Journal of Archaeological Science 1978, **5**, 317–341

Lithostratigraphy of Border Cave, KwaZulu, South Africa: a Middle Stone Age Sequence Beginning *c*. 195,000 B.P.

K. W. Butzer[a], P. B. Beaumont[b] and J. C. Vogel[c]

Border Cave is well-known for its Middle Stone Age (MSA) sequence and associated hominids, as well as for the earliest demonstrable Later Stone Age (LSA) (*c*. 38,000 b.p.) strata in southern Africa. Detailed lithostratigraphic and sedimentological study permits identification of 8 Pleistocene sedimentary cycles, including 6 major cold phases and 2 intervening weathering horizons. The 2 youngest cold phases are associated with the LSA and have 8 ^{14}C dates 38,600–13,300 b.p. By gauging sedimentation rates in finer and coarser sediments, duration of sedimentary breaks, and allowing for differential compaction, the excellent radiocarbon framework provided by 28 available ^{14}C dates can be extrapolated to the 6 cold intervals and 2 palaeosols that are older than 50,000 b.p. These clearly span oxygen-isotope stages 4, 5 and 6, placing the base of the MSA deposits at *c*. 195,000 b.p., *Homo sapiens sapiens* at *c*. 90,000–115,000 b.p. and the sophisticated, microlithic "Howieson's Poort" industry at 95,000 b.p. These results require radical reassessment of the age and nature of the MSA complex and of the earliest evolution of anatomically-modern people.

Keywords: BORDER CAVE, CAVE SEDIMENTOLOGY, EBOULIS SECS, GEO-ARCHAEOLOGY, *HOMO SAPIENS SAPIENS*, ISOTOPE STRATIGRAPHY, MIDDLE AND LATER STONE AGE, PALAEOCLIMATOLOGY, PALAEOSOLS, RADIOCARBON CHRONOLOGY.

Introduction

Border Cave first drew attention when fossilized human bone was uncovered by Mr W. E. Horton, digging for guano in 1940. Excavation in 1941–42 revealed a detailed sequence of strata with Middle Stone Age (MSA) industries, an infant burial *in situ* within these deposits, and raised the probability that the earlier hominid finds came from the same strata (Cooke *et al.*, 1945; the detailed geological section by H. B. S. Cooke is unpublished and is now in the possession of the Archaeological Research Unit, University of Witwatersrand, Johannesburg, Archaeological Survey File B20/1/2). Renewed large-scale excavation in 1970–71 exposed additional younger MSA levels, an early Later Stone Age horizon, and a capping Iron Age deposit (Beaumont, 1973). Subsequently, in 1974, a hominid mandible was found in context, within the MSA deposits (Beaumont *et al.*, in press). All these human remains are those of anatomically modern *Homo sapiens sapiens* (Wells, 1950; DeVilliers, 1973, 1976; Rightmire, in press). Yet the detailed suite

[a] Departments of Anthropology and Geography, The University of Chicago, U.S.A.
[b] McGregor Museum, Kimberley, South Africa.
[c] National Physical Research Laboratory, CSIR, Pretoria, South Africa.

0305–4403/78/040317+25 $02.00/0

of radiocarbon dates (Beaumont & Vogel, 1972; Beaumont, 1973; Beaumont *et al.*, in press) indicate that even the youngest MSA levels are in excess of 49,000 b.p. In this light the Border Cave sequence assumes a primary importance for human biological and cultural evolution.

The Regional Setting

Border Cave (Zulu: Ingodini) is located at 27°1′19″S, 31°59′24″E, within KwaZulu (or Zululand, annexed to Natal in 1897), 400 m from the undemarcated border with Swaziland (see South Africa 1 : 50,000 topographic sheet 2731 BB/2732 AA "Ingwavuma", 1969). The cave faces W toward the Lowveld from the steep escarpment of the southern Lembobo Mountains (Figure 1). This range, with an average width of 15 km and crest elevations above 650 m, trends N–S, parallel to the 35 km-wide Lowveld erosional plain. These lowland flats have a gently undulating surface (average slope less than 2°), with an elevation of 170–220 m. The escarpment footslope rises at 10–12°, with smooth midslope segments of 18–24° punctuated by high cliffs (72–88°) formed by a succession of thick lava flows; depending on lithology, crest slopes range from 35° to over 80°. Border Cave is situated at a little over 600 m elevation, just below the escarpment rim (to 676 m locally), and is accessible only by a small ledge from above, along a near-vertical face, or by a long, steep, crude talus slope below. By direct line,

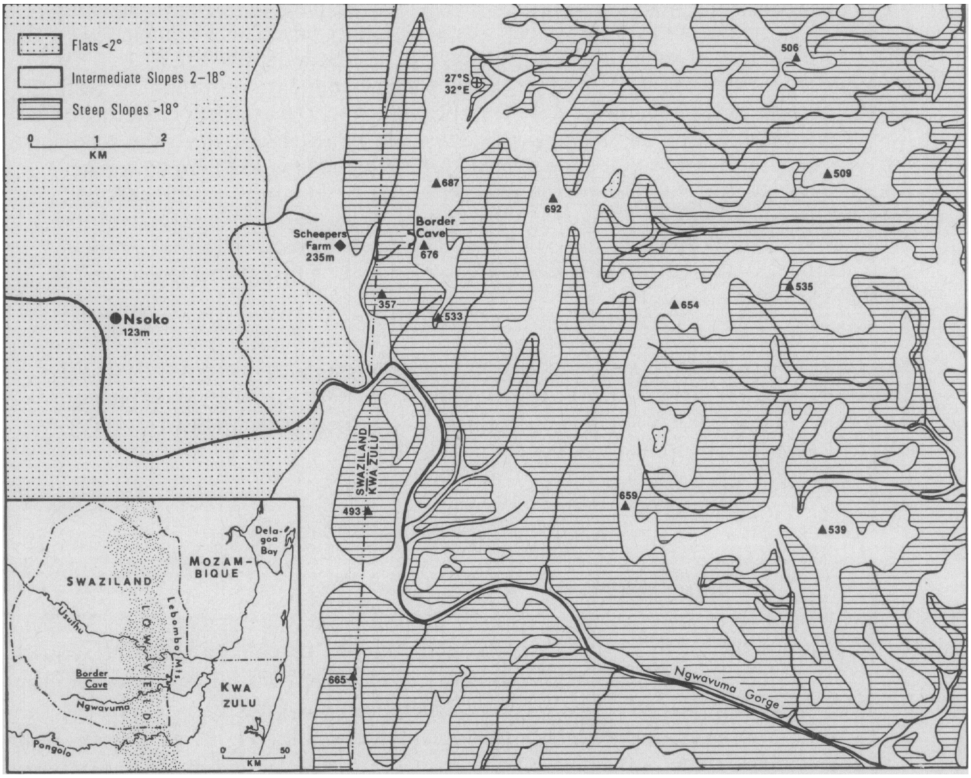

Figure 1. Geomorphic setting of Border Cave. Generalized slope classes derived from 1 : 50,000 topographic maps.

the cave is 1 km E of the G. F. Scheepers farm complex (Canterbury Estates) and 5 km E of the small agricultural centre, Nsoko (183 m), in Swaziland; 1·85 km N of the Ngwavuma River; 12 km N of the district centre, Ingwavuma (610 m), in KwaZulu; and 82 km from the Indian Ocean. The Lebombos form an irregular mountainous upland cut by deep, steepsided valleys (Figure 1) and sloping eastwards, with a regional gradient of 2°, towards a fringe of low mountains that merges with the Zululand–Mozambique Coastal Plain.

The major regional drainage lines (Usuthu, Ngwavuma and Pongolo Rivers) flow from W to E, cutting through the mountains as superimposed streams, ultimately emerging in Delagoa Bay via the Maputo River (Figure 1). It is not surprising, therefore, that the area has for a long time been of special geological and geomorphic interest. The Lebombo Mountains consist of up to 9000 m of rhyolitic extrusions, related to a N–S crustal fissure (King, 1967*a*, pp. 142, 249; Wachendorf, 1973). These rhyolites are under- and overlain by basalt sequences, and all pertain to the uppermost, Stormberg Series of the Karroo System; adjusted rubidium-strontium isochrons indicate an age of 191 ± 13 m.y. (terminal Triassic or basal Jurassic) for the rhyolites, i.e. slightly older than the Drakensberg basalts (Fitch & Miller, 1971). Although the Lebombo rhyolites dip as much as 30–40° eastwards (Wachendorf, 1973), their 2–3° surface projection has been attributed to Miocene ("Post-African") erosion and Plio-Pleistocene tilting, as part of the Lebombo or Natal monocline (King, 1967*a*, pp. 249–250, 1967*b*, pp. 297–298). The eastern margins are gently inclined at 5–10° and conformably overlain by late Cretaceous sandstones, conglomerates and shales that dip below the undifferentiated, late Cenozoic sands of the Coastal Plain (see Geological Map of the Republic of South Africa, 1 : 1,000,000, Southeastern Sheet, 1970).

The Lowveld represents a younger erosional surface cut across older Karroo rocks, specifically Stormberg basalts and Ecca shales. No faults delimit the rhyolite escarpment, so that creation of the Lowveld depression can be attributed to differential erosion of the physically weaker shales and chemically weaker basalts. On the other hand, King (1967*a*, p. 248) has attributed erosion to the readily-weathered crystalline rocks of the Basement Complex, although the basement is only exposed further W, beneath the higher and older Middleveld surface (see Baillie, 1970, for a map of Swaziland geomorphic regions). A problem is also posed by some 500 m of vertical erosion across a 35 km-wide surface since the inferred Plio-Pleistocene uparching of the monocline, as described in King's (1967*a*, p. 250, 1974) stratigraphic framework. Such extensive erosion in less than 2 m.y. is difficult if not impossible to accept in default of detailed regional studies.

The almost unique geomorphic setting of Border Cave is nonetheless unquestionable. Cooke *et al.* (1945) attributed development of the cavern to differential weathering of welded agglomerate (pyroclastic interbeds) within a sheer rhyolite face, just below the cuesta rim of the erosional Lebombo Escarpment and 450 m above the Lowveld. Wachendorf (1973) described the uppermost 100 m or so of Lebombo rhyolites as a poorly laminated, slightly banded, uniform rhyolite with a granophyric groundmass and containing phenocrysts of feldspar and occasional quartz. Differentiation reflects a series of textural zones due to differential rates of cooling and crystallization. The dimensions of the cave at present (Figure 2) are some 40 m in width and a maximum of 30 m in depth, with a semi-circular shape (Cooke *et al.*, 1945, figure 1). Considering the slow rates of later Pleistocene change, as outlined further below, and a total absence of seepage water through the roof or walls, the opening of such a large cavern presumably took place throughout the Pleistocene. This does not allow for rapid undermining and active backwearing of the escarpment face during the later Pleistocene. Monoclinal tilting of the Karroo System rocks, basic entrenchment of the major rivers, and removal

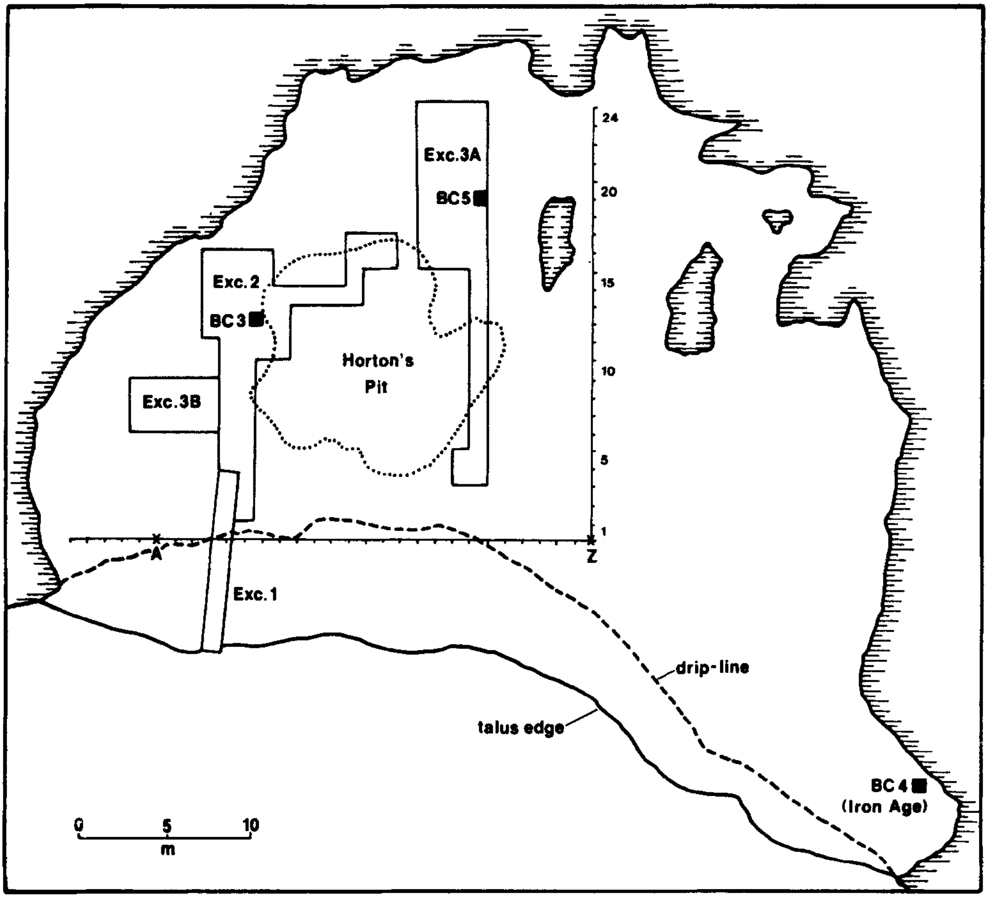

Figure 2. Plan of Border Cave. After Cooke *et al.* (1945) and Beaumont (1973). Excavation 1 due to R. A. Dart, 1934.

of the bulk of the sediment derived from erosion of the Lowveld would seem to date well into the late Tertiary.

Climatically, the Border Cave area belongs to the summer-hot, mesothermal, winter-dry Cwa type of Koeppen, with a tropical savanna climate (Aw) extending down from Mozambique to the adjacent Coastal Plain. Using the Thornthwaite system, the drier Lowveld is warm-mesothermal, semi-arid, with no water surplus at any season (DB'_4d), whereas the crest of the Lebombo Mountains is subhumid ($C_1B'_4d$) (see Schulz, 1958). In terms of actual statistics, local rainfall varies from 500 mm in the lowlands to 900 mm in the highlands, with 75–80% of the precipitation received during the summer half year (Climate of South Africa, 1965*a*, 1965*b*). The Nsoko temperature record (7 yr) and that of other Lowveld stations indicates a warmest monthly mean (January) of 25–26 °C, a coldest monthly mean (June) of 16–18 °C, and a mean annual range of 7·5–10·0 °C, compared with a mean diurnal amplitude of 12–15 °C (see, Climate of South Africa, 1954). A mean daily range greater than the annual range is often considered to be characteristic of tropical climates, and frost is sporadic in the Lowveld at the present time, occurring every few years in low-lying areas with cold air drainage and strong inversions. The mean annual low at 5 stations is +0·5 to +5·7 °C. Analogues for the Lebombo Mountains are provided by Stegi, Swaziland, at 653 m elevation, and Melmoth, Natal, at 770 m. At the former the mean annual low is 6·2 °C, the record low 3·3 °C (52 yr record), while at the latter the values are 5·0 °C and 2·0 °C (30 yr record). This indicates that a ridge site such as Border Cave would be frost-free.

The native vegetation of the region is subtropical, deciduous savanna and bush, much degraded by pastoral land-use and deliberate burning or cutting, and edaphically conditioned by bedrock lithology and slope. The characteristic Lowveld vegetation, according to Acocks (1975, p. 30; also 1 : 1,500,000 vegetation map, accompanying original 1951 edition), is dominated by acacia (*A. nigrescens*), marula (*Sclerocarya*) trees as well as *Digitaria*, *Themeda* and *Eragrostis* grasses. This gives way to dense bush or thickets on the rocky hillsides and low-order valleys, or open acacia (*Ficus*) forest along riverbanks. The Lebombo Mountains, on the other hand, maintain a cover of bush savanna and open acacia savanna, although forest and scrub forest may have been dominant in the recent past (Acocks, 1975, pp. 23–24, "Zululand Thornveld"); the broken country under 450 m elevation includes vestiges of a former mantle of humid-tropical, arboreal genera (*Rauvolfia*, *Protorhus*, *Trichilia*, *Combretum*), with aloes, fig, and Euphorbiaceae on steep slopes and acacia (*Themeda*) savanna on level ground; the high ridges and the more extensive, rolling uplands suggest an original cover of sub-humid, subtropical scrub forest (*Turraea*, *Tricalysia*, *Commiphora*) with larger tracts of open thorn savanna.

A good soil map (at 1 : 125,000) is available for Swaziland (Murdoch, 1970), but soils in the KwaZulu sector of the Lebombo Mountains have not been mapped or classified in any detail. The basic regional type is a brown, clayey soil with limited horizonation (Murdoch, 1970; also Van der Merwe, 1962). On the basaltic terrain of the Lowveld, red to brown (Munsell hue 5–7·5 YR), well-structured clays can commonly be seen in 60–100 cm profiles. Black or dark-grey (Munsell hue 10 YR) clays with coarse blocky to prismatic structure, usually containing calcareous concretions, are localized in flat, low-lying areas. All slope soils are thin and stony, especially on rhyolite.

This biophysical mosaic represents the diversified, three-dimensional catchment accessible to the prehistoric occupants of Border Cave under contemporary climatic conditions. The cave sediments indicate a fourth, temporal dimension, showing evidence of repeated and substantial changes in the regional environment. It is within this complex contextual framework that the Border Cave archaeological record must be interpreted.

Laboratory Procedure

During a visit to Border Cave by Butzer and Beaumont in August, 1973, the stratigraphic sequence was examined in terms of bedding properties, pedogenetic features such as calcification, gypsum or sodium salt horizons, and the prominence of cultural features such as organic hearths, ash horizons, or disconformities. A total of 22 sediment samples was collected from excavations 3A and 2, chosen to emphasize the sedimentary matrix, rather than zones of intensive cultural or organic components. In addition, 3 gravel, 2 external soil samples, and a variety of bedrock specimens were sampled. In April, 1974, Beaumont collected 12 further sediment samples from excavations 3A and 3B, and 2 samples of gravel. The gravel was morphometrically analysed by Butzer in South Africa, while the sediment samples were later processed in the Palaeo-Ecology Laboratory of the University of Chicago.

Sediments were first examined macroscopically, including colour determination (by the *Munsell Soil Colour Charts*, natural dry state), structure, consolidation, stratification (as far as still preserved), calcification or oxidation features, and organic structures. The detailed analytical work was undertaken in several stages:

(1) Full hydrometer analyses, using a 5% solution of sodium pyrophosphate as

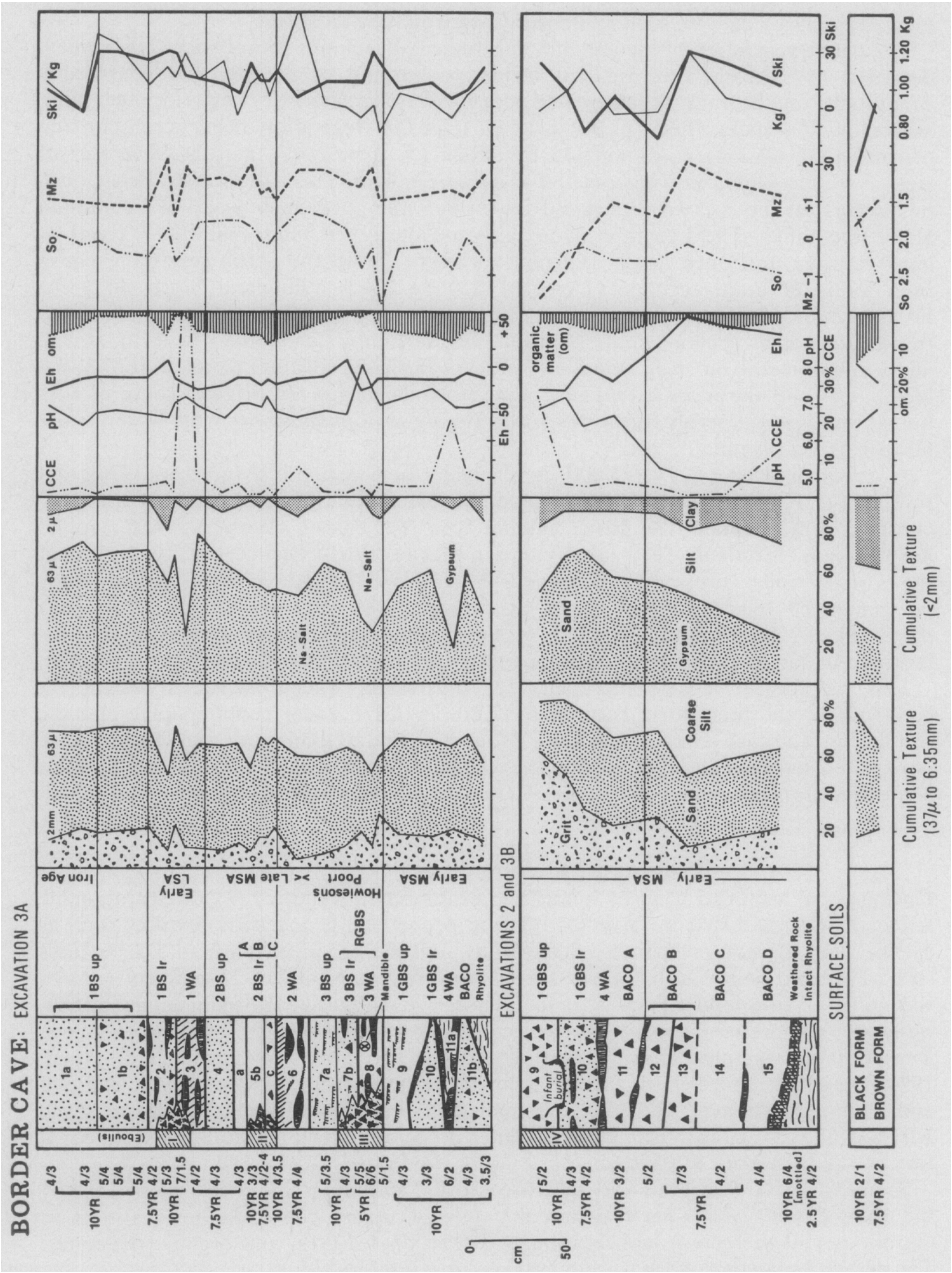

Figure 3. Sedimentological data for Border Cave.

peptizing agent. After determining the 2, 6, 20, and 63 micron fractions, the same sample was subsequently passed through a set of standard sieves (37, 63, 210, 595 microns, 2 and 6·35 mm), with water flushing.

(2) Textural categories were determined—clay (under 2 microns), silt (2–63 microns), sand (63 microns—2 mm), and grit (2–6·35 mm). The clay-silt-sand fractions are shown as a separate cumulative curve in Figure 3 and allow textural classification. The terminology of Link (1966) was followed here, except for soil and morphological designations, which were given according to *Soil Taxonomy* (Soil Survey Staff, 1975).

(3) Since the coarser fraction provides potential information as to the nature and prominence of mechanical weathering, the grades between 37 microns and 6·35 mm were examined in detail. Firstly selected values were plotted as a cumulative graph in Figure 3. This was followed by drawing cumulative curves for each set of values to obtain the 5, 16, 25, 50, 75, 84 and 95 percentiles. These were processed by a mini-computer programme to calculate the mean (Mz), sorting (So), skewness (Ski), and kurtosis (Kg) parameters of Folk & Ward (see Folk, 1966). Since these measures require representative samples to provide environmental information, 19 of the 37 sand samples were pre-treated in sodium hydroxide to remove carbon, calcium phosphate, colloidal aggregates, or "fired" particles, and then sieved and weighed a second time. These parameters consequently apply to rhyolitic residues only.

(4) The sand and grit grades retrieved by sieving were scanned microscopically for lithology and micromorphology.

(5) Calcium carbonate equivalent (CCE) was determined by the Chittick gasometric apparatus, in part also by mass loss in dilute hydrochloric acid. pH and electrical resistance (Eh, in millivolts) were determined electrometrically in distilled water.

(6) Five samples of gravel were analysed morphometrically by the modified Lüttig technique (see Butzer, 1971, pp. 166ff.). Since all edges were angular, irregular and uncorroded, no meaningful index of rounding could be devised. The results instead provide two measures of flattening as well as size.

(7) Finally, a part of each sample was selected (matrix under 2 mm) for determination of organic matter content (om), through the courtesy of the University of Wisconsin, Department of Soils, Extension Division.

The most diagnostic categories of analytical data are incorporated into Figure 3 and have subsequently been used to describe and interpret the various lithostratigraphic horizons. These units coincide with those of Beaumont (1973; Beaumont *et al.*, in press), but a system of Arabic numbers is employed here, counted from the top down, to simplify reference to cumbersome field level designations.

In the following sections, unless otherwise stated, it is assumed that the units are powdery, unconsolidated, vesicular and weakly-structured, moderately stratified, and separated by abrupt (0–2 cm) straight to slightly wavy contacts. With respect to Figure 3, calcium carbonate equivalents are mainly in the order of 0·5–5%, and no comment has been made on such low values. Similarly, pHs in the neutral to slightly alkaline range of 6·4–7·2, and Eh's of 0 to −25 warrant no further comment. Modal values of organic matter in "background" sediments (as opposed to hearths and other lenticular concentrations) are between 2·5 and 6·5%; only lower or higher values deserve mention.

In regard to the 37 micron to 6·35 mm fraction, the following results were obtained:

(a) Mean particle size (Mz) ranges from −1·65 to +2·07 φ, but generally lies between +1·0 and +1·5 φ; when the mean is less than +1·0, the sands will be labelled "coarse", and when it is above 1·5, "fine".

(b) Sorting is poor (So 1·0–2·0, see Folk, 1966) to very poor (So 2·0–4·0), ranging from 1·64–2·91. Values under 1·75 will be referred to as "moderately" sorted, those above 2·25 as "very poor".

(c) Skewness (asymmetry of grain-size distribution) is relatively subdued, with the occasional fine-tailed sediments beyond Ski −0·2 and coarse-tailed sediments above +0·2 referrred to here as "negatively"or "positively" skewed, respectively.

(d) Kurtosis (peakedness of grain-size distribution) is near normal; values above 1·2 will be referred to as "leptokurtic", i.e. with coarser and/or finer tails, those below 0·85 as "platykurtic", i.e. bimodal.

Description of the Strata

The successive units can be described from top to bottom:

(1a) *15–45 cm* ("First Brown Sand, Upper").

Dark-brown, organic silty coarse sand, with rare roof spall, some hearths and well-preserved vegetable fibre. (Iron Age; 9 ^{14}C dates of 90 to 650 b.p., see Table 1). Lower boundary diffuse and poorly defined, probably irregular due to cultural disturbance, e.g. storage pits; some sharp disconformities preserved locally (Beaumont *et al.*, in press).

Table 1. ^{14}C dates from Border Cave. All determinations on large charcoal fragments except Pta-777 and Pta-1318 on bone collagen. Samples pre-treated in acid and alkali, unless otherwise noted. La Jolla dates courtesy of J. L. Bada.

Level	Square	Laboratory Number	Data (b.p.)	$-\delta^{13}C$(‰)
1a	T21 (8–15 cm)	Pta-1728	90±105	10·9
1a	T21 (8–15 cm)	Pta-870	170±45	17·6
1a	T19 (30–38 cm)	Pta-715	440±55	21·6
1a	T22 (7·5–15 cm)	Pta-703	500±45	20·3
1a	T22 (30–38 cm)	LJ-2889	500±70	
1a	T22 (38–46 cm)	LJ-2890	590±70	
1a/b	Outside grid: Iron Age Skeleton, limb bone	Pta-777	340±45	9·5
1a/b	Ditto: rib	Pta-1318	480±45	11·8
1a/b	T22 (46–53 cm)	LJ-2891	650±70	
1b	S19 (38–46 cm)	Pta-506	2010±50	25·7
1b	S19 (46–53 cm)	Pta-721	13,300±150	24·2
1b	T22 (61–69 cm)	LJ-(?)	28,500±1800	
2	T22 (top)	LJ-2892	33,000±2000	
2	S21 (base)	Pta-704	38,600±1500	24·3
3	T21 (top), residue	Pta-422	36,800±1000	24·3
3	Ditto: acid only	Pta-446	37,500±1200	23·9
3	T21 (mid)	Pta-423	36,100±900	24·2
3	T21 (base)	Pta-424	35,700±1100	24·2
3	R19 (base)	Pta-1190	45,000 +2750, −2200	24·1
4	T23	Pta-872	>42,300	25·3
4	Q22	Pta-877	45,400 +3000, −2000	25·0
4	R21	Pta-1244	>48,800	24·8
4	Q20	Pta-1274	47,200 +4200, −2750	25·7
4	Q21	Pta-1275	>49,100	24·4
7b	A7	Pta-489	>48,700	24·8
8	OZ7	Pta-459	>48,350	24·6
8	OZ7, OZ9	Pta-719	42,000 +3000, −2000	24·6
8	A8	Pta-488	>48,500	25·4

(1b) *15–25 cm*

Yellowish-brown, silty coarse sand, negatively skewed and leptokurtic, with considerable roof spall (larger than 6·4 mm fraction comprises 15–25% of total weight at back of cave); relatively low in organic matter but with some colloidal aggregates present. (Archaeologically sterile; 3 ^{14}C dates of 2010, 13,300 and 28,500 b.p., the first possibly based on mixed charcoal fragments, see Table 1).

(2) *15–20 cm* ("First Brown Sand, Lower").

Dark-brown, silty coarse sand, very poorly sorted, negatively skewed; gritty, and with abundant roof spall near base, grading laterally into the upper part of an angular spall horizon with limited fine matrix (Eboulis Horizon I). Generally low in organic matter, except in thin but prominent hearth zones, which consist of clayey silt-sand (fine). (Early LSA; 2 ^{14}C dates of 33,000 and 38,600 b.p., see Table 1).

(3) *12–20 cm* ("First White Ash").

Dark-brown, silty fine sand, grading laterally in the lower part of Eboulis Horizon I. Numerous thin, black, highly organic hearths, and lenticles of light-grey to brownish-grey, silty calcareous ash, rich in calcium phosphate, bone fragments, and fire-oxidized aggregates. (Early LSA; 5 ^{14}C dates ranging from 35,700–37,500 b.p., see Table 1, indicating that units 2 and 3 are close in age; Pta-1190 may represent derived charcoal or mixing).

(4) *12–18 cm* ("Second Brown Sand, Upper").

Dark-brown, silty sand. (Late MSA; 5 ^{14}C dates ranging from 45,400 to "greater than" 49,100 b.p. [Table 1], with greater confidence given the "infinite dates", so indicating a probable hiatus of at least 12,000 yr between units 3 and 4).

(5a) *7–8 cm* ("Second Brown Sand, Lower A").

Dark-brown, silty sand (Late MSA).

(5b) *7–10 cm* ("Second Brown Sand, Lower B").

Dark-brown to brown, silty fine sand, rich in fire-oxidized organic aggregates, grades laterally into Eboulis Horizon II. Some diffuse hearths (Late MSA).

(5c) *7 cm* ("Second Brown Sand, Lower C").

Dark-brown to brown silt to sandy silt, highly organic, with some spall but laterally interdigitated with the base of Eboulis Horizon II. Some minor hearths (Late MSA).

(6) *15–23 cm* ("Second White Ash").

Dark-brown, silty fine sand, slightly compact, moderately sorted and leptokurtic; interbedded with a complex of prominent black hearths, light-grey, calcareous ash lenses, and reddish brown (5 YR 5/4) "fired" horizons, rich in charred vegetable matter. Small lenticles of mesocrystalline sodium salts (see Beaumont, 1973, Table 1, for analyses) are present near and below the base of this horizon complex (Late MSA).

(7a) *15 cm* ("Third Brown Sand, Upper").

Yellowish-brown, silty fine sand, moderately sorted, well stratified to laminated, slightly compact, and low in organic matter ("Epi-Pietersburg" or "Howieson's Poort").

(7b) *10–12 cm* ("Third Brown Sand, Lower").

Dark-brown, silty sand, slightly compact; some thin, black hearths and dark ashy lenses but otherwise low in organic matter; rare roof spall, but grades laterally into top of Eboulis Horizon III ("Rubbly Grey-Brown Sand, Upper"). ("Epi-Pietersburg" or "Howieson's Poort"; ^{14}C age infinite, see Table 1).

(8) *15–20 cm* ("Third White Ash").

Complex of reddish brown to yellow, sandy to fine sandy silt, rich in fire-oxidized aggregates, in part very poorly sorted or negatively skewed; light grey to greyish brown ash with a texture of gritty, coarse sandy silt, very poorly sorted and platykurtic; some black, organic hearths. Zones of roof spall, a local rock fall at the contact of beds 7b and 8, and grading laterally into the base of Eboulis Horizon III ("Rubbly Grey-Brown Sand, Lower"). Voids among the rock fall blocks show white (10 YR 8/2), mesocrystalline sodium salts. ("Epi-Pietersburg" or "Howieson's Poort"; ^{14}C age infinite, see Table 1).

(9) *17–35 cm* ("First Grey-Brown Sand, Upper").

Dark-brown to greyish-brown, silty sand, finely laminated towards top, slightly compact; dispersed spall in cave centre (Excavation 3A), grading into a spall-grit-soil horizon (Eboulis Horizon IV) with a calcareous, clayey-silt sand matrix, rich in fire-oxidized aggregates and very poorly sorted, laterally (Excavation 3B) (Early MSA).

(10) *10–20 cm* ("First Grey-Brown Sand, Lower").

Dark-brown, silty sand, highly organic, slightly compact. Grades into a grit-and-spall horizon (Lower Eboulis Horizon IV) with a matrix of silty coarse sand, very poorly sorted and positively skewed, near the cave's N end (Excavation 3B). Variable development of hearths (Early MSA).

(11a) *5–10 cm* ("Fourth White Ash").

Lens of light greyish-brown, highly organic silt, mainly a phosphatic ash, with feathering hearths. Forms a conspicuous marker. Locally rests on bedrock, where there are local lenticles (square S-17), 3–8 mm thick, of vertically precipitated, macrocrystalline gypsum (Early MSA).

(11b) *20–30 cm* ("BACO A").

Brown to dark-brown, silty sand or clayey-sand silt with some roof spall and slightly compact, in cave centre (Excavation 3A). Thickens to N (Excavations 2 and 3B), where it consists mainly of very dark greyish-brown, gritty, silty coarse sand with some roof spall (Early MSA).

(12) *15 cm* ("BACO B", Upper).

Brown, gritty, silty coarse sand with moderate spall concentration, very poorly sorted and positively skewed; acidic (pH 5·3) and high Eh (+25). Packed with artifacts. This and lower units restricted to Excavations 2/3B. (Early MSA).

(13) *15–18 cm* ("BACO B", Lower).

Pink, clayey-silt sand (fine), a moderate concentration of spall, negatively skewed; coarse angular blocky structure; compact, due to extensive impregnation with meso to cryptocrystalline gypsum; low in organic matter; acidic (pH 5·0) and high Eh (+55) (Early MSA).

(14) *25 cm* ("BACO C").

Dark-brown, clayey-sand silt, negatively skewed; slightly compact; acidic (pH 4·9) and high Eh (+45). Minor hearths, extensive evidence of "firing" (Early MSA).

(15) *25 cm* ("BACO D").

Dark-brown, clayey-sand silt to sandy-clay silt, with plant residues; very poorly sorted; slightly compact with crumb structure; locally calcareous due to abundant corroded, bone debris, yet acidic in general (pH 4·8) and high Eh (+35) (Early MSA).

This lower sequence rests on chemically weathered, salt-veneered, slightly cavernous, friable, light yellowish-brown, rhyolitic bedrock with fine, yellowish (2·5 Y) and reddish yellow (5YR) mottles. Intact bedrock is weak red ("violet") (10 R) and indurated.

The brown surface soils, developed on similar bedrock above the cave roof, are qualitatively similar to the basal stratum of Border Cave (Figure 3): a highly organic, stony, sandy-silt clay (or "loam", in pedological usage), very poorly sorted and with micro-crumb structure. However, the surface soils are neutral rather than acidic. Horizonation is poorly developed, in part because organic O-horizons have been eroded to produce "black form" colluvial soils in concavities. One such black soil was sampled. It is a moderately sorted, silty-sand clay (or "clay loam"), negatively skewed, and with over 13% organic matter.

Analytical Interpretation of the Strata

The Border Cave depositional sequence, as described above, is highly informative in terms of sedimentology. The inclination of the cave floor and the setting within a steep cliff face precludes natural introduction of mineral sediment from the outside, either by wind or water through the entrance, or by infiltration through roof or wall fissures. Access has always been difficult so that importation of mineral sediment by man or animal has also been limited, if not minimal, with the exception of lithic artifacts and associated debitage (components that were systematically excluded from the above statistics). Nonetheless, organic agents have significantly modified the sequence by introducing plant and animal matter, and through fire, by volatilizing carbon, breaking down bone, creating new aggregates (fire-oxidized grains and ash), and comminuting mineral grains from sand to silt size. Although secondary aggregates were eliminated from the analyses by sodium hydroxide application, organic-mineral colloids do contribute to the clay fraction in several levels.

Environmental interpretation of the sedimentological data consequently requires prior discussion of the several components to the cave fill.

Cultural Components

The biological factor in Border Cave is essentially cultural. Other tangible contributions are limited to variable quantities of minute, fragmentary rodent bone; since rodent burrows are nowhere in evidence in the standing sections, this has probably been due to the occasional owl roosting within the cave (see Beaumont, 1973). Cultural modification is apparent in many ways:

(i) Basic fine sediment colour in unit 1B is yellowish-brown (10 YR 5/4); that of weathered bedrock, light yellowish-brown (10 YR 6/4). Diffuse organic matter has discoloured the strata (other than hearths or ash lenses) to an average dark-brown (8·98 YR 4·35/2·78) colour. This is corroborated by a mean organic matter content of 4·05% for these same strata. Organic matter ranges from diffuse humic acids to charcoal and plant-fibre, but pollen appears to be rare (Beaumont, 1973). Rodent micro-bone concentrations are greatest in those levels with yellowish-brown colour and less than 3% organic matter, i.e. units 1b and 7a (see Beaumont, 1973).

(ii) Concentrated, lenticular hearths, of very dark-grey or black colour, are prominent in about half of the strata. These and other discolourations serve to highlight the stratification details of the cave, showing that occupation accelerated sedimentation rates (probably through reworking of superficial sediment into lenticular cultural deposits) and created disconformities (by mobilizing or deliberately removing existing sediment). It is probable that no natural, erosional breaks exist in Border Cave.

(iii) Reddish, fired horizons, rich in oxidized aggregates ("micro-brick"), are conspicuous in unit 8, and in a more subdued way contribute to levels 3, 5b, 6, 9 and 14. Such features suggest more intensive or persistent fires, with more complete volatilization of carbon than in the black hearths.

(iv) The light-grey, ashy lenses range from non-calcareous, reduced mineral ash to calcareous, phosphate-rich "bone meal" with fragmentary, brittle and porous bone, all with some admixture of diffuse organic matter. It is probable that most of these horizons, best developed in units 3, 6, 8 and 11a, are distinguished by a variable degree of bone ash. Generally, bone preservation is poor, not only because of fragmentation during initial food processing, but above all because of post-depositional trampling and fire. Of some 139,000 bone fragments from Excavation 3A (Beaumont *et al.*, in press), Klein (1977*b*) identified only 313 individual bones of various mammals (other than rodents).

(v) Figure 3 shows a close correlation between clay-sized particles and organic matter in Excavation 3A. It is probable that, in this totally dry sector of the cave, there never has been measurable, authigenic clay mineral formation. However in Excavations 2 and 3B, clay and organic matter trends are inverse, and clays are substantially more prominent. From this it can be inferred that clay-mineral formation and genuine clay-humus compounds (not just organic colloids) are present in units 9 and 12–15.

(vi) Several silt peaks of Figure 3 coincide noticeably with intensively disturbed cultural strata, particularly in units 3, 8 and 11a. The 10–40 micron fraction is most affected. Microscopic examination of the sands of these levels reveals them to be porous, brittle, and mottled (pale-brown to light-grey), presumably due in part to intensive heating. Consequently the sand-silt ratio in Excavation 3A has little non-cultural significance.

(vii) The pH and Eh fluctuations of Figure 3 show little relationship with cultural phenomena but the minor details above unit 12 can be linked to concentrations of sodium salts and calcium phosphate.

(viii) The lithic artifacts of the various levels vary in terms of their relative mass with respect to sediment matrix, and in terms of the ratio of tools to debitage. Micro-debitage was common in the samples from units 3, 4, 9, 11a and 13; tools are most plentiful in units 5c, 6, 7b, and in 10 and below (Beaumont *et al.*, in press). The basic raw material is rhyolite, with some artifacts in chert, chalcedony and quartz, obtained from generally rare amygdales weathered out of the middle units of the Lebombo rhyolites, with rare quartzite from the Ngwavuma River (Cooke *et al.*, 1945; Beaumont, 1973). A few bone and wooden tools are present in the Late MSA levels, ostrich egg shell beads in the Early LSA, and potsherds in the Iron Age deposits (Beaumont, 1973; Beaumont *et al.*, in press).

Rubble Components

The most interesting sediment variations in Border Cave are expressed by the grit (2–6·35 mm) and rubble (above 6·4 mm) components. The first measure is shown in Figure 3, while the second, as determined from profile examination and semi-quantitative approximations, is recorded in the generalized profile by black triangles. Selected morphometric rubble analyses (of fragments longer than 1·5 cm) are presented in Table 2.

The northeastern corner of the cave has 3 distinct rubble horizons that have minimal fine matrix. They rest on bedrock and are laterally interdigitated with Excavation 3A as shown in the generalized profile of Figure 3. In this sector, these masses of crude debris lack evidence of chemical weathering, free salts are absent, and the sedimentary strata show that fires were rarely built here. Insolational heating or selective, local

Table 2. Morphometric rubble analysis, Border Cave. Lithology, rhyolite; minimum size, 1·5 cm major axis; all specimens angular, with highly irregular edges. L (major axis or length), l (minor axis or width), E (thickness)

Unit (and area)	Sample size	E/L ratio %	E/l ratio %	L cm	$\sigma(L)$ cm
Northeast corner					
Eboulis I	100	22·5	39·4	3·13	0·69
Eboulis II	100	19·2	35·5	3·30	0·99
Eboulis III	100	17·2	31·7	3·67	1·22
Excavation 3A					
Eboulis II	60	27·5	50·8	2·97	0·90
Excavation 3B					
Eboulis IV	100	20·9	54·6	3·39	0·64

Table 3. Synthetic interpretation of the Border Cave sedimentary sequence. Unit thicknesses are averages; bracketing ages derived from radiocarbon dates; only significant prehistoric occupations mentioned

Level 1a (30 cm)	Limited grit production. Modern conditions of sedimentation and climate. 700 b.p. to present. Iron Age occupation.
Hiatus	*c.* 700–13,000 b.p.
Level 1b (20 cm)	Moderate éboulis and grit production. Moderate frost-weathering. Climate cold, possibly dry. *c.* 13,000–29,000 b.p.
Hiatus	*c.* 29,000–33,000 b.p.
Levels 2–3 (40 cm)	Important éboulis horizon. Effective frost-weathering: first accelerating, then decelerating. Climate mainly cold, possibly wet. *c.* 33,000–38,000 b.p. Early Later Stone Age occupation.
Hiatus	*c.* 39,000 to before 49,000 b.p.
Level 4 (15 cm)	Limited grit production. Climate much like today. Late Middle Stone Age occupation.
Hiatus	
Level 5a (7·5 cm)	Moderate grit production. Climate cooler.
Level 5b–5c (15 cm)	Major éboulis horizon. Effective frost-weathering. Climate cold; initially wetter? At first, late Middle Stone Age occupation.
Hiatus	
Level 6–7a (35 cm)	Minimal grit production. Climate warmer or drier. At first unoccupied, then late Middle Stone Age habitation.
Level 7b–8 (30 cm)	Major éboulis horizon. Maximum of effective frost-weathering, decelerating with time. Climate cold, initially wetter. "Howieson's Poort" occupation.
Hiatus	Minor Soil Horizon. Chemical weathering, with gypsum mobilization (cs-horizon at −60 to −90 cm). Greater cave moisture. Climate warm and wet.
Level 9 (25 cm)	Éboulis-and-grit horizon, grading up into finer, laminated beds. Climate initially cold, then becoming temperate and/or drier. Early Middle Stone Age occupation.
Level 10 (20 cm)	Major éboulis-and-grit horizon. Effective frost-weathering. Climate cold and probably wetter. Early Middle Stone Age occupation.
Level 11 (30 cm)	Moderate éboulis production. Frost-weathering. Climate colder. Early Middle Stone Age occupation.
Hiatus	Major Soil Horizon. Protracted chemical weathering, with clay mineral formation in an acidic pedogenetic environment (over 80 cm). Greater cave moisture. Climate warm and exceptionally wet.
Level 12 (15 cm)	Moderate grit and éboulis production. Effective frost-weathering. Climate cold. Early Middle Stone Age occupation.
Hiatus	
Level 13 (15 cm)	Some éboulis production. Some frost-weathering. Climate cooler. Early Middle Stone Age occupation.
Level 14–15 (45 cm)	Some grit production at first, but sediments comparable to 1a. Climate cool, becoming warm; no wetter than today. Early Middle Stone Age occupation.
Bedrock, weathered	Significant chemical weathering probable prior to deposition of level 15; mechanisms of removal of previous sediment enigmatic.

pressure unloading cannot be invoked to explain the concentration of spall production in this part of the cave. Since the spall here, and in each of the excavation areas, consists of the same banded to porphyritic rhyolite, lithological variation is not involved. Equally significant is that both this section of the cave and the excavation areas have discrete horizons with spall concentration that are separated by finer beds or sedimentary breaks; additionally, the morphometric statistics show systematic vertical variation in spall size. These facts show that spall production was neither continuous nor catastrophic, and reflected long-term periodicities of an environmental nature. The only reasonable explanation is frost-weathering (for a detailed discussion of mechanical and frost-weathering relevant to spall production within a South African quartzite cave, see Butzer, 1973*a*). This process should be favoured by the more restricted air circulation, slower thaw rates, and increased atmospheric moisture to be expected in the most shallow, interior parts of the cave. The statistics shown in Table 2 confirm the visual impression that these 3 rubble units become increasingly and consistently finer in grade and less flattened in shape from base to top. The units can be identified as typical *éboulis secs* (see Butzer, 1971, pp. 208–209), and are here labelled as "éboulis horizons". Less typical rubble is found within the excavation areas, amid sandy to silty matrices. In the case of Eboulis Horizon II in Excavation 3B, this rubble was notably less flat and smaller in size, presumably reflecting lateral, micro-environmental differentiation. A lower rubble zone in units 9 and 10 of Excavation 3B is identified as Eboulis Horizon IV, despite its abundant matrix; flattening and size are similar to those of the true *éboulis secs*, but the rock plates are narrower here, possibly reflecting local differences of rock joint spacing; the low standard deviation of spall size (Table 2) may imply stronger jointing due to roof rock dilation near the entrance. Crude rubble is also relatively abundant in units 1b and 12, but was not systematically collected; semi-quantitative appraisal suggests comparability with that of Eboulis II in Excavation 3A.

It is reasonable to assume that large, flat and plentiful rubble indicates those episodes of most effective frost-weathering. On these criteria the episodes can be rated as follows: III (most effective), II, IV and I (moderately effective), and units 1b and 12 (least effective). In a very dry cave such as Border Cave, this would not reflect cold as much as an opportune combination of freeze-thaw intensity and abundance of interstitial rock moisture. In fact, the variation evident was probably influenced as much by available moisture as by intensity of cold.

But such significant frost-weathering does require substantially colder temperatures. A record minimum of +2 °C, probable for Border Cave today, is quite inadequate to generate frost. The site is not liable to temperature inversions and has westward insolation exposure. Effective frost-weathering could not be expected without bringing the mean daily minimum temperature of the coldest month below the freezing point. This would require a mid-winter temperature depression of at least 8 °C, judging by the Nsoko and other Lowveld station data (Climate of South Africa, 1954). This is a conservative estimate that is similar to that suggested for Nelson Bay Cave (Plettenberg Bay) (Butzer, 1973*a*, *b*). However, this does not by any means imply a mean annual temperature depression of 8 °C. As a result of increased continentality, stations in the Drakensberg foothills at 800 m elevation and with a similar mean temperature do experience frost. The Pleistocene glacials increased continentality (Butzer, 1976), and a greater frequency of cold winter weather patterns, possibly accompanied by seasonal weakening of the warm (easterly) Mozambique Current, may have been adequate to produce frost-weathering in Border Cave. Annual temperatures certainly were lower, but their deviation cannot be estimated from the available criteria.

The grit statistics complement the crude rubble data, although more in relative than absolute terms. Grit production is clearly accelerated near the dripline and along the walls of the cave, as represented in Figure 3 by the parameters for units 1a/1b (from Excavation 3A, rear) and 9–15 (Excavations 2/3B). To be roughly comparable, grit percentages for those segments of the column would need to be reduced by some 50%. This infers below-average grit production in units 1a, 3–4, 6–7a and 13–15. Combined with the crude rubble data, the implication is that units 1, 4, 6–7a and 14–15 accumulated under conditions similar to those in Iron Age times, i.e. warm; units 1b, 2 (lower) and 3 (upper part), 5b–5c and 7b–12 are related to a particularly cold climate; and the remaining beds suggest intermediate conditions.

Fine Components and Pedogenetic Phenomena

The physical residues smaller than 2 mm appear, at first sight, to vary almost erratically in Figure 3. Yet closer analysis of the detailed patterning provides critical evidence of weathering trends, occupation intensity and sedimentological discontinuities, that may record depositional breaks. Together with the basic geochemical data, the matrix information is essential to a reconstruction of the sedimentary history of Border Cave.

The sand fraction consists of physically comminuted rhyolite, with some released feldspar and quartz crystals in the finer fraction, as well as organic and other cultural admixture. All are angular, except in lenticles of intensive occupation residues, where the sands prove to be more brittle, edge-rounded, porous, and corroded. There is no evidence of subrounded to rounded quartz grains of potential eolian origin, although exotic micro-debitage is found in some levels.

The clays of levels 9 and 12–15 are significant. They attest to chemical weathering (hydration and hydrolysis) in Excavations 2 and 3B.

The lower, clayey beds—coincidental with low pH and high Eh—indicate a protracted period of hydrolytic weathering, following deposition of unit 12 and preceding that of unit 11. The analytical data argue that units 12–15 represent that rare species, a true cave palaeosol, i.e. older deposits significantly altered during a sedimentary break. The external climate had to be substantially moister. At distances of 8–14 m inside the dripline, and with an adverse 15° bedrock floor inclination, cave soil moisture was probably derived from rain splash, capillary seepage and condensation.

The weathered bedrock below Excavation 2 may date to this same phase of soil formation, but it is equally probable that it reflects an earlier period of chemical decomposition, prior to deposition of the earliest preserved sediments. Removal of earlier fills poses a problem, since no erosional agents are in evidence today. Yet the bulk of the original cave materials have long been removed. It is possible that chemical weathering ultimately reduced both the size of the components and the bulk of such older sediment. Early human occupants may also have been instrumental in clearing out much of the older fill.

Unit 9 suggests a lesser degree of post-depositional weathering, that may have begun during accumulation of the upper, laminated beds found near the centre of the cave. Laminations in such a non-erosional setting can be attributed to repeated, possibly periodic variations in weathering intensity. The finer nature of these terminal beds suggests decelerating accumulation rates. The overlying unit 8 is sedimentologically distinct. This fact and the éboulis contacts argue for a sudden resumption of deposition at a later time, following a hiatus. In other words, an interval of weak pedogenesis separates units 8 and 9. The 10–15 cm thick, secondary gypsum horizon that extends from Excavation 3A (in unit 11a, on bedrock) across to 3B (in unit 13) presumably represents a pedogenetic cs-horizon related to partial leaching and soil development. These features imply a minor period of some cave moisture in a cave that today is powdery, dusty and water-repellant, both in terms of accumulating surface sediment and samples removed from any part of the depositional column.

Unit 7a is laminated as well as sorted. However, it was not necessarily followed by a major depositional break, since the overlying stratum 8 is sedimentologically identical, except for the cultural components—introduced when the first Late MSA group in Border Cave replaced roosting owls as occupants.

Two sedimentation breaks are indicated by the radiometric evidence, namely between units 1b and 2, and between 3 and 4. These are reasonable in terms of the sediment data, but there is no evidence of interdepositional weathering.

Finally, the sedimentology indicates sharp discontinuities between levels 4 and 5a, 5c and 6, and 12 and 13. These almost certainly indicate depositional breaks, confirming macroscopic impressions.

Calcium carbonate equivalents are generally under 5%, with a few local peaks in units 3, 6, 9, 11a and 15. Any calcite present is not dispersed in the sediment mass but is aggregated in the form of soft, silt or sand-sized concretions. When CCE are less than 5%, bulk sediments do not disassociate in acid nor do they show visible effervescence. This confirms the microscopic impression of organic carbonates, little mobilized by soil moisture. CCE need show no relationship to pH, suggesting that variation reflects on the original occupational residues rather than post-depositional geochemistry.

Beaumont (1973) notes traces of diffuse sodium salt in most levels of Excavation 3A. In addition crystalline salts are evident near and below the base of unit 6 and in the upper part of 8. These salt concentrations are subhorizontal, parallel to the occupation levels. Since sodium salts are hygrophytic and highly mobile, even in a hyperarid soil environment, they would be more readily transferred by capillary processes than gypsum or calcium carbonate. Presumably, condensation moisture or urine would, at times, be adequate for this task. The relationship of these sodium horizons to two intensive occupation complexes strongly favours the urinary hypothesis. Beaumont (1973) suggests that these sodium salts are due to evaporation from sea mists and, indeed, such mists do penetrate the Lowveld, particularly during summer. This explanation finds some support in whitish evaporites locally adhering to the cave roof, near the entrance. However, sodium salts were also observed coating weathered rhyolite at the base of the sediment column, so that breakdown of the dominantly sodic plagioclase feldspars is at least equally possible.

Altogether the sedimentological information serves not only to identify grit-and-rubble horizons but suggests the presence of 8 depositional breaks within the preserved cave fill. Two of these disconformities were accompanied by soil formation. Since deposition of unit 8, the cave soil environment has remained hyperarid, even though a high degree of atmospheric humidity was prerequisite to the frost-weathering discussed previously.

Climato-Stratigraphic Interpretation

The various categories of analytical and interpretative information discussed above, the sedimentary data, facies, external climates, radiocarbon dates and prehistoric occupations inferred for the Border Cave sequence are summarized in Tables 3 and 4.

The available radiocarbon framework of 28 assays can be utilized to extrapolate an approximate age for the sedimentary column, assuming that the spacing and duration of depositional breaks remained broadly comparable. Utilizing the representative average unit thickness of Table 3, levels 1–3 and the first 3 breaks spanned at least 49,000 yr at a theoretical mean rate of 1·84 cm per 1000 yr. Allowing for negligible compaction, this suggests a time span of about 186,000 yr for 342·5 cm of cumulative sediment thickness *plus* an earlier hiatus with bedrock weathering. This should be seen as a minimum figure since compaction is evident below level 6, and particularly below 11. Using a figure of 1·84/1000 for levels 1–6, 1·66/1000 for 7–11 (10% compaction), and

Table 4. A tentative climato-stratigraphic framework for Border Cave. The sedimentary breaks probably coincided with an essentially modern climate. Deep-sea isotopic stages and dates after Shackleton (1975; Shackleton & Opdyke, 1976)

Sedimentary cycle/unit		Inferred climate	(Extrapolated) ^{14}C basal ages ($\times$1000 yr)	Deep-sea isotope stage	Isotope stage basal ages
I	1a	Modern	0·7	1, in part	
H	Break		13	1, in part	13
	1b	Cold; ? dry	29	2	
G	Break		33		
	2–3	Cold; ? wet	38	2/3 transition	32
F	Break		49		
	4	Warm		3, middle	
E	Break		(57)		
	5a	Temperate		3/4 transition	64
	5b–5c	Cold; ? wet		4	75
D	Break		(69)	5a, late	
	6–7a	Warm or dry		5a, early	
	7b–8	Cold, wet		5b	(95)
C	Minor Palaeosol:	Warm, quite wet	(105–108)	5c	(110)
	9	Cold to temperate		5d, late	
	10	Cold, wet		5d, middle	
	11	Cold to temperate		5d, early	
B	Major Palaeosol:	Warm, very wet	(145–154)	5e	128
	12	Cold; ? dry		6, late	
A	Break		(154–165)		
	13	Temperate		6, middle	
	14	Warm		6, early	
	15	Temperate		6, early	195
?	Weathering:	Warm, wet	(186–208)	7	

1·38/1000 for 12–15 (25% compaction), the basal extrapolation increases to 208,000 yr. The true age probably lies somewhere between these two estimates, the basic results of which have been applied to Table 4.

The Border Cave sequence provides a striking climato-stratigraphic sequence of cold and warm intervals, that are reasonably well dated, and that can be readily compared with the detailed succession of dramatic environmental changes documented in the loess and palaeosol record of eastern Central Europe (see Kukla, 1975). There is, then, no reasonable objection to the amplitude or wave length of climatic changes inferred for Border Cave. However, direct stratigraphic correlations are best made with a global, marine record rather than with a regional, continental sequence. The deep-sea zonation of oxygen-isotopic deviations is well suited for this purpose, following the basic chronostratigraphy of Shackleton (1975; Shackleton & Opdyke, 1976), as amplified by the dated glacial-eustatic sea-level curve (Broecker *et al.*, 1968; Bloom *et al.*, 1974; Butzer, 1975). Another potential hemispheric reference is provided by the Greenland and Devon Island ice-core oxygen-isotopic record (see Paterson *et al.*, 1977).

Allowing for minor phase shifts and dating inconsistencies, the Border Cave cold episodes of cycles G and H *c.* 38,000–13,000 b.p. record full glacial conditions of the late Last Glacial, i.e. isotope stage 2 and the terminal parts of 3; the minor episode of temperate climate centred *c.* 32,000 b.p. suggests an interstadial oscillation. The temperate to warm interval between mid-cycle E and the base of G coincides with the temperate, mid-Last Glacial, i.e. the central segment of isotope stage 3. The cold spasm in cycle E represents isotope stage 4 and the full-scale onset of the Last Glacial, variously dated at 65–75,000 b.p. by different criteria and authors. Major frost-weathering at Border Cave, in cycle D, correlates comfortably with isotopic stage 5b, the cold Orgnac interval of the Mediterranean Basin, which saw the replacement of forest by steppe-grassland in both southern and central Europe *c.* 90–95,000 b.p. (see Shackleton, 1975; Butzer, 1975; Kukla, 1975).

The minor palaeosol of Border Cave cycle C fits well in isotopic stage 5c, and the preceding cold phase in 5d. Up to this point the radiometric and extrapolated ages at Border Cave allow ready correlation with global events. Sedimentation rates in units 9–11 were probably above average (there is no evidence for a hiatus), so producing the first age discordance, that of the cycle B palaeosol and its obvious correlate, isotopic stage 5e. Detailed correlations for units 12–15 are best avoided, but a general correspondence with the Penultimate Glacial, isotope stage 6, is obvious enough. A basal date of 195,000 b.p. for the Border Cave sediments falls within the age range suggested by radiometric extrapolation.

The Border Cave sequence is indeed remarkable in terms of its internal resolution, internal dating and ready external correlation. The lower units 12–15 can confidently be assigned to the late Middle Pleistocene, while units 1b–11 span the entire Upper Pleistocene. The geo-archaeological implications for the Middle Stone Age are momentous.

Dating the Middle Stone Age

The unusual stratigraphic and radiometric control at Border Cave shows that, despite multiple occupations, the cavern was only occupied intermittently. Yet these discrete phases of habitation substantially modified the sediment body, which is overwhelmingly cultural in disposition.

The variable thickness of Iron Age deposits, cutting across or into late Last Glacial beds, has bracketing radiocarbon dates of 90 ± 105 b.p. and 650 ± 70 b.p. (Table 1). Calibrating the maximum $1\,\sigma$ range, these suggest sporadic use by ancestral Swazi herders (see Beaumont, 1973) beginning as early as 1250 AD.

The Early LSA of cycle G is also radiometrically defined, *c.* 38,000–33,000 b.p., placing a small flake industry, with ground-bone points, small bored stones, ostrich egg shell beads, and incised (decorated) bone and wood fragments earlier than the Upper Paleolithic of western Europe (Beaumont & Vogel, 1972; Beaumont, 1973; Beaumont *et al.*, in press).

Of particular interest is the unexpectedly early age of the MSA which, until a decade ago, was believed to be contemporary with the Upper Paleolithic (see Klein, 1970). Vogel & Beaumont (1972), and Beaumont & Vogel (1972), have presented a detailed case that the MSA began well before 50,000 b.p., and largely unpublished evidence in South Africa has since been accumulating that shows the MSA to extend back to the beginning of the Last Interglacial. In particular, at Klasie's River Mouth the MSA "I" rests directly on and in regressional deposits from the earliest, +7 m Last Interglacial beach, and is associated with marine shell linked to isotope stage 5e (Wymer, 1973; Klein, 1974, 1976, 1977*a*; Butzer, 1978; Shackleton, in press). A number of other sedimentary sequences studied by Butzer, both in the interior and on the coast, confirm this pattern.

The Border Cave sequence demonstrates that the earliest MSA is even substantially older than the Last Interglacial, dating back to the beginning of the Penultimate Glacial. The following approximate ages are indicated by our results:

Late MSA ("Post-Howieson's Poort") *c.* 80,000–50,000 b.p.

"Howieson's Poort" ("Epi-Pietersburg") *c.* 95,000–80,000 b.p.
Early MSA ("Pietersburg") *c.* 195,000–95,000 b.p.

The artifactual composition of these industries will be published shortly by Beaumont *et al.* (in press), while Sampson (1974) provides a general background to the various terminologies and their shifting significance.

A late Middle Pleistocene age for the earliest MSA is compatible with a uranium-series minimum date of 174,000 ± 20,000 b.p. for a younger generation of lake beds overlying deposits with terminal Acheulian of Fauresmith facies at Rooidam, near Kimberley (Butzer, 1974; Szabo & Butzer, in press). It is equally compatible with Butzer's unpublished study of (a) the major open-air site of Duinefontein (Melkbos) (Klein, 1976*a*), where a non-Acheulian industry predates Last Interglacial nearshore dunes; (b) Bushman Rock Shelter, where a long MSA sequence older than 51,000 b.p. (Vogel, 1969 and unpublished), extends through at least 4 éboulis horizons and two significant cave palaeosols; and (c) Florisbad, where Peat I and the skull can be shown to be a whole landscape cycle earlier than the stratocomplex including Peat II, a horizon of classic MSA, and with a radiocarbon date of greater than 42,600 B.P. (Pta-1108). Furthermore, would it be in line with the apparent K-Ar dating of MSA in Ethiopia at prior to 181,000 B.P. (Wendorf *et al.*, 1975).

Dating the Border Cave Hominids

Fossils pertaining to at least 5 hominid individuals were recovered from Border Cave. All represent anatomically modern *Homo sapiens sapiens* (DeVilliers, 1973, 1976; Rightmire, in press; Beaumont, 1973; Beaumont *et al.*, in press). The surprising fact is

Table 5. Microanalytical data from Border Cave fossils. Courtesy of K. P. Oakley, T. Molleson and J. L. Bada.

Level			Laboratory number	N(%)	U (ppm)
Macrofauna from Excavation 3A					
1a			BM-SA 162	0·95	
3 (upper)			BM-SA 161	0·77	
3 (upper)			UCLA-1754C	0·80	13
3 (lower)			BM-SA 160	0·62	
3 (lower)			UCLA-1754D	0·83	17
5c			BM-SA 159	0·85	
6			BM-SA 158	0·62	
6			BM-SA 157	0·57	
6			UCLA-1754E	0·98	17·5
7a			BM-SA 156	0·63	
7b			BM-SA 155	0·48	
8			BM-SA 154 (partly charred)	0·24	
8			BM-SA 168	0·74	
9			BM-SA 153	0·55	
10			BM-SA 152	0·51	
11			BM-SA 163	0·84	
Hominids					
1a/b	Outside grid:	BC 4	BM-SA 166	0·93	
8	Excavation 3A:	BC 5	BM-SA 167	0·48	
9	Excavation 2A:	BC 3	BM-SA 151	0·44	
			UCLA-1754A	0·44	
9 or 10	Horton's Pit:	BC 1	UCLA-1754B	0·41	
			BM-SA 164	0·28	
9 or 10	Horton's Pit:	BC 2	BM-SA 165	0·29	

that only one of these specimens (BC 4) is Iron Age (an iron bracelet was attached to the arm), and that the other 4 come from the Middle Stone Age deposits.

The cranial fragments of BC 1 and the incomplete mandible of BC2 came from Horton's "guano" pit. These diggings were made in a section of the cave where only MSA deposits are represented. Cooke *et al.* (1945) considered provenance carefully; they identified the material filling the small crevices of the skull with the colour and consistency of the matrix of (our) level 10, and precluded an intrusive burial younger than (the equivalent of our) level 7b. The almost complete infant skeleton, BC 3, was excavated from a burial, contemporary with (our) level 9, projected down into (our) level 10 (Cooke *et al.*, 1945); Cooke's detailed stratigraphic profile leaves no doubt about this particular provenance. A mandible (BC 5) was removed directly from level 8 in 1974 (Beaumont *et al.*, in press).

The microanalytical data (Table 5) demonstrate that BC 1, 2, 3 and 5 have substantially lower nitrogen levels than does Iron Age ungulate and hominid (BC 4) bone from Border Cave. The nitrogen readings indicate particularly intensive leaching and remineralization of the older hominid bone, although the amino-acid analyser printouts of BC 1–2 samples make charring seem unlikely (Bada, unpublished). Further, the minimal collagen level determined by Vogel for BC 3 further supports that the fact that the hominid fossils are indeed very ancient, and that no possibility exists of confusion with intrusive Iron Age burials. Despite a continuing degree of uncertainty surrounding BC 1 and 2, it is our considered judgment that BC 5 is some 90,000 yr old and that BC 1, 2 and 3 are in the order of 115,000 yr.

Indications that cultural and biological evolution in southern Africa were indeed precocious are given by the so-called Howieson's Poort or "Epi-Pietersburg" industry (not necessarily identical with that of the Howieson's Poort holotype) recovered at Klasies River Mouth (Wymer, unpublished) and Border Cave from contemporaneous, cold-climate deposits. This is a blade industry with relatively small, slender blades, that also includes backed crescents, trapezoids and knives (some of Chatelperronian or Abri Audi type). At Klasies, a high proportion of the blades, geometrics and flakes are made on non-local, cryptocrystalline siliceous rock; at Border Cave the proportion of chalcedony used also is anomalously high, increasing progressively from levels 15 to 9. This putative "Upper Paleolithic" lithic industry, immediately preceded and accompanied by anatomically modern humans, argues for astonishing evolutionary trajectories at the southern periphery of Africa (Beaumont, 1973; Beaumont *et al.*, in press; Butzer, 1977; Rightmire, in press).

Palaeo-Environmental Discussion

The present vegetation mosaic of the Lebombos and adjacent Lowveld is predicated on a complex topography and considerable mesoclimatic differentiation. Would the amplitude of climatic changes postulated here change only the floristic dominants or would it change the fundamental vegetation physiognomy?

A number of modern ecozones in southern Africa provide potential analogues for the climatic anomalies inferred from the Border Cave sediments.

(a) Warmer and wetter conditions are represented today in the Coast Belt Forest of northern Natal, at elevations under 450 m, with 900–1500 mm precipitation as well as high relative humidities (Acocks, 1975, pp. 13–15). These are semi-tropical, short to tall, evergreen forests, very dense and tangled, with shrubs, climbers and ferns. Such closed forest may have replaced the thornveld-forest mosaic of the Lebombos but left savanna patches in the drier parts of the Lowveld. The palaeosols of Border Cave cycles B and C are compatible with such an environment.

(b) Warm and drier conditions cannot be distinctly identified in the Border Cave record, but they would probably have favoured expansion of sweet-grass savanna at lower elevations and a reduction of closed woodland in the Lebombos.

(c) Cooler, relatively moist anomalies find potential analogues in the eastern foothill and escarpment region of the Drakensberg (see Acocks, 1975, pp. 82–85). At 800–1500 m elevation, this ecozone can support temperate forest and scrub forest with *Podocarpus*, abundant shrubs and climbers, and patches of sour-grass savanna or *Protea* heath. Precipitation here is in the 700–1000 mm range, with regular winter frosts. At higher elevations, up to 2150 m elevation on valleysides, a similar temperate forest, with fewer species and climbers, and shifting dominants, is found in areas with severe winter frost and some snow. Such warm- to cold-temperate forests might well have replaced the semitropical vegetation mosaic of the Border Cave area at times of effective frost-weathering, provided that precipitation did not decrease.

(d) Analogues for cold-dry conditions can be sought in the central Drakensberg, between 1850 and 3000 m, in areas with from 600 to well over 1500 mm precipitation, severe and sustained winter frosts, and periodic snow cover. These are grassland habitats, with *Protea* savannas and valleyside scrub-forests (see Acocks, 1975, pp. 95–97). The grass constellation is "alpine", but most of the species also occur at intermediate elevations in man-made or edaphic savannas. Given a significant decrease in available moisture, greatly increased continentality, and somewhat lower temperatures, such temperate to alpine grasslands could be established in the Lebombos and even in the adjacent Lowveld.

This discussion shows that the ecological mosaic of the Lebombos and Lowveld would have responded to variations of continentality, precipitation, and temperature in a complex way. Furthermore, floristic as well as physiognomic changes must have occurred during later Pleistocene times. Forest expansion can be expected with constant thermal regime and increased rainfall, or with constant precipitation and a cooler climate. Grassland expansion can be expected with constant thermal regime and decreased rainfall, or with substantially colder climate and decreased rainfall.

Pollen in Border Cave appears to be poorly preserved, but there is much macrobotanical material, particularly in levels 1–3, that would be suitable for flotation analysis. Exploratory examination indicates abundant grass bedding (?) in levels 2–6, and utilized *Acacia karroo* thorns are present in levels 2–5 (Beaumont, 1973; Beaumont *et al.*, in press). This species is widespread in the savannas of Natal and the South African interior and, in isolation, implies no more than local persistence of savanna habitats.

The fauna from Excavation 3A, although poor in identifiable bone, is far more

Table 6. Frequency of Excavation 3A squares with bones of grazers and browsers: based on Klein (1977b, Table 3)

Level	Sample number	% Browsers	% Grazers
1a	3	33	67
2–3	44	70	30
4	4	75	25
5a	15	13	87
5b–5c	40	17	83
6–7a	22	18	82
7b–8	4	75	25
9–10	27	59	41

informative. Klein (1977*b*) has partially resolved the problem of low numbers of individuals identified, by utilizing the number of excavation squares in which various species occur, to obtain usable frequency data. He shows that high concentrations of grazers (warthog, zebra and alcelaphine antelopes) alternate with high concentrations of browsers (bushpig, Cape buffalo, tragelaphine antelopes and impala), in a statistically significant way. His data can be reorganized by arranging the data by levels of similar facies, and grouping the animal/square counts in preferred-habitat frequencies; grazers include zebra, warthog, waterbuck, roan/sable, blesbok, hartebeest, wildebeest and Bond's springbok; browsers include bushpig, steenbok, impala, kudu and Cape buffalo (Table 6). Ignoring the small samples of levels 1a, 4 and 7b–8, the results suggest the following:

Levels 2–3	Woodland habitats dominant
Levels 5a–7a	Grassland/savanna habitats dominant
Levels 9–10	Woodland-savanna habitat mosaic

This information allows refinement of the palaeo-environmental deductions of Table 4, as based solely on sedimentological criteria:

Levels 2–3	Cool and wet
Levels 5a	Cool and very dry
Levels 5b–5c	Very cold and dry
Levels 6–7a	Warm and dry
Levels 9–10	Cool and moderately wet.

If the limited faunal data are representative, level 4 times may have been wetter than today, levels 7b–8 both cool and wet. Hopefully similar faunal information will eventually be forthcoming from Excavation 3B, levels 11–15.

Synthesizing the previous information, the Border Cave environments corresponding to the Upper Pleistocene isotope stages can be characterized as follows:

Stage:	2	? Cold-temperate grassland	(Upper Hypothermal)
	2/3	Temperate woodland	
	3	Subtropical woodland	(Interhypothermal)
	3/4	Temperate savanna	
	4	Cold-temperate grassland	(Lower Hypothermal)
	5a	Subtropical savanna	(Upper Hyperthermal)
	5b	Temperate woodland	(Interhyperthermal II)
	5c	Subtropical forest	(Middle Hyperthermal)
	5d	Temperate savanna-woodland	(Interhyperthermal I)
	5e	Semitropical forest	(Lower Hyperthermal)

These palaeo-environmental trends appear to be compatible with Maud's (1968) soil stratigraphy for coastal Natal, but do not quite match those of the southern Cape Coast (latitudes 33–34°30′S) (see Butzer & Helgren 1972; Helgren & Butzer, 1977; Butzer, 1973*a*, and in press) nor those of the interior, Lower Vaal Basin (latitudes 27°30′–29°30′S) (see Butzer *et al.*, in press), despite identical, superposed thermal cycles. This would indicate that KwaZulu and Swaziland constitute a distinct palaeoclimatic province, probably spanning latitudes 26–29°S.

In terms of the potential catchment of Border Cave, some form of habitat mosaic would have been accessible to its hunters within less than 5 km, with exception of the forest intervals of isotope stages 5c and 5e. Occupations of the cave coincided preeminently with colder phases, but not exclusively. At some times either grassland or forest habitats were relatively scarce, but were never absent within a convenient distance. Broad-spectrum hunting was practised at all times (Klein, 1977*b*), and the temporal lithic trends (Beaumont *et al.*, in press) show no discontinuities at times of environmental disjunction. This would seem to argue for flexible, homeostatic subsistence systems during the course of the Upper Pleistocene, if not the last 195,000 yrs. Only a far more detailed and multifaceted archaeological data body could hope to reveal the nature of the repeated, minor readjustments (implied by a homeostatic model) or the degree to which such adjustments coincided with tangible innovations.

Acknowledgements

The geomorphological field and laboratory work (K.W.B.) were supported by National Science Foundation grants GS-39625 (to R. G. Klein and K. W. Butzer) and BN574-12223 (to K. W. Butzer), and by the Department of Anthropology of the University of Chicago. The excavations and archaeological analysis (P.B.B.) were made possible by the Anglo American Corporation Chairman's Fund. ^{14}C dates (J.C.V.) were run at the Centre for Scientific and Industrial Research, Pretoria; several dates were also provided by J. L. Bada (La Jolla). Nitrogen readings were made available through the courtesy of K. P. Oakley and Theya Molleson (British Museum, Natural History) as well as J. L. Bada. Information on the modern soils was kindly provided by George Murdoch (British Ministry of Overseas Development). The illustrations were drawn by C. Mueller-Wille (Chicago).

References

Acocks, J. P. H. (1975). Veld types of South Africa. *Memoir of the Botanical Survey of South Africa* **40,** 1–128.

Baillie, J. C. (1970). Some Swaziland examples of localized control of base levels: the middle Ngwempisi Basin. *South African Geographical Journal* **52,** 77–86.

Beaumont, P. B. (1973). Border Cave—a progress report. *South African Journal of Science* **69,** 41–46.

Beaumont, P. B. & Vogel, J. C. (1972). On a new radiocarbon chronology for Africa south of the equator. *African Studies* **31,** 65–89, 155–182.

Beaumont, P. B., Vogel, J. C. & DeVilliers, H. (in press). Modern man in sub-Saharan Africa prior to 49,000 years B.P.: a review and evaluation with particular reference to Border Cave.

Bloom, A. L. *et al.* (1974). Quaternary sea level fluctuations on a tectonic coast: ^{230}Th/^{234}U dates from the Huon Peninsula, New Guinea. *Quaternary Research* **4,** 185–205.

Broecker, W. S. *et al.* (1968) Milankovich hypothesis supported by precise dating of coral reefs and deep-sea sediments. *Science* **159,** 297–300.

Butzer, K. W. (1971). *Environment and Archeology: an ecological approach to prehistory.* Chicago: Aldine, and London: Methuen.

Butzer, K. W. (1973*a*). Geology of Nelson Bay Cave, Robberg, South Africa. *South African Archaeological Bulletin* **28,** 97–110.

Butzer, K. W. (1973*b*). Pleistocene "periglacial" phenomena in southern Africa. *Boreas* **2,** 1–12.

Butzer, K. W. (1974). Geo-archeological interpretation of two Acheulian calc-pan sites: Doornlaagte and Rooidam (Kimberley, South Africa). *Journal of Archaeological Science* **1,** 1–25.

Butzer, K. W. (1975). Pleistocene littoral-sedimentary cycles of the Mediterranean Basin: a Mallorquin view. In (Butzer, K. W. & Isaac, G. L. Eds) *After the Australopithecines: stratigraphy, ecology and culture change in the Middle Pleistocene.* Chicago: Aldine, and The Hague: Mouton, pp. 25–71.

Butzer, K. W. (1976). Pleistocene climates. *Geoscience and Man* **13,** 27–44.

Butzer, K. W. (1977). Environment, culture and human evolution. *American Scientist* **65,** 572–584.

Butzer, K. W. (in press). Sediment stratigraphy of the Middle Stone Age sequence at Klasies River Mouth, Tzitzikamma Coast, South Africa. *South African Archaeological Bulletin* **33.**

Butzer, K. W. & Helgren, D. M. (1972) Late Cenozoic evolution of the Cape Coast between Knysna and Cape St. Francis, South Africa. *Quaternary Research* **2,** 143–169.

Butzer, K. W., Stuckenrath, R., Bruzewicz, A. J. & Helgren, D. M. (in press). Late Cenozoic paleoclimates of the Gaap Escarpment, Kalahari margin, South Africa. *Quaternary Research* **10.**

Climate of South Africa (1954). *Part 1. Climate Statistics.* Pretoria: South African Weather Bureau.

Climate of South Africa (1965*a*). *Part 8. General Survey.* Pretoria: South African Weather Bureau.

Climate of South Africa (1965*b*). *Part 9. Average Monthly rainfall up to the end of 1960.* Pretoria: South African Weather Bureau.

Cooke, H. B. S., Malan, B. D. & Wells, L. H. (1945). Fossil man in the Lebombo Mountains, South Africa: the "Border Cave", Ingwavuma District, Zululand. *Man* **3,** 6–13.

DeVilliers, H. (1973). Human skeletal remains from Border Cave, Ingwavuma District, KwaZulu, South Africa. *Annals Transvaal Museum* **28,** 229–256.

DeVilliers, H. (1976). A second adult human mandible from Border Cave, Ingwavuma District, KwaZulu, South Africa. *Southern African Journal of Science* **72,** 212–215.

Fitch, F. J. & Miller, J. A. (1971). Potassium-argon radioages of Karroo volcanic rocks from Lesotho. *Bulletin Volcanologique* **35,** 64–84.

Folk, R. L. (1966). A review of grain-size parameters. *Sedimentology* **6,** 73–93.

Helgren, D. M. & Butzer, K. W. (1977). Paleosols of the southern Cape Coast, South Africa: implications for laterite definition, genesis and age. *Geographical Review* **67,** 430–445

King, L. C. (1967*a*). *South African Scenery: a textbook of geomorphology.* Edinburgh: Oliver and Boyd.

King, L. C. (1967*b*). *Morphology of the Earth: a study and synthesis of world scenery.* Edinburgh: Oliver and Boyd.

King, L. C. (1974). Uloa revisited. *Transactions of the Geological Society of South Africa.* **73** (1970), 151–157.

Klein, R. G. (1970). Problems in the study of the Middle Stone Age of South Africa. *South African Archaeological Bulletin* **25,** 127–135.

Klein, R. G. (1974). Environment and subsistence of prehistoric man in the southern Cape Province, South Africa. *World Archaeology* **5,** 249–284.

Klein, R. G. (1976*a*). A preliminary report on the "Middle Stone Age" open-air site of Duinefontein 2 (Melkbosstrand, SW Cape Province). *South African Archaeological Bulletin* **31,** 12–20.

Klein, R. G. (1976*b*). The mammalian fauna of the Klasies River Mouth sites, southern Cape Province, South Africa. *South African Archaeological Bulletin* **31,** 75–98.

Klein, R. G. (1977*a*). The ecology of Early Man in southern Africa. *Science* **197,** 115–126.

Klein, R. G. (1977*b*). The mammalian fauna from the Middle and Later Stone Age (Upper Pleistocene) levels of Border Cave, Natal Province, South Africa. *South African Archaeological Bulletin* **32,** 14–27.

Kukla, G. J. (1975). Loess stratigraphy of Central Europe. In (Butzer, K. W. & Isaac, G. L., Eds) *After the Australopithecines: stratigraphy, ecology, and culture change in the Middle Pleistocene.* Chicago: Aldine, and The Hague: Mouton, pp. 99–188.

Link, A. G. (1966). Textural classification of sediments. *Sedimentology* **7,** 249–254.

Maud, R. R. (1968). Quaternary geomorphology and soil formation in coastal Natal. *Zeitschrift für Geomorphologie, Supplement* **7,** 155–199.

Murdoch, G. (1970). *Soils and Land Capability in Swaziland.* Mbabane: Swaziland Ministry of Agriculture.

Patterson, W. S. B., Koerner, R. M. *et al.* (1977). An oxygen-isotope climatic record from the Devon Island Ice cap, arctic Canada. *Nature, London* **266,** 508–511.

Rightmire, G. P. (in press). Significance of fossil human remains from Border Cave, South Africa. *Current Anthropology* **19.**

Schulze, B. R. (1958). The climate of South Africa according to Thornthwaite's rational classification. *South African Geographical Journal* **40,** 31–53.

Shackleton, N. J. (1975). The stratigraphic record of deep-sea cores and its implications for the assessment of glacials, interglacials, stadials and interstadials in the mid-Pleistocene. In (Butzer, K. W. & Isaac, G. L., Eds) *After the Australopithecines: stratigraphy, ecology and culture change in the Middle Pleistocene.* Chicago: Aldine, and The Hague: Mouton, pp. 1–23.

Shackleton, N. J. (in press). *Stratigraphy and chronology of the Klasies River Mouth deposits: oxygen isotope evidence.* Unpublished manuscript.

Soil Survey Staff (1975). Soil Taxonomy: a basic system of soil classification for making and interpreting soil surveys. *U.S. Department of Agriculture Handbook* No. **436,** 1–754.

Sampson, C. G. (1974). *The Stone Age Archaeology of Southern Africa.* New York and London: Academic Press.

Szabo, B. J. & Butzer, K. W. (in press). Uranium-series dating of lacustrine limestone from pan deposits with Final Acheulian assemblage at Rooidam, Kimberley District, South Africa.

Van der Merwe, C. R. (1963). Soil groups and subgroups of South Africa. *Department of Agricultural Technical Services, Pretoria, Science Bulletin* No. **356,** 1–355.

Vogel, J. C. (1969). Radiocarbon dating at Bushman Rock Shelter, Ohrigstad District. *South African Archaeological Bulletin* **24,** 56.

Vogel, J. C. & Beaumont, P. B. (1972). Revised radiocarbon chronology for the Stone Age in South Africa. *Nature, London* **237,** 50–51.

Wachendorf, H. (1973). The rhyolitic lava flows of the Lebombos (SE Africa). *Bulletin Volcanologique* **37,** 515–529.

Wells, L. H. (1950). The Border Cave skull, Ingwavuma District, Zululand. *American Journal of Physical Anthropology* **8,** 241–243.

Wendorf, F. *et al.* (1975). Dates for the Middle Stone Age of East Africa. *Science* **187,** 940–942.