ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

THE RELATIONSHIPS BETWEEN STRUCTURAL LANDFORMS, EROSION SURFACES AND THE GEOLOGY OF THE ARCHAEAN GRANITE BASEMENT IN THE BARBERTON REGION, EASTERN TRANSVAAL

by

Y. LAGEAT and L.J. ROBB

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ABSTRACT

The Archaean granitic basement of the Barberton region, Eastern Transvaal, represents an ideal locality for an integrated study of the relationships between geology and geomorphology. The degree of erosion and the nature of landforms in this granitic terrane are clearly shown to be related to a number of parameters including granite type (i.e. its composition and mineralogy), texture, grain size and porosity.

Three distinct erosion surfaces (termed the Highveld, Intermediate and Lowveld surfaces) are shown to transect the crystalline basement in this region. Significant differences in the depths of weathering mantles occur between the various surfaces, this being a function of the age of the erosion surface and the climatic conditions prevailing during the formation of the regolith. The evolution of the planation surfaces is related to sporadic episodes of epeirogenic uplift with respect to the continental margin; an amended chronology for the formation of the surfaces is suggested in the light of recent sedimentological information obtained from off-shore drilling programmes.

A complete understanding of the geomorphological evolution of the Eastern Transvaal basement can only be obtained if consideration is given to the diversity of geological variables that characterize what has up until fairly recently been regarded as a relatively homogeneous granitic terrane.

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THE RELATIONSHIPS BETWEEN STRUCTURAL LANDFORMS, EROSION SURFACES AND THE GEOLOGY OF THE ARCHAEAN GRANITIC BASEMENT IN THE BARBERTON REGION, EASTERN TRANSVAAL

I. INTRODUCTION

The Archaean terrane of the Eastern Transvaal has long been recognized as a region of considerable interest in terms of both its geological and geomorphological features. When considering the relationships between these two topics, the Barberton region is ideally suited because of the well-defined expression of landforms and the excellent nature of the rock exposures. Furthermore, the geological diversity which characterizes this area encourages the examination of a number of different relationships between rock type and relief.

This study examines the Archaean granitic terrane between Bushbuckridge and Lochiel in a strip to the west of the Kruger National Park and the Swaziland border (Fig. 1). This region comprises essentially two components: first, a metavolcano-sedimentary sequence, the Barberton greenstone belt, and second, a varied assemblage of granitoids which are considered to postdate the greenstones. In spite of its marked topographic expression this paper does not consider the Barberton greenstone belt, but chooses to concentrate on the granitic environment and its geomorphological expression.

The earliest description of granite-related landforms in the Barberton district formed part of a Geological Survey Memoir (Hall, 1918), a contribution which, although remarkable for its lucid observations, did not, however, recognize the presence of distinct erosion surfaces. It was not until the 1950's that the stepped nature of the crystalline basement enabled King (1951) to incorporate this terrain into a broader scheme describing pediplanation cycles in southern Africa. However, the large scale at which these erosion surfaces were portrayed limited recognition of the effects that geological parameters had, not only on the evolution of planation surfaces, but on the development of landforms as well. Consequently, the main purpose of this paper is to present an interdisciplinary approach which explores in detail the relationships between topography and geology specifically in the Archaean granitic basement of the Barberton area.

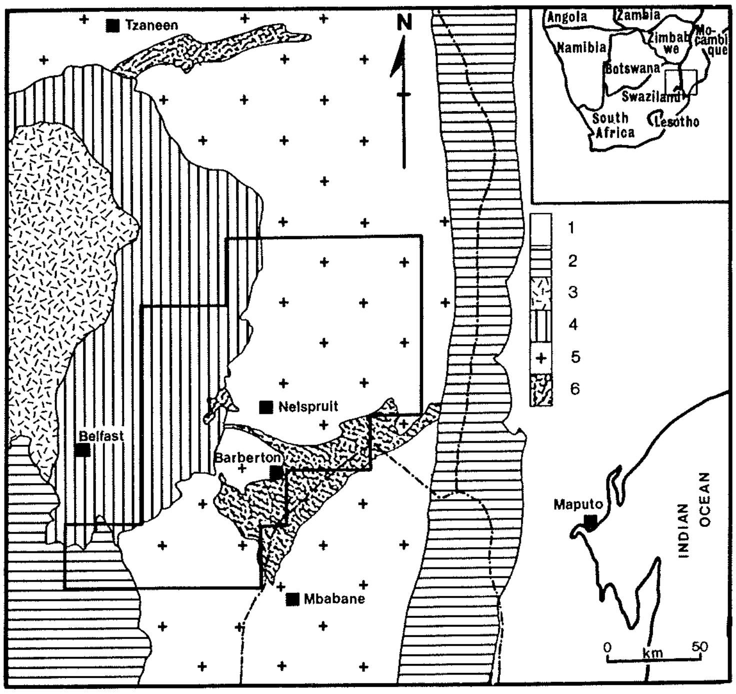


Figure 1 : Simplified geology of the eastern Transvaal and the outline of the study area centred around Barberton. 1- Cretaceous and Tertiary sediments : 2- Karoo Supergroup : 3- Bushveld Igneous Complex : 4- Transvaal Supergroup : 5- Archaean granitic basement : 6- Swaziland Supergroup (Barberton and Murchison greenstone belts).

II. THE BARBERTON AREA: CRATONIC MARGIN AND SCARP EDGE

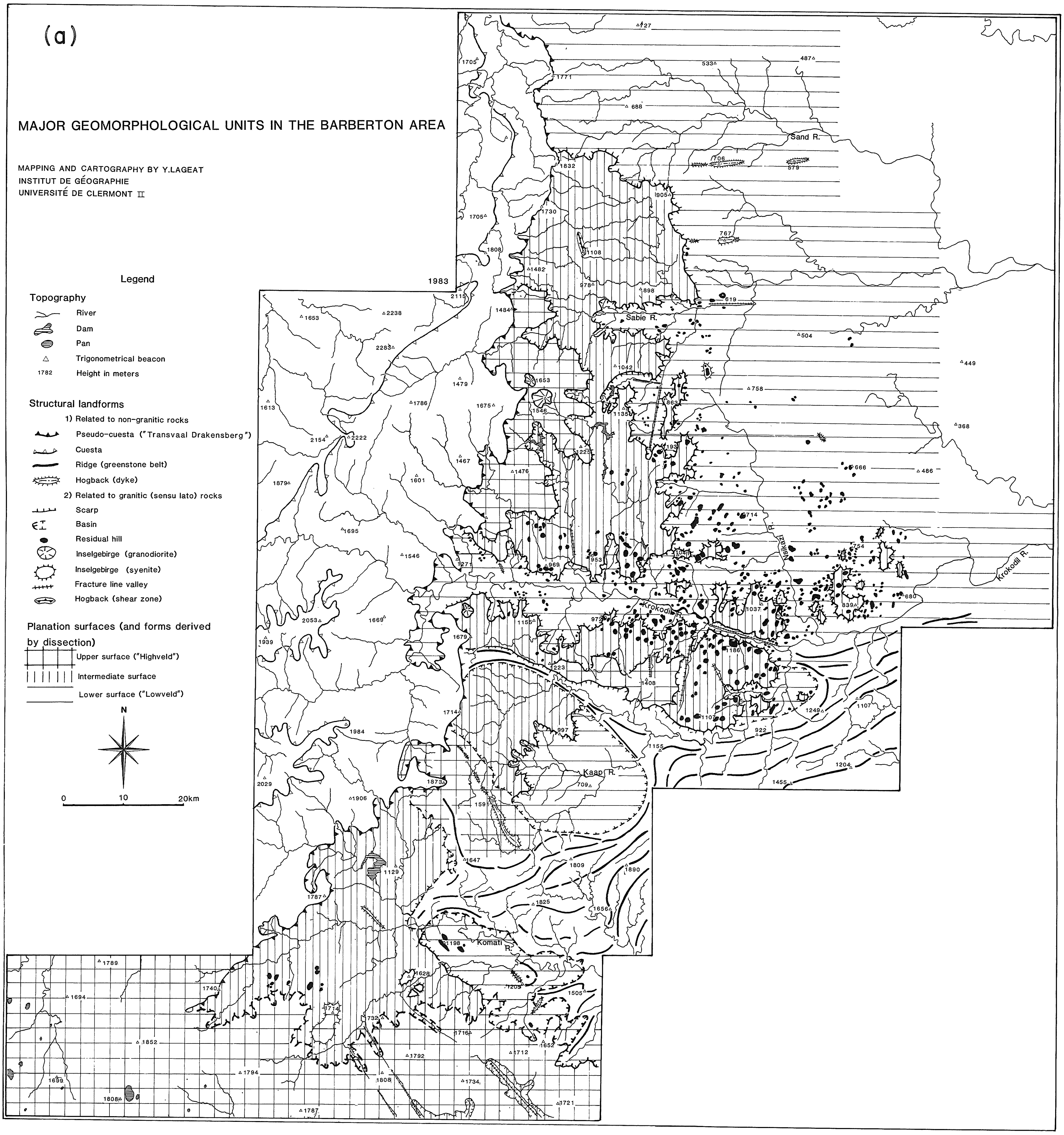
The region described in this study is located to the east of the prominent Transvaal Drakensberg Escarpment, the eastward-facing side of which forms a series of stepped benches along the flexured edge of the Archaean Kaapvaal craton. The Archaean basement below this escarpment is sufficiently variable for it to be characterized by marked relief and a diversity of geomorphological features.

A. Major Features of the Landscape

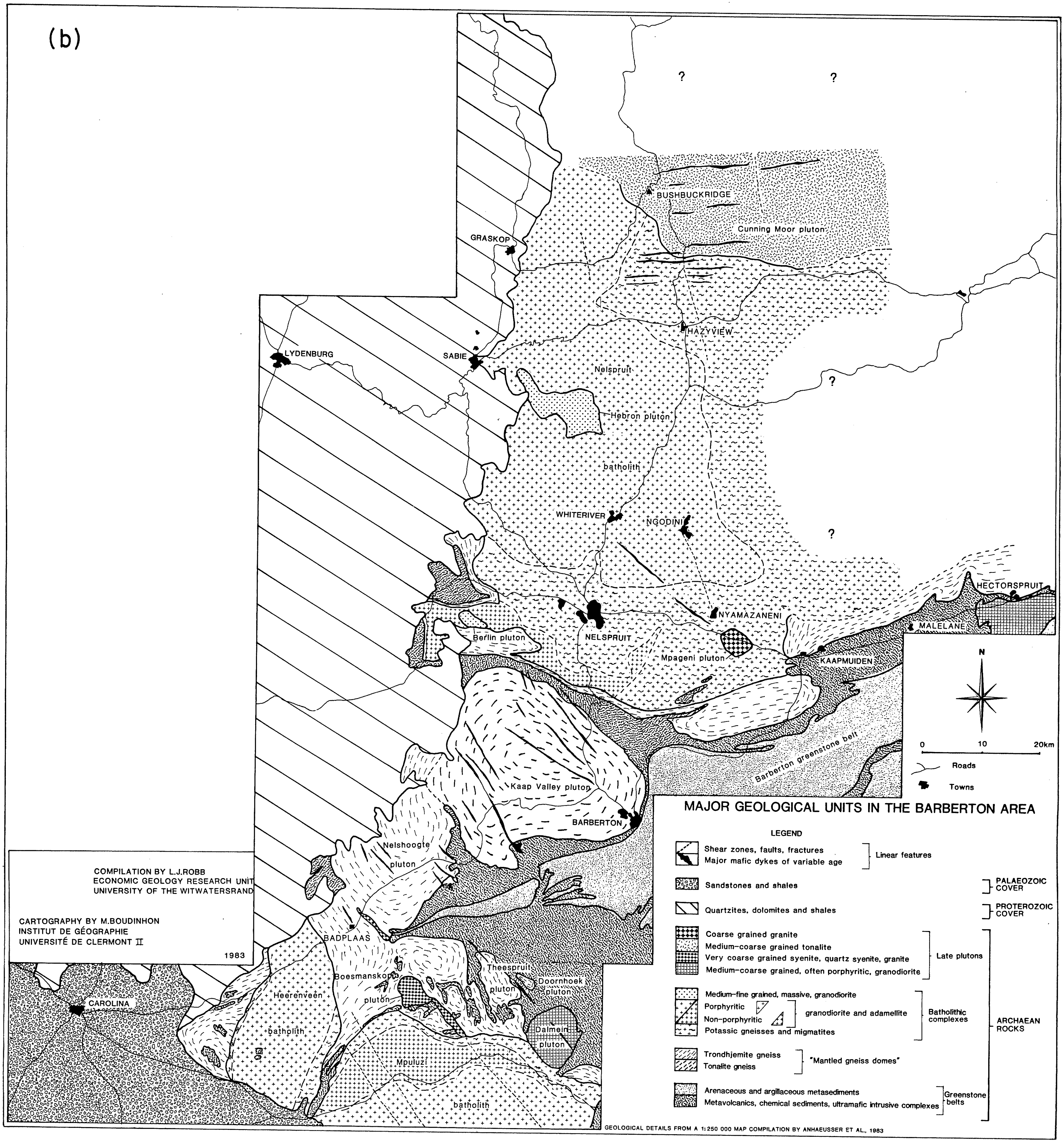
The 240 km long Eastern Transvaal section of the Great Escarpment is strictly defined more as a structural* feature than simply in terms of its topographic relief. Between Carolina in the south and Letaba

* "Structural" is used here in a geomorphological sense and refers to a landform which is due to the specific character and properties of a rock or sequence of rocks.

Figure 2a and b : *Overlay maps showing the major geomorphological units (a) and the major geological units (b) in the Barberton area.*


(a)
MAJOR GEOMORPHOLOGICAL UNITS IN THE BARBERTON AREA
MAPPING AND CARTOGRAPHY BY Y.LAGEAT
INSTITUT DE GÉOGRAPHIE
UNIVERSITÉ DE CLERMONT II
Legend
Topography
River
Dam
Pan
Trigonometrical beacon
1782 Height in meters
Structural landforms
1) Related to non-granitic rocks
Pseudo-cuesta ("Transvaal Drakensberg")
Cuesta
Ridge (greenstone belt)
Hogback (dyke)
2) Related to granitic (sensu lato) rocks
Scarp
Basin
Residual hill
Inselgebirge (granodiorite)
Inselgebirge (syenite)
Fracture line valley
Hogback (shear zone)
Planation surfaces (and forms derived by dissection)
Upper surface ("Highveld")
Intermediate surface
Lower surface ("Lowveld")
N
0 10 20km
Sand R.
Sabie R.
Krokodil R.
Nelspruit R.
Kaap R.
Komati R.

(b)



MAJOR GEOLOGICAL UNITS IN THE BARBERTON AREA
LEGEND
Shear zones, faults, fractures
Major mafic dykes of variable age
Linear features
Sandstones and shales
PALAEOZOIC COVER
Quartzites, dolomites and shales
PROTEROZOIC COVER
Coarse grained granite
Medium-coarse grained tonalite
Very coarse grained syenite, quartz syenite, granite
Medium-coarse grained, often porphyritic, granodiorite
Late plutons
Medium-fine grained, massive, granodiorite
Porphyritic
Non-porphyritic
granodiorite and adamellite
Potassic gneisses and migmatites
Batholithic complexes
Trondhjemite gneiss
Tonalite gneiss
"Mantled gneiss domes"
Arenaceous and argillaceous metasediments
Metavolcanics, chemical sediments, ultramafic intrusive complexes
Greenstone belts
ARCHAEAN ROCKS
GEOLOGICAL DETAILS FROM A 1:250 000 MAP COMPILATION BY ANHAEUSSER ET AL., 1983
N
0
10
20km
Roads
Towns
COMPILATION BY L.J.ROBB
ECONOMIC GEOLOGY RESEARCH UNIT
UNIVERSITY OF THE WITWATERSRAND
CARTOGRAPHY BY M.BOUDINHON
INSTITUT DE GÉOGRAPHIE
UNIVERSITÉ DE CLERMONT II
1983
BUSHBUCKRIDGE
Cunning Moor pluton
GRASKOP
HAZYVIEW
LYDENBURG
SABIE
Nelspruit
Hebron pluton
batholith
WHITERIVER
NGODINI
HECTORSPRUIT
NYAMAZANENI
MALELANE
Berlin pluton
NELSPRUIT
Mpageni pluton
KAAPMUIDEN
Barberton greenstone belt
Kaap Valley pluton
BARBERTON
Nelshoogte
pluton
BADPLAAS
Boesmanskop
pluton
Theespruit
pluton
Doornhoek
pluton
Heerenveen
batholith
CAROLINA
Dalmein
pluton
Mpuluzi
batholith
?
?
?
?

Point in the north (around Haenertsburg), the escarpment is, in effect, a "pseudo-cuesta" (Demangeot, 1961) since the basal Black Reef quartzite of the Proterozoic Transvaal Supergroup unconformably overlies the crystalline Archaean basement. The interface between the Black Reef quartzite, which thickens progressively from south to north (9 m thick east of Carolina, 60 m at Sabie and 760 m at Wolkberg) and the basement, is marked by a palaeosol developed on the basement granites. This palaeosol, which varies from 1,5 to 15 m in thickness, has a uniform mineralogical composition comprising quartz (35-38 per cent), sericite† (56-59 per cent), and microcline (up to 8 per cent) (Visser and Verwoerd, 1960).

The Transvaal Drakensberg Escarpment marks the eastern limit of an area known as the Bankeveld (Wellington, 1946) which is formed by a series of homoclinal ridges in sediments of differing weatherability in the Transvaal Supergroup. The topography of the Bankeveld, and its entirely contrasting nature with respect to the Archaean basement, has been described by Hall (1918) as follows: "With its uniform and low westerly dips, its regular alternation of hard and soft strata, and generally undisturbed arrangement, the country of the Transvaal System from the edge of the Drakensberg westwards presents fairly simple and more readily intelligible surface features, which strongly contrast with the highly complex topography of the extensive and thoroughly diversified region towards the east".

At the base of the "pseudo-cuesta", the extensive and diversified Archaean basement is characterized by three principal landforms:

(i) fairly well preserved plains and plateaux which correspond to planation surfaces of varying maturity,

(ii) scarps of differing heights which separate the abovementioned planation surfaces, thus forming stepped terraces, and

(iii) sub-parallel Appalachian-type ridges which form the greenstone terrane known as the Barberton Mountain Land. The highest peak in this area is Mount Emlembe (1 838 m) which occurs along the Swaziland border. This ridge and valley morphology is essentially a result of differential erosion within a volcano-sedimentary greenstone complex where quartzites form prominent narrow ridges separated by deep valleys underlain by basic schists.

In contrast to the Barberton Mountain Land, whose "intricate physiography ... rests principally on simple geological principles" (Hall, 1918), the granitic basement is characterized by the development of discrete erosion surfaces. This is illustrated in Fig. 2a and b, where, the various landforms and planation surfaces developed over the Archaean granitic terrane of the study area are shown. The area is characterized by the presence of three stepped surfaces (Fig. 2a) which, although generally easily identifiable one from the other, may in places represent isolated fragments of dubious origin. The three surfaces are as follows:

(i) the fundamental surface* south of the Bankeveld is termed the *Highveld surface*. Its mature nature was recognized very early on by Davis (1906) who described it as follows: "We crossed miles and miles of plains that repeated in nearly every respect the features of the ideal worn-down land surface". In the mapped area this reference level cuts across Karoo sediments in the vicinity of Carolina before intersecting the intra-Ecca basement surface towards Swaziland. The Lochiel plateau, forming the watershed along the Carolina-Mbabane road, preserves this old planation surface exhumed from argillaceous Permo-Triassic sediments. The highveld surface is fundamentally different from lower levels as it is never punctuated by residual granitic hills.

(ii) at the base of the "pseudo-cuesta", an *intermediate bench* is developed which was first noted by Fair (1954) and subsequently described in the following way by Visser and Verwoerd (1960): "From the Great Escarpment steep slopes trail down eastwards and merge with the granite hills of the typical Middleveld". This level (which is also present further north in the vicinity of Tzaneen) contrasts with the featureless Highveld surface by the existence of numerous interfluves all of which have a similar altitude and impart a multiconvex aspect to the terrane (Figure 7A).

(iii) the lowermost level, which is developed over the widest area, is referred to as the *Lowveld surface* and is characterized by "wide, level, sandy plains with sporadic clumps of inselbergs" (Hall, 1918). As a result of erosion by the major drainage arteries, this low-lying surface cuts back in a westerly direction (Fig. 15) to form a series of transverse basins of which the Nelspruit, Barberton, and Komati River basins are prominent. In this study the latter features are regarded as part of the Lowveld surface, an interpretation which differs from that of Fair (1954) who regarded them as belonging to an intermediate bench.

The problem of defining and dating these planation surfaces in the Eastern Transvaal has been addressed on a number of occasions. Most attempts at definition in the past were based on altimetry, a method which does not take the subsequent deformation of surfaces into account. It is evident that a stepped topography of this nature must have formed from a succession of epeirogenic uplifts. However, because of the absence of post-Karoo sediments, it is difficult to reconstruct the timing of the development of the various steps occurring in marginal warped areas. Consequently, the ages of surfaces are considered to be relative rather than absolute and this is discussed in more detail in a later section.

The study of planation surfaces should not be carried out at the expense of other features in the topography. It is evident that the formation of the various benches did not completely destroy pre-existing structural landforms present in the landscape. In fact, planation has served to emphasize the geological diversity of the crystalline basement and it is one of the objects of this paper to draw attention to the relationship between this diversity and the imposition of geomorphological processes.

B. Geological Characteristics of the Granite-greenstone Basement

The Archaean granite-greenstone terrane of the Barberton area is one of the geologically most intensively studied regions in southern Africa, having been the object of economic interest as well as two major research programmes in the form of the "Upper Mantle Project" (1965-1969) and the "International Geodynamics Programme" (1975-1981). Numerous publications have emerged of which some of the more important overview papers include those

† According to Button and Tyler (1981), this sericite is a product of the recrystallization of illite under conditions of low metamorphic grade.

* It should be noted that the existence of elevated Appalachian-type relief in the Barberton Mountain Land raises the question of the existence of an original surface from which this ridge and valley morphology was subsequently carved by differential erosion.

by Anhaeusser (1973), Anhaeusser and Robb (1981), Barton (1981), Condie and Hunter (1976), Hunter (1974), and Viljoen and Viljoen (1969).

Centrally situated in the study area is the Barberton greenstone belt which comprises a sequence of metamorphosed volcano-sedimentary rocks deformed into a steeply-dipping synclinorial keel (Fig. 4b). The basal unit in this assemblage is made up of the Onverwacht Group, which includes mafic and ultramafic lavas of komatiitic to tholeiitic composition, mafic to felsic volcanic and pyroclastic rocks of calc-alkaline affinity and minor chemical sediments. Overlying this are two sedimentary units, the lower, argillaceous Fig Tree Group comprising shales, greywackes, banded iron-formations and cherts, and the arenaceous Moodies Group consisting mainly of quartzites and conglomerates. Numerous xenolithic remnants of the Barberton greenstone belt also occur within the surrounding granitic terrane and they have been shown to consist of assemblages mainly characteristic of the Onverwacht Group. The metavolcanics of the lower Onverwacht Group yield a Sm-Nd age of 3 540 ± 30 Ma (Hamilton *et al.*, 1979).

Surrounding the Barberton greenstone belt is a varied sequence of granitic *(sensu lato)* rocks* which can be sub-divided into three broad categories, termed "magmatic cycles" (Anhaeusser and Robb, 1981). The *first magmatic cycle* was active between approximately 3 500-3 200 Ma ago and consists mainly of leucocratic biotite trondhjemites and hornblende tonalites as well as complex migmatites and bimodal gneisses. These rocks are characterized by a penetrative mineral fabric displayed as a foliation and, less commonly, as a lineation. As a result, in Fig. 2b they are described as "mantled gneiss domes" in recognition of their texture, their close affinity to greenstone material, and to their mode of emplacement which is regarded as being diapiric (Anhaeusser and Robb, 1981).

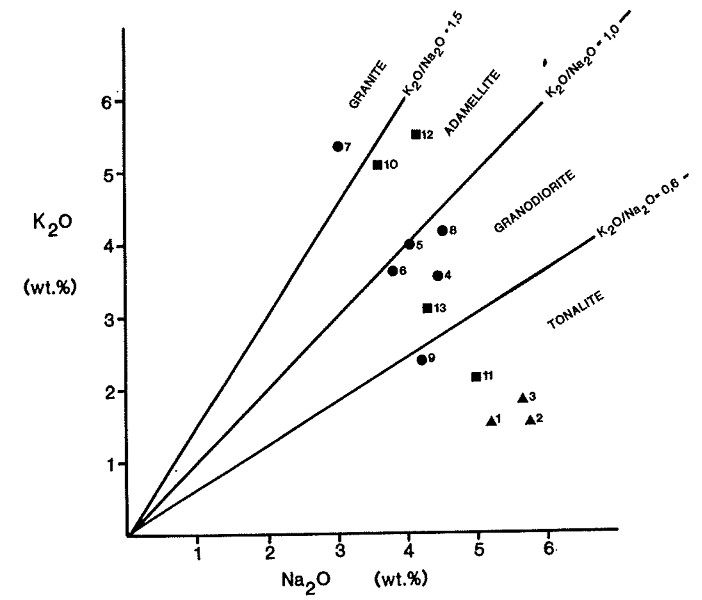


Figure 3 : *Classification of the Archaean granites in the Barberton area according to the scheme of Harpum (1963). Data points 1-13 correspond respectively to the analyses presented in Table I. Triangles represent the first magmatic cycle, circles the second magmatic cycle and squares the third magmatic cycle.*

Rocks of the *second magmatic cycle* were emplaced between approximately 3 200-3 000 Ma ago and represent the areally most extensive of the three units. During this event K-rich magma was emplaced as large batholithic complexes both to the north and south of the Barberton greenstone belt (Fig. 2b). The potassic batholiths are characterized mainly by a coarse-grained, porphyritic granodiorite or adamellite (Fig. 3) but may locally be granitic *(sensu stricto)* or even tonalitic in composition (see Table I). All three batholiths in the region (i.e. the Nelspruit, Mpuluzi, and Heerenveen batholiths, Fig. 2b) are characterized by the ubiquitous occurrence of K-feldspar megacrysts, although the development of the porphyritic texture varies from intense, usually in the centre of the batholiths, to slight on their margins. All three batholiths are also characterized by the marginal development of migmatitic or gneissic zones containing schlieren and partially assimilated portions of pre-existing greenstone or tonalitic crust (Figs. 2b and 4). Other genetically coeval phases also occur within the batholithic complexes; in the Nelspruit batholith the Hebron granodiorite occurs both as a small medium- to fine-grained pluton in the centre of the batholith (Fig. 2b) and as veins intruding the main porphyritic phase. Similar granodioritic veins also occur in the Mpuluzi batholith to the south of the Barberton greenstone belt. The Mpuluzi batholith is further characterized by the development of a prominent spine of homogeneous, medium-grained, pinkish-grey adamellite referred to as either the Lochiel or Homogeneous Hood phase (Fig. 2b).

The *third magmatic cycle* is characterized by the intrusion of numerous, discrete granitic *(sensu lato)* bodies which, although highly variable in composition and mode of origin, are unified by a transgressive mode of emplacement which postdates all other basement rocks in the region. The cycle was active between about 2 900-2 500 Ma ago and effectively terminated the construction of the Archaean continental crust. Within the area

* The classification of granitic rocks in this paper is carried out according to the scheme of Harpum (1963) and is illustrated in Fig. 3.

TABLE I

Major Element Compositions of Various Granites in the Barberton Area

Wt. %	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	65,05	71,30	71,00	70,21	66,57	67,44	73,78	73,75	74,90	73,20	68,97	59,04	69,47
TiO_2	0,49	0,27	0,27	0,28	0,48	0,58	0,14	0,20	0,15	0,26	0,36	1,04	0,33
Al_2O_3	15,75	14,00	14,70	15,34	15,46	15,15	14,27	13,75	14,30	13,80	15,80	15,08	15,40
Fe_2O_3	4,40	2,49	2,15	1,96	3,38	3,59	1,29	1,56	0,92	1,87	2,52	6,83	2,62
MnO	0,06	-	-	0,04	0,09	0,06	0,01	0,02	0,03	-	0,06	0,17	0,06
CaO	4,47	2,57	2,67	1,96	2,36	2,28	0,46	1,78	1,46	1,40	2,72	3,79	2,41
Na_2O	5,18	5,74	5,63	4,41	4,08	3,78	3,00	4,50	4,20	3,54	4,98	4,15	4,29
K_2O	1,52	1,50	1,85	3,55	3,98	3,61	5,36	4,17	2,37	5,03	2,13	5,48	3,09
P_2O_5	0,20	-	-	0,04	0,12	0,08	0,06	0,06	0,06	-	0,01	0,73	0,18
L.O.I.	1,01	-	-	0,51	0,58	0,72	0,60	0,50	0,39	-	0,45	0,75	0,58
Totals	100,64	99,03	99,07	99,10	98,83	99,29	99,23	100,36	99,08	99,55	99,61	99,21	99,38

MESONORM

	1	2	3	4	5	6	7	8	9	10	11	12	13
Quartz	18,45	25,28	24,59	27,82	24,41	28,28	36,43	27,89	39,80	31,34	27,24	6,32	29,06
Orthoclase	3,35	8,68	10,87	17,26	16,27	12,88	30,68	25,07	12,60	27,20	6,08	26,00	13,31
Albite	45,15	50,32	49,33	38,31	36,25	33,00	26,35	38,73	36,70	30,72	43,62	36,94	37,31
Anorthite	11,65	4,35	6,67	8,71	9,72	9,05	1,46	3,99	6,53	6,20	12,60	2,38	9,90
Corundum	0,00	0,00	0,00	1,16	1,10	1,87	3,13	0,00	2,59	0,33	0,87	0,00	1,51
Hornblende	11,84	11,53	8,88	0,00	0,00	0,00	0,00	3,23	0,00	0,00	0,00	12,54	0,00
Biotite	8,85	0,76	0,67	6,42	12,64	13,69	3,28	0,00	2,78	4,93	10,41	12,09	8,18
Sphene	1,24	0,69	0,69	0,71	1,24	1,47	0,36	0,50	0,38	0,65	0,91	2,68	0,83
Apatite	0,37	0,00	0,00	0,07	0,23	0,15	0,11	0,11	0,11	0,00	0,02	1,40	0,34
Totals	100,90	101,61	101,70	100,46	101,85	100,37	101,81	101,83	101,50	101,37	101,76	100,34	100,44

Column 1. Kaap Valley pluton (average of 41 samples of hornblende (± biotite) tonalite after Robb, (1981)
2. Theespruit pluton - typical analysis of biotite trondhjemite (+) after Condie and Hunter, (1976)
3. Nelshoogte pluton — typical analysis of biotite trondhjemite after Condie and Hunter, (1976)
4. Nelspruit porphyritic granite - average of 12 samples after Robb *et al.*, (1983)
5. Nelspruit migmatite and gneiss terrane - average of 16 samples after Robb *et al.*, (1983)
6. Hebron pluton - average of 3 samples after Robb *et al.*, (1983)
7. Mpuluzi porphyritic granite - typical analysis after Anhaeusser and Robb, (1983)
8. Lochiel or "Homogeneous Hood" granite - typical analysis after Anhaeusser and Robb, (1983)
9. Heerenveen porphyritic granite - typical analysis after Anhaeusser and Robb, (1983)
10. Mpageni granite pluton - average of 2 analyses after Condie and Hunter, (1976)
11. Cunning Moor tonalite pluton - average of 9 analyses after Robb, (1978)
12. Boesmanskop syenite pluton - typical analysis after Anhaeusser and Robb, (1983)
13. Dalmein granodiorite pluton - average of 10 analyses after Robb, (1983)

(+) The distinction between tonalite and trondhjemite is viewed in terms of Barker's (1979) definition of a trondhjemite, namely, that a trondhjemite is a leucotonalite. Barker provided the following quantitative major element distinctions between trondhjemites and tonalites :

	Trondhjemite	Tonalite
SiO_2	>68%	<68%
Fe_2O_3 + MgO	<3,4%	>3,4%
CaO	1,5-3,0%	>3,0%

shown in Fig. 2b five "late plutons" of the third magmatic cycle occur; these are the Dalmein and Salisbury Kop granodiorite plutons which both intrude rocks of the Onverwacht Group in the Barberton greenstone belt, the Boesmanskop syeno-granite pluton which intrudes trondhjemite gneisses of the first magmatic cycle, the Mpageni granite pluton and the Cunning Moor tonalite (Fig. 3) pluton both of which intrude migmatites and gneisses of the Nelspruit batholith. All the late plutons are post-tectonic in character and have massive, coarse-grained and/or porphyritic textures.

C. Typology of Granitic Landforms

Although only essentially a reconnaissance map, the comparison between geology and geomorphology in Fig. 2a and b shows thatlandforms are derivatives of both the diversified geological nature of the basement as well as the preserved remnants of planation surfaces. A simplified synthesis of these maps shows that three main types of relief can be differentiated:

1. Basins Along the southern section of the Transvaal Drakensberg Escarpment regional factors, such as the variable thickness of the Black Reef quartzite as well as localized undulations within this sedimentary unit, are both functions of the presence or absence of basins in the basement granite (Birot *et al.*, 1974). The best preserved occurrence in the study region of a markedly inscribed basin is the "Kaap Valley granite basin" (Hall, 1918), of which, to the authors' knowledge, no better example is known anywhere, at least in terms of its dimensions (30 km by 25 km with an area of approximately 550 km²) and the perfection of its elliptical shape. "It has the appearance of a vast depression surrounded on all sides by an amphitheatre of prominent ranges, from which the only outlet lies east of Caledonian Siding where the Queen's River runs through a narrow gorge-like break towards Kaapmuiden" (Hall, 1918). As a result of its remarkable hydrographic unity, this elliptical basin has been perfectly sculpted out of a hornblende-bearing tonalite pluton, the limits of which can be accurately determined by topographic breaks. The Kaap Valley basin actually comprises two levels (Fig. 2a), an upper bench with an altitude of between 950 to 1 050 m occurring at the foot of the Duiwelskantoor, and a lower floor, located around Barberton, and having an altitude of between 700 to 750 m. The only ridges present in this otherwise flat-lying terrain are formed by Proterozoic diabase dykes with a dominantly north-westerly orientation (see Fig. 10). These form narrow "hogbacks" which can be up to 100 m high in places. Close examination of the Kaap Valley basin, reveals that erosion of the pluton is not complete. South of the basin, a strip of tonalite bounded by two prominent diabase dykes (the Jambila and the Devil's Knuckles dykes) forms a high-lying bench occurring at an altitude of around 1 500 m, a level which coincides with the adjacent Nelshoogte plateau. This plateau with an area of about 150 km², separates the Kaap Valley basin from the Badplaas basin.

Less perfectly sculpted than the Kaap Valley basin, the Badplaas alveole, which is drained by the Komati River, can be distinguished from the former by three main features: (i) its amoeboid shape, which results from the deep weathering of six different, coalescing trondhjemie plutons as well as the southern section of the granodioritic Dalmein pluton; (ii) its less well-defined limits because of the absence of prominent enveloping greenstone successions and/or cover rocks; and (iii) a more diversified topography (ranging between 1 000-1 150 m) which results from numerous cross-cutting dykes, the presence of large syenitic inselgebirge (i.e. the 1 628 m high Boesmanskp, which is transected by the Theespruit River; Fig. 7B), and the occurrence of "kopjes" formed by quartz-rich trondhjemitic gneisses and greenstone remnants* (Viljoen and Viljoen, 1969).

A third example of a basin is provided by the Nelspruit basin which differs from the two previously described features in terms of its shape (i.e. oblong, about 40 km in length) and the rock type underlying it (mainly gneisses and migmatites of the Nelspruit batholith). The basin, which is orientated east-west along the Crocodile River (Fig. 2a), is also characterized by numerous exfoliation domes. The topographic limits of the Nelspruit basin do not necessarily correspond with only one particular rock type (as in the case of the Kaap Valley basin) and south of Nelspruit, for example, the edge of the basin is characterized by massive non-porphyritic granodiorite and adamellite as well as diverse gneisses and migmatites. The Nelspruit basin is closed to the east by the 1 190 m high Mpageni granite pluton which is transected along a prominent fracture plane by the superimposed Crocodile River.

2. Plateaux and Plains All the landforms present in the granitic terrane are essentially derived from an original summit topography which is remarkably well-preserved around Lochiel. The shape of this elevated landscape is moulded by a network of alternating trough-shaped valleys (formed along northwest-southeast-trending faults) and prominent elongated interfluves (1 750 - 1 850 m high) which preserve the Highveld surface.. This surface remnant, which now represents a major watershed in the drainage system (i.e. shedding towards the Komati River in the north and the Great Usutu River in the south) has been preserved because of the resistance of the Mpuzuli and Heerenveen granite batholiths to erosion.

The "intermediate bench", described by Fair (1954), is mainly preserved as a plateau over the Nelspruit batholith (Figs. 2 and 4). This batholith, with a surface area of approximately 4 000 km² (Robb *et al.*, 1983), is characterized by irregular relief formed by a system of hills between 900 and 1 100 m high (Fig. 7A). The original plane of dissection in relatively homogeneous porphyritic granite is clearly visible between the Crocodile and Sand Rivers. Considerable variations in this otherwise uniform landscape are formed by:

(i) extensive clusters of domes derived by dissection of the Highveld surface, of which the most characteristic is the Krokodilpoortberg (1 408 m at its highest point) separating the Nelspruit from the Kaap Valley basins. This feature has been described by Hall (1918) as "... bold rugged hills scattered with many hummocky blocks of grey granite ...",

(ii) massive dome-shaped residual hills (which, for lack of a better term, have been termed inselgebirge) associated with the unusually resistant Hebron (1 653 m) and the Berlin (1 521 m) granodiorite plutons,

(iii) long ridges such as the Sterkspruit hill (1 108 m) which correspond to south-southeast-north-northwest-trending quartz-rich mylonitic zones, and

(iv) resistant plateau-like interfluves which correspond to diabase sills particularly well-developed north of the Sabie River where they cap the Nelspruit porphyritic granite.

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* Note that greenstone successions totally surround the negatively weathered Doornhoek pluton which represents the smallest of the trondhjemite bodies in the Badplaas basin (i.e. 1 km long and 0,4 km wide).

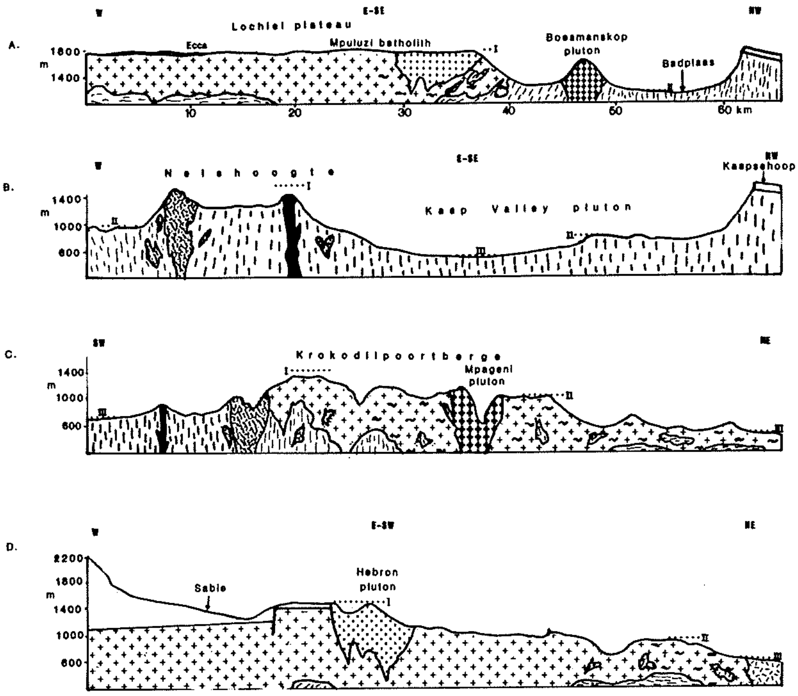


Figure 4 : *Selected cross-sections in the Barberton area showing the relief (Vertical Exaggeration = 6,25) and underlying geology. Symbols used are identical to those in Figure 2b. Planation surfaces are indicated by I (Highveld), II (Intermediate) and III (Lowveld).*

In the study area the Lowveld erosion surface is limited to areas underlain by easily-erodable rocks, namely potassic gneisses and migmatites in the southern and eastern parts of the Nelspruit batholith and the Cunning Moor tonalite pluton east of Bushbuckridge (Figs. 2 and 4). It is pertinent to note here that were it not for the presence of the Nelspruit porphyritic granite the Lowveld surface would extend right to the base of the Transvaal, as it in fact does north of Bushbuckridge. Where the Lowveld surface, which is inclined to the east and occurs at elevations between 450 to 650 m, is underlain by the Nelspruit gneisses and migmatites (for example around the Crocodile River) its surface is less regular than to the north where only the occasional east-west orientated dyke punctuates the otherwise flat-lying terrain.

3. *Scarps* Although scarp slopes do not necessarily always coincide with geological contacts, a good correlation can, nevertheless, be established between structure and the extensions of planation surfaces. This feature can be demonstrated in the case of three examples:

(i) the southern scarp of the Badplaas basin where "... the valley of the Komati River is closed by the high, bare and rolling granitic plateau in which runs the Breyten-Mbabane road ..." (Hall, 1918). The plateau of the Lochiel region comprises two distinct granitic bodies known as the Heerenveen and Mpuluzi batholiths (Anhaeusser and Robb, 1983) which are separated by a thin septum of greenstone material, the Schapenburg schist belt (Fig. 2b). In the Heerenveen body a north-facing scarp slope is developed in the proximity of the contact betwen porphyritic granite and older trondhjemite gneisses. In the case of the Mpuluzi body the existence of a resistant cupola of medium-grained granite (the "Hood" granite of Viljoen and Viljoen, 1969) above the central porphyritic granite is responsible for defining an approximately 500 m-high scarp along the northern flank of the batholith (Fig. 7C),

(ii) because of the relatively modest relief due to the Jamestown Hills, the northern flank of the Kaap Valley basin is effectively defined by the Krokodilpoortberg. Consequently, the Nelspruit granite and the hornblende-bearing Kaap Valley tonalite can be easily distinguished by their markedly different morphological expression. The contact, therefore, is marked by a steep slope, 200 to 300 m high, the significance of which Hall (1918) once again recognized in the following phrase "... The lower schist belt of hills is practically lost in the scenery due to the much higher and bolder chain of granite which overtowers them from the north", and

(iii) a scarp slope occurs on the north-eastern side of the Middleveld surface, the definition of which is closely demarcated by the contact between the Nelspruit batholith and the Cunning Moor tonalite. The contrast in relief resulting from differential erosion between the higher-lying Nelspruit granite and the lower-lying Cunning Moor tonalite is particularly evident around Bushbuckridge which is perched some 250 m above the Lowveld plain (Fig. 2).

The usefulness of geomorphology and the importance of recognizing the significance of different landforms in geological studies of crystalline rocks is particularly well emphasized in the above examples. Conversely, detailed geological mapping, as in the case of the Archaean basement at the foot of the Transvaal Drakensberg Escarpment, clearly provides insight into some of the causes behind the complex geomorphological expression evident in this region.

III. DIFFERENTIAL WEATHERING IN THE GRANITE BASEMENT

The Barberton area comprises numerous landforms developed by differential erosion and these are largely responsible for revealing the heterogeneity of the granitoid basement. This feature has been observed by numerous workers in the region, notably Viljoen and Viljoen (1969) who stated that "It is partly on the ... topographic expressions that the concepts concerning the development and evolution of the granitic rocks of the Barberton region have been based".

A. Direct Observations of Differential Weathering

Figure 5 illustrates the relationship observed in the field between relative weatherability and the various granite types in the study area. The relative weatherability of one granite type with respect to another is obtained by the intersection of the relevant row and column and the indication at the intersection (by a plus or minus sign) of whether the first granite type is either more or less resistant than the second. If there is no indication of relative weatherability at any one intersection this implies that a direct observation (i.e. a contact between the two granite types in question) was not available. From Fig. 5 it is possible to establish a crude hierarchy of weathering with respect to the main granite types referred to in Fig. 2b. This ranking, from most resistant to least resistant is as follows:

1. The Mpuluzi granite batholith,
2. The Boesmanskop syenite pluton,
3. The Hebron granodiorite pluton,
4. The Mpageni granite pluton,
5. The Heerenveen granite batholith,
6. The Nelspruit granite batholith,
7. The Dalmein granodiorite pluton,
8. The Nelspruit gneisses and migmatites (i.e. part of the Nelspruit batholith),
9. The Theespruit and Nelshoogte trondhjemite gneiss plutons,
10. The Kaap Valley tonalite gneiss pluton, and
11. The Cunning Moor tonalite pluton.

The use of names in the above list is justified in view of the fact that there is not always necessarily a consistent relationship between the rock type *per se* (i.e. granite, granodiorite, gneiss, etc.) and resistance to weathering. Consequently, differential erosion must be explained, not simply in terms of rock type alone, but in terms of a number of integrated factors. As has, in fact, recently been shown by Twidale (1982), the relative weatherability of granitic rocks needs to be considered in terms of at least three parameters, namely (i) chemical composition and, hence, mineralogy, (ii) texture, and (iii) porosity and permeability. Each of these is discussed in more detail below.

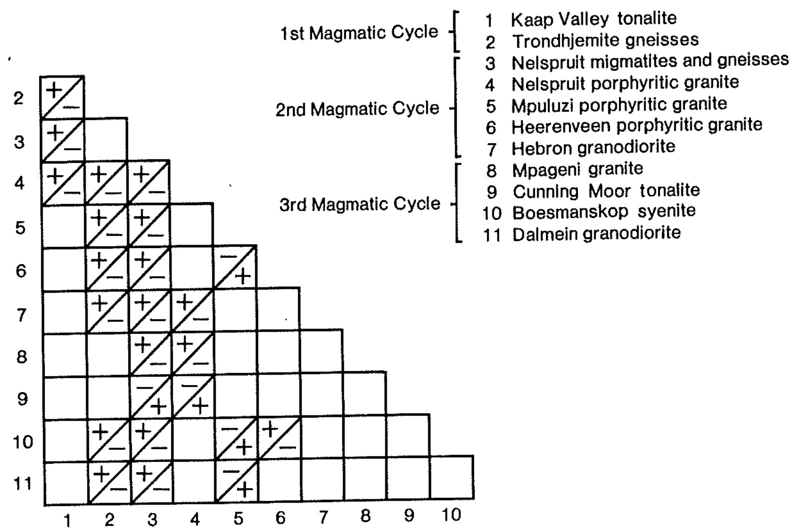


Figure 5 : Scale of relative resistance to weathering in granites from the Barberton area. Intersecting squares in which -/+ signs occur demonstrate the relative resistance to weathering between any two granite bodies where the relationshop can be directly observed. Blank spaces indicate that direct observation regarding relative weatherability cannot be made.

B. Chemical Composition and Mineralogy

This factor alone is probably the most influential in considerations of differential weathering. Comparison of chemical compositions (Table I) with relief profiles (Fig. 4) shows that a reasonable correlation exists between the most siliceous and potassium-rich granites and the existence of positive topography and, conversely, between the more sodic, basic granitoids and the presence of negative, flat-lying relief. This relationship is demonstrated in a series of plots (Fig. 6) which show that a positive correlation exists between the hierarchy of relative weathering (see above) and increasing SiO_2 and K_2O contents on the one hand, and decreasing CaO, Na_2O and MgO contents on the other. This correlation can be expressed differently in the form of a scale of relative mobility of elements. Such a sequence is derived by mass balance considerations (with alumina constant) of eight pairs of related weathered and fresh granitoid samples from the Barberton region. The following scale of relative mobility is apparent:

$$SiO_2 < K_2O < MgO < CaO < Na_2O$$

A further consideration concerns the relative stabilities of rock-forming minerals in the weathering environment, a sequence which has already been well established by Goldich (1938) among others. The fact that the major rock-forming minerals exhibit varying stabilities in the surficial environment is a clear indication that their relative abundances must play an important role in the differential weathering of crystalline rocks.

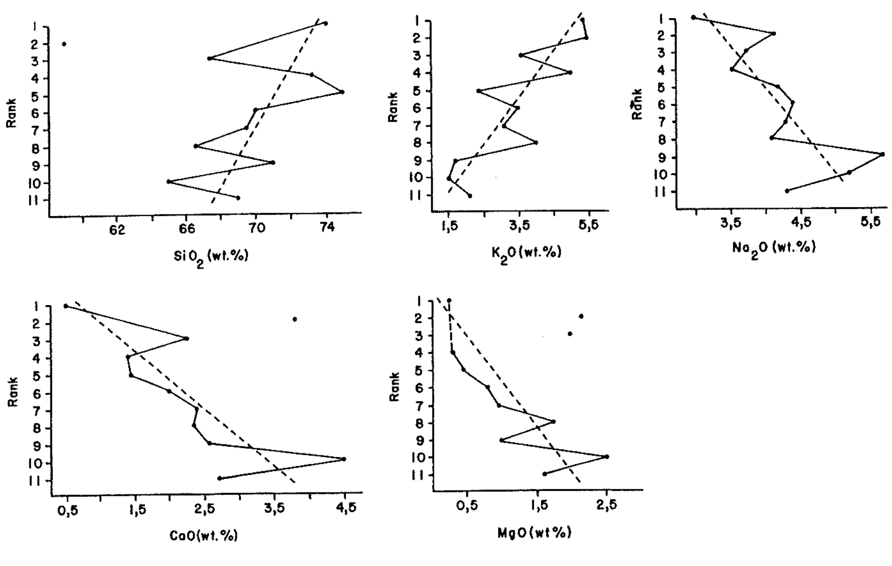


Figure 6 : Plots showing the relationship between ranked relative resistance to weathering (inferred from the relationships in Fig. 5 and discussed in the text) and the content of certain major elements in the granites (chemical data from Table I).

TABLE II

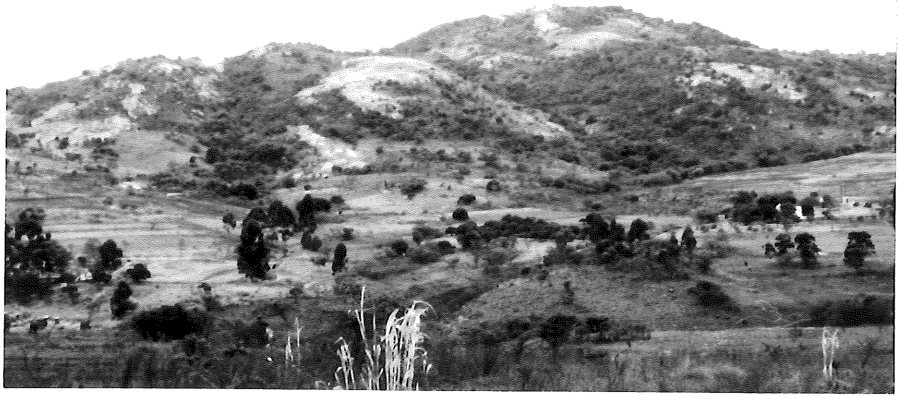
Modal Analyses of Select Granite Types from the Study Area

Sample No.	2	3	4	6	7	9	10	11
Quartz	2	32	30	25	28	30	22	28
Alkali feldspar	76	44	36	34	35	10	8	6
Plagioclase	5	12	28	32	29	48	56	55
Biotite	-	12	6	8	7	12	-	11
Hornblende	25	-	-	-	-	-	14	-

Sample numbers 2, 3, 4 etc. refer to rankings derived from the hierarchy of resistance outlined above.

In Table II, the average modal compositions of certain of the granite types in the Barberton area are listed according to the hierarchy of weatherability outlined previously. It is apparent that more so than the quartz content alone (this mineral is, for example, noticeably absent in the Boesmanskop syenite pluton) it is the differing ratios of the feldspar-types which serve to distinguish between the various granites and their resistance to weathering. In accordance with the parameters established by Lagasquie (1982), the authors consider the "feldspathic index" as probably the most important mineralogical factor which can be related to differential weathering. This index, which is expressed as

$$\frac{\text{alkali feldspar}}{\text{alkali feldspar + plagioclase}} \times 100$$



A. Rolling landscape formed over the Intermediate surface north-west of White River, and underlain by the Nelspruit porphyritic granite.

B. Large "inselgebirge" formed by the Boesmanskop syenite pluton. Surrounding plains are underlain by tonalite and trondhjemite gneisses.

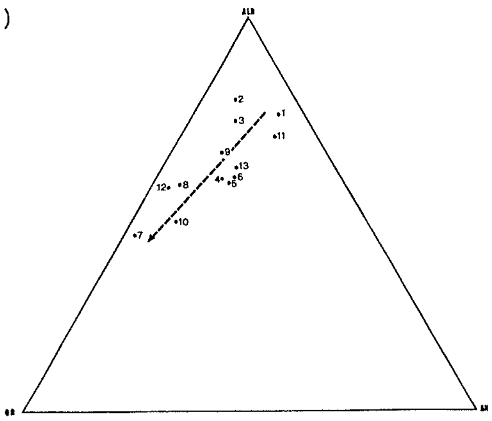
C. View of the prominent scarp which defines the northern edge of the Lochiel plateau and also the approximate contact between the Mpuluzi granite batholith and older trondhjemite gneisses within the Badplaas basin.

allows the distinction of five petrographic classes of granite. These can be arbitrarily defined, in terms of the feldspathic index, as:

holoplagioclasic rocks	-	(0-10)
subplagioclasic rocks	-	(10-40)
monzonitic rocks	-	(40-60)
subalkaline rocks	-	(60-90)
alkaline rocks	-	(90-100)

In terms of the rock types present in the study area, the tonalites and trondhjemites fall into the holo-subplagioclasic categories whereas most of the other granitic rocks are monzonitic with the exception of the Mpuluzi granite which is subalkaline. Figure 8a and b, showing a ternary plot of mesonormative albite-anorthite-orthoclase and a binary plot of feldspathic index versus rank, emphasizes the marked correlation between the nature of feldspars and the resistance to weathering of granites. In addition to plagioclase feldspar, the ferromagnesian minerals (biotite and the amphiboles) rank low in terms of stability in the weathering environment. However, with the exception of the Kaap Valley tonalite, the most mafic rock in the study area (with up to 25 per cent hornblende) is the resistant Boesmanskop syenite pluton and, hence, the amount of the ferromagnesian component in itself is not necessarily a diagnostic parameter. The existence of a fabric in these rocks also appears to play an important role in their relative weatherability. Consequently, considerations of texture must be regarded as an additional, often very important, parameter in assessments of differential weathering.

(a)



(b)

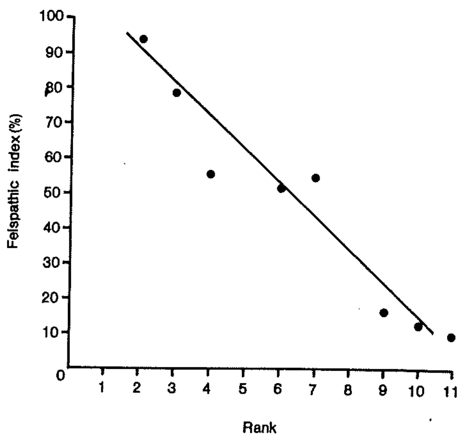


Figure 8a : *Ternary albite-anorthite-orthoclase plot of the various granite bodies in the Barberton area (mesonormative data from Table I). Dashed trend indicates increasing resistance to weathering.*

8b : *Plot of Feldspathic Index (100 x Alkali Feldspar/Alkali Feldspar + Plagioclase) versus relative resistance to weathering (ranked) as inferred from the relationships in Fig. 5 and described in the text.*

C. Texture

In certain cases it can be shown that this factor is in fact more important than chemical and mineralogical composition in the control of differential weathering. This fact has long been recognized in metamorphic rocks where foliation or layering is the result of preferred crystal growth along stress planes. In the specific case of the Nelspruit gneisses and migmatites, successive layers of resistant quartz- and microcline-bearing leucosomes interdigitate with foliated, less resistant, mafic layers (i.e. melanosomes). These migmatites and gneisses are clearly less resistant than the adjacent Nelspruit porphyritic granite (Fig. 2b) which, although considered cogenetic with the former (Robb *et al.*, 1983), is characterized by a considerably more homogeneous, massive texture. Similar features can also be observed in other granite bodies, particularly the tonalite and trondhjemite plutons, which often have a marked planar fabric. This foliation explains why the plutons are described as "gneiss domes" (Robb and Anhaeusser, 1983) with the orientation of this gneissocity often being a reflection of the geometry of the pluton. It is interesting to note that in the case of the Doornhoek pluton, which is devoid of a fabric, prominent outcrops are preserved along the trondhjemite-greenstone contact (Fig. 2), whereas in other gneiss plutons, where a marked foliation is best developed along the margins of the body, the rock is deeply eroded and contacts are poorly exposed.

It is evident that the "weakest" textures, in so far as differential weathering is concerned, are those in which unstable minerals are differentiated into layers or veins. In such cases, the process of hydrolysis is concentrated along certain of the less resistant layers and breakdown of the rock becomes rapid. This feature can be demonstrated, for example, in the Dalmein and Salisbury Kop plutons in which the mafic minerals (mainly chloritized biotite) are frequently concentrated as trails and schlieren around phenocrysts of perthitic microcline. Consequently, on weathered surfaces large microcline crystals are often observed jutting out prominently from the remainder of the rock. Conversely, in the Mpageni granite, which has a somewhat similar mineralogical composition, biotite occurs as individual laths amongst the other major minerals and no grain-sized scale differential weathering occurs.

It is evident in places that individual grains of little-resistant plagioclase and ferromagnesium minerals occur as inclusions within larger, more resistant minerals such as microcline. The existence of such poikilitic, porphyritic textures usually results in the preferred preservation of the rock. In the Nelspruit, Heerenveen, and Mpuluzi batholiths there are widespread occurrences of porphyritic granites in which phenocrysts of potash feldspar poikilitically enclose quartz, biotite, and plagioclase crystals. These *"dents de cheval"* which are often up to 5 cm long, occur preferentially in the central portions of the batholiths of the second cycle and are probably the principal reason why such portions are so well preserved and have remained relatively resistant to erosion (Robb, 1977). Other textures such as the densely packed, cumulus-textured phase of the Boesmanskop syenite pluton probably also contribute to the well-preserved character of the latter body.

It is important to point out that it is difficult to assess the importance of grain size alone on the relative weatherability of granites as very often the influence of other factors is superimposed on the latter. For example, the fine-grained phase of the Doornhoek trondhjemite pluton is better preserved, and occurs at a slightly higher altitude, than the remainder of this body. The occurrence of muscovite, the relative stability of which is high in the weathering environment, may, however, in certain portions of the pluton, contribute to differential erosion.

A relationship between differential weathering and grain size can also not be excluded in certain cases. Although there is no general consensus of opinion that finer-grained rocks are necessarily more resistant than their coarser equivalents, this parameter may be important in explaining unusually resistant features. Two examples illustrate this suggestion:

(i) the equigranular, Lochiel or "Hood" phase along the northern flank of the coarser-grained, generally porphyritic Mpuluzi granite batholith (Fig. 2) which is responsible for defining the steep cliffs above the Badplaas basin (Fig. 7C), and

(ii) the medium-grained, equigranular Hebron and Berlin granodiorite plutons which outcrop within the coarser, porphyritic Nelspruit granite and stand out as prominent "inselgebirge" of higher altitude than the surrounding rock types (Fig. 2).

The above examples testify to the fact that both texture as well as composition and mineralogy may have an important bearing on considerations of differential erosion. However, a third factor concerning the ease with which fluids can pass through a rock is also likely to play a role.

D. Porosity

Porosity is a factor which must be regarded with caution as a simple relationship only rarely exists between differential erosion and the global porosity of crystalline rocks (see Fig. 9). It was tentatively suggested by Lageat (1978) and Robb (1979) that low porosity might explain the otherwise unexpected positive relief exhibited by the Hebron granodiorite in comparison to the porphyritic Nelspruit granite. However, although porosity may have been a contributing factor in this case, a general relationship between basement relief and porosity does not exist, as is demonstrated in Fig. 9. Table III summarizes the results of global porosity measurements on various granites in the study area obtained by four different analytical techniques, namely:

(i) measurement by absorption of water in a cube of rock under atmospheric pressure,

(ii) water absorption in a weak vacuum created by a rotary pump,

(iii) water absorption under a pressure of 100 bars, and

(iv) absorption of mercury under a pressure of 500 bars.

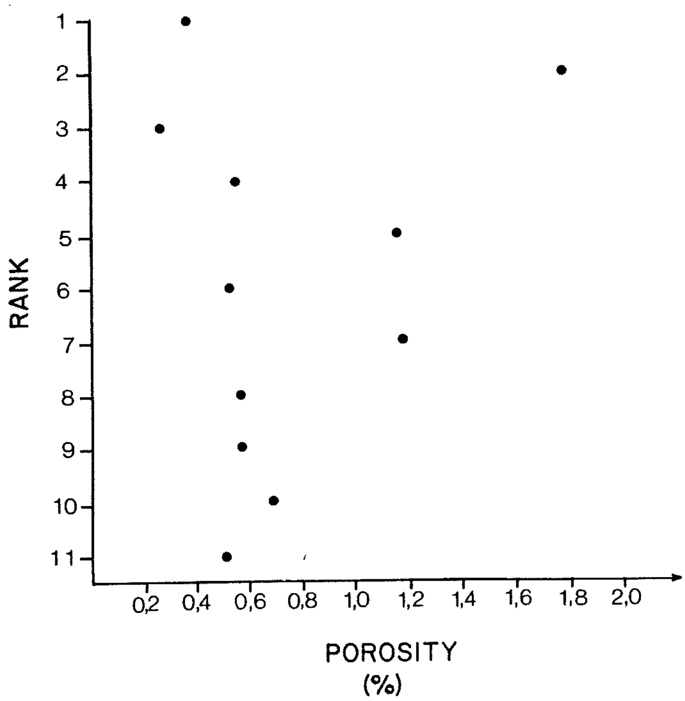


Figure 9 : Diagram showing the relationship between ranked relative resistance to weathering (from Fig. 5) and porosity (data from Table III).

A good example of the difficulties encountered in evaluating the significance of global porosity measurements is provided by the Boesmanskop syenite which, although having a high porosity, is characterized by a prominent relief. Such discrepancies are best explained in terms of considerations such as the porometry (i.e. the shape of the discontinuities) of the rock (Lageat, 1980). Distinction of two types of pore spaces can be made:

TABLE III

Porosity Determinations on Various Granites from the Barberton Region

ROCK	SAMPLE	METHOD 1	$\bar{X}$	METHOD 2	$\bar{X}$	METHOD 3	$\bar{X}$	METHOD 4	$\bar{X}$
Mpuluzi porphyritic granite	1	0,31	0,36	0,18	0,35	0,27	0,43	-	
	2	0,40		6,51		0,59		-	
Boesmanskop syenite	1	1,49		1,94		1,99		1,6	
Hebron granodiorite	1	0,24		0,31		0,22		-	
Mpageni granite	1	0,50		0,62		0,70		-	
Heerenveen porphyritic granite	1	0,98	1,15	-		-		1,0	
	2	1,31		-		-		-	
Nelspruit porphyritic granite	1	0,32	0,46	0,46	0,57	0,46	0,64	-	0,45
	2	0,33		0,34		0,46		-	
	3	0,41		0,57		0,63		-	
	4	0,58		0,78		0,86		-	
	5	0,54		0,71		0,77		-	
	6	0,39		-		-		-	
	7	0,65		-		-		-	
	8	0,42		-		-		0,5	
	9	0,36		-		-		0,4	
	10	0,56		-		-		-	
Dalmein granodiorite	1	0,66	1,11	0,82		0,91		-	
	2	1,56		-		-		-	
Nelspruit migmatites and gneisses	1	0,39	0,54	0,47	0,48	0,53	0,50	-	
	2	0,45		0,49		0,47		-	
	3	0,36		-		-		-	
	4	0,96		-		-		-	
Trondhjemite gneisses	1	0,38	0,55	0,56	0,47	0,59	0,52	-	0,65
	2	0,35		0,37		0,44		-	
	3	0,29		-		-		-	
	4	0,86		-		-		0,8	
	5	0,51		-		-		-	
	6	0,55		-		-		0,5	
	7	0,92		-		-		-	
Kaap Valley tonalite	1	0,74	0,62	1,36	0,94	1,46	0,69	1,1	0,75
	2	0,51		0,56		0,60		-	
	3	0,71		0,89		1,02		-	
	4	0,69		-		-		-	
	5	0,72		-		-		-	
	6	0,61		-		-		-	
	7	0,51		-		-		0,4	
	8	0,48		-		-		-	
Cunning Moor tonalite	1	0,50	0,45	0,57		0,62	0,57	-	
	2	0,40		-		0,51		-	

$\bar{X}$ - mean values

All measurements in per cent

Descriptions of the four methods used are provided in the text

(i) cavities which are more or less equidimensional, and are responsible for the dominant volume of pore space, and

(ii) linear fractures, which occupy only a small volume of pore space but significantly influence the rates of penetration and circulation of water within the rock.

In that the second factor is likely to be of more importance to differential weathering than the first, it is suggested that in addition to global porosity a measure of the degree of fracturing in quartz grains might not only correlate better with actual observations but also indicate to some extent the degree of tectonic disturbance experienced by the rock (Birot, 1958a,b). Preliminary data on the degree of quartz fracturing in various granites of the study region are presented below; however, no data on rock permeabilities are as yet available.

The ranges of percentages of fractured quartz in a number of granitic bodies are listed below and exhibit a fair correlation with the observed hierarchy of weathering as established previously (Fig. 5):

Kaap Valley tonalite - 59 to 86

Trondhjemites - 48 to 76

Hebron granodiorite - 31

Mpageni granite - 20 to 26

Dalmein granite - 38 to 54

Nelspruit porphyritic granite - 36 to 48

Cunning Moor tonalite - 30 to 56

Hood phase of the Mpuluzi batholith - 28 to 44

The above figures suggest that the degree of microfracturing in a rock is important in terms of rock-water interaction and this parameter cannot, therefore, be underestimated in considerations of chemical weathering. It would appear, however, that abnormally compact textures are required, at least in view of the constraints imposed by present methods of measuring global porosity, before it can be said with any degree of certainty that porosity is dominant over other factors in considerations of differential weathering. For example, the highly compact texture of diabase dykes, three samples of which have yielded very low porosity values (i.e. 0,00 per cent, 0,09 per cent and 0,17 per cent, measured by the method of water absorption under 100 bars pressure), is a very significant, probably even the dominant, factor in explaining the positive physical expression of these intrusions.

Although all the variables have probably not been taken into account it is evident from the study of granitic landforms in the Barberton region that a number of geologically related factors (composition, mineralogy, texture, porosity) all, to a greater or lesser degree, play a role in controlling denudation of the terrane. It is, however, often difficult to establish the *relative* importance of each of these factors in influencing differential weathering. It is also often difficult to evaluate the significance of variables evident on outcrop scale as opposed to hand-specimen scale. For example, the existence of a network of pegmatitic veins probably could significantly affect the overall resistance to weathering of bodies such as the Nelspruit or Mpuluzi porphyritic granites. Consequently, the heterogeneity of the granitic terrane must be regarded as paramount in understanding the wide range of landforms that have developed in the study area. That these landforms are clearly secondary in nature, as they have been moulded from a fundamental planation surface, is basic to the understanding of the geomorphological evolution of the region and this is discussed in more detail in the following section.

IV. PLANATION SURFACES AND THE GEOMORPHOLOGICAL EVOLUTION OF THE EASTERN TRANSVAAL

In the Barberton area it is evident that a clear-cut relationship exists between relief and structure (or geological heterogeneity). This is even more the case when it is realized that the planation surfaces themselves are a function of the geological terrane which they underlie (Figs. 2 and 4) and their actual preservation is closely linked to the rock types themselves. Structure alone, therefore, does not, in every case, hold the key to understanding the diversity of the landscape.

A. The Recognition of Planation Surfaces

Although the study and recognition of planation surfaces has often been over-emphasized and excessive (mainly due to the over-use of purely graphic techniques), it is clear that certain surfaces transect the crystalline basement and have formed independently of structure. Geological contacts are not always exposed along scarp edges as shown in the case of basins formed by differential weathering. In the Barberton area, low-lying basins preserve remnants of a pre-existing floor which forms the base of the Drakensberg "pseudo-cuesta". A good example is provided by the Kaap Valley basin in which a clear-cut distinction is evident between the intermediate and lower surfaces (see Fig. 10), the latter having been shaped independently of tonalite types within the Kaap Valley pluton (i.e. the distribution of hornblende- and hornblende + biotite tonalites as outlined in the mapping of Robb, 1981). Moreover, the scarp between the two surfaces is cut perpendicular to the orientation of the main dykes in the Kaap Valley basin (Fig. 10) so that these intrusions cannot have influenced the development of the surfaces.

The development of the larger basins in the Barberton region (e.g. the Kaap Valley and Badplaas basins) occurred in a sporadic fashion after the formation of the regional Highveld surface. These basins tend to be well-defined below the Highveld surface and in certain cases extend right down to the Lowveld surface (Fig. 4). This was also recognized by Hall (1918) who said, "If elevation is the chief criterion, the designation of Low Country might be extended to the floor of the Kaap River Valley".

The existence and recognition of the Lowveld erosion surface is made, not only on the basis of altitude, but also by its concave nature, an appearance which contrasts markedly with the higher-lying plateaux and their undulating forms. This contrast is similar to that noticed in Tanzania by Louis (1964) who distinguished between the wide "gutter-shaped" valleys (the reine Flachmuldentäler) with "ramped" slopes (the Rampenhänger) which are similar to the Lowveld surface, and the narrow valleys (the Kehltäler) with steep "valley-side" slopes characteristic of the Highveld and Middleveld surfaces.

In addition to the recognition of erosion surfaces on the basis of landscape and altitude, an independent and totally objective criterion is available which involves an assessment of the nature of the weathering mantle. For the purposes of this study a total of 55 samples of decomposed granite was evaluated with the object of assessing their degree of alteration and comminution. The results of these analyses indicate that a clear-cut distinction can be made between the thin, sandy, weathering mantle developed over the Lowveld surface and the relatively thick, clayey, evolved, saprolith of the higher-lying plateau areas. These differences have no significance in terms of differential erosion on a regional scale, but probably reflect the influences of heritage and temporal changes in palaeoclimate.

Systematic variations in the extent of alteration fronts become evident only if data pertaining to maximum depths of the weathering mantle to basement are available. Such data (see Fig. 14 for example) indicate that alteration profiles do not exceed 10 m in the Lowveld (e.g. 4,6 m and 4,1 m in the Pretoriuskop and

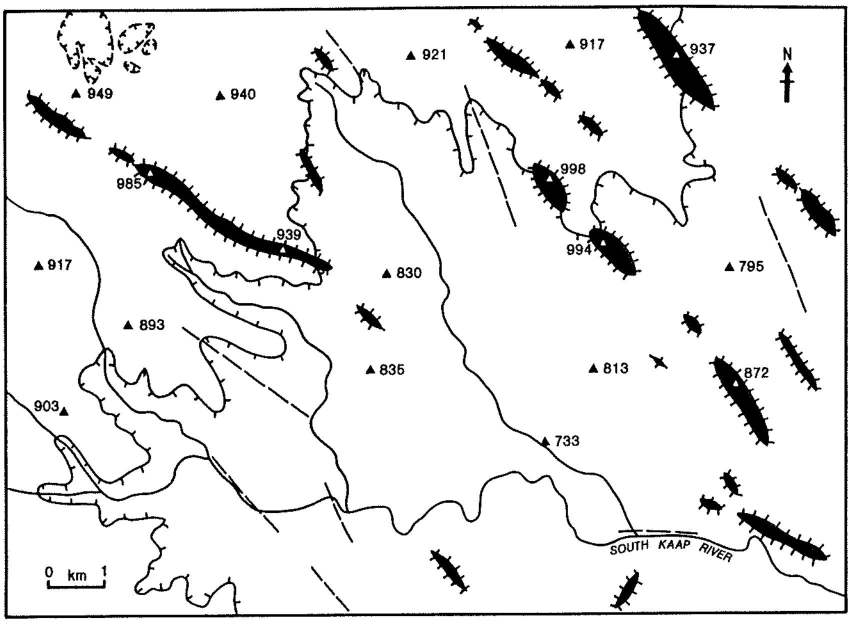


Figure 10 : *Sketch showing the nature of the talus slope between the intermediate and lower benches in the Kaap Valley basin to the northwest of Barberton. Dykes are shown in black; the depression at upper left is a lavaka-like feature (see text for explanation).*

Wilsonskop areas, respectively), whereas depths in excess of 50 m are commonplace on the higher plateaux (.e.g. 44,2 m at White River, 62 m at Da Gama, 57 m at Highlands, all on the intermediate bench north of Nelspruit). In addition to their depth of formation, the two distinct suites of residues, which correspond to the two upper and the lower erosion surfaces, are easily distinguished in terms of their grain size and mineralogy. Global granulometric composition is a good measure of the degree of alteration and, in particular, an increase in the fraction of the fines in decomposed material (more so than an increase solely in the clay fraction) is a sensitive indicator of progressive alteration. Table IV and Fig. 11 summarize the results of granulometry for each of the three erosion surfaces defined and outlined in Fig. 2a, and highlights the contrasts between the two types of regolith.

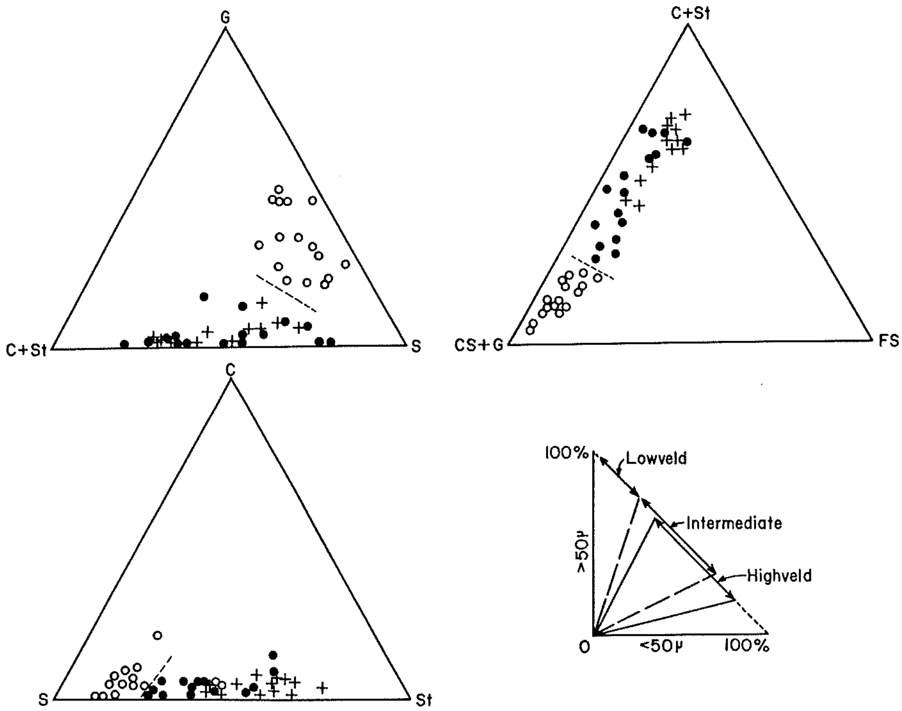


Figure 11 : *Granulometric characteristics of the decomposed weathering mantle or regolith overlying granite from the Highveld (+), Intermediate (•) and Lowveld (o) erosion surfaces. (G – gravels, >2000µm; CS – coarse sand, 200-2000µm; S – sand, 50-2000µm; FS – fine sand, 50-200µm; St – silt, 2-50µm; C – clay, <2µm).*

TABLE IV

Granulometry Results for the Three Erosion Surfaces in the Eastern Transvaal Basement

Level	1(Highveld)	2(Intermediate)	3(Lowveld)
Fine gravel (> 2mm)	4%	6%	33%
Coarse sand (200μm-2mm) Fine sand (50 - 200μm)	37%	50%	51%
Silt (2 - 50μm) Clay (< 2μm)	59%	44%	16%

The weathering product over level 3 is characterized by a preponderance of gravel and sand and is quite different in character to the fines-dominated saprolith of levels 1 and 2*. This distinction (Fig. 11), although never quantified previously, had been observed by Hall (1918) who stated, "The granite either disintegrated to a coarse, sand deposit or else thoroughly decomposed into a pinkish-grey or reddish tenacious clay, sometimes to a considerable depth". X-ray diffraction studies of the clay fraction from the various samples analysed further enhance the distinction established above and by Hall. Kaolinitic clays occur mainly within the most evolved weathering mantles and are found on the upper and intermediate benches in the approximate proportions; kaolinite 75 per cent : illite 25 per cent. Traces of gibbsite and goethite also occur, and smectite was detected in samples from the intermediate bench. Kaolinite occurs in much smaller quantities on the Lowveld surface, with clays occurring in the following relative proportions, kaolinite 45 per cent : illite 30 per cent : smectite 10 per cent : vermiculite 15 per cent. In this type of environment bisiallitization is considered to be the dominant alteration mode.

Although it is not possible, using the above methods, to correlate specific soil types with the inferred age of planation surfaces, it is clear that the systematic progressive comminution of the crystalline basement implies that the profiles formed over different lengths of time. On the Highveld and Middleveld surfaces the presence of thick volumes of regolith† reflects a considerable duration of weathering processes. By contrast, the final stages of Lowveld morphogenesis occurred over a shorter period of time in a climate that was obviously sufficiently dry to enable an arenaceous form of alteration to occur, but with subsequent flushing of fines down-slope.

The study of granitic domes provides a further indication of the evolution of planation surfaces and this topic is discussed in the following section.

B. Domes and the Development of the Granitic Landscape

In the Eastern Transvaal rock domes are not randomly distributed, and do not form without some relationship to the geomorphological cycle. The same can probably be said to be true of domes in Swaziland, although this aspect was not mentioned by Gibbons (1981) in the description of tors (*sensu lato*) in that region. The various dome-like forms in the region can be subdivided, according to the classification scheme of Godard (1977), into the following types**:

(i) monoliths which cap prominent physiographic features such as the Krokodilpoortberg. The latter range has been cut by a network of faults and fractures which control the pattern of superimposed drainage (note that such a pattern contrasts markedly with the dendritic drainage pattern developed over the Kaap Valley tonalite pluton, see Fig. 2a). Characterized by curved joint sets, these monoliths (or "dwalas", after Visser *et al.*, 1956) are localized along interfluves (see Fig. 12), but are too small to be resolved at the scale of the regional geomorphological map (Fig. 2a). The domes of the Krokodilpoortberg are formed in homogeneous rock below the level of the Highveld surface and clearly originate as a result of irregularities in the depth of the weathering front. By contradistinction, above the Highveld surface, on the Lochiel plateau, for example, no domes are exposed and the rock is largely soil-covered. The reasons for the lack of relief on the Lochiel plateau are, firstly, because of the extended period of stability arising from successive episodes of planation and, secondly, because of the ineffectiveness of erosion, which tends to be restricted to the dominant structural (fracture) trends on both sides of this watershed,

(ii) prominent geomorphological features along the major slopes separating one erosion surface from another. North of the Lochiel plateau, for example, domes coalesce along the sides of fracture-related valleys or along the scarp slope separating the Lochiel plateau from the Badplaas basin (Fig. 13). A similar situation exists above the Crocodile River valley both to the north and south of this east-west-trending fluvial axis (Fig. 14).

* The thick, decomposed weathering mantle described here is often dissected by ovoid or lobate trenches (see Fig. 10, upper left) similar to the "lavaka" of highland Madagascar, which result from linear incision and side-wall collapse. Similar features and processes were noted by Van der Merwe (1941). The lavaka-like features differ from gullies (or "dongas") which tend to dissect the coarser-grained regoliths.

† This excludes the pockets of fine-grained, *in situ* derived, weathered material located beneath the Ecca cover, which can be explained as a crypto-decomposition product of the underlying Heerenveen batholith.

**The control of lithology on the shape and occurrence of granite domes should be emphasized. For example, in the Pietersburg district of the Northern Transvaal domes occur preferentially in a sequence of granites, gneisses, and migmatites (Brook, 1978) which can probably be equated with rocks of the second magmatic cycle in the Barberton context. Strictly speaking the term "tor" can only be applied to a prominent pile of boulders such as is evident over the Mpageni, Salisbury Kop, and Dalmein plutons. The tonalite and trondhjemite gneiss plutons tend to give rise to smooth, flattish, domes or "whalebacks".

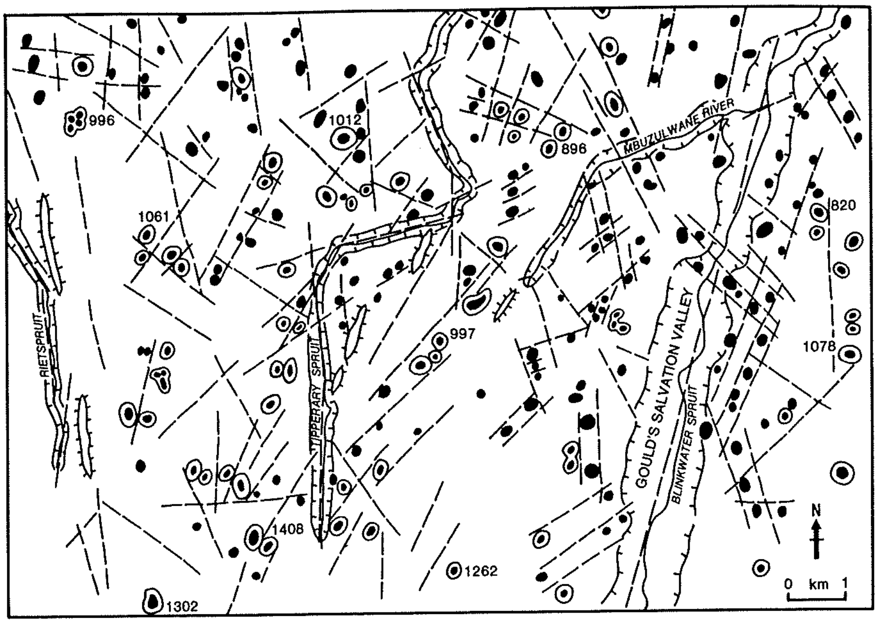


Figure 12 : *The distribution of tors and domes in the Krokodilpoortberg, southeast of Nelspruit. Tors and domes (in black) are shown in relation to linear features or fractures (dashed lines), river valleys and mafic dykes. Domes formed along interfluves are outlined.*

Birot *et al.* (1972) drew attention to a belt of pediment developed along the Lydenburg-Nelspruit road around Brondal (at an altitude of between 900-950 m) which is indicative of a stage of cyclic stability during the development of the intermediate surface. This pediment, which is covered by a mature soil overlying a bleached layer, is dissected further downstream to reval a series of domes. The development of this category of dome by processes of denudation, implies active ablation occurring preferentially along the sides of valleys or on the slopes separating two erosion surfaces, and

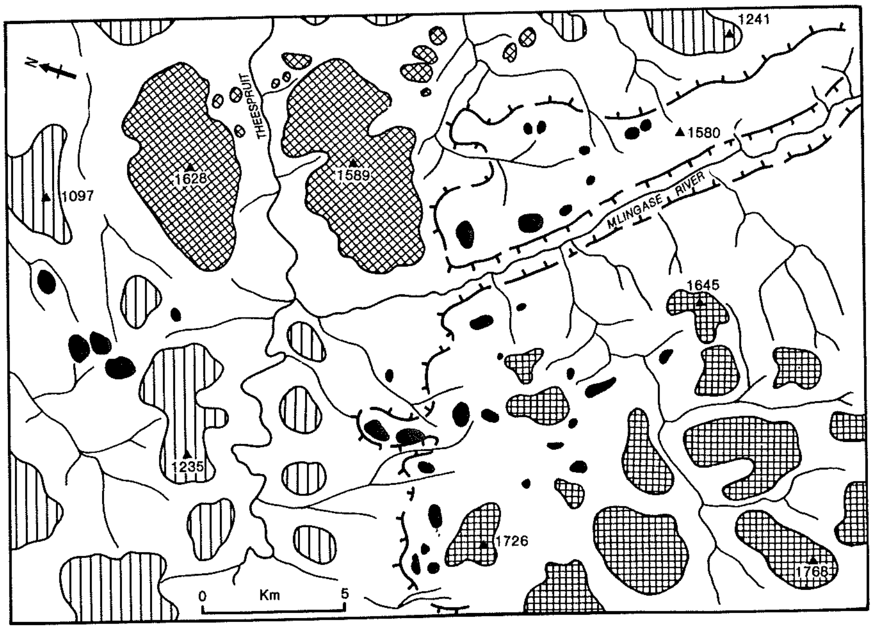


Figure 13 : *Sketch showing the nature of the scarp separating the Lochiel plateau (where the interfluves preserve portions of the Highveld surface, cross-hatched) from the Badplaas basin (where the Intermediate surface (vertical stripe) is developed). The Boesmanskop syenite body is shown in diagonal cross-hatch. A number of domes (in black) are seen developed along the dissected scarp edge.*

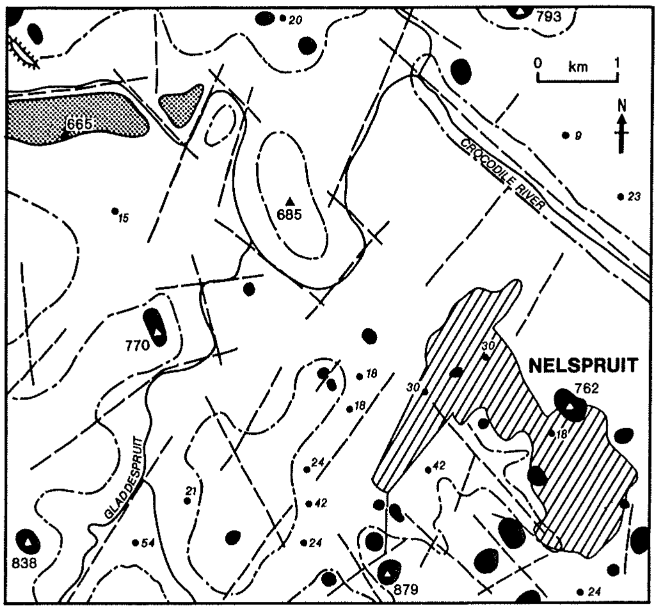


Figure 14 : *Sketch showing the southern edge of the Nelspruit valley drained by the Crocodile River. The distribution of isolated domes (in black) is shown and also the depth (in metres) of the weathering mantle. Nelspruit town is shown by diagonal hatching. Stippled area represents a fluvial terrace.*

(iii) isolated, individual, or small groups of domes apparently randomly dispersed over the Lowveld surface (Fig. 15). The development of these "inselberg-domes"* is a debatable topic in the light of current differences of opinion regarding "backwearing" as opposed to "downwearing" processes of erosion. In the first two categories

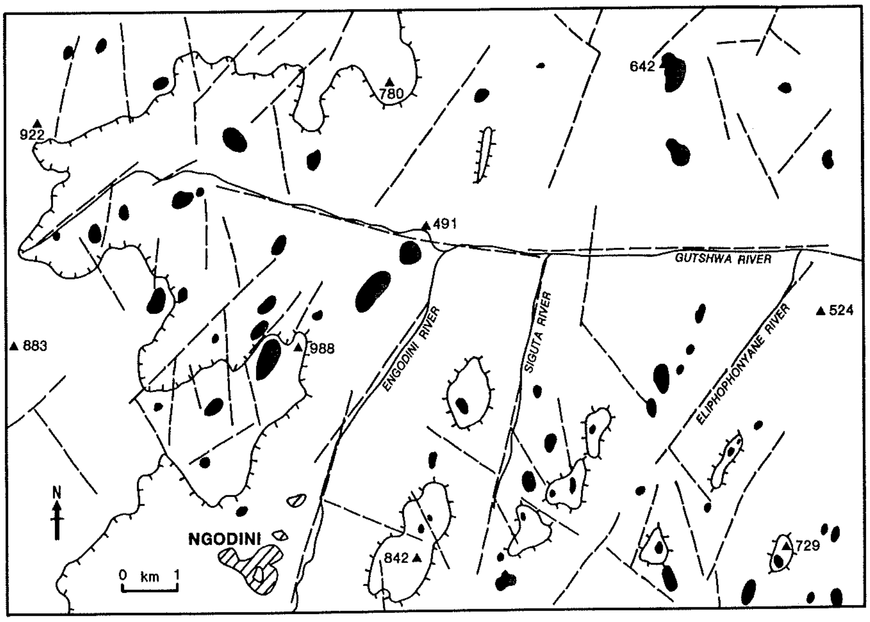


Figure 15 : *Sketch showing the scarp between the Middleveld surface and the Lowveld surface in the region due east of White River (see Fig. 2). The lowveld surface is characterized by westward embayments into the Middleveld surface. The area is mainly underlain by the Nelspruit porphyritic granite, which grades eastwards into the migmatite and gneiss terrane (see Robb et al., 1983).*

* The definition of "inselberg" needs to be restricted in this sense to that of a residual feature outcropping starkly above a planation surface. Such features accord with the "island landscape" described for the Lowveld by Hall (1920).

of dome formation the presence of a thick weathering mantle favours exposure of residual, unaltered material, whereas the thin arenaceous weathering mantle of the Lowveld surfaces militates against this process. These domes may, therefore, represent the remnants of erosion by lateral planation, but their random occurrence with respect to the drainage network is not in accord with their status in terms of position (i.e. "Fernlinge"). Rather, the domes could have formed by the slow, progressive lowering of the landscape, a process which must have been combined with only moderate alteration and removal of comminuted debris by slope-wash processes. Whatever was the relative role of either back- or downwearing the almost total destruction of interfluves on the Lowveld surface is demonstrated by:

(a) "degeneration" (Thomas, 1974) of domes into tors or "kopjes" by release of compressive stress and the development of vertical joints,

(b) the presence of quartz pavements on ablation surfaces (Visser and Verwoerd, 1960) formed by the erosion of shear zones which, elsewhere, occur as prominent quartz ridges, and

(c) the exhumation of prominent east-west-trending dyke swarms between Hazy View and Bushbuckridge which, at a higher level further west, occur as laterally extensive sills (Fig. 16).

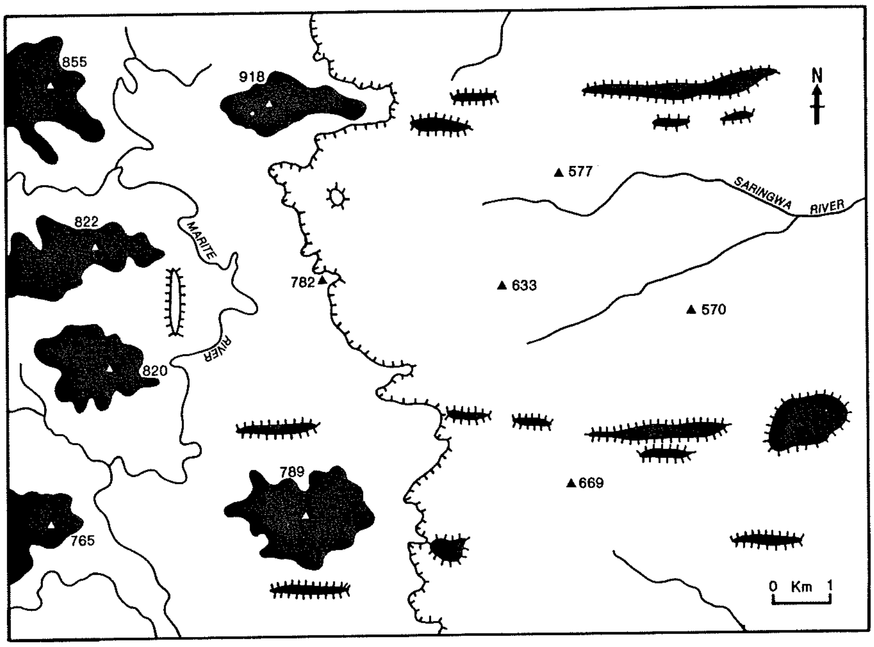


Figure 16 : Sketch showing the easterly limit of the Middleveld surface between Hazyview and Bushbuckridge (see Fig. 2). Note the distribution of sills (in black) on the higher lying surface and the presence of (feeder?) dykes on the adjacent Lowveld surface to the east.

The morphotectonic conditions which gave rise to the stepped planation surfaces (in particular the Lowveld surface) in the Eastern Transvaal are still problematic. Are such surfaces the result of scarp retreat with the steep-sidedness of the original valleys (i.e. those formed along planes of weakness or fractures in the first instance) being preserved during such a process, or, have they formed as the result of periodic, lengthy rejuvenation of an initial surface which at some stage has been tilted in such a way as to inhibit vigorous rejuvenation processes? Even if it is possible to partially reconstruct the geomorphological evolution of this region, it is clear that any answers regarding the intensity of deformation in the basement are still distant.

C. Geomorphological Evolution of the Eastern Transvaal

The present paper deals with the formation of landforms on the edge of the Archaean Kaapvaal craton in the Barberton region of the Eastern Transvaal; logically such processes must be intimately related to the evolution of the south-east African continental margin. In the absence of a prominent fault or linear suture zone (since the concept of the "Great Eastern Fault" advocated by Molengraaf and Draper in Hall (1925) has been discarded by modern workers) the principal tectonic feature deemed responsible for the formation of the Great Escarpment is regarded as being a major monoclinal flexure. Such a structure was envisaged at an early date by Davis (1906) who stated that "... when the profile of the descending slope is drawn on true scale a very gentle warping without faulting seems to satisfy all the requirements of the case". The sediments of the Ecca Group constitute a good marker as to the nature and amplitude of this monoclinal flexure. These sediments outcrop at an altitude of about 1 800 m to the east of Carolina plummeting, some 100 km eastward, to about 300 m in the Swaziland lowveld. Having influenced sediments of Ecca age, it is evident that the age of this flexuring event and its significance to the geomorphological evolution of the region are problematic questions.

Of considerable benefit in recent years to this problem has been the study of the nature of sedimentation on the margins of cratonic blocks and its relationship to the evolution of geomorphological processes within them. In this regard studies of Cretaceous and Tertiary marine sediments below the existing coastal plains of Mocambique and Zululand could shed light on the development of cratonic landforms. King (1951, 1962) has attempted to relate the various cyclically developed planation surfaces on the continent to unconformities in adjacent sediments. Using geometric projections it was possible to establish a lateral continuity between inherited landforms and their buried equivalents. This apparently well-established correlation, after King (1962), is summarized in Table V.

TABLE V

Correlation of Erosion Surfaces and Sedimentary Successions

Erosion Surface	Age	Sedimentary Series
Gondwana	Jurassic	Neomanian
post-Gondwana	Cretaceous	Cenomanian
African	Eocene	Burdigalian
post-African I	Miocene	Pliocene
post-African II	Pliocene	Pleistocene

After a re-examination of recently available sedimentological information, however, it is suggested that certain aspects of this correlation may be doubtful in view of the opinion (Lageat, 1983) that certain unconformities, recognized on the basis of stratigraphic boundaries, need not necessarily be correlated with a discrete episode of erosion in the hinterland. Moreover, the Gondwana and post-Gondwana correlations provided in Table V are still conjectural, as indeed are the ages of the interior plateaux and the Lebombo summit.

The apparent age of the Highveld surface is constrained by the intrusion of kimberlitic pipes during the Turonian-Coniacian periods (90-83 Ma). These pipes are truncated by the Highveld surface in the northern Cape Province and southern Orange Free State. The continuation of the Lowveld surface towards the Mocambican coastal plain is punctuated by the westerly-facing Lebombo escarpment which is defined by a succession of basaltic and rhyolitic lavas. The summit of the Lebombo range defines a surface of altitude 600 to 700 m and up to 15 km wide, and is tentatively linked to the intermediate surface (Fig. 2). Furthermore, the 14 streams which run transversely across the Lebombo range have been superimposed onto this surface. In addition the location and extent of a sub-horizontal basal conglomerate of Miocene age in southern Mocambique (Förster, 1975) reveals that the ocean shore-line once ran parallel to the Lebombo range. Consequently, the summit of the Lebombo range had already been bevelled by the time of the Miocene whereas the marginal Lowveld surface must correlate with sedimentation in the Neogene. This was, in fact, recognized very early on by King (1951) when he stated, "The Lowveld ... is, cyclically, the hinterland equivalent of the coastal plain of Mocambique". In this light it is difficult to attribute a Neogene age to the two most recent erosion surfaces, as suggested by King (1962).

The use of off-shore drilling data, and the assessment of the nature and average rate of sedimentation, facilitates the reconstruction of the periodicity of uplift along the coastal margin and adjacent continental erosion surfaces. The recognition of stepped planation surfaces implies spasmodic uplift, the scenario for which is briefly described in the following six stages (after Lageat, 1983):

(i) initial development of a monoclinal flexure during the Cretaceous,

(ii) period of stability between the end of Cretaceous and the Palaeocene with subsequent formation of the Highveld surface,

(iii) tectonic activity (and uplift) in lower and middle Eocene times,

(iv) epeirogenic quiescence between the Middle Eocene and upper Oligocene during which time the intermediate erosion surface developed, as well as the deposition of a limited amount of sediment,

(v) continental uplift during the lower Miocene and the supply of abundant arenaceous sediment into the ocean, and

(vi) formation of the Lowveld surface in continuity with the Mocambique plain.

The paucity of detailed off-shore sedimentological data clearly places constraints on the extent to which the polycyclic relief at the base of the Transvaal Drakensberg Escarpment can be fully explained. The work of De Swart and Bennett (1974) on the relief of the Natal lowveld represents an indication of the usefulness of such data — usually only the result of oil exploration programmes — to studies of this nature.

V. CONCLUSIONS

The above, somewhat preliminary, attempt at relating the geomorphological evolution of the region to the nature of the Archaean granitic terrane has taken objective cognizance of three distinct factors:

(i) a geological factor — where the recognition and distribution of a wide range of granite types is often lucidly reflected in the nature of the topography. The relationships between morphology and petrographic factors such as composition, mineralogy, and texture provide many of the clues to explaining the concept of differential erosion, but is a complex topic which has only been cursorily examined here,

(ii) a morphotectonic factor — where the evolution of relief is controlled by the deformation of the Highveld erosion surface. The intense erosion and weathering during the Tertiary era was imposed on a terrane characterized by a pronounced structural fabric, and

(iii) a morphoclimatic factor — which determined the depth of erosion and thickness of the weathering mantle or regolith, and influenced the shape of the structural landforms.

The geomorphological evolution of the Barberton terrane is envisaged as being a consequence of numerous interrelated parameters and it is evident that the interpretation of relief on the basis of only a single principal or tenet is clearly prone to oversimplification and error.

ACKNOWLEDGMENTS

In borrowing numerous quotes from the writings of A.L. Hall, this paper pays tribute to the remarkable perceptiveness and understanding exhibited by this pioneer geologist regarding the relationship between geology and geomorphology. The authors are grateful to the late Professor P. Birot and Professor A. Godard for encouragement and advice on draft versions of the paper. Professor C. Anhaeusser is thanked for the loan of certain of the photographs and Ms. I. Paris for assisting in the translation from French. A number of people, including R. Lewis (EGRU) and H. Duroy, M.N. Lecoustumer, M. Levant, Y. Delehaye and C. Blanchet (Centre de Geómorphologie, Caen) assisted with various of the technical aspects of the paper. Grateful thanks are extended to N. Gomes and M. Boudinhon for drafting the diagrams and to Doris Amaler for typing the manuscript.

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