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Late Cenozoic Evolution of the Cape Coast Between Knysna and Cape St. Francis, South Africa

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The southeastern coast of South Africa's Cape Province underwent complex geomorphic evolution during the late Cenozoic, leaving a variety of erosional forms and a detailed, complementary record of distinctive sediments. The latter include several new lithostratigraphic units and paleosol horizons. An almost ubiquitous planation surface, the 200-m Coastal Platform, is associated with the fanglomeratic and deltaic Keurbooms Formation (late Tertiary?). A major sea level at +120 m truncated a laterite paleosol and was followed by accumulation of land rubble and littoral deposits to 101 m, constituting the Formosa Formation. Then follow sea level stages at +60, +30, and +15–20 m, as well as several generations of weathered eolianite, including the Brakkloof Formation with the deep superposed Brakkloof Soil. Beaches at +5–12 m, with thermophile mollusca and C^{14} dates of >40,000 yr mark the Swartkops horizon, probably of Eem interglacial age. Next are cryoclastic screes and cave deposits, and ultimately the podsolic Brenton Soil of the Würm Interpleniglacial. Transgressive eolianites and coastal dunes after 16,000 BP were interrupted by pedogenesis ca. 7500 BP and stabilized after 4200 BP when sea level reached +2.5 m. Geomorphic instability in stream valleys after 1000 BP was followed by man-induced activation of the coastal dunes, since the late 18th century. Environmental patterns accompanying this succession at various times included (1) semiarid pediplanation, (2) interior dune formation, and (3) intensive, cold-climate denudation, all under open vegetation in what is now closed, humid forest; by contrast, some of the more aberrant paleosols indicate warmer, perhumid conditions.

INTRODUCTION

The southeastern margin of South Africa's Cape Province is a rugged coastland dominated by extensive platforms that rise abruptly some 100 or 200 m above the shore. The sector between Knysna and Cape St. Francis (23–24° 50′ E) is formed primarily by west–east oriented cliffed coasts, interrupted by short segments of open longitudinal bays (Fig. 1). The cliffs and platforms are cut into and across folded quartzites and meta-shales of the mid-Paleozoic Cape System. This area is at approximately 34°S, at a similar latitude as the Atlas Mountains of the Maghreb, but the climate is moist and warm-temperate with little seasonality of rainfall (*Cfb* in the Koeppen classification). Precipitation normally (see *Climate of South Africa* 9, 1965) ranges from 600 to 1000 mm, falling to 500 mm near sea level in areas of low relief or enclosed topography, and increasing to 1200 mm or more on the seaward flanks of the coastal ranges. Maximum moisture is re-

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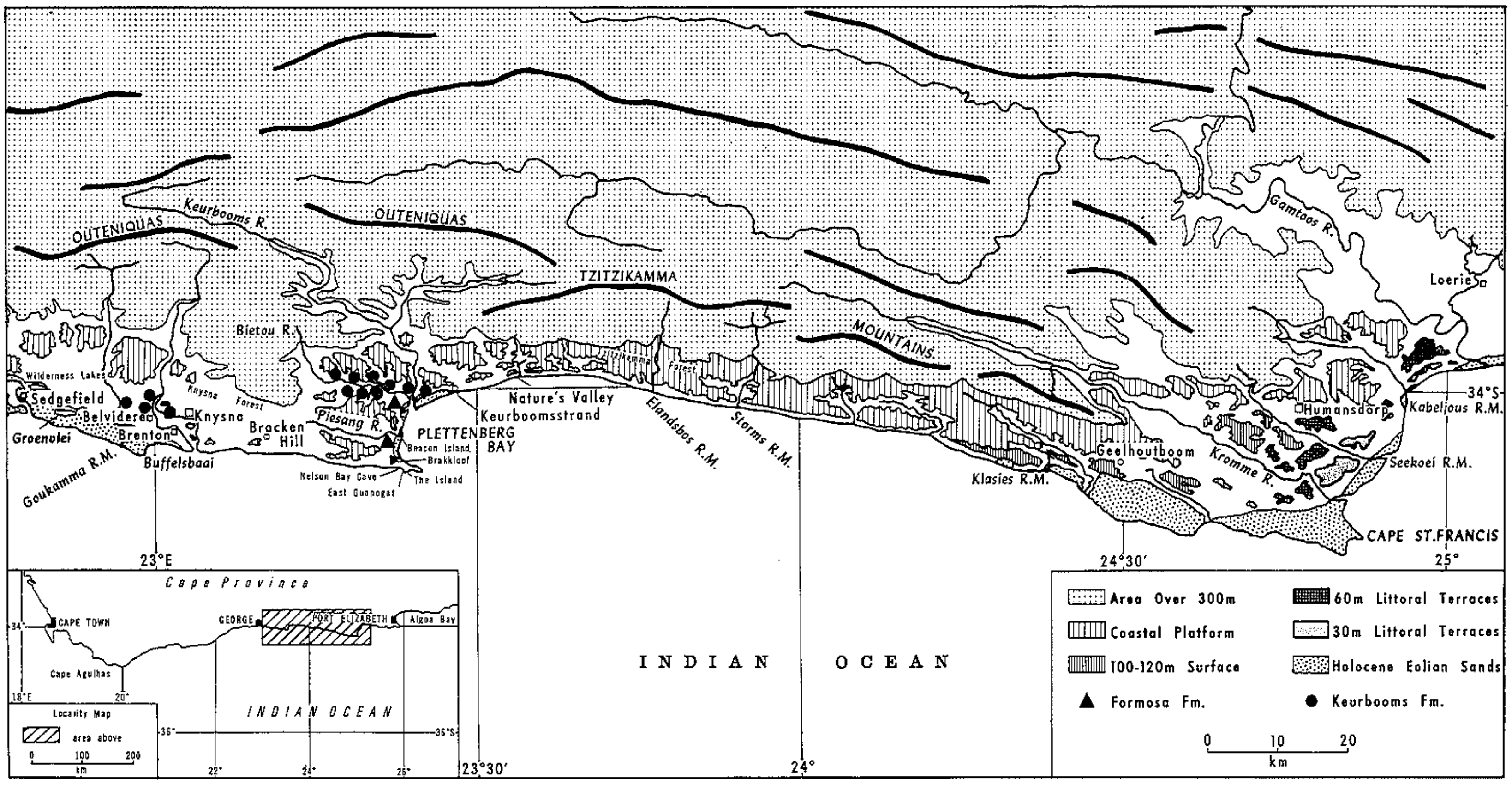

FIG. 1. Major planation surfaces of the Southeastern Cape Coast.

ceived during the transitional seasons. Mean temperatures (see *Climate of South Africa* 1, 1954) of the coldest month (July) lie in the mid-50's (°F) (12.3–14.2° C) with mean daily minima in the high 40's (7.0–10.0° C). The warmest months (January–February) average near 68° F (18.9–20.8° C). The natural vegetation is an evergreen, broadleaf forest with mixed heathland and scrub forest along some coastal stretches and in the drier valleys of the eastern part of the study area (Acocks, 1953; Phillips, 1931).

Despite this equitable climate, the little-studied Pleistocene record includes laterites and other paleosols, eolianites, fanglomerates as well as cryoclastic cave sediments that fall completely outside the range of contemporary processes. In part, these past features can be associated with the complex sequence of high beaches. In order to study this unusual Pleistocene record, the writers carried out field work from mid-July to early October, 1970, subsequent to a reconnaissance in 1969 and with follow-up investigations in September, 1971 (by K. W. B.). Planation features and surficial deposits were mapped at 1:18,000 for the Plettenberg Bay area and, in preliminary fashion, at 1:50,000 for the remaining coastal sector east to the Gamtoos River.[3] Several dozen sedimentary sections, including three major cave sequences, were recorded in detail and some 150 sediment and soil samples subsequently analyzed in the Paleoecology Laboratory of the University of Chicago. Some 60 additional samples are currently in process of study so that the present paper is intended to be no more than an interim report.

[3] The Knysna region, further west, was mapped by Miller (1963), the Gamtoos Valley, to the east, by the Geological Survey of South Africa (Haughton *et al.*, 1937), both at 1:50,000. A small part, the Robberg Peninsula, has also been mapped at 1:7200 by Rogers (1966).

THE COASTAL PLATFORM AND THE KEURBOOMS FORMATION

The most striking geomorphic feature of the southeastern Cape is the Coastal Platform (also known as Upland Plateau) that can be traced almost continuously from the Wilderness Lakes to Cape St. Francis. This 5–10-km wide surface—cut across steeply folded quartzites—was originally smooth and inclined less than 1°, but has been intensively dissected as well as extensively mantled by sheets of now-weathered eolianite and other surficial deposits. In certain sections there are indications of differential warping, while other segments appear to suggest two substages in the erosional development of this surface. The dominant elevation and projected gradients indicate planation with respect to an apparent sea level of + 170–200 m.

The Coastal Platform adjacent to the Bietou Valley and Keurboomsstrand is associated with a massive but sterile suite of rounded to well-rounded, coarse-to-boulder-grade gravels, with a matrix of pink to red, clayey silts. This sedimentary suite extends up onto the edge of the Coastal Platform where it thins out and disappears; beds here dip at 2° and maximum elevation is 211 m (Fig. 2). The deposits then pass from over the Table Mountain Quartzite to the Bokkeveld Shales, without disturbance above the contact (contrary to the claim of MacFarlane, 1958), continuing down the tectono-erosional slope of the Paleozoic rocks to below sea level in the Bietou Estuary, where comparable beds were tapped by bores at −34.5 m (see Martin, 1962, Appendix I). Within the Bietou Valley bedding is primarily inclined, at 5–11°, with subhorizontal interbeds at 1–2°, and deltaic crossbeds at 15–25°.

This detrital suite has a thickness of at least 250 m and is not affected by deformations within the adjacent mid-Paleozoic strata, although local slump tectonics are evident in undercut sections. The oldest beds

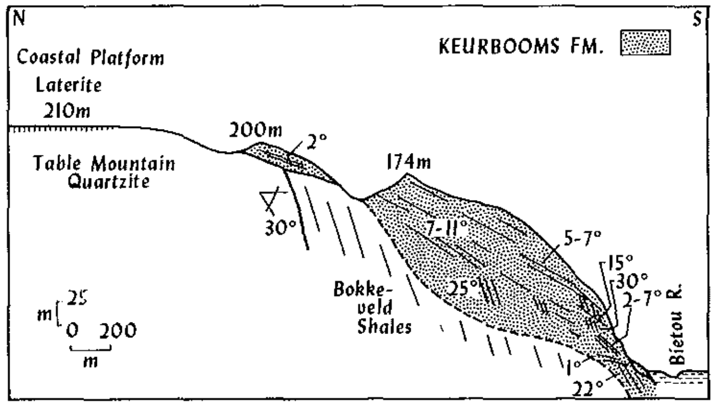

FIG. 2. Simplified section of the Keurbooms Formation at the type area, north of Wittedrif (see Fig. 3). The complex structural details of the Bokkeveld meta-shales are inadequately exposed.

were stratified almost parallel to the surface slope of the underlying bedrock, with increasing differentiation into subhorizontal and deltaic interbeds indicative of a complex fluvial and fluvio-marine facies interdigitation. Morphometric studies (see techniques outlined in Butzer, 1971, 166 ff) indicate that the gravels of the landward and higher units are less rounded and more spherical in shape, altogether most compatible with fanglomerates. Lithology is nearly 100% quartzite except in close proximity to the underlying Bokkeveld Series, where metashale components may amount to 15% or more. The fact that this detrital suite laps up onto the Coastal Platform—both north and southwest of the Keurbooms–Bietou Estuary—as well as the progressions of bedding and facies all indicate deposition from the land margins into an existing, deep embayment of the sea, although isostatic readjustments in an old tectonic valley are probable.

These detrital sediments are here defined as a legitimate, lithostratigraphic entity, the *Keurbooms Formation*, after the Keurbooms–Bietou Estuary. A suitable type section is exposed along the new road-cuts north of Wittedrif. The distribution of the Keurbooms Formation in the type area is shown in Fig. 3, which differs substantially from the 1:1,850,000 map of Schwarz (1906), who classifies these coarse detrital deposits as Cretaceous "Enon Conglomerates," a practice uncritically followed by later authors with the exception of Dingle (1971). Related beds, undoubtedly pertaining to the Keurbooms Formation, have been mapped to the north and west of Knysna by Miller (1963), "The Geology of the Knysna District." Unpublished Honors Project, University of Cape Town, 36 pp.), who also accepts Schwarz's (1900, 1906) correlation with the Enon Conglomerates of the eastern Cape Province. Lateral facies changes are particularly well exposed at Knysna, with increasing significance of clayey interbeds and reduced gravel size in present coastal proximity. The Keurbooms formation in the type area and at Knysna is distinct from and older than weathered eolianites in the Piesang Valley (correlated with the Cretaceous "Sundays River Beds" by Schwarz [1900, 1906], Rossouw [1933] and Taljaard [1949, 99 f]) and the Knysna Forest (included in the heterogeneous "Knysna beds" of Miller [1963, 26 f]). The Keurbooms Formation at Knysna is lithologically and stratigraphically incompatible with the late Jurassic, gleyed shales with manganese nodules (see Dingle and Klinger, 1972; Miller, 1963, 18 ff) exposed to +6 m above the Knysna

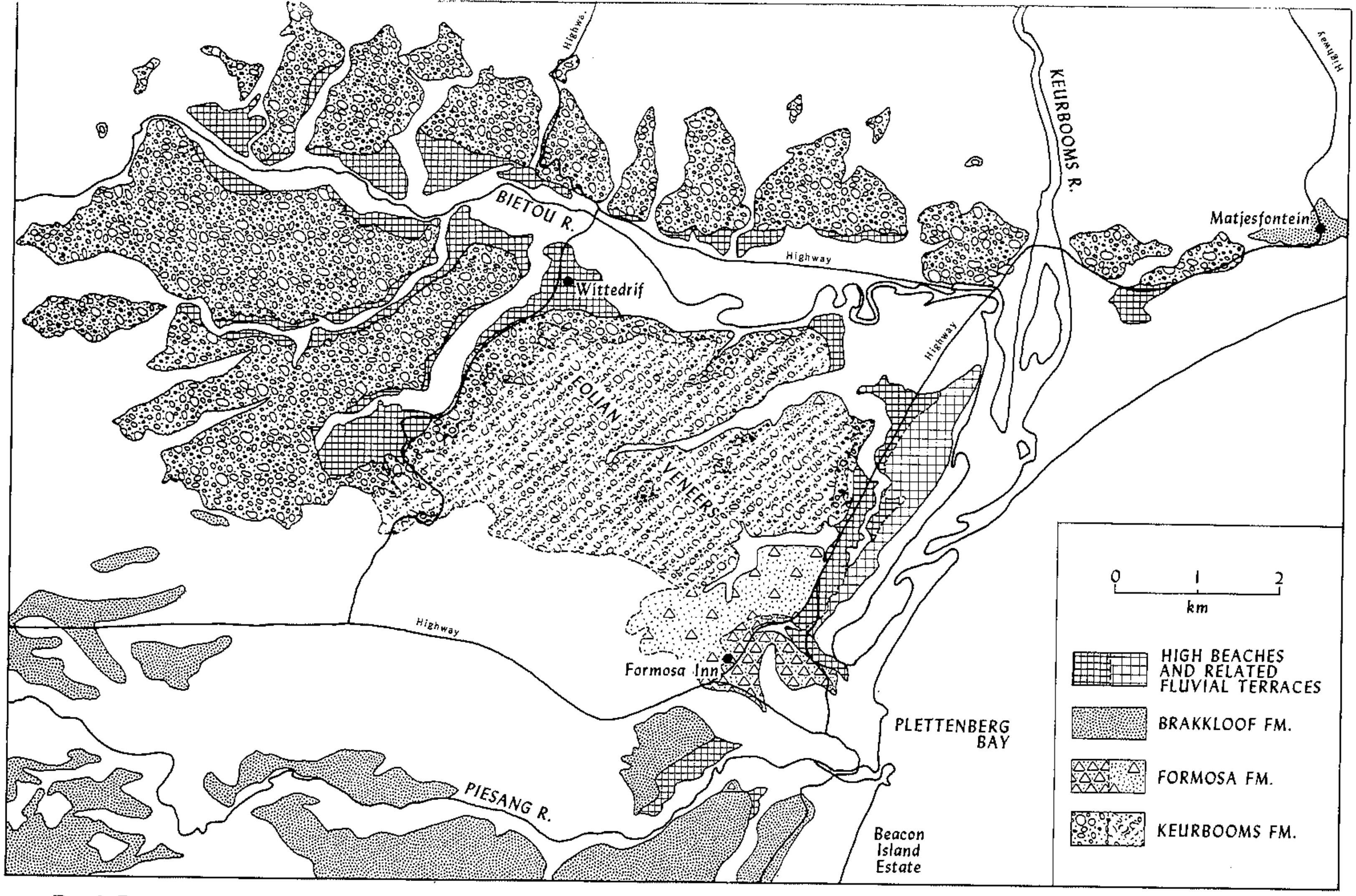

FIG. 3. Partial surficial geology of the Keurbooms–Bietou Estuary and Plettenberg Bay. Simplified by not differentiating facies or identifying beach deposits and alluvia of various ages. Eolian sands and estuarine terraces younger than Brenton Soil omitted. Broken patterns indicate exposures masked by sands.

Estuary near Brenton. It is equally incompatible with the warped and tilted quartzitic sandstones and conglomerates—with Cretaceous fossils—exposed on Robberg (Schwarz, 1900, 1906; Rogers, 1966 "The Geology of Robberg, Plettenberg Bay." Unpublished Honors Project, University of Cape Town, 87 pp.). Finally, the Keurbooms sedimentary suite is distinct in terms of tectonic precedents and temporal facies development from the apparently Cretaceous (? or early Tertiary) sequence of the Gamtoos Valley (see Haughton *et al.*, 1937), despite a broad similarity with the gravel units.

The Keurbooms Formation is a distinctive, regional, lithostratigraphic unit and it cannot simply be lumped with a mixed assortment of post-Paleozoic sedimentary units found scattered along the southern and eastern Cape coasts. It is partly coeval with (? and partly younger than) the Coastal Platform, for which King (1963, 263 ff) suggests a "post-African," late Tertiary age. The available evidence indicates that such a date is reasonable, and possibilities for a firmer dating are given in the Knysna Forest, at Brackenhill. Here a sequence of estuarine clays, sand and lignites are found over the Coastal Platform at about 250 m, underlying a series of weathered eolianites. The lignite attains 1.5 m in thickness and contains macrobotanical remains of *Podocarpus, Gonioma, Curtisia,* and ferns (Phillips, 1931), while preliminary pollen tests also indicate a flora comparable to that of the extant Knysna Forest (E. M. van Zinderen Bakker, personal communication). Pending further geological and paleobotanical work, these deposits would appear to preclude a Cretaceous or early Tertiary age for the (? latest) submergence of the Coastal Platform

The regional geomorphic and sedimentologic evidence supports King's (1963, p. 264) interpretation of the Coastal Platform by subaerial pedimentation, with local and temporary submergence. The mode of sediment transfer during this very long period of planation indicates rapid runoff and torrential stream discharge, with open vegetation and incomplete ground cover. Certainly a Knysna-type forest is incompatible with any reduction and more marked seasonality of rainfall, and we are tempted to see analogs in the pedimentation processes of semiarid climates such as those of the northern Transvaal (see Meyer, 1967) or the American Southwest.

THE 120-METER TRANSGRESSION AND THE FORMOSA FORMATION

Either the continental margins rose or sea level fell at the time the Keurbooms Formation ceased to accumulate. A new equilibrium of shorter duration eventually allowed a narrow planation surface to develop locally at 140–145 m, followed by further dissection. A new equilibrium set in with relative sea level at or below 120 m and with development of a laterite soil on both the 140–145-m surface and the Coastal Platform. Truncated mottled horizons of this laterite are exposed in some sections, and as much as a meter of indurated, banded "ironstone" caps parts of the Coastal Platform. Particularly common are reworked plinthite from this laterite, found as widespread colluvial mantles on the uplands, and interdigited with littoral formations at 98–120 m.

A relative transgression to 120 m truncated this laterite near Plettenberg Bay, cutting an abrasional terrace across kaolinized bedrock. Overlying clayey and sandy beds of littoral origin contain reworked soil from the mottled horizon as well as well-rounded beach cobbles with chatter marks (see Fig. 4). A recession of sea level ensued, during which a coarse, subangular to subrounded land rubble was swept from the uplands down a coastal slope to be interdigited with marine barrier bars that now crest at 98–101 m. This rubble horizon averages 0.5–5.0 m thick and is widespread on concave, lower slopes above

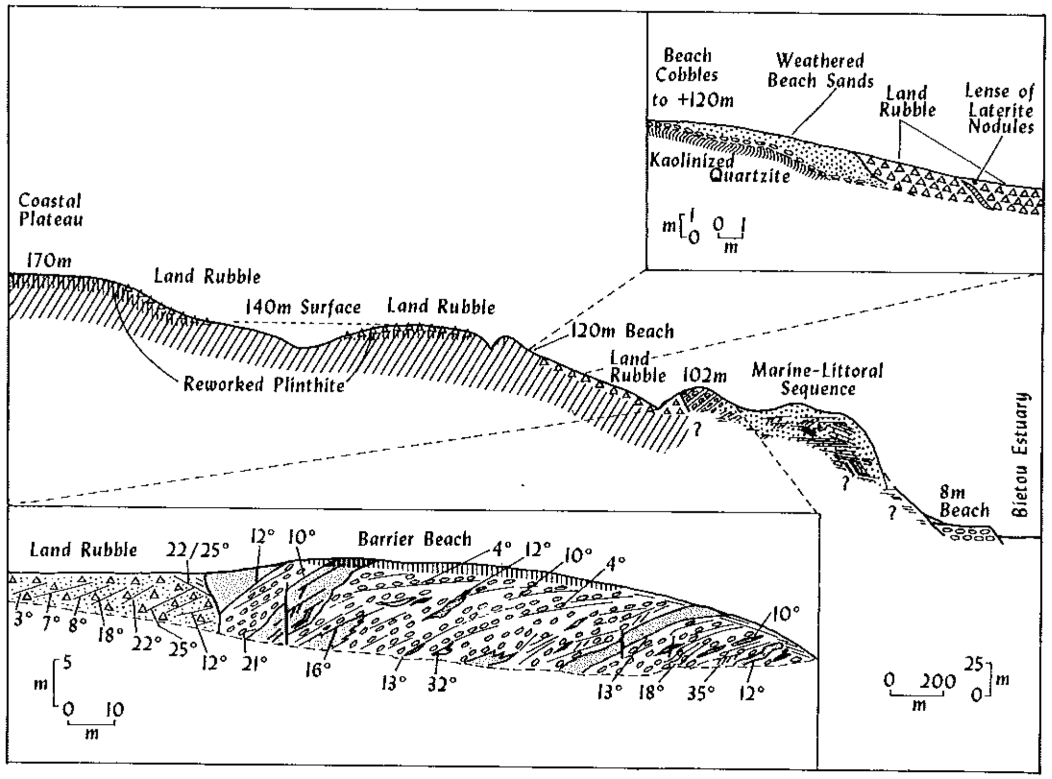

FIG. 4. Erosional surfaces and key sections of the Formosa Formation in the type area, west of Plettenberg Bay.

the contemporaneous shoreline. Lithology is quartzite, with some lenticles of derived plinthite nodules. The quartzite rubble has only been transported short distances and is barely modified from the paralleologramic cross sections dictated by jointing and cleavage intersection in the Table Mountain Quartzite. This sudden and aberrant production of fresh, angular rock waste can best be explained by intensive frost-shattering, although proof will be impossible for this interpretation. Intensive and equally unusual subaerial denudation was responsible for distribution of the rubble. It is suggested that these terrestrial deposits mark the first major cold episode of the (? early) Pleistocene. In this connection it is probably relevant that several quartzite artifacts (simple flakes) were found *in situ* in this land rubble. They will be described in due course by Leon Jacobson (University of Cape Town).

Below the watermark, quartzite rubble was reworked into massive barrier beaches, consisting of well-rounded coarse-to-cobble-grade gravels, moved primarily by rolling motions and with a matrix of white sands and silts. Bedding is inclined shoreward at 1–10° with frequent foresets, dipping as much as 35° and interdigited with white or light red silts and clays. Offshore, these barrier gravels grade rapidly into well-stratified, cross-bedded, gleyed sands and clays that can be traced in a massive sequence from 85 m elevation to below 15 m. Altogether this littoral–marine sedimentary suite, with a thickness of over 85 m, is here defined as the *Formosa Formation*. It is partly contemporary with the land rubble unit, which forms a facies of it, and records a long transgression to a maximum elevation of some 100 m (Fig. 4).

The littoral gravels at the type site below the Formosa Inn, Plettenberg Bay, are bedded differently and are morphometrically distinct from the Keurbooms Formation: degree of rounding is greater and more homogeneous, the indices of flattening are reduced, and sorting is better. North of Plettenberg Bay the 100–120-m transgressions cut erosional platforms—unfortunately veneered by young eolian sands—and near the Keurbooms River older gravels of the Keurbooms Formation were reworked into veneers of flattened beach shingle at 95–110 m.[4] Related platforms in 100–120 m but without exposed sediments are well developed southwest of Plettenberg Bay and at Nature's Valley. Finally, exposures of the sandy–clayey offshore facies can be seen in the Piesang Valley as well as south of the Bietou Estuary, but unfortunately contacts are masked by veneers of eolian sand (Fig. 3).

The geomorphic evolution of the southeastern Cape coast in late Tertiary and early Pleistocene times can now be outlined in Table 1.

STRATIGRAPHY OF THE EOLIAN SANDS AND PALEOSOLS

At least six generations of weathered eolianites or loose eolian sands can be recognized in the southeastern Cape on the basis of paleosol stratigraphy.

(1) The oldest (complex of ?) eolianites can be seen in the Knysna Forest lying, base unseen, on the Coastal Platform and retaining a fair degree of dunal topography. Eolianite with the same weathering profile rests directly on the Keurbooms Formation in the Wilderness Area, northwest of Goukamma. The relict or buried paleosol has a red (2.5 YR), loamy B-horizon typically some 4–5 m deep. This *Knysna soil* (informal designation) suggests a "mature," red podsolic soil, (i.e., a typic tropudult in the terminology of the *"Seventh Approximation,"* 1967), although truncation of the former topsoil is quite general and makes classification uncertain. In the Goukamma Valley, the Knysna paleosol can be seen extending well below 120 m without evidence of marine truncation, indicating that it must be younger than the pedogenetically distinct Formosa soil. A comparable profile is developed on eolianite mantles west of Humansdorp.

(2) The second generation of eolianites is widespread on the Coastal Platform from the Keurbooms River to near Humansdorp, but can also be recognized in the Piesang Valley, the Knysna Forest, and the Wilderness Area. The leithorizon is a soil profile with the characteristic plinthite, mottled, and pallid horizons commonly attributed to a laterite (see Sivarajasingham *et al.,* 1962). The clayey, brownish to yellowish, B-horizon is 2–3 m thick. These units will be here defined as the *Brakkloof Formation* and *Soil,* from the type area of that name just west of Robberg. Hence some 10 m of eolianite rest on a fresh beach platform with nips at 57, 60 and 63 m and veneered with beach cobbles. These beds grade up from a coarse nearshore facies (80% of sands in 200–600 μ grade) to finer textures (70% or less in 200–600 μ grade), implying decreasing coastal proximity. These sorted sands consist of quartzite and quartzite-derived grains quite similar to modern littoral sands in rounding and surface texture. It is therefore inferred that eolian sedimentation at Brakkloof began immediately after regression of the sea from the 57–63 m beaches, as freshly exposed littoral sands were deflated. Neither a depositional hiatus nor syngenetic weathering can be demon-

[4] These pebbles are now found further reworked as colluvial deposits. They include most or all of the Acheulian artifacts reported by Mortelmans (1945) and Davies (1971) from the Old Road sections here.

TABLE 1

LATE TERTIARY TO EARLY PLEISTOCENE EVOLUTION OF THE SOUTHEASTERN CAPE COAST (SEE ALSO TABLE 8)

7	Development of beach barrier bars (to +98–101 m) with fine offshore deposits, comprising *Formosa Fm* (over 85-m thick). Interdigited with spreads of land rubble (cryoclastic in origin?) containing plinthite reworked from laterite, as well as simple artifacts
6	Regression of sea (amplitude at least 20 m)
5	Cutting of beach platforms at +120 m, with truncation of laterite
4	Regression (at least 20 m), followed by development of major laterite (*Formosa soil*)
3	Cutting of planation surface at 140–145 m
2	Regression of sea (amplitude at least 60 m)
1	Protracted planation of Coastal Platform with accumulation of fanglomeratic and deltaic *Keurbooms Fm* (over 250 m thick; sea level +170–200 m). (?) Related to estuarine Brackenhill beds with lignite (late Cenozoic flora)

strated here, although groundwater oxidation horizons are evident.

(3) The Brakkloof Soil is described in Table 2: This type profile lacks a plinthite horizon but has been chosen because it preserves the remaining horizons intact. Numerous adjacent sections expose 50–130 cm of plinthite nodules, in part consolidated and resting on basal horizons of the original profile. The nodules themselves are reddish-yellow (7.5 YR) with 3–12.5% free Fe_2O_3. The abundance of groundwater horizons (dipping at 4–6°) reflects a local spring seep that persists to the present. However, the heavy clay of the mottled horizon, always overlying a light gray or white, clayey pallid horizon, makes this profile highly distinctive throughout the study area. X-ray diffractogram studies are presently underway. Classification of tropical soils (see Sivarajasingham *et al.*, 1962; Paton and Williams, 1972) remains difficult and controversial. Quite obviously this profile suggests intergrades with certain types of reddish podsolics (specifically the plinthudults of the "Seventh Approximation," 1967) and could also be labeled either as a lateritic ferrisol in the terminology of D'Hoore (1964) or as a variety of Rotlehm in that of Kubiena (1954). In any event comparable paleosols have not yet been recognized from the Cape Province [5] despite sporadic mention of reworked ferriginous or "lateritic" nodules.

(4) The next generation of eolianites maintains dune relief in the Knysna Forest, and forms the core of three of the great dune cordons running parallel to the coast among the Wilderness Lakes, as described by Martin (1962). The oldest of the Wilderness ridges (Cordon II) is calcreted and superficially oxidized, under a veneer of younger sands; the other two (Cordons III and IIIa) are unconsolidated—although they appear to have spines of older, calcreted eolianite—but conspicuously weathered, under encroaching younger sands. Primary sand accumulations in the Wilderness ridges exceed 150–250 m. All three of these ridges and their correlatives in the Knysna Forest have a similar soil profile, defined

[5] Ironically the red-yellow podsolic profiles described by van der Merwe (1963; 164 ff) from the eastern Cape and Natal are plinthudults rather than typic tropudults, in the terminology of the *"Seventh Approximation"* (1967). At least the two profiles illustrated (van der Merwe, 1962, pls. 15–16) are polygenetic. These problems of classification have been recently resolved by a new terminology specifically tailored to South Africa (van der Eyk, MacVicar and De Villiers, 1969). Furthermore, the relict, polygenetic nature of the Natal laterites, which are mainly oxisols, is explicitly recognized by De Villiers (1965; also Maud, 1968).

TABLE 2

THE BRAKKLOOF PALEOSOL [a]

Depth (cm)	
0–60	*A1-horizon.* Dark gray-brown (10 YR) sandy loam; pH 6.0. (Includes coarse eolian components younger than underlying profile)
60–80	*B21-horizon.* Strong brown to yellow (7.5–10 YR) sandy clay, with clay–humate skins and prismatic structure; pH 6.1. (Illuvial humus and clay resulting from podsolization after erosion of plinthite horizon)
80–155	*B22-horizon.* Yellowish-brown (10 YR) clay with clay skins and prismatic structure; pH 5.8. (Polygenetic)
155–265	*B23-horizon.* (Former, upper Mottled Horizon). Yellowish-brown (10 YR) clay with many large and prominent mottles of reddish-yellow (7.5 YR), red (10 R) and light gray (5 Y) color; prismatic structure; pH 5.8
265–340	*B3g-horizon.* (Former, lower Mottled Horizon). Light gray (10 YR) sandy clay with many large and prominent mottles of brownish-yellow (10 YR) and red (2.5 YR) color. pH 6.1
340–450	*g-horizon.* (Former Pallid Horizon). Light gray (2.5 Y) sandy clay with common, faint, medium mottles of yellow or brownish-yellow (10 YR); pH 6.5
450–470	*ir-horizon.* Red or weak red (7.5–10 R) and strong brown (7.5 YR), ferricreted, sandy clay loam; pH 6.0
470–510	*ir-horizon.* Reddish-yellow (7.5 YR), sandy clay loam with many large and prominent mottles of red (2.5 YR), weak red (10 R) or light gray (2.5 Y) color; pH 6.0–6.7
510–710	*Cg-horizon.* Very pale brown, white or light gray (10 YR–2.5 Y), sandy clay loam, with common, medium and distinct mottles of brownish yellow (10 YR); pH 6.7. (Rests on several other horizons modified by groundwater oxidation)

[a] Horizons of derived plinthite are preserved in lateral exposures where the B-horizon has been truncated. Terminology modified after U.S. Soil Conservation Service; color notations after Munsell, dry.

as the *Brenton Soil* below, and, pending clarification of the stratigraphic details, are here informally designated as the *Brenton beds.*

(5) The Brenton Soil varies in depth according to topography but represents a distinctive but "youthful" red–yellow podsolic profile, with a reddish to yellowish, sandy to loamy B-horizon about 1–2 m thick. The shallow variant is more typical for dune outcrops and is selected here from the type area along the new road to Brenton, 1 km south of Belvidere. The profile is outlined in Table 3 and requires no further commentary. A deeper phase on similar parent material is represented by the buried soil first described by Martin (1962) from Sedgefield, where the B-horizon is a yellowish-red (5 YR), loamy sand followed below by zones of groundwater oxidation to a total depth of 3 m or so. Optimal development includes conspicuous clay–humate skins in the upper B-horizon, but soils of this type are restricted to wetter parts of the study area and less permeable alluvial or colluvial deposits.

(6) Eolian sands younger than the Brenton Soil are mainly unconsolidated. Three such ridges, with elevations of 70–100 m, run parallel to the coast between Brenton-on-Sea and Buffelsbaai. Similar multiple ridges are found east of the Keurbooms–Bietou Estuary (see Mortelmans, 1945), with crest elevations of 15–40 m. Informative sections are provided by the triple cordon of dunes between Robberg and Plettenberg Bay, in the residential development known as the Beacon Island Estate. Here semiactive dune sands with a minimal soil profile rest on stabilized dunes with a humic paleosol dating back to a few centuries ago (Table 4); these dunes in turn lie on weathered, decalcified sands with the distinct ABC-profile of an incipient podsolic soil, here defined as the *Beacon Island Soil.*

TABLE 3

TYPICAL BRENTON PALEOSOL PROFILE UNDER YOUNGER SANDS WITH INCIPIENT A-HORIZON

Depth (cm)	
0–35	*A1-horizon.* Dark gray-brown (10 YR) loamy sand; pH 6.1, 0.5% $CaCO_3$
35–65	*A2-horizon.* Brown (10 YR) loamy sand; pH 6.0, no $CaCO_3$
65–90	*B21-horizon.* Yellowish brown (10 YR) loamy sand with zones of ferruginous consolidation; pH 6.2, 0.2% $CaCO_3$
90–180	*B22-horizon.* Strong brown to reddish-yellow (7.5 YR) loamy sand; pH 6.2, no $CaCO_3$
180–280+	*B3-horizon.* Very pale brown to light yellowish-brown (10 YR), sand to loamy sand, with sub-horizontal zones of reddish-yellow (7.5 YR) oxidation by groundwater seepage; pH 5.7, 0.2% $CaCO_3$

An identical soil profile is developed in the decalcified eolian sands that overlie the Brenton Soil at Sedgefield, as well as in similar sands that rest on a +8−10-m barrier beach, with Brenton Soil, south of the Keurbooms–Bietou Estuary. The sequence of post-Brenton sands and paleosols is completed by two successions on Robberg, namely on the eolianite stack, "The Island," connected to the shore by a tombolo, and on the adjacent wind funnel, where sands are swept from the tombolo up and across the Robberg headland. The "Island" sequence is given in Table 5: the eroded base is formed of calcreted eolianite, probably equivalent to the older Brenton beds; two younger humic paleosols developed before 16,000 BP (Paleosol 1) and before 7000 BP (Paleosol 2). In the "Wind Funnel" sequence of Table 6 the Brenton Soil itself is preserved (Paleosol 1), followed by remnants or intact profiles of three younger paleosols. Impressive is a multiple humic soil complex dating in the fourth millenium BP (Paleosol 3 a/b).

That neither these humic paleosols nor their ^{14}C determinations are random can be deduced from the cave sediments of Nelson Bay Cave (or Wagenaar's Cave) (Butzer, 1972) and East Guanogat (or Hoff-

TABLE 4

DUNE SANDS AND PALEOSOLS ON BEACON ISLAND ESTATE, PLETTENBERG BAY

(Thickness, cm)	(Top)
500	Loose, stratified, very pale brown (10 YR) sand; pH 7.8, 26% $CaCO_3$. Forming active dune cordon with local relief of 3–5 m, in process of deflation
240	Loose, stratified, very dark gray to gray-brown (10 YR), humic sand and loamy sand, increasingly clayey and organic toward middle. pH 7.8, 17% $CaCO_3$. Paleosol 2, marking landsurface and interrupted by two thin lenses of Late Stone Age shell middens. Upper shell horizon (at -100 cm) has C^{14} date of 440 ± 60 BP (UW-200) on marine pelecypods
(>20 m)	Loose, well-stratified, very pale brown (10 YR) sand, forming fixed, older dune cordon with local relief of 10–20 m
45	Loose, brown to light brown-gray (10 YR), slightly humic sand; pH 5.7, 1.2% $CaCO_3$. A1-horizon of Paleosol 1 (*Beacon Island Soil*), delimiting undulating surface of oldest dune cordon with relief of 12–25 m, crest of ridge lying 400–700 m inshore of coast
50	Loose, weakly stratified, brown to pink (7.5 YR) loamy sand; pH 5.8, 2.9% $CaCO_3$. B2-horizon of Paleosol 1
(>15 m)	Loose, well-stratified, very pale brown (10 YR), coarse-grained, eolian sand; pH 6.3, 0.5% $CaCO_3$. Probably includes a core of older dune
	(Base)

TABLE 5

DUNE SANDS AND PALEOSOLS ON ROBBERG'S "ISLAND"

(Thickness, cm)	(Top)
25–200	Compact, weakly stratified, very pale brown (10 YR), eolian sand; pH 8.8, 47% $CaCO_3$. Lines of land snails in lower half with C^{14} date of 7030 ± 120 BP (UW-201) on *Achatina zebra* near base
110	Compact, dark gray-brown (10 YR), humic loamy sand; pH 7.4, 12% $CaCO_3$. A11-horizon of Paleosol 2. Profile spans "The Island" surface with a dip of up to 10°. Locally overlain directly by Late Stone Age shell midden
50	Compact, very dark gray-brown (10 YR), humic sand. A12-horizon of Paleosol 2
40	Semicemented, pale brown (10 YR) sand; 66% $CaCO_3$. ACa-horizon of Paleosol 2
800	Consolidated to semicemented, well-stratified, very pale brown (10 YR), coarse-grained eolianite with abundant root-drip and secondary calcification. 56% $CaCO_3$
60	Compact, brown (10 YR), humic loamy sand with fragments of land snails; pH 8.1, 34% $CaCO_3$. Truncated, A1-horizon of Paleosol 1. Covered by 1–2 cm of semicemented, laminated, very pale brown (7.5–10 YR), caliche (57% $CaCO_3$) and protruding root-drip with C^{14} date of 16,000 ± 220 BP (UW-198) on inorganic carbonates
(>30 m)	Semicemented, well-stratified, very pale brown (10 YR), coarse-grained eolianite; pH 8.4, 62% $CaCO_3$. Calcrete *Brenton beds*
	(Base)

man's Cave) (Table 7) on Robberg. A complex of groundwater oxidation horizons within Nelson Bay Cave indicates an unusual mobilization of iron in runoff and soil waters penetrating the cave, and a correlation with the Brenton Soil is pedogenetically reasonable and stratigraphically compatible. Interpolating between the high interglacial beach and cryoclastic debris at the base of this cave sequence, and 18,000-yr dates above, this ferriginous complex and a subsequent hiatus must be dated within the Würm

TABLE 6

DUNE SANDS AND PALEOSOLS ON ROBBERG'S "WIND FUNNEL"

(Thickness, cm)	(Top)
600	Loose, well-stratified, very pale brown (10 YR), sand; pH 8.3, 26% $CaCO_3$. Near top interrupted by an erosional break and a local humic A-horizon (15–20 cm) (Paleosol 4)
15–20	Unconsolidated, grayish-brown (10 YR) humic sand. pH 7.6, 18% $CaCO_3$. A1-horizon of Paleosol 3b
20–25	Loose, stratified brown (10 YR) sand. pH 8.0, 32% $CaCO_3$. AC-horizon of Paleosol 3b
5–15	Loose, dark brown (10 YR) humic sand. pH 7.8, 32% $CaCO_3$
30	Loose, well-stratified, pale brown (10 YR) sand. pH 8.0, 26% $CaCO_3$. AC-horizon of Paleosol 3a
20–110	Compact, stratified, light brown-gray to white (10 YR), humic loamy sand (above) or clean sand (below) with root drip and land snails (*Achatina zebra*, *A. ustulata* Lam., *Helix* sp.), with C^{14} date of 3740 ± 70 BP (UW-199). pH 7.7–7.9, 31–34% $CaCO_3$. Transitional ACa to CaCl horizon of Paleosol 3a. The complex 2-m soil profile of Paleosol 3 dips at 3–12°, and indicates varying rates of eolian accretion and humification/decalcification
(18 m)	Loose, well-stratified (6–7° dips), very pale brown (10 YR), medium-grained eolianite. pH 8.3, 42.5% $CaCO_3$. Interrupted midway by discontinuous lense of reddish-yellow (7.5 YR) sand (pH 7.9, 29% $CaCO_3$) representing reworked soil (Paleosol 2)
50	Unconsolidated, reddish-yellow (7.5 YR), sandy loam, with surface ferricretion (2.5–7.5 YR dusky red/very dark gray) and reddish-yellow (5 YR) mottles. pH 8.1, 3% $CaCO_3$. Surface dips at 14°. Truncated Paleosol 1 (*Brenton Soil*), over partly consolidated eolianite (pH 8.1, 31% $CaCO_3$) (*Brenton beds*)
	(Base)

TABLE 7

SIMPLIFIED SEDIMENTARY SEQUENCE OF EAST GUANOGAT CAVE, ROBBERG

(Thickness, cm)	(Top)
90	Late Stone Age midden with matrix of very dark gray-brown (10 YR), humic sandy loam, including eolian components; pH 7.5, 44% $CaCO_3$. C^{14} date on marine shell near top: 3610 ± 110 BP. (UW-204)
25	Wedge of clean, very pale brown (10 YR), eolian, coarse sand; pH 8.0, 24% $CaCO_3$
110	Late Stone Age middens with matrix of brown (10 YR) humic sand, including strong eolian components; pH 7.5, 28% $CaCO_3$. C^{14} date on marine shell near base: 4180 ± 110 BP. (UW-205)
>350	Clean, very pale brown (10 YR), coarse sand, pH 7.7, 23% $CaCO_3$
	(Base)

Interpleniglacial (as defined by van der Hammen *et al.,* 1967). In addition to the obvious implication of a perched water table within the sediment column, two younger oxidation horizons which both contain concentrations of free Fe_2O_3 (to 8%), also suggest increased cheluviation in the external soil environment. The intervening ^{14}C dates would indicate that the earlier of these two oxidation horizons predates 19,000 BP while the younger postdates 18,000 BP. It appears, therefore, that Paleosol 1 on the Island is broadly contemporary with the two younger oxidation horizons of Nelson Bay Cave.

Deposition of 8 m of eolianite over Paleosol 1 on the Island was underway by 16,000 BP, and the mantle of eolianite mapped by Rogers (1966) on the southeastern flanks of Robberg is lithologically comparable[6] although equivalent deposits are absent around Plettenberg Bay. Paleosol 2 on the Island and Paleosol 1 of the Beacon Island Estate infer a period of pedogenesis and geomorphic stability during the encroachment of littoral zone in the course of the Flandrian Transgression. Of identical age is the period of peat formation—accompanied by a temporary advance of the forest—in the Wilderness prior to 6870 ± 160 BP (Y-466) (Martin, 1968), preceded and followed by periods of open vegetation and eolian activity in coastal proximity (Martin, 1962, 1968). Judging by the faunas (Klein, 1972b) and the increasing proportions of eolian quartz grains in Nelson Bay Cave (Butzer, 1972), the shoreline approached close to Robberg a little before 9000 BP. The Island profile (Table 5) shows that dune sands were again accumulating by 7000 BP, while the cave profiles (Butzer, 1972; Table 7) document major eolian activity after 6000 BP. Partial stabilization is indicated by reduced eolian activity in the open East Guanogat Cave (Table 7) shortly before 4200 BP, corroborated by the date of 3750 on Paleosol 3a in the Robberg Wind Funnel (Table 6). Subsequent eolian activity was esentially restricted to the Wind Funnel, with sands absent in the cave sites and with only limited accumulation in the Beacon Island Estate (Table 4), where we correlate the lower part of Paleosol 2 with the Robberg Paleosol of the fourth millenium B.C. In fact the Beacon Island dunes only appear to have been reactivated in response to human interference during the last century or two.[7]

[6] The absence of appreciable quantities of extraneous sands from coeval strata in Nelson Bay Cave has no ready explanation. By contrast there is a major eolianite horizon in Klasie's River Mouth, Cave 1, dating from the same period.

[7] The first cattle Boers appear to have penetrated the Knysna and Tzitzikamma Forests after A.D. 1730–1750, with the first permanent settlement established in 1787, at Plettenberg Bay.

ASSOCIATIONS AND INTERPRETATION OF THE EOLIAN SANDS AND PALEOSOLS

Archeological and faunal associations. The earliest archeological associations of the eolianite sequence are in the Piesang Valley, where a mint cleaver-biface was recovered from the undisturbed sands of the Brakkloof Formation, in the pallid horizon of the overlying soil. Of broadly similar age is another isolated find, a rectangular cleaver—slightly worn or corroded, chipped (by use?), and hematite stained—in the mottled horizon of the same soil exposed in the highway cut at Matjesfontein, just north of Keurboomsstrand (see also Mortelmans, 1945; Davies, 1971). It therefore seems probable that primary Acheulian occurrences may eventually be discovered within the Brakkloof Formation. In this connection, the extensive Acheulian surface occurrence at the Brakkloof type site may well have been derived from the eolianite. However, those artifacts that are in geologic context are all reworked into colluvial horizons of plinthite nodules.

The Brenton Soil has a number of interesting associations. The Acheulian occurrence of Geelhoutboom (see Laidler, 1947) is in part found within a sandy colluvium derived from the Brenton Soil. Another major Acheulian occurrence, in the Wind Funnel of Robberg, appears to be restricted to areas where the Brenton Soil is being eroded. Presumably derived artifacts rest on this old landsurface. A third Acheulian occurrence is currently eroding from a colluvium within a Brenton profile, over Brakkloof dune, near the road passing south out of the Piesang Valley. Middle Stone Age artifacts may also be found in comparable contexts. So, for example, east of Brenton-on-Sea, flakes of Mossel Bay type are eroding from the Brenton Soil or a former, superposed land-surface, while similar artifacts have been recovered from 7 m below the surface of the (? Brenton) dune sands at an uncertain locale elsewhere in the Knysna region (see Goodwin, 1929, 136 ff). Mortelmans (1945) reported Middle Stone Age artifacts from the highway cut at Matjesfontein, and we were able to recover further materials here, including cleaver flakes and segmented Levallois flakes. These are stratified in a single detrital horizon within an oxidized, sandy clay loam (up to 2.5 m thick) reworked from the Brakkloof Soil and within the BC-horizon of the Brenton Soil. The implication of these associations is that the great bulk of Acheulian occurrences are found derived in much younger deposits, while the Middle Stone Age occurrences in part predate the Brenton Soil, as they clearly do in Nelson Bay Cave, where Middle Stone Age occupation was contemporary with the +5–12-m beach (Butzer, 1972).

Near Sedgefield there is an interesting faunal occurrence in the calcreted Brenton dune ridge north of the Lake Pleasant Hotel. Fossils are found in a light yellow-brown (10 YR), loamy sand that fills a number of fissures (corroded ?) in the eolianite surface. The material is a soil wash either predating or derived from the Brenton Soil. Richard G. Klein has kindly provided an identification list of the fossils collected in 1971 as well as of the earlier collection by Hilary Deacon and Hjalmar Thesen: Dolphin (*Delphinidae* indet.); Cape clawless otter (*Aonyx capensis*); Steenbok/grysbok (*Raphicerus* sp.); Grey rhebuck (*Palea capreolus*); Reedbuck (*Redunca arundinum*); Blue antelope (*Hippotragus leucophaeus*); Buffalo (*Syncerus caffer*).

The Lake Pleasant site is now found at 100 m elevation and well inland, so that the presence of dolphin and possibly also the coastal otter suggest a sea level at least as high as today, most reasonably the +5-m shoreline indicated at Sedgefield. Further investigations at this site should prove highly profitable.

Finally, the youngest dune generations at and near Robberg are frequently associated with Late Stone Age middens, that either remain to be studied or published.

Environmental interpretations. Six or more generations of ancient eolian sands in what is now a humid environment demand an explanation. The thickness of eolianites in the Knysna Forest exceeds 150 m, that in the Wilderness Area, 300 m; cumulative stratigraphic thickness is considerably greater. Mantles of eolianites also cover the greater part of the Coastal Platform through the Tzitzikamma Forest to Humansdorp. In assessing implications it is necessary to note several aspects of this sand distribution: (1) Dunal topography is restricted to the Knysna Forest and, further east, to those segments of the coast that recurve southward. (2) The basic sand forms of the Wilderness and Plettenberg Bay are coastal cordons with eolian remodeling or dune superimposition. (3) The relatively thin eolian veneers on other parts of the Coastal Platform lack distinctive morphology. (4) Macrodunal topography away from the immediate littoral zone is restricted to the oldest generations of sand, predating the Brenton Soil. (5) Microdunes of low amplitude but great wavelength, primarily W-dunes, of very recent origin, are common in parts of the Knysna Forest as well as on the Coastal Platform west of Plettenberg Bay; comparable eolian remodeling of cover mantles would be next to impossible to recognize in the older, Pleistocene record.

Wind observations are available from George, to the west of the study area, and Port Elizabeth, to the east (see *Climate of South Africa* 6, 1960). At George moderate to high-velocity winds (over 40 km/hr) come primarily from westerly to northerly directions, during the winter months. This agrees with the easterly transport of sand from the Wilderness to the Knysna Forest, and explains the paucity of sands on south and east-facing coastal segments around Plettenberg Bay. At Port Elizabeth strong SW to WNW winds are common at all seasons, conciding well with recent and fossil dune lines east of Cape St. Francis and helping explain active sands on all coastlines with southwesterly exposure. Easterly winds are important during the summer months, and serve to remodel the recent dune fields; they may, in the past, have been responsible for the eolianite veneers in th Tzitzikamma Forest. In general, paleowind directions are difficult to assess. Old macrodune patterns, other than coastal cordons, have been destroyed by stream dissection reexcavating structurally-patterned drainage lines, and stratification has been widely masked by veneers of younger sands or deep weathering. A few good sections are available in the Knysna Forest, but only the calcreted eolianite of the Island has been studied to date. Here the dominant bedding is foreset at 25–30° by SSE (primary direction) and SW (secondary direction) winds; interbeds, mainly topsets and backsets at 3–13°, are restricted to the lower half of the sequence. This indicates that the Island once formed part of a coastal cordon similar to those of the Wilderness. Even moderate SSE winds above 25 km/hr are very rare today, suggesting that storm patterns have shifted. By contrast, post-Beacon Island dunes correspond closely to modern wind vectors.

The eolian sands of the southeastern Cape coast are only in part "regressional," i.e., deflated from freshly exposed littoral zones during the course of glacial–eustatic regressions. The coastal cordons of the Wilderness and Plettenberg Bay, as well as the recent littoral dunes from Cape St. Francis to Port Elizabeth, are a function of close beach proximity and an ample supply of sand. Ridges of this shape and orientation could not have formed at these locations if sea level were more than 50 m lower than today (see reconstruction by Dingle and Rogers, 1972). In fact, these cordons and the recent littoral dunes could only have formed (1) during periods of high sea level, (2) during the earliest stages of an incipient regression, or (3) during the later phases of a renewed transgression. The case of the complex ^{14}C-dated sand stratigraphy from Robberg and Plettenberg Bay is conclusive that most or all of the post-Brenton dunes—which are in large part of the cordon type—are younger than 16,000 BP, with increased stabilization after 4000 BP. This points strongly to a transgressional facies, presumably fed by littoral erosion and reworking of late Pleistocene subaerial sediments on the Agulhas Shelf (see Dingle and Rogers, 1972). Accordingly we favor a late glacial/early interglacial stratigraphic position for the Pleistocene littoral cordons. However, the origin of the eolian mantles and older dune fields on top of the Coastal Platform is more ambiguous and at least some of these features are regressional, e.g., the Brakkloof eolianite. Some dunes do date from early glacial phases, although such a distinction can seldom be made by field criteria.

Littoral dunes can form in any climate where there is abundant sand and therefore provide little paleoclimatic information. Extensive dune fields with examples of good stratification or cross-bedding as found in the Knysna Forest are another matter. The forest was entirely displaced at the time that those eolianites predating the Brakkloof Soil were laid down. A modern analog is provided by the recent microdunes which are precisely restricted to those parts of the Knysna Forest cut over and burned in the 19th century, prior to restocking with plantations of foreign pines and eucalypts.[8] Eolian remodeling has since ceased. There are indications, too, that the amorphous Pleistocene cover mantles elsewhere were deposited under drier conditions; in the Tzitzikamma Forest they are locally interdigited with coarse-grade alluvial fans deposited by minor streams draining the coastal ranges (Fig. 5). These coarse-to-cobble-grade gravels fall outside the modern geomorphic balance with its sedimentation of suspended matter and sands. A climate with marked seasonality of rainfall and reduced vegetation is indicated (see discussion of alluvial deposits later). Altogether the eolian sands of the interior indicate periods of much drier climate with the Knysna-type forest eliminated except for relict stands in more mesic microenvironments. Closed forest is now absent from areas with less than 600 mm precipitation, and even the adjacent vegetation types—scrub forest and bushveld—are by no means ideal for eolian activity. Consequently a 50% decrease in precipitation must be regarded as a conservative, minimum estimate for periods of interior dune development.

The Beacon Island Soil and other humic paleosols represent different phases of the standard Holocene soil profile on nutrient-poor, highly permeable, silica sands. However the representative sections at Plettenberg Bay, in the Wilderness, and near Cape St. Francis have no more than 600 mm precipitation; more effective podsolization is taking place in wetter parts of the forests, as suggested by podsolic profiles in the youngest generation of dissected alluvium (Fig. 5). Measured against this yardstick the Brenton Soil differs only in degree from Holocene pedogenesis, and the apparent difference of weathering intensity may reflect more on time than on rates of weathering. Be that as it may, the Brakkloof and Knysna soils fall outside of the norm, as do many other cases of relict deep weathering in mid-latitudes (see Dury, 1971). Since the Knysna soil has not yet been studied in de-

[8] Major despoliation of the indigenous forests was underway in the 1820's, aided by a catastrophic forest fire along most of the Coastal Platform in 1869. Indiscriminate cutting was first checked beginning in 1873, when a full-time conservator of forests was appointed in Knysna (Tapson, 1963; p. 75 and Chap. 11). Reforestation began in the 1880's but only since 1909 on a large scale.

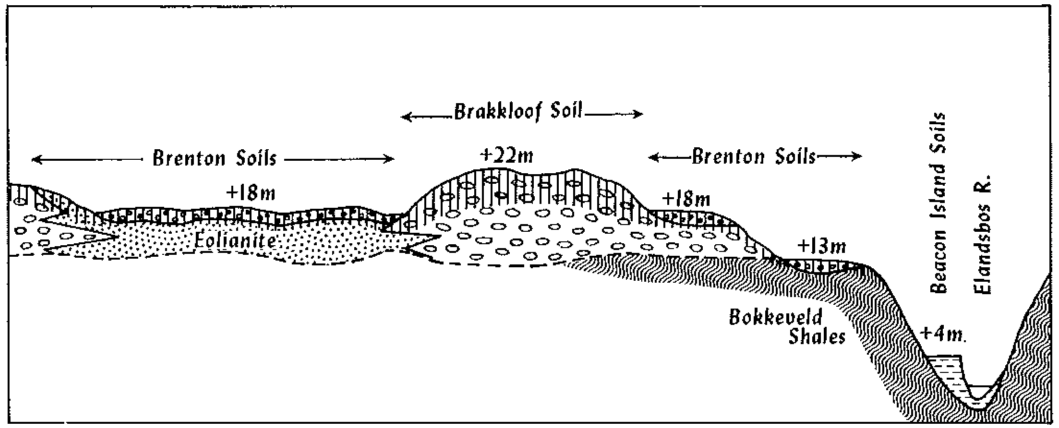

FIG. 5. Schematic cross section of alluvial fans, eolianite and relict soils on Coastal Platform, near Tzitzikamma Mountains. Not to scale.

tail, the subsequent commentary is restricted to the Brakkloof paleosol.

The Brakkloof profile differs both in degree and kind from the sum total of post-Brakkloof pedogenesis. However, the neoformation of clays and sesquioxides in eolianite parent material of almost pure quartz/quartzite sand poses a problem. Contemporary coastal dunes include almost nothing beyond silica and lime sand or molluscan debris (25–40% on the average) with a little glauconite and only a trace of other heavy minerals (see also Rogers, 1966, p. 21). Admittedly there are precedents in the red soils developed on lime-and-quartz eolianites or on pure limestones in the Mediterranean region and the West Indies, where Syers *et al.* (1969) attribute clay minerals to trans-Atlantic aerosolic dispersal. Whatever the explanation, and considering the many edaphic problems, the Brakkloof Soil as well as the old laterites under the Formosa Formation and on top of the Coastal Platform must be attributed to a warmer and wetter climate. Whether we accept the analog of true laterites actively forming in the Amazon lowlands or, preferably, of deep ferrisols such as those of the Congo Basin (see Sys, 1960; Sombroek, 1966; UNESCO, 1971), it must be assumed that annual temperatures were at least 8°F (5°C) higher and that precipitation was 60–80% greater than today. In any case these older paleosols infer a high degree of geomorphic stability and a completely closed vegetation mat.

HIGH PLEISTOCENE BEACHES

The southeastern Cape coast preserves a sequence of high littoral terraces, with or without related sediments, that range in relative elevation from +60 to +5 m. These shorelines are frequently linked with estuarine–alluvial terraces that allow a variety of deductions on the evolution of the coastal streams. Due to the prominence of sheer quartzite cliffs or valley walls falling off below the Coastal Platform, development of shorelines and terraces is relatively poor and generally discontinuous. Nonetheless a basic stratigraphic framework is available.

The oldest, post-Formosa shoreline is recorded by the 57–63-m platform at the base of the Brakkloof Formation and which can apparently be traced across the crest of the Robberg Peninsula. Only much further east can level surfaces at 60 m be seen cut across bedrock along the Kabeljous River and at Cape St. Francis (Fig. 1), where there also is a set of younger shorelines that suggests a similar sequence to that near Robberg and so serves as a frame of reference. Although documentation for the 60-m shoreline is rudimentary, we found absolutely no evidence for either the local faulting or the large-scale upwarping in the Tzitzikamma Forest suggested by Davies (1971) for most apparent complications to a universal sequence of shorelines at identical levels. Not only do multiple substages complicate any shoreline "stage," e.g., at the Brakkloof-type site, but differential development and preservation are dictated by lithology, preexisting coastal articulation, and exposure of the coast to subsequent undermining. Above all, the Coastal Platform maintains an almost uniform elevation from west of George to east of Port Elizabeth—through the Tzitzikamma Forest—and any deformations have been limited to minor warping of restricted extent.

Next is the 30-m shoreline. The evidence includes a subcontinuous nip or line of accordant cave entrances cut into the Cretaceous quartzites of Robberg (see also Rogers, 1966, Table 12); cobble beaches and a ferricreted estuarine terrace in the Bietou estuary; platforms along the Kromme and Seekoei Rivers near Cape St. Francis; and a cobble beach near the mouth of the Kabeljous River (Fig. 1). These four examples (compare Davies, 1971) are particularly impressive since they are chosen from local sequences that preserve older or younger beaches and that are simultaneously free from deformation; consequently they seem to indicate a 30-m shoreline of moderate duration.

More ubiquitous are the minor but nonetheless distinctive traces of another shoreline at 15–20 m above the present. Ignoring a host of inconclusive nips and sea caves that might be of structural origin, this stage is adequately recorded by at least five localities (see also Davies, 1971): (1) a widespread estuarine terrace along the eastern side of the Knysna estuary; (2) a terrace of mixed littoral–estuarine facies around the Bietou Estuary; (3) beach gravels interbedded with screes at Keurboomsstrand; and (4) massive estuarine terraces in both the Kromme and the Seekoei Valleys.

Most impressive are the vestiges of a shoreline at 5–12 m above present watermark. The key sites (see also Davies, 1971) are as follows: (1) shelly littoral beds to +5 m with thermophile mollusca in interdunal swales at Sedgefield (Martin, 1962); (2) an erosional bench on the western side of the Knysna Estuary, where limited outcrops of related beach sand at +4–6 m include a rich molluscan fauna of thermophile character (Miller, 1963, 29 f); (3) a gravel beach at +10–12 m inside Nelson Bay Cave, Robberg (cf. Butzer, 1972); (4) extensive barrier beaches at +7–12 m, possibly representing two or three substages, on both sides of the Keurbooms–Bietou Estuary, with a related estuarine–alluvial terrace at +10–12 m in the Bietou drainage; (5) an extensive cobble beach at +8–5 m in Natures Valley; (6) wave-cut platforms with cliffs at +8–5 m as well as caves with nips and beach gravel at +7–9 m, at and near Klasie's River Mouth; (7) a +5.5-m estuarine terrace and a +7.5-m barrier beach in the Kromme and Seekoei valleys, respectively; (8) "beach rock" at +7.5 m near Cape St. Francis, and (9) a +6.5-m estuarine terrace along the Kabeljous River.

The deposits related to the +5–12-m shoreline show the Brenton Soil profile, so for example at Sedgefield and in the Bietou Valley, where over 120 cm of brown (10 YR) loamy B-horizon are exposed under covering sands with a Beacon Island profile. Downvalley the coeval barrier bars (Fig. 6) have a 160-cm A/B-profile over a deep groundwater oxidation horizon. Soil profiles on the deposits of the +15–20-m shoreline are more eroded but otherwise indistinguishable, suggesting that the two stages are relatively close in time. A second stratigraphic aid in characterizing the +5–

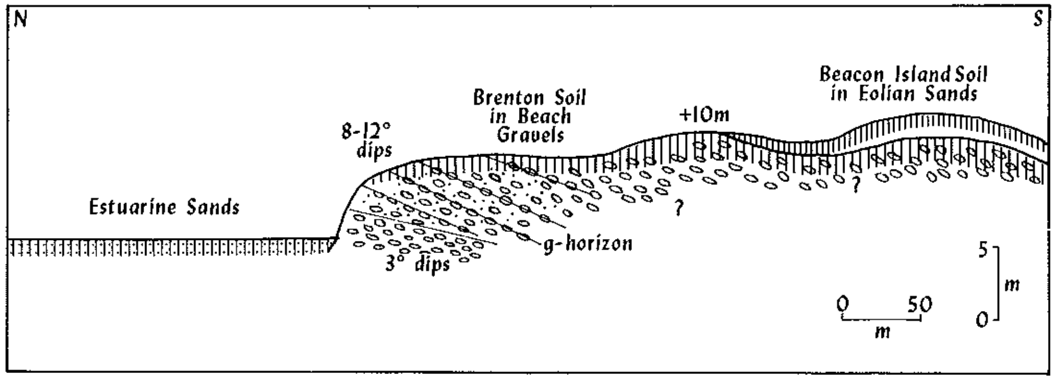

FIG. 6. Ten-meter barrier bar exposed by highway south of Keurbooms–Bietou Estuary.

12-m beaches is the presence of thermophile mollusca, which link several beaches at comparable levels along the Cape coast (Davies, 1971). These fauna include species now restricted to warmer Indian Ocean currents off the eastern Cape, Natal, or even Mozambique (Martin, 1962; Davies, 1970, 1971). The key faunal site at the mouth of the Swartkops River is at the same elevation (+6–8 m) as an estuarine terrace in the lowermost Coega River. On its landward edge the Coega deposit has a Brenton Soil while pelecypod shells we collected from the topmost molluscan horizon gave an apparent age of 42,850 ± 4150 BP (UW-168). This age agrees sufficiently closely with a determination at 37,700 ± 2000 BP (Y-468) (Martin, 1962, 1968) from the Sedgefield counterpart. Since minimal recrystallization will simulate such barely finite ages in mollusca, these determinations can only be regarded as minimum values for what are shells of "infinite" radiocarbon age.

Consequently we believe that the 5–12-m beaches and estuarine deposits pertain to the last, i.e., Eem Interglacial. However, in preference to an altimetric definition or an external correlation we prefer the informal designation of Swartkops horizon, after the key faunal site of Davies (1971). Whether this horizon requires subdivision is impossible to ascertain with the available evidence; correspondingly, correlation with the thermophile Tyrrhenian II or III (or both) faunas of the Mediterranean Basin (Butzer and Cuerda, 1962a, 1962b; Stearns and Thurber, 1965, 1967) is still open-ended.

Beaches younger than the Swartkops horizon and lacking Brenton Soil profiles can be identified only in the estuaries of the study area. The Keurbooms–Bietou estuarine zone has alluvial terraces at 1–2 m and 3.5–4 m above floodplain/high tide and which show nothing but intrazonal soil profiles. The same applies to the 1.5-m Swartvlei estuarine terrace at Sedgefield.[9] Most convincing is Martin's (1962, 1968) remarkable Holocene sediment and pollen section at nearby Groenvlei indicating a transgression to +2.5 m a little after 6870 ± 160 BP (Y-466) with sea level returning to its present datum a little before 1905 ± 60 BP (Y-467). Abrasional features are another matter, and we do not believe that any nips or wave-cut platforms of post-Swartkops age can hope to be identifiable in the study area, even if they do happen to exist.

External correlation of the pre-Swartkops shorelines will necessarily remain speculative in view of the inadequacies of the field evidence in the study area. However, massive and widespread littoral sequences of interdigited beach deposits and eolianites are

[9] Reexamination of the soils in this terrace yielded no indication of a podsolic profile (see Martin, 1962).

found inland of Algoa Bay. These have been mapped in general outline by Ruddock (1968) but remain to be studied in detail. Our reconnaissance indicated the presence of multiple facies and of fauna exposed in good sections that promise to provide a standard stratigraphy for the South African coasts and that compares in many ways with the unique Pleistocene littoral sequence of the Balearic Islands.

VALLEY DEVELOPMENT, STREAM AND SLOPE DEPOSITS

The major rivers of the southeastern Cape Province run parallel to west–east structural lineaments, and only occasionally do antecedent streams cut across the Cape Folded Ranges. In the study area similar structural influences result in a subrectangular drainage pattern for high-order streams that intermittently seek out weaker shale belts while cutting back into the synclinal valleys. Such streams, including the Keurbooms and Storms Rivers, are deeply incised (as much as 200 m) across the width of the Coastal Platform, with occasional entrenched meanders. At the coast, bedrock has been eroded to well below channel floor and deep sections of recent fill have been tapped by cores excavated while preparing bridge pilings. On the other hand, the subparallel streams of lower order are incised into the peripheries of the Coastal Platform, but these canyons terminate rapidly in knickpoints, cataracts or hanging valleys, that lead upstream to shallow valleys barely etched into the surface of the Coastal Platform; these are fed by steep-gradient watercourses draining the flanks of the Outeniqua and Tzitzikamma Mountains.

This picture of entrenched coastal valleys raises the matter of how valley evolution was related to planation of the Coastal Platform, to the subsequent high shoreline stages, and to periods of marine regression.

The great majority of the streams on the Coastal Platform appear to postdate its planation. Exception to this are larger rivers such as the Keurbooms and Kromme as well as the Gamtoos system, which even within the Cape Folded Ranges are locally followed by rock-cut platforms graded to the Coastal Platform. Also of greater antiquity is the Bietou Valley, which antedates the Keurbooms Formation and which is probably of tectono–erosional origin within an ancient syncline of the Bokkeveld Shales.

Considerable planation of the littoral zone is indicated in the Plettenberg Bay area for both the 140–145-m surface and the 100–120-m Formosa shorelines, but the extent to which drainage systems were regraded must remain conjectural. Similar, vague inferences can be made for the littoral planation accompanying the 60-m shoreline near both Plettenberg Bay and Cape St. Francis (see Fig. 1).

Major dissection and perhaps even valley overdeepening had taken place by the time of the 30-m beach. In particular, the related estuarine terraces of the Bietou drainage indicate that lateral and vertical valley dimensions were already substantially the same as today. By inference, the glacial–eustatic regression accompanying deposition of the Brakkloof eolianite was well below modern sea level for a considerable span of time. Considerable bedrock excavation of the larger streams further east is indicated by the rock-cut platforms developed along the lower Kromme and Seekoei Rivers at the same time. Finally the location of the beaches and estuarine terraces contemporary with the Swartkops horizon show that little significant valley modification has occurred during late Quaternary times, contrary to the opinion of Mountain (1945).

All the alluvial terraces of immediate coastal areas appear to be related to high shorelines, aggraded in relation to higher sea levels. However, this does not necessarily apply for the midstream and upvalley parts of the major stream valleys east of Cape St. Francis, where the distinction of climatic versus eustatically controlled terraces requires careful and detailed field investigation. In the study area, midstream segments are so deeply incised into bedrock along highly irregular and stepped stream profiles as to preclude direct relationships of the coastal terraces with alluvial fans and associated stream terraces found within and along the foot of the Cape Folded Ranges. The eustatic terraces of the coastal zone offer some paleoclimatic information. In the Bietou system (see Fig. 3) these alluvia were reworked from the Keurbooms Formation, with strong, lenticular sorting, torrential bedding of gravel, and some marked valley-margin-dips that all suggest rapid runoff. By contrast the Holocene estuarine terraces are humic and loamy, with little stratification and next to no gravel. A similar trend is suggested by the limited exposures in the Cape St. Francis area, where eustatic terraces include crude detritus. These "interglacial" alluvia all suggest a reduced vegetation mat and accelerated runoff, and therefore imply that climatic as well as eustatic factors were responsible for aggradation.

Slope breccias and other colluvial deposits are widespread both on the seaward and landward margins of the Coastal Plateau. Along the coastal slopes, colluvia are best developed on Bokkeveld Shales and consist of angular rock rubble, crudely stratified in a matrix of grayish to brownish (10 YR) loam, but lacking lenticular sorting. Gradients are from 5 to 35° or more and in some areas are projected to below modern sea level. Similar deposits form shallow, dissected talus cones on the seaward slopes of the Outeniquas and Tzitzikammas. Comparable rubble is rarely seen to be forming today and these colluvia are not compatible with undisturbed modern vegetation. Just as the cryoclastic roof debris of Nelson Bay Cave (see detailed arguments in Butzer, 1972), the rubble itself must be attributed to frost weathering, although frost is now extremely rare. Of 12 climatic stations in the general study area (see *Climate of South Africa* 1, 1954) mean minimum temperatures of the coldest month range from 34–43°F (+1.4–5.3°C) and only three have ever observed subfreezing conditions, the coldest being 27°F (−2.8°C) in the 67-yr record of Storms River (241 m elevation). The mean soil temperature (at −30 cm) for the coldest month of Deepwalls (519 m elevation is 51°F (10.6°C). We therefore believe that an 18°F (10°C) lowering of winter temperatures would be necessary to produce effective frost weathering along the southeastern Cape Coast for the type of cryoclastic debris found in these slope breccias and in the lower beds of Nelson Bay Cave. The same probably applies for the land rubble of the Formosa Formation.[10]

Although we attribute the origin of much or most of these materials to frost weathering, we do not invoke soil frost phenomena in their transport and bedding. These are typical slope deposits transported by sheetwash, creep and other gravitational movements, with or without accessory frost-generated motions. Comparable deposits have been studied by one of use at high elevations in the Balearic Islands (Butzer, 1964) and at low elevations in northwestern and northern Spain (Butzer, 1967, and unpublished). We attribute such deposits to a rupture of slope equilibrium and intensified denudation, presumably related to an opened, incomplete vegetation cover, with marked rainfall periodicity and/or intensity (see Butzer, 1971b, 306 ff). Unfortunately workers from

[10] Biological considerations such as those of Levyns (1962) would imply that the limited frost-tolerance of the Knysna forest associations precludes cold Pleistocene climates of the severity suggested in this paper. Such apparent contradictions are not unique to South Africa. The refuges in which warm-temperate European floral elements survived harsh glacial climates remain to be located. More problematic still are the thermophile Tertiary relicts of the Pontic and Hyrcanian floras in western Asia which also survived severe Pleistocene frost regimes.

high latitudes repeatedly consider such deposits in lower middle latitudes as "periglacial" and Linton (1969) has recently invoked geliflual transfer for a great variety of Pleistocene deposits in the Cape Province. Although we too have recognized such features above 1500 m or so in other sections of the Cape Folded Ranges, those phenomena described by Linton (1969) from lower elevations are decidedly not "geliflual." In fact we have not found a single example of *grèzes litées* or other geliflual deposits in the thick, well-exposed mantles of slope deposits found at angles from less than 5° to greater than 60° around the Cape Peninsula.

The majority of the slope deposits in the study area show moderately deep podsolic profiles of Brenton type, and appear to coincide with the Würm glacial–eustatic regression. The Nelson Bay Cave profile (Butzer, 1972) suggests that most should be correlated with the Lower Würm Pleniglacial (in the terminology of van der Hammen *et al.,* 1967). Older slope screes are also present and in the Tzitzikamma Forest are represented by reddish-yellow (7.5 YR) clays including badly corroded but stratified detritus, intruded by root or burrow fills of younger slope detritus. Possibly of comparable age are the coarse alluvial fans that interfinger with Brakkloof eolianites (Fig. 5) along the footslopes of the Outeniqua and Tzitzikamma Mountains. Such alluvial fans, often quite steep and grading into talus cones, are a common anomaly—in relation to modern vegetation cover and sediment transfer—along the coastal mountains as far west as Cape Town. Altogether it is impossible to avoid the conclusion that intensive denudation and incomplete vegetation mats were characteristic of much of the glacial periods, just as in the Mediterranean region (Butzer, 1971b, Chap. 19). This picture is compatible with the prominence of open-country mammals in the Nelson Bay Cave sequence ca. 18,000–12,000 BP (Klein, 1972b).

During the course of the Würm regressions the lower courses of the major coastal streams were overdeepened. Krige (1927), Martin (1962, Appendix I) and Davies (1971) have described or discussed most of the available data: the Keurbooms–Bietou Estuary has fine marine or estuarine sediments to below −40 m, the Goukamma River to below −24 m, and the Gamtoos River to −46 m (profiles made available to the writers by South African Piled Foundations, Ltd.). This explains the drowned aspect of many stream mouths. In fact, erosional or depositional features of the once-extended channels of the Keurbooms and Gamtoos Rivers can be traced out across the width of the continental shelf (Dingle and Rogers, 1972; Dingle, 1971; Leyden *et al.,* 1971). Overdeepening further provides an explanation for the lack of alluvial terraces that can be directly linked with colluvial mantles, although screes or alluvial cones do rest on or interrupt older "interglacial" terraces along the margins of the Bietou Valley.

Holocene estuarine terraces can be identified in at least several valleys. Humic loams without coarse detritus are most common. Of unusual interest are the Holocene alluvia upstream of Loerie, near 100 m elevation in the Gamtoos drainage (Fig. 1). Here three generations of fill can be identified. The first consists of over 12 m of loams and sandy loams, primarily colluvial products derived from Cretaceous shales and sandstones exposed on the valleysides, forming terraces at +12 m (primary level) and +5 m (erosional stage). The second generation includes 2–4 m of channel fills, deposited within the oldest beds and including sands, humic loams, and loamy peats. The peat, primarily due to growth of palmetto vegetation on a ponded stream bed, has C^{14} dates of 4010 ± 70 BP (UW-169) near the base and 1330 ± 110 BP (UW-203) near the top. By about 1000 BP geomorphic equilibrium was upset, with dissection followed by rapid aggradation of 2.5 m of coarse sands along steeper longitudinal gradients (2–3° compared with 1–2° for the modern stream bed and older fills). The Loerie recently began downcutting once again, although it is now partly flooded by a water conservation dam. The subtle but fundamental changes in stream character typified by the Loerie speak against a stable environmental balance during Holocene times and provide apparent analogs to repeated cut-and-fill cycles in the Orange–Veal drainage of the interior (see Butzer, 1971a). It is also of more than incidental interest that the Loerie peat was first deposited at the same time that the litoral dunes near Plettenberg Bay were stabilized by humic soils, a little before 4000 BP (see Table 8).

Pollen has been recovered from the Loerie peat (H. J. Deacon, personal communication). However, no faunal remains have

TABLE 8

MID-PLEISTOCENE TO HOLOCENE EVOLUTION OF THE SOUTHEASTERN CAPE COAST (COMPLEMENTING TABLE 1)

24	Deforestation and reactivation of littoral dunes, as well as gullying in low-order stream valleys, since 18th or 19th centuries A.D.
23	? Increasing geomorphic instability in low-order stream valleys after 1000 BP
22	Stabilization of littoral dunes, development of humic soils or local peat formation; "optimal" period of Holocene dynamic equilibrium. Sea level stable or falling. ca. 4200–1000 BP
21	Accumulation of littoral dunes and, in Loerie Valley, of fine slope wash and valley fill. Sea level rising, ultimately +2.5 m. ca. 7100–4200 BP
20	Stabilization of littoral dunes with development of weak podsolic or humic soils (*Beacon Island Soil*). Early Holocene
19	Accumulation of littoral dunes during Flandrian Transgression, after 16,000 BP. Late Würm to Early Holocene
18	Slow development of humic soils on littoral sands during period of limited geomorphic and pedogenetic activity. Upper Würm Pleniglacial
17	Development of "youthful," red–yellow podsolic *Brenton Soil* on Brenton eolianites and Swartkops beaches and fills. Würm Interpleniglacial
16	Regression to below modern sea level accompanied by fill dissection and overdeepening of lower valleys, as well as active frost-weathering and accelerated denudation, with deposition of slope breccias or soil colluvia. Lower Würm Pleniglacial
15	Aggradation or cutting of beach forms at +5–12 m, possibly in several substages. Related estuarine fill terraces in lower valleys. Thermophile *Swartkops* mollusca. Dated >40,000 BP and correlated with Eem interglacial
14	Marine Regression (at least 8 m), accompanied by fill dissection in lower valleys. Followed by accumulation of unconsolidated *Brenton* eolianite (Cordons III A and III in Wilderness Area)
13	Cutting of minor beach features at +15–20 m, with related estuarine fill terraces in lower valleys. Early *Brenton* eolianite (? Cordon II in Wilderness Area)
12	Regression (at least 15 m), with further valley cutting in coastal areas
11	Cutting of beach platforms at +30 m, with related fluvial platforms and fill terraces in lower valleys. Development of lateritic podsolic *Brakkloof Soil* (plinthudult)
10	Regression (at least 30 m), accompanied by further bedrock incision of major stream valleys to approximately contemporary dimensions. Accumulation of *Brakkloof Fm* (eolianite) on +60 m platform and on uplands, interdigited with alluvial fans in foothills of Cape Folded Ranges
9	Cutting of beach platforms at +57–63 m, with related fluvial platforms in lower stream valleys. ? Development of "mature," red podsolic soil (*Knysna soil*)
8	Marine regression from Formosa transgressive levels (at least 40 m), accompanied or followed by bedrock incision of major stream valleys. Earliest (?) eolianite on uplands

been found in the alluvial or colluvial deposits of any part of the study area, and archeological associations are of limited interest: some Middle Stone Age or Acheulian materials in colluvium (e.g., Matjesfontein, see previously), and MacFarlane (1958) mentions Middle Stone Age material from deposits on the 10–12-m Bietou estuarine terrace, Acheulian from within 15–20 m terraces.

GENERAL EVALUATION

The step-by-step evolution of geomorphic parameters along the southeastern Cape coast since the late Tertiary is outlined in Tables 1 and 8. The picture derived from the available evidence is necessarily incomplete, and the 24 stages of evolution represent a minimum number. Both here and in the level of resolution of each event there will be much to be gained and improved by continued field work and laboratory analyses. But even within these severe limitations, the evidence points unmistakably to a sequence of changing environmental factors that include tectonic deformation, eustatic fluctuations of sea level, and fundamental changes of vegetation and climate.

Perhaps the most surprising conclusions, at least to the writers, are those concerning repeated and drastic changes of vegetation and climate in what is today the most mesic environment of southern Africa. The evergreen Knysna and Tzitzikamma Forests were essentially eliminated on several occasions, e.g., during the accumulation of the Keurbooms fanglomerates, the Formosa land rubble, the Brakkloof eolianite, and the pre-Brenton slope breccias and colluvia. In other instances, e.g., during the early phases of the Würm glacial and probably also contemporary with the Formosa land rubble, frost weathering was so potent in what is now an equitable, mesothermal climate, that a 10°C drop of winter temperature must be postulated. At other times deep weathering, suggestive of perhumid, semitropical, or tropical conditions, produced a paleosol such as the Brakkloof Soil. These environmental shifts appear to include precipitation means from less than 50% to 160–180% or more of the present normals, and average temperatures probably ranging from 10°C below to 5°C above those of today. Seasonality and intensity of precipitation were also affected in a fundamental manner. Some of these changes date from the late Tertiary, the majority from the Pleistocene alternation of glacials and interglacials, each with their complex and varying circulation patterns. Most unexpected of all, perhaps, is the record of changing geomorphic equilibrium conditions during the Holocene. Late Stone Age man may have played a part in some of these youngest incidents of disturbance, as indeed have the European colonists of the last two centuries. Yet whatever the differences of emphasis or interpretation of this or that detail, there have been repeated and basic changes of vegetation and climate throughout the late Cenozoic. And these metamorphoses of the environment were of a kind and magnitude either not realized or appreciated by earlier workers in South Africa.

Given this continuing variability of geomorphic parameters through time it is impossible to view landscape evolution in the southeastern Cape as a unidirectional process, affected only by time and rates of dynamism. The whole balance of geomorphic forces has been repeatedly upset in so radical a fashion that we must envision at least two models of dynamic equilibrium—in the original sense of G. K. Gilbert—one under closed forest with deep chemical weathering and restricted denudation, the other under open and incomplete vegetation with shallow soils and active morphogenesis. Such rudimentary models were first formulated by Erhart (1956) but can be improved and adjusted to match the regional data input. Only then, in the full realization that landscape evolution is a multivariate process, temporally as well as spatially, can we hope for a more realistic interpretation of contemporary landforms. Historical geomorphology, when concerned with real events and the rational interpretation of their related phenomena, is more than mere historicism. Stoddart (1969), in his critical evaluation of environmental ("climatic") geomorphology, concentrated on methodological and general writings, overlooking the substantive contributions of the environmental approach in historical geomorphology. Yet no matter how sophisticated an open system is devised, based on measured contemporary energy fluxes, it cannot hope to do credit to the true evolutionary complexity of landforms. It is in this perspective that we may ultimately hope for a balanced understanding of the geomorphology of South Africa.

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