4 Geomorphology and Sediment Stratigraphy

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The Environmental Setting

The KRM caves today lie near the watermark, at the foot of 60–100 m cliffs that rise abruptly to a coastal upland, here some 8–10 km wide (fig. 4.1). The seaward margin of this tabular upland is veneered with patches of dune sand that thicken and grow more extensive from west to east. These sand ridges at KRM attain a maximum elevation of 200 m and a presumed thickness of up to 120 m. The coastal upland rises in three steps—the first at 90–120 m elevation, the second at 140–60 m, and the third at 200–250 m—to the foot of the coastal range, locally formed by the Kareedouwberge of the Tzitzikama range. The Kareedouwberge have an average crestline elevation of 500–700 m, and the highest peak, Wolfkop, attains 739 m.

On the basis of the station data (see *Climate of South Africa,* part 2, 1954), rainfall decreases rapidly across the coastal upland from west to east, from about 1,100 mm at 24°E to 975 mm at 24°20′E and under 700 mm beyond 24°45′E. There also is a noticeable but far less marked increase of rainfall from the coast to the crest of the coastal range, with increasingly accentuated rainshadow effects in the transverse valleys of the Cape Folded Ranges, e.g., north of the Kareedouwberge. Therefore, average precipitation at KRM is estimated at about 750 mm; it is distributed relatively evenly throughout the year, with a late autumn maximum. Temperatures can be inferred from Cape St. Francis, where the coldest month (July) has a mean temperature of 14.2° C, a mean daily minimum of 10° C, a mean lowest monthly temperature of 5.7° C, and a record low of +2.2° C (70 year average; see *Climate of South Africa,* part 1, 1954). Significantly, frost is unknown at sea level. The warmest months are January and February with means of 20° C and a mean daily maximum of 22.9° C. Thus, KRM belongs to the humid mesothermal, *Cfb* climate of Koeppen and the subhumid mesothermal C_2B_2r climatic type (with little or no water deficit) of Thornthwaite.

The "natural" vegetation of the coastal upland near KRM is "forest and scrubforest" of Knysna type, i.e., broad-leaved and evergreen, according to Acocks (1975). However, the actual vegetation of the area includes (i) evergreen scrubforest of the "dry" type on the western slopes of the adjacent Kaapsedrif valley; (ii) sclerophyllous macchia (fynbos) and scrub on the sand ridges and coastal cliffs; (iii) a broad expanse of grazed grassland, interspersed with the xerophytic rhenoster bush (*Elytropappus rhinocerotis*) or patches of planted conifers and eucalyptus, across the coastal upland; and (iv) mountain macchia and scrub along the flanks of the coastal range, relatively dense in the valleys but sparse on stony ridges. Although this vegetation pattern reflects drastic modification by deforestation and overgrazing, it is nonetheless improbable that closed evergreen forest dominated the area in late prehistoric times. Instead, there probably was a mosaic of vegetation types, including macchia, scrub, and parkland, with forest restricted to entrenched gorges or kloofs, much like on the western fringes of the Knysna Forest (see Martin 1968).

Soil distributions are equally fragmentary, and complicated by extensive areas of relict soils. Steeper slopes (the coastal ranges, most valley walls, and the coastal cliffs) have bare rock, scree lithosols, or thin, humic A-horizons, locally grading into dark, humic podsolic profiles on the colluvial or alluvial surfaces of the lower slopes. Similar humic, podsolized soils appear to be dominant on the sandy veneers that overlie the 90–160 m surfaces of the coastal upland, while deep, reddish ferruginous soils, often with reworked or *in situ* lateritic plinthite, are found on the sands that mantle most of the 200–250 m surface. Finally, wherever stable, the coastal sand ridges have humic A-horizons, although relict reddish soils or soil sediments are locally exposed on older substrates.

Regional Lithology and Geomorphology

Folded and metamorphosed rocks of the mid-Paleozoic Cape System form the cliffs, upland, and ranges of the KRM area. These strike west-northwest to east-southeast, and consist of Table Mountain quartzite with slate/shale interbeds and synclinical occurrences of Bokkeveld metashales. The steep-sided coastal ranges with their angular crests and subangular footslopes are of structural and erosional origin. The tabular coastal upland, on the other hand, cuts smoothly across lithological variations and structural grain, and clearly is erosional. Nonetheless, the drainage lines have trellis organization

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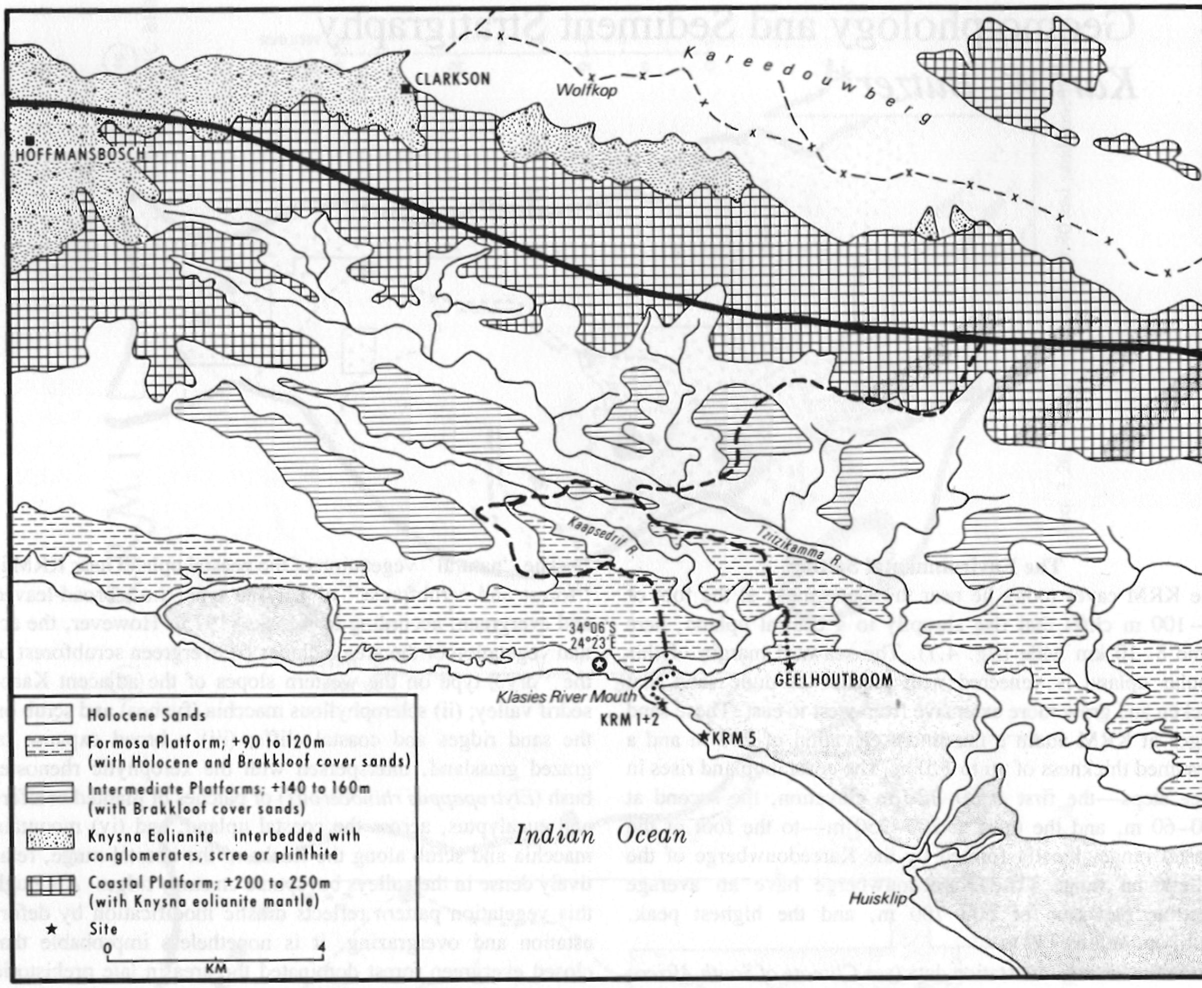

FIG. 4.1. Geomorphic setting of Klasies River Mouth.

(fig. 4.1) and the deeply incised, major valleys follow the weaker shales in close conformity with structural lineaments. Thus, the longer stream segments are oriented N 60–75°W, parallel to the coastal ranges, while shorter sections strike N 10–30°E. Although somewhat obscured by entrenched meanders, the stream segments intersect at near-right angles. The coast itself is poorly articulated and compartmentalized into long, rectilinear units (fig. 4.1) that follow the general structural pattern.

The dominant feature of the coastal upland is the early Tertiary planation surface at 200–250 m (fig. 4.1) (see Butzer and Helgren 1972, Helgren and Butzer 1977). No coeval deposits are preserved on this oldest portion of the Coastal Platform, although the gently undulating surface is covered by 3–8 m of overlying, intensely weathered, quartzose sands. These ancient eolian sands typically have 3–5 m deep, red oxic or argillic B-horizons, comparable to the early Pleistocene Knysna Soil of Helgren and Butzer (1977). *In situ* ferricretes (plinthite) may locally be observed at depth. More common are near-surface colluvia of reworked lateritic concretions, commonly found on the shoulders of drainage lines. Near the foot of the Kareedouwberge there are thicker eolianites (up to 30 m) that merge with coarse alluvial fans or interfinger with stream conglomerates or talus breccias. Relict, reddish B-horizons of 3–5 m thickness are generally present under shallow Holocene humic horizons. In addition, there are patches of younger eolianite as well as alluvial cones with yellowish ultisols that recall the Middle Pleistocene Brakkloof Soil of Helgren and Butzer (1977).

At least some of the weathered eolianites on the 200–250 m platform are younger than the lower marine platforms cut by relative sea levels at 140–60 m and 100–120 m (fig. 4.1). The last level appears to represent the early Pleistocene Formosa beach of Butzer and Helgren (1972), and along the road to Hengelaarskroonstrand (34°04′S, 24°14′E), Davies (1971) found beach cobbles at +107 m near a possible marine nip. Cover eolianites on the lower platforms are generally obscured by younger sands, but Brakkloof plinthite profiles can be observed along the valley shoulders. An informative sequence is also preserved at the Acheulian site of Geelhoutboom. (34°6′05″S, 24°25′15″E). Here the upper part of the eolianite complex includes vestiges of late Pleistocene to Holocene paleosols, namely, the Brenton and Beacon Island Soils as defined in the Knysna–Plettenberg Bay area (Helgren and Butzer 1977). These marker soils indicate the presence of late Middle and Upper Pleistocene transgressive eolianites beneath unconsolidated, later Holocene sands.

Since the formation of these extensive abrasional platforms, the dominant geomorphic trend of the study area has been bedrock dissection, with selective incision into metashales. So, for example, the Tzitzikama River, which enters the sea via a drowned gorge, with a relief of over 120 m, still follows a canyon that is 60 m deep some 20 km (via channel trace) upstream (fig. 4.1). Similarly, the smaller Kaapsedrif River descends rapidly over a series of nicks to an overdeepened embouchure, locally designated as Klasies River Mouth. It is probable that this incision was accelerated and made possible by Pleistocene glacial-eustatic regressions. Entrenched meanders are restricted to the lower valleys (fig. 4.1), suggesting that the middle and upper stream courses were incised in the course of progressive headward erosion. This in-turning confirms the impression that regional drainage developed along structural lines only after the cutting and subsequent emergence of the several platforms of the coastal upland. Thus, the gross articulation of the coast and its drowned river mouths may be no older than mid-Pleistocene.

Younger glacial-eustatic fluctuations of sea level have left few traces along the steep cliffs, and although there are fragmentary wave-cut platforms, sea caves, and notches, these are inadequate to establish an independent sequence of marine stages. At KRM 1 the archeological cave is obviously wave cut in quartzites that dip steeply at 22–28°; there is a notch at 9 m above mean sea level (m.s.l.) or 7 m above the modern storm beach; the upper cave, KRM 2, is also marine, and has its major notch at +23 m (m.s.l.); 200 m to the east there is a conspicuous wave-cut platform reflecting a m.s.l. of about +11 m. The cave at KRM 5, on the other hand, is not a clear wave-cut feature (D. M. Helgren, personal communication), although Singer and Wymer (chap. 10) found beach shingle on the floor at +19 m. Further east, Krige (1927) and Davies (1972) were able to verify a 24 m marine cave at Huisklip (34°08′S, 24°27′E), while to the west there are 6 m and 9 m platform fragments at Hengelaarskroonstrand and Oubosstrand (34°04′S, 24°12′E). The writer predicts that a variety of minor platforms at 1–4 m are too small to distinguish on account of (*a*) the bizarre structural-lithological relief of the various "reefs," and (*b*) the complexities of a 1.6 m tidal amplitude, combined with effective storm-wave sculpture to at least 1 m above spring high-tide level.

Only in view of the more compelling evidence from complex depositional sequences studied in the Cape area, at Swartklip, Melkbosstrand, and Saldanha Bay (Butzer, in preparation), as well as along the Coega River (Butzer and Helgren 1972), can the writer suggest that the +6 to +9 m shoreline features of the KRM coastal sector generally pertain to a sea level stage associated with the maximum of the last, Pleistocene interglacial (deep-sea isotopic stage 5e). Relative elevations corresponding to the high sea levels of the late Last Interglacial (deep-sea stages 5a, 5c; see Butzer 1975, Shackleton 1975) were near or only a few meters higher than modern watermark along the Cape coasts. This information implies that the 9 m sea cave known as KRM 1 was created, or at least significantly remodeled, by marine action at the very beginning of the Upper Pleistocene, c. 125,000 B.P. This provides a critical datum for the archeological cave fills. Other, higher sea caves in the region are substantially older, i.e., Middle Pleistocene, at least in terms of their marine origin.

Sedimentological Procedures

The writer removed sediment samples at KRM 1 in 1970 and again in 1973. Additional samples from KRM 1A, collected during the archeological excavations, were searched out in the South African Museum by R. G. Klein in 1972 and shipped to Chicago. The total of 38 samples selected for full analysis represent the entire stratigraphic sequence.

The procedural routine followed during study in the Paleo-Ecology Laboratory of the University of Chicago is as follows: (1) Decalcify the samples in 25 percent hydrochloric acid after removing shell or bone fragments coarser than the 2 mm sieve. (2) Do hydrometer analyses, using a 5 percent solution of sodium pyrophosphate as peptizing agent, to determine the 2, 6, 20, and 60μ fractions. (3) Sift the sand (wet), using standard sieves (37, 63, 210, and 595μ, 2.0 and 6.4 mm). (4) Carry out textural classification according to Link (1966), with sand percentages defined as the 60μ–2 mm fraction. (5) Determine textural parameters for the 37μ–6.4 mm fraction by the indices of Folk and Ward (see Folk 1966): mean (Mz), sorting (So), skewness (Ski), and kurtosis (Kg). (6) Calculate the calcium carbonate equivalent (C.C.E.) on the basis of mass loss during application of HCl to bulk samples finer than 2 mm. (7) Determine the pH, electrometrically, in distilled water. (8) Perform semiquantitative estimates of sand-grain micromorphology and composition, including degree of rounding and frosting. (9) Color, dry, by the *Munsell Soil Color Charts*.

In addition to these quantitative studies, all samples as well as several trench faces in KRM 1 were qualitatively examined, in the field, in terms of structure, consolidation, stratification, calcification or oxidation, humus and other organic forms. Two gravel samples were analyzed morphometrically by the modified Lüttig method (outlined in Butzer 1971, p. 166f., and applied by Butzer 1973*a*).

The more significant data are synthesized in figure 4.2. The schematic profile is based on the writer's sections for KRM 1 as well as on the archeological profiles (figs. 3.3–3.6). Unless otherwise reported, all samples are moderately sorted (So 0.7–1.0), slightly negatively skewed (Ski 0 to −0.2), with intermediate Kg values (0.8–1.2), representing matrices that are well stratified, horizontal, of fine granular to medium subrounded blocky structure, and loose or unconsolidated. Except for traces of glauconite in four samples (KRM 1, levels 40, 17, 16, and 13) and hematite in one (KRM 1A-38), no heavy minerals were noted. The remainder of the sands and fine gravel consists of quartz, quartzite, "fused" quartz of quartzite derivation, and occasional pegmatite.

Sediment Stratigraphy

The representative sedimentary sequence of KRM 1/1A can be described as follows, from base to top, as resting on quartzitic bedrock with some ancient knobs of stalagmite. Organization follows the broad archeological horizons and specific layers as described in chapter 3 (especially with respect to "Major Cutting East Face").

Middle Stone Age I

(KRM 1-40) *20–25 cm*. Grades from a basal, angular gravelly sand of white or pink quartzite, to a poorly sorted, silty sand with abundant quartzite grit. The gravel is subrounded on the average but ranges from angular to well rounded (index of rounding ρ, 24 percent; coefficient of variation of ρ, 59.3 percent); the pebbles are relatively flat (ratio of breadth to major axis *E/L*, 30.7 percent, breadth to minor axis, *E/l*, 45.4 percent) and coarse in grade (mean length *L*, 4.44 cm, with coefficient of variation 33 percent). Once this was a typical beach gravel, moved mainly by sliding motions, but post-depositional alteration has led to partial disintegration: most pebbles are brittle and some appear freshly fractured. Whereas the gravel matrix has few quartzite-derived sands that show mechanical wear or rounded quartz grains, these may account for as much as 30 percent of the coarse sand (200–600μ frac-

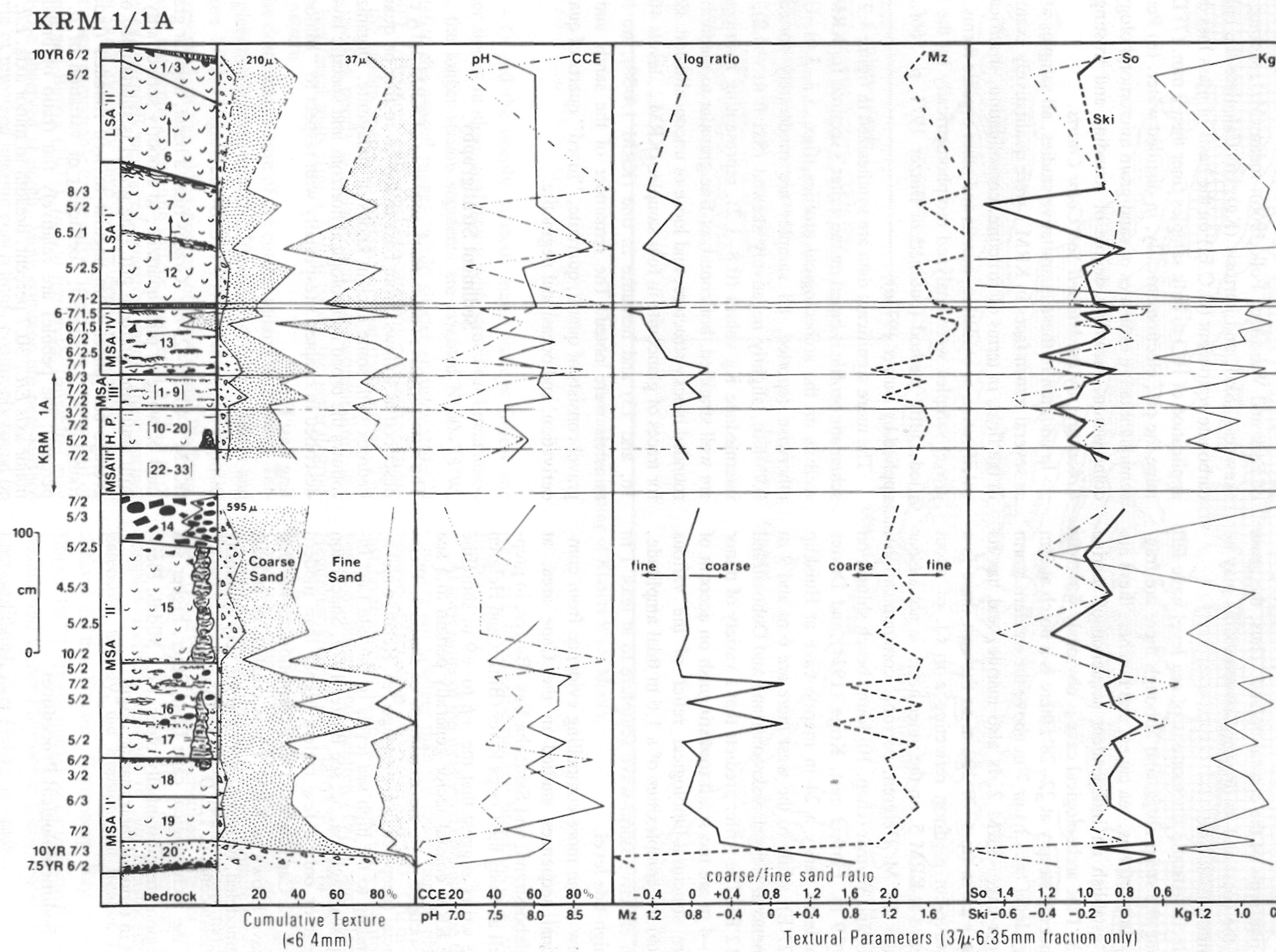

FIG. 4.2. Composite sedimentary profile for KRM 1/1A. Sediment thickness in Shelter 1A shown at half-scale. Basic stratigraphy based on description in chapter 3. Note that the layers for MSA I (col. 2) are numbered *as excavated*. For equating with layers in the text, see chapter 3. Thus, in Cave 1, layers 18 to 20 = 37 to 40.

tion) in the upper, finer facies. Although there is some microbone, this level has been largely decalcified and most of the localized carbonates appear to be secondary. Limited artifacts, a little bone, and some shell fragments. Broken, reworked fragments of dripstone verify at least one generation of older stalagmites or stalactites in the cave.

(KRM 1-38) *35 cm*. Basic matrix of very pale brown sand, mainly modified by organic residues and cultural components to a pale brown, light gray, or dark grayish brown silty sand. Compact, with coarse, angular blocky structure. Some 25–50 percent of the coarse sand is worn quartzite or subangular to subrounded polished quartz not immediately derived from the cave bedrock. Inclined 2° to the back of the cave, where the dip is reversed. Artifacts, debitage, bone, partly decalcified or fragmented marine shell, nacre, and some small land snails are generally related to thin hearths with humus and ash, or reddish oxidation.

(KRM 1-37) *30 cm*. Very dark grayish brown, highly organic silty sand. Up to 25 percent worn quartzite in coarse sand fraction. Artifactual materials, ash and charcoal, as well as partly decalcified or fragmented shell are present.

Middle Stone Age II

(KRM 1-17) *40 cm*. Grayish brown, organic silty sand; up to 25 percent worn quartzite in coarse sand fraction. Shell partly decalcified at base, intact at top; active stalagmite accumulation, leading to cementation of top of level 17, and subsequent creation of local calcrete lenticles. Diffuse archeological debris.

(KRM 1-16) *15–40 cm*. Grayish brown, organic silty sand with dispersed, well-rounded marine pebbles, probably introduced by man, as was the abundant marine shell debris. Interbedded with several lenticles of primary, eolian sand (coarse, well sorted, in part positively skewed, no cultural debris) derived from adjacent beaches. However, coarse sands from layer 16 are highly variable in terms of rounding. The terminal deposits, including discontinuous flowstone lenticles, comprise markedly finer sands. Stalagmites developed locally, with extensive, irregular zones of cementation. Diffuse archeological materials.

(KRM 1-15) *50–170 cm*. Brown to grayish brown, organic silty sand, poorly sorted and leptokurtic. Includes the back debris-slope (12–18° dips) of a midden accumulating fairly rapidly just in front of the cave, whereas the interior deposits suggest intensive, primary occupation, possibly a stone workshop. Up to 50 percent of coarse sands worn. Stalagmites resumed development, but in different locations.

(KRM 1-14) *30–50 cm*. Brown, organic silty sand, as matrix to chaotic rubble of battered eolianite and dripstone-cemented sediment, intermixed with well-rounded, spheroidal beach cobbles. The rubble is not in primary context but reworked, probably from older deposits near the cave entrance.

At the back of the cave (Rear Chamber) layer 14 intergrades with 50 cm of well-stratified, mainly undisturbed gravel to +9.5 m m.s.l., and that is partly sealed under younger deposits (KRM 1-13). Morphometric analysis gave an index of rounding of 52.9 percent, with a coefficient of variation of 48.9 percent, *E/L* and *E/l* ratios of 29.2 and 47.8 percent, respectively, and a mean length of 2.84 cm. Descriptively, this is a homogeneously rounded, medium-grade gravel, very flat in shape because of a dominance of sliding motions. Some 28 percent of the pebbles were mechanically fractured before final rounding. There is next to no fine matrix other than a little coarse sand. This typical beach deposit rests on older stalagmites, probably pertaining to KRM 1-15 to 17. Since the layer 14 deposits of the main cave are as much as 1 m lower than the gravel lens in the Rear Chamber, effective sea level was somewhat lower than +9.5 m. The beach gravel presumably was laid down by a funneled swash, and the main cave deposits were probably reworked by wave action. An alternative explanation is proposed in chapter 3, viz., rubble rolling down the steep slope next to the cave. However, I contend that the original field designation of layer 14 as a "storm beach" may be correct.

The next two depositional complexes, MSA III and Howieson's Poort, are absent from KRM 1, either because the cave entrance was partly blocked by existing middens or because occupation shifted to the talus piedmont in front of the cave or because KRM 1 was abandoned at about the time of storm-wave ingression (KRM 1-14) in favor of a higher and drier site on the slope. It is possible that part of the MSA II sequence of KRM 1A (layers 22 to 33) is unique. Unfortunately, this possible sedimentary gap in our composite profile was not apparent during the field visits nor at the time that samples were selected during excavations. In any event only one sample from the topmost layer (KRM 1A-22) was available for analysis.

(KRM 1A-22 to 33) *330 cm*. Alternating well-stratified hearth zones and light gray silty sand. Local development of a stalagmite knob (30 cm) on top of this final MSA II bed suggests a protracted period with little or no detrital sedimentation.

Howieson's Poort

(KRM 1A-10 to 21) *100 cm*. Alternating beds of light gray and dark grayish brown silty sand, positively skewed, with color variation reflecting organic and other cultural admixture. Coarse sands are of subordinate importance, and include up to 30 percent worn quartzite. Marine shell rare in upper half of horizon; relatively abundant microbone. An abri deposit with little evidence of scree slope admixture.

Middle Stone Age III

(KRM 1A-1 to 9) *90 cm*. Alternating beds of light gray and very dark grayish brown silty sand, reflecting variable cultural admixture, including abundant artifactual debris and bone. Basal unit includes up to 50 percent worn quartzite and exotic quartz in the coarse sand fraction, whereas the middle and upper parts consist predominantly of unworn, locally derived sands. Despite the presence of secondary carbonate aggregates, increasing from bottom to top, the shell is in poor condition. The lower, culturally modified deposits are poorly sorted, negatively skewed, and leptokurtic because of the fine "tail." The characteristic fine sands of the Howieson's Poort deposit continue into the lowest part of the MSA III unit.

Bone, shell, and artifacts are cemented to the cliff face behind KRM 1A as much as 5 m above the extant MSA III midden, indicating major subsequent erosion. Undercutting by high post-Pleistocene sea levels may have been responsible, but the edge of a cone of crude slope rubble, incorporating angular quartzite spall, rests against the edge of the eroded MSA III deposits (Wymer, personal communication). Such rubble mantles are characteristic of the late Pleistocene of the southern Cape coast (Butzer and Helgren 1972) and suggest an alternative explanation of Pleistocene slope wash erosion.

Middle Stone Age IV

(KRM 1-13) *40–85 cm*. Mainly light gray sand or silty sand, with planar, laminated bedding and traces of adhesion ripples;

dips as much as 8° to cave interior. Basal unit is poorly sorted and negatively skewed, with traces of angular gravel, macroshell, and glauconite; increasingly well sorted and finer in upper part. Coarse sand fraction consists mainly of worn quartzite with some exotic quartz. Laterally, layer 13 grades (Rear Alcove and Rear Chamber) into a prismatic, light gray or grayish brown (10YR 6-7/1-2) sandy clay-silt, with over 50 percent C.C.E., i.e., a marl; includes terrestrial snails and some plant stem impressions. Scanty and diffuse archeological residues, mainly near base.

In the main cave, layer 13 represents a typical, fine-grade, regressional eolianite; it was accompanied by deposition of calcareous suspended material in pools of standing water near the cave rear. The cementation of the now-eroded MSA III deposits above KRM 1A may have taken place at this time.

Post–Middle Stone Age

A long hiatus, with next to no detrital accumulation, followed. There was some accumulation of thin, discontinuous flowstones with a small residue (2.5 percent) of silty sand-clay that includes abundant amorphous silica and oxides. These light gray flowstones are related to development of a great stalagmite boss with a relief of 1.3 m below a joint fissure in the ceiling at the entrance to the Rear Chamber. In a quartzite cave with limited travertine development such a stalagmite almost certainly requires tens of thousands of years to develop. During this time the cave appears to have been essentially sealed off from detrital sediment sources. Subsequent reopening of KRM 1 can best be explained by wave erosion of a blocking eolianite or shell midden, when sea level returned to its present position in mid-Holocene times. At any rate the next detrital deposits of KRM 1 are all younger than 5,000 years.

Later Stone Age

(KRM 1-7 to 12) *50–120 cm.* Shell debris with a limited soil matrix of grayish brown, organic silty sand, including thin ash laminae and very rare beach cobbles. The stratification is at least partly cultural in origin, with dips of 8–12° to the interior once again suggesting the back slope of a midden. A degree of moisture is suggested by local development (Rear Alcove) of incomplete flowstone laminae, both midway and near the top of this unit (10–25 cm thick). The limited sand fraction is generally fine grained, presumably because the midden at the entrance reached almost to the roof of the cave, so allowing only culturally filtered sediment to enter. An approximate time range of 4850–4500 B.P. can be inferred from the sigma ranges of two radiocarbon dates (see Singer and Wymer 1969); a third relevant date from KRM 5 may extend this sedimentary complex to as late as 4000 B.P.

(KRM 1-4 to 6) *60–90 cm.* Loose shell rubble with negligible soil matrix, inadequate for representative sampling. Well-stratified and dipping 8–15° into the cave. A ^{14}C range of c. 2850–2450 B.P. is indicated.

(KRM 1-1 to 3) *35 cm.* Grayish brown silty sand, poorly sorted and leptokurtic, with traces of angular rubble. These uncompacted beds are foreset (at 20–45°) near the cave entrance, where they rest against the truncated slope of layers 12 to 4; further inside, they are backset (at 10–25°) and conformable. This demonstrates substantial erosion of the earlier middens, prior to accumulation of layers 3 to 1. A temporary rise of sea level to a maximum of as much as +4 m is suggested, not too long after 2450 B.P. The coarse sand fraction consists mainly of worn quartzite of beach origin. There is some shell and evidence of occupation.

Capping Flowstone

0–5 cm. Cemented, banded to laminated, light grayish brown impure flowstone, with a 25 percent residue of organic silty sand. Probably was forming more actively in the recent past than today, since there now is dry dust on the flowstone. Predominantly worn quartzite and exotic quartz in sand fractions.

Interpretation of the Sedimentary Facies

Coarse Rubble

Perhaps the most striking aspect of the KRM sedimentary column is the absence of incontrovertible roof spall. Coarse clasts are prominent in several horizons, but detailed study suggests better alternative explanations. The one important exception is the angular scree that abuts the eroded edge of the MSA III deposits (Wymer, personal communication); this rubble, which includes spall from the walls above, probably dates to the major hiatus between KRM 1-13 and 12.

The clasts of basal, gravelly sand, or grit (KRM 1/1A-40) originally were a typical flat, sandy-beach gravel. The post-depositional disintegration of beach gravel abandoned on the cave floor as the sea recede from its +7 m stand may have been favored by salt hydration, provided that the cave microenvironment was sufficiently dry. Frost-weathering is unlikely since the pebbles are highly brittle and have evidently been subject to a degree of decomposition.

The coarse clasts of KRM 1-15 to 19 and 4 to 12 include dispersed marine cobbles in a matrix of low-energy cultural deposits, or fractured pebbles with evidence of stone-working. These pebbles and cobbles must have been brought into the cave, from an adjacent high-energy beach, by human agency. Even the grit component is largely a matter of débitage when examined under the microscope. Other apparent clasts in these levels are calcrete aggregates of sand or cultural residue representing dripstone formation.

The dispersed cobbles, the battered dripstone rubble, and a lens of primary beach gravel in layer 14 have already been attributed to storm-wave activity in the cave. The basal angular gravel of layer 13 may represent roof spall, but there was not enough for systematic morphometric analysis without destroying a large block of the witness section; some pieces clearly are débitage, however, and the possibility of derivation from layer 14 must be considered. Even in KRM 1A, where spall would be likely (below a cliff), most coarse material can be identified as débitage.

It is therefore apparent that mechanical weathering of all kinds has been ineffectual in enlarging the KRM 1 cavern since its inception. This is in striking contrast to Nelson Bay Cave (Robberg), where frost-shattered clasts are often very prominent in an identical microclimatic context (see Butzer 1973*a*, *b*). The difference is that KRM is cut into Table Mountain quartzite, whereas Nelson Bay Cave is developed in Cretaceous breccias, with a friable matrix and crude quartzite rubble evidently predisposed to fracturing by lines of weakness. Evaluation of the sand residues in the two caves also shows substantial differences. Roof matrix sands are prominent at Nelson Bay Cave but are probably absent at KRM, where two major sedimentary breaks, coincident with human abandonment, failed to produce any detrital sediment. As discussed further below, almost all the sand in KRM is primary eolian or reworked beach sand. As a consequence, the KRM sequence fails to provide information on mechanical weathering and, by implication, on thermal fluctuations of the cave microenvironment. This does not imply an absence of Pleistocene frost-weathering; instead it reflects on a geomorphic threshold too high to provide a sensitive record of those changes that have occurred.

Sea Level Changes

The cave record is particularly informative as to sea level changes. (1) KRM 1-40 represents a regressional cave deposit that is only slightly younger than a long-term sea level of about +7 m. (2) Layers 17 and 16 include lenticles of typical foreshore eolian sand, and artificially introduced beach cobbles are common in 16; this argues for a relatively high, or oscillating, sea level, with a sandy beach initially exposed on the platform, then an adjacent shingle beach as the watermark once again approached the cave entrance. (3) Layer 14 coincided with a rising sea level that brought storm-wave action directly into the cave. Estimating the maximum sea level responsible for layer 14 is difficult; the modern storm beach is 2 m above m.s.l., but storm surges can be doubly effective in a confined space such as an elongated cave; it is unlikely that the responsible level was more than 4 or 5 m above that of the present. If the storm beach reflected once-a-year events (e.g., spring-tide storm swash), or even one-in-ten-year storms, no more than a few millennia would be required to generate these deposits. (4) Layer 13 is a typical regressional eolianite, recording a falling sea level that was initially near the cave but ultimately quite distant. A major glacial-eustatic regression is indicated. (5) The temporary high sea level between layers 4 and 3 served to destroy much of the MSA deposit (in part now found as rolled cobbles in the modern beach) as well as the substantial LSA middens. Storm surges were effective to about +6 m, implying a m.s.l. at least 1 m and more probably 2 m above the present.

These direct records of marine activity in and adjacent to KRM 1 are complemented by the faunal record. Marine shells of the littoral or sublittoral zone are abundant in most KRM 1 horizons, except layer 40 (due to partial decalcification) and middle and upper layer 13 (where there are land snails but no marine shells). In KRM 1A, shell generally is poorly preserved, but absolute shell quantities also are relatively low between layers 1 and 16, i.e., above the lower third of the Howieson's Poort unit (see also Voigt 1975). Marine mammals (Cape fur seal, rare dolphins) are found in all layers except the upper MSA III unit and the middle and upper part of KRM 1-13 (Klein 1976*a*); the less complete record of marine birds appears to be much the same (R. G. Klein and G. Avery, personal communication, and see also chap. 12). These data demonstrate that most but not quite all of the KRM 1/1A deposits record coastal occupations. The important exception is middle and upper KRM 1-13.

The cliffs of this coastal sector continue offshore as an initially steep submarine slope. Consequently, the littoral environment would have been less than 5 km distant with a relative regression of 50 m, but 78 km distant with a regression of 125 m (see Dingle and Rogers 1972; also World Nautical Chart no. 3838, U.S. Naval Oceanographic Office 1963). In relation to the offshore topography, the sedimentological criteria argue that all of the primary eolian or secondary beach deposits within KRM, even the regressional eolianite, were predicated on a littoral zone within 5 km of the cave. In effect, all deposits other than travertines are related to *relatively* high sea levels—from 7 m above to several tens of meters below—as opposed to glacial-eustatic sea level minima.

The sand component of the sedimentary column is remarkably sensitive to sea level proximity, or at least to littoral sediment supply and cave aperture. This can be inferred from scanning of the mean size (Mz) of the 37μ–6.4 mm fraction (fig. 4.2), which is broadly proportional to the sea level trends inferred from the direct evidence discussed above. An additional parameter was devised to gauge the details of sand availability and transport: the ratio of coarse sands (200–2000 μ) to those less coarse (60–200 μ). This ratio is shown in figure 4.2 as a log function. It demonstrates a reduced supply of, or access for, coarser sand at the bottom of KRM 1-15, through most of the Howieson's Poort unit and the basal MSA IV, and again in the middle and upper segments of KRM 1-13. Since none of the sedimentary units prior to the final deposition of KRM 1-13 was affected by limited access, most of the MSA deposits should be diagnostic of periods of relatively lower or higher sea level. Accordingly, the sea level inferences are summarized in table 4.1.

Travertines

Calcareous precipitates are incidental in KRM 1, and dripstone and flowstone formation was local and sporadic. All of the dissolved carbonates appear to have entered via joints and fissures in the roof, the loci of deposition shifting repeatedly as some cracks were sealed with lime. Since carbonates are absent in the quartzitic bedrock, the various laminated travertines must be attributed to percolating soil waters coming from high up, above the cliffs, in response to leaching of eolian sands rich in ground-up marine shell. Leaching within the cave sediments of KRM 1 is either incomplete or absent, except in layer 20, judging from the preservation of marine shell or land snails; the sediments themselves appear to have contributed little to the solubles represented by the flowstones and other calcareous concretions. It is probable that, under these circumstances, active travertine formation reflects on active leaching among the dune sands above the cliffs, and vice versa. In other words, travertine development in KRM 1 was probably proportional to the intensity of external pedogenesis.

Coeval dripstones are rare or absent only in KRM 1-37 and 38 or 1 to 6 and during the KRM 1 hiatus spanned by KRM 1A-1 to 33. On the other hand, the cave environment of KRM 1 experienced an abundance of water during the accumulation of layer 40 (late) (decalcification), layers 16 to 17 (widespread cementation), layer 13 (ponding in back), and layers 7 to 12 (local cementation). Except for layer 13—a regressional eolianite—sea spray and dew may have contributed substantially to the cave moisture indicated.

On these criteria of external leaching and cave dampness, KRM-1 layers 37 and 38 and 1 to 6 as well as most of the break between 14 and 13 suggest drier conditions than the mean of the last two millennia. KRM 1-13 and 17 argue for a substantially wetter climate; all other levels infer conditions comparable to those of the recent past or perhaps just a little wetter.

More specific inferences would be possible only by gauging the relative bulk of travertines developed in relation to mean sedimentation rates and cave ventilation. Nonetheless, the variability evident argues for significant changes in external pedogenesis and, by implication, both soil moisture budget and vegetative cover. Such changes are amply verified for the southern Cape coast by the complex nature of the paleosol

Table 4.1. Relative Sea Levels, Environmental Interpretation, and External Stratigraphic Inferences

KRM 1
(Capping travertine) Sea near present. Some external pedogenesis. No occupation.
(Layers 1 to 3) Sea near present. Cave dry. LSA II(?).
(Storm-wave erosion) Sea about +1 to 2 m. Postdates 2500 B.P.
(Layers 4 to 6) Sea probably near present. Cave dry. LSA II. C. 2850-2450 B.P.
(Layers 7 to 12) Sea near present. External pedogenesis, cave damp. LSA I. C. 4850-4000 B.P.
(Major stalagmite) in part, sea near present. In part, wash erosion of KRM 1A, followed by accumulation of angular slope screes. In part, external pedogenesis. No occupation. Interpolated dates, c. 65,000-5,000 B.P. (Includes span of Rubble Horizon; Gray, Yellow, and Brown Stony Loams; Oxidation Horizons 2 and 3; as well as most of the midden sequence at NBC.)
(Layer 13) Sea at first near or slightly above present, then dropping rapidly to well below modern level. Cave wet, major external pedogenesis, e.g., Brenton Soil. MSA IV. Deep-sea stage 4 (c. 70,000 B.P.). (Correlates with major ferricretion [Oxidation Horizon 1] at NBC.)
KRM 1A
(Layers 1 to 9) Sea rising from slightly below to slightly above present, then falling again. Cave dry. MSA III. Deep-sea substage 5a (c. 80,000 B.P.) (Hiatus at NBC.)
(Layers 10 to 21) Sea initially near present, then somewhat below. Cave dry. Howieson's Poort. Deep-sea substage 5b (cool waters in littoral zone) (c. 95,000 B.P.). (Major frost-weathering and Black Loam at NBC.)
(Local stalagmite) External pedogenesis (Brenton Soil).
(Layers 22 to 33) Sea near present at end, no information for earlier segments. Cave dry. MSA II (late). ? Deep-sea substage 5c, late.
KRM 1
(Layer 14) Sea rising to maximum of about +4 to +5 m, reworking cave deposits during rare storms. MSA II (middle). Deep-sea substage 5c (middle) (c. 105,000 B.P.). (Marine incursion at back of NBC.)
(Layer 15) Sea initially slightly below, then near or a little above present. External pedogenesis. MSA II (Middle). Deep-sea substage 5c (early) (c. 110,000). (Pale Brown Loam at NBC.)
(Layer 16/17) Sea rising from somewhat below to about present level. Cave increasingly damp, major external pedogenesis (early Brenton Soil). MSA II (early). Deep-sea substage 5d (late). (c. 115,000 B.P.). (Basal Loam at NBC.)
(Layers 37 to 40) Sea falling from somewaht above to slightly below present, then rising again. Cave initially wet, then dry. MSA I. Deep-sea substage 5e (late) to 5d (early). (c. 120,000 B.P.).
(Cave eroded or remodeled) Maximum transgression +7 m. Deep-sea substage 5e (early). (c. 125,000 B.P.).

Note. Correlations with Nelson Bay Cave (NBC) refer to units of Butzer (1973a), with appropriate stratigraphic revision.

record, which indicates that intervals of moderate or high intensity pedogenesis represent only a modest proportion of later Pleistocene time (Butzer and Helgren 1972; Helgren and Butzer 1977). Significant changes of the Holocene vegetation communities in the Knysna Forest are also verified palynologically (Martin 1968). It is therefore possible to infer a range of variation in the upland and kloof vegetation between drier formations, such as sclerophyllous parkland, on one hand, and wetter formations, such as closed scrubforest, on the other.

We can suggest that later Pleistocene pedogenesis was most effective contemporaneous with KRM 1-17 and 13, at which time it is most probable that the Brenton Soil was actively forming; scrubforest may have been dominant at this time. Pedogenesis was least effective at the time KRM 1-37 to 39 was deposited and during the hiatus between layers 14 and 13; parkland with sclerophyllous elements may have been characteristic, with only small tracts of kloof scrubforest. The remainder of the time, pedogenesis and the vegetation mosaic probably resembled that just prior to the contact period beginning A.D. c. 1750. These deductions are basically compatible with those of Klein's (1976*a*) faunal analyses. He has browsing mammals (*Cephalophus, Raphicerus, Tragelaphus*) increasing in number immediately after deposition of KRM 1-38 and 39, then becoming characteristic and remaining so through KRM 1-14; the limited fauna of KRM 1A-22 to 33 is inconclusive, but open-country equids and alcelaphines are prominent in the remaining MSA levels, through the base of KRM 1-13. The apparent contradiction for the MSA IV may be a result of the limited sample, entirely derived from the lower part of the deposit and in identical state of fossilization as bone of the underlying unit (R. G. Klein, personal communication); it may also reflect a colder environment accompanying a glacial-eustatic regression.

These suggestions in regard to the cave or external, pedogenetic environment are included in table 4.1.

Cultural Components

All the evidence indicates that there is a close relationship between prehistoric occupation and sedimentation at KRM. This is best illustrated by the lack of sediment accumulation in KRM 1 at times of cave abandonment or the absence of further sediment on top of the MSA III levels at KRM 1A. Only a few units or lenses are primarily of nonhuman origin: the various travertines, small eolian lenticles, the eolianite of KRM 1, the gritty facies of KRM 1-20, and the marine components of KRM 1-14. All others, while consisting to one degree or other of mineral components, owe their accumulation to human agencies:

a) Lithic raw material. A great deal of quartzite, in the form of pebbles, or flakes detached from pebbles, was introduced from adjacent beaches and subsequently worked within the cave or on top of middens situated near the entrance. Mesocrystalline quartz, probably derived from veins and other ancient shear and tension zones within the Table Mountain quartzite, was also introduced in limited quantity, probably from no great distance. Finally, several of the archeological levels include small amounts of exotic lithic material, mainly cryptocrystalline siliceous ("silcrete," jasper, agates, also lydianite) of uncertain derivation, probably from well inland. The sum total of such artifactual rock, much of it in the form of fine débitage or partially flaked chunks or hammerstones, accounts for most of the rubble coarser than 2 mm.

b) In a moist littoral environment (tidal, spray, and mist zone), wet sand and soil are readily introduced into a cave or midden on people's feet, on the hide and fur of game, and on or in shells.

c) Plants, fiber, and food were inevitably introduced as food, fuel, dress, and bedding or construction material. In the long run, feces and wood ash would be the principal components, adding organic colloids, amino acids, lignin, nitrates, resins, phosphates, manganese, and potash to the sediment. Plant materials would also be introduced through the digestive tract of slain herbivores or by temporary animal occupants of the cave—mammals or birds.

d) Animal products were also introduced in great quantity and ultimately added to the cultural midden as shell and bone refuse or fecal residues, producing quasi-intact macrorubble as well as decomposition products, e.g., phosphate, nitrogen compounds, organic acids, carbonates, and silica colloids. For example, a good part of the 5 percent median value of clay-size particles consists of colloids released during acid reduction of shell fragments in the fine sediment residue (under 2 mm) during laboratory preparation.

In these various ways the prehistoric occupants of KRM 1/1A, directly or indirectly, contributed substantial amounts of rock, mineral soil, and organic colloids or ions during the course of repeated and protracted occupation. These built up the sand and grit component and augmented the clay-humus fraction by adding specific, soluble mineral compounds and generally increasing the proportion of organic carbon. The great bulk of the clay and finer silt (under 37 μ) fraction shown in figure 4.2 is of such "cultural" origin. These fine residues consequently have no direct environmental significance, e.g., in regard to biochemical weathering processes or rates. Their generally good preservation can be attributed to a relatively dry cave microenvironment, maintained at an alkaline pH by the abundance of shell debris and other carbonates.

The various archeological levels can be informally classified in geoarcheological terms as "primary," "secondary," and "incidental." The *in situ*, minimally disturbed occupation residues would be primary, midden debris-slopes or reworked deposits would be secondary, while strata with limited cultural components would be incidental. Primary cultural deposits include most of KRM 1-16 to 38 and part of 15, KRM 1A-1 to 33, and parts of the LSA levels. Secondary cultural deposits include KRM 1-14 and parts of 15 and 17, and much of the LSA midden debris. Incidental cultural deposits would include KRM 1-40 and 13, as well as most of the key travertines.

Chronostratigraphic Interpretation

The sedimentary sequence recorded in KRM 1 and 1A provides no direct information on regional or global temperature changes, and the moisture inferences derived above are qualitative and difficult to relate to long-term, extraregional climatic anomalies. However, the sea level stratigraphy established for the MSA sequence (table 4.1) is reasonably firm and does allow a measure of correlation with worldwide glacial-eustatic fluctuations. Particular reference can be made to the Mediterranean sea level trace based on interdigitated marine-littoral and continental deposits on Mallorca, as approximately dated by a suite of mainly consistent thorium-uranium dates (Butzer 1975). This Mallorcan trace was established independently of, but correlates satisfactorily with, Shackleton's (1975) deep-sea core microzonation of oxygen isotope composition.

Table 4.1 proposes a suite of correlations between the sea level record at KRM and the deep-sea isotope stratigraphy. The very approximate dates suggested are consonant with the best available estimates for the duration and chronometric subdivision of the Upper Pleistocene. They place the KRM MSA I within a span of perhaps five millennia about or shortly after 120,000 B.P., while intermittent MSA II occupation followed until about 95,000 B.P. The Howieson's Poort would coincide with the cool horizon (Orgnac interval; see Butzer 1975, 1976), c. 95,000 B.P., while the MSA III occupations continued until c. 80,000 B.P. The KRM MSA IV begins at the end of the Last Interglacial complex and extends well into the major regression at the beginning of the Last Glacial, c. 70,000 B.P. As the cave was ultimately separated from the coast by a broad emergent shelf, the site was abandoned, presumably in favor of locations along the new littoral zone. It was not reoccupied until some 65,000 years later.

Intermittent Middle Stone Age occupation at KRM between 120,000 and 70,000 B.P. is compatible with contemporary thinking that most MSA levels are substantially older than 50,000 B.P. (Beaumont and Vogel 1972; Klein 1977). It is also compatible with other lines of independent investigation at KRM:

a) The MSA and Howieson's Poort levels at KRM have a large suite of radiocarbon dates on shell (chap. 14) that are generally infinite (in excess of 33,000 B.P.), but that do include some apparently finite assays (27,500 B.P. and older) with very large stated ranges of error (implying very small samples). These samples were run by a commercial laboratory where pretreatment and date calibration may not have been totally satisfactory. Furthermore, even shell aragonite, under the best of circumstances, represents an open system to the degree that any date greater than 27,000 years may well be infinite (M. Stuiver, personal communication). In effect, therefore, there are no finite radiocarbon dates for the KRM Middle Stone Age.

b) Aspartic acid racemization has also been applied to certain levels at KRM 1. Bone from layers 38, 37, 16, and 13 gave apparent ages of 110,000, 85,000, 84,000, and 61,000 B.P., respectively, using radiocarbon dated bone from Nelson Bay Cave as a reference (Bada and Deems 1975). However, racemization dating is still fraught with difficulties, ranging from the exact nature of the organic components being dated to the paleotemperature assumptions made in assessing the thermal history of the specimen. The very fact that these dates are of an order of magnitude similar to our sea level inferences should be viewed as gratifying to all concerned.

c) Some 200 oxygen isotopic determinations were carried out on a suite of shells from the MSA I (five shells, including KRM 1-38 and samples from KRM 1B and 5), the MSA II (seven shells, KRM 1-15), the Howieson's Poort (one shell only, KRM 1A-40), and the LSA midden (two shells, as reference) (Shackleton, chap. 14). The MSA I shells indicate an isotopic composition essentially identical to that of the LSA reference material and are firmly assigned by Shackleton to isotope substage 5e. The level 15 shell indicates a sea slightly heavier isotopically than it is today; correlation with either substage 5c or substage 5a is proposed. Finally, the single unrecrystallized shell from the lower Howieson's Poort level indicates isotopic conditions intermediate between a full glacial and a full interglacial. Shackleton concludes that this "would be consistent with deposition within stage 3 although a cooler part of stage 5 cannot be excluded." In effect, Shackleton's inferences independently confirm the sedimentological interpretation proposed here.

The cool period about or shortly after 95,000 B.P. is of considerable interest. Regionally, it is noteworthy that the major episode of Upper Pleistocene frost-weathering in South African caves coincides with Howieson's Poort contexts, e.g., the Black Loam units of Nelson Bay Cave (Butzer 1973*a*; T. P. Volman, personal communication) (see table 4.1) or the antepenultimate éboulis horizon ("Third Brown Sand, Lower" and "Third White Ash") of Border Cave (Butzer, Beaumont, and Vogel 1978; Beaumont 1973*a*). Globally, this interval was marked by distinct cooling and replacement of thermophile woodlands with steppe or forest-steppe in the Mediterranean Basin (Butzer 1975) and central Europe (Kukla 1975). Mörner (1975) suggests considerable expansion of high-latitude glaciers c. 90,000 B.P., a point borne out by sea level and oxygen isotopic evidence; cooler conditions at this same time are verified from the isotopic record of both the Greenland and Devon Island ice sheets (Paterson et al. 1977).

By way of conclusion, it can be argued that the KRM sediment sequence is one of the most informative in South Africa, providing a substantial chronostratigraphic context for one of the longest and most complete Middle Stone Age successions anywhere. It shows that the earliest MSA is no younger than 120,000 B.P. and therefore implies that even earlier contexts can be expected elsewhere, as indeed they can be verified at Border Cave (Butzer, Beaumont, and Vogel 1978). The KRM sequence places the so-called Howieson's Poort Industry (which may or may not be identical with the essentially unpublished collection from the type site) in isotopic substage 5b, over 90,000 years ago, identifying it as a remarkably precocious lithic entity. It is further apparent that most of the MSA at KRM predates 65,000 B.P., a surprising fact that could not have been anticipated a decade ago.