1

Paleoecology of South African Australopithecines: Taung Revisited[1]

by Karl W. Butzer

INTRODUCTION

The Taung[2] skull was the first australopithecine fossil discovered and, as *Australopithecus africanus*, gave its name to a gracile lineage of early hominids. Almost a half-century later, the continuing spate of hominid discoveries in East Africa and the problems they have generated lend ever greater pertinence to the South African type fossils and type sites.[3] Yet the key Taung specimen has not been published in full, and the geological context has been established in a broad way only. The stereotyped generalizations about Taung found in the secondary literature have remained unchanged for several decades. In fact, however, the stratigraphic age commonly assigned to the Taung site must be challenged, thus raising new questions about the position of the Taung child in hominid phylogeny.

Ultimately perhaps of greater importance than relative age and basic taxonomy are the ecological implications of the Taung site, located at the highest latitude (27°32′S) of any australopithecine site and on the very edge of the Kalahari Desert. Here, too, recent work indicates a need for fundamental revision of prevailing concepts. Such a revision becomes particularly urgent at a time when paleobiological and paleobehavioral theorists have begun to explore a number of ecological hypotheses to help explain diverse aspects of early hominid differentiation or the specific evolution of the hominine line. Both dietary and locomotory adaptations play a central role in several of these hypotheses.

Whereas the fossils themselves are at long last proving capable of yielding direct information on masticatory activities and locomotory mechanisms, environmental informa-

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[2] Taung is Tswana for 'place of the lion,' composed of *tau* 'lion' and *ng* 'place of,' as I am informed by D. T. Cole and P. V. Tobias. It also means 'place of Tau,' a legendary 18th-century chief (Breutz 1968:15). Since the totem of the local Tlhaping tribe is the kudu (Breutz 1968:99), the latter interpretation is probably correct. The common spelling Ta'ung is therefore as incorrect as the obsolete toponym Taungs.

[3] As became particularly apparent at the Wenner-Gren Foundation workshop "Fossil Hominids from East Rudolf, Kenya," organized by G. Ll. Isaac and R. E. Leakey, New York, February 9, 1973. See also Tobias (1972).

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The present paper, submitted in final form 15 III 73, was sent for comment, along with the papers of Tuttle, Todd and Blumenberg, and Porshnev that follow, to 50 scholars. The responses to all the papers are printed below and are followed by replies from the authors.

tion has traditionally been based on associated faunal assemblages and sediment interpretation. Realistic ecological models will ultimately need to be the product of an interdisciplinary synthesis, employing the input of critically evaluated data processed by the diverse methodologies of the broad spectrum of scientists with paleoanthropological focus or avocation. Thus far there has probably been a little too much assertion of apparent interrelationships that are based on an incomplete appreciation of the complexity and conditional testimony of data from unfamiliar subdisciplines. Despite the continuing compartmentalization of research institutions and funding agencies, individuals must strive to communicate to the degree that they can appreciate that no data of any category is wholly unequivocal. Thus a late Tertiary faunal assemblage cannot be simply equated with a specific vegetation and ecozone, nor can a sediment necessarily yield a reliable prognosis on either macro- or microdepositional environments.

No paleoecological generalizations—as opposed to limited site-specific inferences—relevant to Tertiary and Pleistocene hominids are established beyond reasonable doubt. No matter how quantitative a contributing subdiscipline may aspire to be, the compendium of paleoanthropological sciences is necessarily an inexact one by virtue of the multivariate character of interacting organic and inorganic phenomena in nature. As scientists we remain obligated to continue to question the assumptions underlying our methodologies, and search for new ways to achieve fuller and more accurate resolution. The techniques of the behavioral, biological, or geological subdisciplines relevant to anthropology are never infallible and must therefore remain flexible. Similarly, the body of general information must never be elevated to the status of dogma, whether it be from our own or a cognate subdiscipline with data we are less able to evaluate critically.

The potential contributions of the earth sciences to both data input and synthesis in paleoanthropology are considerable, if for no other reason than that a paleo-physical geography is indispensable in both paleoprimatology and prehistory. But interpretation in geomorphology, sedimentology, and geological stratigraphy is no less difficult than is the isolation of specific variables in any ecological system. Sophistication in data analysis and synthesis does improve with time, even if not necessarily in a linear progression. Older studies, no matter how good for their time or how venerable or beloved their authors, must periodically be reconsidered. Our appreciation of the South African australopithecines can be no exception to this law of disciplinary survival.

Prior to the discovery of australopithecines in Tanzania, Ethiopia, and Kenya, the detailed geological studies of Peabody (1954) and Brain (1958) in South Africa suggested strong support for an explicit ecological differentiation of the gracile and robust lineages. In an earlier paper, I suggested that the patterns inferred were less than proven (Butzer 1971*b*). The present paper attempts to reconsider the case of the Taung australopithecine. The results are equally far from conclusive, but they may help clarify a number of points and suggest avenues for further research.

GENERAL BACKGROUND

In November, 1924, Young (1926) recognized a primate skull[4] recently uncovered by quarry operations at Buxton-Norlim.[5] This specimen was to be published by Dart (1926) as *Australopithecus africanus*. The Buxton-Norlim lime precipitates—"calc-tufas" or "travertines"[6]—from which the fossil was derived had first been briefly described by Wybergh (1920). In view of the interest due to the australopithecine discovery, Young subsequently examined a number of tufas at and near Buxton-Norlim, describing occurrences, recognizing but a single generation of tufa precipitates, discussing their mode of origin (in part by analogy to the Brazilian study of Branner [1911]), and inferring a single cycle of accentuated fluvial activity (with deposition of tufas interbedded with coarse detritus), followed by uninterrupted tufa accretion, and ultimately fluvial erosion. Young also provided a pertinent description of the cave fill in which the australopithecine was found.

A detailed study of the Buxton-Norlim area was finally undertaken in 1948–49 by Peabody (1954), who recognized at least four major generations of tufas or travertines and established a complex geomorphologic sequence. Peabody demonstrated facies patterning within the older tufas, mapped the occurrences at approximately 1:10,000, and reconstructed the appearance of the area prior to quarrying by means of a panorama. A variety of fossiliferous assemblages and archeological occurrences were collected, although with exception of the australopithecine cave proper (Cooke 1963; also Wells 1969 and Freedman and Stenhouse 1972), the faunas have been incompletely published, and only one archeological site (Witkrans; see Peabody 1954) has been systematically analyzed (Clark 1971). Peabody suggested a climatic interpretation for Buxton-Norlim and other nearby tufas and then offered climato-stratigraphic correlations with the controversial Vaal River sequence.

Despite the valuable and fundamental work of Young and Peabody, both the stratigraphic age and paleoclimatic implications of the older Buxton-Norlim deposits remain uncertain (see also Cooke 1967:176). It requires little emphasis that this state of affairs is unfortunate, particularly at a time when the relative ages of the South African australopithecine breccias—with respect to each other and to the East African deposits—are of as crucial interest as the possible but as yet unproven ecological differentiation of the key australopithecine lineages (see Butzer 1971*a*: chap. 25).

In the course of fieldwork in the Vaal and Harts valleys during 1970 and 1971, I made several trips to different parts of the Union Lime Co. concession at Ulco. I also visited Buxton-Norlim and the nearby quarries at Thoming, together with C. K. Brain and R. Liversidge. Fresh perspectives were provided by an aircraft reconnaissance in 1971 and further fieldwork in 1973. Finally, renewed studies

[4] The first partial skulls of small fossil baboons had already been discovered in 1920 and described in an unpublished address to the Royal Society of South Africa by S. H. Haughton in the same year (Tobias 1973*a*). Relationships of the fauna to the hominid are discussed further below.

[5] The older name of Buxton has been changed to Norlim, a contraction of Northern Lime Company. To simplify identification and to avoid confusion with a specific local tufa designated as Norlim, the double name Buxton-Norlim is probably preferable.

[6] There is no generally accepted terminology to describe sheets of lime precipitates. "Travertine" best refers to dense, horizontal, or undulating bands of calcite, with successive increments of macrocrystalline, columnar structure alternating with the more common laminated, nonporous to semiporous, cryptocrystalline calcite. Many authors prefer to limit this term further, to cave flowstones and dripstones. The term "tufa," on the other hand, has often been reserved for calcite precipitated on and between growing or decaying plants; the primary accretions commonly form a spongy, cellular, and somewhat brittle rock, while porous calcite sands tend to fill the voids between the vertical or horizontal organic structures (Butzer and Hansen 1968:355). Such organic tufas are, nonetheless, more often than not embedded within sheets of banded precipitates, and a number of basic studies (e.g., Branner 1911, Gardner 1932) have used "tufa" to designate mixed, external facies of this kind. I consequently suggest that dripstone and flowstone be used to describe carbonate precipitates in caves, while tufa be employed for external deposits, including both organic tufas and travertines *sensu strictu* as facies.

by D. M. Helgren are under way.

Sediment samples collected in both areas were primarily analyzed in the Paleo-Ecology Laboratory of the University of Chicago. The results of this work underscore that correlations of the various escarpment tufas with other presumed sequences of geomorphologic events in southern Africa were premature. However, the tufa generations at widely separated points of the escarpment are remarkably comparable and do suggest that a detailed and systematic study could establish a firm regional stratigraphy that might possibly be linked directly to erosional surfaces and calcrete deposits found to the west of the Vaal and Harts rivers. Furthermore, the sediment analyses provide new insights as to paleoclimatic interpretation, in particular for the matrix of the Taung australopithecine. The present paper attempts to illustrate the mechanisms of tufa accretion and destruction on the basis of the small-scale but exemplary development of a single locality, the Grootkloof. These results are then applied to a revision of the classic Buxton-Norlim sequence.

THE GAAP ESCARPMENT

The Buxton-Norlim and other key tufas of the northern Cape Province are found along the Campbell Rand (from Afrikaans *rand* 'ridge, rim') or, as it is now more usually termed, the Gaap (=Kaap) Escarpment. This prominent scarp, averaging approximately 100 m in relief and 1,150–1,200 m in elevation, extends some 280 km from 27°7′S near Vryburg to 29°7′S near Douglas, trending from northeast to southwest. The cliffed escarpment (40–70°) and the generally flat plateau (less than 0.5°) behind it are formed of gently warped, Precambrian dolomites of the Transvaal System. Small facets on the scarp face reflect minor lithological contrasts in the gray dolomites and the dark gray shaley interbeds (see also DuToit 1907, Young 1926) that are locally important as impermeable aquiludes, controlling spring lines and cavern development. The scarp rim is angular, the footslope more often smoothly concave, averaging 25° as it descends onto a rock-cut plain descending to the valley margins of the Vaal and Harts with average gradients of less than 0.5°.

The Gaap Escarpment is an exhumed, early Paleozoic erosional feature, subsequently buried under Karroo sediments during the late Paleozoic and reexposed by late Tertiary planation in the Vaal Basin (DuToit 1910; Stratten 1968; D. M. Helgren, personal communication). Although this relatively recent erosion has cut across outcrops of underlying Precambrian dolomites, quartzites, and slates (see DuToit 1907–8), Karroo sediments commonly extend into proximity of the escarpment, so that there can have been little significant scarp retreat in Cenozoic times (see fig. 1). Consequently, although the major drainage lines have continued to incise short, V-shaped gorges along the edge of the escarpment, tufas could have formed at any time since the Karroo cover was stripped off in Mio-Pliocene (and later) times (see King 1968:272, fig. 119).

Drainage is primarily controlled by surficial sediments, subsurface lithology, and climate. (*a*) Water-worked quartz sands are locally prominent in the shallow, intermittent watercourses above the escarpment. They appear to be derived by wind and water action from the thick and extensive Kalahari cover sands (see Grove 1969) further west,[7] and they absorb a high percentage of any initial

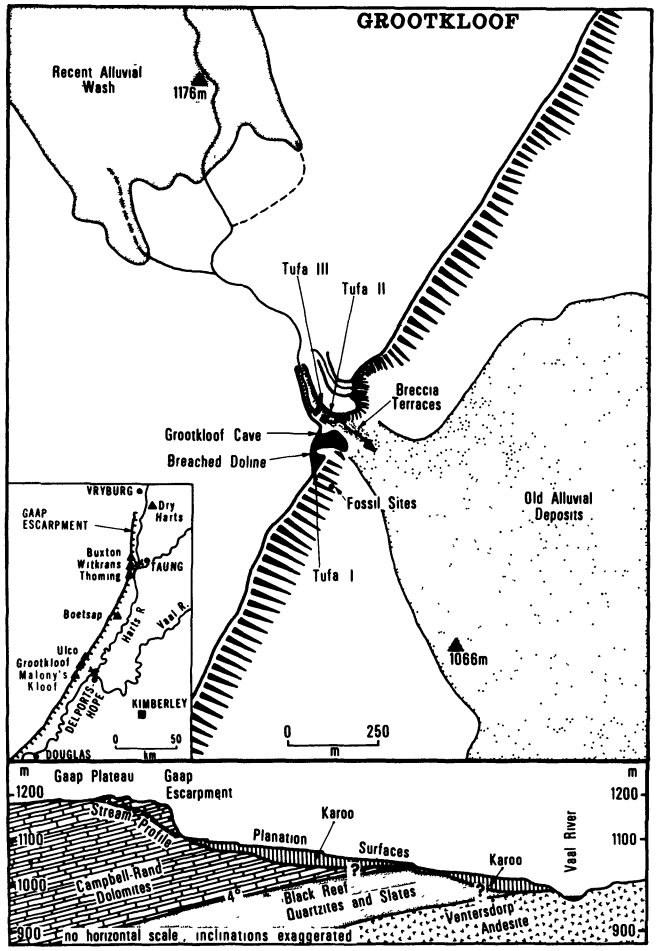

FIG. 1. Geomorphologic setting of the Ulco Grootkloof (*above*) and generalized geological section of the Gaap Escarpment and related surfaces (*below*).

runoff. Similar multicyclic sands of eolian morphology have found their way into most of the tufas, both at the time of primary accretion and during later periods of corrosion and redeposition. (*b*) Karstic erosion of the dolomite upland is relatively insignificant, being limited to restricted development of underground caverns, with associated solution shafts (ponors) and superficial microfluting (lapies). Dolines are rare, at least in scarp proximity. Nonetheless, surface drainage occurs only after protracted, heavy rains, when all caverns and fissures are periodically filled with vadose water. At that point streams "rise in flood, descending in raging torrents from the plateau" (Young 1926:55). Active channel erosion is confined to such sporadic floods, although spring sapping continues through much of the year (see also Young 1926). Most of the effective rainfall is, in fact, converted into spring discharge, primarily seasonal in nature, both above the scarp rim and along the aquiludes exposed in the escarpment itself. (*c*) Precipitation in scarp proximity today appears to increase from 300

[7] However, on a recent reconnaissance of the Gaap Plateau to beyond Kuruman and Griquatown, D. M. Helgren (personal communication) failed to find widespread intervening mantles of "Kalahari Sand." Free-standing bodies of sand or sandy soil mantles appear to be rare, of limited extent, and irregularly distributed on the plateau, except for the area immediately south of Kuruman. Thus the derivation of eolian components in the older Gaap deposits remains problematical. For modern prevailing and effective wind directions, see *Climate of South Africa* (1960).

mm at the latitude of Douglas to 375 mm near Ulco and 450 mm near Buxton-Norlim.[8] By the Koeppen classification this yields a winter-dry, cool steppe climate (***BSkw***), by the Thornthwaite system a semiarid, mesothermal climate with no water surplus at any season ($DB_3' \, d$) (Schulze 1958) and, theoretically, no runoff except of a local and sporadic type. This regime is reflected by the discharge statistics of the Dry Harts at Taung, a large catchment representative of the northernmost escarpment with over 450 mm precipitation; average annual flow 1923–45 was 88 days, with a double maximum, in March (26%) and November (19%), and a minimum in July (0.1%) (Wellington 1955:374–76). Runoff is restricted far more by mechanical percolation and evaporation than by the incomplete and degraded vegetative mat. The "thornveld" of the Gaap Escarpment and its forezones is an acacia scrub-parkland with a subcontinuous grass cover.[9] Where protected, as through the efforts of L. Matter south of Ulco, a dry thorn woodland may develop, but torrential runoff and sheetwash remain characteristic.

The escarpment is well developed south of the Ulco Quarries, where relief attains 90–120 m.[10] Structural ridges (hogbacks and cuestas) and outliers, amid local planation surfaces above the rim, create an additional local relief of 20–50 m, yielding an undulating topography marked by smooth inflections of slope. At the Ulco Quarries the scarp is completely obscured by a complex tufa fan some 4 km wide and 1.3 km deep, while further north, smaller tufa aprons continue to mask the cliffs. The Ulco Grootkloof (Afrikaans for 'great cleft') lies 3.3 km southwest of the quarry fan. Another major fan complex, Malony's Kloof,[11] projects from the scarp another 2.8 km farther south. Drainage above the escarpment is generally shallow, with repeated divergence and convergence amid various structural lineaments until the scarp is reached. Here Grootkloof is the most conspicuous erosional feature, although similar deep valleys are presumably found under the tufa fans at Ulco Quarries and Malony's Kloof. Below the scarp, drainage once again dissipates and diverges into multiple rills that run perpendicular to the Vaal-Harts system.

LABORATORY TECHNIQUES EMPLOYED

The Gaap Escarpment now has two major agencies of sediment transfer and deposition: water—both surface and spring—and wind. The primary purpose of applying sediment analyses is to attempt to differentiate between fluvial, spring, and eolian components in the geological record. The analytic techniques offer no conclusive answers, but instead provide criteria for differentiating between deposits and allow comparisons with modern "standards," where available, collected from specific depositional environments.[12]

In addition to a sample from the matrix adhering directly to the Taung skull, 32 sediment samples were collected from Ulco Grootkloof, nearby fossiliferous exposures, the Ulco Quarries, Buxton-Norlim, and alluvial fills of the Harts and Dry Harts rivers at the Delportshope and Buxton bridges respectively. These samples cannot be considered representative of the range of geological units, and modern counterparts were barely sampled. However, the selection is adequate to provide a more objective description of several depositional suites and to allow some informative comparisons. After preliminary processing, 23 samples were analyzed in some detail (for selected results, see table 1).[13]

Two problems of assessing the significance of eolian components warrant further discussion here:

1. Almost every sample has a textural maximum in the fine sand grade (60–200 μ) with a secondary clay maximum (under 2 μ). This bimodal distribution underscores the mixed derivation or transport of the sediment and renders difficult statistical manipulation by available techniques (see Folk 1966). An additional complication is the nature of the clay component, including clay minerals as well as silica—ranging the full spectrum from crystalline to mobile, amorphous forms. Titration and filtration after boiling in acid removed only an arbitrary part of this silica, and rigorous statistical techniques cannot be applied to this mixed suspended and colloidally dissolved component. As a result, the sieve components above 37 μ were treated independently, allowing discrimination in terms of median grades and sorting and skewness coefficients. In the present context, Trask sorting values under 1.40 are "good," 1.40–1.90 "moderate," and greater than 1.90 "poor." Good sorting can be expected with eolian and constant-velocity fluvial transport; poor sorting is typical of colluvial sheetwash or the torrential deposits of intermittent streams. Optimal sorting will occur with eolian derivatives dominant in fluvial deposits because of a persistent moderate-velocity current. Trask skewness values above 1.00 and below 0.60 reflect asymmetrical grain-size distributions and imply mixed sand origins. In particular, higher values have a "tail" of coarser sands, while lower values have a "tail" of silt, both types of skewness commonly reflecting colluvial redistribution.

2. An established procedure that has also been applied to South Africa (see Bond 1954, Brain 1958) claims to

[8] Generalized from over 50 stations with records in excess of 25 years (*Climate of South Africa* 1954). These values differ appreciably from the 250–450 mm range estimated by Clark (1971:1223) from precipitation maps, or the patently erroneous value of 150 mm long quoted for Buxton-Norlim.

[9] For a detailed and accessible outline of modern vegetation communities, based on the work of J. P. H. Acocks, see Clark (1971:1226).

[10] See the South African 1:50,000 topographic series, map 2824 AC ("Ulco"), as well as the airphotos.

[11] This sector is perhaps better known as Gorrokop or Gerrakop.

[12] General discussions of sedimentary processes and analyses are available elsewhere (e.g., Butzer 1971*a*), and most of the techniques and nomenclature employed here are either outlined or documented in Butzer and Hansen (1968:13–16, 461–63), Pettijohn (1957:30–38), and Soil Survey Staff (1960:30–33 with references, appendix).

[13] The analysis consisted of the following steps: (*a*) Decalcification in 15% hydrochloric acid measured calcium carbonate content for bulk samples as well as provided residues suitable for further study. Since the rare dolomite sand grains do not appear to have been affected by cold acid, the resulting sand fraction remains representative. (*b*) Wet-sieving of the residues remaining after decalcification and removal of the mobilized amorphous silica provided textural information on sand-sized materials. Standard-mesh sieves (37, 63, 210, and 595 μ, 2.0 and 6.35 mm) were employed. Textures quoted refer to the noncarbonate, detrital residue (i.e., after removal of the mobile silica) and follow the textural classification of Link (1966). Table 1 gives the textural components greater than 37 μ, after exclusion of the finer grades in order to apply Trask's coefficients of size sorting, $So = \sqrt{Q_1 / Q_3}$, and skewness, $Sk = Q_1 Q_3 / (Md)^2$, where Q_1 is the first quartile, *Md* the median, and Q_3 the third quartile of the cumulative textural curve, with $Q_1 > Q_3$. (*c*) Hydrometer analyses, using a 5% solution of sodium pyrophosphate as peptizing agent, were applied to the Harts and Dry Harts suites and to the *Australopithecus* matrix (eight samples) to differentiate the clay and silt components into four classes: under 2 μ, 2–6 μ, 6–20 μ, and 20–60 μ. X-ray diffractogram analyses were also carried out on the matrix sample. (*d*) pH values and electrical resistance (mV) were determined for the ten friable samples. The former were generally alkaline and ranged from 7.0 to 8.9, the latter varied but little, from +80 to +150. (*e*) Sand-sized residues were microscopically scanned for minerals other than quartz, with semiquantitative estimates of quartz-grain rounding and frosting. In addition, four sand samples were examined under the scanning electron microscope.

differentiate quartz sands on the basis of shape (degree of rounding) and surface texture (frosting versus polish). In effect, eolian sand grains are supposed to be rounded and frosted (the frosting being due to microscopic impact scars), while river-transported grains have a luminous polish and are less symmetrically rounded (see Cailleux and Tricart 1963:53–102; compare Shepard and Young 1961). However, Kuenen and Perdok (1962) have shown that such interpretations, based on low-magnification analyses, are facile and of dubious quantitative application.[14] Far more conclusive are the results obtained from the electron microscope at very high magnifications that allow differentiation of various distinctive surface textures, many of them peculiar to certain environments (Krinsley and Doornkamp 1973). Unfortunately, this complex and expensive technique is also not foolproof. Of four samples analyzed from the Gaap Escarpment, one (Ulco Quarry) showed quartz sands of glacial modification (Permocarboniferous Ice Age!), another (Buxton *Equus* cave fill) was multicycle eolian, a third (Buxton dry-phase cave fill) fluvial with eolian overprinting, and the fourth (Buxton wet-phase cave fill) a mixture of all these agencies. Yet all four samples represented colluvial cave or fissure infillings. Thus the electron microscope elucidates the history of sand grains, not of the sediment in which they come to rest. There are, then, no simple criteria for evaluating the eolian "appearance" of a sand grain. This is particularly true in the case of the deep sands of the Kalahari Basin. Initially probably of fluvial or marine origin, these sands have been repeatedly reworked by various processes, primarily by wind. Polycyclic sands of this type together with more local, residual types have been successively introduced into the Harts and Vaal drainage by fluvial as well as eolian forces (see Van Rooyen 1971: chap. 5). In general, these suspected "eolian" components of "Kalahari" type are subrounded to rounded, either frosted or polished, and partly discolored by microscopic skins of ferric oxide. The degree of rounding slowly increases with transport, while frosting may be added or eliminated; the oxide coatings appear to be commonly removed in highly alkaline lakes or after appreciable river transport. Altogether this allows no more than a subjective evaluation of the exotic sand grains, although the authigenic quartz sands of the local dolomite are fortunately quite distinctive: angular, glossy, and fine-grained.

TABLE 1

SELECTED SEDIMENT DATA FROM THE GAAP ESCARPMENT AND HARTS DRAINAGE

Unit	$CaCO_3$ (%)	Residual Textural Components above 37 μ: First Quartile (μ)	Median (μ)	Third Quartile (μ)	Sorting	Skewness	Textural Classification
Harts River (Delportshope Bridge)							
Flood Silts	12.1	125	89	54	1.52	0.85	Clayey-sand silt
Younger Sandy Marl	64.4	145	101	80	1.34	1.03	Sandy-clay silt
Basal Silts	20.4	115	87	54	1.49	0.82	Clayey-sand silt
Dry Harts River (Buxton Bridge)							
5.0 m Terrace	0.4	120	68	46	1.62	1.19	Sandy-clay silt
8.5 m Terrace (2)	0.9	340	180	107	1.79	1.12	Silty sand
8.5 m Terrace (1)	1.1	170	113	80	1.49	1.07	Silty-clay sand
Younger Sandy Marl	54.6	186	124	92	1.42	0.87	Silty-clay sand
Ulco Grootkloof							
Cave Floor	46.0	145	105	71	1.43	0.85	Clayey-silt sand
Tufa III	99.6	145	110	88	1.28	1.05	Sandy-silt clay
Breccia II	87.9	190	118	71	1.63	0.97	Silty-clay sand
Tufa II	86.3	145	110	85	1.31	1.02	Clayey sand
Breccia I	86.3	1020	180	105	3.12	3.31	Clayey sand
Fossil Beds (2)	60.5	–	–	–	–	–	–
Fossil Beds (1)	81.9	145	105	85	1.31	1.02	Sand
Tufa I	97.9	125	80	51	1.56	1.00	Silty-sand clay
Ulco Quarry							
Fissure Fill	42.9	162	112	89	1.35	1.15	Sand
Buxton-Norlim							
Channel Alluvium	50.0	162	115	88	1.36	1.08	Silty sand
Equus Cave Fill	37.1	145	102	70	1.44	0.89	Silty-clay sand
Oxland Apron	96.4	145	106	70	1.44	0.83	Silty-sand clay
Norlim Carapace	98.4	145	95	59	1.57	0.95	Clayey-silt sand
Wet-Phase Cave Fill[a]	88.4	118	82	53	1.50	0.93	Clayey silt
Dry-Phase Cave Fill	81.3	145	115	84	1.32	0.92	Sand
Thabaseek Carapace	99.1	115	66	48	1.55	1.27	Clayey-silt sand

[a] Taung fossil matrix

[14] Experimental work indicated that "eolian" frosting was impossible to reproduce by mechanical abrasion, but must be largely attributed to chemical micropitting, while in the case of fluvial sands chemical attack produces either total frosting or total polish, depending on the chemical properties of the particular water body. These conclusions were confirmed by a comprehensive study of over 14,000 sand grains from different past depositional environments in Egypt (Butzer and Gladfelter 1968).

TUFAS OF GROOTKLOOF

Description

Tufa I, the oldest preserved, is a steeply dipping body that extends over 80 m from the scarp rim to the footslope (fig. 2). Contacts with the dolomite are irregular, corroded, and marked by subrounded to rounded, cobble conglomerates bedded into former fissures. Beds are primarily foreset at 45–65° and constitute a "carapace" (in the terminology of Peabody 1954). All these deposits are well indurated, with extensive recrystallization and typical wavy "banding" of variable crystallinity and discoloration. Materials range from mesocrystalline, white (10 YR), clean travertines to cryptocrystalline, pink (5–7.5 YR), oxide-rich precipitates, interbedded with manganese-enriched laminae of light gray (10 YR) color. (All colors cited were obtained from the *Munsell Color Charts* for dry samples.) Amorphous silica amounts to 17% of the noncarbonate residue, while the detrital residue is a silty-sand clay, with the above-37 μ component moderately sorted. Except for a trace of shale/slate, the sands are angular to subrounded, polished quartz. Although undoubtedly badly weathered today, Tufa I includes primary interbeds of clayey, reddish soil derivatives. The sands include a high proportion with ferric oxide skins otherwise characteristic of eolian "Kalahari" sands.

± 620 B.P. (SI-1301) above, indicating a mid-Upper Pleistocene age.[15]

A phase of erosion followed, removing part of Tufas I and II, while leading to some scarp retreat of the dolomite walls of the kloof.

Breccia Terrace I, 2–3 m thick, is a crudely stratified rubble of grit, pebbles, cobbles, and boulders, generally angular to subangular, and consisting primarily of uncorroded dolomite, with some blocks derived from Tufas I and II. The matrix is a very pale brown (10 YR), poorly sorted and heavily skewed clayey sand, subsequently calcreted (Tufa III phase) and even later dissected to form the 6–7 m terrace of today. The sand component includes both abundant shale/slate and traces of black chert from the dolomite, while the quartz sands range from angular to rounded, with some typical frosted, oxide-coated grains of eolian type. Some diffuse as well as macroscopic organics are present, but little amorphous silica (2%).

Tufa III is another restricted carapace within the gorge, falling some 50 m with bedding dips of 40–70°. The material

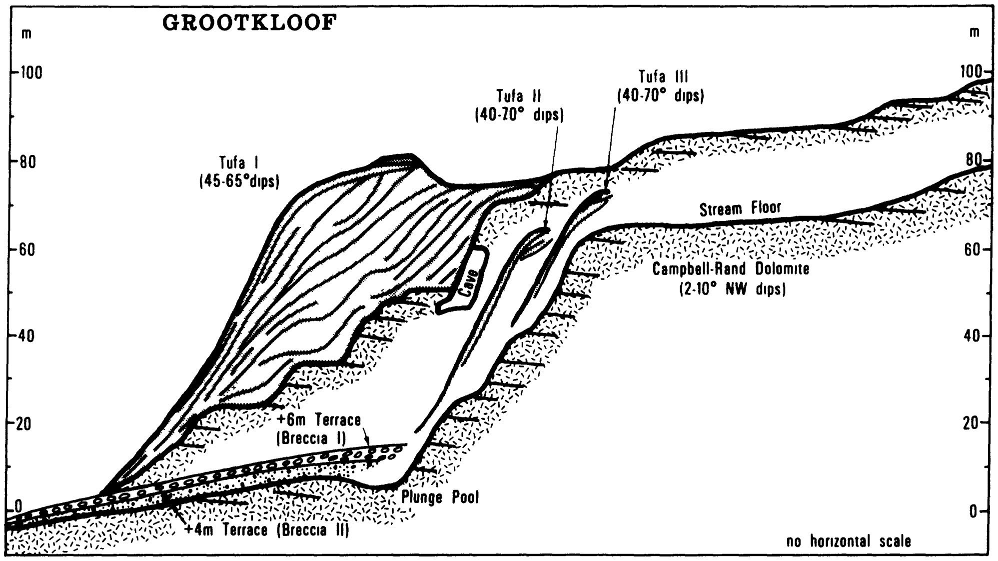

FIG. 2. Cross-section of the Ulco Grootkloof.

The Gaap Escarpment has suffered next to no retreat since deposition of Tufa I, and a valley-like incision at the kloof preceded initial accumulation. Possibly contemporary is a hanging valley at 70–75 m immediately north of the kloof (fig. 1). During a long, subsequent interval of erosion, the kloof was deeply incised and elongated to approximately its present configuration. Several stages of dissection are indicated by conspicuous steps at 20 and 35 m above the modern kloof floor (fig. 2). Related deposits and any intermediate tufa generations, such as are represented on the Gaap Escarpment opposite Douglas, appear to have been completely removed.

Tufa II is relatively minor, falling some 35 m, with 40–70° dips (fig. 2). The material is an impure, cryptocrystalline, wavy-bedded, light gray to very pale brown (10 YR) precipitate, cemented and with evidence of some secondary recrystallization and 18% amorphous silica in the noncarbonate residue. The detrital residue is a well-sorted but skewed clayey sand, with half of the exclusively quartz sand component frosted, subrounded to rounded, and oxide-coated. Samples of dense, cryptocrystalline calcite gave consistent C^{14} ages of 30,760 ± 1,035 B.P. (SI-1639) below and 26,130

is a wavy, banded to laminated, cryptocrystalline precipitate, varying in color from very pale brown (10 YR), light gray (10 YR), to pinkish gray (7.5 YR). Although the tufa is cemented, recrystallization is uncommon, and diffuse organic matter is evident. The noncarbonate residue is a well-sorted but skewed sandy-silt clay, with an angular to subrounded sand component of quartz, predominantly frosted, and a trace of shale/slate. The cumulative textural curve shows small but distinct "tails" of coarse sand and of silt. Hygrophytic salts are indicated, but little or no amorphous silica. The C^{14} date of 20,825 ± 230 B.P. (SI-1640) suggests a late Upper Pleistocene age.

Another period of erosion followed, with 2–3 m down-

[15] Samples were washed in 0.5 NHCl before CO_2 evolution in H_3PO_4 (Robert Stuckenrath, personal communication). Although "dead" carbonates are indisputably available it is equally pertinent that fresh atmospheric carbon dioxide would have been incorporated during the breakdown of the dolomite into a bicarbonate, and again at the time these bicarbonates remained in solution; similarly, younger carbonates have been repeatedly or continually added through postdepositional re-solution. It is therefore probable that the apparent C^{14} age gives a true order of magnitude.

cutting into Breccia I, destruction of much of Tufas II and III, and some concomitant scarp retreat. This material accumulated at the bottom of the kloof as Breccia II.

Breccia Terrace II is a 2-m-thick mass of poorly stratified, angular dolomite grit and rubble, with a noncarbonate residual matrix of light gray (10 YR), moderately sorted silty-sand clay as well as almost 25% amorphous silica. In addition to a moderate concentration of diffuse organic matter, there are numerous microimpressions of rootlets or grass stems, as well as terrestrial snails (*Xerocerastus* sp.). The sand is rich in shale/slate, with the quartz predominantly frosted and angular to rounded. The matrix is primarily derived from breakdown of local materials, with little evidence of fresh external sediment.

Cementation of Breccia II was completed during accretion of minor kloof-wall tufa cascades (*Tufa IV*), rich in organic matter. One such deposit has a C^{14} age of 9,310 ± 105 B.P. (SI-1641), indicating an early Holocene age.

A final phase of erosion was responsible for dissection of Breccia II which, in conjunction with a corroded bedrock channel, now forms a 4 m terrace.

Spring activity during the dry season is today limited to a trickle of water over bedrock cascades into a plunge pool below. Contemporary sedimentation involves a grayish brown (2.5 Y) sand (58% $CaCO_3$), covered with abundant algae and some mosses. The snails, identified as *Xerocerastus* cf. *psammophilus* (O. Boettger), are widespread in the Kalahari Basin.[16]

Discussion

The three generations of tufa at Grootkloof reflect different depositional trends:

I. A long period, initiated by crude basal detritus, but mainly involving slow accretion of pure, vertically crystallized travertines and clayey, laminated tufa. The limited quantity of polished sands presumably includes both fluvial and eolian components. Any initial organic impressions and snail faunas have probably been destroyed through repeated recrystallization.

II. A brief phase of accretion of sandy and clayey tufa, unusually low in carbonates and with a prominent component of derived or primary eolian-type sands.

III. Another brief phase involving slow accretion of a laminated tufa, rich in silt and clay, with a trace of organic matter and salts. Some eolian-type sands are in evidence.

Thus the three generations have points in common as well as significant differences. All imply low to moderate discharge velocities, but protracted periods of spring and stream flow. All indicate that infiltration waters—issuing from an underground, dolomitic honeycomb reservoir—were the primary contributors of carbonates. Everything points to sustained rains capable of maintaining a high phreatic watertable in the dolomite and abundant quantities of vadose water in general. Similarly, the upland vegetative mat must have been relatively complete to ensure adequate percolation and effectively inhibit surface runoff. Nonetheless, the ratio of eolian-type sands changes with each generation, as do the coarser detrital components (clay → sand → silt) and the nature of (perennial → sporadic → seasonal?) fluvial activity.

Despite superficial resemblances, the Ulco Grootkloof tufas are different from the escarpment tufas of the Libyan Desert Plateaus originally described from the Kharga Oasis by Gardner (1932; also in Caton-Thompson 1952:1–14) and studied in greater detail at Kurkur by Butzer and Hansen (1968: chap. 7). The Grootkloof tufas are primarily foreset and well bedded, with few identifiable organic impressions or structures, even though algal laminations are probably an integral part of the accretion process. In contrast, the Kharga and Kurkur tufas are primarily horizontal, occasionally current-bedded, with crude basal detritus generally followed by massive organic tufas, related to multiple spring vents, spring-fed pools, and vegetation thickets, and lateral facies including pond marls rich in plant casts and impressions. On the other hand, the Catinga limestones of northeastern Brazil include great valley-floor lime sheets aggrading by sheetwash and stream discharge (Branner 1911) in areas with 650–700 mm precipitation; their similarities with the Grootkloof tufas are remarkable.

The breccia terraces are a different matter. They record the debris produced during phases of erosion that destroyed great masses of the Grootkloof tufas. Thus formation of breccias is antithetical to tufa accretion. Similarly, the fine residues of the breccia terraces are abnormally rich in very coarse sands and otherwise different from those of the tufas (see table 1). Consequently, although the tufas are nowhere preserved directly overlying the breccias at Grootkloof, they are temporally distinct, although they are not separated by appreciable time intervals.

The breccia record of kloof cutting is highly informative, since the fresh, angular dolomite detritus testifies to either violent corrasion or accelerated mechanical weathering rather than protracted corrosion. The issue of mechanical abrasion versus weathering is resolved by the sediment record of the Grootkloof cave (see fig. 2), where the lower part is filled with angular dolomite blocks in a matrix identical to that of the breccia terraces and overlain by flowstone cascades (with *Xerocerastus* sp.) that can best be linked to Tufa III. In other words, the cave breccia is contemporary with Breccia Terrace II. Yet the cave breccia is not the result of torrential fluvial activity, but is best explained by cumulative roof collapse below the ponor at the apex of the cave. Thus mechanical weathering, almost certainly frost-shattering prompted by cold Pleistocene climates, was primarily responsible.

If frost-weathering is indeed invoked to explain breccia formation here, a winter temperature depression of at very least 2.5° C must be inferred, since the mean monthly minimum for July at Kimberley is −2.4° C (*Climate of South Africa* 1965) and only the modern 56-year record lows of −5 to −7° C would be adequate to produce the deep frost-wedging implied by block-by-block disintegration in highly resistant, massive dolomite.

Fissures or caverns filled with reddish sands are not developed in the Grootkloof tufas. The floor sediment of the Grootkloof cave is shallow, dark brown (7.5–10 YR), calcareous, organic, and loamy. It is identical to the much thicker floor fill of dark grayish brown (10 YR), clayey-silt sand (table 1) in a cave that opens on the breached doline just south of Grootkloof. Here, hyrax and some bat dung, as well as baboon feces, contribute a high proportion of the sediment. However, the detrital residue of the cave fill is well sorted, with a grade maximum near 100 μ. The almost exclusively quartz sand is angular to rounded, with a moderately high proportion of oxide skins. These obvious eolian components, which constitute some 20% by total weight, must be obtained primarily from sandy upland soils that are washed in through fissures, with a small part introduced organically. The cave entrance is sheltered from blowing sand, and silt-sized components are almost absent. Decomposition of the organic matter could ultimately produce a reddish sandy sediment similar to those found in older fissures and caverns at the Ulco

[16] Little is known about the ecological preferences of this archaic genus, which has been recovered from a number of tufa occurrences (A. Zilch, personal communication).

Quarries and at Buxton-Norlim. Yet there are no primary eolian deposits above the kloof today. Consequently, eolian components in the geological record are presumably derived in similar ways by (*a*) fluvial reworking of mixed eolian and residual materials into colluvial or alluvial deposits—ultimately transported to the escarpment edge by running water—and (*b*) direct but slow contribution of eolian materials to developing soils.

Three fissure fills were analyzed from the major quarry tufa at Ulco, a sediment body lithologically identical to Tufa I at Grootkloof.[17] Each fissure deposit was a colluvial wash with a well-sorted but skewed detrital residue of medium-grade sand, its quartz component subangular to rounded, polished, and partly oxide-coated. Carbonate content varied from 8 to 60%, with a high pH (8.8) and colors ranging from reddish brown and yellowish red (5 YR) to pink (7.5 YR). One example was sufficiently fresh to preserve traces of carbonized macro-organics. Excellent section faces in the Ulco Quarries show that the larger fills are found in geometrically or vertically as well as horizontally arranged solution hollows. This leaves little doubt that most of the responsible corrosive activity was postdepositional. "Constructional" hollows are limited to pockets with maximum dimensions of 15 cm, generally in association with rapidly aggraded organic tufas (D. M. Helgren, personal communication). Consequently, most or all of the larger examples of red sandy pockets, inclusions, and fills within the Ulco Quarry tufa must be considered as intrusive rather than primary deposits, with a full range of sediment age from the present back to the initial phases of postdepositional karstic erosion. This does not preclude some tufa accretion after karstic erosion began, since minor carbonate cycles are initiated repeatedly by minor shifts of the hydrological balance. Nonetheless, primary accumulation of the key tufa masses would have been inimical to the development of any deep fissures.

The various points of interpretation raised here will be applied to a new consideration of the Buxton-Norlim sequence and then synthesized in the concluding section. The stratigraphic framework is collated in table 2.

Except for Bushman paintings in the Grootkloof cave, no archeological or fossiliferous occurrences are indicated in the gorge itself. However, below the breached doline immediately south, there is a veneer of younger tufa (II or III) on the escarpment face, and a small core and a Levallois flake of Middle Stone Age aspect were found embedded in this tufa.

More interesting are the strongly eroded former fissure fills exposed on the footslope some 200 m south of Grootkloof. Both of these contiguous "sites" contain fragmented and disarticulated bone of large and small mammals. In one instance the matrix is a stratified accumulation of reddish yellow (5 YR), well-sorted silty sand interbedded with a 10–15-cm travertine horizon. In the other the matrix is a laminated, pink (5–7.5 YR), calcreted and recrystallized sediment with a detrital residue of well-sorted ($So = 1.31$) sand, interbedded with clean, white (10 YR), cryptocrystalline tufa similar to that of Tufa I. It is debatable whether these fills antedate or postdate Tufa I, although I provisionally suggest that they form the base to the Tufa I aggradation. These modest finds, made by L. Matter and recently examined by J. Kieser and R. Hockman for the University of the Witwatersrand Anatomy Department, are symptomatic of numerous incidental discoveries or collections made along the scarp over the past several decades.

TABLE 2

Geomorphologic Evolution of Ulco Grootkloof

9.	Bedrock dissection and corrosion (4 m downcutting). Minimal spring activity.
8.	*Tufa IV.* Minor kloof-wall cascades; cementation of Breccia Terrace II.
7.	Accelerated mechanical weathering of cliffs, with accumulation of *Breccia Terrace II* and, through ponor enlargement, of breccia in cave.
6.	Bedrock dissection and corrosion (2–3 m downcutting).
5.	*Tufa III.* Accumulation of carapace, with some eolian-type sands, derived silts, and traces of salts. Seasonal (?), mainly spring-generated fluvial activity. Cementation of Breccia Terrace I.
4.	Accelerated mechanical weathering of cliffs, with accumulation of crude, angular rubble in *Breccia Terrace I.*
3.	*Tufa II.* Relatively rapid accumulation of carapace with high proportion of eolian-type sands. Sporadic torrential fluvial activity with local spring flow. ?Local embedding of Middle Stone Age artifacts on escarpment; cascades and dripstones in cave.
2.	Protracted and complex interval of bedrock dissection and corrosion. Local karst development (dolines, ponors, caves in Tufa I and escarpment dolomite).
1.	*Tufa I.* Slow accumulation of carapace facies, with some basal, cobble conglomerate; contains intermixed, older, reddish clayey soils as well as some eolian-type sands. Perennial (?), mainly spring-generated fluvial activity. Apron and carapace preserved in contemporary tufa fan at Ulco Quarries; local fossiliferous cave fills near Grootkloof may represent another basal facies.

TUFAS OF BUXTON-NORLIM

The tufa sequence of Buxton-Norlim (Peabody 1954) accumulated with respect to two successive bedrock valleys of the Thabaseek River, which now occupies a canyon measuring as much as 200 m from shoulder to shoulder and 50 m in depth. The Thabaseek River begins some 30 km to the west, amid a poorly defined watershed on the Gaap Plateau. This large surface catchment and groundwater basin presumably explains the dimensions of both the erosional and depositional forms at Buxton-Norlim.

The *Thabaseek Tufa,* the oldest recognized by Peabody (1954), formerly extended some 35 m down the escarpment face (see fig. 3). The material is conspicuously white (10 YR 10/2) and correspondingly pure (table 1); the limited detrital residue is a clayey-silt sand, moderately sorted and skewed, with a trace of hygrophytic salts, and subrounded, polished quartz sands. Cavitation and macrosolution are correspondingly well developed, and pink to reddish yellow (5 YR) soil pockets are commonplace. Two points of major interest are (*a*) the australopithecine breccia, discussed further below, and (*b*) the basal breccia ("apron"). The latter (*Thabaseek Breccia*) is described as "a thick surface rubble of dolomite and shale from pebble to boulder size" cemented into "a coarse compact breccia" (Peabody 1954:677 and fig. 6). These field similarities to the breccia terraces of Grootkloof are impossible to overlook, so the basal Thabaseek detritus may well be a frost-weathered footslope rubble. Significantly, too, it lacks derived, older travertines (see also Peabody 1954).

The *Norlim Tufa* is represented by a carapace extending 65 m down the escarpment face. The macroscopic properties are identical to those of Grootkloof Tufa I. The detrital residue is a moderately sorted clayey-silt sand. The sands

[17] M. E. Marker and a student spent time between the Ulco Quarries and Malony's Kloof in 1972 and collected C^{14} samples from the main quarry tufa. These are all older than the effective dating range of C^{14} (J. C. Vogel, personal communication).

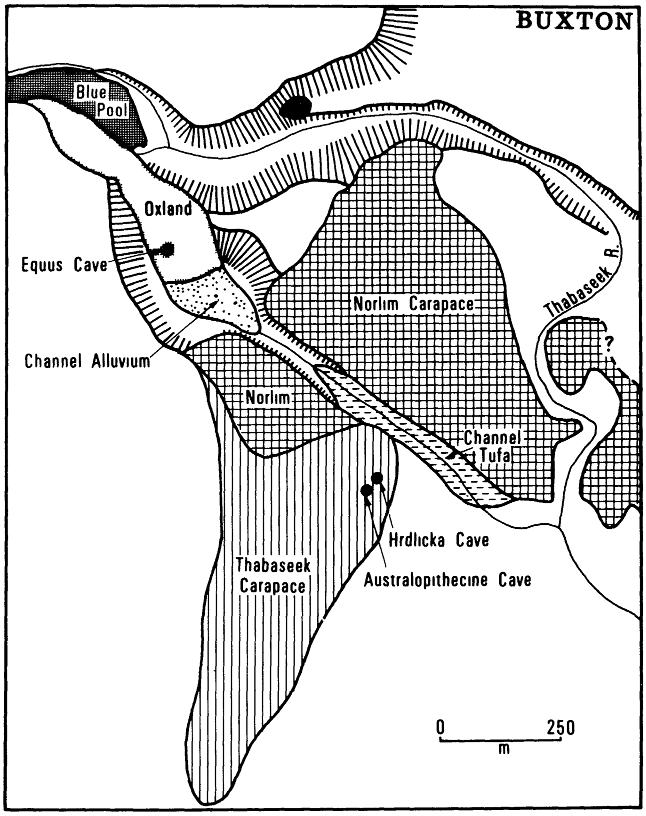

FIG. 3. Tufas at Buxton-Norlim (modified after Peabody 1954:fig. 2).

are exclusively quartz, subangular to subrounded and overwhelmingly polished. Of interest are local pockets of cemented breccia, consisting of crude, angular dolomite rubble in a sandy, reddish-yellow (5 YR) matrix.

This generation of tufa is currently being exploited in a large quarry at Thoming, 8 km south of Buxton-Norlim (see fig. 1). Here Peabody (1954) identified one of two examples of his typical facies sequence[18] with a subhorizontal tufa "apron" embedding sand and rubble, disconformably overlain by inclined, foreset beds of an encroaching tufa fan or "carapace." An identical vertical progression can now be observed in the lower of the two Ulco quarries, with a relatively pure apron limestone dipping at 1° or less, the superposed carapace inclined at 5–10° or more. Both the Ulco and Thoming quarries have yielded valuable organic inclusions from local interbeds or pockets in what are, by all lithologic and geomorphologic criteria, analogous and coeval tufa bodies. These were collected by the respective general works managers of the two companies, Mr. Matter and Mr. Duffy. They include molluscs, a freshwater crab now common to both the Thabaseek and Vaal rivers, and impressions of mosses, reed stems, and broad-leaved plants provisionally identified by Richard Liversidge as *Olea capensis, Zizyphus* sp., and another unidentified broad-leaved tree now absent from the escarpment. (The 13 plant species identified for Peabody [1954:694] by Robert Rodin are not listed; 11 of them are reported to be found there today and the others apparently restricted to moister parts of the Transvaal.)

The Norlim Tufa was followed by a long period of bedrock dissection, during which a 35-m-deep, now abandoned gorge was cut some 900 m back into the escarpment. The terminal period of cutting left a record of crude, footslope talus "of sand and angular boulders of bedrock and of the oldest breccia" (Peabody 1954:678). As visible today, these beds (the *Oxland Breccia*) offer close genetic parallels to the Grootkloof breccia terraces and demonstrate unequivocally that bedrock dissection involved rapid backwearing that included accelerated mechanical weathering.

The *Oxland Tufa* developed within the uppermost part of a gorge eventually choked by the 30 m of total accumulation. The apron facies is exposed to a thickness of 10–12 m, with a basal conglomerate followed by 4–5 m of well-stratified or current-bedded, semicemented, reddish yellow (5 YR) silty sand with dolomite grit and lenses of rounded, coarse to cobble-grade dolomite gravel. The upper half of the apron consists of wavy banded or laminated, very pale brown (10 YR), porous and cryptocrystalline precipitates including bulbous, spring-vent interbeds. Abundant diffuse humus is present, as well as traces of macro-organics, with a detrital residue of moderately sorted silty-sand clay. The finer sands are mainly subangular and polished, the coarser ones rounded and frosted; all are of quartz, and ferric oxide skins are absent. The carapace limestones are steeply foreset at 40–70° but otherwise lithologically almost identical.

After accumulation of the Oxland Tufa, a widespread patina of pyrolusite was formed on most surfaces in the Buxton-Norlim area, an event of evident stratigraphic import (see Peabody 1954) although there is no ready paleoclimatic interpretation (see Engel and Sharp 1958).

The *Channel Alluvium* is a 4–5-m fill that dips 2° downvalley within the defunct pre-Oxland valley. This material grades up from (*a*) a stratified, calcreted, light reddish brown (5 YR) silty sand with angular dolomite grit and lenses of subrounded, coarse to cobble-grade gravel, to (*b*) an unconsolidated, brown (7.5 YR) silty sand with columnar structure, grit, and reworked concretions and finally (*c*) a calcified, reddish yellow (7.5 YR) subsoil with slightly humified top soil. The material is well sorted but skewed, and the sands include quartz with some oxide skins as well as grains of shale/slate. The coarser quartz is rounded and frosted, the finer subangular and partly polished. The Channel Alluvium must be considered as a valley fill derived from colluvial deposits, from a source other than the Oxland Tufa. It includes both residual dolomite soil and reworked or primary eolian sands from above the escarpment. It has no attributes of a swampy, waterhole deposit (*contra* Peabody 1954:697). The topographic and facies parallels of the Oxland Breccia, Oxland Tufa, and Channel Alluvium with the Tufa II/III complex and related breccias at Ulco Grootkloof are unmistakable.

The final stages of geomorphic evolution at Buxton-Norlim were marked by bedrock dissection of the present Thabaseek canyon, followed by accretion and partial blocking of the channel by some 30 m or so of the *Blue Pool Breccia* and *Tufa*. This carapace is macroscopically identical to the Oxland. The two C^{14} dates of 15,980 ± 230 B.P. (SI-1642) and 14,010 ± 170 B.P. (SI-1643) show that the top of the Blue Pool Tufa is temporally equivalent to Tufa III at Ulco Grootkloof. Furthermore, it implies that the Blue Pool Breccia is equivalent to Breccia Terrace I. It is currently being corroded and dissected (Peabody 1954). Peabody's (1954) *Channel Tufa* is probably an equivalent of the Blue Pool Tufa in the old Thabaseek valley.

[18] Peabody (1954) correlates the northern end of the Thoming exposures with the (younger) Oxland Tufa at Buxton. However, the current exposures in the southern half of the quarry are lithologically typical of the Norlim Tufa. The possibility of two generations at Thoming remains open.

THE AUSTRALOPITHECINE DEPOSITS AND OTHER CAVE FILLS

The Taung australopithecine was recovered from a cave fill intrusive within the Thabaseek Tufa. The exact site had already been destroyed by quarrying at the time of Young's visit in 1924 (Young 1926), but Peabody (1954) has meticulously attempted to reconstruct the destroyed cavern topography and its successive fills on the basis of available reports, test excavations, local testimony, matrix adhering to the various fossils, and the exposures remaining in 1947–48. Peabody (1954:681–85) identified four deposits from bottom to top (fig. 4): (1) a massive, reddish, sandy "limestone," fossiliferous, representing a "dry phase"; (2) pure lime intercalated with lenses of reddish, sandy limestone, fossiliferous, marking a "wet phase"; (3) semicemented, coarse reddish sand, sterile; (4) unconsolidated "black earth" with Middle Stone Age artifacts. Whereas deposits 1 and 2 are conformable, 3 and 4 fill successive generations of solution fissures. Peabody marshalls sound evidence that the australopithecine skull was recovered from the "wet-phase" deposits. Unfortunately, the petrographic analyses he obtained were highly generalized and allowed no differentiation of deposits 1, 2, and 3.[19] I have analyzed samples of "dry-" and "wet-phase" deposits, and they are indeed quite distinctive.

A sample of well-cemented, sandy breccia was selected from one of several occurrences in solution hollows of the Thabaseek Tufa, from a point very close to the former australopithecine cave (see fig. 3). This is a pink (5 YR 8/4), inhomogeneous sediment with dispersed grit and small pebbles of corroded, reworked travertine; it has a detrital residue of well-sorted, medium-grade sand (see table 1) and colloidal silica (8% of the total 19% noncarbonate residue) and is marked by pyrolusite streaks. Except for a trace of chert, the sand is quartz, overwhelmingly subrounded to rounded and frosted, with some oxide skins. The electron microscope reveals fluvial marking with strong eolian overprinting. In other words, this is a wash derived in major part from eolian-type sands, with a little local rubble. It clearly represents the sediment type described by Peabody (1954) as his "dry" phase, sandy limestone, and it is similar to other, cemented reddish fillings that carry fossils, primarily baboons, from various points on the Gaap Escarpment.

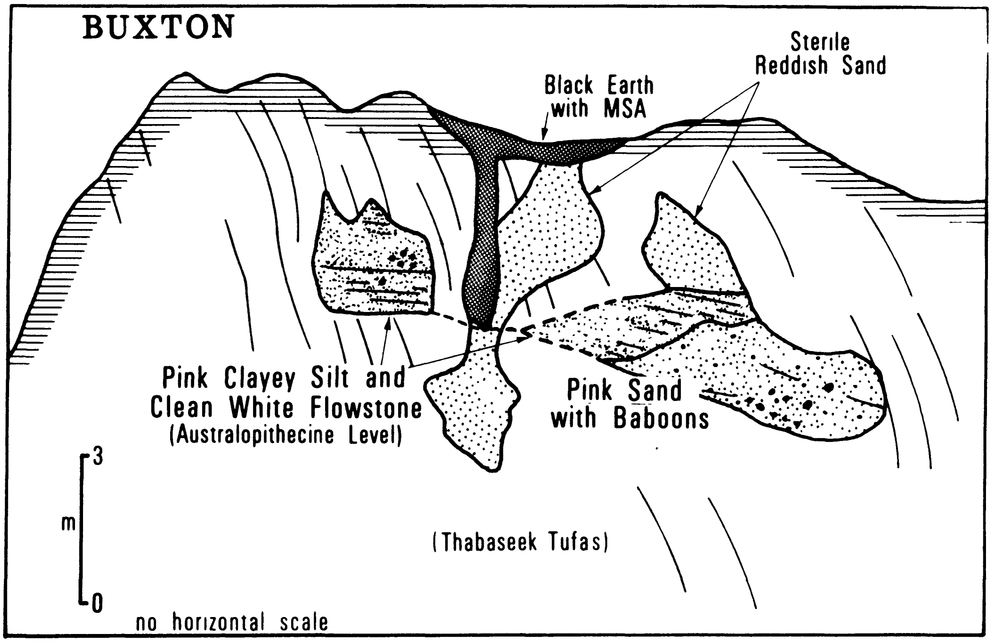

FIG. 4. Section of the Hrdlička Cave, part of the australopithecine cave complex (modified after Peabody 1954:fig. 4).

A sample of the matrix adhering directly to the Taung skull was kindly provided by P. V. Tobias. This is a pink (5 YR 7/4), fine-grained sediment with contorted ("marble") veins of white, cryptocrystalline calcite and small hollows with mesocrystalline calcite. The residue is a moderately sorted clayey silt with a primary clay maximum under 2 μ (41.5% compared with only 3% in the "dry-phase" deposits) and a secondary silt maximum between 6 and 20 μ (23%). The primary component above 37 μ is quartz, mainly polished, and increasing with size from subangular/angular to subrounded/rounded. Many grains have "ferric" skins which, according to the X-ray diffractogram, include 9–10A clay minerals. Eight diffractograms—with various preparations and several fractions—show a strong dominance of montmorillonitic clay, the other minerals, in decreasing order of importance, being illite, muscovite, kaolinite, potassium feldspar(s), quartz, calcite/dolomite, goethite, and rutile (?). Petrographic examination shows the presence of some gray dolomite, ferric-sandy aggregates and opaque iron (either ilmenite or magnetite). Study of the 63–250 μ sand fraction with the electron microscope indicated the presence of some characteristic eolian components, but in general the sample is of extremely mixed provenance. This and the cumulative textural curve argue strongly for a derived soil, incorporating an incidental

[19] These sediments were collectively described as quartz grains in a calcite (totaling over 55%) matrix with less than 1% chert and 2% feldspar; the only heavy minerals noted were traces of zircon; average grain diameter is near 100 μ, with quartz grains occasionally coated with oxide skins and generally hyperangular to subrounded (Ada Swineford, cited by Peabody 1954:683). Young (1926:62) also noted the ferric oxide coatings, but described the quartz grains as angular to rounded, further recovering magnetite, rutile, and tourmaline in the heavy-mineral category. Finally, G. Bond (cited by Oakley 1954:n. 5) found the quartz grains to be of eolian type, presumably rounded and frosted.

amount of secondary, eolian sand.

Consequently, there is a fundamental difference between this "wet-phase" sediment and the "dry-phase" sandy limestone: the Taung matrix is neither a reworked eolian sand, as are most other secondary tufa fills, nor a highly calcified cave flowstone. It is a cemented soil sediment whose calcite has been recrystallized several times and whose coarser components compare most closely with those of the Norlim Tufa (see table 1).

Accordingly, one can suggest the following evolution for the australopithecine cave and its successive fills:

1. Since the australopithecine cave complex was found at variable depths of 5–15 m below the surface of the Thabaseek Tufa, dipping steeply in places as it cut across the bedding planes (Young 1926; Peabody 1954:682–85 and pl. 3, fig.1), it is unquestionably of erosional origin. It is unlikely that active karstic solution would accompany tufa accumulation, and the cavern itself must have been excavated shortly after the Thabaseek aggradation had ceased, while vadose water was still circulating in abundance.

2. After solution became negligible, eolian sands were blown across the tufa land surface or washed down across the escarpment. Ultimately sands of this type found their way into deep fissures, together with a little tufa debris. The excellent sorting, the micromorphology, and the durable class of heavy minerals suggest fairly direct eolian transport from mantles of "Kalahari"-type sands, but the bedding of the "dry-phase" deposits speaks for waterlaid fissure/cavern fill, incorporating large proportions of reworked eolian sand and subsequently impregnated by carbonates.[20]

3. Eventually rainwash began to erode and transport residual soils, while spring activity once more increased and lime-charged vadose waters began circulating again. The resulting "wet-phase" deposits correspondingly include interbedded soil wash, clayey flowstones, and clean travertines.[21] These deposits can be correlated with the initial accretion of the Norlim Tufa and date the Taung fossil accordingly.

4. Following the tufa-accretion phase, a number of fresh, primary fissures were created by fresh karstic solution.

5. Accumulation of sterile reddish sands in these new fissures, or in empty pockets of the old caverns, probably preceded the Oxland Tufa.

6. Further fresh fissures were formed after renewed karstic solution, at the same time that other caverns were dissolved in the Oxland Tufa.

7. Finally, a dark soil—either vertisolic or highly organic—with Middle Stone Age artifacts filled a variety of fissures, including one in the australopithecine cave (fig. 4). Travertine associated with the lower part of the Middle Stone Age breccia at nearby Witkrans Cave yielded a C^{14} age of 33,150 ± 2,500 B.P. (Clark 1971). Furthermore, sound C^{14} dates on the South African Middle Stone Age now run ca. 20,000 to greater than 55,000 B.P. (Klein 1970, Beaumont and Vogel 1972), with coastal occupation extending back well into the Last Interglacial transgression (Butzer 1973*a*). Consequently, an early Upper Pleistocene age for the post-Oxland solution phase seems plausible.

The australopithecine cave stratigraphy outlined here is readily reconciled with the tufa sequence (table 3). It is further corroborated by the evidence from several minor caves described by Peabody (1954), particularly the massive

Equus cave fill (fig. 3). The deposits[22] occupy a solution cavern in the Oxland Tufa apron, below an erosional surface that grades down below the Channel Alluvium. The cave fill is a stratified, partly calcified, reddish brown (5 YR), moderately sorted silty-clay sand, with dispersed, reworked tufa as well as angular dolomite debris.[23] As also verified by electron microscope, the sands are in good part of eolian type—subrounded to rounded, mainly frosted quartz, with some oxide skins—with a few grains of gray chert. This *Equus* cave fill includes eolian components, soil wash, and evidence of mechanical weathering, all indicative of a new aggradation hemicycle. These deposits were originally separated from the Channel Alluvium by some intermediate conglomerates, but are probably only a little older (see table 3).

TABLE 3

GEOMORPHOLOGIC EVOLUTION OF BUXTON-NORLIM
(in part based on Peabody 1954)

12.	Limited dissection and corrosion, with karstic fissures in several tufas, including Later Stone Age soil wash.
11.	*Blue Pool Tufa.* Relatively rapid accumulation of carapace (? coeval with *Channel Tufa* in old Thabaseek valley) and local fissure fills (? "black earth" of australopithecine cave and Witkrans archeological level) with Middle Stone Age artifacts.
10.	Initial accumulation of soil wash, eolian derivatives, and angular rubble in fissures (*Equus* cave and basal Witkrans deposits), with Middle Stone Age artifacts, followed by aggradation of *Channel Alluvium* and thick, basal *Blue Pool Breccia.*
9.	Protracted bedrock dissection and corrosion, with limited karst development in all older tufas. Manganese discolorations on exposed surfaces.
8.	*Oxland Tufa.* Accretion of apron tufas and, ultimately, carapace deposits with soil and eolian derivatives. Seasonal (?), increasingly spring-generated fluvial activity.
7.	Accelerated mechanical weathering of cliffs, with accumulation of crude, angular talus in *Oxland Breccia.* Followed by accumulation of basal fluvial conglomerates and finer alluvium, contemporary with reworked eolian derivatives or angular detritus in numerous Norlim and Thabaseek fissures, including australopithecine cave "sterile red sands."
6.	Protracted bedrock dissection and corrosion, with karst development in Thabaseek and Norlim Tufas, including the solution fissure penetrating the australopithecine deposits.
5.	*Norlim Tufa.* Slow accumulation of carapace facies, overlying apron facies at Thoming. Contains soil derivatives and some eolian-type sands. Perennial (?), mainly spring-generated fluvial activity. Initial aggradation recorded by reddish clayey soil wash and by flowstone interbeds of the upper, "wet" australopithecine deposits. Hominid level.
4.	Colluvial accumulation of eolian derivatives into valley and fissure fills, including the lower, "dry" australopithecine deposits and local breccias. Faunal level.
3.	Dissection and local karst development in Thabaseek Tufa, creating australopithecine cave complex.
2.	*Thabaseek Tufa.* Slow accumulation of carapace facies with minimal impurities of mixed derivation. Perennial (?), spring-generated fluvial activity.
1.	Accelerated mechanical weathering of cliffs, with accumulation of crude rubble in *Thabaseek Breccia.*

[20] These are comparable to Brain's (1967*b*) "Phase II" deposits of the Transvaal Caves, i.e., derived from the surface outside of the cave.

[21] Comparable to Brain's (1967*b*) "Phase I" deposits, i.e., mixed sediment from both outside and inside and inside of the cavern.

[22] Examined by C. K. Brain, Richard Liversidge, and me in 1971.

[23] Peabody (1954) noted fossil fragments, including the tooth of a small *Equus*. P. Verhoef (University of South Africa) recovered a further collection of bones in 1971; these are being studied by C. K. Brain.

AN ENVIRONMENTAL MODEL FOR THE GAAP TUFAS

The sequences outlined for Grootkloof and Buxton-Norlim show that a cyclic form of erosion and deposition has been typical of the Gaap Escarpment during the recent geological past. Table 4 suggests a possible explanatory model for these cycles and allows opportunity for more comprehensive discussion of the related environmental changes. This model has four phases, as follows:

TABLE 4

AN EXPLANATORY MODEL FOR GEOMORPHOLOGIC CYCLES ON THE GAAP ESCARPMENT

PHASE	DOMINANT GEOMORPHIC PROCESS	VEGETATION AND CLIMATE
4	Declining spring and fluvial activity, leading to erosion; karstic solution with fissure and cave formation.	Grassveld and groundcover deteriorating; increasingly dry and warm.
3	Maximum spring discharge and protracted fluvial activity, leading to large-scale tufa accumulation—initially of subhorizontal aprons, later of steep carapaces; clayey beds and flowstones in cave fissures of previous tufa sheets ("wet-phase" australopithecine level), with cementation of older breccias and cave fills.	Grassveld providing optimal groundcover and infiltration; humid and probably cool.
2	Accelerated fluvial and colluvial activity, washing together surficial sediments into valleys and cave fissures (including "dry-phase" baboon deposits); accelerated frost-weathering leading to talus accumulation.	Incomplete groundcover with poor infiltration; increasingly wet and cool.
1	Accelerated eolian activity, with limited colluvial and fluvial processes, leading to thin but extensive mantles of eolian sediments and wash.	Thornveld with limited groundcover and infiltration; dry and warm, in part drier than today.

Phase 1. During long periods of time there is little significant geomorphic change along the escarpment. Most rainfall evaporates or percolates into surficial sediments. Any excess rains lead to local sheetwash that, in view of the incomplete vegetation mat, serves to redistribute loose sediment and soil. Surficial materials include humified residual products, stream alluvium, colluvial wash, and veneers of eolian sands blown in from the west or north by the dominant storm winds. Caves are dry, with slow accumulation, much of this organic. The limited groundwaters feed a small number of insignificant springs, mainly seasonal. Most of these springs are sufficiently lime-charged to deposit carbonate precipitates, algal travertines, and plant tufas on a small scale. However, occurrences are too few and restricted to be of geomorphic significance.

The inferred vegetation is comparable to that of the early 19th century—a thorn scrub-woodland and grassy parkland with limited groundcover and infiltration. Since rainfall ranges from 300 to over 450 mm along the escarpment today, this "warm-dry" morphostatic model allows for considerable latitude of variation to the dry side of modern averages.

Phase 2. Protracted rains capable of outpacing infiltration begin to increase, leading to active sheetwash or sheetflooding and intermittent torrential discharge in streams. Diffuse surficial deposits of diverse origin are washed together in concentrated colluvial spreads, as valley-floor fills, and into cave fissures. Limited, lime-charged cavern waters favor fossilization of bone embedded in sandy cave fills ("dry-phase" baboon deposits). Parallel with accelerated fluvial and colluvial activity, accelerated frost-weathering produces unusual quantities of crude slope rubble, forming talus below the cliffs and markedly increasing the rate of headward stream-cutting into bedrock.[24] Major canyon formation and extension are made possible both by stream dynamism and preparatory frost-wedging.

This morphodynamic model presupposes a cooler and increasingly wet climate. Since the severity of winter frosts has only an indirect relationship with the evaporative losses of surface discharge from heavy summer rains, an absolute increase of precipitation to somewhat above the 450-mm mark is suggested. Vegetation types are difficult to assess, since colder climates would affect many species of the woody thornveld. Groundcover was incomplete, however, and infiltration poor. This precludes a closed grassy mat of sweetveld type and suggests a transitional type of vegetation, perhaps including elements of both the thornveld and the more cold-tolerant karroo shrub.

Phase 3. Eventually the environmental change responsible for Phase 2 crosses a critical threshold, and a new dynamic equilibrium is established between the interacting variables vegetation, weathering, erosion, and deposition. This equilibrium is not established simultaneously everywhere, beginning earlier where hydrogeological conditions favor an early crudescence of spring discharge as groundwater reservoirs increase. The relative increase of spring versus surface waters in the key sedimentary areas is gradual. At first surface discharge transports and deposits detritus—gravels, sands, silts—in the wake of heavy rains; but spring discharge persists throughout the rainy season and a little thereafter, impregnating these deposits with lime and ultimately accumulating in thin sheets of chemical precipitates. Clayey soil wash alternates with primary precipitates in caves and fissures ("wet-phase" australopithecine bed).

Vegetation cover in the catchment ultimately increases to the point where next to no soil products are exposed to erosion and the velocity of surface runoff is inhibited, while infiltration accounts for a higher proportion of the rainfall. True fluvial activity is diminished in favor of stronger and increasingly sustained spring flow, most of it vadose water with only limited underground trajectories. Sheets of relatively pure lime now begin to accumulate along the valley floors and as broad fans ("aprons") below the embouchures of the canyons and kloofs. Each rainstorm produces sheetfloods that sweep across these aprons, carrying a little clay and sand or an occasional pebble, but the major impact is temporary, surface corrosion that is more than compensated for after resumption of spring-fed discharge. In this way the characteristic tufa banding and lamination is produced.

Eventually, significant spring discharge at higher elevations along the scarp walls is favored by a rise of the watertable in the scarp dolomites. Spring waters now cascade down the walls of kloofs or plunge into canyons over lime-encrusted waterfalls. These deposits build forward at

[24] At least two phases of substantial Pleistocene cooling are recorded in the Drakensberg (Ellenberger 1960, Harper 1969, Hastenrath and Wilkinson 1972) and at least three in the southern Cape Province (Butzer and Helgren 1972; Butzer 1973*a*, *c*).

steep angles as "carapaces" that locally replace the aprons. The angles of these carapace sheets decline from almost 90° in waterfalls to less than 40° at the scarp front and 5° or so in low cones that locally build out onto the flat plains below the escarpment. The surfeit of lime-charged waters ultimately leads to thorough cementation of any permeable cave and fissure fills.

The inferred vegetation for Phase 3 is a closed mat of grass with abundant aquatic forms and fringing trees near springs, seeps, and streams. Analogous plant associations may have been found early in the 19th century in the higher grassveld, which now enjoys 500–1,000 mm rainfall and cooler temperatures.[25] Probably the Würm Pleniglacial vegetation of Florisbad—grassveld with local aquatic plants (Van Zinderen Bakker 1957; also Coetzee 1967)—and the climate of Kimberley—over 800 mm precipitation and much cooler (Butzer et al. 1973)—are most applicable.[26] By implication, Phases 2 and 3 saw a rainfall increase from 450 mm to as much as 800 mm along the Gaap Escarpment.

Phase 4. The water supply begins to fail. As spring discharge wanes, surface discharge becomes dominant and tufa attrition outweighs accretion—except near spring vents and seeps. Carapaces and aprons cease to grow and begin to show evidence of superficial corrosion. The watertable falls, too, and incipient underground caverns are rapidly enlarged as vertical fissure networks begin to channel water through the nonfunctional tufa masses, both old and new. In this way new fissures or caves are created in both newer and older tufa bodies liable to circulation of vadose waters. Increasingly sporadic stream discharge eventually carves out new channels through the tufas while conditions return to those of Phase 1.

Groundcover is initially still complete enough to inhibit soil stripping. But protracted rains are decreasing in importance, so that as the grassveld deteriorates, the frequency of sheetflooding is already limited and geomorphologic adjustments remain incomplete. As the climate becomes warmer and drier, a thornveld vegetation returns and essentially morphostatic conditions prevail once again.

The australopithecine cave complex was first eroded during Phase 4, whereas the younger, corrosion fissures represent identical stages within successively younger cycles.

MORPHO-STRATIGRAPHIC CONTEXT OF THE GAAP TUFAS

The preceding model is based on the three and four cycles represented at Grootkloof and Buxton-Norlim respectively. An internal correlation of these cycles is suggested by table 5. Peabody (1954), whose study encompassed the major tufas of the northernmost third of the escarpment, suggested the presence of pre-Thabaseek deposits at Boetsap; further stratigraphic details can be expected from work currently in progress between Douglas and Ulco by D. M. Helgren.

More difficult is the task of external correlation. Direct links with the alluvial terraces of the Harts and Vaal may ultimately be provided by the local sheets of increasingly dolomitic travertines that extend from the escarpment to the valley margins, as tested by the Union Lime Co. (L. Matter, personal communication). Whether or not sufficient bore data can be obtained in an area of minimal exposures remains a moot point. Pending further study by D. M. Helgren of the general planation surface rising from the Vaal and Harts valley-margin to the foot of the escarpment, the best possibilities of external correlation available are the facies alternations of the Harts terrace deposits (see table 1). These allow the tentative stratigraphic suggestions of table 5. The nature of the Harts sequence is basic to our argument and can be summed up as follows:

1. The lowermost Harts is followed by a subrecent floodplain deposit at 2.5 m above low water. This flood terrace continues below the Harts-Vaal confluence and along the Vaal River provides a reference datum at the type site of the late-Pleistocene-to-Holocene Riverton Formation (Butzer et al. 1973). These Harts flood silts consist of well-stratified, light brownish gray (2.5 Y) clayey-sand silts that are moderately sorted (table 1). Quartz sands are mainly subrounded and polished.

2. The Harts also has nonfunctional +3 m (5.5–6.0 m above low water) and +6–8 m terraces. These can be readily related to interfingering Vaal terraces that are identical with Members V and IV of the Riverton Formation. Near the Vaal confluence, these two alluvia consist of brown flood silts identical to those along the Vaal, which appears to have ponded into the lowermost Harts channel. However, upstream, along the Dry Harts at the Buxton Bridge, the two sedimentary bodies are both distinct and informative (see table 1). The lower is 5 m above low water and consists of well-stratified, reddish brown (5 YR) sandy-clay silt, moderately sorted but skewed, with angular, polished quartz dominant in the finer sands and subrounded, frosted quartz with oxide skins in the coarser grades. The coarse sand "tail" and disposition suggest a mixture of eolian-type sands with other fluvial deposits, laid down on the floor of an intermittent stream. The higher terrace, at 8.5–9.5 m, is a massive bedded, vertically structured, brown (10 YR) sediment grading up from silty-clay sand to a silty sand. Sorting decreases and skewness and coarseness increase upwards.

The implication is that of channel sediments deposited in a stream with increasing contrasts in current velocity and briefer, more violent flood crests. There is a significant proportion of oxide-coated, subrounded quartz sands throughout. As in other parts of the northern Cape Province and Orange Free State, downcutting and alluviation were in response to broad regional shifts of the geomorphologic balance (see Butzer 1971*b*), and at Riverton itself there is indirect evidence that Members IV and V are of mid- and late-Holocene age respectively (Butzer et al. 1973). For the Harts drainage, this tentatively suggests that eolian-type components have been available throughout the Holocene, although a more favorable hydrological balance obtained in mid-Holocene times; discharge has since been sporadic.

3. The youngest calcified deposits are found immediately west of the Vaal, Harts, and Dry Harts, where they form the "Younger Sandy Marl" terrace (+7.5 m at Delportshope, but eroded and partly suballuvial upvalley). The material is white to light gray (2.5–5 Y), calcreted by over 50% $CaCO_3$, and has bimodal residues quite similar to the

[25] In terms of geomorphologic processes, both the Brazilian analog of Branner (1911) and the Mediterranean counterparts (e.g., Yugoslavia, Mallorca) presuppose a precipitation of at least 600–650 mm. Yet such conditions are not replicated today in the even wetter dolomite country of the eastern Transvaal (see Marker and Brook 1970). M. E. Marker (personal communication, November 16, 1972) concurs that "indications are that tufa formation required adequate seasonal rainfall and a denser vegetation cover than now obtains, even in areas of ± 500–600 mm rainfall in the northeastern Transvaal."

[26] Contrary to the conclusions of Young (1926) and Peabody (1954), I believe that the major tufas record optimal moisture. Young and Peabody interpret the dramatic record of fluvial erosion in my Phase 2 as the period of maximum rainfall; I, instead, attribute it to rupture of equilibrium and to the torrential discharge typical of semiarid environments without adequate groundcover. See also the analogous interpretation of freshwater limestones of the Kimberley District (Butzer 1973*b*).

younger, Riverton Member IV alluvium (see table 1). Lithologically this terrace allows a correlation with Riverton Member III, which has terminal C^{14} dates of ≥ 17,000 B.P. Correlations with the youngest tufas of the Gaap Escarpment are reasonable both on geomorphologic grounds and on the basis of the Tufa II/III dates from Grootkloof. Consequently, Tufa II/III and Breccia I/II at Grootkloof, as well as both the Channel Alluvium and Blue Pool Tufa at Buxton-Norlim, can be confidently assigned to the Upper Pleistocene. Rolled Acheulian and fresh Middle Stone Age artifacts recovered by Jones (1920) from Harts River lateral gravels near Taung Mission clearly come from this Younger Sandy Marl.

4. At the Delportshope Bridge, an older body of truncated flood silts is found under the Younger Sandy Marl terrace. This "Basal Silt" is a prismatic-structured, gleyed, light gray (5 YR) sediment otherwise quite similar to the modern flood silts (see table 1). Its significance lies in lithological and stratigraphic analogs to Riverton Members I and II at the type site, providing strong confirmation for the terrace correlations offered here.

5. Finally, there are two "Older Sandy Marl" terraces at +18 m and +26–27 m, just below the Vaal-Harts confluence. The older of these terraces comprises gravels interdigitated with calcretes that slope up towards the Gaap Escarpment, where they can alternatively be correlated with the Oxland Tufa or with Grootkloof Tufa I and the Norlim Tufa. This also happens to be the west bank Vaal facies of the "Younger Gravels" substage "A" (D. M. Helgren, personal communication; see Butzer et al. 1973) with its Middle Pleistocene fauna (Cooke 1963, Wells 1964) and Acheulian industries.[27]

This Harts sequence, although based on fragmentary exposures, is almost as complete as the post-"Older Gravel" alluvial sequence of the Vaal at either Riverton or Windsorton. It therefore presents a stratigraphic yardstick of some value for the younger part of the Gaap sequence.

If the preceding argument is accepted and if major geomorphologic cycles of the Gaap and Vaal are placed side by side, the Thabaseek and Norlim cycles can be no older than the last two Vaal terraces of a fourfold Older Gravels complex (see Butzer et al. 1973). Specifically, this would place the australopithecine level of early Phase 3 of the Norlim cycle as equivalent to the rupture of equilibrium suggested by the final ("70-ft.") unit of the Older Gravels. Alternatively, the Norlim cycle could be correlated with Younger Gravels "A," the Oxland cycle with Younger Gravels "C." Although either correlation is possible, I feel that this is the best approximation possible on available evidence and certainly stronger than any existing geological arguments.[28] I further suggest that the Norlim cycle is

TABLE 5

STRATIGRAPHIC RELATIONS BETWEEN BUXTON-NORLIM AND ULCO GROOTKLOOF, WITH POSSIBLE HARTS-VAAL CORRELATIONS

BUXTON-NORLIM	GROOTKLOOF	HARTS (AND VAAL) RIVER	SUGGESTED GEOLOGICAL AGE
(Dissection, solution)	(Dissection) *Tufa IV* (9,300 B.P.)	Floodplain Terrace +6–8 m Fill (Riverton Member V)	Holocene
Blue Pool Tufa and *Breccia;* ?Channel Tufa (≥ 16,000–≤ 14,000 B.P.) *Channel Alluvium;* cave fills with Middle Stone Age artifacts (Dissection, solution)	*Tufa II/III* and *Breccia I/II* complex (≥ 31,000–≤ 20,000 B.P.) (Dissection)	Younger Sandy Marl (Riverton Member III with Middle Stone Age artifacts, ≥ 17,000 B.P.) Basal Silt (Riverton Member I or II) (Dissection)	Upper Pleistocene
Oxland Tufa *Oxland Breccia* (Dissection, solution)	(Dissection)	Older Sandy Marl (Vaal Younger Gravels "C"; Acheulian, with Middle Pleistocene fauna) (?Vaal Younger Gravels "A") (Dissection)	Middle Pleistocene
Norlim Tufa; cave clays and flowstones with *Australopithecus africanus*	*Tufa I*	(Vaal Older Gravels, stage 4: "70-ft."; alternatively, Younger Gravels "A")	Lower Pleistocene
Colluvia, partly eolian, sandy cave fills and local breccias (baboon deposits) (Dissection, solution of australopithecine cave)	(Dissection)		
Thabaseek Tufa		(Vaal Older Gravels, stage 3: "100-ft."; alternatively, stage 4)	
Thabaseek Breccia			
?Older tufas at Boetsap		(Vaal Older Gravels, stage 2: Holpan Platform) (Vaal Older Gravels, stage 1: Nooitgedacht Platform)	Upper Pliocene

[27] The artifactual associations of the Buxton-Norlim area are compatible with this, since all *post*-Oxland cave fills have either Middle or Later Stone Age materials.

[28] The only other line of geological argumentation has been based on incorrect climatic interpretation for the Taung australopithecine correlated with unacceptable climatic inferences from the Vaal terrace sequence (by Peabody [1954]) and from the climatic cycles purportedly reflected in the Transvaal australopithecine breccias (see Brain 1958, and Cooke 1963, *contra* Butzer 1971*c* and 1971*a*:427–31).

of late Lower Pleistocene or even early Middle Pleistocene age, although concepts such as Lower and Middle Pleistocene cannot yet be generally defined by rigorous criteria in southern Africa, even if we accept the Matuyama-Brunhes geomagnetic boundary (700,000 B.P.) as the base of the Middle Pleistocene.

IMPLICATIONS OF THE TAUNG FAUNA

The fauna derived from the australopithecine cave complex in the 1920s raises problems of provenience and interpretation.

The great mass of baboon deposits, including those from Hrdlička Cave, clearly came from the "dry-phase" sands (see in particular Peabody 1954). In fact, most and perhaps all of the mammalian fauna, other than the hominid, appears to come from these lower sands. A piece of turtle carapace was recently found in the hominid matrix (P. V. Tobias, personal communication), so the turtle and freshwater crab probably come from the upper, "wet-phase" clayey silt. The basic Taung faunal assemblage therefore pertains to phase 2 and has only limited applicability to the hominid of phase 3.

Over half of the Taung fauna consists of murid and bathyergid rodents (15 genera or species) or insectivores (3 species or genera) (De Graaf 1960, Cooke 1963), while half of the remainder are forms specifically adapted to rocky outcrops or caves: 2 species of hyrax, a klipspringer (*Oreotragus*), a bat, a small owl, and—if recent baboon occupation serves as a guide—5 species of baboon (*Papio* and *Parapapio*). Thus at least 28 of 33 mammalian species were adapted to cave, rocky, or edaphic microhabitats, and 30 of 33 (91%) are nonmigratory (in the sense of Clark 1971:1228). Pending further work on the microfauna of the Transvaal cave breccias, this renders difficult any stratigraphic and ecological comparisons with the Transvaal faunas, in which large, mobile mammals are well represented.

Cartmill (1967) has attempted to analyze the rodent paleoecology, indicating that 6 out of 8 species with ecological preferences point to a rainfall in excess of 300 mm, compared with 9 of 10 at Sterkfontein, 8 of 8 at Kromdraai, and 13 of 15 at Makapansgat. This essentially argues that the Taung "dry-phase" context was almost as moist as that of the Transvaal cave breccias, a point that is not unreasonable. Significantly, too, the closest modern counterparts of the two most commonly represented forms, which include several species each of *Mystromys* and *Otomys*, are overwhelmingly found in moist, well-vegetated areas. Of equal interest is that at least several of the genera represented may have preferred dry, sandy soil for their burrows, probably not a fortuitous coincidence when their remains come from sandy sediments. Of the remaining mammals, the silver-backed jackal (*Canis* cf. *mesomelas*) and African hare (*Lepus* cf. *capensis*) range from open grassland to deciduous forest; further, an extinct kudu (*Tragelaphus*) and primitive bushpig (*Potamochoerides*) argue for a savanna-woodland mosaic, while a small duiker (*Cephalophus* cf. *caerulea;* see Wells 1967) and Cercopithecoidea required at least some forest.

As an assemblage, the "dry-phase" fauna would be most compatible with the complex of microhabitats offered by a rocky escarpment flanked by plains and dominated by grassy vegetation, yet broken by sizeable stands of thick, fringing woodland near water.[29] This accords well with

[29] As mentioned earlier, the plant impressions from Thoming include two species that argue for moister conditions (Peabody 1954).

the more mesic, transitional vegetation posited above for phase 2. Omitting the sand-burrowing rodents, it would also be a reasonable fauna to expect with the grassland and fringing forest suggested for phase 3.

Traditionally, the Taung skull has been accepted as the oldest australopithecine known from southern Africa. This case has been most comprehensively argued on faunistic grounds by De Graaf (1960), Cooke (1963, 1967), and Ewer and Cooke (1964), who placed the Taung fauna in the earliest segment of the Sterkfontein-Swartkrans "faunal span." A strong reiteration of this view was recently given by Sampson (1971). However, Wells (1967:105–6; 1969) has repeatedly questioned this assignment, and R. F. Ewer (in Wells 1967:105) has admitted that the supporting arguments are slim indeed. Instead, the new short-faced baboon (*Papio wellsi*) from Taung seems to be very close to one from Swartkrans (Wells 1967:105). Similarly, the cercopithecoids from Taung tend to align that site with Swartkrans and Kromdraai rather than with Sterkfontein and Makapansgat (Freedman and Stenhouse 1972). It is, in fact, quite striking that *Parapapio broomi,* the commonest cercopithecoid at Sterkfontein and Makapansgat, is totally lacking from Taung.

Although the revised Taung geology, as presented here, does not allow direct correlation with the Transvaal australopithecine breccias, it demonstrates that the Taung fossil is significantly younger than previously supposed and consequently provides implicit support that Taung is indeed no older than Swartkrans or Kromdraai. Indirectly, too, the Taung matrix is basically similar to the Transvaal breccias, since all are derived by colluvial processes from residual soils of mixed origin and subsequently accumulated in sizeable caverns. A large suite of X-ray diffractograms currently under study shows that the Swartkrans and upper Sterkfontein deposits are often dominated by illite and montmorillonitic clays, whereas hillwash exposed in the Sterkfontein valley today is characterized by illite, possibly in combination with kaolinite. Consequently the weathering environments responsible for the pedogenesis on dolomite that preceded soil erosion in the two areas were fundamentally similar.

CONCLUSIONS

Since the original publication of the Taung discovery by Dart (1926) it has been believed that the type specimen of *Australopithecus africanus* lived on the treeless margin of the Kalahair Desert, with a way of life different from that of extant forest-living apes (see also Tobias 1973*a*). This concept ultimately led to the theory of ecological differentiation between gracile and robust australopithecines. A belief in the great antiquity of the Taung fossil was maintained while further australopithecines were discovered, and it is still widely asserted today that Taung is as old as any early hominid in southern Africa. The evidence marshalled here argues that neither of these claims is acceptable:

1. The Taung australopithecine was penecontemporaneous not with the Thabaseek Tufa (as Peabody suggested), but with the younger Norlim Tufa. Even the solution responsible for creating the cavern postdates accumulation of the Thabaseek Tufa.
2. The fossil is now conclusively associated with the "wet-phase" deposits of the australopithecine cave, whereas most or all of the faunal assemblage appears to have come from the older "dry-phase" deposits.
3. The "dry-phase" deposits reflect intensive denudation

contemporary with the onset of the Norlim sedimentary hemicycle; they are sands with a strong eolian component. The "wet-phase" deposits date from the early phases of Norlim tufa accretion; they are clayey silts, interbedded with flowstones and overwhelmingly derived from residual dolomite soils.

4. A new environmental model for the geomorphologic cycles of the Gaap Escarpment argues strongly for a wetter and possibly cooler climate contemporary with the Taung hominid. A precipitation mean of 600–800 mm (compared with 450 mm today) is suggested, implying that this hominid of the gracile lineage lived in a subhumid or humid and not a semidesert environment. Unfortunately, the new geological evidence offers no clues as to whether the Taung remains were primary or derived, i.e., occupant, prey, or intrusive accident.

5. Since the Sterkfontein valley only receives some 750 mm rainfall today,[30] the Taung context speaks for an environment similar to that coeval with the Transvaal australopithecines. This is compatible with the overall geological evidence from both areas,[31] although the Transvaal breccias span a much longer period of time that was admittedly not homogeneous in terms of geomorphologic trends.

6. Recent reinvestigation of the Harts and Vaal valleys shows that the youngest tufa generation (Blue Pool) can be correlated with Upper Pleistocene alluvia (Riverton Formation Member III), while the penultimate tufa and its basal breccia (Oxland) were generally contemporary with the Vaal Younger Gravels. These have a Middle Pleistocene fauna and evolved Acheulian industries. By extrapolation, the Norlim Tufa would appear to be no older than the last ("70-ft.") stage of the Vaal Older Gravels, presumably of late Lower Pleistocene age.

7. Reconsideration of the Taung "dry-phase" fauna (by L. H. Wells, L. Freedman, and others) shows an increasing number of similarities with those from Swartkrans and Kromdraai.

8. The implication is that the Taung hominid clearly postdates the gracile australopithecines from Sterkfontein and Makapansgat and would therefore also seem to postdate the penetration of true *Homo* into southern Africa. If the Taung specimen is indeed no older than the youngest robust australopithecines of the Transvaal, then such a late, local survival of the gracile lineage would seem to pose new evolutionary and ecological problems.

It requires little emphasis that further stratigraphic work, such as that of D. M. Helgren and myself along the Gaap Escarpment and in the Vaal Valley, will be necessary. Equally evident is the urgent need for palynological testing of the Gaap tufas, systematic study of the plant impressions and fossil invertebrates, and radiometric assays by uranium-series dating on mammalian bone from both the Gaap sites and the Vaal Valley. Substantial improvements in paleoenvironmental interpretation and stratigraphic resolution can, therefore, be expected. As a corollary, the present conclusions may be strengthened or found in need of revision. No less urgent, in my opinion, is attention to two other perspectives of the overall problem: (1) a full publication of the mammalian faunas long ago collected from many different Gaap sites, together with a comprehensive analysis of the rodents recovered from all relevant South African sites, and (2) an up-to-date monographic study of the type specimen of *Australopithecus africanus*.[32] Fresh evaluations in these directions may be no less surprising than my own.

[30] The long-term rainfall records at Kromdraai, Krugersdorp, and Roodepoort range from 716 to 787 mm (*Climate of South Africa* 1965).

[31] As based on unpublished, detailed study of a representative suite of samples from the key Transvaal australopithecine breccias.

[32] In fairness to R. A. Dart, it should be mentioned that Dart did originally write a lengthy monograph on the Taung specimen, but left it unpublished after its appearance in Sir Arthur Keith's writings in 1931 (P. V. Tobias, personal communication).

Abstract

The environmental context and stratigraphic position of the first australopithecine discovery, at Taung, South Africa, need to be reconsidered, since the Taung juvenile, as *Australopithecus africanus*, is the type specimen of the gracile lineage of Plio-Pleistocene hominids. Recent study of the site and its regional setting shows that two generalizations widely held today are either incorrect or dubious. In particular, the Taung hominid is found in deposits that clearly indicate a subhumid or humid environment and not a semidesert, thus questioning the original basis for hypotheses concerning an ecological differentiation of gracile and robust australopithecines. Furthermore, the Taung specimen relates to a younger geomorphologic cycle than postulated by F. E. Peabody, and this cycle appears to immediately predate the Middle Pleistocene "Younger Gravels" of the Vaal River. This and other, faunal criteria suggest that Taung is contemporary with or even younger than Swartkrans and Kromdraai rather than broadly coeval with Sterkfontein and Makapansgat. By implication, the Taung hominid may postdate the arrival of true *Homo* in southern Africa, opening up a new range of problems concerning the phylogeny and ecological adaptations of the australopithecines.