A REVIEW OF LANDSCAPE DEVELOPMENT AND EROSION CYCLES IN SOUTHERN AFRICA

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Contents

INTRODUCTION

The study of landforms has, to a large extent been neglected by exploration geologists. This is surprising because field geology is intimately related with landforms of one type or another. An understanding of the geomorphological history of a particular area will assist in the appreciation of the surficial environment, the processes of weathering, soil formation and duricrust (calcrete, ferricrete silcrete) formation. This has direct application in planning and interpreting geochemical sampling programmes.

In order to understand the evolution of landforms it is necessary to study slope development in some detail. Agents of erosion and denudation constantly at work, remove detritus from hillcrests down to the drainage lines which form the local base level from whence material is transported down to the sea. The system is one of dynamic equilibrium, and the concept of grade is important in understanding hillslope evolution. Thus Section (1) of this discussion deals with past and present theories of hillslope evolution.

Very little work has been done recently on the geomorphology of Southern Africa and the presently accepted classification of land surfaces is based on the work of Prof. L.C. King (numerous publications). However, through the more recent work of De Swardt and Bennet (1974) on the geomorphology of Natal, it is apparent that the present system of landform classification in Southern Africa requires widespread revision. The relationship of erosion cycles in Southern Africa to the late Jurassic - early Cretaceous break-up of Gondwanaland has received insufficient attention in the past. Erosion cycles bear an intimate relationship to offshore Cretaceous and Tertiary - Recent sedimentation. Valuable information on these sediments has only recently become available as a result of offshore exploration for oil. The findings of De Swardt and Bennet (1974) are summarized in Section (2) and the present land surface classification of Southern Africa is reviewed. Finally, some suggestions on a new interpretation of land surfaces in Southern Africa are given.

1. REVIEW OF LANDFORM DEVELOPMENT

Form and Process

In landform study, a distinction is made between form and process. Form refers to the shape of the landscape and the nature of its environment at a given point in time and therefore includes the elements of geology, climate, and vegetation. Process refers to the agents active in bringing about a particular form observed.

Hillslopes are the most common landforms since they include those areas of the landscape between the hillcrests and the drainage lines. Therefore a discussion on landform development reduces chiefly to a discussion of hillslope evolution. Hillslopes display wide variations in form, and in order to understand their evolution, the processes which may have been instrumental in their formation must be appreciated. These processes are summarized below.

Once rivers and streams have eroded their beds to attain a graded profile, their influence on the landscape as a whole, reduces to two important functions, namely :

i) removal of material transported from surrounding hillslopes to the streams by denudational processes and,

ii) their action as a local base level to these denudational processes.

Denudational processes acting on hillslopes are generally slower than erosional processes acting in rivers and streams. It is chiefly through the agents of denudation that hillslopes are sculptured and landscape is lowered. These denudational processes are surface processes acting over entire hillslope area, as opposed to the linear action of river erosion. Surface processes are responsible for the breakdown of bedrock into regolith (unconsolidated material overlying bedrock), and the transport of regolith material across the slopes.

Surface processes include weathering (both physical and chemical), and transportation, the main agents of which are surface wash or gravitational processes. Surface wash processes involve transport by water and gravitational processes involve mass movement of material which can be either slow, as in the case of soil creep and solifluction (slow flow of material saturated with water), or rapid which includes all movements involving rapid flow, slip, or free fall.

Regolith material may be in situ, i.e. directly overlying the parent rock that it was derived from, in which case it represents a residual soil profile, or it may be transported. Reduction (or comminution) is the breakdown of regolith material into finer particles and is caused by weathering processes.

Hillslopes can generally be divided into two basic forms, namely convex or concave slopes, commonly separated by a rectilinear transition slope and/or free face and are best described with respect to the following three factors (Partridge 1968) :

i) Structure (rock types and lithologies and their attitude).

ii) Process (controlled, for given structures chiefly by climate and vegetation).

iii) Stage (the nature and relationship of the local base level of erosion).

Hillslope form is governed mainly by the rate of supply of material (determined by the rate of weathering of the parent rock), and the rate of removal of material. This involves all three of the above factors of structure, process and stage.

Those parts of the slope governed by surface wash processes generally have concave profiles since they attain, or are trying to attain a graded, concave hydraulic curve. Surface wash processes are enhanced under conditions of periodic rainfall of high intensity which favours rapid runoff. Surface wash is also enhanced by tuft grasses, and more arid vegetation types common to semi-arid and sub-humid climates.

Mass movements produce a variety of slope forms depending on the type of mass movement that occurs. Under stable base level, convex slopes are often the result of soil creep which is enhanced under conditions of prolonged rainfall which lead to greater moisture infiltration. Carpet grasses common to humid climates such as coastal Natal, inhibit surface wash and enhance deep weathering and deeper soil profiles.

Three main theories of hillslope evolution

Numerous models of hillslope evolution have been suggested and debated by various workers in the past. Most important among these have been the views of Davis, Penck and King. These are briefly reviewed below, prior to the discussion of the hypothesis of local slope evolution postulated by Partridge (1968). This offers the most complete explanation of hillslope processes and it is broadly applicable to hillslope evolution throughout most parts of Southern Africa.

Davis (slope decline and peneplanation)

Davis correctly interpreted the upper convex parts of hillslopes in the humid climate he worked in, to the action of soil creep, thus producing rounded profiles of drainage divides. However, he over-emphasized the importance of soil creep, regarding it as the dominant agent of transport on hillslopes. By analogy with the graded river profile he argued that hillslopes also attain graded profiles, and in a state of maturity consist of a graded slope down which waste sheets move by soil creep. By continuing the analogy with graded river profiles, Davis derived his theory of slope decline : "Just as rivers slowly degrade their courses after the period of maximum load is past, so graded waste sheets adopt gentler and gentler slopes" (in Young, 1972, p. 26).

The essential changes in slope profile through time in the Davisian system of slope decline are indicated in Figure (1). The major change is the early replacement of a steep, straight sided slope by a convex-concave profile which thereafter decreases in steepness ('declines'), with little further change in geometry. The end result in the Davisian system therefore, in the final, mature stages of an erosion cycle is a gently rolling multi-convex peneplain.

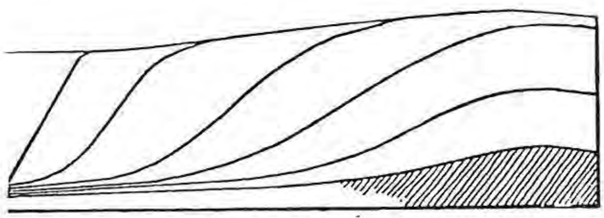


Figure (1). Davis' model of slope evolution. From Young (1972), p. 27.

Davis subsequently modified his 'normal' cycle of slope decline in humid climates to accommodate parallel retreat of slopes, with the development of a lower pediment in arid climates.

Penck (slope replacement)

Penck assumed an initial straight steep rock face ('steilwand') as a starting point in his theory of hillslope evolution. According to Penck, weathering of this face, and rock fall results in the retreat of the cliff face at a constant angle. This produces a second slope ('haldenhang') consisting of loose debris at the bottom of the cliff face which is at a lower gradient than the upper cliff face. The 'haldenhang' then developes independently of the upper cliff face ('steilwand'), and also retreats at a constant angle forming yet another slope of finer grained debris ('abflachungshang') below it, which behaves in the same way as the slopes above it.

This process is continually repeated with slopes of less and less gradient. The net result is a concave slope which, by continued replacement of upper slopes by gentler lower slopes results in a concave profile which becomes more and more gentle (Figure 2). The consequent change in slope profile envisaged by Penck is illustrated in Figure (3).

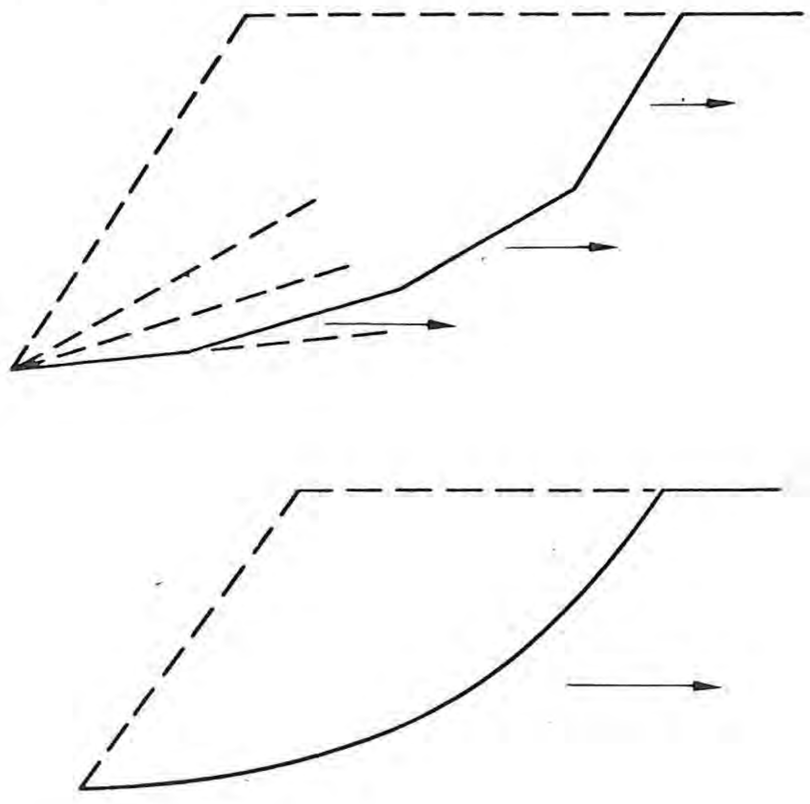


Figure (2). The development of a concave profile according to Penck. From Carson and Kirkby (1972), p. 375.

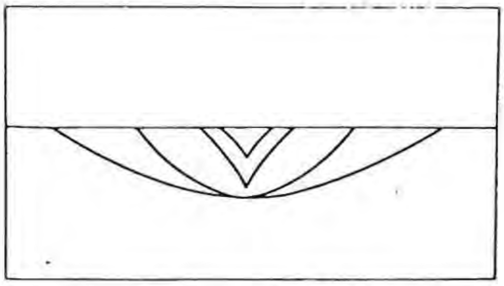


Figure (3). Change in slope profiles envisaged by Penck. From Carson and Kirkby (1972), p. 376.

King (Parallel scarp retreat and pediplanation)

King (1953, 1963) envisages four slope elements (Figure 4) based on the work of Wood (1942) and Fair (1947, 1948), which make up the standard hillslope :

i) the waxing slope, or crest,

ii) the free face,

iii) the talus, or debris slope,

iv) the pediment.

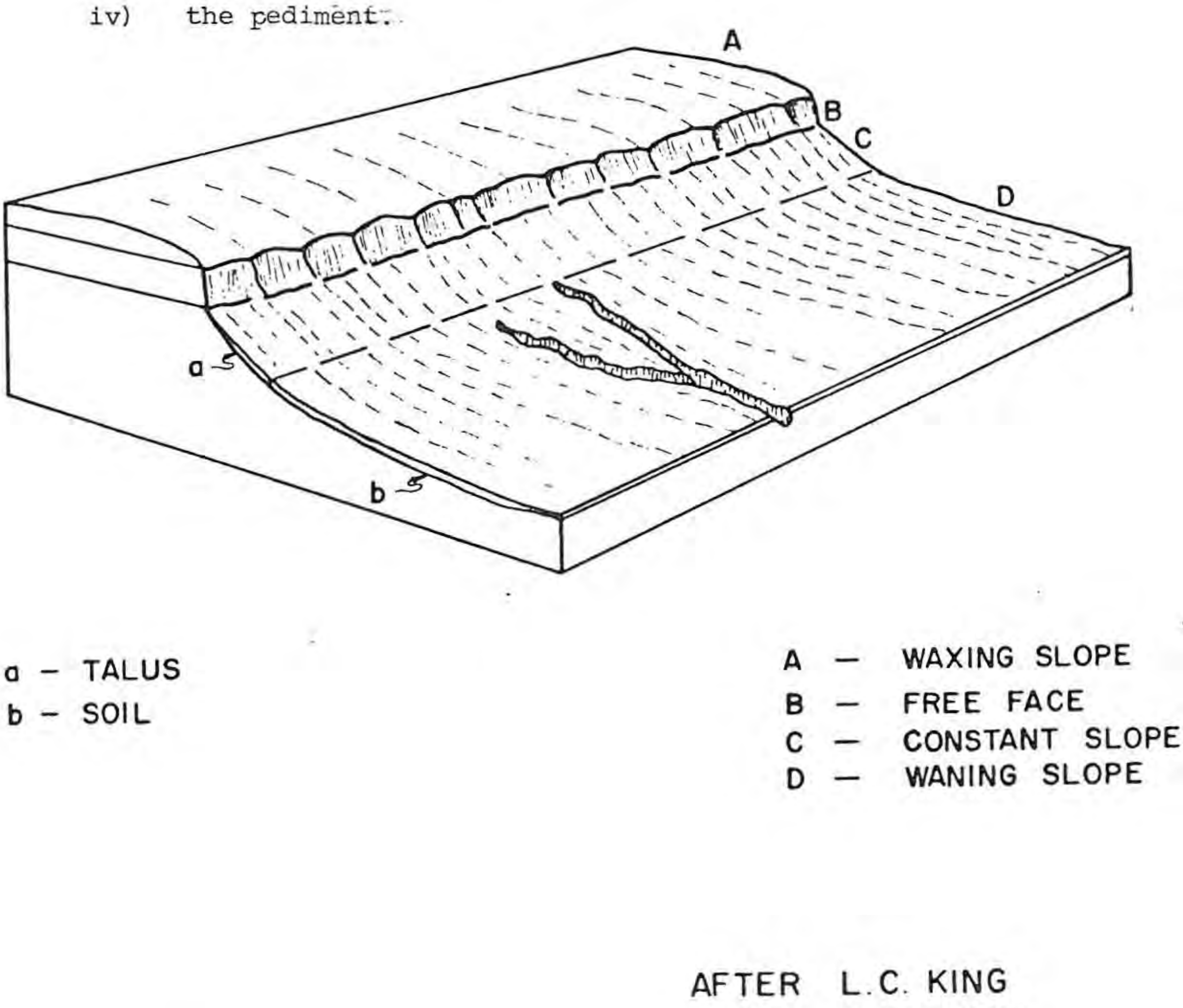


Figure (4). King's standard four element hillslope. From Partridge (1968).

The waxing slope, or crest forms the convex hill summits. King (1953, 1963) suggests that the main denudational processes acting on the crest are weathering and soil creep, the convexity being ascribed to an increase in these processes downslope : "The curve is convex because more waste must pass a point lower down the slope in a unit of time, than passes a point higher up" (King, 1953, p. 729).

This ultimately causes the break in slope forming the free face exposing bedrock outcrop which, by weathering causes the free face to retreat. Debris accumulated at the base of the free face forms the talus slope, the steepness of which is governed chiefly by the angle of repose of the coarser material. This is the rectilinear slope common to many hillslopes and separates the upper slope convexity from lower slope concavity.

The break in slope between the talus slope and the lower concave pediment occurs where size of the material on the slope permits a transition from predominantly gravitative transport to surface wash transport and is therefore often gradational. The pediment slope ideally conforms to a graded hydraulic profile between the base of the talus slope and the drainage line which forms the local base level. The pediment therefore consists of a concave, bedrock surface overlain by a mantle of transported material originating from the upper slope elements.

The most active element in backwearing of the slope as a whole is the free face which, as a result of weathering, retreats at a constant angle (the process of parallel scarp retreat). Therefore the pediment extends in length and must be constantly regraded, and the angle of the pediment slope is progressively reduced. Since a certain minimum gradient must exist on the pediment to enable transport of material across it, and since it cannot lower itself below the level of the drainage lines which form the local base level (assuming this is constant), the upper pediment must increase in height in order to maintain sufficient gradient. It therefore displaces the upper slope elements until the cycle is terminated by meeting of opposing slopes. The end result of this progressive pedimentation will be a multi-concave pediplain.

An important basic concept in parallel scarp retreat and pediplanation is that two surfaces are involved. The older surface which makes up the waxing slope, and extends beyond the zone of scarp retreat is broken down by a younger erosion cycle which forms a younger landscape below the zone of active scarp retreat. This younger landscape, by progressive pedimentation is worn down to a pediplain in the mature stage of the cycle further 'downstream' of the zone of active scarp retreat and degradation (Figure 5). The onset of a new erosion cycle is generally ascribed by King (numerous publications) to epeirogenic uplift of the land and resultant lowering of sea level which forms the ultimate base level.

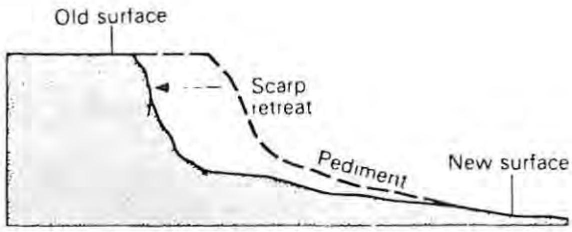


Figure (5). Parallel scarp retreat and extension of pediment. From Buckle (1978), p. 141.

King's standard hillslope provides a convenient model with which landforms in Southern Africa can be compared. It is immediately apparent that observed hillslopes in Southern Africa do not everywhere conform to this standard hillslope. This was recognized by King (1953) and ascribed to the influence of a number of important factors :

i) The mechanism of parallel scarp retreat is favoured by the presence of sub-horizontal resistant strata. Thus it is that the characteristic flat-topped topography of the Karroo came about. Homogeneous, structureless rock masses such as granites, show a tendency to develop convex slopes. Scarp retreat is also often enhanced by the basal undercutting of the free face by erosion of less resistant strata underlying the rocks of the free face :

ii) The standard hillslope is best developed under semi-arid to sub-humid climatic conditions common over most of Southern Africa. This is because surface wash is enhanced by tuft grasses and heavy intermittent rainfall of semi-arid and sub-humid regions. This allows sufficient removal of debris from the talus slope, which would otherwise extend up the free face, finally covering it completely forming a convexo-concave slope. Therefore, convexo-concave hillslopes are found in more humid areas such as the coastal interior of Natal, due to impeded removal of talus as a result of carpet grasses and higher, more continuous rainfall which inhibit surface wash and promote soil creep.

iii) Replacement of the free face by the talus slope may also occur under very arid conditions where material supplied to the talus slope is not removed, due to the absence or very rare occurrence of surface wash processes. However, this probably only occurs in conditions of extreme aridity, a more common modification of the standard hillslope with increasing aridity being the reduction of a talus slope and pediment soil cover due to more efficient removal under flash flood conditions enhanced by lack of vegetation and its stabilizing influence on soils on the pediment. Thus bare rock pediments with little or no soil cover, and reduction of talus accumulation are more common landforms of arid areas.

iv) Convex slopes may represent degenerate forms of the standard hillslope as described above, but may also be a function of the immature stage of the erosion cycle in that the free face may not yet have developed.

v) Parallel scarp retreat is also enhanced by high relief, thus maintaining a clear face and debris slope since sufficient energy exists in the system to maintain the required rate of removal of debris from the talus slope and pediment.

The work of Partridge (1968)

The above concepts are basic to the understanding of landscape development in Southern Africa, but in order to appreciate the complex interaction of structure, process, and stage, more fully the work of Partridge (1968) is discussed below. Although his findings generally agree with those of King (1953, 1963), some important modifications to King's standard four element hillslope concept are required. Chief among these is that convex slopes formed by surface wash processes rather than soil creep may be more common than implied by King (1953, 1963). The work done by Partridge (1968) is discussed in detail because it offers the most complete explanation of Southern African hillslope evolution and his conclusions are here regarded as a useful model with which hillslopes over most of Southern Africa can be compared.

Partridge conducted a detailed geomorphological study of the Pretoria - Witwatersrand area in which he established a morphological classification of landforms to set up a store of information on the characteristic landforms with a view to retrieval and future use for engineering, land use, town planning and hydrological purposes. In the course of his investigations, considerable attention was given to the development of hillslopes and it is these findings with which the following discussion is concerned.

Sixteen land systems were defined and mapped in the Pretoria - Witwatersrand area by airphoto interpretation and field checking. Different facets (or elements) were identified within each land system and characteristic soil profiles established for these different facets by auger drilling. The slopes of two of these land systems were examined in detail, namely the Daspoort and Kyalami land systems. These were selected since they represent completely contrasting landscapes.

The Daspoort land system (Figures 6-8), is characterized by steep hills and mountains with relatively high relief, and a high degree of structural control. It is best developed in areas underlain by Daspoort quartzites and shales, but is also commonly associated with Orange Grove quartzites, Black Reef quartzites, Timeball Hill quartzites, and Magaliesburg quartzites. Dissection has attained maturity and broad valleys separate steep, resistant ridges. South of the Magaliesburg ranges the Daspoort land system ridges bear crestal remnants of the Pre-Karoo surface (e.g. above the Witwatersrand escarpment), or have crest-lines which have been slightly lowered from this surface (e.g. Daspoort ranges). North of the Magaliesburg there is no accordance of summit levels and hillcrests owe their existence to greater resistance during formation of the surrounding Post-African pediplain.

Drainage is superimposed and probably inherited from Karroo cover which has now been stripped off. Major rivers are transverse to the resistant quartzite ridges forming spectacular poorts (Figure 31). Four element hillslopes (after King, 1953) are characteristic, but ridges are assymetrical owing to the dip of underlying resistant strata and development of a prominent dipslope (Figure 6). Denudation is dominated by gravitative processes and soils are poorly developed; outcrop and raw mineral soils predominate. The area of the Daspoort land system selected for study forms part of the Witwatersrand escarpment near Krugersdorp. This escarpment is capped mainly by resistant Orange Grove quartzites of the Witwatersrand Supergroup which overlie less resistant Archaean schists.

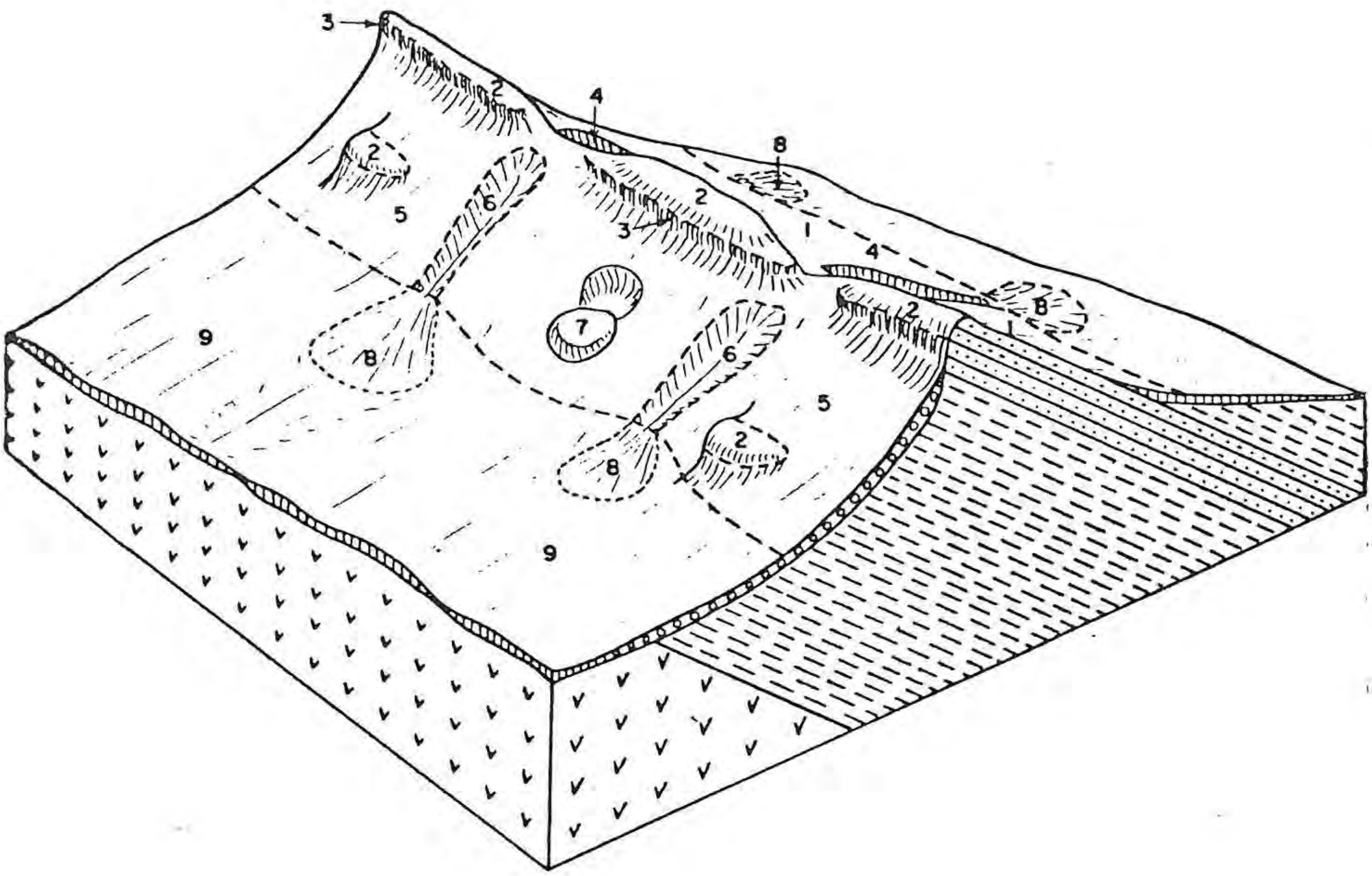


Figure (6). Daspoort land system, block diagram. From Partridge (1968).

Facet	Form
1	Dipslope
2	Waxing slope
3	Free face
4	Rockbound gully or gorge
5	Talus slope
6	Gully
7	Slump platform
8	Fan
9	Upper pediment

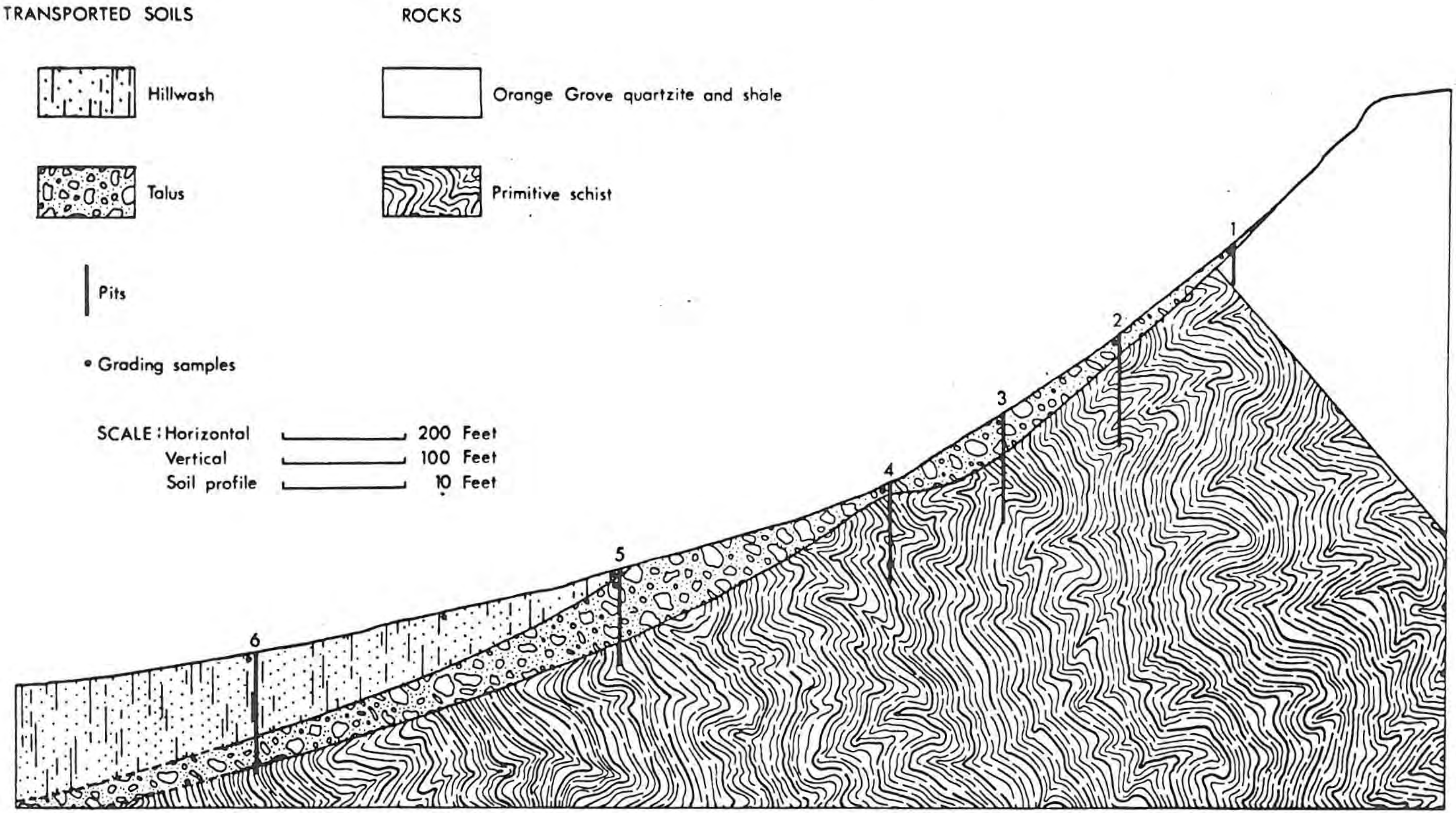


Figure (7). Section along a typical concave hillslope, Daspoort land system. From Partridge (1968).

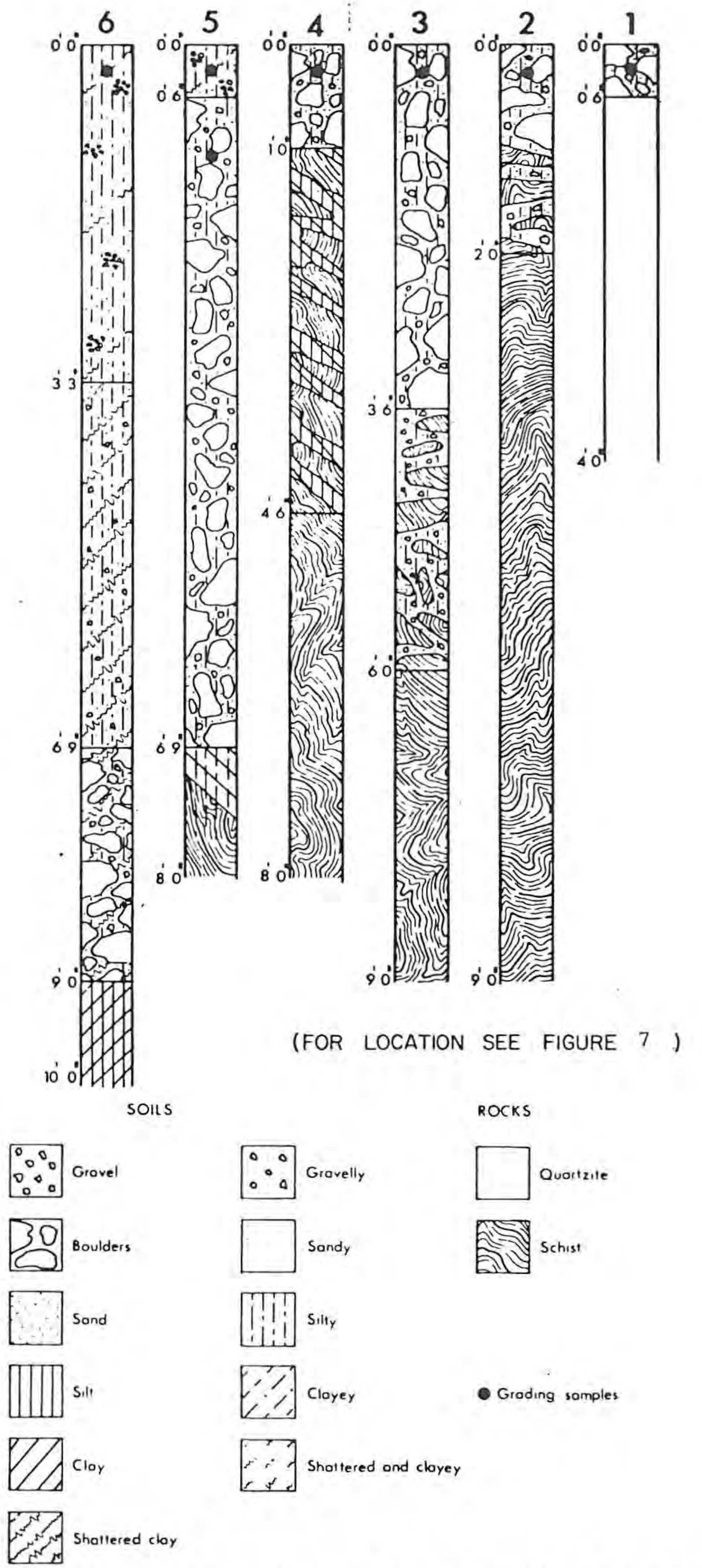


Figure (8). Downslope variation in soil profile for concave hillslope, Daspoort land system. From Partridge (1968).

The Kyalami land system (Figures 9-11), is the most extensive land system in the area studied and is underlain by the Halfway-House granite with patches of Archaean, basic metamorphic schists. The landscape has been produced by youthful dissection of a relatively flat surface coinciding with the Pre-Karroo surface. This was exumed during pediplanation in the African erosion cycle and is now preserved as occasional summit remnants which have withstood dissection in the younger Post-African erosion cycle now current in the area. Major drainage lines were probably inherited from Karroo cover still present to the east; smaller tributaries however, show structural control due to jointing and faulting.

Gently convex hillslope profiles characterize the Kyalami land system and are the result of an immature cycle of erosion and relatively homogeneous lithology. Surface wash and gravitative processes operate and soils are mainly fersiallitic (fairly weathered) with patches of ferrallitic (highly weathered) soils corresponding with the superposition of the Pre-Karroo surface and an African cycle pediplain. Major hillslope facets are the convex hillcrests and convex side slopes.

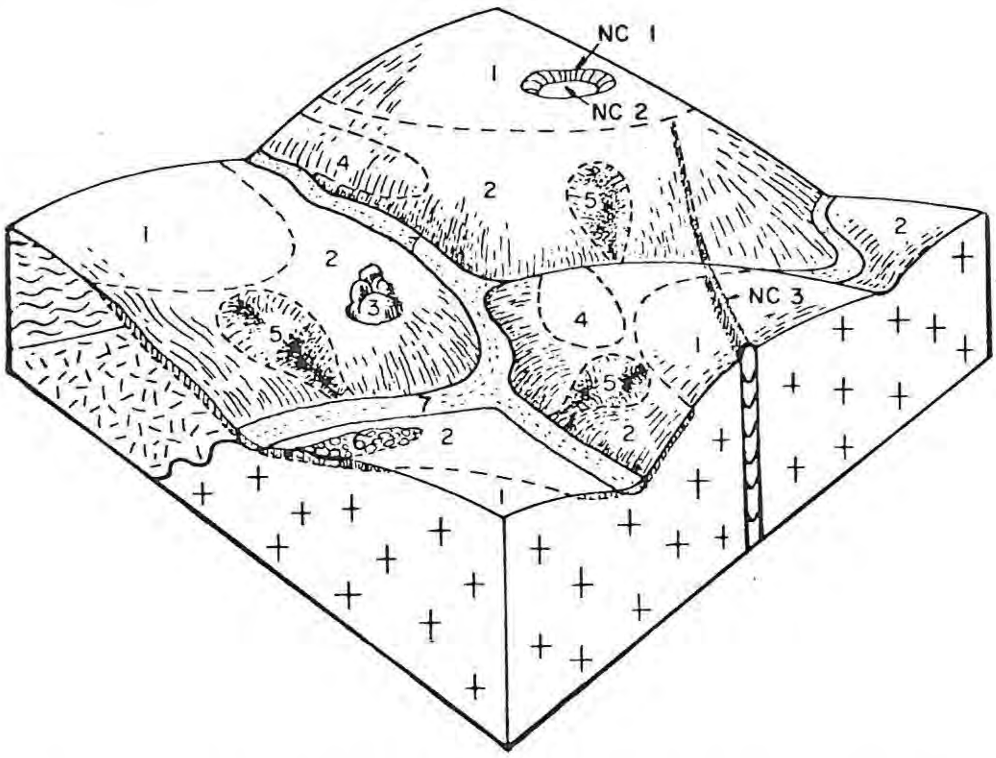


Figure (9). Block diagram for Kyalami land system. From Partridge (1968).

Facet Index :

Facet	Form	Soils
1	Hillcrest	i) (Old erosion surface). Residual sandy clay with collapsing grain structure or granite. Sometimes overlain by reworked soil. Ferrallitic soil.

Facet	Form	Soils
		ii) Residual expansive clay on schists and basic metamorphic rocks with occasional low outcrop. Fersiallitic soils.
		iii) Weathered granite sometimes covered by thin, vein quartz gravel and/or reworked soil. Fersiallitic soil.
2	Convex side slope	i) Hillwash of silty sand derived from granite on granite, schists or basic metamorphic rocks Sol lessive´ (leached sands).
		ii) Hillwash of expansive silty clay derived from schists or basic metamorphic rocks on granite, schists or basic metamorphic rocks. Fersiall-itic soil.
3	Tor slope	Fresh granite outcrop on side slope.
4	Whaleback	Fresh granite outcrop on side slope.
5	Gully	i) Sandy gully wash derived from granite. Regasol or sol lessive´ (leached sands).
		ii) Expansive clayey gully wash derived from schists and basic metamorphic rocks on granite, schists and basic metamorphic rocks. Hydromorphic (gleyed) or fersiallitic soils.
6	Alluvial terrace	Sub-angular gravel and boulders of mixed origin on granite, schists and basic metamorphic rocks. Raw mineral soil.
7	Alluvial flood-plain	Expansive alluvial clays and sands on granite, schists and basic metamorphic rocks. Hydromorphic (gleyed) soil.

Non cognate (N.C.) facet

1	Pan side slope	Hillwash of silty sand derived from granite, on granite. Sol lessive´.
2	Pan floor	Poorly drained, black expansive clay on granite. Halomorphic or hydromorphic (gleyed) soil.
3	Dyke ridge	i) Bouldery outcrop-diabase syenite, or felsite.
		ii) Residual expansive clay on diabase, syenite or felsite. Fersiallitic soils.

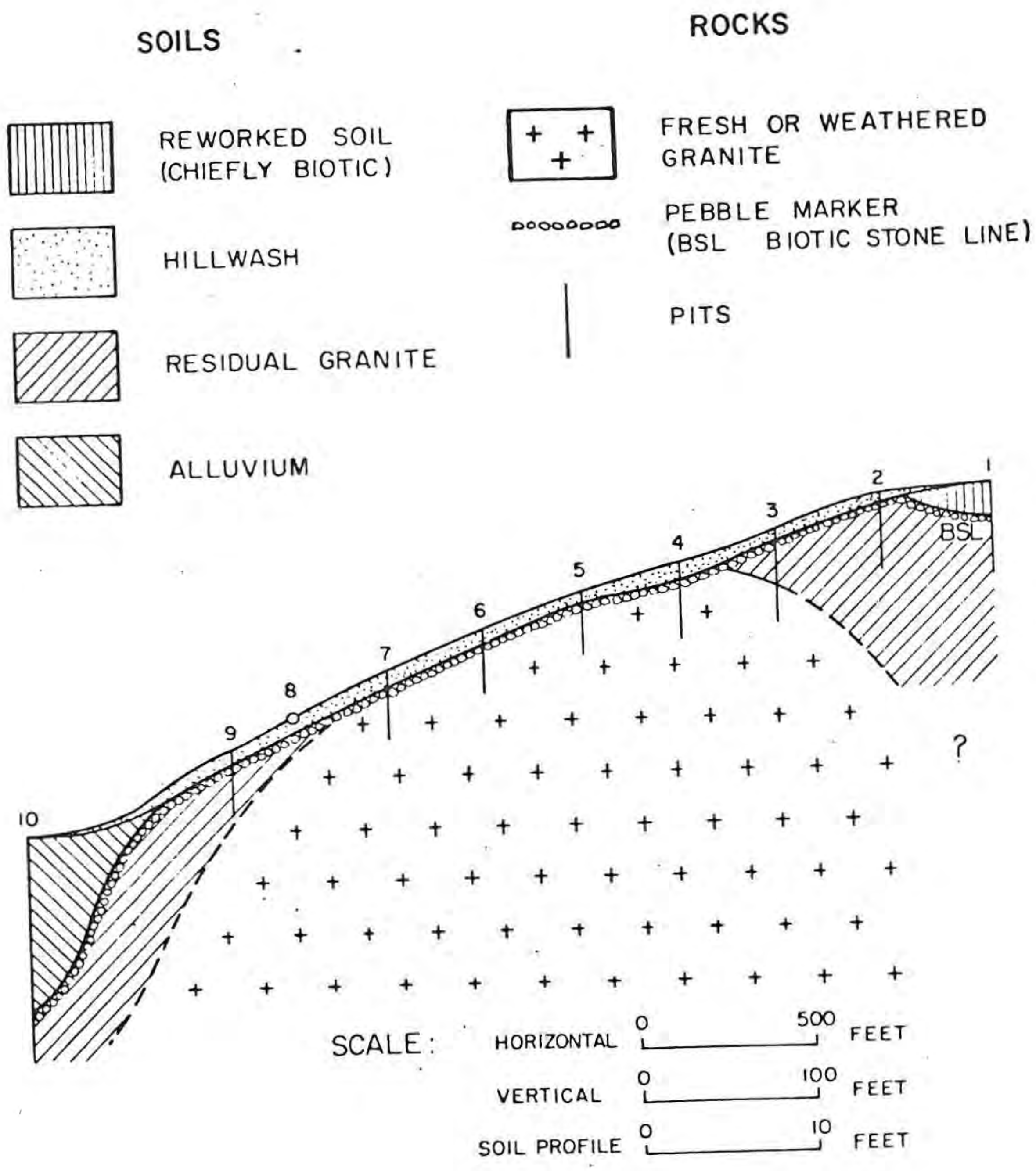


Figure (10). Section along typical convex hillslope, Kyalami land system. From Partridge (1968).

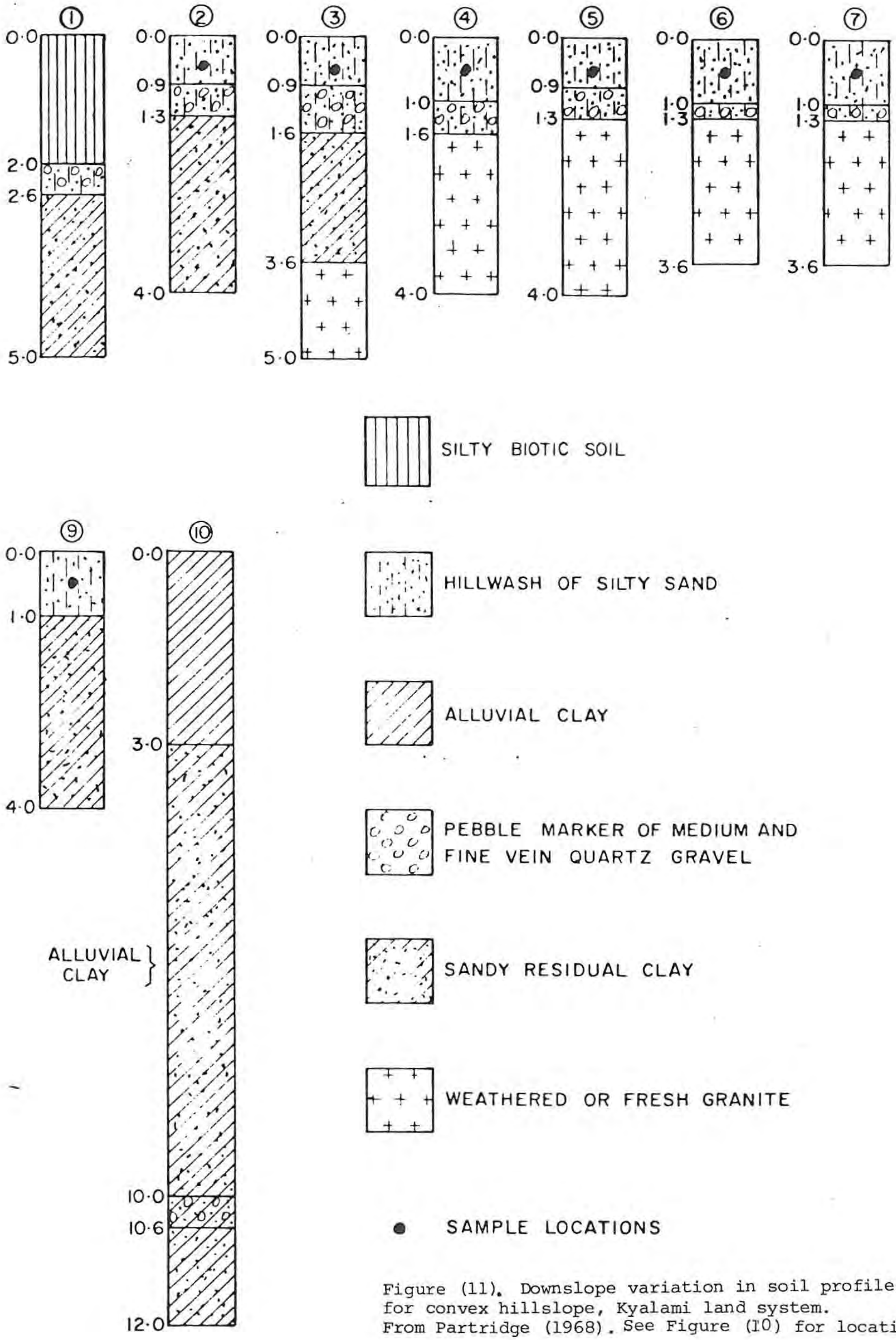


Figure (11). Downslope variation in soil profile for convex hillslope, Kyalami land system. From Partridge (1968). See Figure (10) for locatio

Description of the main slope elements

As can be seen from Figures (6) and (9) a number of hillslope facets or elements are described by Partridge which are additional to the four hillslope elements of King (1953), (Figure 4). Many of these are of minor importance in the description of the landscape as a whole. These include the rock-bound gullies or gorges, gully, slump platform, and fan (Figure 6), and tor slope, alluvial terrace, alluvial floodplain, pans and dyke ridge (Figure 9). Other minor facets identified by Partridge in various land systems include sinkholes and vleis. However, land facets not described by King's four element hillslope which often form a major part of the landscape and have important implications in hillslope evolution are the convex side slope and whaleback (Figure 9), and the dipslope (Figure 6). Dipslopes need not be further considered here since their presence is due solely to bedrock structure and is therefore readily explanable. However, dipslopes emphasize the important part which can be played by structure in hillslope evolution.

The convex side slope however is a major slope facet and is found in many of the other land systems as well. It is therefore described below, along with the four major slope elements of King (1953), namely : the waxing slope (convex hillcrest), free face, talus slope, and pediment. In addition, attention is given in the following discussion to the generation of the whalebacks of the Kyalami land system, the transition zone between talus slope and pediment, and the effect of incision of the younger Post-African cycle of erosion on the landforms of the older African erosion cycle. Constant reference to Figures (6) to (11) should be made in the ensuing discussion.

a) The waxing slope

This is the highest element of any hillslope and represents the initial expression of a younger erosion cycle encroaching on the upper (older) of the two surfaces inherent in advance of a new erosion cycle. It is strongly influenced by the presence of a free face below it, particularly when the free face is cut in a resistant cap rock or is retreating rapidly, since both factors tend to inhibit the formation of broad convexities. Convex slopes are enhanced in easily weathered rocks which inhibit the development of a free face.

Form : The waxing slope is generally poorly developed on the Witwatersrand escarpment and in places is superseded by a crestal concavity due to the presence of two resistant lithologies on the hillcrests, the lower of which forms the free face in these instances. Jointed quartzite blocks and a thin soil cover are the main materials on the waxing slope.

The hillcrests of the Kyalami land system however, are well rounded and smooth due to the homogeneity of the bedrock and the fact that they represent remnants, or have been lowered in remnants of the Pre-Karroo surface and African pediplain, and therefore carry deep, residual soils which offer little resistance to weathering. This is illustrated by profiles 1 to 3 in Figures (10) and (11). Fine grained biotic soil on the hillcrest is separated from underlying residual granitic soils by a thin vein quartz line (biotic stone line) thought to be formed by sorting of residual soil by termites and other organisms.

This biotic soil horizon gives way down slope to a thin, fine grained hillwash horizon derived mainly from the biotic soil, and separated from underlying residual soils and granite by a thin gravel horizon (pebble marker). This hillwash horizon maintains its thinness downslope (Figure 10).

The residual granite soils may be as deep as 25 metres where the crest coincides with the Pre-Karroo surface and African pediplain, but it is generally about half this depth. This residual soil is commonly sandy clay material and is highly leached particularly where it corresponds with the Pre-Karroo surface and African pediplain, with the result that feldspars and their weathering product, clays have been removed by leaching forming soils with a collapsing grain structure (Figure 30).

Process : Convex slopes are generally thought to be the result of weathering and soil creep (King 1953), thus slow movement under the influence of gravity is regarded as the main process of formation. However it appears that the action of water work on hillcrests may also be responsible for convex slope formation. The dictum that "the curve is convex because more waste must pass a point lower down the slope in a unit of time than passes a point higher up" (King 1953, p. 729), is not readily applicable to the upper slopes of the Witwatersrand escarpment since soils are nowhere thick enough on the crest (due to resistance of the quartzites and shales to weathering) to enable efficient function of soil creep processes. Convex slopes cannot be regarded as a function entirely of rate of transmission of material since depth of soil on hillcrests often decreases downslope. However, on the Kyalami hillcrests, creep is probably of greater importance in producing the broad crestal convexities owing to the greater depth of soil on the hillcrests. The waxing slope can also often be attributed to the result of weathering attack from two sides, especially in homogeneous igneous rocks (this is analogous to the spheroidal weathering of rectilinear jointed basic igneous rocks).

Partridge considers that water transport of material is of greater importance in the generation of convex hillslopes than has previously been recognized. This is ascribed to the fact that water, running off the hillcrest carries progressively larger quantities of material, thus requiring steeper slopes in order to transport this material, i.e. water wash becomes more erosive downslope establishing a steeper slope in order to transport its increasing load. Thus a zone of no erosion exists on the highest portions of the crest where erosive force of surface wash is insufficient to overcome shear resistance of soil materials. The width of this belt is increased by factors which inhibit surface wash (e.g. carpet grasses) and decreased by factors which enhance surface wash (e.g. tuft grasses). It is this belt of transport without corrasion that forms the waxing slope.

This is well illustrated in Figure (10), which shows that no transported material exists on the highest part of the slope but appears further downslope as a thin hillwash horizon on the surface. Its constant downslope thickness indicates a sufficiently high rate of removal from the foot of the slope which is borne out by the vigorous nature of most Kyalami streams which are still degrading their beds.

Development : Three factors have an important influence on the development of the waxing slope, namely :

i) The waxing slope length cannot exceed a critical distance beyond which gravitative forces can overcome shear resistance of the material producing rapid mass movements. Thus in dense drainage areas (such as the Kyalami land system), summit convexities will occupy greater portions of the landscape.

ii) The rate of scarp retreat is generally faster than the rate of convex slope development, consequently, where well developed free faces exist, summit convexities are often insignificant.

iii) The stability of local base level is important in the developmentof a convex slope since, under conditions of falling base level, surface wash processes have insufficient time to develop their concave equilibrium forms but retain convexities as slopes lengthen due to stream incision. This is the case in the Kyalami land system,where arrival of the Post-African erosion cycle has caused stream rejuvination.

b) The free face

This is the youngest and most actively eroding element on a hillslope and is important in maintaining the steepness of the slope. It is common along the Witwatersrand escarpment, but absent from the Kyalami land system. Emergence of the free face on an evolving hillslope occurs when removal of material from the foot of the immature convex slope steepens it to such an extent that gravitative forces overcome shear strength of the soil causing rapid mass movement and exposure of fresh bedrock on the free face.

Rate of removal of material greater than the rate of supply is enhanced by resistant rock types (which limit the supply rate), degradation of streams in youthful valleys, and basal sapping at the foot of the slope by broadening of river meanders. The first of these conditions, namely the presence of a resistant rock type, is met in the Witwatersrand escarpment. Encroachment of a younger erosion cycle on an existing free face of an older erosion cycle will accelerate removal of debris at the base of the free face thereby enhancing its presence. This is evident in the Witpoortjie Falls area on the Witwatersrand (African) escarpment due to advance and cyclic rejuvination by the younger Post-African erosion cycle. The absence of a free face from the Kyalami land system is ascribed to the lack of relief owing to the relatively recent arrival of the Post-African erosion cycle and also to the absence of a suitable resistant cap rock.

Form : Slumping of the talus slope in areas where the free face is poorly developed on the Witwatersrand escarpment indicates an insufficient rate of removal of talus debris in these areas. Waterfalls in stream profiles along the escarpment are the result of the Post-African erosion cycle encroaching on the escarpment.

Structure is important in determining the form and development of the free face as evidenced by the common occurrence of resistant Orange Grove quartzites on the free face. The free face is better developed in shallow dipping strata and is confined to two resistant quartzite horizons. Where the upper quartzite horizon forms the crest, the lower horizon forms the free face some distance below, often giving rise to a crestal concavity between these two resistant horizons. When the lower horizon forms the crest, the free face is generally immediately adjacent to the crest.

Process : Partridge points out that those areas subject mainly to gravitative processes (free face, talus slope and sometimes the waxing slope as well) evolve independently of local base level and are therefore unaffected by the rules of grade. This is because transport is not by surface runoff of water, which will tend to establish a graded profile.

The main denudational agent modifying the free face is weathering which, in the case of the chemically inert Orange Grove quartzites is mainly mechanical and ascribed to root wedging and frost action on the joint planes of the quartzites. The joint spacing determines the size of the blocks broken off the free face and accumulated on the talus slope.

Due to impeded removal of the debris from the talus slope, the free face in some areas has become completely buried by talus debris which has extended beyond the lithological boundary between the Orange Grove quartzite and Archaean schists. As a result, convex, debris covered slopes have formed on which the original position of the free face is represented by quartzite outcrop protruding through the talus covering.

Development : From the above, it can be seen that the following factors have an important influence on development of the free face :

i) Due to minimum height requirement for development of the full, four element hillslope, the free face is often poorly developed or absent in areas of low relief. It is the first hillslope element to disappear, this being affected by advance of the talus debris up (and sometimes beyond) the free face thus increasing the waxing slope length. This results in convexo-concave slopes by the junction of the convex waxing slope with the concave pediment below.

ii) The resistance ofthe Orange Grove quartzites has been an important factor in the preservation of the free face along the Witwatersrand escarpment.

iii) Rejuvination by a younger erosion cycle may re-expose and further develope a free face buried by talus debris. This is caused by an increase in the rate of removal of the accumulated talus debris and has occurred in the vicinity of the Witpoortjie Falls along the Witwatersrand escarpment.

c) The talus slope and side slope

The talus slope occurs immediately below the free face and is a slope of accumulation and transportation rather than active denudation. The ideal talus slope is at the angle of repose of the accumulated material, has a rectilinear profile, and is the result of transport by gravitative processes alone.

The side slope is an important element in hillslopes not included in King's four element standard hillslope (Figure 4). It occurs adjacent to the waxing slope, and contrary to the talus slope is dominated by transportation of material removed from the suprajacent hillcrest. Depending on bedrock and local base level stability, it can be either concave or convex in profile.

A talus slope is ideally a repose slope, occurring under conditions of rapid supply from a receding free face. Side slopes are transportation slopes occurring where the free face is absent or undergoing slow weathering and a thin layer od detritus is present lying below the normal repose angle of the material. Only transportation slopes are subject to the rules of grade and under conditions of falling base level,(e.g. Kyalami land system) can be convex as opposed to the normal concave graded profiles.

The Kyalami land system side slopes exhibit very gentle, broadly convex profiles. Rate of curvature increases slightly with decreasing slope length but is everywhere less than that of the hillcrests. Most of the side slope contains a thin (less than 30 cms) veneer of sandy hillwash separated from underlying residual granite by a thin, vein quartz 'pebble marker' (Figure 10).

Over most of the side slope, granite occurs at shallow depths but at the base of the slope is overlain by clayey residual soils which differ from the residual granite soils on the crest in that they have not undergone prolonged leaching on an older surface, and consequently have a high clay content. The basal zone of residual granite is sometimes replaced by a broad whaleback outcrop of fresh granite which has a much higher rate of curvature than the side slope or crest.

Process : True repose slopes are generally poorly developed along the Witwatersrand escarpment. The talus material accumulates due to insufficient rate of removal and encroaches on the free face, thereby causing reduction of supply from the free face. This stagnating situation enables the action of weathering, creep, and to a certain extent surface wash processes, on the talus material thereby reducing the slope angle to below the repose angle of the material which would normally result from unhindered action of gravitative forces alone on the talus slope. Thus, only the upper part of the talus slope is a true repose slope. Downslope thickening of regolith material below the repose zone occurs as a result of impeded removal of material from the base of the slope (see Figure 7 profiles 1 to 3).

No accumulative features occur in the Kyalami side slopes due to the lack of a free face and the efficient removal of material from the base of the slope. Thus these are transportation slopes as is evident from the thin layer of hillwash material (Figure 10). This is shown even more clearly by the constant presence of the thin, pebble marker horizon below the transported material, indicating a dominance of transportation over erosion processes.

Further evidence for the activity of transportation processes on the talus and side slopes is the lack of pedogenic differentiation in the soils. Transportation is enhanced by tufted grasses and rapid runoff found over large areas of Southern Africa thus accounting for the immaturity of most South African soils. Comminution of regolith material usually occurs downslope as a result of transportation, particularly on the Witwatersrand escarpment where initial material supplied is in the form of large, jointed quartzite blocks broken from the free face. On the Kyalami side slopes however, material is supplied from denudation of residual granite soils from the weathered crest. These consist mainly of small quartz grains which suffer minimal comminution downslope.

Although creep is thought to play some part in the transportation of material on the Witwatersrand talus slopes, the main transportation agent is surface wash due to the presence of tuft grasses and the shallow depth of weathering, both of which inhibit the action of soil creep. Creep is likewise thought to be insignificant in the evolution of the Kyalami side slopes despite their convexity (commonly attributed to creep), this being rather attributed to other processes as discussed above.

Similarly, gravitative processes have played no part in the generation of the Kyalami side slopes and in the Witwatersrand escarpment, apart from the upper talus slopes have been relatively unimportant and have operated only in those areas where slumping on the talus slope has occurred. These slumps have always developed in Archaean schist bedrock and have invariably begun at the contact between these rocks and the Orange Grove quartzites. These slumps have sometimes resulted in short free face exposures at the head of the slump.

In short, surface wash processes, acting to local base level (the local drainage), are the main processes acting on the talus slopes of the Witwatersrand escarpment and the side slopes of the Kyalami land system. High rainfall intensity, tufted grasses and a relatively steep slope favour erosion on the talus slopes of the Witwatersrand escarpment. This mainly affects the easily erodible fine grained sandy matrix, while larger blocks are moved downslope through the erosive undermining of this fine grained matrix. Thus the concept of grade applies and is demonstrated throughout by flattening of the talus slope. On the Kyalami side slopes however, the gradient is insufficient for continuous erosion to take place and hillwash particles are only temporarily entrained, resulting in a slow discontinuous transport of the hillwash material downslope leaving the underlying pebble marker virtually undisturbed.

Development : Since gravitative processes are ungraded, steep slopes are maintained and parallel retreat of scarps is favoured where these processes operate. Where transportation by surface wash processes on the talus slope occurs however, these portions of the slope must be subject to the rules of grade. In the advanced, old age stage of an erosion cycle (the African cycle along the Witwatersrand escarpment), the transportation power of the streams which act as local base level decreases. Thus the load supplied to them from the hillslopes must consequently be reduced to maintain the equilibrium of the process. The talus slope therefore becomes more accumulative, the free face becomes partially or completely buried by talus thereby reducing rate of supply of material to the talus slope. The graded portion of the talus slope of the Witwatersrand escarpment will therefore undergo slope decline.

A completely different style of development is evident in the Kyalami land system, where streams belonging to the immature phase of the Post-African erosion cycle are still incising their beds, and decline in transporting power has not yet set in. Slopes are being lengthened by deepening of stream valleys leading to a gradual steepening in slopes due to the necessity for increasing gradients to accommodate the increasing transported sediment load. Concave profiles would supervene only when the limiting gradient for non-erosive flow is exceeded. This would only occur fully in the mature stage of the erosion cycle once the rate of local stream incision decreases sufficiently to allow stream activity to become mainly transportational. Thereafter, the concave portions of the slope would progressively decline in gradient as described for the Witwatersrand escarpment. A pediment would probably develop and extend itself at the expense of the upper slope elements, but due to the absence of a resistant cap rock in the Kyalami land system, the broad crestal convexity would probably be maintained throughout the course of the cycle.

d) The transition zone

A transition zone occurs along the Witwatersrand escarpment which joins the talus slope and pediment in a regular curve with an average rate of angular change greater than either of these two elements. Since it has been shown that the talus slope has been moulded mainly by running water, this change in slope cannot be attributed to a change in the agent of denudation (i.e. from gravitational to surface wash processes). Rather, this transition zone is due to a change in the type of surface wash from highly turbulent surge flow on the talus slope, to less turbulent sheet flow on the pediment. The decrease in thickness of regolith material shown in Figures (7) and (8), (profile 4) may be the result of increased denudation in this area of the slope resulting from the action of two types of surface wash in the transition zone.

However the transition zone in some cases does represent a change in the agent of denudation, namely from gravitative processes on the talus slope to surface wash processes on the pediment. This is the case in arid regions where surface wash processes are virtually non-existent on the talus slope and the transition zone is much sharper. (This transition zone is also called the piedmont zone by other workers, e.g. Young 1972).

e) The basal outcrop (whaleback)

This slope element occurs in the Kyalami land system and consists of a broad convex exposure of fresh granite characterized by sheet exfoliation. Partridge offers two explanations for its origin :

i) Undercutting of one or other banks of a stream by the lateral migration of the stream in its floodplain causing removal of the thin hillwash horizon and underlying residual granite soil and exposing a relatively fresh granite surface. Steepening of this surface towards the stream may result from further undercutting by the stream or greater depth of weathering of the granite on the side of the stream due to increased moisture content.

ii) If the gradient of the side slope increases to beyond the limit for non-erosive transport of material, active erosion would ensue. Unconsolidated materials (hillwash veneer and residual granite soil) would be preferentially eroded and the exposed fresh granite would represent the start of a free face which would be maintained if sufficient relief was generated by active downcutting of the stream bed.

f) Zone of talus on the upper pediment

In the upper pediment zone of the Witwatersrand escarpment, a thin, fine grained hillwash horizon overlies a thick talus horizon (Figures 7 and 8, profile 5). This is most probably the result of the resistance of the quartzite talus rubble to comminution so that rate of scarp retreat has exceeded rate of comminution.

Material not yet prepared for transportation across the pediment will accumulate on its upper sections until sufficiently reduced for transport to occur, or until it becomes buried under accumulating hillwash. Thus this zone represents talus residual remaining behind after retreat of the talus slope and buried beneath the advancing pediment soils.

g) The pediment

Pediments occur all along the Witwatersrand escarpment but not in the Kyalami land system. It is also mainly a transportation slope and therefore approximates a hydraulic profile and is graded to local base level. Thickness of regolith material is determined by rate of supply and removal of material. If supply exceeds removal, deposition occurs on the pediment and the bedrock becomes covered by a mantle of detritus. If supply and removal of material are balanced, a thin cover of transported material is present on the pediment.

Form : The length of the pediments on the Witwatersrand escarpment varies considerably due to the transverse, rather than parallel nature of the major drainage lines. Pediments approximate exponential curves (i.e. their curvature is not constant). Pediments of the Witwatersrand escarpment are all modified to various degrees by Post-African incision (this modification increasing with decreasing distance between crest and new incision).

The predominantly straight transverse sections of the pediments are broken by the main axial drainage lines, as well as by streams and gullies normal to the escarpment which have grown headwards under the influence of Post-African incision. Convex side slopes to these drainage lines are present, being youthful versions of convexity associated with hillslopes of the Kyalami land system. Four transverse profiles drawn at intervals of 1000 yards downslope from the upper pediment zone, between Little Falls and Witpoortjie Falls are illustrated in Figure (12). As can be seen from the depressions in profile (a), the lower pediment slopes have a higher drainage density than upper pediment slopes, this being due to the fairly recent arrival of the younger Post-African erosion cycle.

The pediment is ideally a cut-rock feature which, under conditions of impeded removal of material (as in the Witwatersrand escarpment), can be covered by a thick mantle of detritus. Hillwash is the characteristic regolith material on the pediment which is frequently underlain by a residual talus zone which decreases in thickness downslope forming a 'pebble marker' marking the junction between residual soil and transported material (Figures 7 and 8).

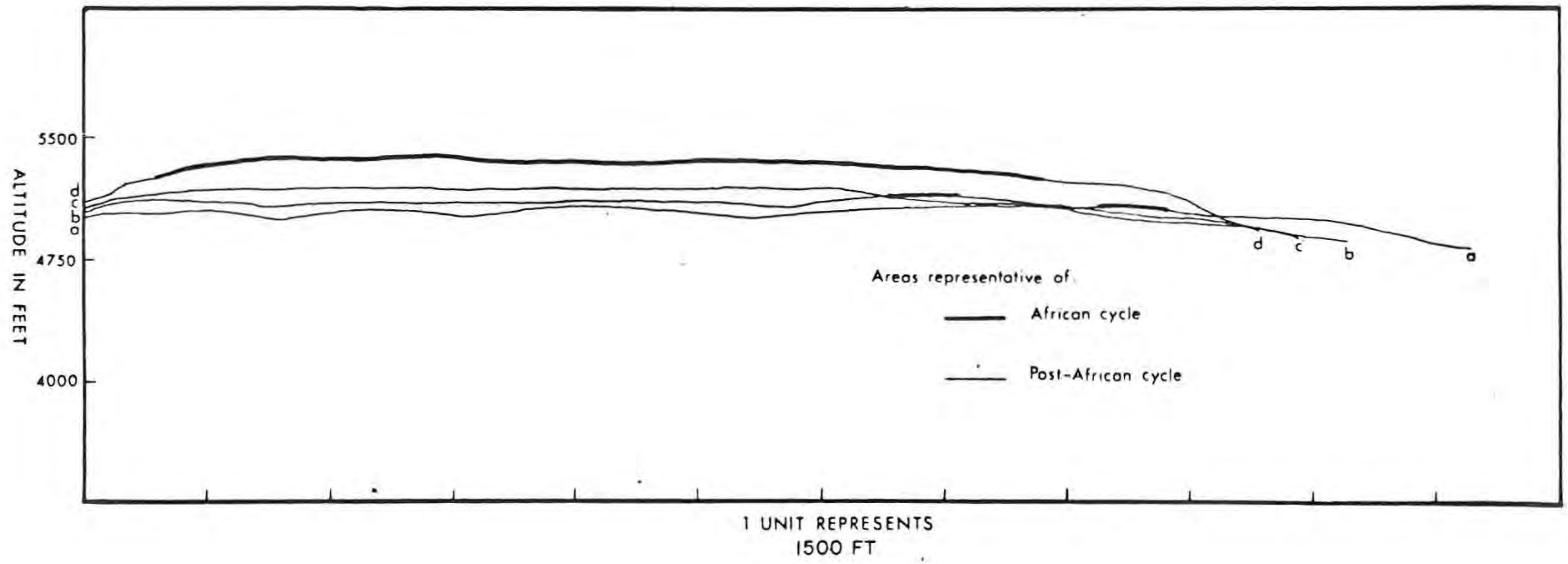


Figure (12). Daspoort land system. Transverse profiles of pediments at 1000 yd downslope intervals. From Partridge (1968).

On the Witwatersrand escarpment, the pebble marker has resulted from colluvial deposits of talus material during slope recession. In other areas, a pebble marker horizon may also have been formed as a basal alluvial lag deposit on cut-rock terraces, or as deflation residues under aeolian conditions,and is of widespread occurrence throughout most of Africa. Since it is a good aquifer, gleization often occurs in the vicinity of the pebble marker (profile 6, Figure 8). As with the talus slopes, pedogenesis has been inhibited on the pediment and soils are characteristically immature.

Comminution on the pediment is accomplished by weathering and corrasion,thus the rate of comminution on pediments along the Witwatersrand escarpment is slow owing to the resistant nature of the Orange Grove quartzite. Consequently the pediment has become littered with quartzite pebbles as the scarp recedes.

The pediment - talus slope junction is marked by the increased rate of curvature of the transition zone,reflecting a change in process from concentrated erosive flow and to a lesset extent gravitative transport on the talus slope, to low erosive sheet flow on the pediment. Transport on the pediment can only occur at a certain minimum stage of comminution, thus process replacement will be gradational, resulting in a smoothly concave transition zone.

Process : The pediment is formed by predominantly surface wash processes. Surface wash on the pediment is of a smoother, less turbulent nature than on the steeper talus slope. Flow approaches laminar flow, but due to surface irregularities becomes channelled into numerous small runnels and becomes concentrated and corrasive. Formation of larger rills and gullies is however prevented by vegetation on the pediment which breaks up the flow, thus preventing concentration and consequent gully formation. Partridge (1968) notes that in areas cleared of vegetation cover a "dendritic pattern of rills and gullies developed in contrast to the conspicuous absence of minor channels on the undisturbed (pediment) surface" (p. 300).

King and Fair (1944) observed that the formation of dongas in the Natal interior was almost always the result of destruction of natural vegetation on pediment slopes. Since the hillwash consists of fairly unconsolidated material which, due to its finer grain is more easily erodible than the coarse detritus of the talus slopes with its higher infiltration capacity, dongas are nearly always confined to the gentler pediment slopes. Donga formation is also enhanced by advance of a younger erosion cycle which, due to its greater potential energy may overcome the stabilizing effects of vegetation cover.

A certain amount of drainage on the pediment also occurs along the porous pebble marker (residual talus) horizon causing marked gleization along this zone.

The nature of the flow on the Witwatersrand pediments is suggested by Partridge to be as follows : Under conditions of high intensity rainfall, volume run-off increases downslope due to the cumulative effect of rain falling on a surface of low infiltration capacity. Thus turbulence and corrasion of flow increases due to the greater depth of flow. However, effective erosion is limited by an increasing sediment load. Run-off velocity is thereby prevented from increasing significantly downslope and a low erosive force is maintained. The main activity on the pediment is therefore transportational, not erosional. The concave pediment profile is thus a function of three main factors :

i) Comminution of regolith material permitting transportation over decreasing gradients;

ii) increasing transportation power of the sheet wash due to increasing run-off volume;

iii) low and fairly constant erosive capacity of sheet wash when subject to a large sediment load and subdivided, or surge flow.

Development : The transporting power of the streams to which detritus is supplied from the pediment is an important factor governing pediment profiles. The pediment profile is also a function of age and width of the pediment. Comminution of material on the pediment proceeds further as the pediment grows in width; this declining size of material on the lower pediment slopes is reflected by declining gradient of the pediment slope. Continuous regrading to decreasing transportational requirements on the lower pediment slopes occurs. Steeper slope angles are retained on the upper pediment to allow transportation of coarser material.

Slope decline occurs on most pediments moulded by sheet wash, and sometimes on the talus slope as well due to the operation of surface wash processes which are subject to the dynamic equilibrium rules of grade.

h) The zone of Post-African incision

The talus slope and pediment along the Witwatersrand escarpment described above have been developed under conditions of stable, or slowly falling base level. Those sections of the hillslope conforming to the rules of grade are dominated by surface wash processes which are capable of regrading the slope provided that the rate of fall in local base level does not exceed a certain critical value.

When this critical rate is exceeded, the axial streams incise their beds below the pediment, and a new erosion cycle is initiated. The upper limit of the new cycle of erosion becomes the base level for the original older slopes which undergo a reversal of the normal cycle, since distance to the new local base level is constantly decreasing owing to the advance of the younger cycle.

This is true of the Witwatersrand escarpment, where pediments of the old age stage of the African cycle are being encroached on by the Post-African erosion cycle. This results in two main modifications of the original pediment, namely the development of an ungraded convex slope adjacent to the drainage lines during the initial stages of rejuvination which alters to a graded concave slope once rejuvination has become fairly widespread. Partridge ascribes this early convexity to a dominance of soil creep processes resulting from slope steepening during initial stream degradation. However, I can see no reason why this convexity cannot have originated in a manner analogous to the convex Kyalami slopes.

Once streams have attained a graded profile, the slope angle is reduced and a new concave 'regraded pediment' forms which, in the area of the Witwatersrand escarpment is cut mainly in unconsolidated material of the African pediplain and graded to the new, local stream base level which is stabilized not far below the original pediplain. The boundary between the zone of Post-African incision and the original pediment is sharp and forms the new base level to the surface wash process acting on the original pediment. Thus the new pediment progressively declines in curvature as a result of its increasing width at the expense of the older pediment which is constantly regraded to profiles of increasing curvature due to decreasing distance between hillcrest and the new base level caused by advance of the younger erosion cycle.

Since development of the new Post-African pediment is accomplished at the expense of the older pediment material, the regraded pediments so formed commonly have only thin soils, and bedrock is exposed in many places. The upper limit of the Post-African incision can best be established by plotting the hillslope profiles on semi-log paper which invariably gives a sharp inflection point at the upper limit.

Partridge's hypothesis of local slope evolution

The distinction between gravitative and surface wash processes is significant in considering controls of hillslope processes. The concept of grade, or dynamic equilibrium is also an important factor in determining hillslope evolution. The potential energy of an erosion cycle is reduced once streams have become graded, and transporting power of streams decreases, causing adjustments throughout the entire drainage basin.

Thus, while gravitative processes result in the development of time independent forms, and are not subject to the rules of grade, surface wash processes strive to attain a graded hydraulic profile, and will ultimately result in reduction in overall declivity of the surfaces over which they operate. Thus the four main factors determining the extent to which either parallel retreat or slope decline will occur in a particular hillslope are :

i) the part played by gravitative processes,

ii) the part played by surface wash processes,

iii) the rates of supply and removal of debris,

iv) the stability of base level.

This is summed up by Partridge (1968 p. 314) as follows :

"*Gravitative processes, if not restricted in their operation, being time - independent, favour parallel retreat. Fluvial (surface wash) processes are subject to the rules of grade, and under conditions of stable base level promote slope decline. If the supply of debris exceeds removal, progressive accumulation obstructs the source, and fluvial (surface wash) processes may supervene, for example after burial of the free face. When removal outstrips* *supply, gravitative or fluvial (surface wash) processes may predominate depending on the characteristics of the bedrock and the nature of the run-off. A falling base level tends to maintain or increase the gradient of slopes related to it, but once downcutting has ceased, the foregoing factors supervene to produce slope decline".*

The reactions of the different hillslope elements of the Witwatersrand escarpment and the Kyalami land system can be predicted from the observations made above.

The waxing slope is governed by surface wash and to a lesser extent gravitative (creep) processes. Waxing slopes on the Witwatersrand escarpment maintain sharp convexities due to undercutting of it by the suprajacent receding free face below. Limits to the waxing slope in the Kyalami land system are determined by initiation of partly erosive flow and crests are therefore broader and gentler.

The presence of the free face is enhanced by uniform resistant lithologies and undergoes parallel retreat as a result of weathering and gravitative processes and may become buried by accumulated talus debris due to impeded removal of this material from the foot of the slope.

The angle of the talus slope is determined by the repose angle of the talus material where it is governed by gravitative processes alone. However, the talus slopes of the Witwatersrand escarpment are partly subject to transportation by surface wash processes and therefore undergo slope decline.

The side slopes of the Kyalami land system have similarly been moulded mainly by surface wash processes and are constantly increasing in length and gradient due to local stream incision. Active erosion occurs only once a certain minimum gradient has been exceeded, exposing whaleback outcrops at the base of slopes which may in time develop into a free face.

The pediment is moulded by sheet wash which requires a certain minimum declivity for transportation to occur. The pediment grows at the expense of the talus slope, thereby undergoing slope decline consequent on increasing width of the pediment.

Another important concept is that under unstable base level conditions, denudation involves formation of successive slope elements in the order : waxing slope - free face - talus slope - pediment. Elimination of the upper slope elements occurs after the attainment of a stable base level. The pediment ultimately displaces all other slope elements and forms a planar, gently rolling multi-concave pediplain characteristic of the mature old age phases of an erosion cycle. This process of progressive pedimentation was first suggested by Fair (1947). Progressive pedimentation can only fully occur after long periods of stillstand of the landsurface at a constant base level.

Parallel retreat can only occur as a result of headward incision of a new erosion cycle due to a fairly rapid fall in regional base level. Parallel retreat slows down considerably in advanced stage of an erosion cycle due to the loss in potential energy of the system,and consequent effect of rivers decreasing in transportation capacity as a result of attaining local base level. Under these conditions, material accumulates on talus slopes due to inhibited removal and encroaches on the free face, causing a change from gravitative to surface wash processes effectively causing cessation of parallel retreat,and initiating slope decline characteristic of slopes dominated by surface wash processes. Such degenerate landforms can be rejuvinated by advance of a younger, more active erosion cycle; slopes will be steepened and parallel retreat will be renewed.

Partridge's evidence does not fully agree with the model of hillslope evolution formulated by King (1953). It has been shown that hillslope convexities in the Kyalami land system are chiefly the result of surface wash processes and not soil creep as suggested by King (1953). This is more than likely often true for the rest of Southern Africa characterized by a semi-arid to sub-humid climate.

As shown by Partridge, the evolution of slopes dominated by surface wash processes (the pediment, side slope and often the talus slope as well) is intimately related to the rivers and streams which form the local base level to these processes. Thus hillslopes do not evolve independently of the local streams as stated by King (1953, p. 728) : "Hence , with stable base level, hillslope evolution is independent of the later stages of the river cycle".

Independent evolution of slope elements can only occur when controlled mainly by gravitave movements and "parallel retreat can only occur under a constant rate of stream degradation or headward retreat of polycyclic incision" (Partridge, 1968 p. 321).

Some important principles

The above discussion of Partidge's work has been treated in some detail since it involves important principles which are relevant to the discussion of erosion cycles in Southern Africa dealt with in Section (2). Partridge's work is regarded here as the standard treatise on hillslope evolution in Southern Africa,and I feel that it broadly applies to much of the rest of the country outside the Pretoria - Witwatersrand areas as well.

Some modification is required for changes in climate, vegetation, and structure as mentioned above,but these do not significantly alter the mode of operation of the hillslope forming processes described by Partridge. Perhaps the most important modification occurs in humid areas of continuous low intensity rainfall where soil creep,due to the influence of more complete vegetation such as carpet grasses,and higher moisture infiltration becomes dominant over surface wash processes. Thus convex slopes are more common in these areas as recognized by Fair (1947, 1948). Such conditions also occur within the mountain mist belts such as the Barkley East area.

Some important principles arising from the preceding discussion of hillslope evolution are mentioned below.

Relief

Sufficient available relief is an important prerequisite to the full development of the standard four element hillslope (crest - free face - talus slope - pediment),and the continued action of parallel retreat implied by the development of such a hillslope. Relief can be generated by incision of stream beds accompanying rejuvination by a younger erosion cycle, thus increasing the distance from the stream bed to the hillcrest. Relief can also be tectonically induced, for example by faulting,which may produce an immediate increase in relief,thus initiating vigorous erosion.

Structure and nick points

Apart from the local influence of structure, (e.g. in producing a dipslope on a resistant horizon) structure can also modify development of the landscape as a whole. The effect of structure on an advancing nickpoint at the head of a new erosion cycle has also been described by Partridge (1968). The advance of a new cycle of erosion is frequently marked by the presence of a nickpoint in longitudinal stream profiles below which, rates of profile curvature are steeper than the older channel above the nickpoint.

This nickpoint advances upstream by headward incision at a fairly constant rate in homogeneous rock types, but will be held up by resistant lithologies until the barrier is breached. In many instances however, a resistant rock barrier may split the advancing nickpoint so that part of the erosion cycle moves on upstream beyond the resistant barrier. This splitting process may be repeated again upstream across further resistant barriers. Thus, advance of a single erosion cycle may be broken up into a number of stucturally controlled nickpoints. These nickpoints are more evident in younger landscapes and tend to disappear as the landscape evolves.

If such split nickpoints remain stabilized for long enough periods, stabilization of local base level of the rivers immediately upstream of the nickpoints occurs and pediplanation may result in areas of 'temporary' local planation related to the different split nickpoints due to structural inhomogeneities. These can be thought of as 'perched pediplains' since they will be regraded to a new base level once the resistant barrier is broken through and the rest of the cycle advances upstream.

Further downstream, where denudation has been active for longer periods, the true residual pediplain of the new erosion cycle will have formed, since the cycle will here be at an advanced stage. Thus the final pediplain is often separated from the zone of active headward incision by a zone of 'perched pediplains' related solely to structurally controlled nickpoints.

Thus a single erosion cycle could conceivably be represented by a number of intermediate planation stages before the final pediplain is formed. Even in the absence of split nickpoints, the mature pediplain will usually be separated from the zone of active scarp retreat by an area of incomplete planation characterized by intermediate forms such as valley floor planation phases, in which planation is well advanced in the valleys but has not yet reduced the surrounding higher areas.

Differential scarp retreat

An analogy can be drawn between the advance of a nickpoint up the river beds, and the parallel retreat of an escarpment face. In the same way that nickpoints may be split about a resistant barrier it is proposed that retreating scarps may 'split' at a lithological boundary as a result of differential erosion of two, (or more) rock types which originally formed part of the same free face.

The flat topped Cave sandstone capped foothills of the Drakensberg (the Little Berg), are suggested as having formed in this way (Figure 13). Cave sandstones directly underlie Stormberg basalts in the Natal Drakensberg. I suggest that an initial free face existed east of the present Drakensberg which may have consisted of Cave sandstone at the base, overlain by Stormberg basalts.

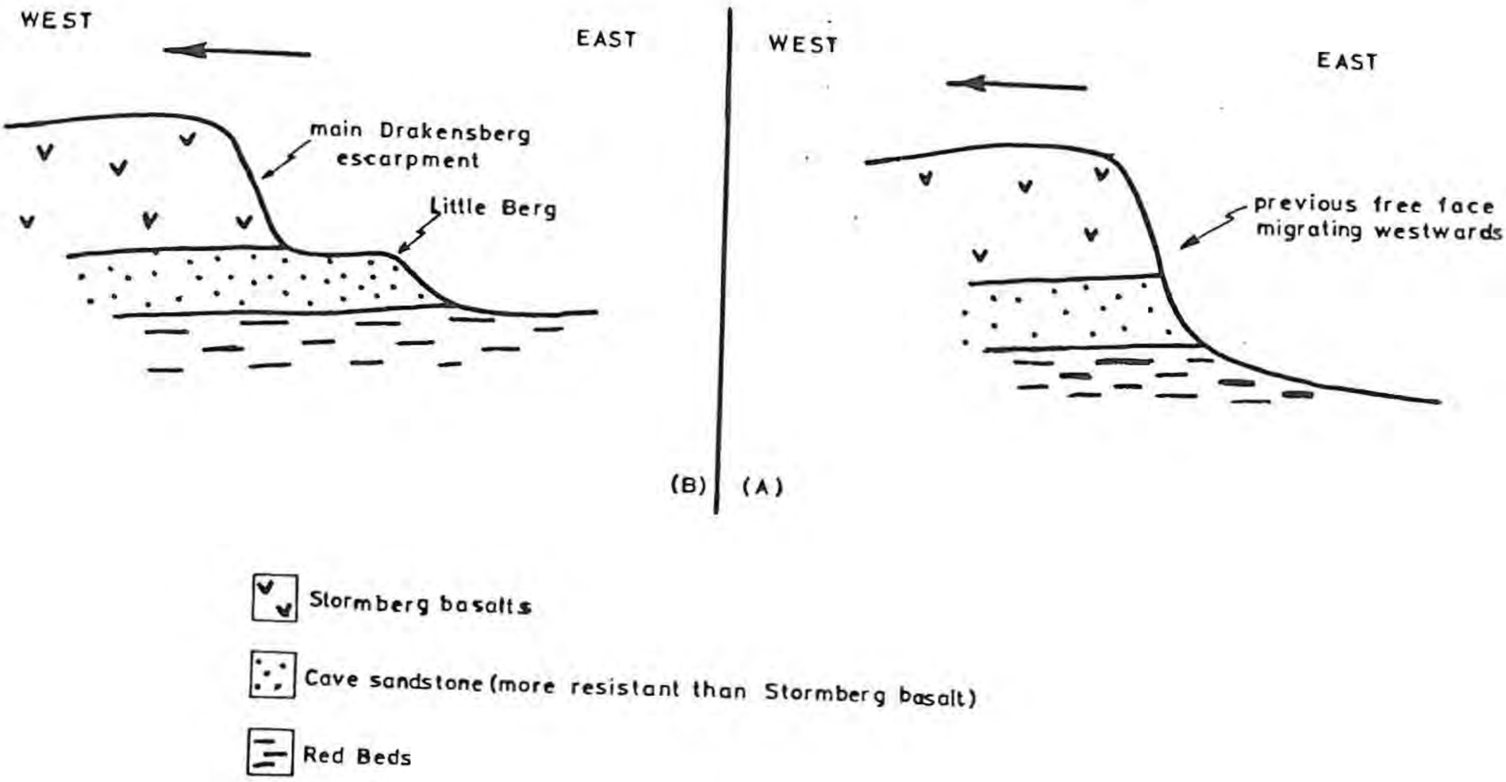


FIGURE (13). Differential scarp retreat – a possible origin for the Little Berg.

It is proposed that the basalt is broken down more rapidly by weathering than the underlying Cave sandstones because of its greater susceptibility to mechanical weathering, due to its well developed columnar jointing which, along with its basic igneous composition would enhance chemical weathering under the fairly high rainfall conditions present on the Drakensberg. The Cave sandstone on the other hand, because ot its high silica content and massive unjointed structure, is much more resistant to mechanical and chemical weathering. Thus, differential erosion of the original free face may have occurred resulting in more rapid retreat of that part of the free face made up of basalt, a process which would be facilitated by the sub-horizontal attitude of the rocks.

This raises some doubt on King's (1972, 1976) interpretation of those Cave sandstone capped spurs of the Little Drakensberg as being part of his African surface correlated with other flat topped residuals in the interior of Natal. This differential scarp retreat mechanism may offer a plausible explanation for the flat topped kopjes stranded at different heights throughout most of the Natal interior to which King (1963, 1972, 1976) presently attributes cyclic significance.

This process can only occur where the overlying rock type is less resistant to weathering than the underlying rock type, otherwise differential erosion of the weaker rock would only result in undercutting of the free face, a process which is presently occurring at the base of the Cave sandstone cliffs by preferential erosion of the less resistant Red Beds.

Residual remnants

The process of parallel scarp retreat across a land-surface may produce resistant residuals by-passed by retreat of the free face, containing on their summits remnant landforms of the older surface destroyed in surrounding areas by the active degradation caused by scarp retreat. These residuals may owe their survival to folded resistant rock types such as the quartzite ridges in the Cape fold belt (Figure 14), or to sub-horizontal strata capped by resistant rock types. The Cape fold belt mountains may also have been formed by differential scarp retreat which in this case would have stripped of any Karroo cover that may have overlain the quartzites.

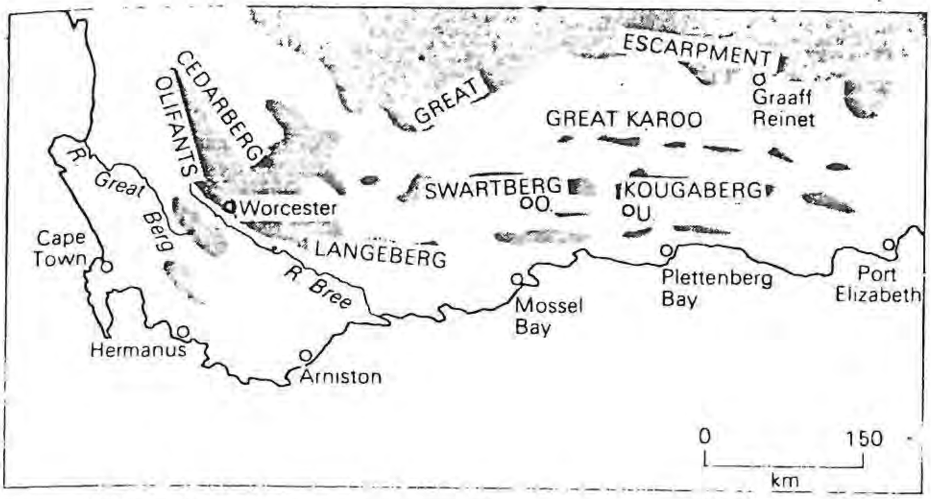


Figure (14). The Cape ranges. From Buckle (1978), p. 31.

There is an important difference between differential scarp retreat and generation of by-passed residuals. In differential scarp retreat, a new surface is produced on top of the more resistant rock type remaining behind. In by-passed residuals, remnant landforms of the older cycle existing on the older surface being broken down by scarp retreat,are cut off from the older surface by retreat of the free face (Figure 15).

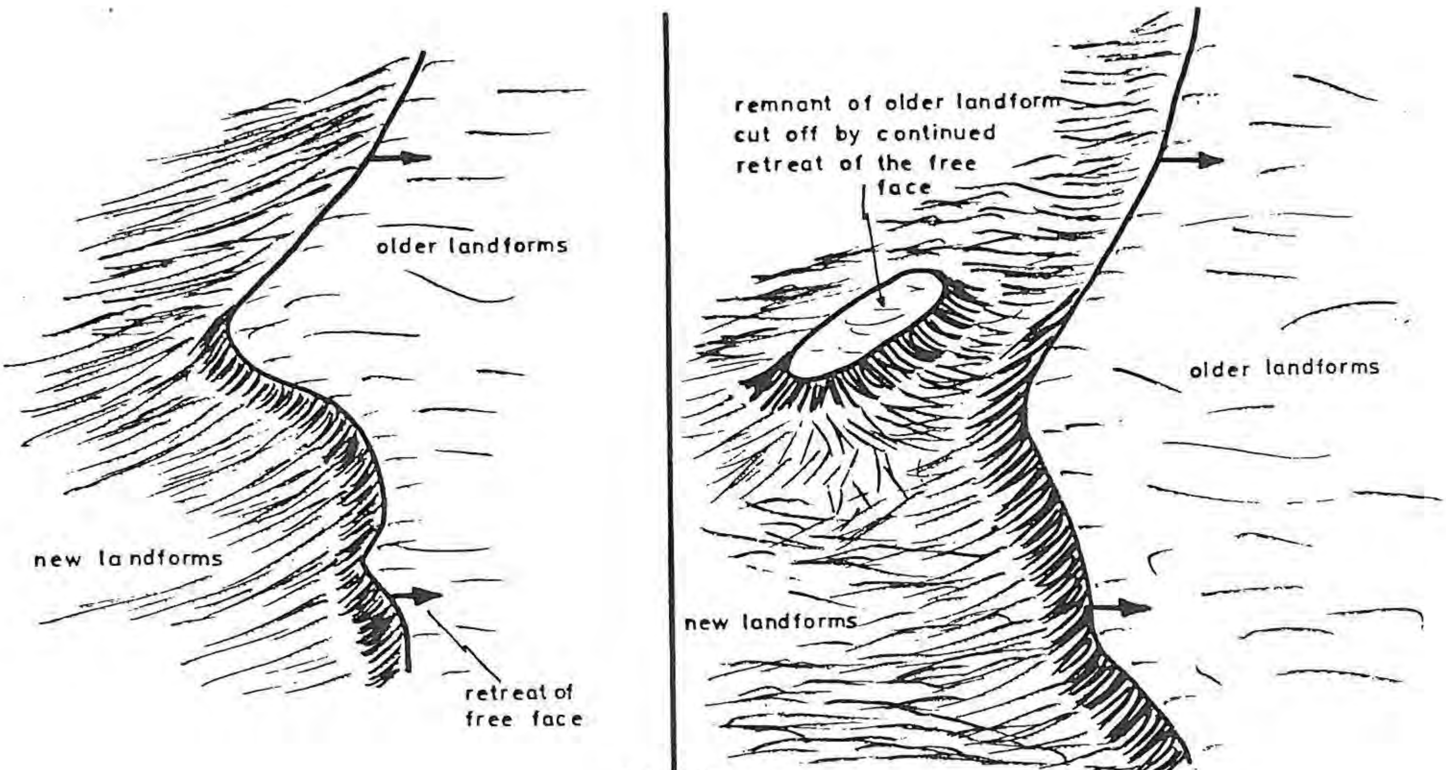


FIGURE (15). Generation of by-passed residuals by retreat of the free face.

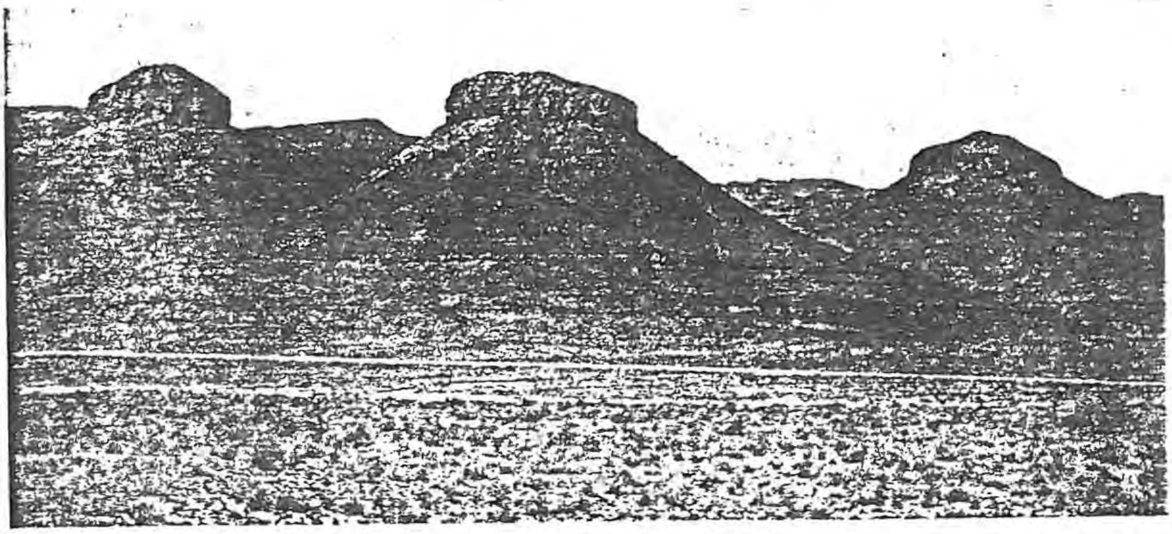


Figure (16). Three sisters kopjies NE of Beaufort West, capped by remnants of a dolerite sill. From Buckle (1978), p. 55.

Horizontal dolerite sills and other resistant lithologies in the Karoo Supergroup have often formed flat topped buttes or kopjes characteristic of most areas underlain by Karoo Supergroup rocks, a well known example being the Three Sisters kopjes in the southern Karroo (Figure 16).

Tilting

Rejuvination of landsurface may also have occurred as a result of drainage rejuvination on tilted landsurfaces. Tilting of a surface will rejuvinate all drainage on the surface with the result that rivers will simultaneously begin to incise their beds due to the steeper gradient produced. Thus rejuvination of the landsurface will start simultaneously at all the drainage lines and work back into the older landsurface. The ultimate effect on the landsurface will be the same as that described by Partridge (1968), except that the new cycle is initiated everywhere at the same time instead of advancing up the drainage lines behind a nickpoint marking the upper point of headward incision of the new cycle, as occurs with sudden drop in regional base level.

Drainage basins

Rivers and streams act as local base level to lower hillslope elements dominated by surface wash processes. Therefore landscapes of different drainage basins may not be at the same stage in a particular erosion cycle since this cycle may have advanced to varying degrees in different drainage basins.

2. EROSION CYCLES IN SOUTHERN AFRICA

As explained in Section (1), the uninterrupted advance of a younger erosion cycle on an older landscape ultimately results in the production of a mature pediplain at the expense of the older surface (Figure 5). Geomorphological work in Southern Africa has been directed at identifying and classifying landforms attributed to different erosion cycles. A study of the voluminous literature on this subject shows a confusing variety of ideas and correlations. An example is the difference of opinion which existed for years between Dixey and King.

King is today recognized by most workers (e.g. Partridge, 1968; Buckle, 1978) as the authority on Southern African geomorphology and his latest views are briefly reviewed below. However, it is now apparent from the work of De Swardt and Bennet (1974) that these views require widespread revision and far from being the final answer to Southern African geomorphology, may represent a starting point inthe evolution of a new hypothesis on Southern African geomorphology, begun by De Swardt and Bennet (1974), which is still a long way from completion.

Therefore the work of De Swardt and Bennet (1974) is reviewed in some detail below and some important considerations on a new interpretation of Southern African geomorphology are discussed. These do not purport to be the final solution. New information has become available which cannot be reconciled with the presently accepted framework of Southern African geomorphology. These and other factors demand explanation and it is hoped that the present review will progress some way to providing this explanation.

The views of L.C. King

King's latest views on the geomorphology of Southern Africa are described by him in King (1963, 1972) and in King and King (1959) as well as numerous other publications and are briefly presented below. They are summarized in Figure (17) (from Partridge, 1975) and the aereal extent of King's different erosion surfaces are shown on Map (1) (drawn by Partridge, 1968).

Denudational	Depositional		Date of Inception
	Continental	Marine	
"Gondwana" planation			Late Triassic - Early Jurassic (± 190 m.y.B.P.)
Fragmentation of Gondwanaland			
"Post-Gondwana" dissection		Early Cretaceous series of south-east coast.	Early Cretaceous (± 135 m.y.B.P.)
Mid-Cretaceous disturbances			
"African" planation	Late Cretaceous dinosaur bed of Bushmanland, early Cainozoic Botletle beds, Kalahari marls.	Littoral Senonian strata of east coast with succeeding Eocene in Mocambique; Late Cretaceous and Eocene strata of Angola. Upper Cretaceous and Palaeogene strata of Continental Shelf.	Mid-Cretaceous (± 100 m.y.B.P.)
Widespread eperiogenic uplift of a few hundred metres			
"Post-African I" valley floor planation	"Plateau Sands" of the Kalahari-Congo region.	Burdigalian marine series.	Miocene (± 20 m.y.B.P.)
Slight Uplift			
"Post-African II" valley floor planation	Pipe sandstone of mid-Zambezi valley.	Sands unconformably over-lying Burdigalian and transected by coastal plain of East Africa.	Mio-Pliocene (± 5 m.y.B.P.)
Strong Cymatogeny			
"Quaternary" gorge cutting in coastal hinterlands; locally multi-phase.	Kalahari sands, Port Durnford Beds and Red "Berea" sands.	Recent coastal sands of the Zululand plain and other littoral areas.	Plio-Pleistocene (± 2 m.y.B.P.)

Figure (17). Cyclic episodes of Southern African geomorphology - a summary of King's views. From Partridge (1975), p. 38.

Pre-Karroo surface

Remnants of this Palaeozoic surface exist throughout Africa, having been exumed from beneath Karroo Supergroup rocks by later erosion. It is therefore most often found in areas bordering outcrop of Karroo rocks and in other areas, although completely removed by later erosion may have been an important factor in shaping the landscape.

The Gondwana surface

"From the close of Karroo times ..... erosion reigned supreme over Central and Southern Africa until before the end of the Jurassic period the terrain was reduced, except for a few residual hilly tracts to a plain of vast extent" (King 1963, p. 205).

Since this planation occurred before break-up of Gondwanaland, King feels that this cyclic land surface covered all of Gondwanaland. King claims to have identified vestiges of this ancient erosion surface occurring as accordant plateau summit bevels on many of the present highlands of Southern Africa, in particular immediately inland of the great escarpment (Map 1) its present elevation being attributed to later epeirogenic uplift of the continent.

Post-Gondwana surface

Between mid-Jurassic and early Cretaceous times, rifting of Gondwanaland created new base levels (the early Cretaceous sea) to which the Post-Gondwana erosion cycle was graded. Thus the Gondwana erosion surface was dissected, the broad U-shaped valleys occurring below the Gondwana surface (e.g. on the Drakensberg highlands - Map 1) being formed during this Post-Gondwana dissection. Early Cretaceous sediments, produced as a result of this erosion were deposited on downwarped extensions of the Gondwana surface in the early Cretaceous depositories along the new coastline, and in inland basins such as the Kalahari. Mid Cretaceous tectonic disturbances particularly in southern Zululand terminated the early Cretaceous cycle.

African surface

"There followed a phase of crustal quiescence lasting from the late Cretaceous until the mid Tertiary during which time a fresh smooth planation spread vastly over Africa" (King 1963, p. 207). Since this cycle was younger, many more remnants of it have been preserved than the earlier Gondwana surface. Planation is regarded to have been even more advanced than in the earlier Gondwana cycle as a result of approximately 80 million years of planation. King regards this surface as the "true ancestral planation from which the modern topography of Southern Africa has been carved" and that "by the mid Tertiary, vast plains standing at relatively low levels above the sea, and with only a few residual highlands of the Gondwana and Post-Gondwana cycles, represented the physiography of Africa" (King 1963, p. 207).

Deposition during this time formed the Kalahari marls in the Kalahari Basin,and the upper Cretaceous sediments along the coast. King (1963) states that marine sediments of lower Cainozoic age are rare because planation in the African cycle had advanced to such an extent by the end of the Cretaceous that very little detritus was supplied, thus explaining an apparent hiatus in sedimentation from upper Cretaceous to Miocene times.

The present elevation of the African surface is ascribed by King to differential uplift of this surface of between 2000 and 10000 feet since mid Tertiary times.

Post-African cycles

According to King, updoming of the sub-continent terminated the African cycle and initiated the first of two late Cainozoic cycles (Post-African I) which is today the most widely represented cycle in Southern Africa, forming a gently rolling landscape.

The second (Post African II) cycle is not as extensively developed but is characterized by well developed pediplains in places. The two cycles merge into one in certain areas where separated by only a small vertical interval. Deposition of the Plateau Sands in the Kalahari Basin above the calcrete capped Kalahari marls occurred during the Post-African II cycle, as well as the Pipe Sandstones of the Zambezi valley. Seaward tilting of the coastal landscapes during late Tertiary times resulted in the deposition of the early Miocene and Pliocene sediments overlying late Cretaceous and Eocene beds deposited during the African cycle.

Quaternary uplift

Major uplift of Southern Africa occurred in late Tertiary - Quaternary times, which elevated the country to its present altitude. According to King this involved upwarping of the interior plateau with sagging of the interior Kalahari Basin and strong seaward tilting of the coastal margins (Figure 18). Marginal flexing occurred intermittently about a monoclinal axis with the point of no relative movement situated near the coast.

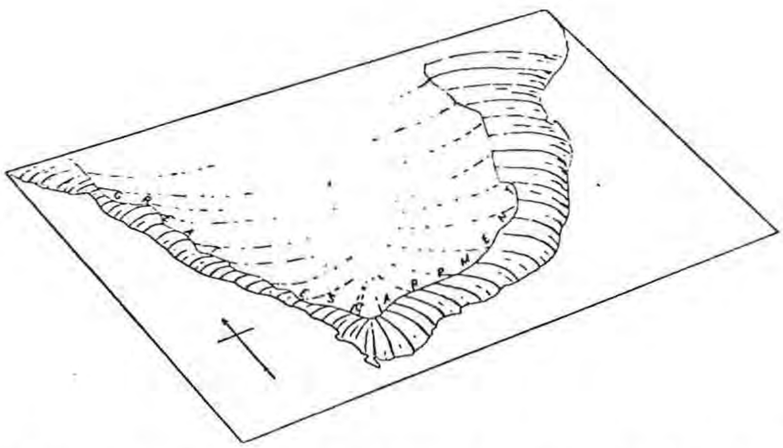


Figure (18). Idealized block diagram to illustrate major deformation of Southern Africa in Tertiary times as envisaged by King. From King (1963), p. 167.

Vigorous rejuvination of the coastal rivers occurred resulting in deep gorges being cut into the older landforms and the development of a new Quaternary erosion surface along the coastal margins such as the Lowveld of the Eastern Transvaal and Rhodesia. Large waterfalls along the major rivers (e.g. Ruacana, Augrabies, and Victoria Falls) mark the upper extent of this cycle. Incised river beds and terrace formation in interior rivers resulted from downwarping of the central area (Kalahari Basin). The red Kalahari sands of the Kalahari were formed at this time.

Geomorphology of Natal

Much of King's work was done in Natal and his conclusions are mentioned here by way of introduction to the discussion which follows on the work of De Swardt and Bennet (1974) on the geomorphology of Natal. The earlier views held by King are briefly reviewed in De Swardt and Bennet (1974) and only King's later conclusions (King 1963, 1972, 1976; King and King 1959) are mentioned below. Figure (19) from King (1976) shows King's interpretation of the geomorphology of the area south of Giants' Castle in the Natal Drakensberg.

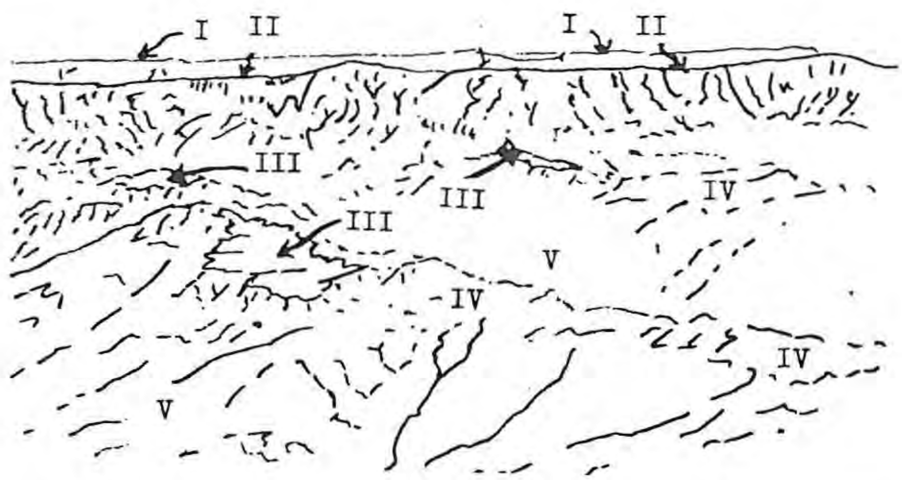


Figure (19). The face and foreland of the Drakensberg south of Giants' Castle (from King, 1976).

I The skyline above the snowy scarp represents the Gondwana planation, of Jurassic age.

II The lower landscape above the black face of the Drakensberg is the early to mid-Cretaceous post-Gondwana planation.

III Upon the long foothill spurs reaching out from the base of the Drakensberg face, appear planed remnants of the early-Tertiary African planation.

IV Upon the distal ends of the spurs accordant skyline at lower level record the former presence there of the rolling post-African landscape (Miocene).

V The valley floors and sides are extensions from the Pliocene basin plain of Himeville-Underberg.

King (1972) has summarized his latest views on the geomorphology of Natal as follows (in De Swardt and Bennet, 1974) :

Accordance of summit levels on the highest ridges of the Lesotho highlands above the Drakensberg escarpment indicate the presence of the late Jurassic Gondwana surface remnants, which are surmounted in places by small hills representing Jurassic watersheds. Incision of the Gondwana surface following break up of Gondwanaland produced broad valleys which make up the Post-Gondwana surface of early Cretaceous age. Monoclinal warping of the Gondwana surface during break-up of Gondwanaland preserved it below the lower Cretaceous sediments evident in the Umfolozi River on the northern Natal coast.

Subsequent deformation was related to successive rejuvinations through time of the Natal monocline, the first of which occurred in mid-Cretaceous times initiating the African cycle of erosion and its accompanying widespread planation. Upper Cretaceous sediments accumulated offshore accompanied by seaward tilting of the sea bed. An hiatus in deposition occurred from upper Cretaceous to Miocene times owing to a lack of supply of detritus due to extreme planation of the African surface. The foothills of the Drakensberg (Little Berg) form part of the African surface, which arched up onto the Highveld plains of the Orange Free State and Transvaal.

The rolling Post-African I landscape formed by dissection of the African surface resulting from epeirogenic uplift of a few hundred metres during Miocene times. Coastward tilting about the axis of the Natal monocline during this uplift led to deposition of fossiliferous, shallow water marine sediments of early Miocene age. At the end of the Miocene, uplift of about 800 metres occurred, resulting in increased erosion of the Post-African II cycle causing terracing, scarp retreat and pedimentation of the inland basins. This was accompanied by a marine transgression which cut across the Miocene sediments and formed the Natal coastal plain on which Pliocene marine sediments were deposited.

Quaternary uplift and strong seaward tilting raised the African surface to 1900 metres along the northern Natal Drakensberg and was responsible for the vigorous incision of coastal rivers in Natal and development of the Pliocene coastal erosion surface, which extends up the major rivers forming the Pliocene valley plains (e.g. Himeville-Underberg Pliocene basins plain in Figure 19). These Pliocene basin plains extended up the Umzimkulu, Umkomaas and Tugela rivers almost to the Drakensberg accounting for the low lying basin plains in the headwaters of those rivers (see Map 1). This Quaternary uplift also resulted in a fall in sea level to beyond the present coastline.

Finally, additional seaward tilting of the monocline with a westward shift of the axis caused a return of the sea and drowning of the coastal gorges.

The Pietermaritzburg step, a prominent scarp behind Pietermaritzburg is regarded by King and King (1959) as being non-cyclic in origin and is the result of 'treppen' formation during uplift at the end of the Miocene, the same uplift which initiated the Post-African II cycle. 'Treppen' are large slip scarps formed as a result of arching a surface beyond a critical height. Once formed. the scarp was preserved by parallel retreat.

Thus King's latest views generally agree with those of Dixey (1942) who concluded that a Cretaceous erosion surface exists on top of the low Drakensberg (the highveld of the Orange Free State and Transvaal), which correlates with a Natal Midlands surface and separates a Jurassic erosion surface in the Lesotho highlands from a lower Miocene surface. Furthermore Dixey also recognized a younger ('end Tertiary') surface occurring below the Pietermaritzburg step and along the Tugela River in the Ladysmith basin which correlates with King's Pliocene valley plains.

The work of De Swardt and Bennet (1974)

Regional aspects

Recent offshore work by Soekor has shown that late Jurassic sediments were deposited in downwarped troughs and grabens off the southeastern Cape coastal regions (e.g. Algoa and Gamtoos Basins). They ascribed the formation of these basins to the results of rifting during break-up of Gondwanaland. They suggest that if the break-up of Gondwanaland took place as a result of rifting, an analogy can be drawn with the break-up of Gondwanaland and the more recent East African rift systems in which the effects of rifting on the landsurface can still be seen (Figure 20).

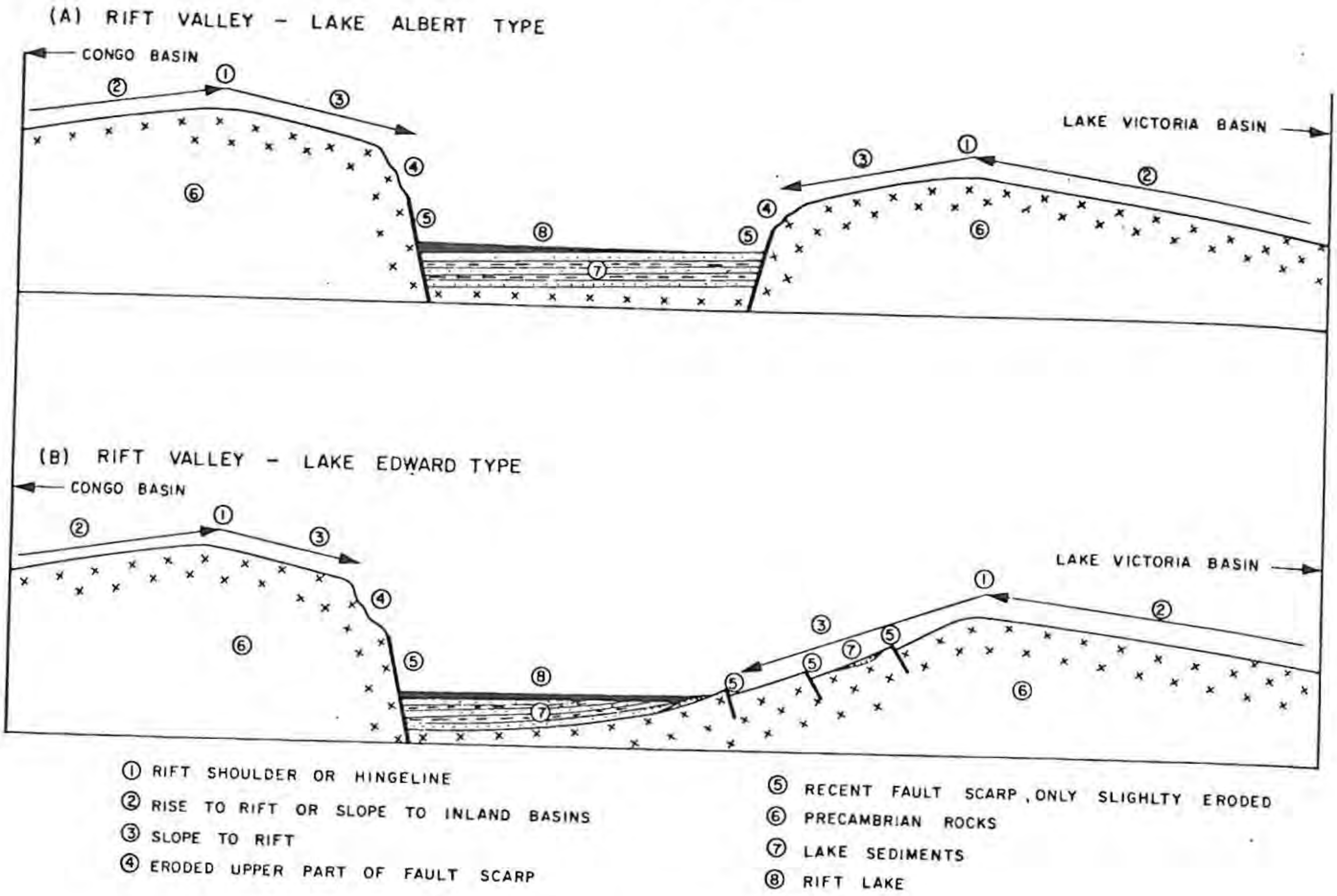


Figure (20). Recent East African rift systems. From De Swardt and Bennet (1974), p. 312.

Crustal upwarping results in downwarping of the graben floor ('keystone collapse') hense the upwarped shoulders of the rift remain some distance above the graben floor. This results in a gentle slope of the landsurface away from the rift shoulders and a much steeper slope towards the graben (Figure 20).

Lake Victoria occupies a large depression between the upwarped shoulders of the Western and Gregory rift systems (Figure 21), and De Swardt and Bennet suggest that the large interior basins of Southern Africa (e.g. the Kalahari Basin) shown in Figure (22) originated in a similar way.

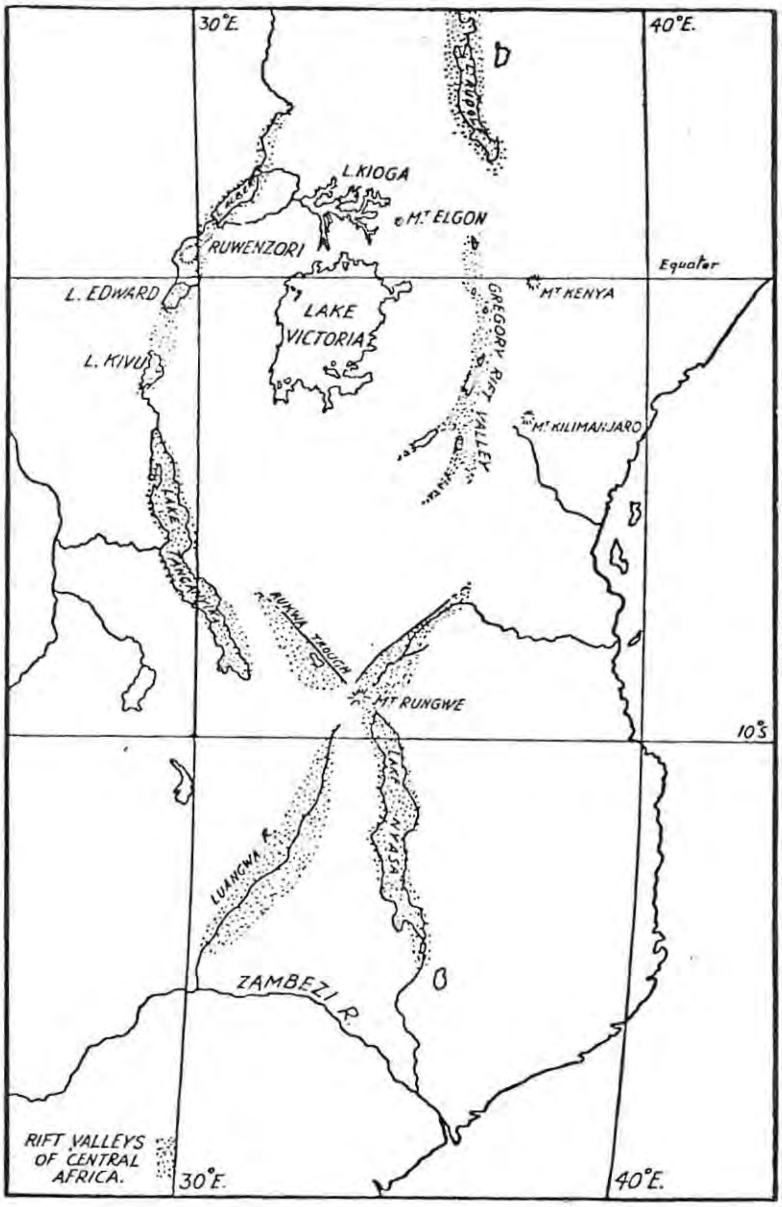


Figure (21). The rift valleys of Central Africa. From King (1963), p. 177.

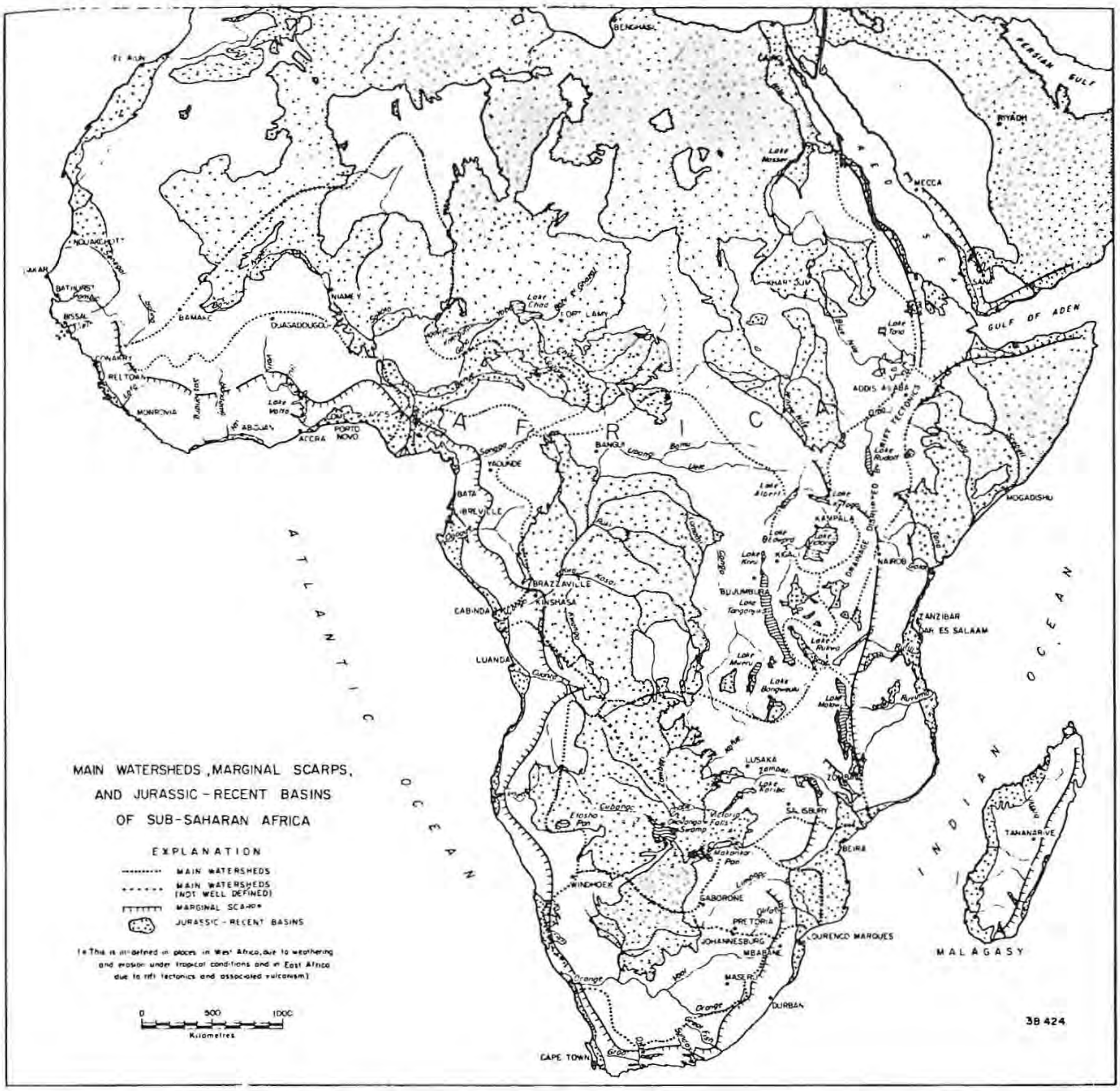


Figure (22). Main watersheds, marginal scarps and Jurassic - Recent Basins of sub-Saharan Africa. From De Swardt and Bennet (1974), p. 313.

Thus, immediately after the graben faulting associated with the break-up of Gondwanaland, Africa was surrounded by an elevated rift shoulder from which the landsurface sloped gently towards the centre (i.e. interior basins) and steeply towards the graben sides. In section (1) it was noted that a high relief is conducive to the initiation and continued action of parallel scarp retreat, thus a significant free face would have formed very quickly and under the influence of the vigorous erosion cycle would have begun migrating inland by parallel scarp retreat. De Swardt and Bennet suggest that by continued parallel retreat this scarp has migrated to its present position along the great escarpment.

The result of this vigorous erosion of the coastal belt, and accumulation of eroded material offshore was the formation of a coastal arch due to isostatic uplift which migrated inland some distance behind the retreating escarpment, shedding vast amounts of sediment. The coastal arch in Natal appears to have been stabilized since early Cretaceous times.

Offshore sedimentological work indicates a number of alternating transgressions and regressions since the late Jurassic, the cycle suggested by De Swardt and Bennet being : Erosion on land and deposition at sea causing slow subsidence of the sea floor, transgression accompanied by slow sedimentation. Uplift of the land due to unloading was probably too slow for isostatic compensation to be achieved, thus faulting occurred with resultant rapid uplift, seaward tilting, and regression due to delta progradation, accompanied by exposure and erosion of sediments deposited during the previous transgression.

An important result of the landward tilting of the upwarped rift shoulders was the establishment of a large inland drainage system developed with the inland basins as base level, the headwaters of which were situated on the landward side of the gently sloping rift shoulders. The major rivers of Africa, reaching into the interior pass through relatively narrow gaps in the great escarpment (Figure 22). De Swardt and Bennet, on evidence presented by various workers on the sediments near the mouths of some of these rivers suggest that they only became major rivers in about early Eocene times as a result of capture of the vast inland drainage systems by headward erosion of coastal rivers through the great escarpment. This would have resulted in the removal of large quantities of post-Jurassic terrestrial sediments (Kalahari Formation) from the interior basins.

Past workers commonly regard the erosion surfaces of Southern Africa as being due to intermittent epeirogenic uplift of the continent followed by planation which often reduced the African continent to vast plains standing at low altitudes above sea level (e.g. King 1963). The present elevation of the highlands of Southern Africa is ascribed to major updoming of the central plateau area with accompanying downwarping of the continental margins during Plio-Pleistocene times (e.g. King 1963, see Figure 18).

This is difficult to reconcile with eustatic equilibrium requirements and De Swardt and Bennet make an alternative suggestion, namely that Southern Africa, since Gondwana times always stood relatively high and that differential uplift of parts of the continent was accompanied by downwarping or downfaulting elsewhere. This is to be expected since Southern Africa originally formed the centre, and presumably the highest portion of Gondwanaland.

King (1972, 1976) states that Natal has been subjected to differential uplift with the zone of relatively little movement situated near to the present coast, while uplift of the Drakensberg area has been in the region of 2500 metres. Perhaps the strongest evidence against King's model of uplift is the map showing contours of the base of the Cape and Karroo Supergroups in Natal relative to sea level (Figure 23). De Swardt and Bennet point out that drilling by Soekor in the northern Orange Free State indicates that depth to basement of the Karroo Supergroup in the Drakensberg area, on the same lattitude as Durban should be at least 900 metres below sea level, not at sea level as indicated on Figure (23). Thus, if King's views are correct and conditions prior to break-up are restored, the base of the Karroo must go down to about 3500 metres below sea level in the central Drakensberg area, whilst on the Natal arch, where it is presently at about 1200 metres above sea level it was probably only a thousand metres or so lower. This suggests that in the late Jurassic, the base of the Karroo in the region of the Natal trough stood 4000 metres higher than its flanks on the present Lesotho border which is highly unlikely.

Furthermore, if the point of relatively little movement existed close to the present coast as suggested by King (1972; 1976) virtually the whole of the Karroo and Cape successions would have to have been planed off in some areas prior to the break-up of Gondwanaland, since Precambrian basement is exposed along the coast (De Swardt and Bennet, 1976).

As suggested by De Swardt and Bennet, the present configuration of the base of the Karroo and Cape systems (Figure 23) is better explained by large amounts of uplift along the Natal arch and relatively little movement in the Drakensberg area (and therefore in the interior). They conclude (p. 315) "Africa always stood relatively high and has been dissected by two basically different drainage systems with different base levels and under disparate climatic conditions for most of the time since the initial rifting of Gondwanaland".

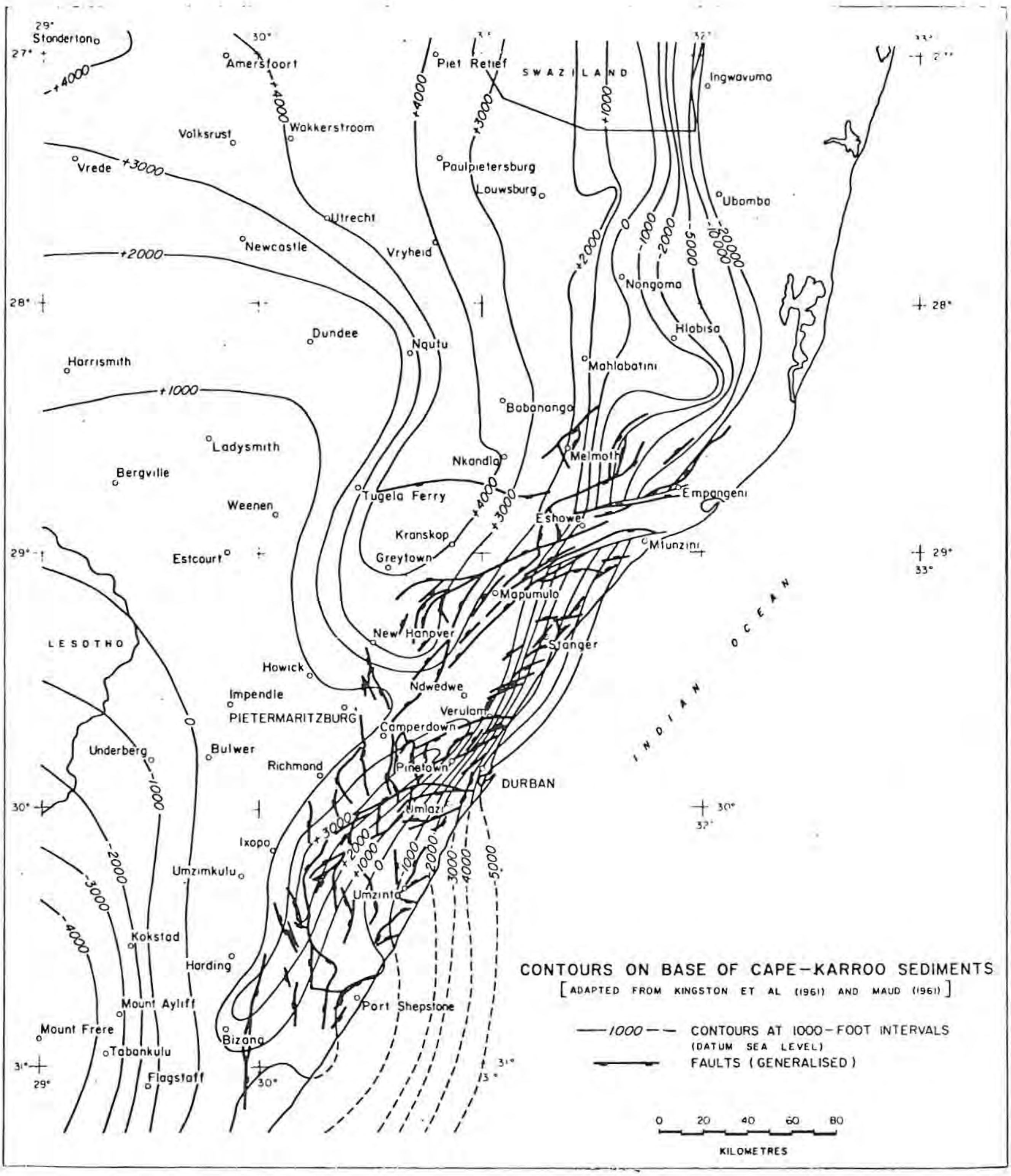


Figure (23). Contours on base of Cape Karroo sediments. From De Swardt and Bennet (1974), p. 314.

The position changed considerably with capture of the interior drainage by the coastal rivers during Eocene, or possibly earlier times and De Swardt and Bennet attribute the major nickpoints along these rivers (e.g. Augrabies, Victoria Falls) as being formed in this way.

Erosion surfaces of Natal

Erosion surfaces of Natal are shown by De Swardt and Bennet on Map (2) and are described by them with reference to four physiographic features, namely :

i) The Drakensberg,

ii) The Pietermaritzburg step and a similar step running from northwest of Greytown towards Giants Castle (Map 2). These are giant slip scarps formed during rapid uplift over the Natal arch and since migrated inland,

iii) The Natal hingeline coinciding with the crest of the Natal arch which runs parallel to the coast just east of Cato Ridge.

iv) The straight coastline of Natal.

The coastal erosion surface: This is a belt of deeply dissected country which extends up to 80 km upstream from the coast along the rivers. Presence of nickpoints indicate a possible polycyclic nature and where it has been cut back to the Pietermaritzburg step it merges with an earlier polycyclic surface. De Swardt and Bennet report a decrease in depth of incision towards the coast.

Richmond-Dalton surface: This surface is polycyclic (i.e. it has two phases) east of the Pietermaritzburg step and merges westwards into a landscape which is still undergoing erosion between the Pietermaritzburg step and the Drakensberg (Map 2). The upper phase of this surface is a smooth, gently rolling landscape containing some low mesas on resistant rock types. The lower phase has a much denser drainage pattern and is more uneven.

East of the Natal hingeline this surface slopes gently towards the coast, has a fairly dense drainage pattern, especially over basement rocks and is surmounted by resistant mesas capped by resistant Table Mountain sandstone. West of the hingeline, landward flattening of the regional slope occurs, best seen around Dalton (Map 2) where the landsurface is flat with shallow valleys showing no sign of incision. North of Dalton the surface loses height westwards and drainage becomes progressively more incised downstream.

These relationships indicate the former presence of a planed surface surmounted by low residual mesas between the Pietermaritzburg step and the coast which was strongly tilted east of the Natal hingeline leading to active incision of the flat surface producing the uneven, dissected lower phase of the Richmond Dalton surface.

Around Melmoth in northeastern Natal the effect of tilting is much less and consequently there is very little distinction between the east and west parts of the Richmond Dalton surface.

Country west of the Pietermaritzburg step: The country west of the Pietermaritzburg step consists of hilly areas and wide valley plains which "represent parts of an uneven landscape that have been stranded at various times on resistant lithologies as the country was lowered" (De Swardt and Bennet, 1974).

This landscape is attributed to the same cycle of erosion that has produced the Richmond Dalton surface and which is still active in the area, planation being only imperfectly developed in the valley plains.

De Swardt and Bennet claim that there is no accordance of summit levels of cyclic significance in the Natal Midlands, which can be correlated with accordant summit levels of the interfluves of the Richmond Dalton surface east of the Pietermaritzburg step, as stated by King (1972, 1976). Summit heights that may be locally accordant are due mainly to the sub-horizontal attitude of the Karroo rocks in the area and the presence of resistant lithologies (chiefly dolerites) within these. Inclined dolerite sheets that produce smooth topped hills surrounded by prominent scarps, which merge elsewhere into the valley plains, are common.

This is shown by the mergence of the Richmond-Dalton surface with the smooth, upper plains of the upper reaches of the white Umfolozi River, an area removed from the influence of the Pietermaritzburg step. Mergence of the Richmond Dalton surface with the valley plains of the Natal midlands may also occur up the valleys of the Umzimkulu and Umkomaas Rivers (Map 2). The upper plains of these two rivers coalesce in the Himeville area and extend to the upper valley plains of the Umzimvubu River to the southwest as well. These valley plains are attributed by King to the Pliocene erosion cycle (Figure 19). Similar mergence of the Richmond Dalton surface with the valley plains of the Tugela River also occurs.

The above observations are in accordance with some of the important principles expressed in Section (1), namely that a single erosion cycle may be represented in a landscape by mature landforms (Richmond Dalton surface), and immature landforms (hill and valley topography of the Natal Midlands). The state of maturity depends on the distance from the zone of active scarp retreat (in this case, the Drakensberg).

Furthermore, the important role that structure plays in the evolution of a landscape is clearly demonstrated by the fact that even on the well planed Richmond Dalton surface, resistant mesas not yet fully reduced by pediplanation have survived. The postulated formation of the Little Berg due to differential scarp retreat has been mentioned (Figure 13).

The varying extent to which the same erosion cycle may evolve in different drainage basins is exemplified by the upper valley plains of the Tugela River in the north and the Umzimvubu River in the south which form wide, fan shaped embayments behind an area dominated by rivers flowing directly to the coast. This is ascribed to more vigorous erosion in these two drainage basins. This has resulted from capture of headwater streams of the rivers which now flow directly to the coast. This resulted from the fact that the Tugela and Umzimvubu Rivers had easier access to the interior since they are situated north and south of the main uplift which occurred along the Natal arch. In addition the Tugela was assisted in this by its location along a laterally persistent fault. The Umzimvubu River since its lower course is situated in Karroo strata less resistant than the hard quartzites predominant along the Natal hingeline, was able to erode more easily. Therefore planation is more advanced in the upper valley plains of these two rivers than it is between them.

Structural features

Past workers have assigned either a faulted, or monoclinal origin to the Natal coastal belt (c.f. Maud 1961). De Swardt and Bennet suggest an origin which combines these two theories. Several major features are discussed by them, namely (Figure 23 and Map 4) :

Lebombo monocline : The Lebombo monocline extends from Empangeni northwards through the Lebombo Mountains to the Mozambique border and thence along the Transvaal border to the Limpopo River. It is characterized throughout its length by Stormberg lavas which initially dip steeply to the east but flatten out eastwards. Upper Jurassic (?) to lower Cretaceous sediments are deposited on the lavas which probably represent the downwarped surface of Gondwanaland. Except for an hiatus in the mid Cretaceous deposition continued up to the upper Cretaceous, after which erosion occurred followed by a Miocene transgression.

Empangeni fault system : A hinged fault system with increasing northeast throw runs southwest from south of Mtubatuba to Empangeni, and then southwest through Eshowe to just south of Greytown.

The entire Karroo succession is faulted down in the north against basement in the south along this fault system which also marks the southern limit of lower Cretaceous sediments along the coast. However the fault system has not affected the upper Cretaceous rocks (Frankel 1960 in De Swardt and Bennet 1974) which rest on lower Karroo rocks to the south. The J(c) - 1 borehole drilled 24 km off the coast opposite Stanger (Map 2) intersected upper Cretaceous sediments resting on a thin Dwyka layer overlying Cape quartzites (Du Toit and Leith, 1974).

Vryheid and Natal arches and the arcuate fault system : The Vryheid arch is an assymetrical arch (steep limb to west) defined by the base of the Cape and Karroo Supergroups which runs roughly parallel to the Lebombo monocline, about 160 km inland of it.

The Natal arch runs roughly parallel to the coast from southwest of Verulam to the Natal-Transkei border, extending out to sea near Port St. Johns. Its highest point is southwest of Durban where the eastern limb is much steeper and higher than the western limb. The arcuate fault system (Maud 1961) is a southeast concave fault system with a downthrow mostly to the west which runs out to sea in the vicinity of Durban. This fault system is apparently related to the western limb of the Natal arch. Faulting was probably due to uplift along the Natal arch which could not be accommodated solely by flexure of the rocks. The westward throw and superposition of the Natal arch and arcuate fault system discounts the theory that these faults are due to giant land slides down the limb of the Natal monocline (King 1972).

Pietermaritzburg step and the Natal hingeline : The Natal hingeline coincides with the crest of Natal arch and forms the axis about which seaward tilting of the Richmond Dalton surface occurred. Rapid uplift along the Natal hingeline probably formed the Pietermaritzburg steps ('treppen') which have since migrated inland by parallel scarp retreat.

Continental shelf margin : The straight southeastern coastline and parallel shelf break have been the main arguments for ascribing a faulted origin to the Natal coast. De Swardt and Bennet attribute this to relatively recent faulting for the following reasons :

i) If it was of ancient origin it could not have been preserved during substantial erosion and uplift in the coastal interior to the west.

ii) The original monoclinal margin of Africa south of the Empangeni fault system is probably located east of the present continental slope thus the faulting does not represent an original continental edge.

Tectonic development

The original continental margin occurs along the Lebombo monocline north of the Empangeni fault system. South of the Empangeni fault system the original continental margin probably occurs out to sea and was developed en echelon to the Lebombo monocline. The Natal arch does not therefore represent the original marginal flexure of Africa. A similar spatial relationship exists between the Natal and Vryheid arches either side of the Empangeni fault system as probably exists between the Lebombo monocline and the monoclinal margin off the coast of Natal.

Youthful incision of the steep sloping Jurassic graben face resulted in parallel scarp retreat and advance of the coastal erosion cycle into the interior drainage basins. The original coastal arches generated at the rift hinge zone must have migrated inland, since they are much further from the rift margin than in present day rifts (Figure 20). On the Natal arch, this movement was apparently accompanied by faulting, establishing the arcuate fault system. This inland migration of the coastal arches became stabilized in the present positions of the Natal and Vryheid arches.

The Pietermaritzburg step follows an arcuate pattern apparently related to the Natal arch and is ascribed by King and King (1959) to treppen formation on a rising coastal arch during late Tertiary or Quarternary times. De Swardt and Bennet agree with this mechanism but point out that their work suggests that this break occurred during formation of the upper phase of the Richmond Dalton surface, and is therefore much older than late Tertiary or Quaternary (see later).

Later tilting occurring along the Natal hingeline was responsible for the formation of the lower phase of the Richmond Dalton surface. Slight westward tilting may have accompanied this movement accounting for the peculiar characteristics of the Tugela Basin namely that "at comparable distances from the source region each major tributary (of the Tugela River) is flowing at a higher elevation than an adjacent major tributary closer to the head of the drainage basin" (Matthews, 1972, p. 3). This is illustrated in Figure (24). Matthews states that "the entire river system has at some stage been tilted inland or westward, following a major period of continental uplift, so that major tributaries were elevated to successively higher levels away from the head of the basin but the Tugela River was sufficiently active as the main drainage channel to cut downward as this tilting occurred and so maintained its outlet to the coast" (Matthews 1972, p. 5). It is suggested here that this tilting may also have been due to movement on the Vryheid arch which has a steeper western limb.

King (1972) attributes the vigorous coastal erosion cycle to rejuvination of coastal rivers resulting from major uplift along an axis situated just east of the Drakensberg during late Tertiary-Quaternary times. However, as De Swardt and Bennet point out, this cycle was more likely initiated by worldwide eustatic lowering of sea level. They suggest that there may have been renewed tilting along the Natal arch at this time since depth of incision apparently increases inland,but it is unlikely that tilting occurred along a hingeline far to the west as stated by King (1972), since there is no evidence of stream rejuvination west of the Pietermaritzburg step.

It must be pointed out however, that this incision will eventually reach the interior of Natal since although a return of the sea in Pleistocene times (McCarthy 1967) resulted in drowning of the coastal rivers and infilling of large quantities of alluvium, (to a depth of 50 metres in the Umgeni River, McCarthy 1967) the present sea level is still approximately 100 metres below the pre-early Tertiary sea level. Thus rivers will continue to incise their beds but at a slower rate than before this major transgression.

Correlations, summary and conclusions

Summary : Thus it seems that only two erosion cycles are present in Natal. The oldest was initiated by rifting accompanying break-up of Gondwanaland, and retreat of the major scarp formed by vigorous erosion of the steeply

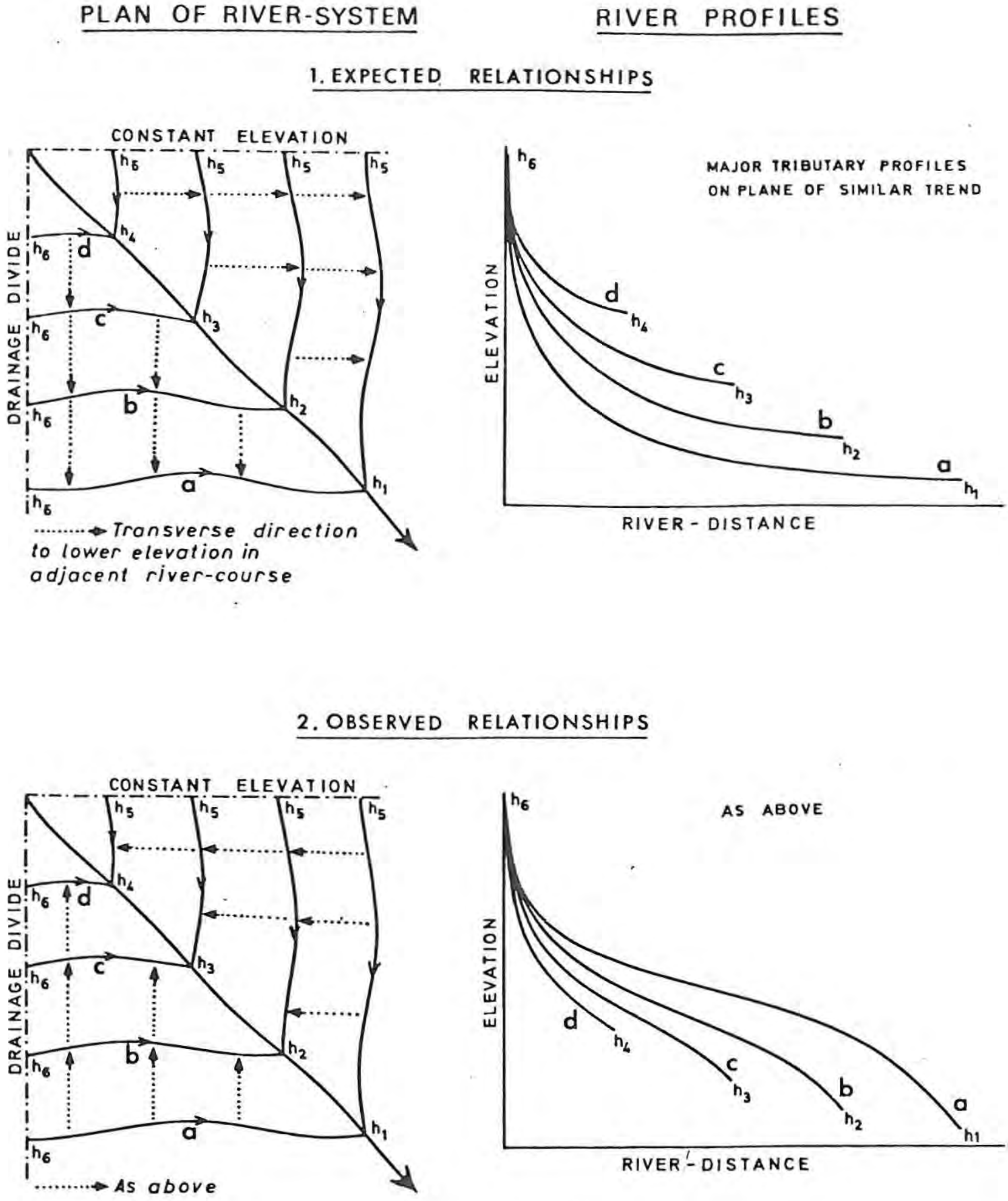


Figure (24). Schematic representation of the Tugela and its major tributaries (a, b, c, d), to illustrate the difference between (1) the expected and (2) the observed relationships in the relative elevations of the major tributaries. From Matthews (1972), p. 4.

sloping graben sides. The scarp so formed retreated back from the original continental edge to its present position along the Natal Drakensberg.

The Richmond Dalton surface, which is surmounted by a few resistant residual mesas, represents a mature phase of pediplanation some distance behind the zone of active scarp retreat. Closer to the zone of active scarp retreat, planation has not yet progressed to the same extent and the topography is dominated by structurally controlled residual hills rising to varying heights above an immature valley floor planation which in places, as planation becomes more advanced towards the coast, merges with the Richmond Dalton surface.

This pediplain has undergone subsequent deformation and consequent rejuvination as a result of later tectonic disturbance along the Natal arch, resulting in formation of the Pietermaritzburg step and later, the lower dissected phase of the Richmond Dalton surface.

The second erosion cycle was probably initiated by major eustatic lowering of sea level resulting in vigorous incision particularly along the Natal arch where further tilting may have occurred. This also formed the coastal erosion cycle extending up the valleys.

East of the Natal hingeline, the two phases of the Richmond Dalton surface were identified by King (1963, 1972) as the African and Post-African surfaces, which he claimed arched over the top of the Pietermaritzburg step and correlated with similar surfaces in the Natal Midlands and Drakensberg foothills occurring above flat valley plains ascribed to the Pliocene cycle of erosion (Figure 19).

However, De Swardt and Bennet indicate that these surfaces (i.e. the two phases of the Richmond Dalton surface), do not rise over the Pietermaritzburg step but abut against it or continue up the main valleys transecting the step. Cyclic erosion surfaces could not be established by De Swardt and Bennet west of the Pietermaritzburg step.

<u>Relationship with offshore sediments</u>: The depositional history of the coast of Natal south of the Empangeni fault system since mid Cretaceous times is summarized as follows (De Swardt and Bennet, 1974; Du Toit and Leith, 1974) :

No information is available on sediments of Jurassic - mid-Cretaceous age since these were deposited out to sea in the region of the original continental margin. The earliest deposition in the coastal region occurred during a transgression lasting from late Cretaceous to early Palaeocene times. Deposition was slow, and in the vicinity of the J(c) - 1 borehole sediments were deposited on a thin horizon of rocks overlying quartzites of the Cape Supergroup.

A sudden increase in sedimentation attributed to uplift and rapid erosion on land occurred during mid Palaeocene times causing shallowing of the sea, and relatively rapid deposition of prograding, turbid, deltaic sequences during a regression which lasted until upper Eocene times.

This was succeeded by a major transgression which started in Oligocene times and reached the present coast in early Miocene times, and reached its highest level in the Mio-Pliocene. This transgression transects progressively older sediments landwards and incorporates reworked microfauna of late Cretaceous to Eocene age. Regression, probably due to eustatic lowering occurred during the Pliocene, initiating the coastal erosion cycle on land. Sea level returned in Pleistocene times to about 100 metres below the upper Miocene level.

Thus, deposition was most rapid during the mid Palaeocene - Upper Eocene regression. As pointed out by De Swardt and Bennet (1974), this is in complete contradiction to King (1963; 1972) who states that there was an hiatus in deposition during early Cainozoic times due to the advanced planation of the African surface. They suggest a possible correlation between this increased sedimentation and strong uplift along the Natal arch. Thus the Pietermaritzburg step, which is regarded by King and King (1959) as having formed during late Tertiary-Quaternary times, may have formed in early Cainozoic times. De Swardt and Bennet (1974) regard the smooth upper phase of the Richmond Dalton surface as corresponding with the culmination of the Oligocene - Miocene transgression.

<u>Conclusion</u>: Some measure of the complexities and difficulties involved in correlating erosion surfaces on land with depositional sequences offshore can be gained from the above discussion. De Swardt and Bennet point out that considerably greater knowledge of offshore sediments and tectonic evolution of the coastal regions is required before reliable regional correlation and dating of land surfaces can be made.

Perhaps the most important conclusion of De Swardt and Bennet's work is the realization that "the physiographic framework of the African continent was established during initial rifting of Gondwanaland in the late Jurassic" and that "Africa always stood relatively high and it is unlikely that the continent as a whole was ever planed down to a surface of low relief" (De Swardt and Bennet, 1974, p. 321). This has far reaching implications and demands a new interpretation of the erosion surfaces of Southern Africa.

Some considerations on a new interpretation of Southern African geomorphology

Introduction

The implications of the above discussion are that there appear to be three erosion cycles operating in Southern Africa. Two of these were generated by the break-up of Gondwanaland namely : the African and Post-African cycles. For the sake of continuity the terminology of Partridge (1968) after King (1963) is maintained, since with some important modifications, they are fairly accurately depicted in Map (1).

The most important modification is that there are probably no vestiges of a Gondwana or Post-Gondwana surface remaining in Southern Africa. The Gondwana and Post-Gondwana surfaces depicted in Map (1) are ascribed either to phases of the African cycle or to rejuvinated African cycle landforms.

The third cycle, namely the Plio-Pleistocene cycle was probably initiated during Plio-Pleistocene times by a major regression of sea level. This is the active erosion cycle present mainly along the coast and encroaching inland along the river valleys.

An important concept is that all three cycles are still active, and different phases in the development in each cycle are evident throughout the country. Thus, the geomorphology of Southern Africa is best described in terms of the different cycles which produced the observed landforms.

The break-up of Gondwanaland is discussed below in view of the work of Dingle and Scrutton (1974), who suggest that the southern and eastern margins of Southern Africa formed by transform faulting and not by tensional faulting, monoclinal downwarping and graben formation. This is in apparent contradiction to the views of De Swardt and Bennet (1974), and is particularly relevant to the origin of the great escarpment, and therefore has an important bearing on the discussion of erosion cycles in Southern Africa which follows.

The tectonic development of Southern Africa since break-up is briefly described since this has affected the landforms of the different erosion cycles. Finally, some implications on the geomorphology of South West Africa are suggested.

The break-up of Gondwanaland

Dingle and Scrutton (1974) suggest that the assymetry of the continental margin of Southern Africa is a result of the mechanism of break-up of Gondwanaland. They subdivide the continental margin into three zones related to different stages in the break-up of Gondwanaland namely (Figures 25 and 26) :

i) the northeastern margin (Mozambique and northern Zululand) - tensional faulting,

ii) western margin (west Agulhas Bank to Walvis Bay) - tensional faulting,

iii) southern and eastern margins (east Agulhas Bank, Transkei, and Natal) - transform faulting.

The characteristics of these different zones are summarized by them in Table (1).

The northeastern margin was formed during the initial phase of rifting between 200 and 160 m.y. B.P. between East and West Gondwanaland (Figure 25). Rifting involved monoclinal downwarping of the Gondwanaland surface, and accompanying graben formation along north-south trending tensional faults. The effects of this rifting have been described by De Swardt and Bennet (1974) and discussed above, namely : formation of the great escarpment by vigorous erosion of the steep graben sides and resultant inland migration of the great escarpment by parallel scarp retreat, with formation of the coastal arches behind the great escarpment.

STRUCTURE	a. Northeast	b. East and south (i) east	(ii) south	c. West coast (i) south	(ii) Orange basin
1. Faulting	tensional; grabens	transform	transform	tensional, (?grabens)	
2. Marginal fracture ridge	absent	absent	present	absent	
3. Age of faulting in relation to main basin formation	older	younger		older	
4. Lineation of main faults relative to margin edge	oblique	parallel		parallel	
BASIN CHARACTERS					
1. Nature of basin edges	fault bounded	well defined, partially fault bounded		no thick sediments	not well defined, controlled by marginal offsets
2. Basement composition	continental and oceanic	continental	continental	do.	continental and oceanic
3. Lineation of basin axis relative to margin edge	parallel	normal and oblique	oblique	do.	parallel
4. Nature of sediment pile	trough infill and prograding	not known	partially intermontane, partially prograding	do.	seaward prograding
MORPHOLOGY					
1. Shelf: width	narrow and shallow east facing,	narrow	wide	narrow	wide
depth	wide and deeper south facing	shallow	shallow	deep	deep to shallow
2. Shelf break	shallow, well defined	straight, shallow well defined	moderately deep, well defined	deep, well defined	variable
3. Nature of slope	steep	steep	moderately steep, very steep at base	steep, incised	moderate gradients
4. Coastal plain	wide	none	narrow	none	narrow to none

Table (1). Margin types in relation to structure, sediment basin characters and morphology. From Dingle and Scrutton (1974), p. 1468

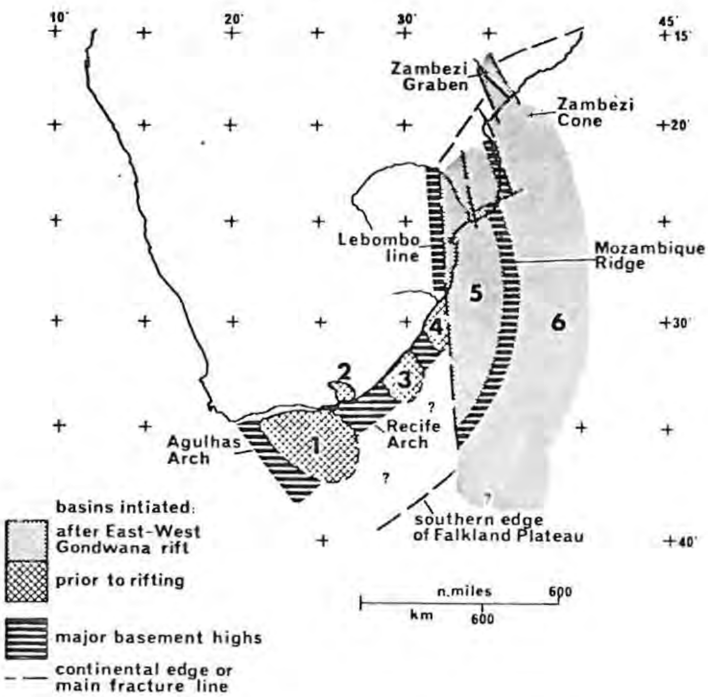


Figure (25). Main sediment basins, basement highs, and fracture lines in existence prior to the breakup of West Gondwana (Late Jurassic time). Key : 1, Outeniqua Basin; 2, Algoa Basin; 3, St. Johns Basin; 4, Durban Basin; 5, proximal Natal Valley; 6, western Mozambique Basin. From Dingle & Scrutton (1974, p. 1469).

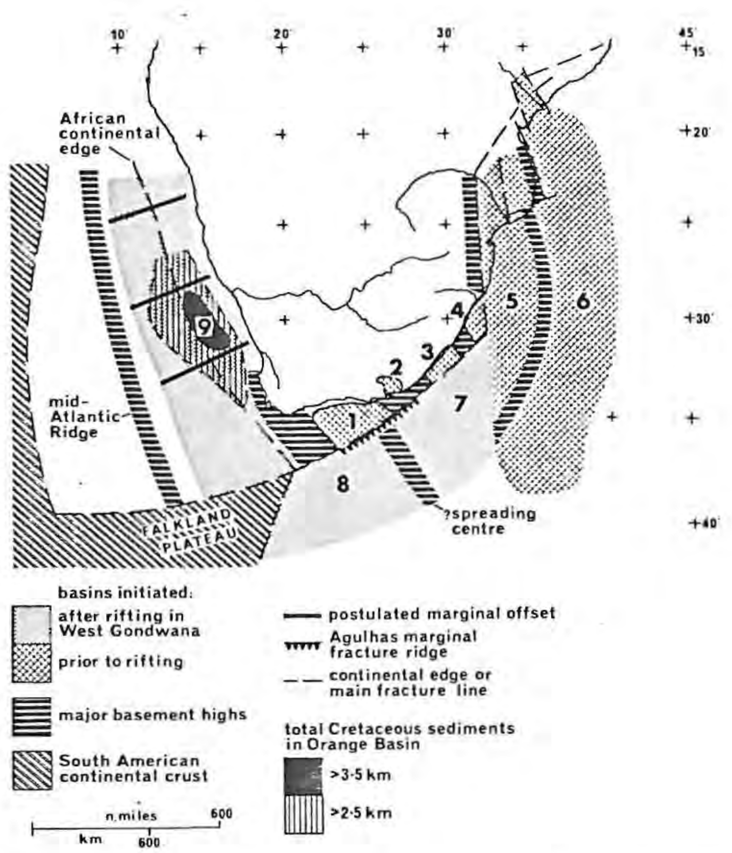


Figure (26). Main sediment basins, basement highs, and fracture lines in existence in "mid-Cretaceous" times (say at 100 m.y.). The possible spreading ridge southeast of South Africa may be represented by the present-day Agulhas Plateau.
Key : 1, Outeniqua Basin; 2, Algoa Basin; 3, St. Johns Basin; 4, Durban Basin; 5, proximal Natal Valley; 6, western Mozambique Basin; 7, distal Natal Valley; 8, Transkei Basin; 9, Orange Basin. From Dingle & Scrutton (1974), p. 1469.

From the en echelon arrangement of the coastal arches it is evident that the monoclinal continental margin probably developed en echelon on either side of the Empangeni transform fault system. Thus the equivalent structure to the Lebombo monocline south of the Empangeni fault system is probably situated some distance off the present coast of Natal. Thus Figure (25), from Dingle and Scrutton (1974), requires some modification and the effects of this early rifting phase must extend further south at least to the Transkei, in view of the southward extension of the Natal arch through Port St. Johns (De Swardt and Bennet, 1974).

Dingle and Scrutton (1974) regard the south and east margins as being due to breakaway of the Falkland Plateau from the Mozambique ridge along a transform fault during fragmentation of Western Gondwanaland by tensional rifting between 125 and 130 m.y. B.P. This transform fault is represented by the Agulhas Marginal Fracture Ridge. Thus they suggest that rifting, and breakaway of South America carried with it a large segment of continental crust (the Falkland Plateau), which originally lay close to the present southern Cape and Natal coast (Figure 26), thus explaining the constant linear steep shelf break evident along these coasts (Figure 27), and the truncation of the Outeniqua, St. Johns and Durban Basins formed before this time.

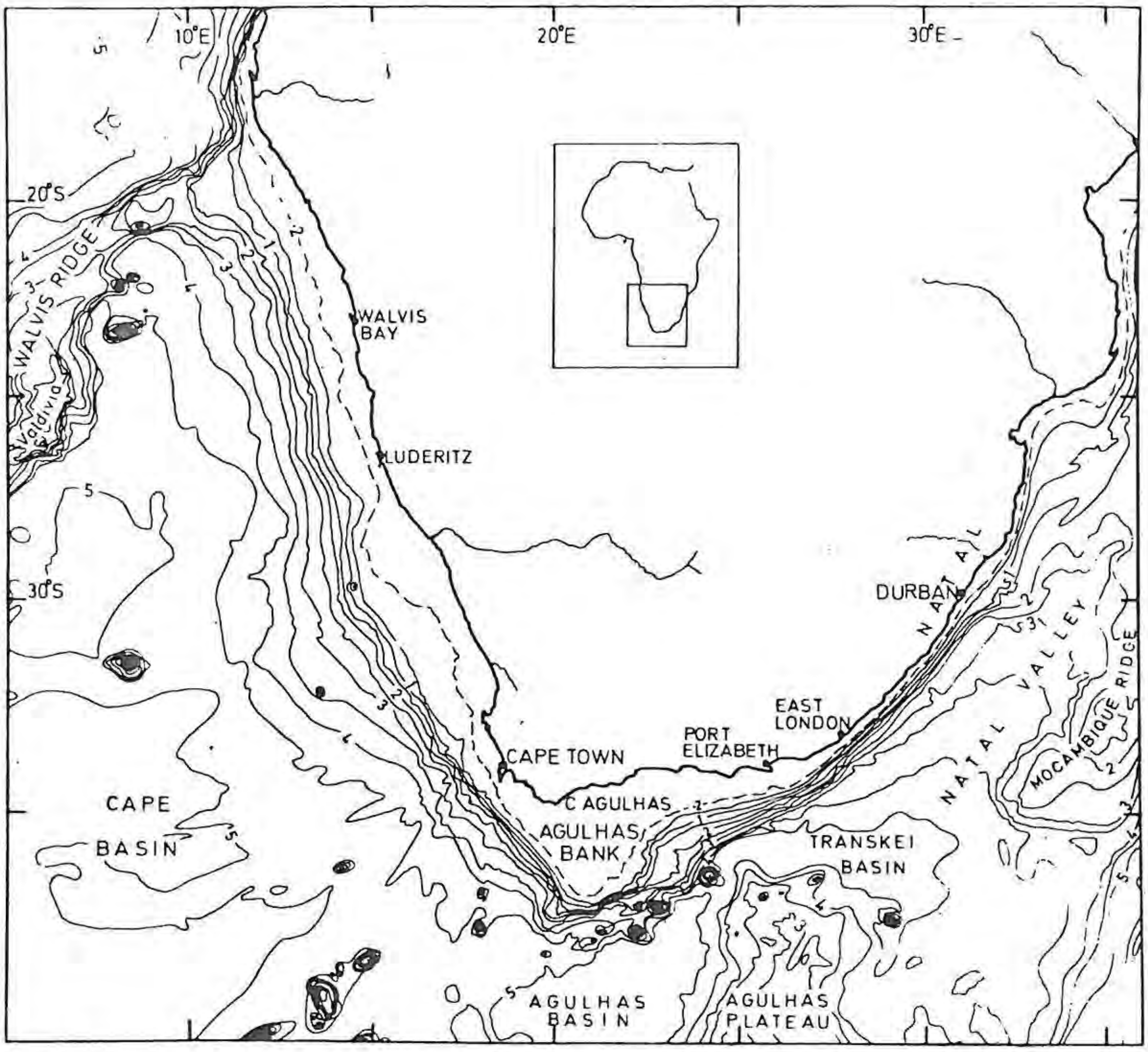


Figure (27). Bathymetric map of the continental margins around Southern Africa, redrawn from a chart compiled by E.S.W. Simpson and E. Forder at the University of Cape Town. Isobaths are at 500m intervals with the addition of the 200m isobath (broken contour). Depths given in km. The inset shows the location of the study area with respect to Africa. From Scrutton et al. (1973), p. 652.

I submit that although it is evident that considerable transform movement may have occurred along these coasts (see also Larson and Ladd, 1973; Scrutton et al., 1973), the interpretation of the Agulhas Fracture Ridge by Dingle and Scrutton (1974) requires some modification. Evidence has been presented in the earlier discussion on Natal (De Swardt and Bennet, 1974) that the original monoclinal continental margin of Natal lies east of the present coast. Du Toit and Leith (1974) report that seismic results indicate the presence of a normal, downthrow to east, fault or scarp situated 1 km west of the J(c) - 1 borehole, 24 kms offshore from Stanger (their Figure 3).

This feature is situated in the approximate locality of the northern extension of the Agulhas Fracture Ridge (Figure 26). A westward thickening wedge of probably lowermost Cretaceous sediments is apparently terminated against this feature. This is similar to the description given by De Swardt and Bennet (1974) of the uppermost Jurassic (?) to lower Cretaceous sediments banked up against the eastern side of the Lebombo monocline. I suggest that this and other westward thickening sedimentary wedges reported by Du Toit and Leith (1974) may be the result of sediment deposited over an original predominantly monoclinal continental margin. Therefore the Agulhas Fracture Ridge in this area (Figure 26) may represent an original monoclinal continental margin rather than one predominantly of transform fault origin. This suggests that the monoclinal continental margin of Natal may be situated closer to the coast than suggested by De Swardt and Bennet (1974) : "If a corresponding monocline or fault exists in this region .... it must be situated way out to sea, possibly even beyond the present shelf break" (p. 317).

Dingle and Scrutton (1974) state that the western margin formed by tensional rift faulting during the break-up of South America from Southern Africa. Of this there can be little doubt, especially in view of the fact that the possible prior existence in this area of upper Palaeozoic marine basins along the Pan African Belt, may have had a strong influence on the break-up of Gondwanaland (Martin, 1973).

An interesting feature of the continental shelf off the southern and western Cape coast is mentioned by Dingle (1971 and 1973). He describes a marked anticlinal feature west of the Olifants River mouth (Figure 28), which he ascribes to "a period of folding .... prior to deposition of the upper Tertiary" (Dingle 1973, p. 347). This feature, which he called the 'Lower Tertiary Ridge', extends northwards for some 320 kms to west of the Orange River mouth (Figure 28) and considerably influenced upper Tertiary sedimentation.

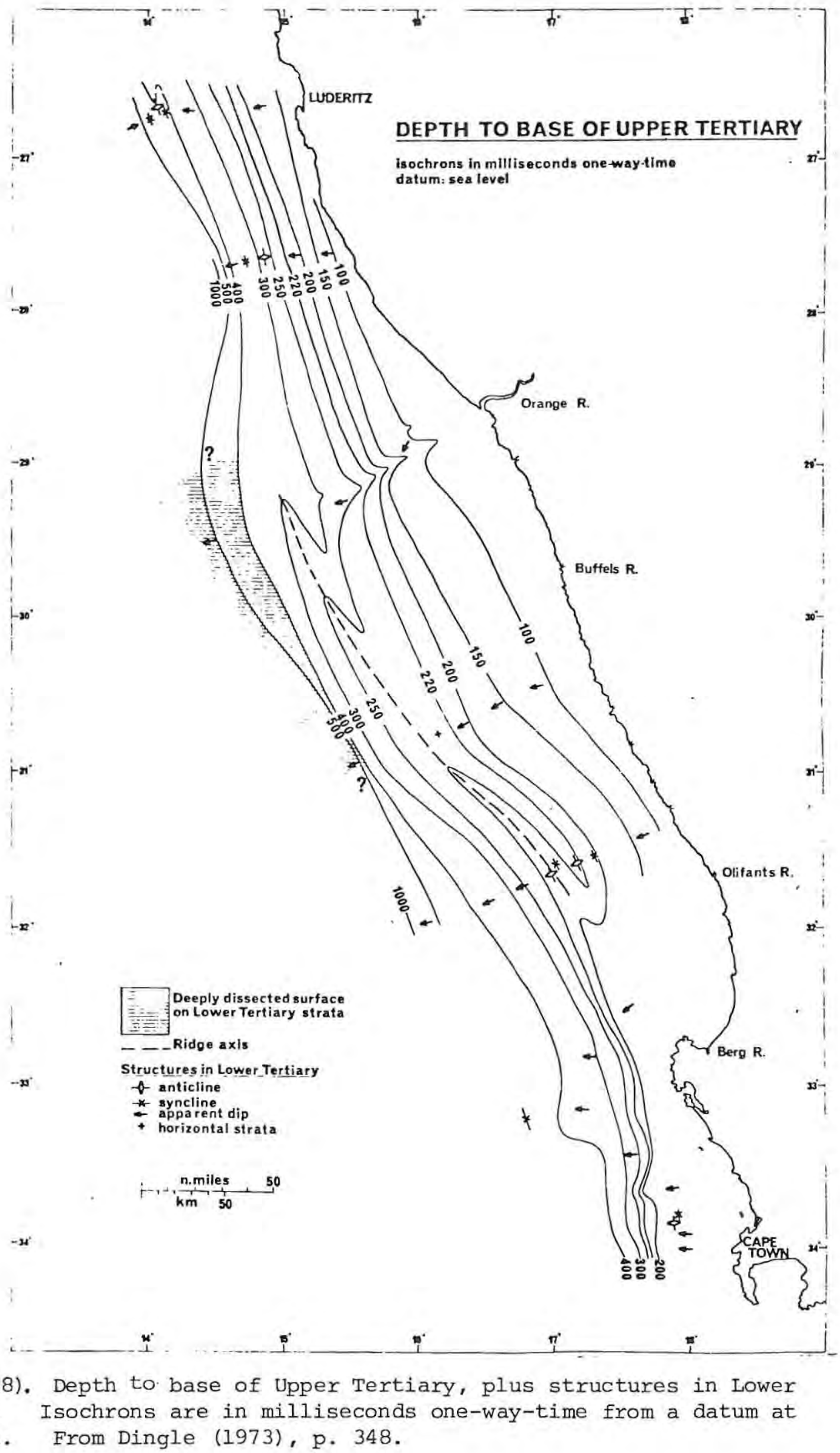


Figure (28). Depth to base of Upper Tertiary, plus structures in Lower Tertiary. Isochrons are in milliseconds one-way-time from a datum at sea level. From Dingle (1973), p. 348.

North of the Orange River mouth, a similar structure occurs west of Luderitz. This is also shown on Figure (28) and it appears that the northern ridge has developed en echelon to the southern ridge. This is not unlike the relationship described earlier between the Vryheid and Natal arches in Natal. Dingle (1973) suggests that this feature may be a secondary effect resulting from differential subsidence over a buried basement high. However, I submit that it was generated in the same way as the Natal and Vryheid arches in Natal, and that they have migrated inland from the original monoclinal continental margins situated further off-shore.

The original continental margin may have developed en echelon on either side of a transverse fault, thus explaining the present apparent en echelon arrangement of the coastal arches, as occurred on either side of the Empangeni fault system in Natal. This also suggests that the Orange River (assuming it was not present here at the break-up of Gondwanaland) may have developed along an inherent zone of weakness formed during initial rifting and graben formation, namely a transform fault.

Dingle (1971) describes a narrow strip of pre-Cretaceous basement rocks, (Precambrian granites and Cape Supergroup rocks) occurring off the present southern Cape coast from Cape Columbine to Cape Seal which, southeast of Cape Agulhas come together in a broad, southeast striking 'antiform', namely the Agulhas arch (see Map 4). I suggest that this structure was generated by the intersection of two coastal arches as they migrated inland, namely the southwest Cape arch which possibly correlates with the Lower Tertiary Ridge further north, and the southern Cape arch from Cape Agulhas to Cape Seal. The original continental margin may be located along the present shelf break, seaward of the Cape arches which along the southern Cape margin is marked by the Agulhas Fracture Ridge.

This relationship of the southern Cape arches suggests that the Agulhas Fracture Ridge off the southern Cape coast, as in Natal, may represent an original monoclinal continental margin. Thus the southern and eastern continental margins, like the northeastern and western margins were probably formed by tensional faulting resulting in monoclinal warping and associated graben formation. This accords with the view of De Swardt and Bennet (1974). It is envisaged that the southern Cape arch of pre-Cretaceous rocks extends northwards up the southeastern Cape coast to meet up with the southward extension of the Natal arch.

This is not to say that transform faulting did not occur along the Agulhas Fracture Ridge. Convincing evidence for this phenomenon has been presented by Scrutton et al. (1973), Larson and Ladd (1973) and others,but it is suggested that this transform movement was preceded by an initial period of rifting and graben formation. Thus,possible later transform movement along an earlier formed rifted continental margin,may have produced the linear shelf break and steep continental slope along the Agulhas Fracture Zone.

Dingle and Scrutton (1974) maintain that initial rifting of the northeastern margin took place between 200 and 160 m.y. B.P., and that later rifting of the western margin probably occurred between 125 and 130 m.y. B.P. I suggest that rifting of the southern and eastern margins took place in the intervening period between rifting of the northeastern and western margins. This rifting probably progressed southwards down the eastern and southern margins, along the southward extension of the Lebombo monocline south of the Empangeni fault system. Thus rifting of the southern and eastern margins could have been well advanced by the time that rifting of the western margin occurred. The western margin rifting may possibly have been initiated by rifting progressing down the southern margin to southeast of the present position of Cape Town and thence northwards up the western margin. Breakaway of South America from Southern Africa would then ensue, and it is not unlikely that this could have carried with it a large segment of crust situated along a developing rift zone on the southern and eastern continental margins of Southern Africa.

This has an important bearing on the generation of the great escarpment since De Swardt and Bennet (1974) have attributed its formation to downwarping and graben faulting during the break-up of Gondwanaland. If, as suggested by Dingle and Scrutton (1974) the southern and eastern margins were not formed by downwarping and graben faulting (i.e. tensional faulting), then we would have to look elsewhere for the explanation of the great escarpment. However, evidence has been presented above that tensional faulting did occur along the southern and eastern margins. If transform faulting took place, it probably only occurred after tensional faulting, by which time the inland migration of the great escarpment by parallel scarp retreat was well advanced. Having established the probable generation of the great escarpment by rifting of Gondwanaland, the implications of this on Southern Africa geomorphology can now be examined by applying the findings of De Swardt and Bennet (1974) in Natal, to the rest of Southern Africa.

The great escarpment

The great escarpment surrounding Southern Africa is still an active zone of scarp retreat, despite its generation in late Jurassic - early Cretaceous times. This can be attributed to the high relief formed by rifting during break-up of Gondwanaland, which provided ample energy for the efficient removal of debris thereby ensuring continuation of the parallel scarp retreat process since Jurassic times, irrespective of climatic variation. The great escarpment is generally closer to the coast in the west than in the east (Figure 22). This is probably due to the time lag between the break-up of the eastern and western margins, mentioned earlier. The spectacular survival of the great escarpment along the eastern and southern parts of Southern Africa must be attributed in part to the thickness of sub-horizontal strata of the Karroo and Transvaal Supergroups, since this would enhance the process of scarp retreat (see Section 1).

The upwarping of the continental margins during rifting in late Jurassic - early Cretaceous times led to the production of two drainage systems on either side of the retreating escarpment, which developed to different base levels. The late Jurassic - early Cretaceous sea became the base level to the short, vigorous coastal rivers, while the vast inland drainage system, with its headwaters on the gently sloping landward side of the rift shoulders, deposited lower Cretaceous sediments on the downwarped surface of Gondwanaland. This formed the Kalahari Basin which acted as base level to the inland drainage system.

As a result of the landward tilting, rejuvination of the Gondwana surface would have occurred. Thus the Gondwana surface cannot be expected to have survived very long after rifting, except where buried under early Cretaceous sediments in the downwarped continental margins, and interior depressions. The presently held view (King 1963, 1972, 1976) is that the Gondwana surface remains as remnants on the high upland areas which have not yet been reached by younger erosion cycles (Map 1). This implies that since Jurassic times this surface has never undergone rejuvination, which in itself is unlikely in view of the large amounts of uplift that the interior of Southern Africa is presumed to have undergone (King 1963). As shown in Figure (29), rejuvination of the landward tilted Gondwana surface, and the encroaching of the vigorous coastal erosion surface and great escarpment on the interior would tend to destroy the Gondwana surface.

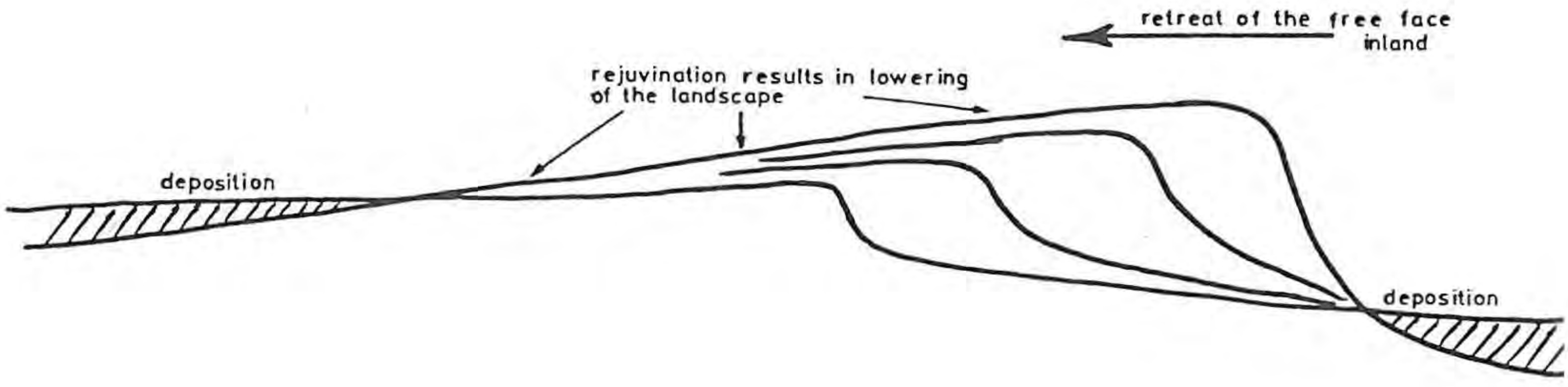


FIGURE (29). Evolution of the landscape as a result of tilting accompanying rifting of Gondwanaland.

Thus, two erosional cycles were generated by the rifting; the inland (African) cycle was developed to a different (higher) base level than the coastal (Post-African) erosion cycle and therefore no correlation between landforms of these two cycles can be made. The name of the Post-African cycle is retained since, although it was initiated at the same time as the African cycle of the interior, it has been extended up the major rivers into the interior due to landward capture of the interior drainage by these rivers and therefore its initiation in the interior of Southern Africa is in a sense 'Post-African'. Any interpretation of erosion cycles in Southern Africa must therefore make the important distinction between erosion cycles generated on different sides of the great escarpment.

African erosion cycle

As with the area between the great escarpment and the coast, the African cycle of the interior, generated by Jurassic - lower Cretaceous rifting must still be active, and will be represented by immature as well as mature forms. There can be no doubt that ancient pediplanation surfaces exist over large parts of Southern Africa corresponding in general to King's (1963, 1972) African surface in the interior highveld plains of Southern Africa (Map 1). The flat plains of the eastern Orange Free State and the calcrete covered interior plains of South West Africa (the so called 'Owambo surface'), are only two examples of this African pediplanation.

Partridge (1968, 1975) has provided ample evidence for the existence of an old erosion surface in the Kyalami land system on granites and greenstone remnants of the Pretoria - Johannesburg dome. Partridge (1975) records an accordance of summit heights between 1650 and 1550 metres corresponding with this surface. There can be no doubt that this represents an ancient erosion surface since it is characterized by deep residual granitic soils. These soils formed by prolonged weathering of the feldspars to kaolinite, and subsequent leaching of this clayey matrix to produce soils with a collapsible grain structure. Where erosion has reduced the landscape below 1500 metres, residual granite soils are largely absent (Figure 30).

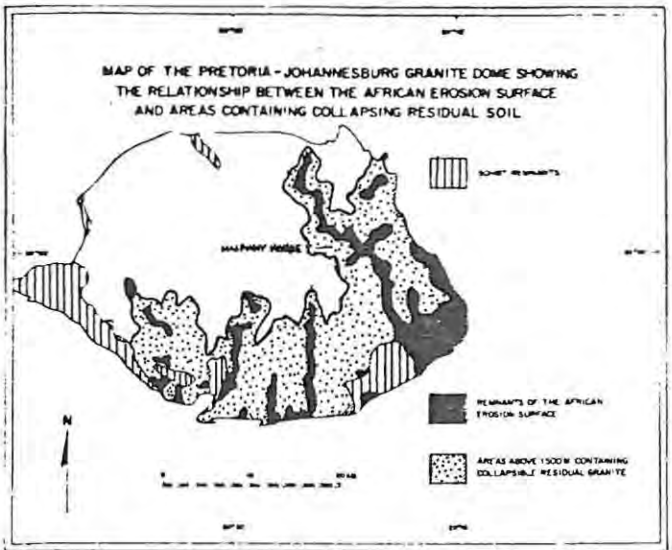


Figure (30). Map of the Pretoria - Johannesburg dome showing the relationship between the African erosion surface and areas containing collapsing residual soil. From Partridge (1975), p. 40.

Another important observation in the Pretoria - Witwatersrand area, is that dissection within the African cycle is still taking place, for example along the Witwatersrand escarpment, where despite a gradual replacement of the free face by talus material, parallel scarp retreat is occurring (Partridge 1968). This has been fully described in Section (1). This does not accord with King's (1963) interpretation of the African surface as representing the "true ancestral planation surface from which the modern topography of Southern Africa has been carved" (p. 207), and that the whole of Southern Africa during the middle Tertiary was planed flat except for a few residuals of the Gondwana and post Gondwana surfaces.

Partridge (1968) also notes the close correlation of the African pediplains with the Pre-Karroo surface in the Pretoria-Witwatersrand area. This is also an important factor, since the Pre-Karroo surface, although generally of low relief due to ice sheet planation is locally irregular where scouring of softer formations occurred (Partridge 1968). The Pre-Karroo surface is preserved south of the Witwatersrand escarpment on resistant rocks of the Witwatersrand Supergroup above the zone of African scarp retreat. This forms an undulating upland dominated by glacially scoured, rounded, parallel quartzite ridges, alternating with broad valleys scoured in less resistant rocks.

Below the Witwatersrand escarpment, an African pediplain is preserved along crestlines of the interfluves in the Kyalami land system. This pediplain formed behind the zone of scarp retreat now situated along the Witwatersrand escarpment. This pediplain was, in general, cut just below the Pre-Karroo but in places, the two surfaces correspond resulting in a significant increase in depth of weathering (Partridge, 1968).

The present drainage of the Pretoria - Witwatersrand area was originally developed on Karroo cover, and became superimposed on underlying resistant quartzite ridges as the Karroo cover was stripped off (Figure 31). This stripping of the Karroo cover must be ascribed to earlier phases of the African erosion cycle. Thus the Witwatersrand escarpment may represent a last nickpoint in the African cycle, developed on resistant Witwatersrand Supergroup quartzites above the final mature African pediplain preserved on interfluves of the Kyalami land system.

Similar accordance of the African cycle pediplains with the Pre-Karroo surface is common throughout Southern Africa. In particular, large areas in the Northwest Cape forming the Bushmanland plateau (Mabbutt, 1955) represent the mature pediplanation stage of the African cycle superimposed on the Pre-Karroo surface. Mabbutt (1955) suggests that the Doornberg, Kuruman Hills, and Langeberg ranges in the Northern Cape were moulded by ice scour during Dwyka glaciation which indicates the possible

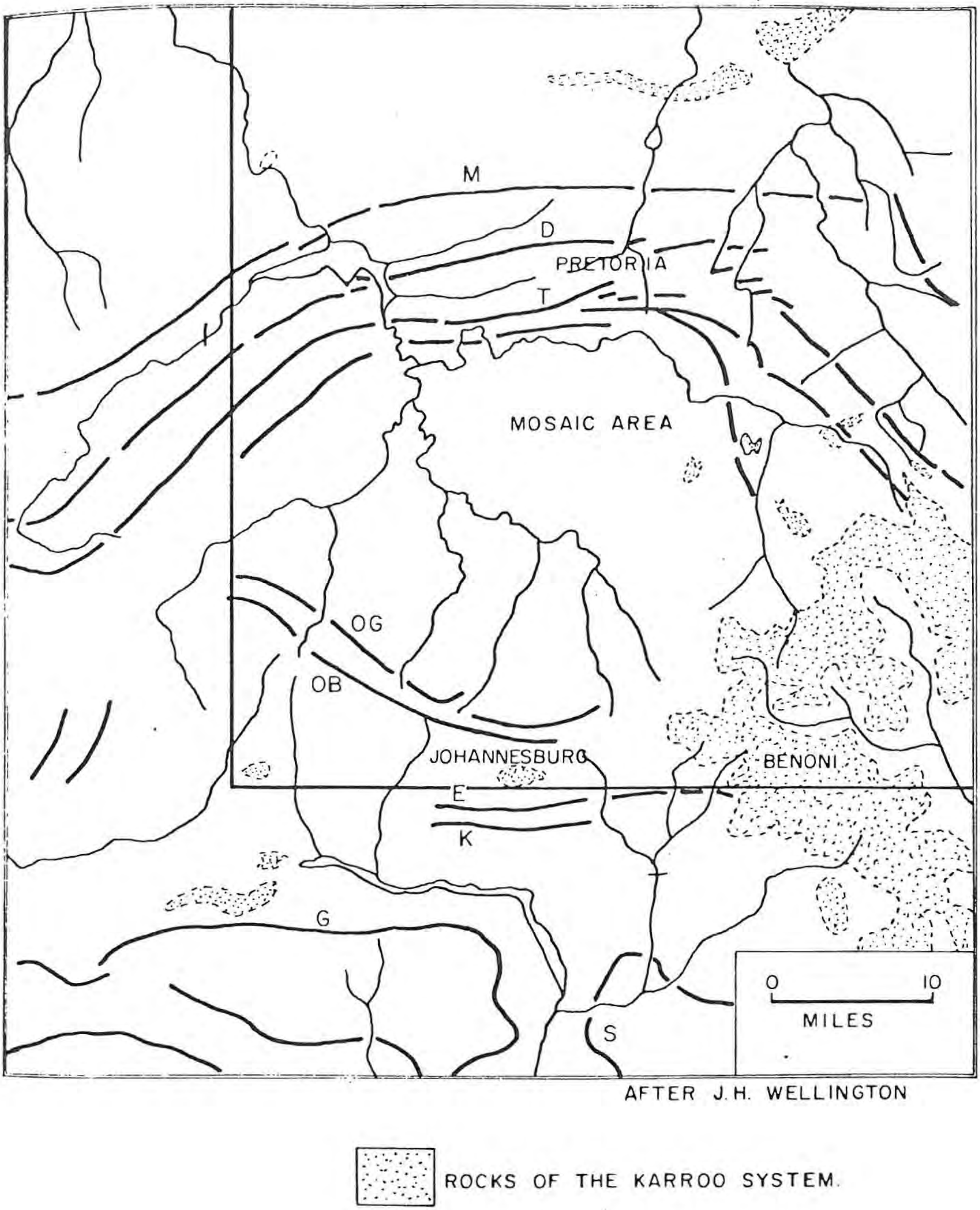


Figure (31). Superimposed drainage and fossil topography in the south-central Transvaal. From Partridge (1968).

prior existence of the Karroo cover to these ranges. In addition, Dwyka gravels preserved on top of the Little Namaqua Highlands around Springbok in the Northwest Cape indicate that Karroo rocks have been stripped off the Little Namaqua Highlands.

Mabbutt (1955) correlates the upper surface of the Little Namaqua Highlands with that of the Doornberg - Kuruman Hills - Langeberg ranges in the Northern Cape. He includes the Aggenysberg, Namiesberg and Kaaien ranges in this surface as well, forming remnants of a 'Namaqua Highland' (Cretaceous) surface. These are all presently ascribed by King to the Gondwana and Post-Gondwana surfaces (Map 1).

It is evident from the argument discussed earlier that the Little Namaqua Highlands cannot represent the Gondwana surface, and the possibility that Karroo strata have been stripped off the Northern Cape ranges indicates that they have undergone erosion in the past, and were probably formed by stripping of Karroo cover during early phases of the African cycle. Thus Mabbutt's 'Namaqua Highland' surface is analogous to the undulating upland above the Witwatersrand escarpment. I suggest that rather than attributing cyclic significance to the resistant quartzite hills and mountains of the Northwest and Northern Cape (Mabbutt's Namaqua Highland surface), they represent resistant residuals to African cycle planation.

The existence of a broad valley in an outlier of his 'Namaqua Highland' surface on the form Kangnas, was ascribed by Mabbutt (1955) to an intermediate phase of valley floor planation between his Namaqualand Highland surface and the Bushmanland Plain. In the light of the above discussion this broad valley probably represents an intermediate phase of the African cycle.

Mabbutt (1955) assigned a Cretaceous age to his Namaqua Highland surface on the grounds of the occurrence of fossil bones of the dinosaur Kangnasaurus Coetzeei (late Cretaceous age) in the broad Kangnas valley. He also assigned a lower 'broadly Tertiary age' and an upper 'early Pliocene' age to the Bushmanland plain on the grounds of further fossil occurrences. If these datings are correct the implication is that the African cycle, (initiated by late Jurassic - early Cretaceous rifting) was at an immature stage for most of the Cretaceous but by end - Cretaceous times had reached an intermediate valley planation stage. Planation appears to have been well advanced by Pliocene times. Thus it is suggested that remnant landforms of the interior African cycle exist throughout Southern Africa.

Inland warping: Du Toit (1933) has presented evidence of widespread upwarping of the interior of Southern Africa along clearly defined NE and ENE axes separating basin areas where sagging occurred (Figure 32). Important watersheds are often located along these axes of uplift. An example is the Griqualand Transvaal axis which, in the Transvaal forms the important watershed between northward (to the Limpopo), and southward (to the Orange) drainage.

Upwarping resulted in some significant modifications to the drainage, such as occurred in the Molopo River. Pebbles found in a gravel 'run' traced upstream from the present headwaters of the Molopo River, have been derived from Bushveld Amygdaloid which is exposed near Pienaars River, far to the northeast at an altitude of 4000 feet, whereas the gravels attain an altitude of 5150 feet in places along the present watershed.

This gravel 'run' therefore indicates the former trace of a major river which used to flow southwest from the Pienaars River area into the present Molopo River,which is today an insignificant river flowing only intermittently in a valley too large for the present river. Thus the drainage has been reversed along the Griqualand - Transvaal axis and now flows northward into the Crocodile and other rivers.

Although uplift along these axes was probably not nearly as much as Du Toit (1933) imagined,(he attributes the present elevation of the interior of Southern Africa to uplift along these axes), the gentle upwarping could have had an important effect on the African erosion cycle of the interior. In order for the Molopo and other drainage reversals to have occurred, the rivers, and therefore the landscape must have been in a mature stage since, if the rivers were actively downcutting they would probably have maintained their original drainage channels and cut through the uprising arches, establishing an antecedant drainage. Therefore, the African cycle of the interior could well have been at a mature stage of pediplanation by the time that uplift occurred. This accords well with Du Toit's (1933) suggestion that uplift took place during mid-late Tertiary times.

The possibility therefore exists that mature phases of the African cycle could have been locally rejuvinated by this uplift. Du Toit (1933) mentions that sagging of the Bushveld Basin occurred at the same time as uplift along the Witwatersrand watershed,which could have assisted the

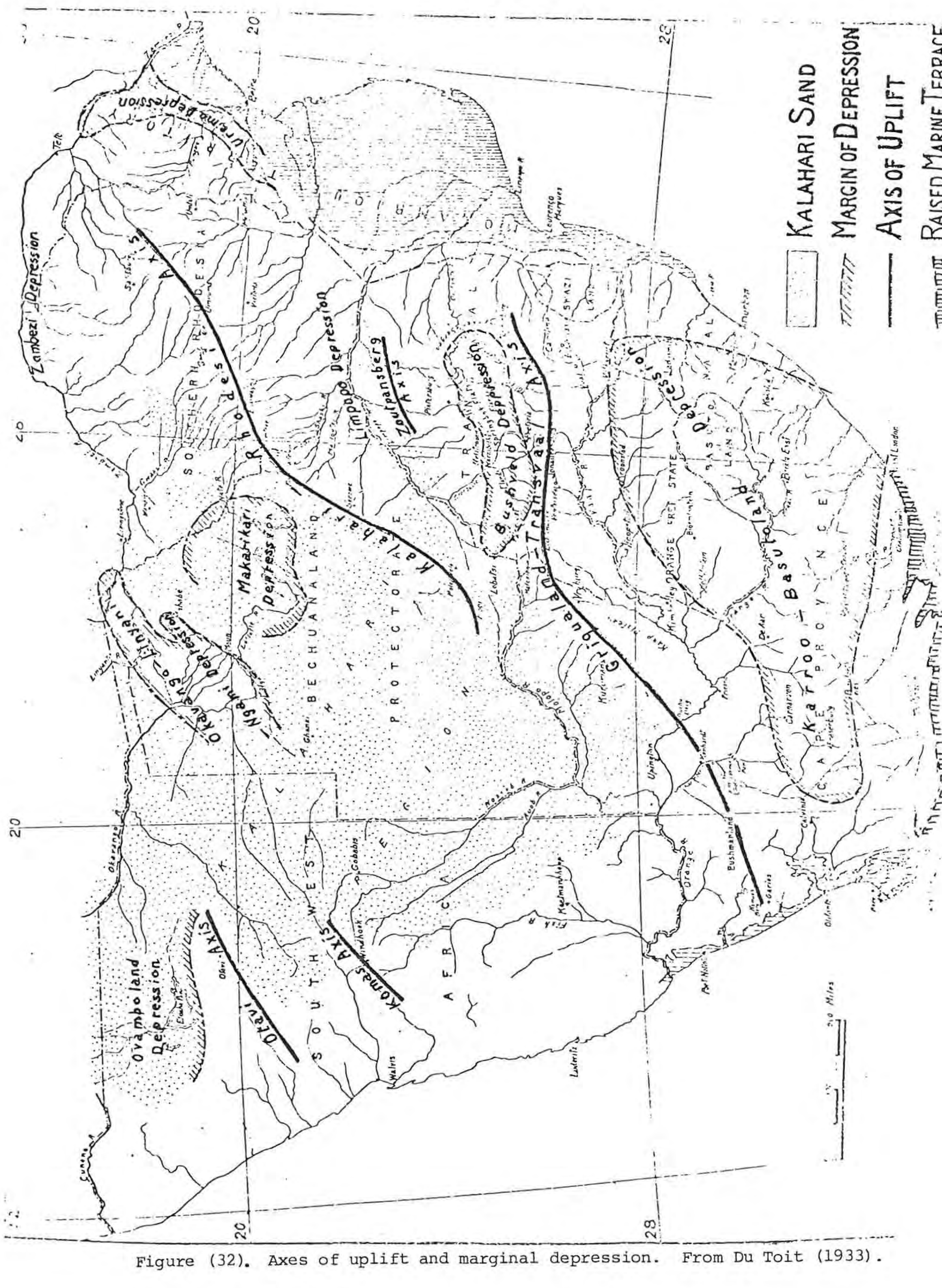


Figure (32). Axes of uplift and marginal depression. From Du Toit (1933).

newly established rivers of the area in cutting down through the resistant quartzite ridges to establish the superimposed drainage characteristic of the Pretoria-Witwatersrand area (Figure 31). Thus the Witwatersrand escarpment could possibly represent a nickpoint between two phases of the African erosion cycle, the lower of which was generated by rejuvination of an older surface by uplift along the Griqualand - Transvaal axis and concomitant sagging of the Bushveld Basin.

This suggests that relationships between different erosion cycles is the Pretoria - Witwatersrand area may possibly be more complex than suggested by Partridge (1968). A possible sequence of events in this area is proposed below :

i) Formation of an extensive African pediplain during the mature phase of the African cycle, related to southwest and west flowing drainage into the Molopo and other rivers. This pediplain may still be preserved in the East Rand as the well-planed surface on Karroo rocks in the Springs - Benoni area.

ii) Uplift along the Griqualand - Transvaal axis, with differential sagging of the Bushveld Basin (Figure 32), causing extensive rejuvination of the pre-existing pediplain and initiating the parallel scarp retreat presently evident along the Witwatersrand escarpment. Thus the cutting of a new ('African II') pediplain below this zone of scarp retreat occurred. This 'African II' pediplain was cut just below the Pre-Karroo surface in the area of the Kyalami land system. Thus the weathering on this surface attributed to the existence of the 'ancient' African surface in this area (Partridge 1968) may be more a result of the coincidence of an African II pediplain with the Pre-Karroo surface.

iii) Advance of the Post-African erosion cycle up the rivers, and the resultant modification to the African landforms described in Section (1).

It will be appreciated that where rejuvination of the landforms due to uplift along the Griqualand Transvaal axis did not initiate active scarp retreat, the effects of this rejuvination on the 'ancient' African pediplain may be difficult to distinguish from modification resulting from advance ofthe Post-African cycle.

Du Toit's (1933) suggestion that the predominantly northeastern orientation of the axes of uplift (Figure 32) indicate a correlation with the East African rift system is valid, particularly with respect to the Khomas axis in South West Africa which is located on an extension of the Okavango lineament where recent, minor tectonic movement is still occurring. Five important upland areas thought to contain remnants of the Gondwana and Post-Gondwana surfaces occur along these axes of uplift (Figure 32), namely : the Central Rhodesian highland belt (King 1951); the Zoutpansberg; the Northern Cape highlands around Kuruman and Prieska; the Windhoek highlands; and the Otavi-Tsumeb mountainland (Map 1 - Partridge, 1968 after King).

It is unlikely that remnants of the Gondwana surface exists on these uplands since they may only have achieved their present elevation fairly recently as a result of uplift along these axes. Therefore they may formerly have been part of a mature landscape fashioned during the African cycle of erosion prior to uplift.

Any interpretation of the African cycle landforms in Southern Africa must take into account the possible effects on the landscape of uplift along these axes. It is suggested that, as in the Pretoria - Witwatersrand area the African cycle may be polycyclic as a result of rejuvination accompanying this uplift.

Post-African erosion cycle in the interior

Partridge (1968) has clearly shown the existence of a younger erosion cycle in the Pretoria - Witwatersrand area. Advance of the younger Post-African erosion cycle on the landforms of the older African cycle, has caused lowering of the landscape of the Kyalami land system by slope decline under predominantly surface wash processes. Along the Witwatersrand escarpment, advance of the Post-African erosion cycle has resulted in more efficient removal of debris and consequent re-exposure, or lengthening of the free face and regrading of the pediments. This has been fully described in Section (1).

The Post-African cycle is more advanced north of the Witwatersrand watershed than it is to the south. This can be attributed to three possible factors :

i) Initiation of the Post-African erosion cycle in the northward directed drainage may have occurred before its initiation in the southward directed drainage, due to the time lag in break-up of the northeastern and western continental margins.

ii) The southward directed drainage along the Witwatersrand watershed is much further from the coast than northward directed drainage. Thus the Post-African cycle may well have arrived at the Witwatersrand watershed sooner along the northward directed drainage than along the southward directed drainage.

iii) The Post-African cycle in the northward directed drainage may have been afforded an easier passage up the Limpopo Mobile Belt than up the southward directed drainage, where a greater variety of rock types including the resistant strata of the Transvaal Supergroup may have hindered its progress.

However, there can be no doubt of the existence of a younger erosion cycle throughout the interior of Southern Africa which has caused large scale rejuvination of the drainage resulting in erosion, or modification of African cycle landforms. Thus the suggestion by De Swardt and Bennet (1974) that "there is only one erosion surface over the greater part of the interior highveld of South Africa" (p. 319) cannot be substantiated.

In view of the general character and extent of the Post-African erosion cycle, namely, advance of the cycle by headward incision and generation of more mature forms (e.g. pediplains) further downstream, the cycle must have migrated up the major rivers from the coast. Thus it was not initiated by major climatic changes, or minor tilting of the landsurfaces of the interior. King (1963) is of the opinion that this cycle was initiated by "gentle updoming of the sub-continent" (p. 209). Partridge (1968) is of the same opinion : "Originating in moderate epeirogenic uplift during the Oligocene and again during the Miocene, this (Post-African) cycle has affected large areas of the interior plateau by way of the major river basins" (p. 34).

In the earlier discussion on the work of De Swardt and Bennet (1974) it was suggested that it is unlikely that large scale epeirogenic uplift on a continental scale has ever occurred in Southern Africa, and that Africa probably always stood relatively high since the break up of Gondwanaland in late Jurassic - early Cretaceous times. Thus the initiation of the Post-African erosion cycle in the interior of Southern Africa cannot be attributed to epeirogenic uplift of the sub-continent.

In view of these observations it is suggested that the Post-African erosion cycle in the interior, owes its origin to landward capture of the vast inland drainage systems by headward incision of coastal rivers beyond the great escarpment into the interior. The Kalahari Basin acted as base level to the interior drainage systems before capture occurred. Thereafter, the sea level became the new base level for the majority of the inland drainage systems.

Thus the majority of the inland drainage systems find an outlet to the sea through relatively narrow gaps in the great escarpment along the major rivers (i.e. Cunene, Orange, Limpopo and Zambezi). De Swardt and Bennet (1974) suggest that these only became major rivers in Eocene or possibly earlier times, due to capture by coastal rivers of the inland drainage. However, they attribute the first major nickpoints along these rivers (e.g. Ruacana, Augrabies, and Victoria Falls) as being formed as a result of this capture. I suggest that these major nickpoints and associated gorges, along with similar features in rivers between the great escarpment and the coast (e.g. Oribi Gorge in Natal), are the result of major eustatic drop in sea level during Pliocene times and were not generated by capture of the inland drainage by these rivers, as suggested by De Swardt and Bennet (1974). The retreat of these nickpoints beyond the great escarpment (i.e. further inland than in the coastal rivers) since this time (Pliocene) can be expected due to their large volume and consequently greater erosive power.

The views of Dingle (1973) and Dingle and Scrutton (1974) appear to contradict the above suggestion that the drainage basins of the interior only achieved access to the coast via landward capture by coastal rivers some time after the break-up of Gondwanaland occurred. They are of the opinion that the interior drainage basins, through the major rivers (Orange, Limpopo, Zambezi) always had access to the coast since the break-up of Gondwanaland. They imply that these drainage basins today, are little altered from the drainage basins of late Jurassic - early Cretaceous times, and that these major rivers always supplied large amounts of sediment to the offshore basins because of their access to the interior. Thus in

Figures (25) and (26) (from Dingle and Scrutton, 1974), the present courses of the major rivers are plotted on their reconstruction of Gondwanaland at the time of break-up.

Dingle and Scrutton (1974) p. 1467, state that "In Mozambique, the earliest rift ($\pm$ 180 m.y. B.P.), between East and West Gondwanaland produced a north-south-trending series of large horsts and grabens which were buried beneath detribus from the Limpopo and Zambezi river systems." They also remark that "when West Gondwanaland broke up (125 to 130 m.y. B.P.), a large sediment wedge (Orange Basin), was initiated on the west coast of Southern Africa by discharge from the Orange River and associated rivers onto a downfaulted tensional formed margin."

Thus the implication is that the thickest sedimentary basins which developed off these river mouths owe their origin in part to the prior existence of these major rivers and their associated large interior drainage basins. However, they also mention the importance of structure in generating these major basins and as a result, drainage into these areas was probably more active than elsewhere along the downwarped margins of Southern Africa, due to the greater relief which existed in these areas. Consequently, these basins accumulated greater amounts of sediment. These rivers were therefore eventually able to cut back through the great escarpment to capture the inland drainage, while other rivers which did not have this advantage of relief, remained on the seaward side of the great escarpment as it receded inland. These rivers may also have been located along structurally weak zones (e.g. transform faults) developed during break-up of the Gondwanaland as suggested earlier for the Orange River (Figure 28).

The effects of this inland drainage capture on landforms of the African cycle would have been identical to the effects produced by widespread, uniform epeirogenic uplift of the continent, provided an outlet to the sea existed prior to uplift. The net result of either process would be a reduction of regional base level. Thus, although the mechanism of initiation given for the Post-African cycle in the interior by Partridge (1968) is probably incorrect, his description of its effects on landforms of the African cycle discussed in Section (1) remains unchallenged.

Although the African and Post-African erosion cycles were generated at the same time on either side of the great escarpment, the initiation of the Post-African cycle in the interior occurred at a later stage when it advanced up the major rivers following capture by these rivers of the inland drainage. Except where rejuvinated landforms of the African cycle exist atop resistant mountains by-passed by retreat of the great escarpment (Figure 15), no correlation can be made between African cycle landforms inland of the great escarpment and landforms between the great escarpment and the coast.

Advance of the Post-African cycle into the interior has resulted in split nickpoints being developed as described in Section (1). This could explain the apparent polycyclic nature of this cycle (King's, Post-African I and Post-African II surfaces). Thus the Post-African cycle is represented in various stages from final mature pediplanation (e.g. the Sprinbok Flats) through intermediate stages (e.g. valley planation; 'perched' pediplains resulting from splitting of nickpoints), to the zone of active erosion and headward incision in the upper, younger stages of the cycle.

The resistant Doornberg ranges northwest of Prieska have caused splitting of a Post-African nickpoint. Du Toit (1933) reports that the gradient of the Orange River is 1,7 feet per mile above the Buchuberg and 2,75 feet per mile below it. In the Pretoria - Witwatersrand area, similar nickpoint splitting in the Post-African cycle has occurred across the Timeball Hill quartzite and the Giant Chert horizon of the Transvaal Supergroup.

The Post-African cycle between the great escarpment and the coast

As explained above this cycle was initiated by rifting of the continental margins and resultant vigorous erosion of the graben sides initiating parallel retreat, which is still occurring. Due to the paucity of published work on erosion surfaces between the great escarpment and the coast for regions outside Natal, only general suggestions based mainly on the work of De Swardt and Bennet (1974) can be made. It appears that the coastal arches seem to have migrated further inland in Natal than in other regions of Southern Africa where they are often apparently situated close offshore (Figures 28 and Map 4). Since later deformation of the landsurface has been centred around the coastal arches, it can therefore be expected that landforms in regions between the great escarpment and the coast, outside of Natal may have undergone less deformation and rejuvination than in Natal.

It will be appreciated from the earlier discussion on the work of De Swardt and Bennet (1974) that the Post-African cycle between the great escarpment and the coast may be represented by immature forms near the great escarpment, and mature pediplains in the coastal interior and that gradations between the two phases will occur, as in Natal, with the mergence of the Richmond Dalton surface with an intermediate valley planation phase closer to the great escarpment.

The importance of structure must be stressed, since in horizontal strata such as the Karroo and (in places) the Cape Supergroups, resistant rock types may give an appearance of locally accordant summit levels to which cyclic significance could mistakenly be attributed. The possible importance of the differential scarp retreat process (Figure 13), and generation of by-passed residuals (Figure 15), must be appreciated when assessing the landforms of an area. By-passed residuals behind the great escarpment will exhibit remnant landforms of the erosion cycle active on the surface before it became cut-off from the interior drainage.

The mountains of the Cape fold belt (Figure 14, Map 1) may be by-passed residuals in which case their summits should exhibit remnant landforms of the African cycle. They may also have been formed by differential scarp retreat, in which case less resistant Karroo Supergroup cover rocks have been stripped off by differential scarp retreat thereby uncovering a fresh surface. However, these summits are not regarded as representing remnants of the Gondwana surface (see Map 1). These resistant ranges have exerted a dominant influence on topography ever since they were exumed by retreat of the great escarpment. Planation has since reduced much of the surrounding country which now represents mature phases of the Post-African cycle. The silcrete covered Grahamstown pediplain is an example of these mature phases of the Post-African cycle, and the influence of structure is clearly deomonstated by the resistant quartzite ranges which surround it in the West. The drainage off these quartzite ridges was probably an important factor in forming the well developed silcrete capping common to this and other mature pediplains of the Post-African cycle in the southeast Cape interior. (Note : Mountain has called this the Grahamstown peneplain but attaches no genetic significance to the term peneplain, pers. comm.)

Features such as the Grahamstown pediplain can be correlated with the Richmond Dalton surface only in the sense that they both represent mature landforms of the Post-African cycle between the great escarpment and the coast. The do not represent remnants of an original surface extending from Natal to the southeast Cape. The Richmond Dalton surface in Natal, particularly where it is formed on dolerite, is characterized by the development of laterites which are bauxitic in places.

Substantial modification to these pediplains of the Post-African cycle may occur as a result of later tilting, and/or uplift which in Natal occurred mainly along the Natal hingeline which coincides with the present crest of the Natal arch. The problem of correlation of different landforms may therefore be resolved to recognition of the deformation which these mature landforms of the Post-African cycle may have undergone. It will be appreciated that since this later deformation is probably related to the coastal arches, and not to epeirogenic uplift of the interior and coastal flexing of the continental margins, this deformation would probably have occurred at different times in different places along the coast. Therefore, no correlation of rejuvinated landforms of the Post-African cycle in different parts of the coastal regions can be made. Likewise, it can be expected that offshore sediments need not always show regional correlation since sediment supply would haye been strongly influenced by local deformation along the coastal arches.

Plio-Pleistocene cycle

Later local deformation of Post-African or African landforms related to tectonic disturbance along the coastal arches or interior axes of uplift respectively have caused local rejuvination of these landforms. However their is strong evidence of a later major event of regional significance which has initiated the younger vigorous erosion cycle evident around most of the coastal margins of Southern Africa. This has caused deep incision of coastal rivers producing the characteristic spectacular gorges common to the coastal regions.

It is suggested that major eustatic sea level regression during Plio-Pleistocene times initiated the coastal erosion cycle. McCarthy (1967) has presented evidence for major sea level regression of about 200 metres off the Natal coast in Pliocene times. Subsequent return of the sea level during Pleistocene times buried the incised coastal rivers and resulted in aggradation of coastal rivers with the result that these rivers now flow in river valleys containing thick accumulations of alluvium.

This Plio-Pleistocene cycle has apparently advanced as far as the great escarpment in the Eastern Transvaal (Map 1), and has further complicated the relationships between the different erosion cycles there. The Post-African erosion cycle is much more advanced north of the Witwatersrand watershed than south of it. Consequently it has, in parts of the Eastern Transvaal eaten back to the great escarpment which, prior to advance of the later Plio-Pleistocene cycle was being eaten back to parallel scarp retreat also within the Post-African cycle.

Dissection along the coastal side of the great escarpment is now polycyclic due to advance of the Plio-Pleistocene cycle. This situation is analogous to the Witwatersrand escarpment described earlier, where dissection is now becoming polycyclic due to the advance of the Post-African cycle on the zone of scarp retreat of the African cycle.

The more rapid advance of the Plio-Pleistocene cycle in the Eastern Transvaal is a result of its proximity to the Limpopo River and the fact that Post-African planation would have been well advanced in this area prior to initiation of the Plio-Pleistocene cycle.

Elsewhere, the Plio-Pleistocene cycle has been extended up the rivers from the coast to a distance proportional to the size of the river. Thus it is that this cycle has extended further than the great escarpment up the major rivers where the first major nickpoints (e.g. Ruacana, Augrabies, Victoria Falls) represent the advance of this Plio-Pleistocene cycle into the interior.

Cretaceous to Recent coastal sediments

Correlation of Cretaceous to Recent coastal sediments and their related wave cut terraces is complex due to later erosion and deformation. The effects of tilting, and/or uplift along the coastal arches, eustatic sea level changes, subsidence of the coastal and/or offshore regions and erosion will modify and sometimes destroy earlier sedimentary sequences or coastal terraces. For instance, variation of terrace levels on the Transkei coast is ascribed to warping of the wave cut terrace after its formation (Thompson, 1942). Ruddock (1968) describes seaward tilting of terraces between transgressions of the Eastern Cape coast.

These Cretaceous to Recent sediments wil not be discussed since they concern the immediate coastal and offshore regions which make up only a small part of Southern Africa. That they may play an important part in dating events on land cannot be denied but, as stated by De Swardt and Bennet (1974) considerably more information of offshore sediments and the tectonic evolution of coastal regions is required before reliable correlation of offshore sediments with events on land can be made. Some of the important references on Cretaceous to Recent offshore and coastal sediments are :

De Swardt and Bennet (1974)
Dingle (1971, 1973)
Dingle and Scrutton (1974)
Du Toit (1920)
Du Toit and Leith (1974)
Frankel (1968)
King (1970)
Lock (1973)
Maud (1961, 1968)
McCarthy (1967)
Ruddock (1968)
Scrutton et al. (1973)
Siesser (1972)
Siesser et al. (1974)
Simpson and Dingle (1973)
Thompson (1942)
van Andel and Calvert (1971)

The Lesotho highlands

The Lesotho highlands have long been the subject of controversy among geomorphologists. The following discussion is an attempt to explain the observed landforms in the light of the above interpretation of the erosion cycles in the interior of Southern Africa.

De Swardt and Bennet (1974) have given the following description of the physiographic features of the Lesotho highlands. Wide westward sloping U-shaped valleys are the dominant features, separated by sharp crested interfluves which, although appearing flat when viewed from a distance (e.g. Figure 19) do not in their opinion represent remnants of an ancient erosion surface. At the junctions of these interfluves, small mesas of resistant lava occur, which may be surmounted by even smaller mesas.

A dissected landscape is being produced by the headward advance of an active erosion cycle up the U-shaped valleys. This dissected landscape is in turn being encroached upon by a later cycle which is carving steep V-shaped valleys. These relationships are represented in Figure (33).

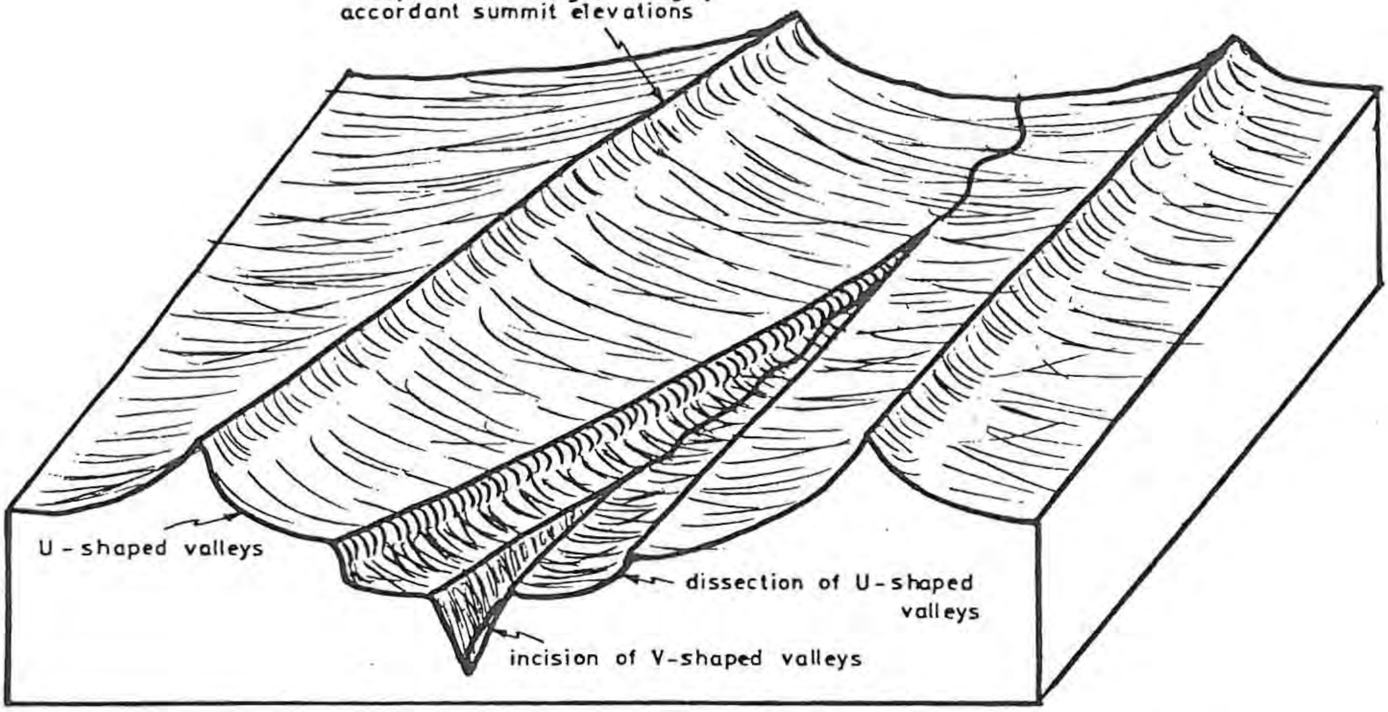


FIGURE (33). Hypothethetical representation of the main physiographic features of the Lesotho highlands.

King (1963, 1976) regards the sharp crested ridges as being remnants of the Gondwana surface preserved in almost pristine condition since the Jurassic break-up of the continents. The U-shaped valleys are ascribed by him as being formed during erosion of the Gondwana surface immediately after rifting to form the Post-Gondwana surface (Figure 19). Map (1) shows most of the rest of Lesotho as belonging to the African surface with the Post-African cycle encroaching up the major river valleys.

De Swardt and Bennet (1974) however, believe that there is no evidence of a Jurassic erosion surface suggesting that at the most, the rough, regional accordance of summit heights of the sharp crested inter-fluves may be ascribed to lowering of some plain which originally stood at a higher elevation (e.g. erosion surface, or structural surface such as the top of the lavas). They claim that there are no grounds for the correlation of the wide U-shaped valleys with any surface or event elsewhere (e.g. King claims this surface was produced during erosion which supplied lowermost Cretaceous sediments to the downfaulted basins off the continental margins). They conclude that the valleys may represent a phase of the present erosion cycle stranded as a result of local uplift or climatic change and that they may have been moulded by periglacial action during Pleistocene times.

The following explanation is offered: Arguments have already been advanced in favour of a fairly rapid destruction of the original Gondwana surface as a result of rejuvination caused by landward tilting and upwarping of the continental margins during rifting (Figure 29). The westward tilt of the landscape is probably a reflection of this original tilting. Note that rejuvination of the drainage by tilting immediately affects all rivers, therefore destruction of the landforms is much more rapid than in rapid changes in ultimate base level where landsurfaces remain untouched by the new erosion cycle until it has advanced up the rivers from ultimate base level. Thus, in agreement with De Swardt and Bennet (1974), the existence of the ancient surface of Gondwanaland in the highlands of Lesotho (and inland of the great escarpment elsewhere) is regarded as highly unlikely.

The wide U-shaped valleys, rather than representing a Post-Gondwana surface probably represent an intermediate valley planation phase of the African cycle in which the sharp crested interfluves are being lowered as a result of the meeting of opposing slopes. These were formed downstream of the more active phase of the African cycle, originally with its headwaters on the landward facing rift shoulders near the original continental margin. These headwaters were gradually reduced by the inland migration of the great escarpment due to the action of the more vigorous Post-African cycle, seawards of the great escarpment.

Consequently, as the great escarpment approached, the flow in the rivers of the present Lesotho highlands was reduced, thereby greatly reducing the rate of removal of detritus by these rivers. Thus, material would tend to accumulate on the pediment which may in part explain the broad U-shaped valleys observed, although these may also owe their origin in part, to Pleistocene periglacial activity. However, as suggested above, these effects were probably superimposed on an already existing topography not unlike the present, namely an intermediate valley planation phase of the African cycle.

Thus these valleys may have formed in a similar manner to the broad intermediate valley planation phase at Kangnas in the Northwest Cape described by Mabbutt (1955).

The two younger erosion cycles advancing up the U-shaped valleys may have resulted from splitting of the Post-African cycle across a resistant barrier. Thus, part of the Post-African cycle may have advanced above a resistant barrier (the lava pile?), producing a dissected topography by incision of the U-shaped valleys. The advance of the V-shaped valleys may therefore represent the main portion of the Post-African erosion cycle.

Some considerations on South West Africa

African and Post-African cycles : These cycles are thought to be fairly accurately represented on Map (1). The African cycle has produced a very well planed surface inland of the great escarpment (the 'Owambo surface'), which is characterized by an extensive calcrete covering. South of Windhoek, the break between the African cycle in the interior and the Post-African cycle to the west is fairly well marked by the great escarpment which clearly separates the arid Namib plain and sandy desert from the semi-arid interior. In part, the lack of relief on this surface can be attributed to the fact that the African landforms are erosional in the west and depositional in the east, i.e. material eroded during planation in the west was deposited in the Kalahari Basin in the east by the inland directed drainage. During a higher rainfall period when most of the calcretes on the surface were formed, calcrete was deposited over the erosional and aggradational phases of the African cycle producing an extremely level surface.

The break between the African and Post-African cycles is not as distinct to the north of Windhoek since the great escarpment is not as well developed. This is probably more a result of structure than anything else i.e. the poorly developed nature of the great escarpment can probably be attributed to the absence over much of this area of sub-horizontal strata such as the Karroo Supergroup. Nevertheless, the breakaway between the interior African erosion cycle and the coastal Post-African cycle can often be clearly demarcated on aerial photographs owing to the better development of calcrete on the African cycle plains.

The Post-African cycle has produced the remarkably smooth Namib plain evident north of the Kuiseb River and also containing fairly well developed calcrete in most places. The Post-African erosion cycle has extended for some distance into the interior up the north-south Fish River which, with its tributary the Konkiep River to the west has affected complete capture of all the streams which originally flowed eastwards off the landward side of the great escarpment into the Kalahari Basin. In places resistant residuals remain on the gently sloping coastal surface which were probably by-passed by the great escarpment on its migration into the interior (e.g. Spitskop)

The Plio-Pleistocene cycle and Quaternary uplift : The Plio-Pleistocene cycle has been extended up the Orange River to Augrabies Falls and also extends for some distance up the Fish and Konkiop Rivers. It is not known how accurately this cycle is represented between Windhoek and the coast. The apparent lack of incision of the rivers immediately adjacent to the coast demands explanation since deep incision of coastal rivers, thought to be due to major eustatic sea level regression, is a common characteristic of coastal regions in the remainder of Southern Africa. This river incision is usually accompanied by planation of new surfaces (e.g. Eastern Transvaal Lowveld), which extends inland from the coast and is usually separated from higher ground representative of the Post-African cycle. It is suggested that the area inland of the present coast does not show evidence of vigorous incision of a new erosion cycle by headward erosion of the rivers starting at the coast and moving inland.

On the contrary, it is apparent that incision of the rivers is minimal at the coast and rapidly increases inland towards the Khomas Hochland, which is arguably the most dissected area in Southern Africa. The apparent lack of incision of these rivers adjacent to the coast would appear to invalidate the previous suggestion that the vigorous coastal erosion cycle evident along the coast in the rest of Southern Africa, was caused by major eustatic regression of sea level, since eustatic sea level changes must affect the entire coast.

These relationships can best be explained by major upwarping of the area around Windhoek in late Quarternary times along the Khomas axis (Figure 32). Further evidence for this uplift is the Windhoek graben which is a broad flat valley trending north-south and bounded by prominent scarps in which the Swakop and Kuiseb rivers rise. The suggested sequence of events is as follows :

i) Major eustatic regression of sea level off the South West African coast during Pliocene times (as suggested for the rest of Southern Africa).

ii) Initiation of a vigorous erosion cycle which advanced by headward incision up the coastal rivers (the Plio-Pleistocene) erosion cycle.

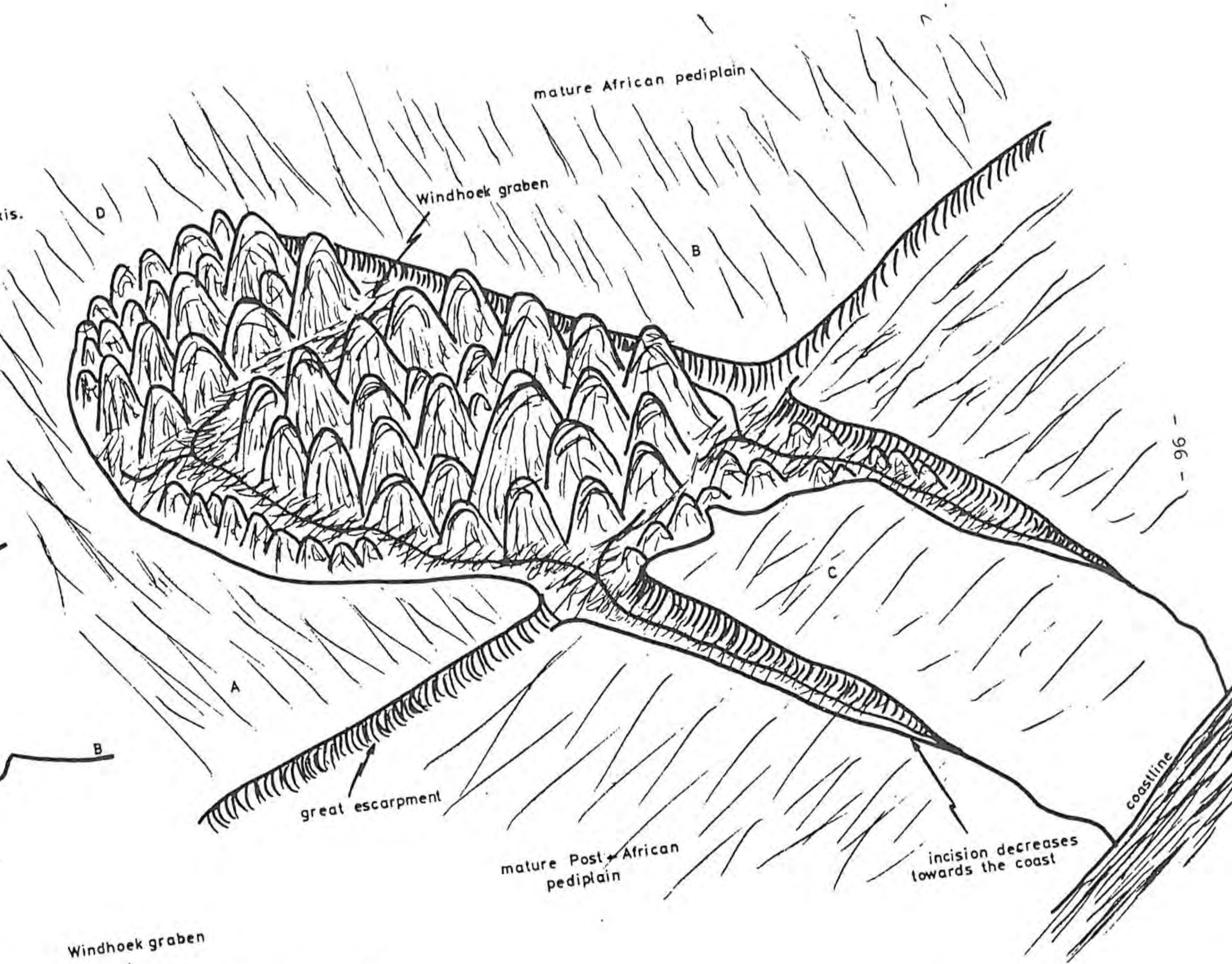
iii) Subsequent return of the sea level to beyond the zone of incision initiated by the preceding regression, thus drowning the newly incised coastal rivers and preventing continued advance of the Plio-Pleistocene erosion cycle. Note that the sea level did not return to beyond the zone of incision in the rest of Southern Africa, thus allowing advance of the Plio-Pleistocene erosion cycle. Therefore the South West African coast must have undergone considerable subsidence after the Pliocene regression which probably occurred at the same time as the uplift along the Khomas axis further inland.

It therefore appears that the upwarping along the Khomas axis occurred in Post-Pliocene times which accounts for the extremely youthful character of the drainage in the Khomas Hochland. It is apparent that this upwarping was confined to pre-existing lines of weakness namely, the boundaries of the early Palaeozoic Khomas trough in the central Damara Belt.

This upwarping complicated the relationship between the well planed surfaces of the African and Post-African erosion cycles as illustrated in Figure (34). Essentially, both surfaces were upwarped and dissected and the line of the great escarpment destroyed. Existing river valleys were deeply incised, this incision decreasing towards the coast, thus the gorges so formed get narrower and shallower towards the coast since the amount of upwarping decreases towards the coast (Figure 34).

The upwarped African and Post-African pediplains are terminated abruptly, often by scarps facing into the dissected area formed by the vigorous erosion accompanying large scale rejuvination of the drainage. The dissected areas, because of the active erosion are characterized by much higher geochemical background values than the calcrete covered African and Post-African pediplains. This can complicate interpretation of geochemical sampling results in areas located near the boundary between the rejuvinated landforms and the older mature pediplains, unless it is realized that two completely different sample populations are present.

FIGURE (34). Effects of upwarping along the Khomas axis.



Sections:-

The present assumption (Map 1) that these highlands represent remnants of the Gondwana erosion surface cannot be upheld. Prior to the recent uplift, this area must have formed part of a mature landscape planed down by the African and Post-African erosion cycles, as attested to by the present stage of these cycles in the area. Remnant landforms of the African cycle may have formed resistant residuals (e.g. Gamsberg and Aus Mountains). Subsequent upwarping and rejuvination resulted in intense erosion of these surfaces so that today, except perhaps in a few places, they have been completely destroyed. It is therefore highly unlikely that remnants of the original Gondwana landsurface could have survived.

3. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The present study suggests that the landforms of Southern Africa have been formed by only three erosion cycles. Two of these were generated by rifting during the late Jurassic - early Cretaceous break-up of Gondwanaland. Vigorous erosion of the steeply sloping graben sides resulted in the formation of a major scarp which has since migrated by parallel retreat to its present position along the great escarpment, this being the head scarp of the Post-African erosion cycle. Landward tilting of the rift shoulders caused widespread rejuvination of the interior drainage, initiating the African erosion cycle which developed with the interior Kalahari Basin as base level. Capture of the vast interior drainage cycles by landward retreat of a few coastal rivers beyond the great escarpment extended the Post-African erosion cycle into the interior. This has caused widespread rejuvination of African cycle landforms, the results of which have been described for the Pretoria - Witwatersrand area by Partridge (1968).

Subsequent local upwarping and tilting causing local rejuvination of the African and Post-African landforms has occurred. This upwarping and tilting has taken place along fairly well defined axes of uplift in the interior, and along the coastal arches in the coastal regions.

A third erosion cycle, namely the Plio-Pleistocene cycle was probably initiated by major eustatic regression of sea level during Pliocene times. This cycle extends up the river valleys from the coast and is responsible for the deep incision of most of the rivers inland of the coast.

It is highly unlikely that remnants of a Gondwana and Post-Gondwana erosion surfaces exist in the highlands of Southern Africa. It is more likely that landforms currently attributed to these surfaces represent remnant landforms of earlier stages of the African cycle of erosion, or are rejuvinated African and Post-African landforms, this rejuvination being due to Quaternary upwarping of these landforms (e.g. the Khomas Hochland).

The currently held theory that Southern Africa has evolved through a series of successive phases of epeirogenic uplift separated by periods of erosion during which the sub-continent was planed down to a few hundred metres above sea level cannot be accepted. The alternative suggestion by

De Swardt and Bennet (1974), that Africa has always stood high since the break-up of Gondwanaland and has probably never been reduced to a low altitude plain is preferred. The interior Karroo, Witwatersrand/Transvaal and Bushveld Basins would probably have been destroyed by erosion if successive periods of uplift and planation had occurred. The upwarping of the continental margins during rifting however would have had the important effect of preserving these basins.

Recommendations

Further study

There are two studies which could arise from the suggestions made in this review. Firstly, there is a need to follow up these suggestions with a far reaching and detailed field investigation in order to establish their validity. This review does not presume to be the final answer and it is fully expected that an investigation of this kind would modify or significantly change the above conclusions.

However, by indicating the discrepancies which exist in the present geomorphological classification of Southern Africa, and by suggesting some important modifications to this classification, it is hoped that a new interpretation has been initiated which will eventually be reconciled with the observed facts.

The second study which could profitably be carried out would involve combining the conclusions of Section (1) and Section (2) to obtain a workable geomorphological - land system classification of Southern Africa which could be practically applied to the important, often maligned field of geochemical soil sampling surveys. A classification of this sort would involve uniting such varied factors as soil formation, weathering, duricrust formation and climate within a geomorphological - land system framework.

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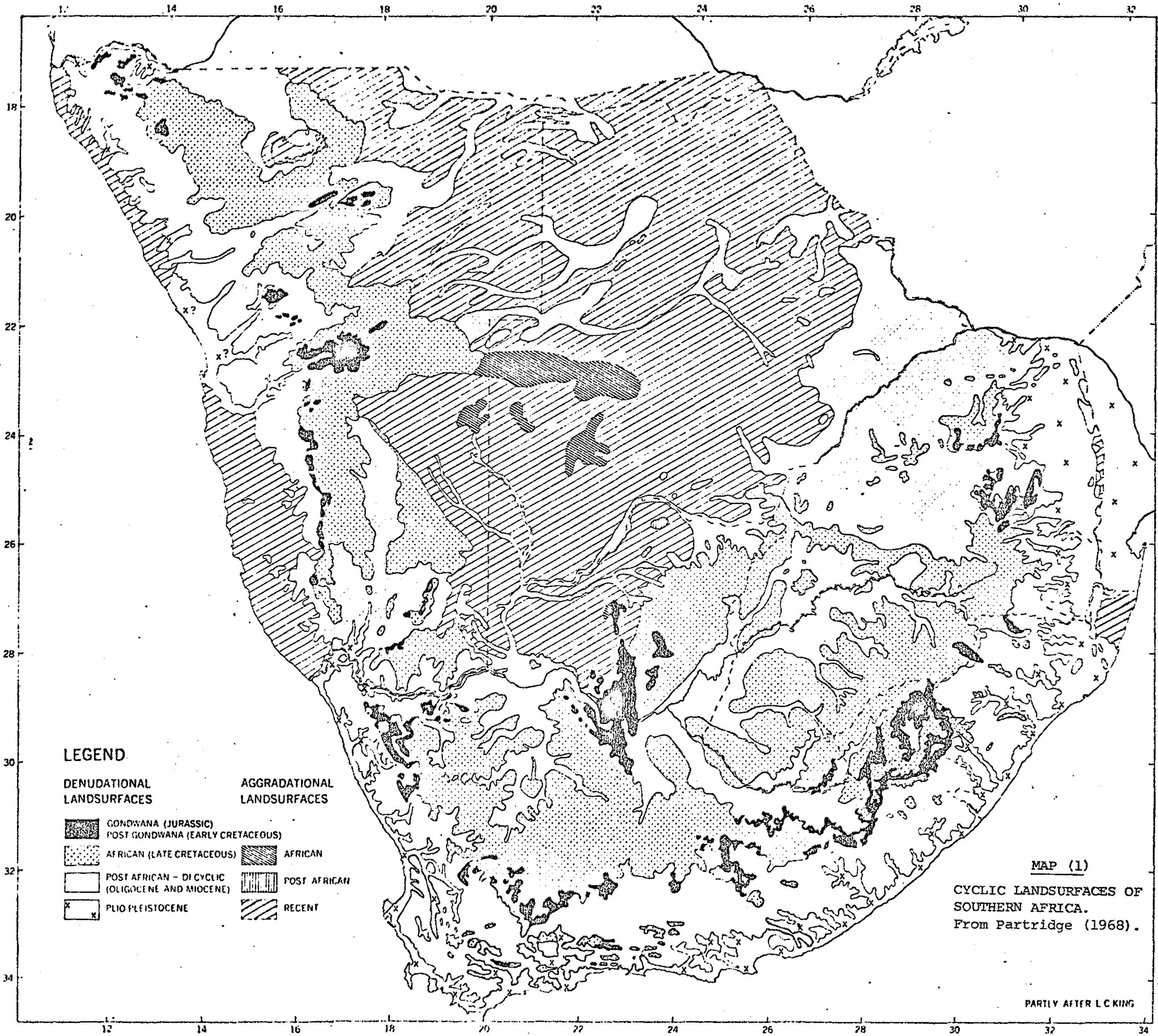
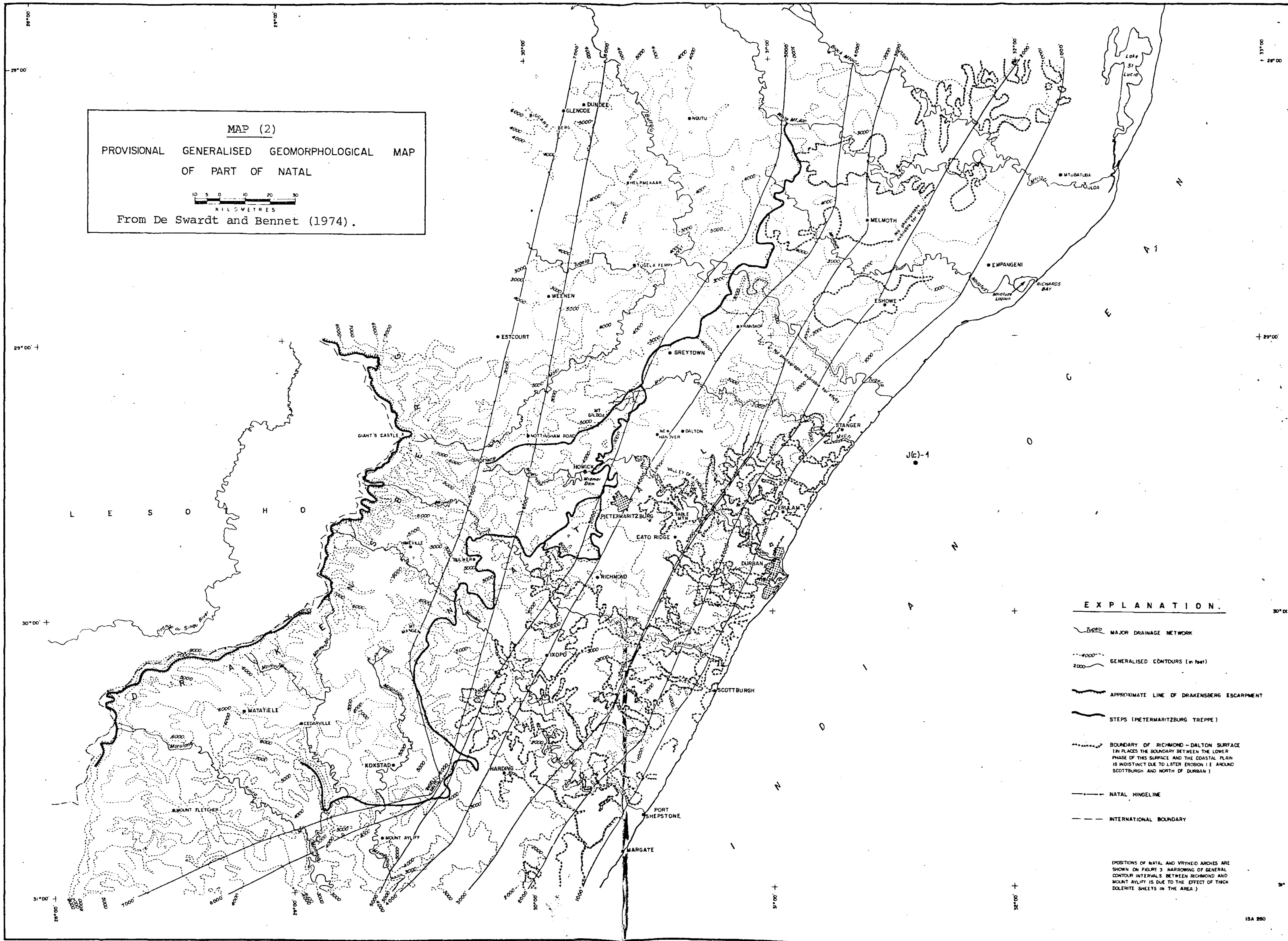
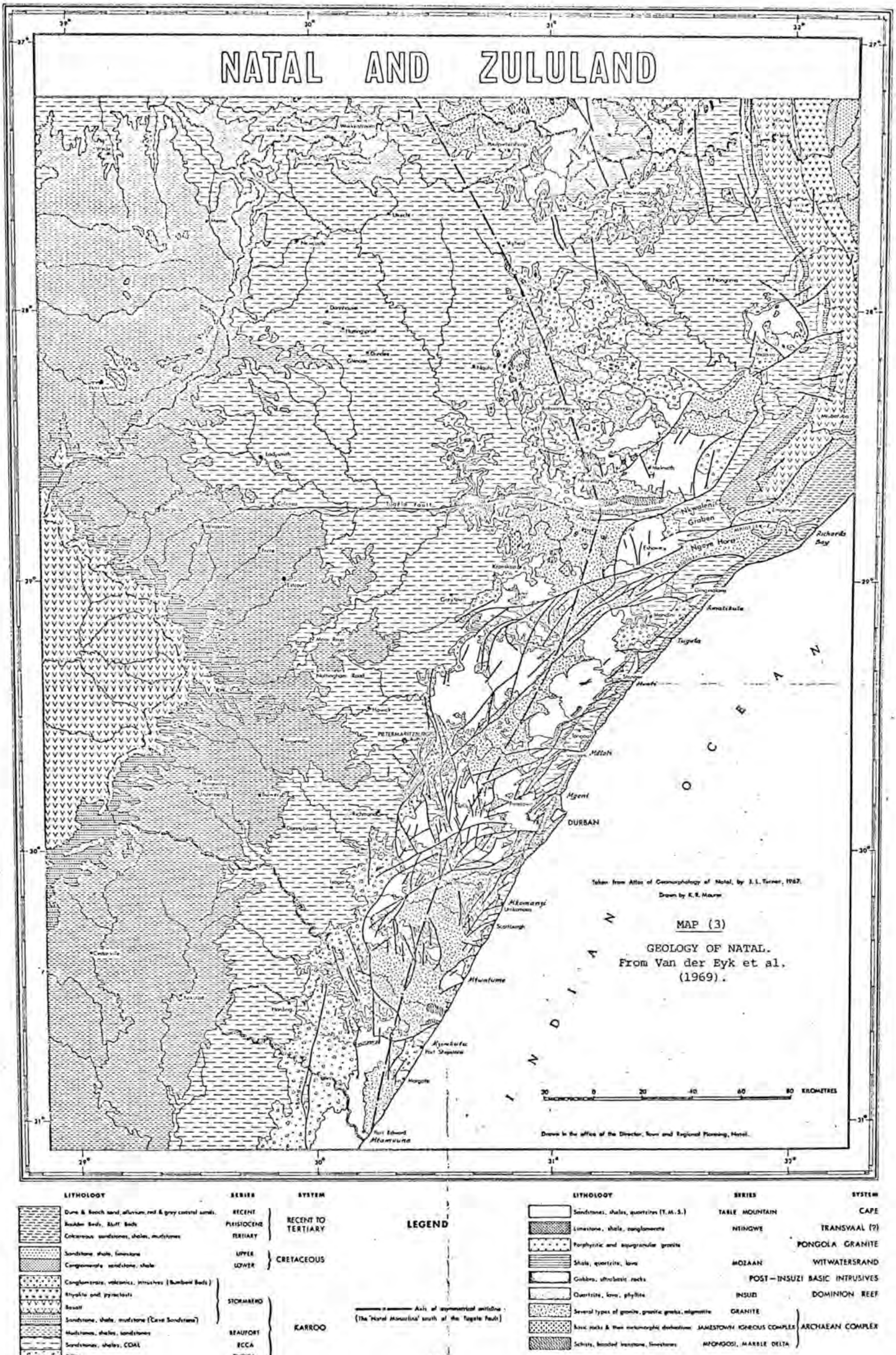


MAP (1)

CYCLIC LANDSURFACES OF SOUTHERN AFRICA.
From Partridge (1968).


MAP (2)
PROVISIONAL GENERALISED GEOMORPHOLOGICAL MAP
OF PART OF NATAL
KILOMETRES
From De Swardt and Bennet (1974).
EXPLANATION.
Tugela
MAJOR DRAINAGE NETWORK
4000
2000
GENERALISED CONTOURS (in feet)
APPROXIMATE LINE OF DRAKENSBERG ESCARPMENT
STEPS (PIETERMARITZBURG TREPPE)
BOUNDARY OF RICHMOND – DALTON SURFACE
(IN PLACES THE BOUNDARY BETWEEN THE LOWER PHASE OF THIS SURFACE AND THE COASTAL PLAIN IS INDISTINCT DUE TO LATER EROSION I E AROUND SCOTTBURGH AND NORTH OF DURBAN)
NATAL HINGELINE
INTERNATIONAL BOUNDARY
(POSITIONS OF NATAL AND VRYHEID ARCHES ARE SHOWN ON FIGURE 3 NARROWING OF GENERAL CONTOUR INTERVALS BETWEEN RICHMOND AND MOUNT AYLIFF IS DUE TO THE EFFECT OF THICK DOLERITE SHEETS IN THE AREA.)
LESOTHO
INDIAN OCEAN
DRAKENSBERG
DUNDEE
GLENCOE
NQUTU
HELPMEKAAR
MELMOTH
MTUBATUBA
EMPANGENI
RICHARDS BAY
ESHOWE
TUGELA FERRY
WEENEN
ESTCOURT
GREYTOWN
KRANSKOP
STANGER
DALTON
NEW HANOVER
GIANT'S CASTLE
NOTTINGHAM ROAD
HOWICK
PIETERMARITZBURG
CATO RIDGE
TABLE MTN
VERULAM
DURBAN
HIMEVILLE
BULWER
RICHMOND
IXOPO
SCOTTBURGH
MATATIELE
CEDARVILLE
KOKSTAD
HARDING
MOUNT FLETCHER
MOUNT AYLIFF
PORT SHEPSTONE
MARGATE
J(c)-1
13A 260



MAP (3)

GEOLOGY OF NATAL.
From Van der Eyk et al.
(1969).

MAP (4)

TERTIARY OUTCROPS ON THE CONTINENTAL SHELF BETWEEN CAPE COLUMBINE AND CAPE SEAL. From Dingle (1971).