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THE NATURE OF THE AFRICAN SURFACE IN THE SOUTHWESTERN TRANSVAAL

T. R. MARSHALL

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by

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ABSTRACT

The extended period of subaerial denudation that occurred during the African cycle of erosion resulted in the formation of thick laterite deposits in the southwestern Transvaal. Deep leaching associated with the succeeding Post-African I landscape-cycle was responsible for the development of pallid zones beneath the laterite and the formation of pseudokarst solution-cavities. Such cavities were later instrumental in trapping colluvially-reworked, diamond-bearing gravels, as the deflation-surface was lowered vertically.

Post-African landscape modifications have resulted in the calcretization of an African paleodrainage system. Both these calcreted deposits and the leached pseudokarst gravel-traps have withstood later weathering, and many have been left as topographically-positive features.

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INTRODUCTION

The landscape-cycle which resulted from the fragmentation of the Gondwana supercontinent is referred to as the African cycle. During and after the final splitting of Gondwanaland in late-Mesozoic times, erosion proceeded simultaneously at different levels above and below the Great Escarpment. In coastal areas, the erosion was controlled by the oceanic base-level, but, in the interior, the base-level to which erosion proceeded was determined by the major inland river-systems of the Orange-Vaal and Limpopo (Partridge and Maud, 1987). The extensive duration of the polycyclic African surface (a period of more than 100 Ma) resulted in advanced planation, intensive weathering and kaolinization of underlying rocks, and the widespread formation of surface duricrust.

In the southwestern Transvaal, the African surface has exposed the pre-Karoo unconformity. Where these two surfaces (the pre-Karoo and the African surfaces) coincide, the former has been modified substantially by the latter. The features which developed on the African surface, as a result of intense weathering due to its extensive exposure, have been instrumental in localizing the diamondiferous alluvial-gravel deposits associated with later Post-African sedimentation.

It is the objective of this paper to describe the features of the African surface as they occur in the southwestern Transvaal and to compare them with those which characterize the African surface elsewhere. Secondly, the paper will review the processes of lateritization and calcretization, as a background to the features observed in the southwestern Transvaal. Finally, the role of the African surface in the southwestern Transvaal will be discussed with reference to the localization of economic deposits of diamondiferous alluvial gravels.

THE NATURE OF THE AFRICAN SURFACE ELSEWHERE

Partridge and Maud (1987) have described in detail the nature of the African surface in South Africa. What is presented here is a brief review of some of their ideas.

The African surface is developed over vastly-different lithologies in different parts of the subcontinent, and its age at any of these localities may vary from late-Cretaceous to the present. In the Lüderitz area, the African surface cuts across the Chalcedon-Tafelberg Silcrete formations, which are likely of Paleocene age (Dingle *et al.*, 1983). In the southern Cape, the African surface extends across upper-Cretaceous-Paleocene marine sediments. Extensive remnants of this surface are preserved beneath silcrete and ferricrete cappings on the Bushmanland Plateau. Although such cappings are present locally in areas of the eastern Transvaal, they have been eroded over large parts, to reveal remnants of the deep residual profile which typically underlies the laterite duricrust. A second example of such a lowered surface is that of the Ghaap Plateau, where much of the ancient calcrete-hardpan surface has been stripped away. In other areas, such as the Pietersburg plain, the southern and western Cape, and the sub-escarpment tracts of the eastern Transvaal, the African surface has been extensively dissected, as a result of local stream-rejuvenation. In many of these areas, the pre-Karoo surfaces have been exposed and coincide with the African and Post-African surfaces.

Irrespective of which rocks underlie the African surface, they are characterized by extensive alteration. The alteration in the southwestern Transvaal is usually in one of two forms, either lateritization or calcretization. The depth of alteration may be up to 6-10 m, depending on how much of the surface has been stripped by later erosion. In some cases, the alteration has proceeded to the extreme, resulting in local minable deposits of calcrete or hematite. In order to understand the features which develop on this surface, it will be necessary, first, to review the processes of lateritization and calcretization.

WEATHERING PROCESSES

(a) Lateritization

Very early models of laterite-formation involved marine, volcanic, and termite activity. These received little support and were readily dismissed. Later controversies surrounded the concept of laterite as a residuum vs. laterite as a precipitate (Fig. 1). In the former concept, lateritic

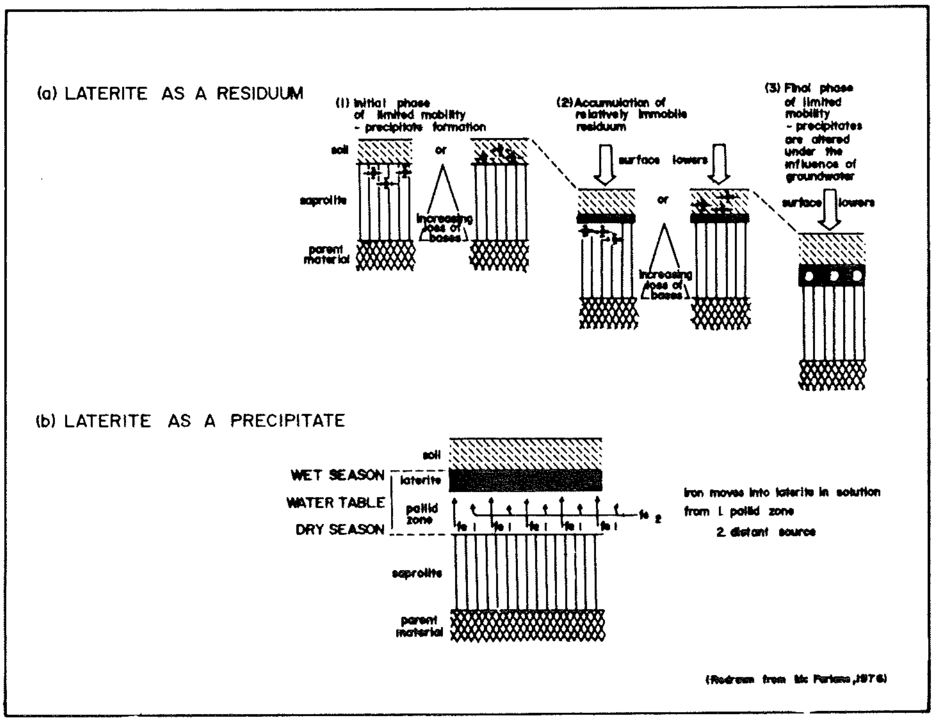


Figure 1 : *A schematic representation of the differences between the two theories of laterite-formation as (a) a residuum and (b) a precipitate.*

accumulations are attributed to the relative immobility of the constituents, whereby iron-rich components are released from their parent material by weathering processes, are regrouped into relatively-immobile precipitates, and, subsequently, are altered by groundwater. The concept of laterite as a precipitate results from the belief that iron and alumina, in solution, move into the enriched zones (from above or below the horizon or from more-distant sources) where they are precipitated. Capillarity and the seasonal fluctuations of the water-table are two of the mechanisms suggested for the enrichment of the laterite horizon (McFarlane, 1976).

The theory that enriched solutions are carried upward in a soil-profile, with seasonal rise of the water-table and precipitation near the upper limits of the range of fluctuation, however, has to be treated with reserve. McFarlane (1976) lists at least three seemingly-insuperable problems associated with this hypothesis :

(a) the postulated mechanisms are inconsistent with the principles of the chemistry of iron, alumina, and fresh vs. solute-rich water;

(b) the scale of many laterites is so large that it becomes necessary to involve unrealistic and non-existent seasonal variations and water-table fluctuations; and

(c) the concept of laterite-enrichment and pallid-zone depletion as synchronous complementary processes is incongruous, since laterite may lie directly on fresh rock, unleached material, or extremely-thin leached horizons; even where deep pallid zones occur, these are quantitatively inadequate to account for the concentration in the lateritic crust.

In more recent years, two other models of laterite-formation have received attention, viz., detrital models and those which compromise between the concepts of laterite as a residuum and laterite as a precipitate. Detrital laterite deposits result from the accumulation of both mechanical and dissolved laterite from topographically-higher positions (where an older laterite may or may not occur). Such low-level laterites, upon further lowering of surrounding unlateritized areas, can be left standing above the adjacent country. The relief, in effect, becomes inverted (Fig. 2). This hypothesis, however, cannot be applied indiscriminantly to all high-level laterites, since there are numerous examples where such laterites are underlain by extremely-resistant rocks which conceivably could not have formed the original lowlands of an old topography (McFarlane, 1976).

The most favourable type of model for laterite-development is that which compromises the concepts of laterite as a residuum and as a precipitate. There are a number of variations on this theme, developed by De Swardt (1964), Du Bois and Jeffrey (1955), Trendall (1962), and McFarlane (1971). The last-mentioned also regards laterite as a residual precipitate (Fig. 3 A-I). The groundwater laterite is believed to accumulate as a mechanical residuum during the late stages of reduction of a downwasting landsurface. The original precipitates form within the narrow range of the fluctuation of the groundwater-table, which sinks as the landsurface is reduced by erosion. These precipitates become incorporated into the lower parts of the soil-mantle, where they accumulate as an increasingly-thick layer. When downwasting has ceased and the

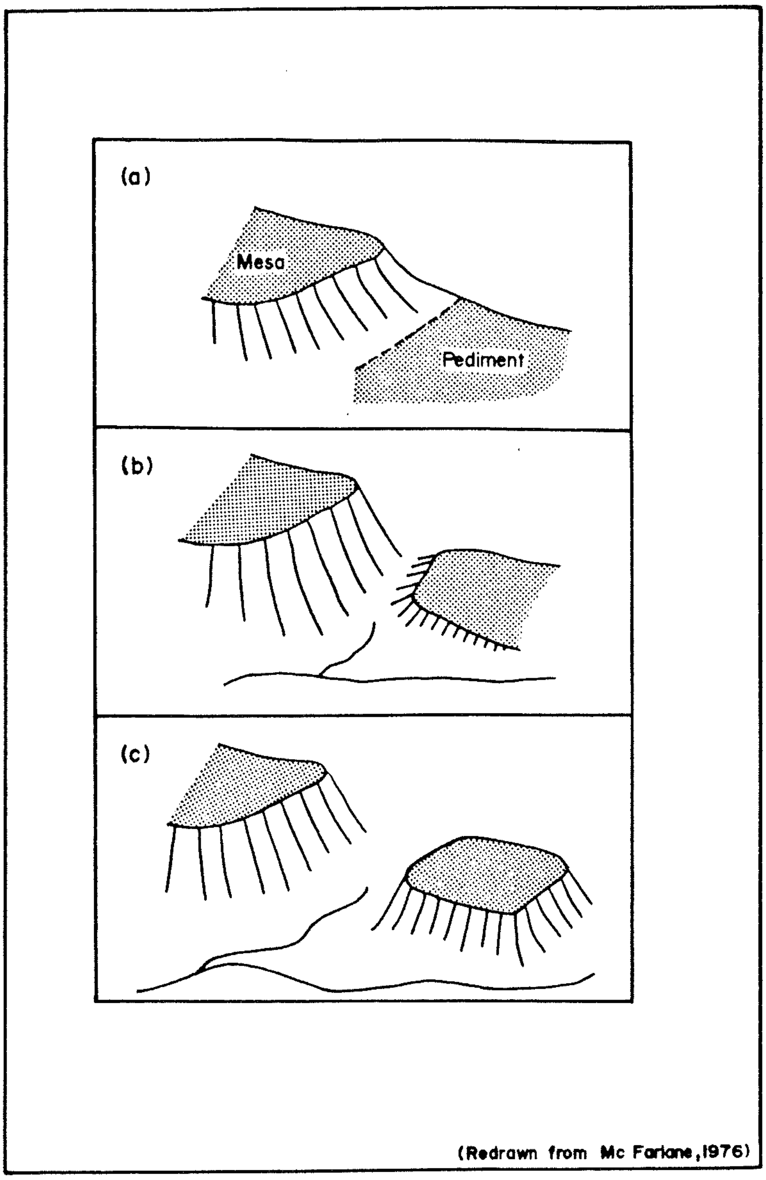


Figure 2 : *Formation of an inverted topography through the lowering of surrounding unlateritized areas.*

water-table has stabilized, the residuum is hydrated and altered into a massive variety of laterite. In this model, no contribution is believed to be provided by the pallid zones. Rather, it is suggested that the permeable nature of *in situ* laterites allows the substrata to be leached after the laterite is incised. The typical laterite profile of massive laterite underlain by a mottled zone and a pallid zone, thus, is believed to be the product of two cycles of erosion (the end of the first and the beginning of the second) (McFarlane, 1976).

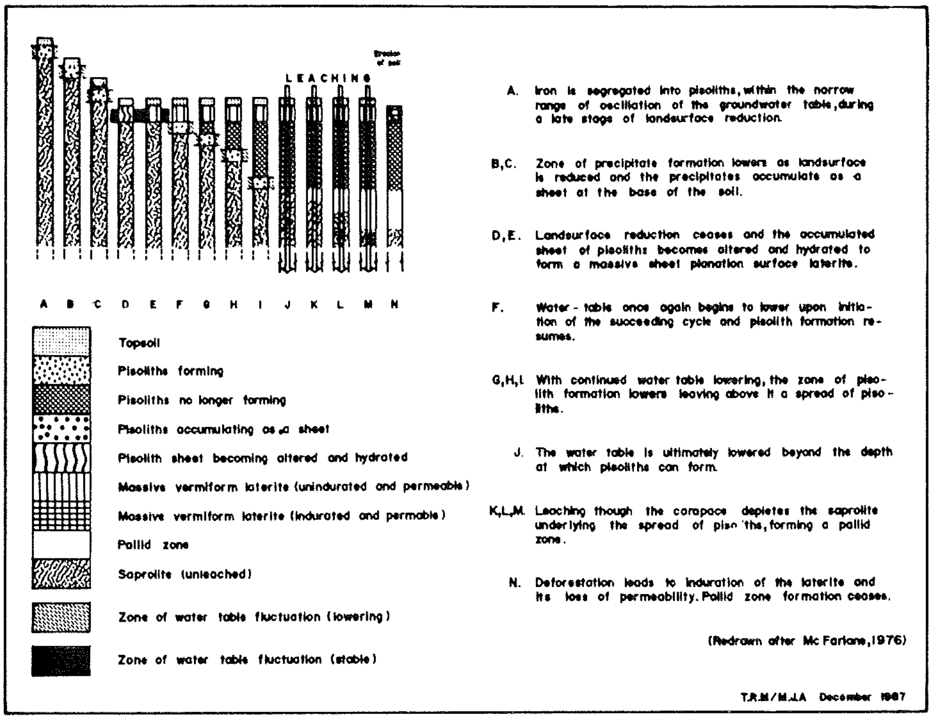


Figure 3 : *A model of laterite-formation, proposed by McFarlane (1971).*

Post-lateritic incision, furthermore, is believed to play an important role in the development of the typical profile. It has been suggested that pallid-zone development is consequent upon incision of the laterite profile and is a post-incision modification by basal sapping and downleaching (Fig. 3 J-N; Fig. 4). The residual laterite develops on a planation-surface and is subsequently incised as a result of uplift associated with the second erosion-cycle. It remains permeable while the original soil-cover and vegetation remain. Leaching through the carapace depletes the underlying saprolite, to form a pallid zone, and pseudo-karst surface features develop. Eventually, deforestation leads to the exposure and induration of the laterite which then loses its permeability. Basal sapping, leaching, and the formation of the pallid zone cease.

Incision as a result of sub-continental uplift and the subsequent covering of the landsurface can allow larger accumulations of laterite to develop by continuous enrichment of the soil from unleached saprolite. In a static profile, only small accumulations of laterite can develop from an overhead or pedogenetic source. Large accumulations of laterite that have an apparently-thin overlying soil-horizon (e.g. laterites on interfluves) can by explained only if the profile is not static, but moves with a vertical component downwards (Fig. 5).

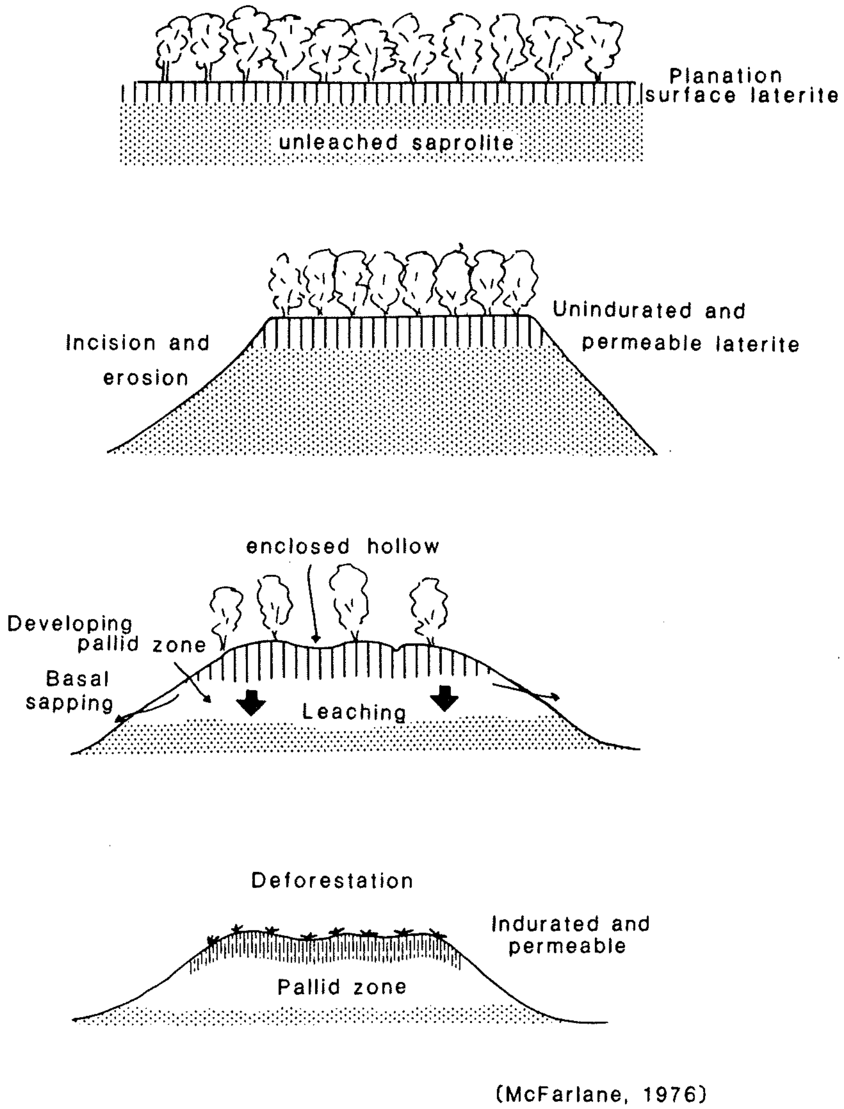


Figure 4 : *Post-incision modification by basal sapping and downleaching results in the development of a leached or pallid zone.*

(b) Calcretization

A detailed analysis of South African calcretes has shown that only two basic types of calcrete seem to be of major importance, viz. pedogenic and non-pedogenic calcretes (Netterberg, 1969). The pedogenic calcrete is a soil formed by solution of carbonate from the upper horizons and deposition in the lower horizons and is subject to all the usual soil-forming factors of climate, parent-material, topography, and time. Non-pedogenic calcrete can be considered as a geological horizon, formed chiefly by the deposition of carbonate in the

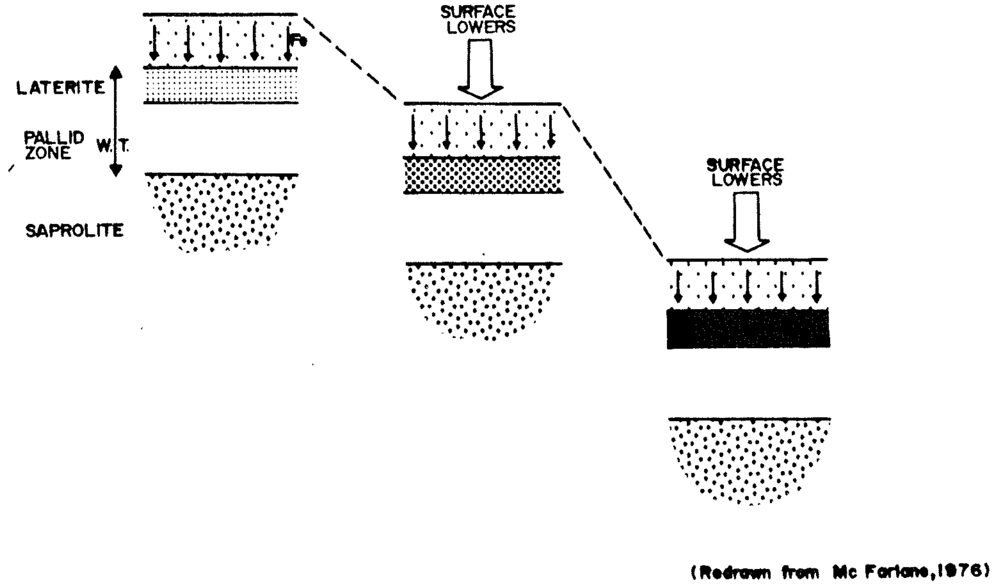


Figure 5 : *Large accumulations of laterite can be explained only if the profile is not static, but moves with a downwards vertical component.*

unsaturated zone above a shallow water-table. Pedogenesis, however, has acted on most calcretes formed by other processes. Many calcretes, therefore, are complex, being both pedogenic and non-pedogenic in origin and, furthermore, also may have undergone more than one phase of calcrete-formation.

Netterberg (1969) has described a number of mechanisms whereby non-pedogenic calcrete may be deposited, the most important of which are evaporation, transpiration, and carbon-dioxide loss. It can be shown that pure evaporation as a mechanism for water-loss becomes almost completely ineffective when the water-table is deeper than 1-2 m and is even less effective in sands and gravels. It cannot be responsible for the calcification of thick alluvial deposits. Transpiration, conversely, can remove greater quantities of water from a soil, and its influence can extend to much greater depths (2-8 m), depending on the nature of the roots responsible for the transpiration.

By far a more important mechanism for calcrete formation, however, is the solution and precipitation of calcium carbonate during changes in pore-water pressure (soil-suction). Changes in pore-water pressure result from water-table fluctuation, which influences the solubility of $CaCO_3$, and, consequently, carbonate-solution and -precipitation can occur at any depth. The implication of this is that, if a water-table consisting of carbonate-bearing river-water descends slowly over a length of time, while fluctuating during the year, it could be expected that this mechanism could calcify (calcretize) any thickness of alluvium without any assistance from evaporation or transpiration. The source of the carbonate is most likely the river-water itself, but the possible influence of the local bedrock also must be considered.

Calcretes have been shown to develop according to a definite genetic sequence. In most soils, the evolution is one of nodules coalescing to form a honeycomb calcrete, the voids of which are finally filled to form a hardpan. In sandy and gravelly sequences, nodules do not form generally, and a calcified sand or gravel results, which proceeds directly to the hardpan stage. The hardpan, which is ultimately sealed by a thin, hard, laminar crust, is the final product of calcrete-formation. If they remain covered by soil, calcretes undergo a form of decomposition, or dissolution of the carbonate, resulting in the formation of *makondos*, an advanced state of solutional weathering which may be infilled with later surface material and may or may not be recalcreted subsequently (Partidge and Brink, 1967; Netterberg, 1969; McCarthy, 1983).

THE AFRICAN SURFACE IN THE SOUTHWESTERN TRANSVAAL

On approaching Wolmaransstad from Ottosdal, it is noticeable that the crests of the hills are a deep reddish-brown in colour and are almost devoid of vegetation. The crests are red in colour for depths of 80-100 m and are separated from the underlying lithologies by a sharp contact (Fig. 6). This has been interpreted as the base to which lateritization has proceeded in the southwestern Transvaal. The original depth of the laterite possibly was more extensive, but later erosion has stripped off an unknown vertical amount.

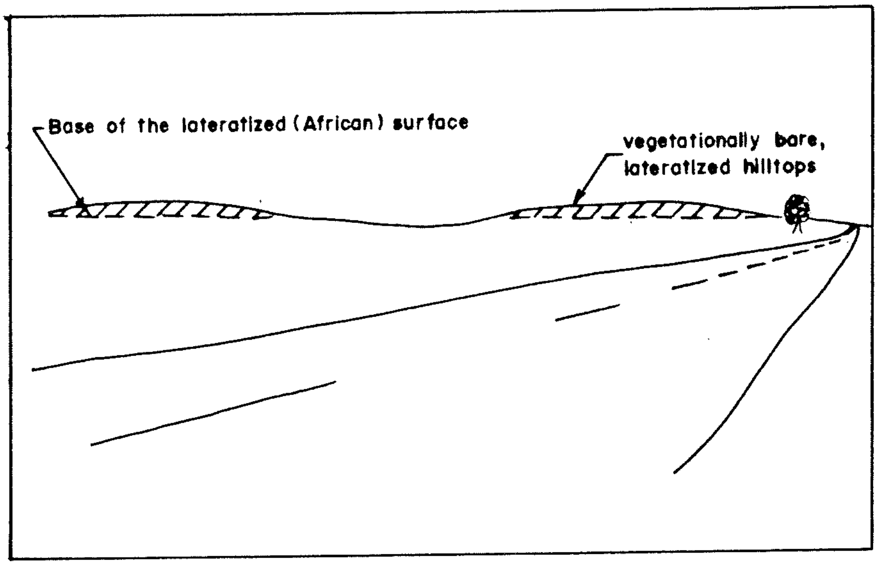


Figure 6 : *Sketch from a photograph, showing the base of the lateritized surface and the vegetationally-bare, reddened hilltops.*

On the road between Wolmaransstad and Makwassie (on the farm Oersonskraal 207 HO) is an abandoned quarry which reveals the detail of the laterite profile to a depth of 3,5 m (Fig. 7a). The surface is littered with

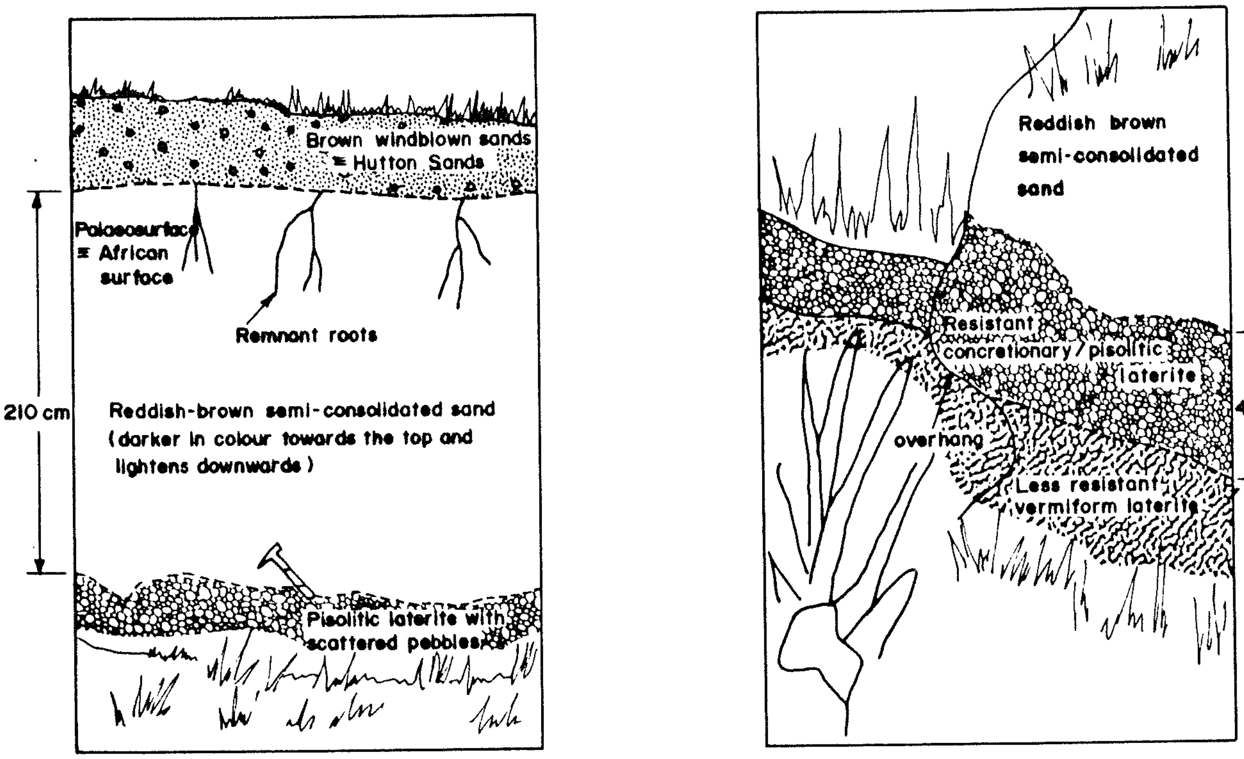


Figure 7 : Sketches of the laterite profile on Oersonskraal 207 HO.

iron-manganese concretions and very little vegetation, in the form of short grass. The top 50 cm of the profile consists of brown windblown sand with a few rounded pebbles. This is part of the Hutton Sands which cover a large proportion of the southwestern Transvaal. The Hutton Sands are redistributed sands of both Kalahari and local origin, that were deposited in the south-western Transvaal and Orange Free State in the late-Pleistocene (Helgren, 1979). As such, the Hutton Sands are not an integral part of the laterite profile on Oersonskraal 207 HO. This is further evidenced by the sharp contact between the Hutton Sands and the underlying sediments. That this contact reflects a paleosurface is confirmed by the presence of root-casts and paleosol developed beneath the surface. The paleosol is characterized by a dark brown horizon, 10-20 cm thick, just below the paleosurface. The paleosol grades imperceptibly into a 200-cm-thick unit, composed of a fine-medium-grained, sandy matrix, with a few larger (2-3ϕ) particles. The entire unit is an orange-red colour. This semi-consolidated unit is separated from the underlying unit by a sharp, undulating discontinuity. The underlying 30-40-cm unit consists of concretionary or pisolitic laterite. Separated from the pisolitic laterite by another sharp, undulating discontinuity is a +30-cm-thick unit of vermiform laterite (Fig. 7b). The vermiform laterite is less resistant than the overlying pisolitic laterite, and the latter forms an overhang, as the softer lithology is eroded away.

The laterite deposits in the southwestern Transvaal are usually no more than 2,5-3,0m thick. On the farm Rietkuil 165 HO, however, deposits 60-80 metres thick have been drilled. The laterite, in this instance, has been totally altered into economic deposits of hematite, presently being mined.

On Goedgedacht 197 HO, the deeply-weathered African surface is associated with a colluvial (or hillslope) deposit. In this vicinity, the overburden consists of 15-20 cm of soil, overlying a 5-10-cm-thick stone-line. Beneath the stone-line, a leached paleosurface is developed. Etched into this surface is a network of solution-cracks (pseudokarst grikes) up to 70cm deep (Fig. 8a). These grikes appear to have etched out the joint-pattern that

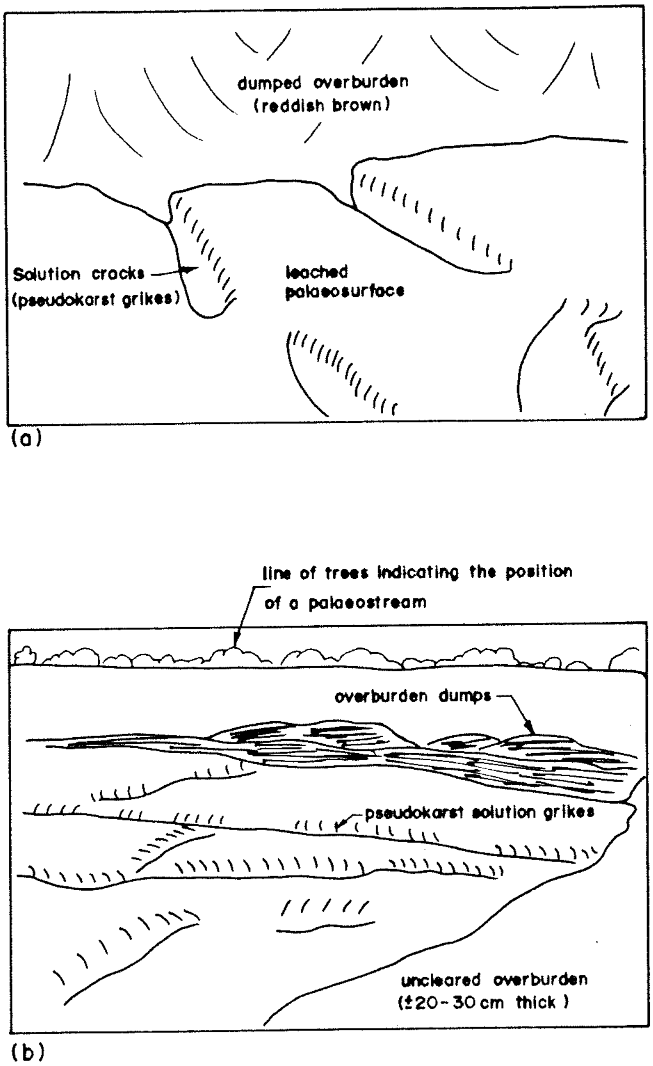


Figure 8 : Pseudokarst grikes on Goedgedacht 197 HO.

dominated the pre-existing lithology which, in this instance, appears to have been either dolerite or Ventersorp lava (Makwassie Porphyry Formation). The depth of the leaching of the lava is unknown. Approximately 500m away from this locality is a line of trees on the present-day interfluve (Fig. 7b), pointing to the presence of a large pseudokarst grike, with dimensions of 2-3m width, between 500cm and 7m depth, and about 800m length (Fig. 9).

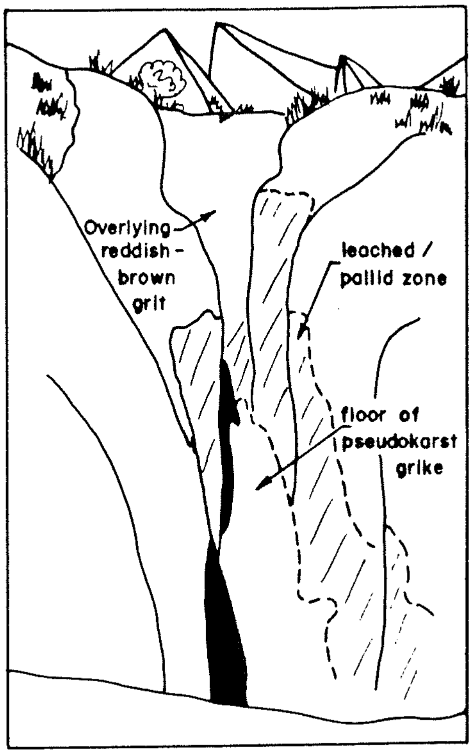


Figure 9 : *Portion of pseudokarst mega-grike on Goedgedacht 197 HO, indicating the extent of the lateritized overburden and its underlying leached or pallid zone.*

On the farm Syfergat 240 HO, similar pseudokarst solution-grikes and potholes are exposed in a trench. The pre-alteration lithology is also Ventersdorp lava (Makwassie Porphyry Formation). The sequence is capped by 5-20cm of soil development and a stone-line (Fig. 10). Lying unconformably below the stone-line is 60-80cm of altered lava which is extremely red in colour, indicating lateritization. The lateritized sequence becomes lighter in colour downwards, until it passes into a totally-bleached zone. A nearby pothole in the lava indicates that, at approximately 6m below surface, the lava is still bleached.

These three instances indicate that the major manifestation of the African surface in the southwestern Transvaal is in the form of a lateritized and extensively-leached paleosurface that has been covered by soil, a stone-

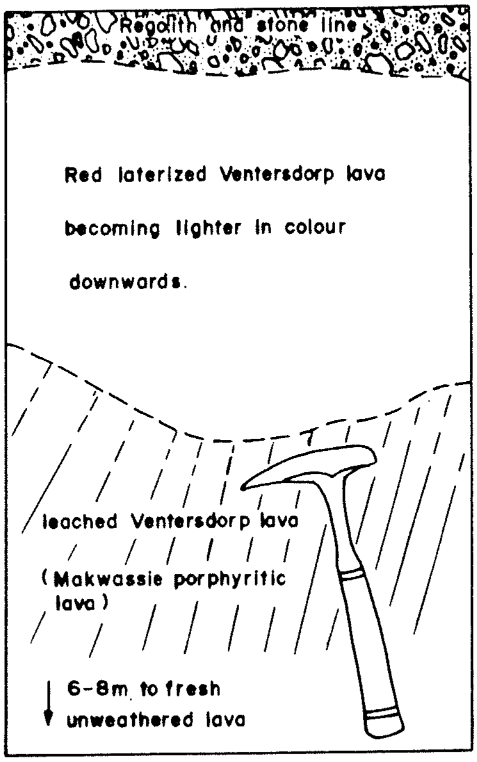


Figure 10 : *A profile through the lateritized and bleached zones of Ventersdorp lava on Syfergat 240 HO.*

line, and Hutton Sands. The extensive sub-aerial exposure of the surface has resulted in the lateritization and subsequent leaching of the landsurface, forming psuedokarst features such as grikes and potholes. These potholes and grikes were subsequently filled with gravel, as a result of the ensuing Post-African I uplift in the mid-Miocene (Marshall, 1987).

Similar gravel-filled potholes also are found in calcrete in the southwestern Transvaal. In such instances, the calcrete deposits are always associated with the paleodrainage system. They are developed beneath 60-100cm of overburden and are infilled by gravel, often diamond-bearing, and soil or Hutton Sands (Fig. 11). The vertical extent of the calcrete below the gravels is unknown.

On the farm Hartsfontein 216 HO, a thick calcrete succession has been quarried for lime. The uppermost unit of the profile consists of 60-70cm of calcreted, brown-grey soil (Fig. 12). The calcrete appears to be the result of late-stage pedogenic processes. This unit is underlain by a 30-40-cm-thick, calcreted, pebble-lag conglomerate. The clasts have been totally calcreted and are cemented together by a second-stage calcretization. The second-stage calcretization is not the result of pedogenesis, but is due rather to the throughflow of groundwater. The lowermost unit of the calcrete profile is a +3,5m-thick unit consisting of almost totally-calcretized, fine-grained sediments,

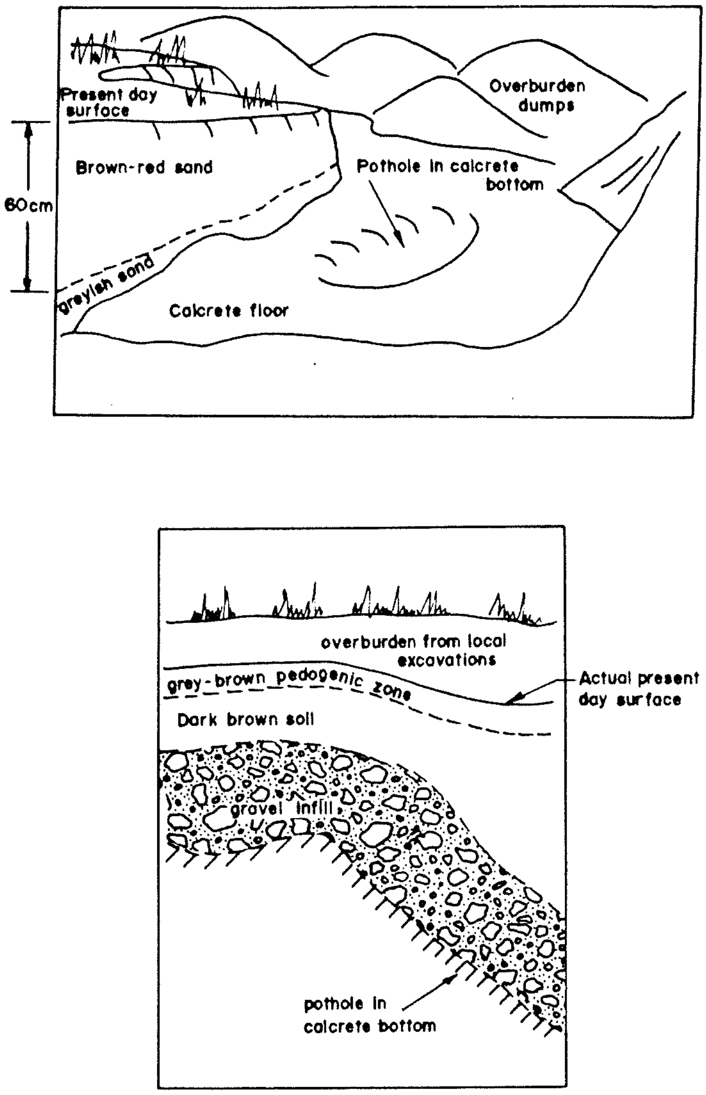


Figure 11 : *Gravel-filled potholes in calcrete on Grootlaagte.*

with a few, scattered, partially-altered clasts of Ventersdorp lava and dolerite and some unaltered siliceous clasts of quartzite and vein-quartz. The replacement of the non-siliceous-lava and dolerite clasts by calcrete has led to the separation of the clasts and an increase in the volume of the calcrete deposit (Fig. 13).

The calcrete profile indicates that there have been at least three phases of calcretization in the southwestern Transvaal. The pedogenic phase is the most recent and is still in the process of forming in many soils. The second phase, associated with the cementing of the gravel-lag, is seen in many of the profiles of the younger Terrace Gravels (Marshall, 1987) and, as such, is likely associated with the Post-African II landscape-cycle of Plio-Pleistocene age. The event responsible for calcretizing the underlying sediments

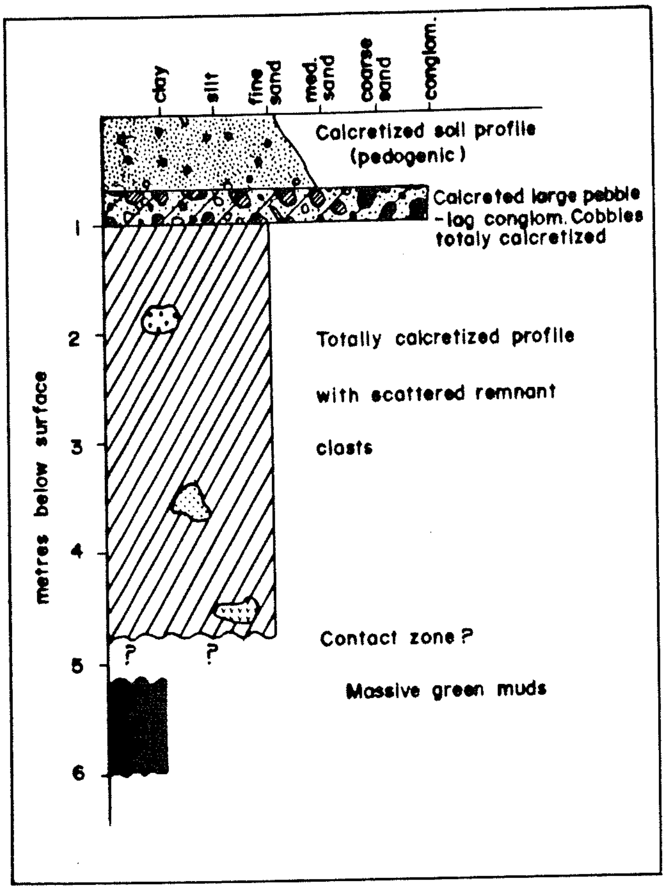
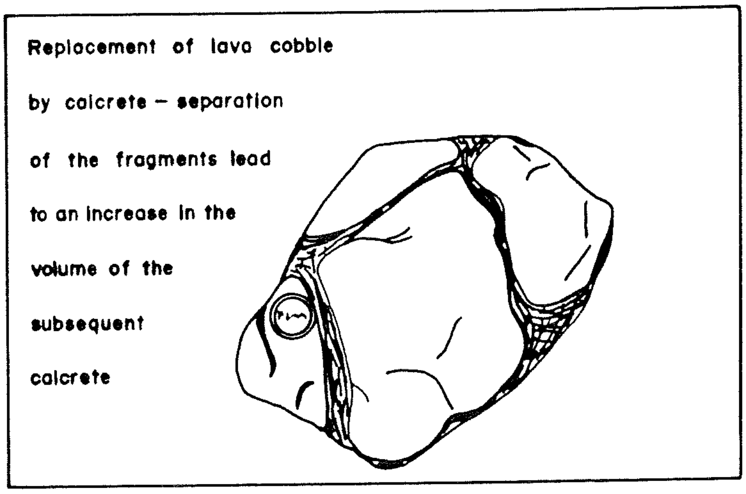


Figure 12 : Schematic representation of the calcrete profile on Hartsfontein 216 HO.

Figure 13 : Replacement of non-siliceous clasts by calcrete, resulting in an increase in volume of the subsequent deposit.



is assumed to be of Post-African I (Mio-Pliocene) age. This is reinforced by the results of a drill-hole on the farm Goedgedacht 149 HO (Mr. A. Rossouw, pers. comm., 1987). This hole indicates that highly-altered (calcretized?) Ventersdorp lavas underlie a similar calcrete ridge. The altered lavas are the same as those which are seen in the lateritized-leached profiles.

On the farm Zevenfontein 240 HO, calcrete *makondos* are filled with gravels. The calcrete deposit is linear, parallels the present, dry valley, and is marked by a row of trees and bushes. Although it occurs on an interfluve, the calcrete *makondos* form in a valley on the crest. The deposit is approximately 15-20m wide and averages 1-1,5m deep, with a few potholes up to 2m deep. Overlying the diamond-bearing gravel infill is a layer of red Hutton Sands. The calcrete bottom is uneven and extremely hard. It has not been drilled to see if primary alluvial gravels lie below the calcrete.

DISCUSSION

The African surface in the southwestern Transvaal is inextricably related to the depositional environment of the ancient diamondiferous gravels. It has previously been shown that the diamond-bearing Rooikoppie Gravels occur as infill to pseudokarst grikes and potholes (Marshall, 1987), as well as in calcrete fluvial channels and *makondos*. Both these features, the pseudokarst traps and the paleochannels, are a result of weathering and erosion attributable to the African cycle.

The calcretized channels likely represent a Tertiary paleodrainage system that developed on the African surface as a result of uplift associated with the splitting of Gondwanaland. During the extended period of sub-aerial exposure of the African erosion-cycle, the planation-surface was subjected to intensive lateritization (Fig. 14a and b). The end of the African cycle thus saw the development of a drainage system on a lateritized surface covered by soil. Post-African I uplift in the Miocene, along with desiccating climatic conditions, resulted in the subsequent modification of the African landscape. Post-incision leaching of the laterite formed pseudokarst solution-hollows or traps which were synchronously filled with deflation-surface gravel-wash by flash-floods and other colluvial processes (Fig. 14c and Fig. 15b).

At the same time, the lowered water-table associated with the desiccating climate was responsible for the calcification of the paleodrainage-lines (Fig. 14c and Fig. 15a). By the end of the Pliocene, the leaching of the laterite and the calcretization of the fluvial sequences were in an advanced stage. The deflation-surface gravels were redistributed colluvially over the leached surface and concentrated into pseudokarst traps. Advanced calcification of the original, fluvial gravels resulted in the formation of a hardpan layer of calcrete and the development of *makondos*. As the hard calcrete layer was leached continually downwards, unreplaced siliceous clasts (remnants of the original alluvial gravels) were released at the surface, forming a derived-gravel component which then infilled the *makondos* as an illuvial deposit (Fig. 16).

As has already been noted, both the illuvial gravels (in the calcreted river channels) and the colluvial gravels (in the pseudokarst solution-traps) occur some distance from the present-day channels and on the upper portions of hillslopes and interfluves. Although laterite is commonly

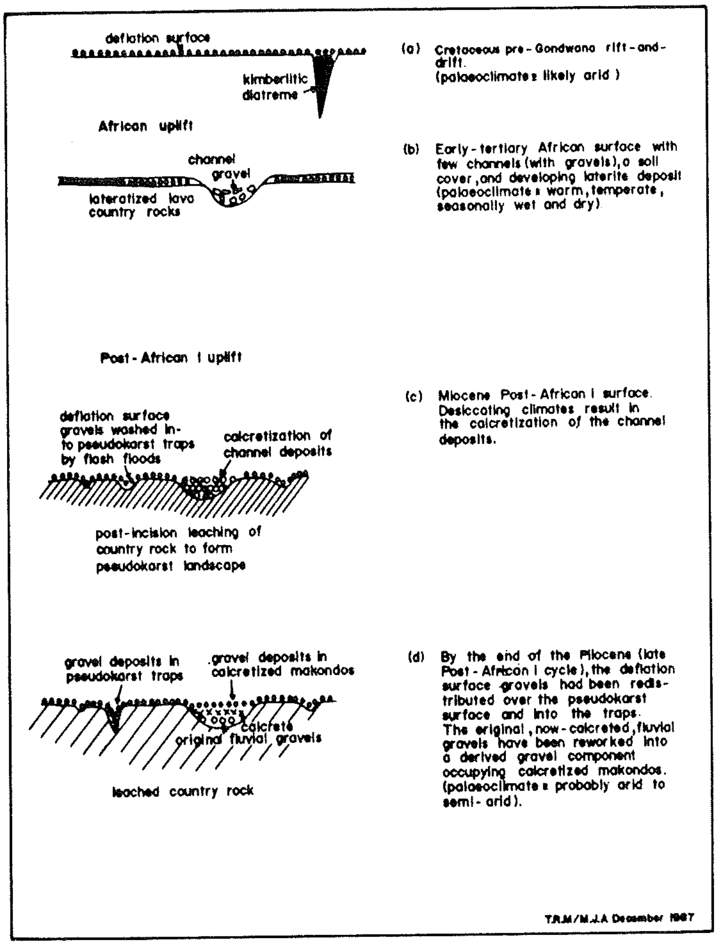


Figure 14 : Schematic representation of the evolution of the African surface in the southwestern Transvaal.

associated with low relief, it is by no means confined to it. It occurs on both mature and sub-mature land-surfaces and has been shown to occur on land-surfaces of considerable relief. Moreover, it is not restricted to shallow slopes, 7-10° being frequently recorded, and laterite has been described on slopes of 20-22° (McFarlane, 1976).

It has also been suggested that the relief is not the original form of the surface, but is due to post-incision modification of the landscape. The calcreted, original, alluvial gravels and the lateritized gravel-traps are more resistant to subsequent erosion than the surrounding rocks and the landscape-topography has become inverted. Erosion associated with the subsequent Post-African II landscape-cycle has largely destroyed this early drainage system, making any paleodrainage reconstruction extremely difficult.

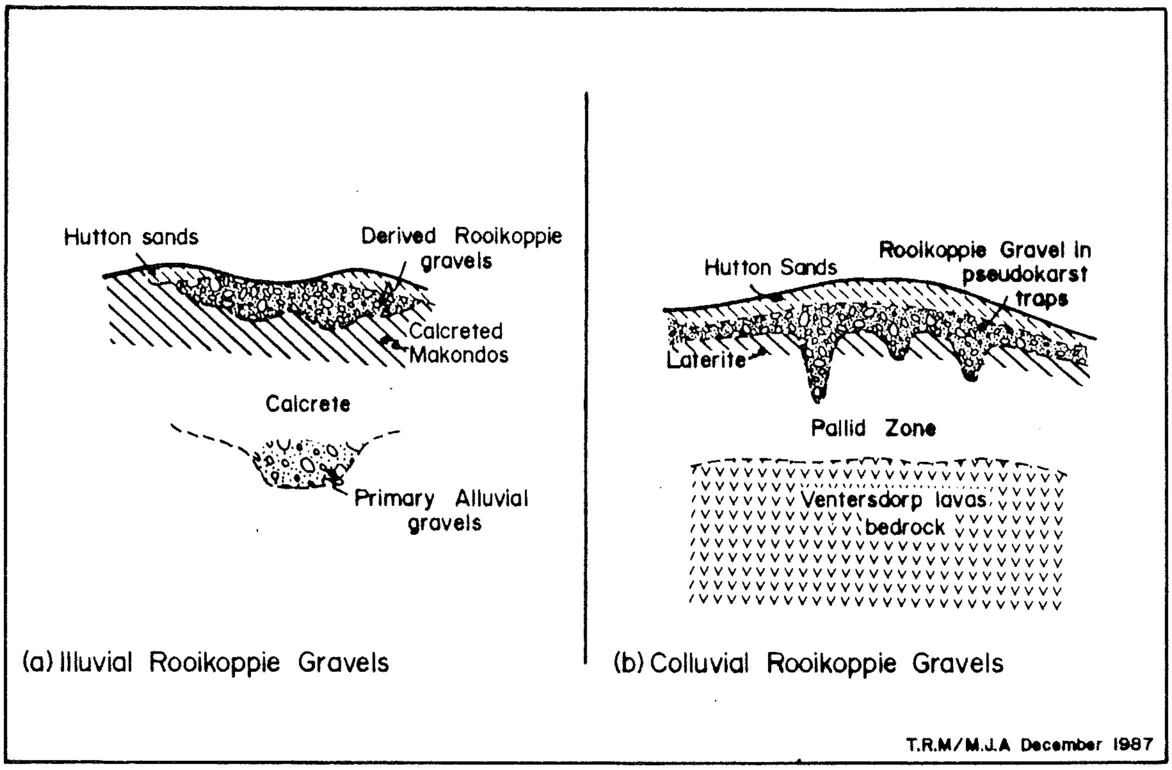


Figure 15 : *The present form of illuvial and colluvial diamondiferous gravels developed on the altered African surface.*

CONCLUSIONS

The African surface in the southwestern Transvaal has substantially modified the exposed pre-Karoo landscape. The erosion-cycle which was initiated by the Mesozoic rifting of Gondwanaland extended from late-Cretaceous to mid-late-Tertiary, a period of more than 100 million years. During this extensive period of sub-aerial exposure and denudation, the landscape of the southwestern Transvaal was deeply weathered through the process of lateritization and, later, calcretization.

The laterite profile in the southwestern Transvaal is of the order of 2,5-3,0m thick and consists of a thick layer of unindurated, pisolithic, uncemented, spaced laterite, overlying a hard, cemented, pisolithic layer, which, in turn, overlies a mature, vermiform, laterite layer. Such a sequence is common in laterite-development associated with a single erosion-cycle. It is not simply a final stage in the development of an erosion-surface. The laterite formed beneath a soil- or deflation-surface cover, as erosion lowered the underlying rock-surface,and the development of the lateritic horizon thus lasted for much of the duration of the African cycle of erosion.

The laterite profile underlain by a mottled or pallid zone is the product of leaching (basal sapping) associated with incision, a consequence of

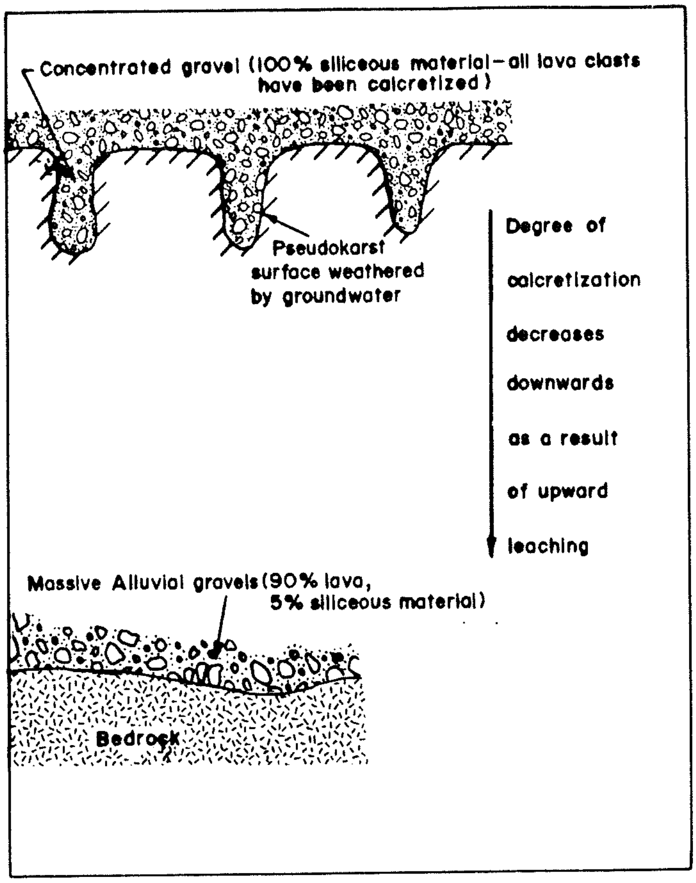


Figure 16 : Schematic representation of secondary concentration of gravels as a result of calcretization.

the succeeding Post-African I erosion-cycle. Not only is the leaching responsible for the development of a thick (> 3m) pallid zone beneath the laterite, but it also resulted in the development of an extensive pseudokarst solution-network. In turn, these pseudokarst solution-cavities became effective trap-sites for the deposition of surficial gravels and diamonds.

Although the deposits are usually no more than 3m thick, laterite up to 60-80m does exist in the southwestern Transvaal. Where such deposits have been sufficiently altered, economic concentrations of hematite have developed.

Linear, calcreted, gravel-filled *makondos* are another important feature of the African surface in the southwestern Transvaal. These may be the weathered remains of an ancient, paleodrainage-pattern developed on the African surface. Careful mapping of all such deposits may assist in reconstructing the early drainage of this area.

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