their presence in the Lower Vaal region has no immediate paleoclimatic implications. The same would appear to apply for the more difficult to interpret silcretes (see Butzer 1973*b*). Finally, the red paleosols are difficult to evaluate since few intact profiles are preserved and all examples known so far are either secondarily calcreted or involve relict soils under no more than a thin colluvial veneer. Interpretations of these soils must therefore await completion of the final fieldwork.

Faunal evidence.—The mixed Vaal fauna includes black rhino, hipparion, several zebrine and caballine horses, hippo, several suines (including warthogs), a giraffid, a variety of hartebeests and wildebeests, an extinct eland, a duiker, impala, springbok, gazelle, a hippotragine antelope, greater kudu, oryx, two genera of buffalo, several elephants, and spotted hyena (see Cooke 1963; Wells 1964). This basic faunal assemblage, no matter how archaic and mixed, corresponds closely with the regional fauna of the nineteenth century as well as with the spectrum of animals depicted by late prehistoric rock engravings in the general area (Fock 1966, 1972). In the context of the Ethiopian faunal province it has little ecological import.

CONCLUSION

The recent field studies reported here provide a new stratigraphic framework (fig. 5) for the Older and Younger Gravels, and for deposits of the subsequent time range. Furthermore, basic interpretation of the several alluvial formations requires considerable revision. Although specific paleoenvironmental interpretations are premature at this time, the present study does underscore that ongoing field and laboratory studies will continue to provide new and substantive data on a stratigraphic sequence truly rich in implications for the Pleistocene record of southern Africa.

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REFERENCES CITED

ACOCKS, J. P. H., 1953, Veld types of the Union of South Africa: Bot. Survey South Africa Mem. 28, 192 p.

BOND, GEOFFREY, 1954, Surface textures of sand grains from the Victoria Falls area: Jour. Sed. Petrology, v. 24, p. 191–195.

——— 1967, River valley morphology, stratigraphy and palaeoclimatology in southern Africa, *in* BISHOP, W. W., and CLARK, J. D., eds., Background to evolution in Africa: Chicago, Univ. Chicago Press, p. 303–312.

BREUIL, H.; VAN RIET LOWE, C.; and DU TOIT, A. L., 1948, Early man in the Vaal River Basin: Archeol. Survey South Africa, Pretoria, Archeol. Ser., v. 4.

BUTZER, K. W., 1971*a*, Fine alluvial fills in the Orange and Vaal Basins of South Africa: Assoc. Am. Geographers, Proc., v. 3, p. 41–48.

——— 1971*b*, Another look at the australopithecine cave breccias of the Transvaal: Am. Anthropologist, v. 73, p. 1197–1201.

——— 1971*c*, Environment and archeology: an ecological approach to prehistory: Chicago, Aldine-Atherton, 703 p.

——— 1973*a*, Spring sediments from the Acheulian site of Amanzi, Uitenhage District, South Africa: Quaternaria, v. 16 (in press).

——— 1973*b*, Geomorphology and geo-archeology of two Acheulian 'Pan' sites in the Kimberley District: Doornlaagte and Rooidam: Cape Provincial Mus. (Nat. Hist.) Annals (Grahamstown) (in press).

——— 1973*c*, Geology of the Cornelia Beds, northeastern Orange Free State: Natl. Mus. Bloemfontein Mem. (in press).

——— 1973*d*, Paleo-ecology of South African australopithecines: Taung revisited: Current Anthropology (in press).

———; FOCK, G. J.; STUCKENRATH, A.; and ZILCH, A., 1973, Paleo-hydrology of late Pleistocene lakes in the Alexandersfontein Pan, Kimberley, South Africa: Nature (in press).

———, and GLADFELTER, B. G., 1968, Quartz-grain micromorphology, in BUTZER, K. W., and HANSEN, C. L., Desert and river in Nubia: Madison, Univ. Wisconsin Press, p. 473–481.

———, and HELGREN, D. M., 1972, Late Cenozoic evolution of the Cape Coast from Knysna to Cape St. Francis, South Africa: Quaternary Research, v. 2, p. 143–169.

COLE, G. H., 1961, Culture change in the Middle-Upper Pleistocene transition in Africa south of the Sahara: Unpub. Ph.D. dissert., Univ. Chicago.

COOKE, H. B. S., 1941, A preliminary survey of the Quaternary period in southern Africa: Bur. Archaeology, Pretoria, Archeol. Ser., v. 4, p. 1–60.

——— 1947, The development of the Vaal River and its deposits: Geol. Soc. South Africa Trans., v. 46, p. 243–260.

——— 1949, Fossil mammals of the Vaal river deposits: Geol. Survey South Africa Mem. 35, pt. 3, 117 p.

——— 1963, Pleistocene mammal faunas of Africa, with particular reference to southern Africa, *in* HOWELL, F. C., and BOURLIERE, F., eds., African ecology and human evolution: Chicago, Aldine-Atherton, p. 65–116.

——— 1967, The Pleistocene sequence in southern Africa and problems of correlation, *in* BISHOP, W. W., and CLARK, J. D., eds., Background to evolution in Africa: Chicago, Univ. Chicago Press, p. 175–184.

——— 1973, The fossil mammals of Cornelia, O.F.S., South Africa: Natl. Mus. Bloemfontein Mem. (in press).

DAVIS, W. M., 1906, Observations in South Africa: Geol. Soc. America Bull., v. 17, p. 377–450.

DEACON, H. J., 1970, The Acheulian occupation at Amanzi Springs, Uitenhage district, Cape Province: Ann. Cape Prov. Mus. (Nat. Hist.) Annals, v. 8, no. 11, p. 89–189.

DIXEY, FRANK, 1938, Some observations on the physiographical development of central and southern Africa: Geol. Soc. South Africa Trans., v. 41, p. 113–170.

DU TOIT, A. L., 1907, Geological survey of the eastern portion of Griqualand West: Geol. Comm. Cape of Good Hope (Cape Town) 11th Ann. Rept. (1906), p. 87–176.

——— 1907–1908, Geological map of the Colony of the Cape of Good Hope: Cape Town, Government Printer Sheets 46 and 42, at 1:238,000.

ERHART, M., 1967, La genèse des sols en tant que phénomène géologique (2d ed.): Paris, Masson [1st ed. 1956].

FLINT, R. F., 1959, Pleistocene climates in eastern and southern Africa: Geol. Soc. America Bull., v. 70, p. 343–374.

FOCK, G. J., 1960, Die Prä-Chelles-Kultur am Vaal, *in* Steinzeitfragen der alten und neuen Welt, Festschrift für L. Zotz: Bonn, Röhrscheid, p. 151–160.

——— 1966, Distribution of animals on rock-engravings in the Northern Cape: Cape Provincial Mus. (Nat. Hist.) Annals, v. 5, p. 85–90.

——— 1972, Wild animals in rock engravings: South African Mus. Assoc. Bull., v. 10, p. 2–11.

GOUDIE, A. S., 1972, The chemistry of world calcrete: Jour. Geology, v. 80, p. 449–463.

HUZAYYIN, S. A., 1941, The place of Egypt in prehistory: Inst. d'Egypte Mém., v. 43, 474 p.

KING, L. C., 1963, South African scenery: a textbook of geomorphology: Edinburgh, Oliver & Boyd.

——— 1968, The morphology of the earth, a study and synthesis of world scenery (2d ed.): New York, Hafner.

KUENEN, PH. H., and PERDOK, W. G., 1962, Experimental abrasion 5. Frosting and defrosting of quartz grains: Jour. Geology, v. 70, p. 648–658.

MAARLEVELD, G. C., 1960, Über die pleistozänen Ablagerungen im südlichen Afrika: Erdkunde, v. 14, p. 35–46.

MAGLIO, V. J., 1970, Early Elephantidae of Africa and a tentative correlation of African Plio-Pleistocene deposits: Nature, v. 225, p. 328–332.

MASON, R. J., 1962, Prehistory of the Transvaal, a record of human activity: Johannesburg, Witwatersrand Univ. Press.

——— 1967, The archaeology of the earliest surficial deposits in the lower Vaal Basin near Holpan, Windsorton District: South African Geog. Jour., v. 49, p. 39–56.

——— 1969, The Oppermansdrif Dam archaeological project: Vaal Basin: South African Archeol. Bull., v. 24, p. 182–192.

NETTERBERG, F., 1969*a*, Ages of calcretes in southern Africa: South African Archeol. Bull., v. 24, p. 88–92.

——— 1969*b*, The interpretation of some basic calcrete types: South African Archeol. Bull., v. 24, p. 117–122.

PARTRIDGE, T. C., 1969, Fluvial features and climatic change during the Quaternary in South Africa: South African Archeol. Bull., v. 24, p. 106–116.

———, and BRINK, A. B. A., 1967, Gravels and terraces of the lower Vaal Basin: South African Geog. Jour., v. 49, p. 21–38.

PIAGET, J. E. H., 1963, Coarse fraction mineralogy and granulometry of selected soils of the Western Orange Free State: Unpub. D.Sc. thesis, Univ. Orange Free State.

RUST, UWE, 1970, Beiträge zum Problem der Inselberglandschaften aus dem mittleren Südwestafrika: Hamburger Geog. Studien, v. 23, p. 1–280.

SCHULZE, B. R., 1958, The climate of South Africa according to Thornthwaite's rational classification: South African Geog. Jour., v. 40, p. 31–53.

SÖHNGE, P. G.; VISSER, D. J. L.; and VAN RIET LOWE, C., 1937, The geology and archeology of the Vaal River Basin: Geol. Survey South Africa Mem. 35, pts. 1 and 2, 184 p.

VAN RIET LOWE, C., 1952, The Vaal River chronology—an up-to-date summary: South African Archeol. Bull., v. 7, p. 135–149.

VAN ROOYEN, T. H., 1971, Soils of the Central Orange River Basin: Unpub. D.Sc. thesis, Univ. Orange Free State.

WELLINGTON, J. H., 1937, The Pre-Karroo peneplain in the south-central Transvaal: South African Jour. Sci., v. 33, p. 281–295.

——— 1955, Southern Africa: a geographical study, v. 1, Physical geography: Cambridge, Cambridge Univ. Press.

WELLS, L. H., 1964, The Vaal River "Younger Gravels" faunal assemblage, a revised list: South African Jour. Sci., v. 60, p. 91–93.

WOLMAN, M. G., and MILLER, J. P., 1960, Magnitude and frequency of forces in geomorphic processes: Jour. Geology, v. 68, p. 54–74.

ZEUNER, F. E., 1959, The Pleistocene period (2d ed.): London, Hutchinson [1st ed. 1945].

——— 1958, Dating the past (4th ed.): London, Methuen.