PALEOSOLS OF THE SOUTHERN CAPE COAST, SOUTH AFRICA: IMPLICATIONS FOR LATERITE DEFINITION, GENESIS, AND AGE*

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L ATERITES and lateritic soils sparked what probably has become the longest and most obfuscating discussion in the history of earth science. Sources of the confusion surrounding the word "laterite" can be identified in terms of two general problems with past research.[1] The all-important problem has been the general failure to develop a functional definitional framework for "laterite." Agronomists, geologists, geomorphologists, and pedologists have applied the term specifically to variably cemented, sesquioxide-rich soil horizons. It has also been widely used to describe any soil profile that contains such a horizon and has even been applied indiscriminately to any reddish colored soil or sediment at or near the earth's surface.[2] In addition, assorted mineralogical definitions have been used, particularly by soil scientists. It is unclear whether any or all of these definitions should be considered correct. The definitional problem has been compounded by the different genetic explanations that have been provided for all possible definitions.

The second problem with past "laterite" research has been the general lack of concern for recognition and dating of laterite-like paleosols, which reflect past rather than contemporary weathering conditions. Even when laterites have been identified according to an acceptable definition, they have often been uncritically ascribed contemporary formation in the environment in which they are now found. It is frequently not appreciated that a surficial sediment or weathering profile may be a relict of past environmental settings yet serves in an only slightly modified fashion as the substrate for the modern vegetation cover.[3] Furthermore, when laterites have indeed been identified as "fossil," dating has generally proved to be difficult. Laterites

[1] For more comprehensive reviews and commentaries see S. Sivarajasingham, L. T. Alexander, J. G. Cady, and M. G. Cline: Laterite, *Advances in Agronomy,* Vol. 14, 1962, pp. 1–60; R. Maignien: Review of Research on Laterites, *Natural Resources Research, No. 4,* UNESCO, Paris, 1966, pp. 11–148; and T. R. Paton and M. A. J. Williams: The Concept of Laterite, *Annals Assn. of Amer. Geogrs.,* Vol. 62, 1972, pp. 42–56.

[2] "Laterites" have been studied from at least five different, not explicitly pedological, perspectives: as relatively static images of the humid tropical environment (W. G. Sombroek: *Amazon Soils,* Centre for Agricultural Publication and Documentation, Wageningen, 1966); as hazards in tropical agricultural development (Mary McNeil: Lateritic Soils, *Scientific American,* Vol. 211, No. 5, 1964, pp. 96–102); as erosion-resistant caprocks (duricrusts) (G. H. Dury: Rational Descriptive Classification of Duricrusts, *Earth Sci. Journ.,* Vol. 3, 1969, pp. 77–86); as both a raw material and a hazard in civil engineering (Benjamin S. Persons: Laterite: Genesis, Location, Use [Plenum Press, New York, 1970]; M. D. Gidigasu: Mode of Formation and Geotechnical Characteristics of Laterite Materials of Ghana in Relation to Soil-Forming Factors, *Engineering Geol.,* Vol. 7, 1972, pp. 79–150; and R. A. Lohnes and T. Demirel: Strength and Structure of Laterites and Lateritic Soils, *ibid.,* Vol. 8, 1973, pp. 13–33); and as paleoclimatic indicators in soil-stratigraphic studies (Richard Foster Flint: Pleistocene Climates in Eastern and Southern Africa, *Bull. Geol. Soc. of America,* Vol. 70, 1959, pp. 343–374).

[3] For a discussion of inherited soils and periodic landscape development, see Karl W. Butzer: Geomorphology from the Earth (Harper and Row, New York, 1976), pp. 323–333.

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tend to occur on erosional surfaces, and the date of such laterites has often been temporally equated with the formation of the surface in question. Quite apart from the major, inherent problem of linking deep pedogenesis with active planation, laterite development on an existing surface could have taken place on several occasions long after planation had ceased. Furthermore, the durability of a sesquioxide-cemented horizon or duricrust vis-à-vis secondary weathering on low-relief terrain would seem to assure it a higher potential for survival than that of any other soil or weathering zone. These contextual problems can only be remedied by representative environmentally and geomorphologically framed soil surveys throughout the perhumid and seasonally humid tropics.

While not closely following the original (1807) description of "laterite" by F. Buchanan-Hamilton,[4] an increasing number of authors have recently defined primary laterites on the basis of a profile characterized by a sesquioxide-enriched concretionary horizon, or plinthite, over a reddish, clay-enriched zone with conspicuous mottling, known as a mottled zone.[5] At the base of the mottled zone an additional, light-colored layer, the pallid zone, may also be encountered. A further requirement of this morphological definition of laterite is that the materials comprising the profile be the product of intensive chemical weathering.

Paleosols that conform to this basic definition are found along the southern coast of the Cape Province, South Africa, near latitude 34°S in what is now a warm-temperate macroenvironment. Two stratigraphically distinct paleosols that exemplify the underlying problems of concept, genesis, and age are evaluated here; the paleosols are the Formosa Soil and the Brakkloof Soil.[6] Our purpose is to describe these profiles and to discuss their implications for the broader problem of laterite research.

CONTEXT OF THE SOUTHERN CAPE LATERITES

Massive and nodular (pisolitic) plinthite is widely distributed along the southern margin of the Cape Province.[7] After his visit during the voyage of H.M.S. Beagle, Charles Darwin first described plinthites near Cape Town.[8] The value of these materials for road surfacing was noted in the southwestern Cape as early as 1852 by

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[4] F. Buchanan-Hamilton: A Journey from Madras through the Countries of Mysore, Canara, and Malabar . . . (3 vols.; British East India Co., London, 1807), Vol. 2, pp. 440–441.

[5] For example, see Michael F. Thomas: Tropical Geomorphology (Macmillan, London, 1974), pp. 53–54; A. S. Goudie: Duricrusts in Tropical and Subtropical Landscapes (Clarendon Press, Oxford, 1973), pp. 15–16; and Lester Charles King: Morphology of the Earth (Oliver and Boyd, Edinburgh and London, 1967), pp. 175–176. The term "plinthite," coined by the U.S. Soil Conservation Service ("Soil Classification, A Comprehensive System: Seventh Approximation" [U.S. Govt. Printing Office, Washington, D.C., 1960], p. 62), has come to generally refer to any pedogenetic sesquioxide concentration. Primary, or autochthonous, laterite profiles are now generally distinguished from secondary laterites (consisting of reworked ferruginous concretions from older laterites, swept together by colluvial processes and frequently cemented into a new matrix by fresh sesquioxide or ferromanganese compounds) and from ironpans or ferricretes (existing sediments or soils impregnated by ferromanganese compounds, frequently from lateral seepage waters; see Maignien, op. cit. [see footnote 1 above]; A. M. J. de Swardt: Lateritisation and Landscape Development in Parts of Equatorial Africa, Zeitschr. für Geomorphologie, Vol. 8, 1964, pp. 313–333; and Butzer, Geomorphology from the Earth [see footnote 3 above], p. 410).

[6] As formally defined by Karl W. Butzer and David M. Helgren: Late Cenozoic Evolution of the Cape Coast Between Knysna and Cape St. Francis, South Africa, Quaternary Research, Vol. 2, 1972, 143–169.

[7] See M. J. Mountain: Pedogenic Materials, Their Engineering Properties and Distribution in South Africa and South West Africa, Proc. Fourth Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Cape Town, 1967, pp. 65–70.

[8] Charles Darwin: Geological Observations on the Volcanic Islands, Visited During the Voyage of the H.M.S. Beagle, Together with Some Brief Notes on the Geology of Australia and the Cape of Good Hope (Smith, Elder, and Co., London, 1844), p. 143.

A. G. Bain.[9] Similarly derived plinthite gravels were encountered in the southern and eastern Cape;[10] and J. M. de Villiers and R. R. Maud have reviewed the physiographic relationships of several relict laterites in Natal.[11]

A number of paleosols were discovered as part of a general investigation of the Quaternary record along the coast of Cape Province between Knysna and Cape St. Francis (about 34°S and 22°45′E to 24°50′E).[12] This margin of the southern Cape is dominated by the eastward-striking ridges of the Cape Folded Ranges, which were formed by complex folding toward the end of the Paleozoic era. These mountains are composed of earlier Paleozoic metasediments, particularly the quartzites of the Table Mountain Series (Silurian?) and slate inliers of the Bokkeveld Series (Devonian). Paralleling the modern coast at a distance of 10 to 20 kilometers, the first of the Folded Ranges extends to above 1,500 meters, and ridge crests further inland reach above 2,000 meters. Between the first range and the sea there is a tabular, coastal foreland that stands at an average elevation of 200 meters.

In this paper we deal with paleosols situated along the seaward margin of this coastal foreland, in areas which were densely forested until the eighteenth century and which even now retain large areas of native and introduced woodland. The natural vegetation of the Knysna and Tsitsikama forests is a species-rich, multitiered, evergreen forest that reaches a height of 18 to 35 meters in wetter locales and is dominated by yellowwood (*Podocarpus falcatus* and *P. latifolius*), stinkwood (*Ocotea bullata*), ironwood (*Olea capensis macrocarpa*), and lancewood (*Curtisia faginea*).[13] There also are abundant lianas and scramblers, archaic tree ferns, native mimosaceae, and a corresponding ground flora of shrubs, ferns, and herbs. Sclerophyll heath with thorny, succulent shrubs as well as open scrub woodland of broad-leaved trees may be found on both drier and littoral sites, but they may represent a subclimax that reflects more than two centuries of severe disturbance.

The mean annual precipitation of this forest belt varies between 600 and 1,200 millimeters, with rainfall at all times of the year. Mean temperatures of the coldest month (July) lie in the 12–14°C. range, with mean daily minima of 7–10°C. and frosts practically unknown; mean temperatures of the warmest months (January and February) vary between 19°C. and 21°C.[14] In terms of the Köppen classification, this is a Cbf climate; in terms of the Thornthwaite system, $C_2B'_2ra'$ or subhumid mesothermal, with no water deficit and minimal summer concentration of potential

[9] A. G. Bain: On the Geology of Southern Africa, *Trans. Geol. Soc. of London*, Vol. 7, 1852, pp. 175–192.

[10] See E. H. L. Schwartz: Geological Survey of the Coastal Plateau in the Divisions of George, Knysna, Uniondale, and Humansdorp, *Ann. Rept. of the Geol. Commission of the Colony of the Cape of Good Hope for 1905*, p. 85; G. Mortelmans: Plages soulevées à industries lithiques de la région de Keurbooms River, District de Knysna, *South African Journ. Sci.*, Vol. 61, 1945, pp. 375–396; E. D. Mountain: The Geology of the Area East of Grahamstown (Geological Survey, Pretoria, 1946); and "Outeniqualand: The George-Knysna Area" (edited by P. D. Tyson; South African Geogr. Soc., Johannesburg, 1971), p. 14.

[11] J. M. de Villiers: Factors and Processes in Tropical and Subtropical Regions, *Soil Science*, Vol. 99, 1965, pp. 50–57; R. R. Maud: Laterite and Lateritic Soil in Coastal Natal, South Africa, *Journ. Soil Sci.*, Vol. 16, 1965, pp. 60–72; and *idem*, Quaternary Geomorphology and Soil Formation in Coastal Natal, *Zeitschr. für Geomorphologie*, Suppl. Vol. 7, 1968, pp. 155–199.

[12] Butzer and Helgren, *op. cit.* [see footnote 6 above].

[13] J. F. V. Phillips: Forest Succession and Ecology in the Knysna Region, *Botanical Survey of South Africa, Memoir 14*, Pretoria, 1931; A. R. H. Martin: Pollen Analysis of Groenvlei Lake Sediments, Knysna (South Africa), *Rev. Paleobotany and Palynology*, Vol. 7, 1968, pp. 107–144; and J. P. H. Acocks: Veld Types of South Africa, *Botanical Survey of South Africa, Memoir 40*, Pretoria, 1975, pp. 20–21.

[14] "Climate of South Africa" (Climate Statistics, Weather Bureau; Govt. Printer, Pretoria, 1954), Part 1; "Average Monthly Rainfall up to the End of 1960" (Climate Statistics, Weather Bureau; Govt. Printer, Pretoria, 1965), Part 9; and Outeniqualand [see footnote 10 above], pp. 11–13.

TABLE I—STRATIGRAPHIC FRAMEWORK FOR SOUTHERN CAPE PALEOSOLS*

SEQUENTIAL PHASE	DESCRIPTION
13	Several generations of transgressive coastal dunes, beginning 16,000 B.P., interrupted by Beacon Island Soil, an inceptisol (eutrochrept), about 7500 B.P., and younger buried entisols. Later Upper Pleistocene to Holocene.
12	Development of Brenton Soil, an alfisol (haplustalf), shortly after formation of +5-to-7-meter beach. Early Upper Pleistocene.
11	Complex of marine regressions and deposition of several eolianites. Late Middle Pleistocene.
10	Development of Brakkloof Soil, an ultisol (plinthic paleudult), probably coeval with +30-meter beach. Mid-Middle Pleistocene.
9	Marine regression, with eolianite deposition. Early Middle Pleistocene.
8	Development of Knysna Soil (complex), including an oxisol (typic eutrorthox), perhaps in part coeval with +57-to-63-meter beach. Late Lower Pleistocene?
7	Eustatic sea-level fluctuations, accompanied by eolianite deposition. Mid-Lower Pleistocene?
6	Marine regression, followed by deposition of barrier bars at +98-to-102 meters, with interdigited (cryoclastic?) land rubble, laterite derivatives, and artifacts (Formosa Formation). Early Lower Pleistocene?
5	Cutting of beach platform at +120 meters, with truncation of Formosa Soil. Late Pliocene?
4	Marine regression, followed by development of Formosa Soil, a plinthic oxisol. Mio-Pliocene?
3	Cutting of lower planation surface at +140-to-145 meters, possibly accompanied by formation of lateritic duricrust on Coastal Platform. Miocene?
2	Deposition of freshwater, Brackenhill beds, on Coastal Platform. Oligocene.
1	Planation of +170-to-200 meter Coastal Platform, with coeval accumulation of fanglomeratic and deltaic Keurbooms Formation. Eocene.

* Chronometry of Pleistocene stages: Lower, 1.8–0.7 million years B.P.; Middle, 700,000–130,000 years B.P.; and Upper, 130,000–10,000 years B.P. For a chronometric definition of Middle Pleistocene, see K. W. Butzer: Geological and Ecological Perspectives on the Middle Pleistocene, *Quaternary Research,* Vol. 4, 1974, pp. 136–148.

evapotranspiration. The major characteristic is the lack of any dry season or dry month,[15] rather than an absolute abundance of moisture. It comes as no surprise, therefore, that modern pedogenesis is not intensive. Low-intensity podsolization is characteristic on inland sites while little more than A–Cca profiles are developing on immobilized coastal dunes.

The geomorphology of the coastal foreland is dominated by planation forms and surficial deposits related to a descending sequence of high sea levels (Table I). The sedimentary sequences consist mainly of multiple generations of eolian sands (in part, cemented into eolianites) deposited during major eustatic sea-level fluctuations and interrupted by a number of paleosols.[16] The highest erosional surface is the Coastal Platform, which cuts across Table Mountain quartzites, Bokkeveld shales, and local

[15] See, for example, W. Lauer, R. D. Schmidt, R. Schröder, and C. Troll: Studien zur Klima- und Vegetationskunde der Tropen, *Bonner Geogr. Abhandl.,* Vol. 9, 1952, pp. 1–182.
[16] Butzer and Helgren, *op. cit.* [see footnote 6 above]. Several altitude frequency histograms depicting the Coastal Platform in "Outeniqualand" ([see footnote 10 above], p. 8) are complicated by the fact that many elevations refer to eolianite outcrops rather than to planation surfaces.
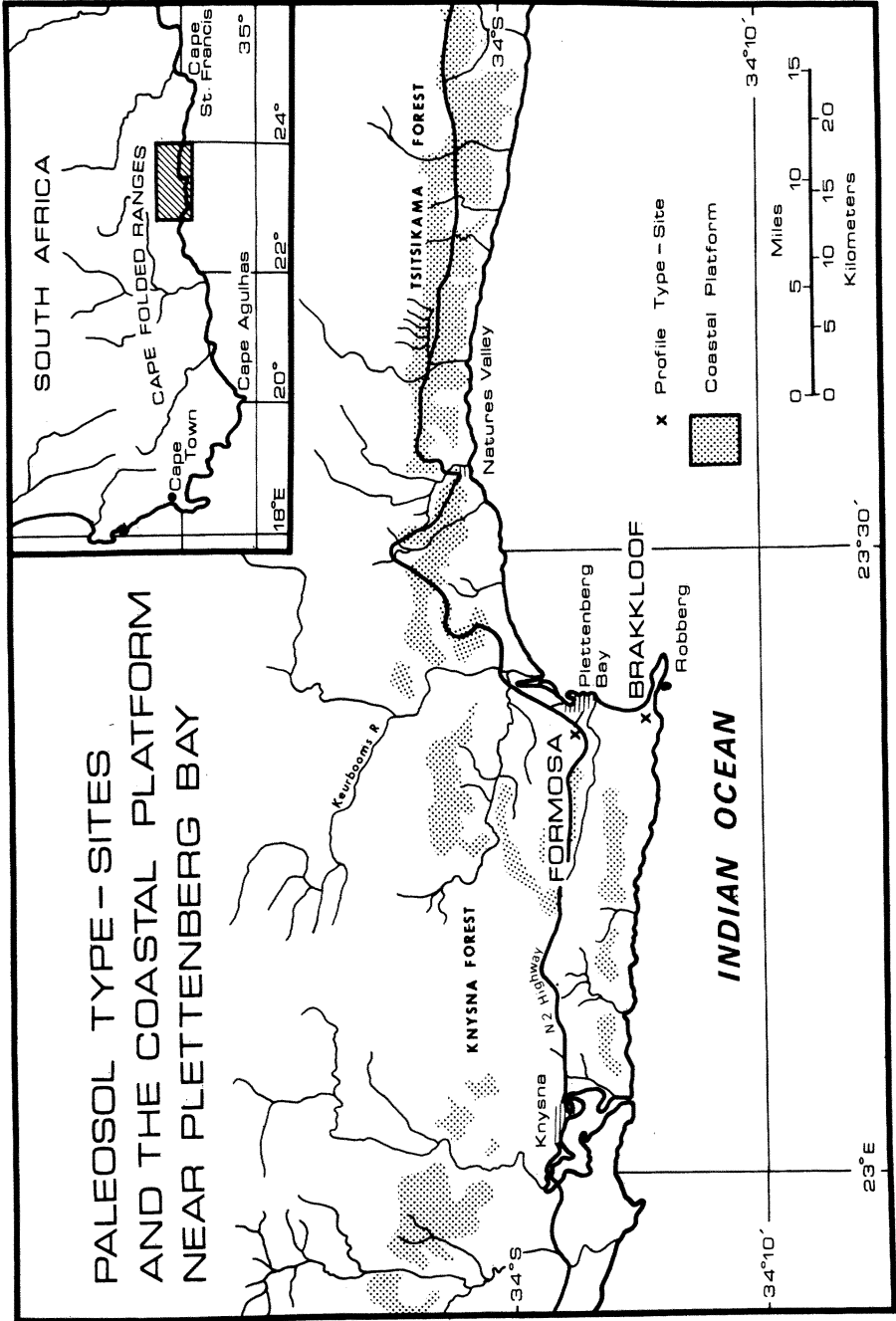
Fig. 1.—Type-site locations and the Coastal Platform near Plettenberg Bay, South Africa. The Coastal Platform is locally veneered by stabilized dune sands.

basins of Cretaceous clastics (Uitenhage Series). This impressive platform is probably unique in terms of its area and sharp definition. It appears to have been planed with reference to a +170-to-200-meter (relative) sea level and is 5 to 10 kilometers wide, extending with little interruption over a 500-kilometer stretch from near Cape Agulhas to east of St. Francis Bay.

Associated with the Coastal Platform in the Knysna-Plettenberg Bay area (Fig. 1) is the Keurbooms Formation, a suite of steeply dipping cobble conglomerates and compact clays that bank against the seaward margin of the platform. These uncemented deposits are distinctively younger than Cretaceous orthoquartzites in the area, and we originally believed they were of late Tertiary age.[17] However, evidence now indicates a substantially greater age. In particular, near Knysna, the Keurbooms Formation is overlain by a freshwater series (Brackenhill beds) of clays, sands, and lignites, followed by a thick, weathered eolianite sequence. One lignite, studied by Louis Scott, is dominated by pollen resembling the present *Jubaeopsis* and probably belonging to monocotyledonous plants that grew in the swamp responsible for peat formation. Proteaceous pollen are common, and grass pollen are present but rare.[18] This spectrum is substantially different from that of the area today, where *Podocarpus*, Restionaceae, Ericaceae, and Compositae are dominants. Because typical Upper Cretaceous as well as late Cenozoic Compositae are absent, but grasses are present, Scott concludes that this lignite is probably of early Oligocene age. However, several levels of lignites are present in these swamp beds. One was found to lack grass pollen;[19] another included macroremains of *Podocarpus*, *Widdringtonia*, *Gonioma*, and *Curtisia*, rather more suggestive of the modern forest.[20] This argues for a broadly Oligocene age, placing the underlying Keurbooms Formation in the Eocene.

The next geomorphic marker is provided by a planation surface at +140 to 145 meters and notched as much as 1 kilometer deep into the Coastal Platform. During a subsequent marine regression, to a relative elevation below +120 meters, a laterite developed on the +140-to-145-meter bench. This is the Formosa Soil, exposed repeatedly at 120-to-145-meter elevation along the highway west of Plettenberg Bay. Pedogenesis was ultimately terminated by erosion, specifically the cutting to a new marine bench at +120 meters, followed by partial emergence and widespread hillslope erosion with mobilization of highly angular (cryoclastic?) detrital material on gentle slopes of less than 5°. This land rubble grades downslope into well-rounded cobble conglomerates of a barrier-beach structure at +102 meters. This complex of soil wash, crude colluvial debris, and beach sediments comprises the Formosa Formation.[21] Simple, man-made flakes are found in the primary land rubble, and Acheulian hand axes have been recovered from colluvial deposits later derived from the beach facies.[22] The vigorous denudation, the reduced vegetation cover, the implicit cold climate, as well as the presence of indisputable artifacts, all suggest a Pleistocene age. The relationship with a "high" beach, preceding four or five other major transgressive sea

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[17] Butzer and Helgren, *op. cit.* [see footnote 6 above].

[18] Letter from Louis Scott to Karl W. Butzer, Aug. 8, 1975.

[19] F. Thiergart, U. Frantz, and K. Raukopf: Palynologische Untersuchungen von Tertiärkohlen und einer Oberflächenprobe nahe Knysna, Südafrika, *Advancing Frontiers of Plant Sciences,* New Delhi, Vol. 4, 1963, pp. 151–178.

[20] Phillips, *op. cit.* [see footnote 13 above].

[21] Formally defined and described by Butzer and Helgren, *op. cit.* [see footnote 6 above].

[22] See Mortelmans, *op. cit.* [see footnote 10 above]; and O. Davies: Pleistocene Shorelines in the Southern and Southeastern Cape Province, *Annals Natal Museum,* Vol. 21, 1971, pp. 183–223; and Vol. 22, 1972, pp. 225–279.

levels, speaks for a relatively early Pleistocene age. By implication the Formosa Soil must be late Tertiary, probably late Miocene or Pliocene.

Later sea-level stands at +57 to +63 meters, +30 meters, +18 to +20 meters, +12 to +15 meters, and +5 to +7 meters are recorded by relatively minor platforms, by notches in coastal cliffs, and by fluvial or estuarine terraces in valleys cut below the Coastal Platform. The +5-to-7-meter stage, associated with thermophile molluscan faunas, can be temporally equated with the sea level that marked the Last Interglacial along the Cape coast, probably in the order of 125,000 years ago.[23] Evidence for high, Holocene sea levels within a few meters of present levels is inconclusive on the exposed, high wave-energy coastlines but finds a record in the estuarine zones.[24]

Quaternary sea-level fluctuations were accompanied by repeated deposition of transgressive or regressive eolianites,[25] which cumulatively are more than 250 meters thick. They rest on top of the erosional surfaces or are embanked against coastal cliffs. Although they still exhibit subdued dunal topography, the older eolianites include several paleosols. The most prominent of these has been informally called the Knysna Soil.[26] The exact position of this paleosol in the eolianite sequence is uncertain, but it clearly pertains to the upper third of these deposits in the Knysna Forest, where it is frequently exposed at the surface. Moreover, it terminates one eolianite generation to extend down to well below +100 meters, without evidence of marine truncation, so that it must be younger than the Formosa Formation. Truncated profiles of the Knysna Soil show yellowish red (5 YR 5/6, dry) B2 horizons of weakly structured clay loam up to 3 meters thick. The even thicker B3 horizon exhibits secondary enrichment of amorphous silica (12 percent or more) and intensive mottling (10YR yellow and light gray, 2.5YR red), with a texture of sandy clay loam or loam. The B2 matches the essential diagnostic properties of an oxic horizon.[27] Eroded B-type sediment may also attain a thickness of several meters in adjacent swales, commonly displaying similar mottling and possibly some amorphous silica; these features suggest several prolonged episodes of intensive weathering. The Knysna Soil thus represents a complex of paleosols, at least the oldest of which qualifies as an oxisol (typic eutrorthox) and which collectively appears to be of early- or even mid-Pleistocene age.

In the Knysna Forest there also are younger, less-pronounced profiles, with truncated red (10R-2.5YR) to strong brown (7.5YR) argillic B horizons of clay texture. Two meters or more thick, they include dispersed or compacted oolitic and pisolitic plinthite. Such truncated plinthic ultisols may well overlap temporally with both the older Knysna Soil complex and the younger Brakkloof Soil. Truncated B horizons of this type may be overlain by up to 50 centimeters of colluvially reworked

[23] Karl W. Butzer, unpublished detailed archeosedimentary sequences from Klasies River Mouth, near Cape St. Francis, and Swartklip, near Cape Town. Also, K. W. Butzer: Geology of Nelson Bay Cave, Robberg, South Africa, *South African Archaeol. Bull.*, Vol. 28, 1973, pp. 97–110; J. L. Bada and L. Deems: Accuracy of Dates Beyond the ^{14}C Dating Limit Using the Aspartic Acid Racemization Technique, *Nature*, Vol. 255, 1975, pp. 218–219; and R. G. Klein: The Mammalian Fauna of the Klasies River Mouth Sites, Southern Cape Province, South Africa, *South African Archaeol. Bull.*, Vol. 31, 1976, pp. 75–98.

[24] A. R. H. Martin: Evidence Relating to the Quaternary History of the Wilderness Lakes, *Trans. Geol. Soc. of South Africa*, Vol. 65, 1962, pp. 19–42; and Davies, *op. cit.* [see footnote 22 above].

[25] See Martin, Quaternary History [see footnote 24 above]; Butzer and Helgren, *op. cit.* [see footnote 6 above]; and M. E. Marker: Aeolianite: Australian and South African Deposits Compared, *Annals South African Museum*, Vol. 71, 1976, pp. 115–124.

[26] Butzer and Helgren, *op. cit.* [see footnote 6 above].

[27] Basic terminology and soil classification follow the Soil Conservation Service's "Soil Taxonomy," *Agric. Handbook 436*, U.S. Dept. of Agriculture, Washington, D.C., 1975. See also suggestions for paleosol nomenclature by P. Birkeland: Pedology, Weathering, and Geomorphological Research (Oxford Univ. Press, New York, 1974), pp. 4–9.

TABLE II—FORMOSA SOIL ANALYTICAL DATA

UNIT	COLOR	TEXTURE SAND/SILT/CLAY: (in percentages)	pH	X-RAY DIFFRACTION MINERALOGY (++ abundant; + present; (+) trace)
1	10YR 4/1	58/28/14	6.2	
2 (matrix)	5YR 4/3.5	47/19/34	6.5	
3 (matrix)	5YR 3/3	44/14/42	7.4	quartz ++, goethite +, smectite (+) kaolin (+)
4	7.5YR 5/6-8	60/13/27	5.6	quartz ++, goethite +, kaolin +
5	5YR 4/4	72/0/28	5.8	quartz ++, goethite +, kaolin (+)

plinthite pisolites which, in turn, are commonly buried by sandy colluvium or younger eolian sands. These colluvial mantles provide the parent materials for soils that have formed since the last period of intensive weathering. Despite morphostratigraphic evidence for multiple generations of eolianites and pedogenetic events, details of the complex pedostratigraphic record between the Formosa and Brakkloof soils remain to be deciphered.[28]

The formal stratigraphic soil zone designated as the Brakkloof Soil is developed on top of an eolianite that rests directly on a +57-to-63-meter beach. This laterite-like paleosol is younger than the Knysna Soil complex, from which it is separated by a major eolianite, but older than a variety of late Middle to Upper Pleistocene sediments and paleosols. The younger eolianites can be stratigraphically discriminated and, in part, radiometrically and archaeologically dated, so that we can specify as follows.[29] The Brenton Soil, formed on dune sand during the early Upper Pleistocene, is an alfisol (halpustalf), with weakly developed zones of ferruginous consolidation in the B horizon. The Beacon Island Soil is an inceptisol (eutrochrept), with an ochric or mollic A horizon. A sequence of buried A–Cca entisols is exposed at some coastal sites, recording two cycles of dune mobilization and pedogenesis. The Holocene sand-and-soil sequence accompanied minor sea-level oscillations and, as verified by palynology,[30] vegetation changes in the littoral zone.

FORMOSA SOIL

The exposure of the Formosa Soil, as preserved on the +140-meter surface at the Formosa Formation type-site near Plettenberg Bay (Fig. 1), can be described as follows, with analytical data presented in Table II:[31]

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[28] Massive and pisolitic plinthite is locally also found directly on top of the Coastal Platform (Martin, Quaternary History [see footnote 24 above]). However, these examples of massive ferruginous duricrusts can be no younger than the Formosa Soil, and they probably antedate the eolianites.

[29] Butzer and Helgren, op. cit. [see footnote 6 above].

[30] Martin, Quaternary History [see footnote 24 above].

[31] Soil and sediment macrodescriptions follow the format outlined in Appendix I of "Soil Taxonomy" [see footnote 27 above]. Colors (dry state) are given according to the Munsell color charts. Sediment analyses were carried out in the Paleoecology Laboratory at the University of Chicago. Textures were determined by the standard hydrometer method, using a 5 percent solution of sodium pyrophosphate as dispersing agent. The size classes recognized are clay (less than 2 microns particle diameter), silt (2–60 microns), and sand (60–2,000 microns). The pH was determined electrometrically in distilled water pastes. "Free" Fe_2O_3 contents were determined, through the courtesy of the Soils Laboratory of the University of Wisconsin, Madison, by reduction to ferrous iron by $Na_2S_2O_4$ in a sodium buffer. The random powder diffractograms were prepared by Romano Rinaldi at the University of Chicago.

Unit 1. Modern soil. 20–35 centimeters thick, gray, sandy loam with weak, rounded struc-
ture, soft, massively bedded, and well rooted. The transition to Unit 2 is smooth
and abrupt, a geological unconformity.

Unit 2. Breccia. 40–80 centimeters thick, reddish brown, sandy clay loam, loose and crudely
stratified; 1.8 percent "free" Fe_2O_3, serving as a matrix to subangular, coarse-
grade gravel (superficially rubefied). This horizon thickens in pockets but forms a
smooth surface that slopes at 0° to 6° toward the Keurbooms River estuary. The
transition to Unit 3 is wavy and clear, a geological unconformity.

Unit 3. Plinthite nodule horizon. 30–40 centimeters thick, dark reddish brown, loose clay;
2.1 percent "free" Fe_2O_3, as matrix to fine to coarse-grade pebbles of very hard,
subrounded to rounded, reddish brown to red (5YR–10R range) plinthite. The
transition to Unit 4 is wavy and abrupt, a geological unconformity indicating
that this is a colluvial deposit.

Unit 4. Mottled horizon. More than 120 centimeters thick, strong brown, sandy clay loam;
3.7 percent "free" Fe_2O_3, slightly hard to hard, with weak structure. Unstratified,
with irregular splotches and subvertical lines of red (2.5YR 4/6–8) mottling and
including sand-sized plinthite. Locally colluvially reworked in its upper portion.
The transition to Unit 5 is diffuse.

Unit 5. Altered bedrock. 75-centimeter maximum thickness, reddish brown, sandy clay
loam; 2.1 percent "free" Fe_2O_3. Slightly hard, weak structure, and unstratified,
embedding weathered, discolored, pinkish white to reddish yellow (7.5YR 8/3–6)
quartzite. Intact, residual quartz veins as well as core-weathered quartzite cobbles
indicate that the weathering profile of Units 4 and 5 is autochthonous.

Unit 6. Bedrock. The bedrock at this site is light gray, highly resistant orthoquartzite of the
Table Mountain Series, which is more than 98 percent quartz set in a siliceous
matrix.

Represented in this exposure of the Formosa Soil is a zone of intensively weathered
quartzite bedrock with a truncated mottled horizon that pertains to a buried, laterite-
like soil (Units 4, 5, and 6). The plinthite nodules (Unit 3) are secondary, and the
sandy sediment (Unit 1) serves as parent material for modern pedogenesis. Unit 1
probably derives from several episodes of eolian deposition and secondary colluvial
reworking during the Upper Pleistocene. The breccia (Unit 2), produced by intensive
mechanical weathering of quartzite exposures upslope, extends across the +140-meter
platform and passes downslope into a barrier beach sequence at +102 meters, thus
providing definition in terms of the eustatic stratigraphy.

The plinthite nodule horizon (Unit 3) records an earlier episode of erosion that
destroyed an adjacent primary laterite. The intact mottled horizon includes plinthite
aggregates near its top and argues that the now-missing plinthite nodule horizon is
represented in Unit 3 as a reworked aggregate. The lower horizons demonstrate the
impressive chemical weathering of a highly resistant bedrock that accompanied
development of the Formosa Soil. The analytical data in Table II illustrate the
relatively high proportions of clay-sized particles (mostly quartz) produced by this
weathering. A plinthite nodule from Unit 3 proved to contain only 3.7 percent "free"

TABLE III—BRAKKLOOF SOIL ANALYTICAL DATA

UNIT	COLOR	TEXTURE SAND/SILT/CLAY: (in percentages)	pH	X–RAY DIFFRACTION MINERALOGY (++ abundant; + present; (+) trace)
1A	7·5YR 5/2	50/35/15	6.0	
1B	10YR 4/2-3	37/36/27	5.8	
2	7.5YR-10YR 5/6	61/6/34	6.1	quartz ++, goethite +, smectite (+)
	7.5YR-10YR 5/6	35/19/46	5.8	quartz ++, goethite +, smectite (+)
3A (matrices)	2.5YR 5/6	47/14/38	7.6	
	10R 4/3	60/28/11	7.0	
	2.5YR 4/4	55/22/23	7.6	quartz ++, goethite (+)
3B	7.5YR 4/2	69/10/21	5.7	quartz ++, goethite (+), kaolin (+)
4	7.5YR 7/6, 6/7			
	10YR 5/4, 4/6	56/13/31	7.3	quartz ++, goethite (+), illite (+)
	2.5YR-10R 5/6	35/18/47	5.8	
	2.5Y-5Y 7/2			
	10YR 7/5	79/11/10	7.3	quartz ++, goethite (+), illite (+)
5	2.5YR 7/1	46/20/35	6.5	quartz ++, kaolin +, goethite (+)
6	7.5R 4-5/6			
	10R 5/7			
	7.5R 4/2	66/13/22	6.0	quartz ++, goethite +
	7.5YR 5/6			
7	7.5YR 6/6	65/14/22	6.0	quartz ++, goethite +, kaolin (+)
	10YR 5/4	69/6/25	6.7	quartz ++, goethite +, kaolin (+)
8	10YR 7/4, 6/1	63/7/31	6.7	quartz ++, kaolin +, illite +, smectite (+)
	2.5Y-5Y 7.5/2			
9, 10, 11	not sampled			
12	10YR 6/6	69/15/16	7.4	quartz ++, goethite (+)
13	10YR 5.5/6	66/10/24	7.4	quartz ++, goethite (+), kaolin (+)
14	10YR 5.5/6	69/0/31	6.8	quartz ++, goethite +, kaolin (+), illite (+)
	2.5YR 5/6			
15	7.5YR 7/2-4	82/2/16	6.9	quartz ++, goethite +, kaolin (+), illite (+)
16	10YR 7/1.5	19/53/28	6.8	quartz ++, kaolin +, illite +, goethite (+)
	5Y 8/1			

Fe_2O_3, and X-ray diffraction of a plinthite oolite from Unit 4 indicates quartz and secondarily kaolinite, cemented by goethite. All of the diagnostic criteria of Units 4 and 5 suggest that they represent the subsoil of a now eroded oxic horizon. The original laterite profile belonged to some type of plinthic oxisol.

BRAKKLOOF SOIL

The Brakkloof Soil is well exposed in a complex erosional gully network between the Plettenberg Bay municipality and the Robberg Peninsula (Fig. 1). The gully system is cut into the footslope of a subdued dunal terrain formed by intensively weathered mid-Pleistocene eolian sands that rest on the +57-to-63-meter littoral terrace. A suite of soil samples was taken throughout the gully system, which is illustrated in composite section in Figure 2. The composite vertical sequence may be described as follows, with analytical data presented in Table III:

PALEO-CATENA
AT BRAKKLOOF

original paleosol surface

4°-6°NE dip

level of unit 6

unit 2
4
5
7
8

unit 3a
3b
4

inferred cliff base
at 68 m

possible
bedrock inflection→
at 63 m

unit 9
12
14

60m

57m

unit 6
7

unit 1

Meters
0   25   50
0 50 100 150
Feet

Meters
Feet
0   15
5   30
0   5   10

Overlying horizons

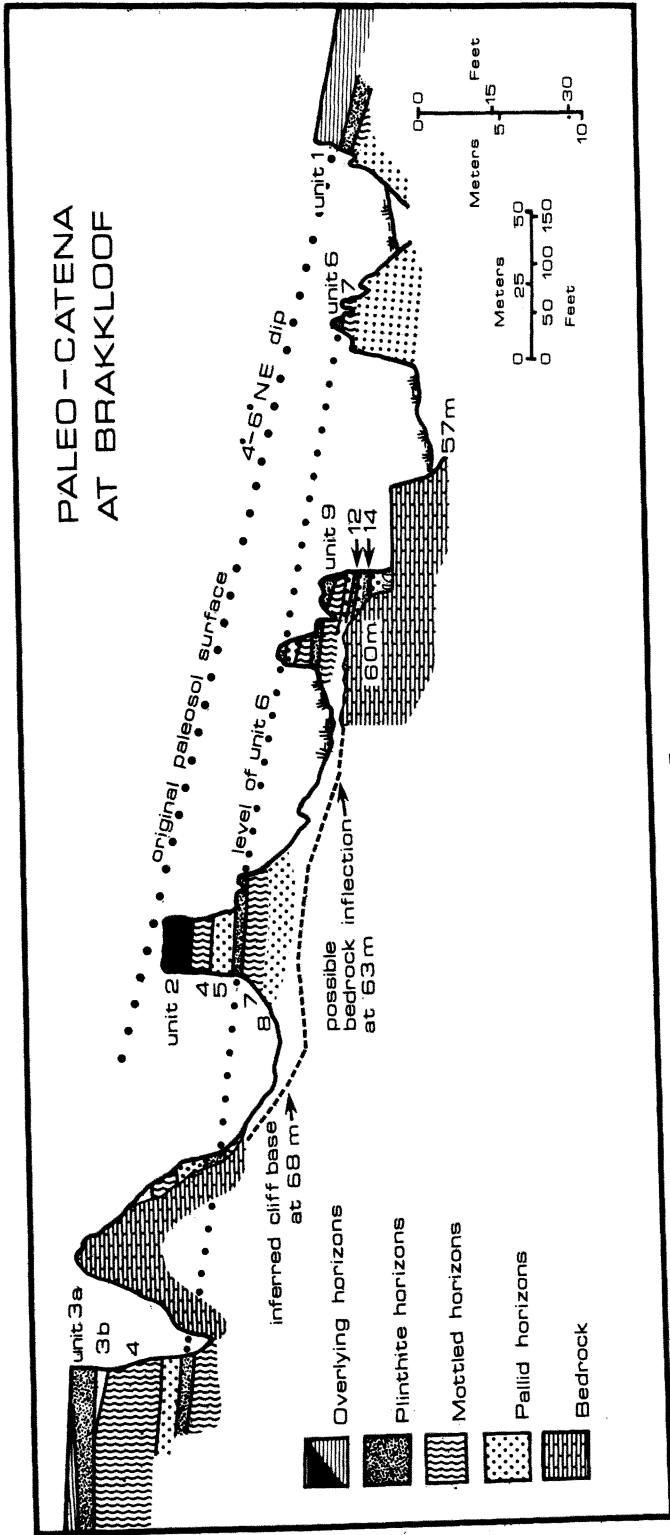Plinthite horizons

Mottled horizons

Pallid horizons

Bedrock

Fig. 2

Unit 1A. Ochric A horizon of modern soil. 40 centimeters thick, brown, slightly humic loam, which is slightly hard and has weakly developed columnar structure. Locally forms a discontinuously wavy-banded, colluvial wash with eolian components.

Unit 1B. Argillic B horizon of modern soil. 0–20 centimeters thick, brown to dark grayish brown, clay loam; 0.5 percent "free" Fe_2O_3. Slightly hard, with strong very coarse prismatic structure and humic skins on the ped faces. This is an older clay wash, subjected to considerable clay illuviation.

Where no plinthite horizon is preserved, Unit 1A or 1B overlies:

Unit 2. Primary clay wash. 75 centimeters thick, strong to yellowish brown, sandy clay loam and clay; 5.6 percent "free" Fe_2O_3. Slightly hard, with strong, coarse prismatic structure; in addition, the clayey facies has slickensides and clay skins. The top 20 centimeters have been altered by later illuviation and have dark reddish to very dark grayish brown (5YR–10YR 2/1.5–2) or dark gray (10YR 4/1) humic films on ped faces; this zone contains occasional Acheulian artifacts.

Where a plinthite horizon is preserved, Unit 1A or 1B overlies:

Unit 3A. Primary plinthite horizon. 90–130 centimeters thick, red or reddish brown, sandy clay, sandy loam, or sandy clay loam as a matrix to very hard pebble-grade, reddish yellow (7.5YR 6–7/6–8) plinthite nodules. In general, this horizon has been secondarily humified, attaining a grayish brown (10YR 4.5/2) to brown (7.5YR 4/2) color. In most areas the capping plinthite horizon is an autochthonous development, but colluvially reworked areas also exist.

Locally developed beneath a section of colluvially derived plinthite nodules is:

Unit 3B. 0–20 centimeters thick, dark brown, sandy clay loam. Slightly hard, with evidence of discontinuous bedding and humate darkening of ped faces and rootlet hollows; includes Acheulian artifacts. The transition to Unit 4 is smooth and gradual.

Below both Units 2 and 3 are Units 4 through 17:

Unit 4. Primary mottled horizon. 110–220 centimeters thick, reddish yellow, yellowish brown, yellow, red, or light gray, sandy clay loam or clay; 1.7 percent "free" Fe_2O_3. Slightly hard, with moderate, prismatic structure, and extensively mottled. In better-drained areas, this unit grades laterally and downward into 120 centimeters of yellow sandy loam, with 0.8 percent "free" Fe_2O_3, which is slightly hard, with mottling or reddish yellow (7.5YR 6/7), very pale brown (10YR 7/4), and red (2.5YR 5/6). The transition to Unit 5 is smooth and diffuse.

Unit 5. Primary pallid horizon. 170–190 centimeters thick, light gray, sandy clay; 0.2 percent "free" Fe_2O_3. Slightly hard, with very coarse platy structure. The upper 70 centimeters have widespread, light yellowish brown to red (10YR 6/4, 2.5YR) mottling, and the lower 100 centimeters have weak, diffuse yellow or brownish yellow (10YR) mottling. The transition to Unit 6 is wavy and clear.

Unit 6. Second plinthite horizon. 20 centimeters thick, red (7.5R 4–5/6, 10R 5/7), weak red (7.5R 4/2), or strong brown (7.5YR 5/6), sandy clay loam; 1.8 percent

"free" Fe_2O_3. Hard to very hard, forming a jagged, eroded surface within the gully. The transition to Unit 7 is smooth and gradual.

Unit 7.   Second mottled horizon. 30–50 centimeters thick, reddish yellow, sandy clay loam; 1.7 percent to 4.8 percent "free" Fe_2O_3. Slightly hard, with red (2.5YR 5/6) and weak red (10R 4/4) mottling. Grading downward, the color becomes brownish yellow. The transition to Unit 8 is smooth and diffuse.

Unit 8.   Second pallid horizon. 200 centimeters thick, very pale brown to white or light gray, sandy clay loam; 0.6 percent "free" Fe_2O_3. Slightly hard, with weak prismatic structure and intensive, brownish yellow mottling of the exterior of the ped faces. The transition to Unit 9 is gradual.

Unit 9.   Third plinthite horizon. 20 centimeters thick, same as Unit 6.

Unit 10. Third mottled horizon. 40 centimeters thick, same as Unit 7.

Unit 11. Third pallid horizon. 30 centimeters thick, same as Unit 8.

Unit 12. Fourth plinthite horizon. 30 centimeters thick, brownish yellow, sandy loam. Slightly hard, with wavy bands of red (2.5YR 5/6) and white mottles. The transition to Unit 13 is smooth and clear.

Unit 13. Fourth pallid horizon. 50 centimeters thick, brownish yellow, sandy clay loam. Slightly hard, with light gray (10YR 7/2) mottling. The transition to Unit 14 is smooth and clear.

Unit 14. Fifth plinthite horizon. 75 centimeters thick, brownish yellow to red, sandy clay loam. Slightly hard, with fine white (10YR) mottling. The transition to Unit 15 is smooth and clear.

Unit 15. Fifth pallid horizon. 130 centimeters thick, pinkish gray, sandy loam. Slightly hard, with reddish yellow (7.5YR) mottling. The transition to Unit 16 is irregular and diffuse.

Unit 16. Basal debris. 45–60 centimeters thick, light gray grading downward to white, silty clay loam. Slightly hard. Serves as matrix to cobble-grade gravel of subrounded to rounded sandstone and quartzite, representing a beach remnant on a wave-cut platform.

Unit 17. Bedrock. White (10YR 8/1) homogenous, intensively weathered, medium-grade sandstone (Cretaceous, Uitenhage Series).

No unweathered examples of the parent materials for the Brakkloof Soil remain. However, unweathered modern dune sands provide an analogue. These sands consist of quartz (40–70 percent) and comminuted molluscan remains (virtually pure $CaCO_3$). Only a trace (less than 1 percent) of glauconite, feldspars, and even rarer micas and heavy minerals occur in such sands.

The Brakkloof Soil site records the development of a laterite-like soil in a near-shore facies of eolian sand. At the top are sandy to clayey colluvial deposits (Units 1, 2, and 3B), produced by soil erosion upslope and now incorporating Acheulian cultural debris. The primary plinthite horizon (Unit 3A) is intact in some areas, but

elsewhere it has been colluvially reworked. Beneath this plinthite are typical mottled (Unit 4) and pallid (Unit 5) horizons. However, even farther below are four additional apparent plinthite horizons and associated mottled and/or pallid horizons (Units 6 through 15). These are not additional paleosols but local groundwater ferricretes related to a still-active spring seep; they probably are younger than the basic pallid-horizon spanning units, 5 to 15. It appears that the processes which produced the primary horizons were subsequently simulated by processes operating along a fluctuating but sequentially lower water table, as the gully system was cut during later Quaternary times. Like the Formosa Soil, the Brakkloof Soil argues for an interval of intense chemical weathering, which differs in both degree and kind from the modern weathering regime. This Brakkloof weathering produced the large, quartz-dominant, clay fractions of many horizons. And, as in the case of the Formosa Soil, the plinthite nodules consist of quartz and a trace of kaolinitic clays, cemented by goethite, and contain only 3 percent to 13 percent "free" Fe_2O_3. The prominent argillic and plinthite horizons, as well as the other diagnostic properties, identify the Brakkloof Soil as a plinthite paleudult. However, the conspicuous illuvial humus and clay skins of the argillic horizon indicate later illuviation, at least in part in response to the weathering responsible for the Brenton Soil.

DISCUSSION AND IMPLICATIONS

The Formosa and Brakkloof soils record distinct intervals of intensive pedogenesis during the late Tertiary and mid-Pleistocene, respectively. These and several other paleosols discussed in more cursory form fit within a broader morphostratigraphic context that includes cyclic periodicities involving erosion, deposition, and pedogenesis (Table I).[32] These repeated changes argue that morphoclimatic and biogeographical shifts have affected the southern Cape in a significant way. The amplitude of these environmental shifts was so great that at one point major dune fields were created or activated in what is now dense forest, whereas at the opposite end of the spectrum, intensive biochemical weathering was able to make deep, clayey soils out of quartzose sands under conditions substantially more humid than today. There is no earlier record of the intermediate conditions reflected by the modest soils developed since the late Middle Pleistocene, but such low-intensity pedogenesis within a sub-humid context must have recurred on many occasions. In effect, paleosols such as the Formosa, Knysna, and Brakkloof soils represent no more than the highlights of pedogenetic trends since the late Tertiary. Consequently, they record only a fraction of the last several million years.

The historical evidence has further implications. Regardless of the classification and specific interpretation of these paleosols, the Formosa, Knysna, and Brakkloof examples differ not only in degree but also in kind from the maximum intensity of pedogenesis during later Pleistocene and Holocene time. Soil formation during the past 130,000 years has been limited to humification, superficial podsolization, and mild oxidation in a slightly acid or neutral parent material. It is apparent that thousands of years are required for complete decalcification, and tens of thousands of years have not sufficed to produce more than a modest alfisol in the southern Cape. It

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[32] For early views on landscape periodicities see H. Erhart: La genèse des sols en tant que phénomène géologique (Masson, Paris, 1956); and B. E. Butler: Periodic Phenomena in Landscapes as a Basis for Soil Studies, *Soil Publications, No. 14,* Commonwealth Scientific and Industrial Research Organisation, Melbourne, 1959, pp. 1–20.

is also noteworthy that the Formosa and Brakkloof profiles are those of laterites, whereas the intervening Knysna profile is not. These facts contradict the underlying assumptions of some pedostratigraphic studies that soil "depth" is a simple function of time, that net rates of weathering do not change significantly in the long term, and that soil trends are unidirectional.[33]

Regardless of the problem of laterite definition per se, or matters of exact genesis, the various paleosols described here are basically amenable to classification by the U.S. Soil Conservation Service's "Soil Taxonomy."[34] This underscores the advantage of a morphological rather than genetic soil classification. The pattern of paleosol categories reflected in Table I is informative in that it provides a means of objective comparison that, more incidentally, serves to show the basic affinity of the southern Cape pedomorphic record with that of other warm, moist, mid-latitude soil land-scapes such as that of the southeastern United States. However, the southern Cape record illustrates that any soils geography that intends to be more than descriptive must necessarily deal directly with pedostratigraphy and overall geomorphic context. A morphological classification, used in conjunction with areal mapping and "histori-cal" field investigation, promises to provide far better results than genetic classifica-tions applied with the assumption of a one-to-one relationship between contemporary environmental parameters and soil type.

Designations such as plinthic ultisol or oxisol convey basic information but by themselves are not satisfactory for dealing with laterites as defined by the presence of plinthite, mottled, and pallid horizons. Laterites deserve special status because of their significance for agriculture, construction, mining, and geomorphology. In these applications they represent an abnormal class of soil, substrate, resource, or caprock. Ready definition in the field, without need for a battery of laboratory tests, is essential for such applied purposes. Equally essential is a convenient field distinction between primary laterite profiles on the one hand and secondary laterites or miscellaneous zones of ferruginous enrichment and cementation on the other. Ferricretion has many origins and is worldwide in its potential distribution, but this does not take away from the fact that it may take distinct and recognizable forms and that these are regionally prominent in some environments but not in others. For this if no other reason, the search for practicable means of classification and for an understanding of historical-genetic contexts remains pertinent.

The standard macromorphological and mineralogical analyses presented in this study have not identified the processes that produced the plinthite, mottled, and pallid horizons in the southern Cape laterites. Whether or not these processes coincided precisely with the time of intensive weathering is unclear, but such weath-ering was definitely a prerequisite. The mineralogical variations between horizons are minor and apparently not systematic. But the color variations indicate selective or relative migration of sesquioxides to create the pallid, mottled, and plinthite horizons. Formation of such laterite profiles from parent materials so low in aluminosilicate and ferromagnesian minerals is unusual. The amounts of goethite and clay minerals, while absolutely low, do represent an extraordinary enrichment in Fe and Al ions.

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[33] For example, R. V. Ruhe: Geomorphic Surfaces and Surficial Deposits in Southern New Mexico, *New Mexico Inst. of Mining and Technol., Memoir 18,* Las Cruces, 1967; and L. H. Gile, J. W. Hawley, and R. B. Grossman: Distribution and Genesis of Soils and Geomorphic Surfaces in a Desert Region of Southern New Mexico, in Guidebook, Soil Science Society of America, *Soil-Geomorphology Field Conference,* Agronomy Dept., New Mexico State Univ., Las Cruces, 1970.

[34] Soil Taxonomy [see footnote 27 above].

This sesquioxide and silicate concentration is more than can be expected from the parent materials, so that some of the Fe and Al ions must have been introduced via aerosolic dust.[35] In addition, the original Brakkloof sands may have had a higher proportion of glauconite than their modern analogues.[36]

The Formosa and Brakkloof soils have been modified by continuing or repeated pedogenesis since they acquired their basic morphology. This is perhaps most obvious in terms of the mildly erratic pH values and the secondary illuviation of humus into subsurface horizons. At Brakkloof, there have also been hydromorphic modifications at depth. Finally, there are 2 : 1 layer clay minerals (illites and/or smectites) in the Formosa Soil (Unit 3) and Brakkloof Soil (Units 2, 4, 8, 14, 15, and 16).[37] Unit 3 of the Formosa Soil and Units 2, 13, 15, and 16 of the Brakkloof Soil either represent colluvial deposits or lie within the zone of modern groundwater fluctuation, and a variety of clay minerals should not be unanticipated in these settings. However, the presence of 2 : 1 layer clays in Units 4 and 8 at Brakkloof is not consistent with the intensive weathering that produced the clay-quartz. Whether such 2 : 1 layer clays are due to more recent illuviation, to throughflow, or to weathering in place remains to be determined. It is also possible that some 2 : 1 layer clays are compatible with formation of plinthic ultisols. Further research, such as microfabric study and scanning electron-microscopy, should provide a better understanding of both the origin of these soils and the dynamics of subsequent modifications. These examples nonetheless serve to show how little the role of polygenetic or bisequential pedogenesis is appreciated in classification or interpretation of inherited soils.

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[35] See, for example, J. K. Syers, M. L. Jackson, V. E. Berkheiser, R. N. Clayton and R. W. Rex: Eolian Sediment Influence on Pedogenesis During the Quaternary, *Soil Science,* Vol. 107, 1969, pp. 421–427; M. L. Jackson, D. A. Gillett, E. F. Danielsen, I. H. Blifford, R. A. Bryson, and J. K. Syers: Global Dustfall During the Quaternary as Related to Environments, *ibid.,* Vol. 116, 1973, pp. 135–145; and D. H. Yaalon and E. Ganor: The Influence of Dust on Soils During the Quaternary, *ibid.,* Vol. 116, 1973, pp. 146–155.

[36] Surveys of offshore sediments support this suggestion (R. J. Parker and W. G. Siesser: Petrology and Origin of Some Phosphorites from the South African Continental Margin, *Journ. Sedimentary Petrology,* Vol. 42, 1972, pp. 434–440).

[37] The samples for units with 2 : 1 layer clays show only minor X-ray diffraction peaks from their basal planes, but in all cases the 4.46 Å and 2.56 Å spacings are well marked, indicating the presence of one or more of these minerals. This diffraction pattern suggests these layer silicates are complexly interstratified, probably with additions of kaolins.