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THE NATURE OF THE ARCHAEAN BASEMENT IN THE HINTERLAND OF THE WITWATERSRAND BASIN: I - THE RAND ANTICLINE BETWEEN RANDFONTEIN AND RYSMIERBULT

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ABSTRACT

The Rand Anticline, between Randfontein and Rysmierbult, is accentuated by the development of numerous basement "windows" in which domal exposures of Archaean granite occur. These rocks are either coarse-grained to porphyritic in texture and adamellitic-granitic *(sensu stricto)* in composition, or gneissic-to-migmatitic with a tonalitic composition. Numerous samples of borehole core reveal that the sub-surface basement is composed of granites equally diverse in texture and composition. Noticeably, however, numerous of the sub-surface samples exhibit an often intense overprint of hydrothermal alteration manifest as sericitization, chloritization, carbonate replacement, carbonate or quartz-carbonate vein-type alteration, pyritization and the development of leucoxene. Also preserved at the contact between the basement granite and overlying sediment is a quartz-sericite rock which possibly represents a palaeo-regolith formed by surficial weathering process during early-Proterozoic times.

The occurrence of regionally extensive alteration zones in granites from the sub-surface basement suggests that the upper portions of granitic bodies, in which hydrothermal alteration and/or mineralization is concentrated, may be preferentially preserved beneath a capping of sediments or volcanics which have inhibited subsequent erosion. The roof-zones or cupolas of Archaean granites have rarely been studied and their existence in the Witwatersrand Basin hinterland lends credence to previous suggestions that granites (or portions thereof) formed the principal source rocks to much of the adjacent placer gold-uranium deposits.

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I. INTRODUCTION

The nature of the Archaean basement forming the hinterland to the Witwatersrand Basin is a subject about which very little is known, either because much of this terrane is covered by Proterozoic and Phanerozoic strata, or because, where exposed, outcrops are extremely scarce. Consequently, the question of the source of the enormous concentrations of placer gold and uranium in the Witwatersrand Basin has always been particularly problematic as it is generally apparent that rocks presently exposed in typical Archaean granite-greenstone terranes (e.g. Barberton) are grossly deficient as a provenance for the conglomeratic ores (Reimer, 1984; Robb and Meyer, 1985). In order to redress this situation a study has now been in progress for some years with a view to shedding light on the nature and characteristics of the Archaean basement specifically in the environs of the known limits of the Witwatersrand Basin. The approach has been twofold; firstly, an examination of the limited outcrop areas of Archaean rocks in the numerous basement domes which occur mainly along the northern flank of the basin, and secondly, a study of the many borehole intersections of the sub-surface Archaean basement that have been made over the past several decades by various exploration and mining companies.

The present report represents the first in a series of such articles which will systematically describe the general geological, petrographic and chemical characteristics of both the surface and sub-surface Archaean basement in various, arbitrarily defined, segments in the hinterland of the Witwatersrand Basin. The present study describes the Archaean granitic basement in a fairly restricted strip between Randfontein and Rysmierbult - a portion of the Rand Anticline - which lies immediately to the west of the Johannesburg dome (Figure 1). The Johannesburg dome has been extensively studied in the past and numerous articles describing the granites, greenstone remants, isotope characteristics, geomorphological setting etc. of the dome are available (Anhaeusser, 1973; 1977; 1978; Anhaeusser and Burger, 1982; Brook, 1970). Few, if any, recent geological descriptions of the Archaean basement adjacent to the Johannesburg dome are, however, available although a description of hydrothermal alteration in granites from the Varkenskraal area has recently been published (Klemd and Hallbauer, 1986).

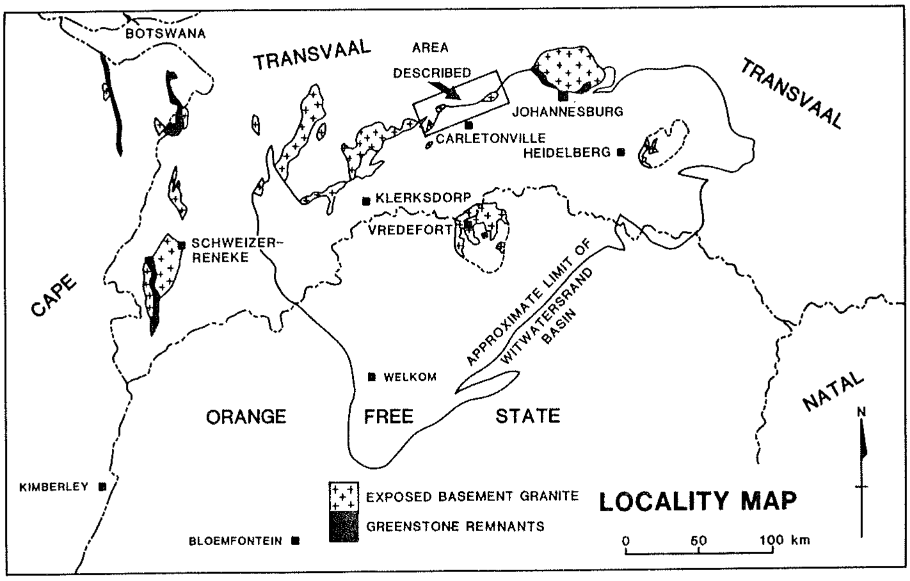


Figure 1 : *Locality map showing the area described in terms of the regional extent of the Witwatersrand Basin and the major domal outcrops of Archaean granite-greenstone basement adjacent to, and within, the basin.*

II. GENERAL GEOLOGY OF THE STUDY AREA

The axial trace of the Rand Anticline between Randfontein and Rysmierbult (Figure 2) is defined essentially by the Black Reef Formation which is flanked to the north and south by shallowly-dipping dolomites of the Chuniespoort Group (Transvaal Supergroup). The structure is further accentuated by a number of domal outcrop "windows" of granitic basement, most of which straddle the axial trace, although at least one apparently occurs on the flanks of the up-warp. The anticlinal structure is shown in very simplified form in Figure 2 and no attempt has been made to unravel the numerous localized complexities that undoubtedly exist as a result of faulting. Four fairly significant basement "windows" occur along the structure and these are termed, from east to west, Doornfontein, De Pan, Varkenskraal and Rysmierbult. A number of much smaller outcrops occur but these do not warrant further mention. All the basement outcrop "windows" which occur along the Rand Anticline in the study area form part of a larger domal structure defined largely by its low gravity signature, which has been referred to in the past as the Vreysrus dome (Pretorius, 1976).

The Doornfontein outcrop area exposes a granite which is overlain to the southeast by the Orange Grove Quartzite Formation, and elsewhere by quartzites of the Black Reef Formation. The outcrop area is essentially underlain by highly weathered, friable granite, sand and ferricrete, although a large area of fresh outcrop is exposed along the edge of a pan. The De Pan outcrop "window" is also flanked by the Black Reef Formation, and exposes a large area of granitic outcrop, also on the edge of the pan. The outcrop area is also characterized by a large north-northeasterly trending, anastomosing diabase dyke, which delineates the approximate contact between two distinct granite types (see later) and may represent a structural break.

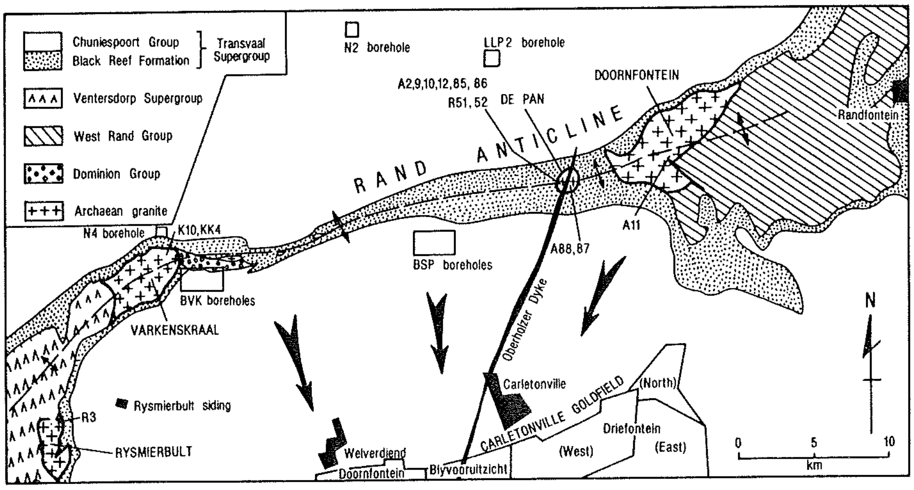


Figure 2 : *Map showing simplified geological relationships along the Rand Anticline between Randfontein and Rysmierbult siding, and portion of the Carletonville Goldfield. Black arrows indicate general directions of sedimentary transport into the goldfield.*

The Varkenskraal outcrop is flanked to the north and south by the Black Reef Formation, but is overlain by the Ventersdorp Supergroup in the west and by sediments and lavas of the Dominion Group in the east. No granitic rocks are actually exposed, although at a number of localities an unconformity between a granitic palaeoregolith or palaeosol and overlying strata is revealed. Similiarly, no actual granite is exposed in the Rysmierbult "window", but good outcrops of a granitic palaeoregolith are preserved along an unconformity between thin basal conglomerate of the Black Reef Formation and the basement. To the east of the Varkenskraal area, two or three small outcrops also reveal regolith-like material, as well as epidotized granite and pegmatite. A number of samples have been collected of exposed basement material and their localities are all shown on Figure 2.

Numerous boreholes intersect the sub-surface basement both along the northern and southern flanks of the anticline (Figure 2). Along the northern flank, two boreholes, N2 and LLP2, intersected granite basement at approximately 3180 metres and 804 metres respectively. A third borehole, N4, intersected basement granite at an unrecorded depth. Borehole N2 was collared in dolomites of the Chuniespoort Group and intersected over 1,5 km of Ventersdorp rocks before being terminated in a fractured, cataclastic granite. The actual Ventersdorp-basement contact is highly silicified and fractured and probably represents a tectonic break. Borehole LLP2 was also collared in dolomite but was located beyond the eastern extremity of the Ventersdorp sub-outcrop and, hence, passed directly from the Black Reef Formation into the basement. Being closer to the axis of the anticline, the basement in this hole was intersected at a much shallower depth, and revealed an unconformable relationship between a basal conglomerate and a granitic palaeoregolith. The regolith, in turn, graded downwards into highly fractured, altered granite.

South of the anticlinal axis two sets of boreholes, one on the farm Varkenskraal immediately to the east of the Varkenskraal basement window, and the other on the farm Bospan to the west of the De Pan outcrop, intersected the sub-surface basement (Figure 2). The Bospan holes (BSP 1/2/4/5/6/7/8/10) were all collared on the lower dolomites of the Chuniespoort Group and usually intersected the Black Reef Formation before being terminated in basement granite at depths varying between 30-440 metres. The boreholes usually revealed a basal Black Reef conglomerate immediately underlain by a granitic palaeoregolith. The latter, in turn grades down into fractured, and in some cases, altered pyritiferous granite. As discussed in more detail later, the Bospan holes straddle a fault, the southern, downthrown, side of which reveals the granite basement at a considerably greater depth than that on the northern side.

The Varkenskraal boreholes (BVK 2/3/4/7/8/9/10/11/14) were mainly collared on lavas of the Dominion Group and usually intersected a thin quartzitic horizon, correlatable with Dominion sediments (i.e. the Rhenosterspruit Formation), before terminating in granitic basement at depths of between 30-120 metres. One hole (BVK 14) was collared in dolomite of the Chuniespoort Group, passed through Black Reef quartzites and the Dominion Group, before intersecting the basement at 416 metres depth. As with the Bospan holes, the overlying strata rests unconformably upon a granitic palaeoregolith which grades downwards into fractured and often altered and pyritiferous granites. In the case of the Varkenskraal intersections, however, the palaeosol represents a much older, pre-Dominion erosion surface than does the palaeoregolith intersected in the Bospan boreholes, which has been preserved only since the deposition of the Black Reef Formation. The difference in age between the two erosion surface identified in the boreholes may, therefore, be as much as 500-600 Ma.

III. PETROGRAPHY

A. Surface Exposures

1. The Doornfontein outcrop.

The Doornfontein granite outcrops over a limited area and comprises a massive, coarse-grained, homogeneous, porphyritic granite which is cut by numerous, often zoned, pegmatitic veins and quartz-epidote fractures. The compositions of two samples representative of this material are shown in Figure 3 where they straddle the fields of adamellite and granite *(sensu stricto)*. In thin section the granite has a distinctly subsolvus texture with separate grains of microcline and slightly sericitized plagioclase. The microcline usually occurs as poikilitic megacrysts containing inclusions of chlorite, plagioclase and quartz. A green biotite forms the dominant platy mineral although in some samples this mineral has been partially altered to an assemblage comprising chlorite, magnetite and epidote.

Secondary muscovite may occur. Zircon and apatite form the main accessory minerals although one sample contains a large (10 mm in length), euhedral, brown, semi-opaque mineral which may be allanite.

2. The De Pan outcrop.

In contrast to the Doornfontein exposure, the De Pan outcrop reveals a complex, heterogeneous assortment of granite types. The outcrop area is truncated by a large, anastomosing diabase dyke (the Oberholzer dyke; Figure 2) which trends north-northeast. To the east of this dyke a coarse-grained adamellitic rock type occurs which is compositionally similar to the Doornfontein granite. Texturally this rock type is not as coarse-grained or as porphyritic as the Doornfontein type and is, furthermore, characterized by intense fracturing, the orientation of which parallels the strike of the dyke. In addition, occassional mafic schlieren occur, a feature which was not noted at Doornfontein. To the west of the dyke the granite type is completely different, namely, a medium-grained, foliated and often migmatitic, tonalite. The compositions of samples from this area all fall in the tonalitic field of Figure 3, and are quite distinct from the more potassic compositions of the Doornfontein outcrop. The De Pan tonalite is medium-grained, grey-cream in colour and contains mafic schlieren, mafic chlorite-biotite xenoliths, dioritic remnants and anatectic veins (sample A85; Table I) which may have a coarse-grained, pegmatitic texture. Samples from the De Pan tonalite have yielded a Rb-Sr whole rock age of 2875 ± 146 Ma and a whole rock Pb-Pb age of 3015 ± 40 Ma (Barton *et al.*, 1986).

In thin section the De Pan tonalite has an equigranular, subsolvus texture with discrete grains of slightly sericitized plagioclase and minor intersticial microcline. The plagioclase is characterized by being preferentially sericitized towards grain margins, a feature which may reflect the restricted sub-solidus circulation of hydrothermal or meteoric fluids along intergranular pore spaces. The main platy mineral is a brown, rutilated biotite which has occassionally suffered incipient alteration to chlorite and epidote. Muscovite is a prominent phase which occurs as large euhedral grains which are probably primary in origin. Apatite is the dominant accessory phase and occurs as large, prominent euhedral grains; zircon is poorly developed. Certain samples are characterized by the presence of an abundant, brown, semi-opaque, Fe-rimmed accessory mineral which is possibly allanite or a monazite-like phase.

The mafic xenoliths which occur within the tonalite are characterized by an assemblage dominated by biotite, chlorite and plagioclase with lesser magnetite, orthoclase and quartz. In one sample biotite is the dominant phase, with chlorite and magnetite occurring as intimately intergrown, but discrete, phases. A further sample was characterized by a dominance of chlorite, with biotite clearly having been introduced later and replacing the latter. This sample has probably been affected by some form of potassic alteration or metasomatism as it occurs adjacent to an anatectic vein marked by a very high potassium content. These anatectic veins almost certainly have a metasomatic origin as they are characterized by an abundance of microcline and plagioclase with only very minor ($< 5\%$) quartz. Such proportions do not reflect the typical eutectic crystallization of magmatic granitoids.

The De Pan and Doornfontein outcrops clearly reveal two distinct granite types which are probably genetically unrelated. As the contact between the two rock types is abruptly delineated by a large dyke, it seems likely that a major zone of dislocation separates them. The magnitude and direction of displacement, if any, along this tectonic break is unknown at this stage and, consequently, it is not possible to comment on the possibility that the two granite types represent different crustal levels.

3. The Varkenskraal and Rysmierbult outcrops.

Neither the Varkenskraal nor the Rysmierbult "windows" preserve any outcrops of basement granite *per se*, but on the flanks of the domes good exposures of the unconformity between early Proterozoic sediments and underlying regolithic material occur. At Varkenskraal the base of the Black Reef quartzite is characterized by a coarse, poorly-sorted, polymictic conglomerate which overlies a palaeoregolith. The latter is clearly oxidized in its uppermost portions, comprising angular quartz fragments in a sericitic matrix which is pervaded by hematite and other Fe-oxyhydroxide stringers. Large flakes of muscovite also occur as well as spongy opaque oxides and an accessory mineral suite comprising zircon, monazite and/or xenotime. Below the first 10cm of the contact zone the palaeoregolith maintains its characteristic texture but is devoid of the abundant Fe-oxyhydroxide component evident higher up.

At Rysmierbult the material preserved beneath the Black Reef quartzite is more akin to a fossilized regolith than a palaeosol. Although fragmented quartz and sericite are again the dominant constituents, it is still possible to detect the relict outlines of K-felspar grains within the sericite matrix. Furthermore, the textural remnants of small pegmatitic veinlets are still evident in the regolith indicating that the breakdown of felspar minerals was incomplete and that alteration/weathering was an *in situ* process.

The altered quartz-sericite rocks described here are referred to as palaeosols or palaeoregolith in spite of the fact that no unequivocally diagnostic recognition criteria for a true fossilized soil have been detected. It is clear that because these rocks invariably occur at major basement-sediment unconformities it is inevitable that they represent sites where primitive weathering must have occurred. This viewpoint concurs with that of Button and Tyler (1981) who first drew attention to the significance of palaeoregoliths in the Witwatersrand hinterland. It is, however, also quite likely that these rocks have suffered from an overprint of later hydrothermal and/or diagenetic alteration and that their chemistry may not entirely reflect that of the original palaeosol. Such an overprint is, for example, clearly evident in the upper portion of the Varkenskraal palaeoregolith profile.

B. Borehole Intersections

1. Intersections along the northern flank of the anticline.

Two boreholes, N2 and LLP2, intersected the Archaean basement several kilometres to the north of the anticlinal axis. The granites sampled in these two boreholes have many similarities, the characteristic ones being their granodioritic composition, intense alteration and a tectonic overprint which is manifest as brecciation, fracturing and mylonitization.

Borehole LLP2 passes through the Black reef quartzite before intersecting a basement palaeoregolith 804 metres below surface. The regolith comprises angular fragments of quartz set in a groundmass of sericite and very fine-grained biotite. Occasional, fragmented relics of plagioclase are still preserved in the groundmass. Accessory minerals consist of large, often broken, zircon grains and occassional sphene/rutile remnants. Pyrite and intergrown chalcopyrite occur as abundant minor phases. Downwards in the borehole section the biotite-rich palaeosol grades into a granite regolith which consists of highly sericitized plagioclase, quartz and minor, altered microcline. Much of the plagioclase preserves relics of pervasive carbonate alteration which itself has apparently been replaced by sericitization resulting from the surficial weathering process. Biotitization is less pronounced lower in the regolith profile indicating that potassium metasomatism was not uniformly distributed. The original mafic constituents in the regolith appear to have been altered to a mass of fine-grained chlorite-sericite-quartz-biotite. The abundance of sulphide minerals is markedly lower than in the upper palaeosol horizon.

Approximately 6 metres below the contact the palaeoregolith grades down into a cataclastic granitoid breccia in which an assemblage consisting predominantly of plagioclase and quartz is fragmented by veins and stringers of biotite and/or sericite plus a carbonate mineral (calcite). In addition, portions of this underlying granite are characterized by stringers and veins of secondary biotite and microcline reflecting a potassic alteration process undoubtedly related to the biotitization described in the palaeoregolith. The original mineralogical composition of the rock is made up almost entirely of quartz, plagioclase and biotite (i.e. a tonalite) but the later alteration has resulted in the considerably more potassic compositions evident in Table II and K_2O contents of 3,6 - 8,2 %. The original biotite in the rock now appears as disaggregated flakes of chlorite plus minor epidote and leucoxene, these contrasting markedly with the pristine stringers of brown secondary biotite which formed during an episode of hydrothermal alteration. Samples which have been little affected by later biotitization (i.e. LLP2 908) nevertheless preserve evidence of an earlier hydrothermal overprint, revealing intense propylitization, carbonate alteration and veining, sericitization and fluorite veining. In summary, the LLP2 borehole exhibits a complex paragenesis of hydrothermal alteration assemblages which are almost certainly related to deuteric phenomena as well as, perhaps, a later tectonic overprint.

Borehole N2 passed through both the Transvaal and Ventersdorp Supergroups before intersecting the Archaean basement at 3180,5 metres. This contact is highly tectonized and silicified and no recognizable palaeosol is preserved at this locality. The basement here is best described as an altered, cataclastic granitoid breccia in which considerable grain size diminution has occurred and stringers of mylonitic material are developed, particularly near to the tectonic contact zone. In addition to the tectonic overprint the granite in borehole N2 is characterized by an intense, pervasive, hydrothermal overprint in which sericitization, chloritization, carbonate alteration and leucoxene form the dominant alteration assemblages. Unlike the LLP2 granite, biotitization (K - metasomatism) is only weakly developed and occurs sporadically throughout the profile. Most samples exhibit a pervasive alteration or replacement of pre-existing minerals by sericite, chlorite and a carbonate mineral (probably calcite). Carbonate and sericite preferentially replace plagioclase (which is the dominant felspar in the rock) whilst chloritization occurs either as a selective replacement of pre-existing biotite, or as a pervasive intergranular replacement product. Leucoxene occurs as discrete stringers or, more commonly, as an alteration product of a pre-existing Fe-Ti oxide phase. A vein-type alteration is also evident and prominent veins of zoned chlorite-carbonate or chlorite-carbonate-quartz-pyrite assemblages occur. A prominent vein comprising the latter assemblage occurs in sample N2 (3209) and was found to also contain an anomalous Au content (Table II). The vein itself is typified by a network of fine fractures filled with cryptocrystalline quartz and abundant pyrite. These fractures do not propogate beyond the edge of the vein and appear to be the result of volume reduction and dessication upon cooling.

2. Intersections along the southern flank of the anticline.

Although a number of boreholes have been drilled along the southern flank of the Rand Anticline, the intersections are clustered into two areas, namely, on the farms Bospan and Varkenskraal (Figure 1). Samples from the two areas share many common traits and are generally only moderately altered and were originally granitic (*sensu stricto*) in composition, with a coarse-grained, in places porphyritic, texture.

The Bospan samples represent a pre-Black Reef basement and are characterized by a late hematite alteration which permeates micro-fractures and grain boundaries. In one sample a distinctive hematite-chlorite vein is developed. Alteration in some of the Bospan samples is clearly not isochemical and certain samples are markedly enriched in K_2O (up to 9wt.%), a feature manifest as intense sericitization of plagioclase and potash felspars (sample BSP2 (42), Table II). It is pertinent to note that the latter sample exhibits marked depletion of Na_2O (i.e. 0,1%, Table II), which is typical of palaeosols developed over granites. Texturally, however, the sample is quite unlike the palaeoregolith described previously and it is evident, therefore, that the base exchange reactions affecting the surficial environment also prevail during hydrothermal alteration. Beside a pervasive sericitization, many of the Bospan samples exhibit carbonate alteration, particularly those from borehole BSP4 (note high loss on ignition, Table II). Carbonate minerals tend to preferentially replace the plagioclase felspars in the rock and appear to post-date the often intense sericitization that characterizes the latter mineral. Chloritization of mafic minerals, as well as a chloritic vein-type alteration occurs in many of the Bospan samples. Large zoned grains of zircon and/or xenotime form the dominant accessory mineral phase in these samples; in addition, large sieve-textured leucoxene-sericite-quartz pseudomorphs after sphene occur, both in the altered granite samples and the palaeoregolith which overlie them.

An interesting feature in the Bospan area is the presence of a fault, the downthrown side of which displaces the granitic basement intersected in two of the boreholes to depths considerably in excess of a remainder of the holes. In these two holes a well-preserved, undisturbed contact between the lower Black Reef quartzite and a palaeoregolith exposes a number of interesting features. The contact zone itself is characterized by the development of tourmaline which post-dates the deposition of the Black Reef quartzite. The tourmaline is acicular and euhedral but also occassionally forms rims around detrital hematite grains. The tourmaline was, therefore, apparently precipitated in a zone of focussed fluid/volatile flow along the contact between sediment and basement. Also present in both the overlying sediments and underlying regolith are zoned veinlets of a quartz-carbonate-pyrite assemblage which have been responsible for remobilizing sulphide minerals subsequent to the deposition of the overlying Black Reef sediments. Significantly, however, evidence for a similar, but obviously older vein-type paragenesis is present in the form of composite calcite-quartz-pyrite pebbles in the conglomerate forming the base of the Black Reef member, indicating that this style of vein-type alteration also existed in the basement prior to Transvaal times.

To the east of the Varkenskraal area a number of boreholes were drilled through a fairly thin succession of Dominion lavas and sediments before intersecting the pre-Dominion basement. The boreholes in this area (prefixed by

BVK) usually revealed the presence of a thin palaeoregolith beneath the overlying sediment before penetrating granite, the bulk composion of which is not significantly different from the granites sampled in the Bospan area (see later). At least two of the samples in the Varkenskraal area can be described as reasonably unaltered (i.e. samples BVK2 (141) and BVK11 (39); Table II) and are medium-to-coarse-grained granites comprising quartz, poikilitic microcline, slightly sericitized plagioclase, chlorite and muscovite. Most of the samples examined, however, exhibit a moderate hydrothermal alteration overprint which is similar to that described for the Bospan samples. Many samples reveal fractured and micro-brecciated textures with which sericite-carbonate-quartz-pyrite vein-type alteration is associated. Plagioclase felspars may be intensely sericitized, but, in addition, sericite has been introduced into the rock in veins and along grain boundaries. Similarly, mafic minerals are chloritized, but, in addition chlorite and chlorite-quartz veins also permeate the rock. The most common vein-type alteration is related to crypto-crystalline quartz and calcite which may occur together in the same vein system or as distinct parageneses.

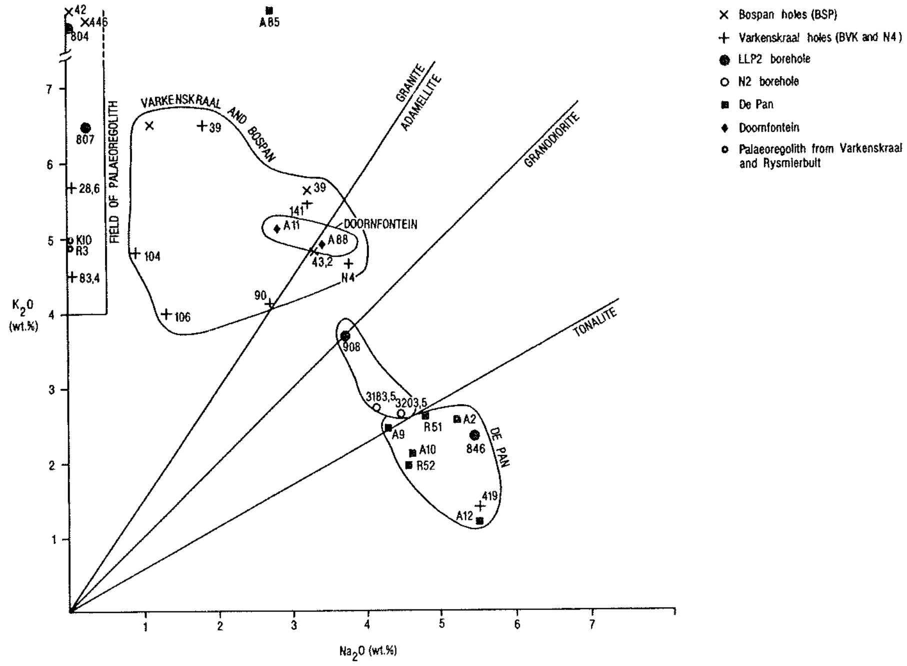


Figure 3 : *Plot of K_2O versus Na_2O for samples of the Archaean granitic basement along the Rand Anticline. Data is from Tables I and II.*

A detailed study of hydrothermal alteration in granites from the Varkenskraal area has recently been carried out by Klemd and Hallbauer (1986). They have recognized a pervasive sericitic-propylitic alteration followed by a vein-related alteration involving quartz ± carbonate ± sulphides. Fluid inclusion studies indicate that this alteration paragenesis is related to the circulation of fairly low temperature (*circa* 180°C) meteoric and connate waters (Klemd *et al.*, 1986).

Palaeoregolith samples from the Varkenskraal area are characterized by extremely low Na_2O and CaO contents, but otherwise do not differ significantly in terms of bulk composition from the hydrothermally- altered granites from which they were derived (see later). Texturally, however, they are quite distinct and comprise angular fragments of quartz set in a groundmass of sericite or sericite + chlorite. A distinction can be made between true "palaeosols", where the alteration process apears to have attained an advanced state (e.g. samples BVK4 (83,4) and BVK11 (28,6); Table II), and material representing a palaeoregolith, where the disintegration and chemical breakdown of the rock is not complete. In the latter case distinct, but fragmented, remnants of K-feldspar grains are still evident within the sericite groundmass (e.g. sample BVK8 (104); Table II). A removal of Na_2O is still apparent in the latter samples, but the complete leaching evident in true palaeosols is not apparent.

One palaeosol profile examined was intensely deformed, exhibiting a pronounced foliation, recrystallization of quartz and muscovite particularly in pressure shadows, and severe grain size diminution. These features probably reflect localized slip along the contact between overlying sediment and underlying basement granite. Minor mineral phases in the palaeosols include zircon and/or xenotime, as well as leucoxene. The leucoxene occurs either as blebs and stringers in the sericitic groundmass, or as pseudomorphs after sphene. Pyrite also occurs as a minor phase in palaeoregolith samples from the Varkenskraal boreholes.

The presence of a fault in the Varkenskraal area is again indicated, as in the case of the Bospan area, by basement intersections in two boreholes that are considerably in excess of basement depths in the remaining holes. Borehole BVK14, for example, was drilled on the down-thrown side of a fault and intersected a rock-type that is significantly different from the granites described previously (i.e. those representing the basement in the up-thrown portion of the structure). Samples BVK14 (419) is tonalitic in composition with a K_2O/Na_2O ratio ≈ 0,6 (Table II), but probably represents a rock that was originally more potassic in composition but has been severely altered and albitized. The rock is dominated by quartz and plagioclase, the latter exhibiting only very slight sericitization. In addition an extremely altered granular perthitic felspar is present which has been extensively replaced by muscovite-sericite, calcite and chlorite. The apparent lack of alteration in the plagioclase is possibly attributable to a sub-solidus origin, possibly related to the presence of an alkali-charged hydrothermal fluid flushing through the system. This rock is also characterized by large (up to 2 mm long), sieve-textured, leucoxene pseudomorphs after sphene, which themselves have been permeated by calcite. The leucoxene-calcite pseudomorphs differ from the sphene replacement products described in the BSP boreholes, where a leucoxene-sericite-quartz assemblage has formed.

In addition to the BVK holes, a further borehole (N4) was drilled just to the north of the Varkenskraal outcrop area (Figure 2). The Archaean basement intersected in this borehole is characterized by a granite exhibiting a highly variable degree of alteration. Certain samples are only slightly altered and comprise quartz, mildly sericitized plagioclase and fresh poikilitic microcline megacrysts containing numerous plagioclase and quartz inclusions. Biotite is altered to an assemblage of chlorite ± leucoxene ± magnetite ± sulphides and, in addition, secondary muscovite also occurs. Other samples, however, are characterized by a very intense, pervasive alteration in which all the felspars are replaced by a sericite + carbonate mineral assemblage, quartz is recrystallized and biotite is extensively broken down to a propylitic assemblage of chlorite ± muscovite ± quartz ± Fe-Ti oxides. Veins and stringers of quartz ± albite ± muscovite ± biotite ± pyrite ± chalcopyrite also occur in these samples. In addition, numerous, small carbon nodules occur, particularly in the more altered samples. It is interesting to note that particulate gold and a range of sulphide phases, in addition to an abundance of carbon nodules, have been recovered from the acid leach residues of the N4 granitoid (R. Klemd, per. comm.).

IV. GEOCHEMISTRY

A. Major Elements

The compositions of granites exposed at Doornfontein and De Pan are shown in a Harpum-type diagram in Figure 3. Sample A11 from the Doornfontein area plots in the field of granite (*sensu stricto*) whereas sample A88, from the De Pan area east of the Oberholzer dyke, is adamellitic. These compositions contrast with the samples collected for the De Pan dome west of the Oberholzer dyke, which all fall in the tonalitic field. The composition of a leucosome vein (sample A85) from a migmatitic portion of the De Pan tonalite reveals an unusually high potassium content (Figure 3).

Palaeoregolith samples from the Varkenskraal and Rysmierbult "windows", as well as from various borehole intersections, plot in a restricted field characterized by Na_2O contents less than 0,5% and K_2O contents in the range 4 - 9%. This indicates that Na_2O has been strongly leached during the surficial processes responsible for the formation of the palaeoregolith, whereas K_2O appears to have been slightly-to-moderately enriched. Potassium enrichment is

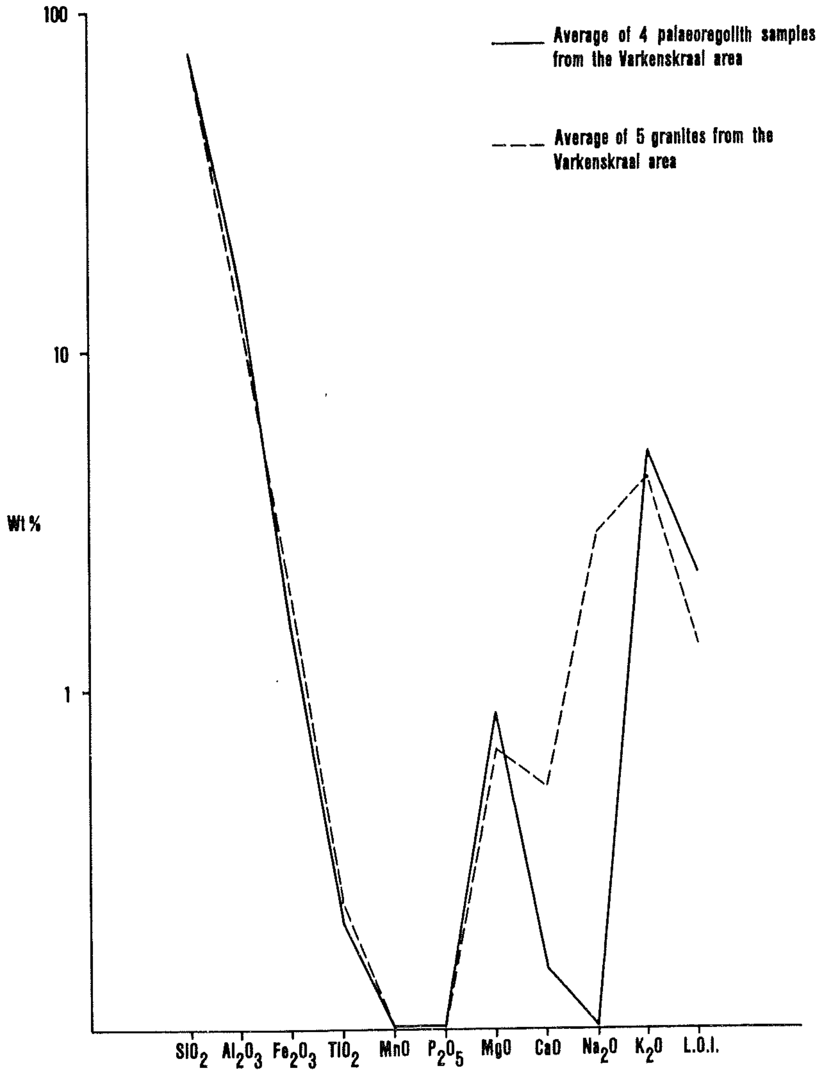


Figure 4 : *Major element "profiles" for the average of 5 granitic samples from the Varkenskraal area, compared to an average of 4 palaeoregolith samples from the same area. Data is from Tables I and II.*

evident in many palaeosols world-wide and is usually attributable to diagenetic processes (Holland, 1984). The behaviour of all the major elements during regolith formation is shown in Figure 4, where the average profile of 4 palaeoregolith samples from the Varkenskraal area is compared to the average for 5 granitic samples from the same area. Comparisons of the trends shows that SiO_2, TiO_2, MnO and P_2O_5 remain relatively constant during regolith formation, whereas weathering processes have been responsible for strong depletion of Na_2O and CaO. K_2O and the water content (loss on ignition) are significantly higher in the palaeoregolith samples.

The compositions of borehole samples of the Archaean basement are also plotted on the K_2O versus Na_2O diagram in Figure 3. Samples from the BVK and BSP boreholes on the southern flank of the anticline generally plot in the granite *(sensu stricto)* field. By contrast samples from the N2 and LLP2 boreholes north of the anticline tend to be more sodic in composition, and occupy the granodioritic and tonalitic fields. It is interesting to note that one of the Varkenskraal samples (BVK14-419) also plots in the tonalitic field. This sample is extensively altered and characterized by the albitization of pre-existing K-felspar.

As mentioned in Klemd and Hallbauer (1986) certain of the samples, particularly from the Varkenskraal region, are weakly peraluminous (i.e. molecular $Al_2O_3/CaO+Na_2O+K_2O > 1,1$). This particular characteristic is, however, *not* regarded as being significant in view of the pervasive sericitization of most of the granites described here, and the tendency for open-system alteration in many of the samples examined. For the same reason it is also doubtful whether this characteristic alone can be used to identify the Varkenskraal and other altered granitoids as S-types, as suggested by Klemd *et al.*, 1986.

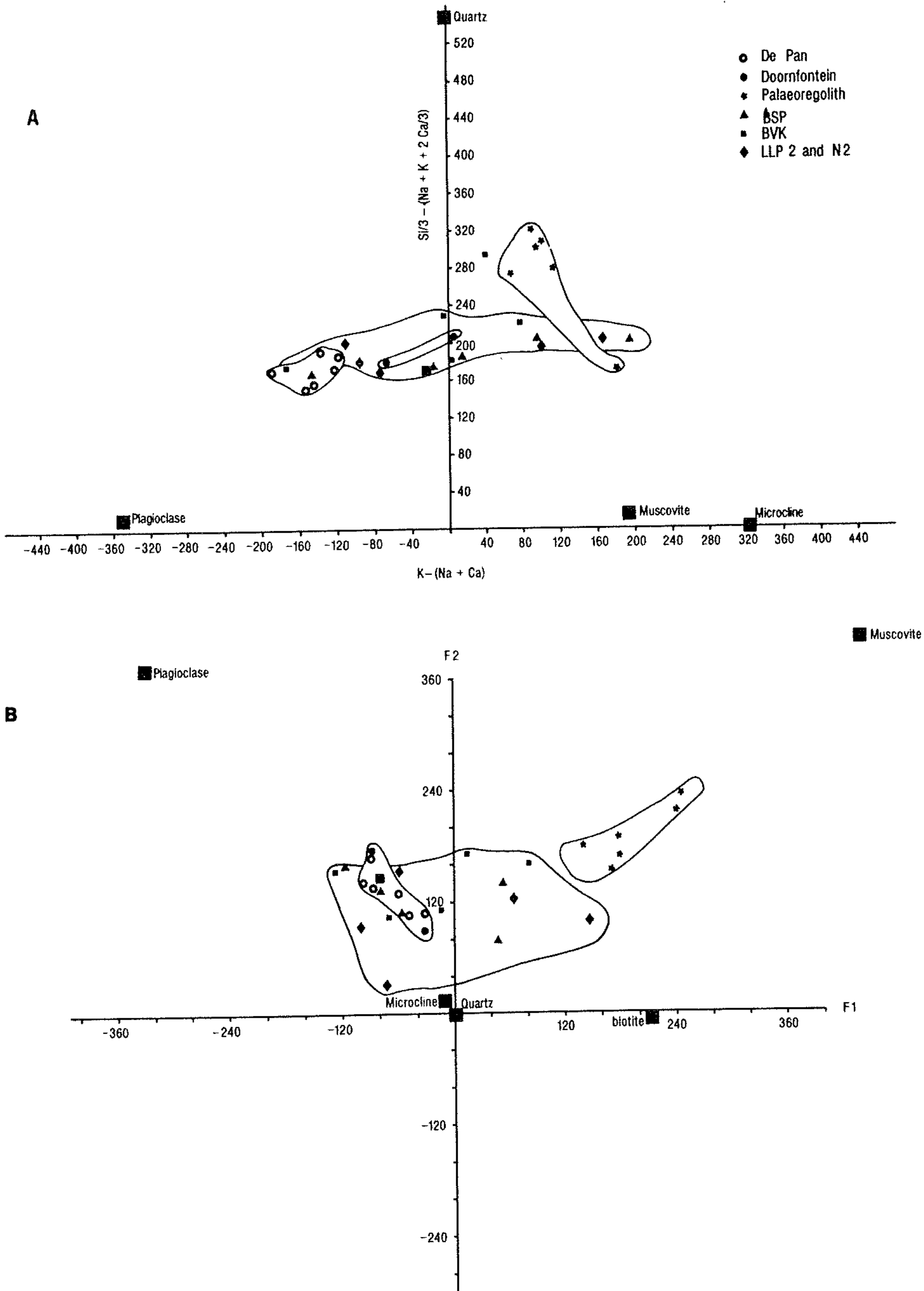


Figure 5 : *Multicationic la Roche - type diagrams for samples of the Archaean granitic basement along the West Rand Anticline.*
A. Si/3 - (Na + K $^2/_3$Ca) versus K - (Na + Ca).
B. F1{(Al - K) - (Fe - Mg) - 2Na} versus F2 {(Al - K) - (Fe - Mg) - 4 Ca}.
(all factors as millications per 100g).

TABLE I

MAJOR AND TRACE ELEMENT CONTENTS OF SAMPLES

FROM SURFACE OUTCROPS OF THE ARCHAEAN BASEMENT

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		A11	A88	A2	A9	A10	A12	R51	R52	A85	A86	A87	KK4	K10	R3
wt.%	SiO_2	74,80	73,50	71,60	72,10	73,00	71,50	73,20	66,90	67,50	51,00	73,10	-	73,50	74,10
	TiO_2	0,19	0,34	0,20	0,26	0,26	0,31	0,23	0,71	0,13	1,31	0,16	-	0,21	0,10
	Al_2O_3	13,10	13,80	16,30	14,60	15,00	14,90	14,70	16,40	18,10	18,80	14,00	-	17,40	17,00
	* Fe_2O_3	1,55	2,07	1,61	2,35	2,57	2,53	2,18	4,53	1,37	12,00	1,13	-	0,68	0,46
	MnO	0,06	0,00	0,00	0,09	0,08	0,02	0,05	0,06	0,00	0,14	0,00	-	0,01	0,00
	MgO	0,46	0,80	0,04	0,67	0,63	0,80	0,55	1,53	0,60	4,30	0,40	-	0,60	0,70
	CaO	0,90	0,30	1,63	1,90	1,90	1,97	1,55	2,66	0,43	0,64	0,19	-	0,06	0,04
	Na_2O	2,76	3,40	5,20	4,27	4,57	5,50	4,75	4,55	2,70	2,20	1,20	-	0,10	0,10
	K_2O	5,12	4,86	2,54	2,45	2,08	1,19	2,62	1,95	8,07	6,01	9,06	-	4,93	4,88
	P_2O	0,02	0,15	0,01	0,01	0,04	0,13	0,09	0,18	0,01	0,42	0,02	-	0,07	0,02
	L.O.I.	1,05	1,01	0,58	0,80	0,42	0,89	0,76	0,75	1,03	3,13	0,62	-	2,35	2,44
TOTALS		100,01	100,23	99,71	99,50	100,55	99,74	99,78	100,22	99,94	99,95	99,87	-	99,91	99,84
ppm	Rb	222	-	119	95	113	95	143	244	-	-	-	255	-	152
	Sr	102	-	279	263	275	295	310	382	-	-	-	191	-	30
	Ba	430	-	-	272	300	-	305	155	-	-	-	447	-	372
	Cs	2,69	-	-	1,95	2,86	-	-	-	-	-	-	3,37	-	2,62
	Zr	159	-	-	211	162	-	-	-	-	-	-	211	-	-
	Hf	4,70	-	-	5,22	4,19	-	-	-	-	-	-	5,83	-	4,28
	Ta	0,82	-	-	1,15	0,99	-	-	-	-	-	-	0,72	-	0,35
	Sc	1,92	-	-	2,58	2,78	-	-	-	-	-	-	3,34	-	2,67
	La	56,3	-	-	29,4	54,1	-	-	-	-	-	-	44	-	13,9
	Ce	121	-	-	49,5	90	-	-	-	-	-	-	142	-	29,7
	Nd	58	-	-	20,8	49	-	-	-	-	-	-	36,3	-	6,55
	Sm	6,21	-	-	2,93	6,75	-	-	-	-	-	-	6,36	-	1,28
	Eu	1,07	-	-	0,61	0,49	-	-	-	-	-	-	0,67	-	0,24
	Tb	0,48	-	-	0,29	0,54	-	-	-	-	-	-	0,81	-	0,28
	Yb	1,59	-	-	0,84	1,06	-	-	-	-	-	-	2,23	-	1,69
	Lu	0,27	-	-	0,14	0,21	-	-	-	-	-	-	0,31	-	0,32
	U	1,16	-	-	1,63	1,44	-	-	-	-	-	-	5,60	-	3,48
	Th	14,1	-	-	18,3	34,5	-	-	-	-	-	-	32,2	-	15,3
	Sb	0,10	-	-	0,12	0,08	-	-	-	-	-	-	1,29	-	0,21
	As	0,72	-	-	0,76	0,86	-	-	-	-	-	-	-	-	-
ppb	Au	1,6	-	-	1,2	7,2	-	-	-	-	-	-	2,6	-	0,9

* Total iron as Fe_2O_3

Analysts: Major Elements - Bergström and Bakker, XRF.
Trace Elements - M. Meyer, INAA, Schonland Research Centre for Nuclear Sciences.

Columns:
1. Granite, Doornfontein dome
2. Granite, De Pan dome east of Oberholzer dyke
3-8. Tonalite, De Pan dome west of Oberholzer dyke
9. Granitic leucosome in tonalite migmatite, De Pan dome
10. Metabasaltic xenolith in tonalitic migmatite, De Pan Dome
11. Quartz-felspar porphyry dykelet in tonalite, De Pan dome
12-13. Palaeoregolith beneath Black Reef Quartzite, Varkenskraal dome
14. Palaeoregolith beneath Black Reef Quartzite, Rysmierbult dome

Chemical variations for both surface and borehole samples are also illustrated in multicationic la Roche-type diagrams (Figure 5A and B). Both diagrams show fairly restricted fields for the unaltered surface granitoids even though their compositions are quite different (i.e. tonalite and granite). By contrast the borehole cores define much broader fields in both diagrams, a feature which can be attributed to the pervasive and vein-related alteration described in most of the samples. Palaeoregoliths form fields which are quite distinct on both diagrams in Figure 5, and these tend to define a tie line between quartz and muscovite compositions.

B. Trace Elements

The chemical differences between the various granite types discussed above are emphasized in the Rb versus Sr plot of Figure 6. Tonalites from the De Pan outcrop contain high Sr and relatively low Rb contents which differ markedly from the higher Rb/Sr ratios of the Doornfontein granite. Granites from the Varkenskraal and Bospan boreholes exhibit uniformly low Sr content with variable Rb abundances in the range 100-350 ppm. Most of the palaeoregolith samples exhibit similar characteristics although these rocks tend to be even more depleted in Sr than the Varkenskraal and Bospan granites. This feature is probably explained by the fact that Sr has been leached from the rocks together with Na, during the surficial weathering process that affected them. Altered granodioritic-to - adamellitic samples from the LLP2, N2 and N4 boreholes plot in a discrete field characterized by low Rb and intermediate Sr contents. One sample, representing a chlorite-carbonate-quartz-pyrite vein (N2 3209), is quite different from the surrounding altered granitoids and is markedly enriched in Rb (Figure 6).

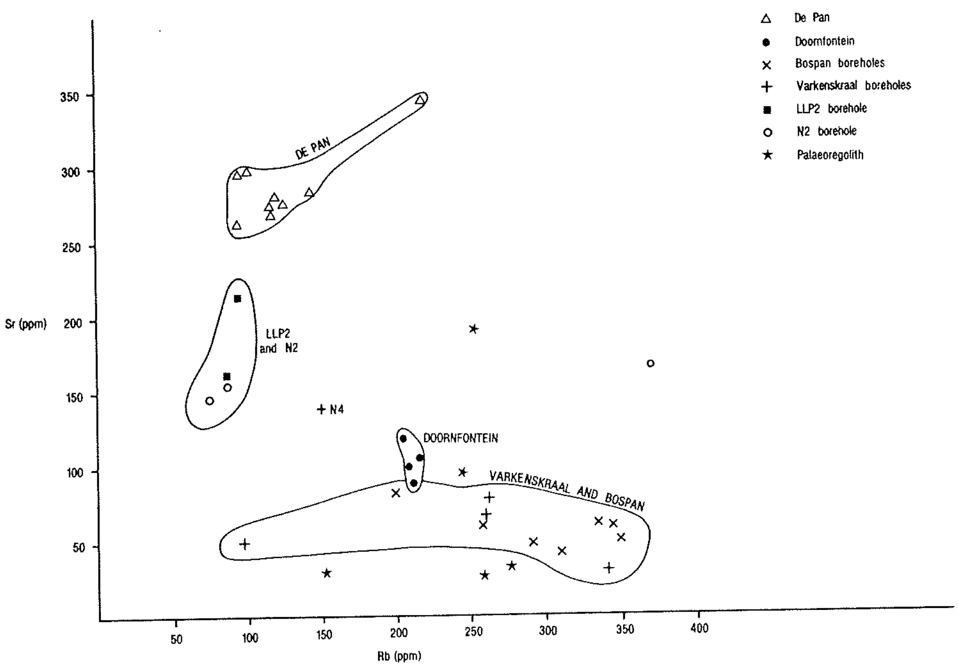


Figure 6 : Plot of Rb versus Sr for samples of the Archaean granitic basement along the Rand Anticline. Data is from Tables I and II.

Chondrite normalized rare earth element (REE) plots of the various granitic samples described are shown in Figures 7 and 8. In Figure 7A the Doornfontein granite is seen to contain a higher total REE content than samples of the De Pan tonalite, although the overall patterns between the two granite types are similar. One sample of the tonalite is characterized by a fairly significant negative Eu anomaly.

Rare earth element patterns for granites from the Varkenskraal and Bospan boreholes are shown in Figure 8A and B. In general, the two sets of data show similar broad patterns which are characterized by steep light REE trends (i.e. high La/Sm ratios), moderate negative Eu anomalies and flattish heavy REE trends (i.e. lower Tb/Yb ratios). In detail, however, certain differences are apparent, the most noticeable being a pronounced variation in heavy REE abundances in the Bospan samples compared to a more restricted variation in the Varkenskraal data. These differences could either be due to a more pronounced alteration overprint accompanied by concentration of heavy REE in the Bospan samples, or a primary affect resulting from differing abundances of heavy REE-bearing accessory mineral phases. The latter alternative is preferred as the zirconium contents of Bospan samples appear to be higher than those of the Varkenskraal granites (Table II) suggesting a higher content of zircon in the former. Alteration may also, however, have contributed to the variability observed in the REE patterns of the two suites in question.

TABLE II

MAJOR AND TRACE ELEMENT CONTENTS OF BOREHOLE INTERSECTIONS

OF THE SUB-SURFACE ARCHAEAN BASEMENT

		1	2	3	4	5	6	7	8	9	10	11	12
		BSP1 (39)	BSP2 (42)	BSP2 (44)	BSP4 (43,2)	BSP8 (445)	BSP8 (446)	BSP10 (196,5	BVK3 (141)	BVK3 (144)	BVK4 (83,4)	BVK4 (90)	BVK8 (104)
wt %	SiO_2	75,90	72,90	69,30	70,80	–	69,30	–	73,60	–	76,20	73,70	73,30
	TiO_2	0,17	0,11	0,62	0,28	–	0,68	–	0,17	–	0,23	0,31	0,20
	Al_2O_3	13,00	13,70	14,30	13,50	–	14,20	–	13,20	–	13,70	14,40	15,30
	* Fe_2O_3	1,62	1,93	4,09	1,99	–	4,39	–	1,42	–	1,89	2,17	2,01
	MnO	0,10	0,08	0,12	0,11	–	0,05	–	0,08	–	0,06	0,08	0,12
	MgO	0,40	0,50	1,30	0,80	–	1,30	–	0,50	–	1,00	0,80	1,10
	CaO	0,18	0,03	0,30	0,87	–	0,08	–	0,63	–	0,23	0,35	0,25
	Na_2O	3,20	0,10	1,10	3,30	–	0,20	–	3,20	–	0,01	2,75	0,90
	K_2O	5,63	9,41	6,52	4,85	–	8,21	–	5,44	–	4,54	4,10	4,78
	P_2O_5	0,01	0,01	0,19	0,07	–	0,07	–	0,01	–	0,01	0,04	0,01
	L.O.I.	0,86	1,16	1,66	3,42	–	0,97	–	0,99	–	1,89	1,42	2,11
TOTALS		99,07	99,93	99,50	99,99	–	99,45	–	99,24	–	99,76	100,12	100,08
ppm	Rb	257	350	293	198	310	345	335	262	96	–	258	261
	Sr	61	52	48	82	40	61	62	78	50	–	64	25
	Ba	318	1115	685	340	659	796	734	399	118	–	282	464
	Cs	3,30	3,34	2,71	1,70	10,4	7,57	8,19	2,54	2,46	–	5,11	6,30
	Zr	–	–	–	–	366	287	322	–	86	–	–	–
	Hf	2,94	4,37	8,85	4,52	10,5	7,06	7,51	4,68	3,31	–	10,6	4,41
	Ta	1,04	0,59	3,42	2,68	6,3	3,39	4,03	1,43	1,20	–	0,78	2,67
	Sc	0,86	1,09	6,27	3,12	5,9	3,65	3,65	2,46	1,72	–	3,51	3,35
	La	36,9	67,7	80,0	84,0	115	57,4	78,9	37,1	6,83	–	136	42,9
	Ce	63,4	117	148	155	285	128	188	80	15,4	–	341	79,1
	Nd	31,7	29,6	35,0	34,1	81,6	42,0	87,2	25,7	6,21	–	66,6	26,0
	Sm	3,75	6,18	9,49	8,72	16,90	8,22	7,87	4,94	1,96	–	10,7	5,14
	Eu	0,49	0,43	0,86	0,59	2,70	1,19	1,94	0,48	0,36	–	1,15	0,45
	Tb	0,37	0,43	0,86	0,46	3,66	1,97	2,99	0,68	0,41	–	0,92	0,79
	Yb	1,49	1,83	4,09	1,76	9,82	5,11	6,86	1,96	1,55	–	2,11	3,76
	Lu	0,18	0,23	0,43	0,19	1,82	0,59	0,77	0,34	0,23	–	0,25	0,50
	U	1,57	3,29	8,3	4,84	8,48	3,09	4,23	7,48	2,71	–	5,84	4,56
	Th	14,7	14,5	14,6	17,5	27,9	18,2	25,7	20,9	8,9	–	35,8	18,6
	Sb	0,07	0,06	0,11	0,09	0,80	0,39	0,42	0,05	1,12	–	0,25	0,26
	As	–	–	–	–	3,23	–	–	–	0,59	–	–	–
ppb	Au	0,3	0,3	0,6	0,2	5,2	3,4	2,0	0,2	5,5	–	0,7	0,8

		13	14	15	16	17	18	19	20	21	22	23	24
		BVK8 (106)	BVK11 (28,6)	BVK11 (39)	BVK14 (419)	LLP2 (804)	LLP2 (807)	LLP2 (846)	LLP2 (908)	N2 (3183,5)	N2 (3203,5)	N2 (3209)	N4 (?)
wt %	SiO_2	76,50	72,60	76,10	71,40	63,60	63,00	71,90	70,60	69,40	74,90	–	72,60
	TiO_2	0,11	0,21	0,16	0,40	0,46	0,69	0,43	0,27	0,57	0,13	–	0,21
	Al_2O_3	12,80	15,90	12,70	13,70	18,20	15,70	14,00	12,40	14,30	12,60	–	14,00
	* Fe_2O_3	1,73	1,55	1,03	2,75	4,13	6,16	2,23	1,72	3,81	1,25	–	1,90
	MnO	0,04	0,06	0,08	0,10	0,10	0,14	0,05	0,12	0,12	0,06	–	0,00
	MgO	0,80	0,70	0,20	0,90	2,20	2,47	1,26	1,00	1,10	0,30	–	0,50
	CaO	0,13	0,05	0,12	1,39	0,05	1,40	0,84	1,84	1,24	1,47	–	0,66
	Na_2O	1,30	0,10	1,80	5,50	0,01	0,30	5,50	3,70	4,10	4,40	–	3,80
	K_2O	3,97	5,66	6,50	1,35	8,59	6,37	2,30	3,66	2,74	2,64	–	4,74
	P_2O_5	0,01	0,02	0,01	0,05	0,01	0,25	0,18	0,04	0,17	0,01	–	0,09
	L.O.I.	1,96	2,36	0,66	1,85	2,32	2,71	1,20	4,20	1,59	1,71	–	0,97
TOTALS		99,35	99,21	99,36	99,39	99,67	99,19	99,89	99,55	99,14	99,47	–	99,47
ppm	Rb	343	–	–	–	246	227	95	86	78	87	371	143
	Sr	29	–	–	–	98	34	215	159	141	155	165	129
	Ba	325	–	–	–	847	388	186	423	665	542	909	–
	Cs	7,30	–	–	–	5,80	8,67	3,24	0,83	1,82	0,79	9,81	–
	Zr	–	–	–	–	–	171	164	–	–	–	483	–
	Hf	4,47	–	–	–	4,69	4,60	5,74	8,35	10,4	3,57	8,54	–
	Ta	0,89	–	–	–	1,41	1,77	1,02	6,66	3,72	0,71	1,10	–
	Sc	1,63	–	–	–	7,94	13,4	4,48	2,07	5,5	1,25	33,7	–
	La	61,5	–	–	–	19,9	21,2	11,5	397	103	55,1	42,9	–
	Ce	129	–	–	–	38,7	47,0	57,9	701	172	87,3	90,8	–
	Nd	37,9	–	–	–	28,3	32,1	12,3	163	51,4	31,9	53,1	–
	Sm	5,63	–	–	–	4,11	4,76	2,57	25,3	14,3	4,78	9,38	–
	Eu	0,41	–	–	–	0,85	0,89	0,65	0,12	0,10	0,67	3,15	–
	Tb	0,42	–	–	–	0,68	0,54	0,55	1,38	1,12	0,28	1,42	–
	Yb	1,26	–	–	–	2,46	2,18	1,52	1,61	4,91	1,10	5,54	–
	Lu	0,19	–	–	–	0,35	0,24	0,28	0,22	0,38	0,11	0,88	–
	U	5,45	–	–	–	0,96	0,62	2,13	1,04	3,09	2,74	1,50	–
	Th	16,3	–	–	–	1,23	2,97	6,93	20,1	23,6	10,6	5,05	–
	Sb	0,32	–	–	–	0,15	0,09	0,47	0,16	0,31	0,10	0,22	–
	As	–	–	–	–	–	6,36	0,44	–	–	–	4,91	–
ppb	Au	0,4	–	–	–	0,2	2,5	8,8	0,7	0,4	0,3	63,5	–

* Total iron as Fe_2O_3

Analysts:- Major Elements – Bergström and Bakker, XRF
Trace elements – M. Meyer, INAA, Schonland Research Centre for Nuclear Sciences

Columns:

- 1-7. Hydrothermally altered granite, Bospan
- 8,9,11, 13,15,16. Hydrothermally altered granite, Varkenskraal
- 10,12,14. Palaeoregolith, Varkenskraal
- 17,18. Palaeoregolith, Leeuwpan
- 19,20. Altered, cataclastic granitoid, Leeuwpan
- 21,22. Altered, cataclastic granitoid, Ireton
- 23. Chlorite-carbonate-quartz-pyrite vein in altered granite, Ireton
- 24. Altered granite, north of Varkenskraal

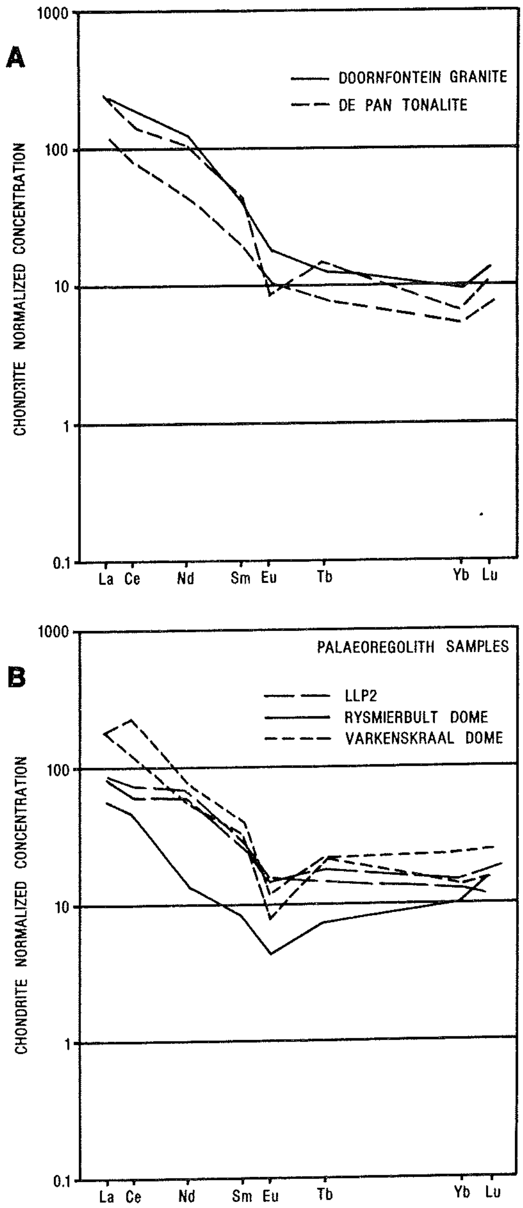
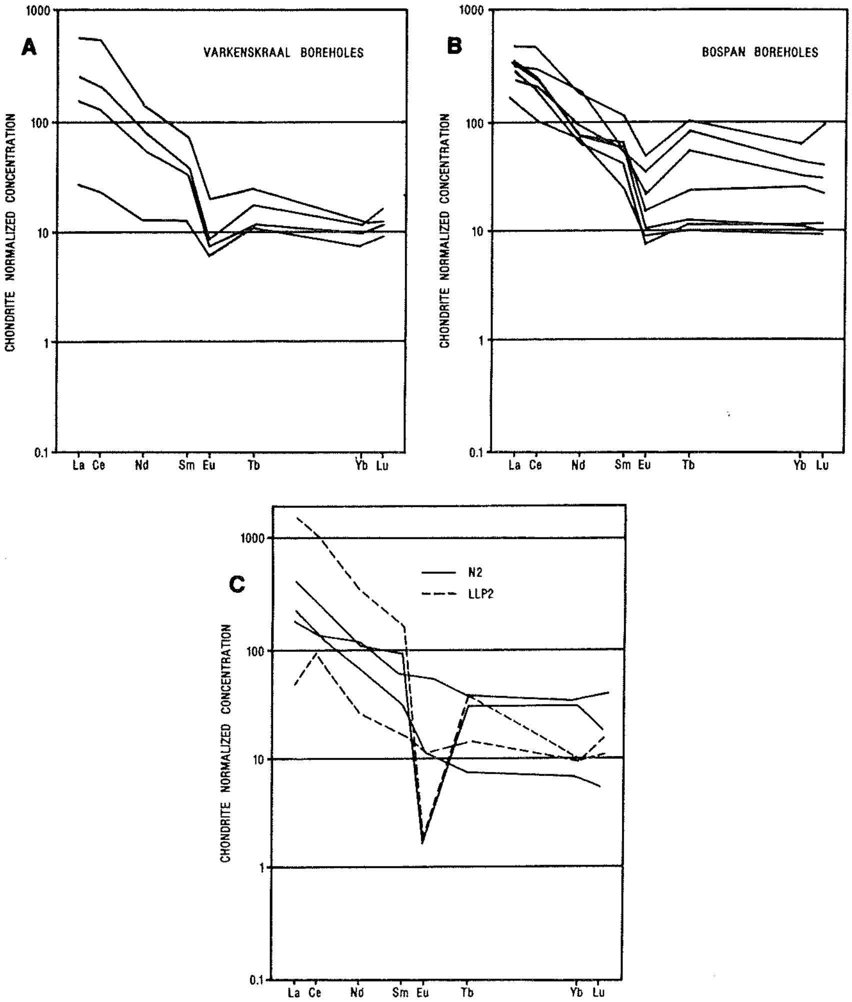


Figure 7 : *Chondrite normalized rare earth element patterns for :-*
A. the Doornfontein and De Pan domes
B. palaeoregolith samples from the Rysmierbult and Varkenskraal domes, and from borehole LLP2.
Data is from Tables I and II; REE abundances normalized against the values of Evenson et al., (1978).

Altered granodioritic samples from the N2 and LLP2 boreholes revealed highly disparate REE patterns (Figure 8C) in spite of fairly consistent bulk compositions. Two of the samples, one from each borehole, exhibit pronounced negative Eu anomalies and also reveal sigificant light REE enrichment. The two other granodioritic samples analysed have lower total REE content and insignificant to slight negative Eu anomalies. The one sample representing a chlorite-carbonate-quartz-pyrite vein (N2 3209)) is characterized by significant heavy REE enrichment, a flattish trend (i.e. low Ce/Yb ratio) and a very slight positive Eu anomaly (Figure 8C). This pattern may be consistent with the precipitation of carbonate minerals in this hydrothermally-derived vein. Indeed, the highly variable REE patterns exhibited by this suite as a whole, clearly point to an alteration overprint which has redistributed the rare earth elements.

Rare earth element patterns for the palaeoregolith samples are plotted in Figure 7B. The samples analysed exhibit broadly similar patterns with steep light REE trends, a slight negative Eu anomaly and flattish heavy REE trends. In detail, however, the palaeoregolith from the Rysmierbult area differs from those sampled at Varkenskraal in that it has a significantly lower total REE content. The Varkenskraal palaeoregolith is similar in terms of its REE pattern to the granite from which it was derived, indicating that, in this particular case, the rare earth elements have remained immobile during the surficial weathering process. The two palaeoregolith samples from the LLP2 borehole exhibit similar REE traces although the upper sample (LLP2 804), which has been more extensively biotitized, is slightly depleted in total rare earth element content with respect to the lower sample. No meaningful comparison can be made between the palaeoregolith and its parental rock because of the highly variable REE patterns in the altered granodiorite.



<u>*Figure 8*</u> : *Chondrite normalized rare earth element patterns for :-*
A. the Varkenskraal (BVK) boreholes
B. the Bospan (BSP) boreholes
C. the N2 and LLP2 boreholes.
Data is from Tables I and II.

Trace element profiles of the various rock types described above are presented in Figure 9A and B as averaged abundances normalized against the "primitive mantle". In these diagrams, ordering of the various trace elements on the abscissa and the slopes of the resultant curves illustrate the different enrichment factors of the elements into the granitic crust relative to the mantle. In detail, comparisons of individual curves facilitate the recognition of relative enrichment or depletion of particular elements from one rock type to another. Certain features, for example, warrant specific mention:-

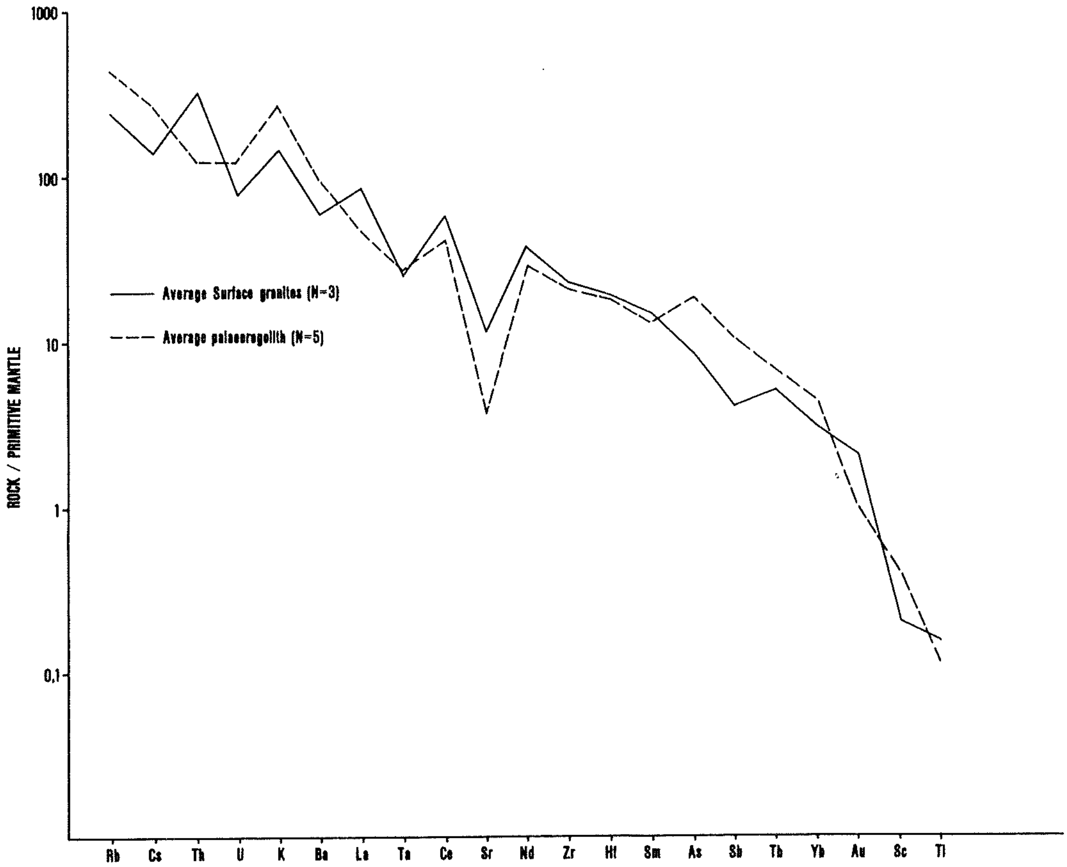
(i) palaeoregolith samples are enriched in K, Rb and U with respect to surface granites, but markedly depleted in Sr;

(ii) palaeoregoliths also appear to be enriched in As and Sb with respect both to surface and borehole granites;

(iii) granites from boreholes BVK and BSP are markedly enriched in the incompatible elements (Rb, Cs, Th, U and K) and strongly depleted in Sr (i.e. they have high Rb/Sr ratios in the range 2-12) indicating that these rocks are highly evolved; and

(iv) although clearly less evolved, the granodiorites from the LLP2 and N2 boreholes appear to be relatively enriched in Ce, Zr and Hf compared to the BVK/BSP samples.

A



B

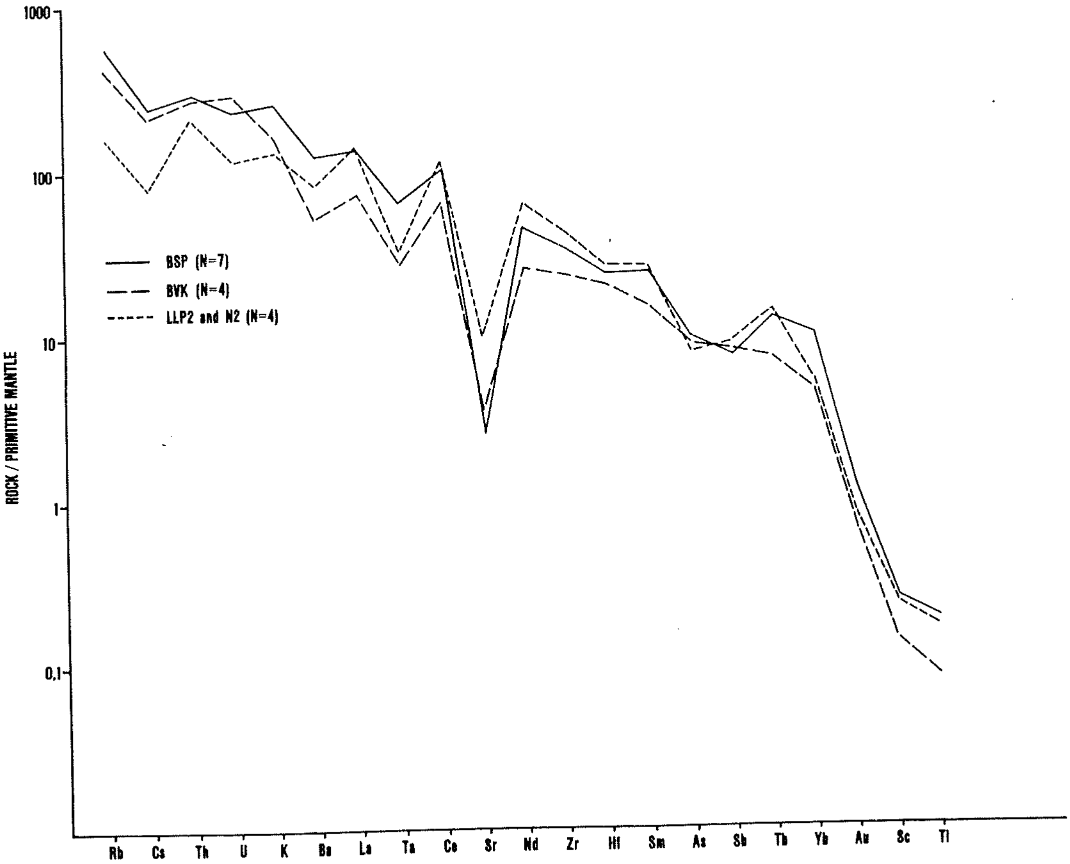


Figure 9 : *Trace element profiles normalized against abundances in the "primitive mantle" (values from Taylor and McLennan, 1985) for samples of the Archaean granitic basement along the Rand Anticline Trace elements along the abscissa are ordered according to a generally decreasing bulk incompatibility with respect to the mantle.*
A. Average traces for palaeoregolith samples and surface granitoids
B. Average traces for borehole cores.
Data is from Tables and II.

V. DISCUSSION AND CONCLUSIONS

Although the study area is fairly small (*circa* 1500 km^2) with respect to the extent of the entire Witwatersrand basin (Figure 1), and the distribution of available samples is sparse, the above descriptions reveal a complex diversity in the nature of the Archaean granitic basement. Granite compositions range from tonalite through to granite (*sensu stricto*) whilst textures vary between coarse-grained, porphyritic and massive, to gneissic and even migmatitic. Certain samples have undergone severe cataclasis whereas others have clearly suffered from an overprint of hydrothermal alteration manifest as intense sericitization, chloritization, carbonate replacement, carbonate or quartz-carbonate vein type alteration, pyrite mineralization and the development of leucoxene. Furthermore, the contact between the basement and overlying sediment very often preserves vestiges of a regolith-like surface which probably formed in response to weathering processes operative in early-Proterozoic times.

In addition, however, to the obvious differences which exist in terms of granite type, texture and composition, the descriptions of basement as revealed in surface outcrop and in subsurface borehole intersections are particularly instructive in that comparisons can be made between granites that have been exposed to the surface for a considerable period of geological time, and those which have remained preserved beneath sedimentary and volcanic cover since 2,8 - 2,2 Ga ago. This difference may be of considerable importance as in the latter case such granites represent portions of the crust which have remained uneroded since early-Proterozoic times, and may, therefore, be expected to preserve higher crustal levels than equivalent bodies which have undergone uplift, exposure and erosion since this period. In this regard it is pertinent to emphasize the observation that samples from the borehole core were generally characterized by an overprint of hydrothermal alteration which is absent to the same degree in the samples described from surface outcrops. A possible explanation for this dichotomy is that the sub-surface granites preserve the high-level cupolas or roof-zones of bodies which elswhere have largely been removed by erosion (Robb and Meyer, 1985). This suggestion is largely hypothetical, firstly because no direct indications are available as to the extent of the vertical differences that might exist in the crustal levels of surface and sub-surface granites, and secondly, because little is known about the origin of the hydrothermal alteration, its distribution in space and time and whether it exists within the upper portions of an intrusive granitic body that has undergone volatile saturation, or in the granitic wall-rocks adjacent to such an intrusion. It is, however, apparent that numerous faults, post-Transvaal Supergroup in age, cut through the Rand Anticline such that it is impossible to predict depths to basement merely on the basis of the known dips and the oversimplified form of the structure shown in Figure 2. Furthermore the presence of sheared or faulted sediment/basement contacts described in some of the borehole cores implies that the domal outcrop "windows" of basement present along the Anticline may reflect, not just upwarped structures, but horst-like features involving more severe vertical movements. Consequently, significant vertical differences probably do exist between the crustal levels exposed at surface and those represented by the sub-surface basement in the borehole cores, and these are consistent with the notion that uneroded segments preserve higher crustal levels in which a preferential development of hydrothermally altered granites may occur. With regards the hydrothermal alteration itself, it is apparent from preliminary studies of the sub-surface basement over much of the Witwatersrand hinterland area that extensive zones are characterized by an alteration overprint that is both complex in origin and diverse in style (Robb and Meyer, 1985; Robb, *et al.*, in preparation). It is likely, therefore, that hydrothermally altered granites (or HAGS; Andreoli *et al.*, 1985) form an extensive component of the Witwatersrand hinterland and that components of both the granitic intrusions that caused the hydrothermal alteration and the altered wall-rocks into which they were emplaced, are represented. Much of the alteration observed in the borehole cores of the present study is regarded as being simply the result of a granite cooling through the stability fields of low-temperature sub-solidus mineral phases (i.e. chlorite epidote, sericite etc.) in the presence of an aqueous phase. This differs from the spectacular vein-type alteration, hydraulic brecciation and greisening evident in many other parts of the Archaean basement in the Witwatersrand hinterland, and considered to be the result of retrograde boiling and deuteric alteration.

The palaeoregolith described from the study area occurs beneath both the Dominion Reef and Black Reef quartzites and, consequently, represent unconformities that date back to *circa* 2,8 Ga and 2,2 Ga respectively. No obvious textural or chemical differences exist between the regolith developed on the two surfaces with the exception of the fact that the pre-Black Reef palaeoregolith at Varkenskraal is hematitized, particularly in the upper portions of the profile. The significance of iron enrichment in this palaeoregolith is difficult to assess as this effect may be due solely to much later processes involving the preferential movement of groundwaters along the contact zone. It is pertinent to point out, however, that iron enrichment has been attributed to the existence of fairly oxidizing surficial conditions during regolith formation which, in turn, can be correlated with topographic elevation (Gay and Grandstaff, 1980; Kimberley *et al.*, 1984). Whether or not such conclusions can be drawn in respect of the basement floor in the study area must, however, await the results of more detailed studies.

The nature of the Archaean granitic basement along the axis and flanks of the Rand Anticline is of direct relevance to the question of the source of placer gold and uranium in the Witwatersrand Basin, particularly in the Carletonville Goldfield (Figure 2). Various studies have shown that detritus in sediments forming the Carletonville Goldfield was derived from source areas situated essentially to the north of the region (Buck and Minter, 1985; Oberthür, 1983) and, furthermore, that the source areas were situated fairly close ($<$ 50 km) to the sites of sediment deposition (Hallbauer and Utter, 1977; Krapez, 1985). Consequently, the granitic basement described above, almost certainly formed part of the source area from which detritus now present in the Carletonville Goldfield was derived. The question arises as to whether the rocks actually observed could have formed a suitable source for the immense quantities of gold currently trapped in the placer deposits. Detailed mineralogical studies of granites along the northwestern margin of the Witwatersrand Basin have revealed the presence of occasional, small gold particles, pyrite and other sulphide phases in these rocks, and that these rocks are commonly characterized by sericitized plagioclase, chloritized biotite, albitization and blue opalescent quartz (Hallbauer, 1982; 1984). Neutron activation analysis of the samples studied in the present report actually show very low Au contents (Table I and II) typical of Archaean granites in general (Saager and Meyer, 1984), with the notable exception of sample N2 (3209) which represents a hydrothermally-derived chlorite-carbonate-quartz-pyrite vein containing $\approx$ 65ppb Au. It is apparent, therefore, that whereas most of the granites analysed are not markedly enriched in gold the potential does exist, particularly in the more severly altered samples as well as those containing pronounced vein-type alteration, for anomalous endowments of gold. It should be pointed out that the low Au values recorded in Tables I and II could, at least partially, be related to the difficulty of analysing samples containing very low levels of an element which is, at best, sporadically distributed. A very significant enrichment of Au (up to 5ppm) was also observed in a hematitized palaeoregolith sample from Varkenskraal, but the occurrence of gold together with Fe-oxyhydroxides suggests that it may have been introduced later from overlying, mineralized Black Reef quartzite.

In conclusion, this preliminary study of the Archaean basement along the Rand Anticline between Randfontein and Rysmierbult, has shed some light on the obviously complex and diverse nature of the hinterland forming the Witwatersrand Basin. Insofar as it has been suggested that the granites making up this provenance may have contributed significantly to both the gold and uranium in the adjacent placer deposits (Hallbauer, 1982; 1984), the question still remains as to the nature of this terrane vis-à-vis typical, better-studied Archaean areas such as the Barberton Mountain Land. The present study, as well as preliminary regional studies (Robb and Meyer, 1985), reveals the presence of an extensive granitic facies characterized by an overprint of hydrothermal alteration. The presence of such rocks in the Witwatersrand hinterland points to the existence of an environment, hitherto not recognized in previous studies of well-exposed (deeply eroded?) Archaean terranes, within which the potential for the development of meso- or epithermal gold (and possibly uranium) mineralization in granites is clearly apparent. Acceptance of this geological framework may ultimately help resolve the problem of the source of the Witwatersrand ores, and also contribute towards a better understanding of the evolution of the basin itself.

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