ECONOMIC GEOLOGY RESEARCH UNIT

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EARLY PROTEROZOIC WEATHERING PROFILE ON THE 2200 M.Y. OLD HEKPOORT BASALT, PRETORIA GROUP, SOUTH AFRICA: PRELIMINARY RESULTS

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by

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ABSTRACT

A very widespread palaeoweathering profile has been identified at the top of the 2200 m.y. old Hekpoort Basalt in the Pretoria Group of the Transvaal Basin. The 5 m thick profile is vertically zoned from very fine-grained sericite at the top to iron-rich chlorite (chamosite) with quartz, sericite and magnetite at the base. Compaction of the originally spongy saprolite (suggested by deformed veins) has resulted in concentration of inert elements such as Al, Ti and Zr. Potassium has been strongly enriched in the profile, sodium and magnesium were depleted, while calcium was almost totally leached. Silica has been strongly depleted in the upper part of the profile, but quartz (formed by breakdown of silicate minerals) is present in the lower parts. Iron and manganese have been leached downward in the palaeosaprolite. The Fe_2O_3/FeO ratio (5 to 87 times greater in the profile than in the parent basalt) decreases downward. The uppermost zone contains pellets of sericite coated by an opaque iron oxide dust. This zone has the highest Fe_2O_3/FeO ratio in the palaeoweathering profile, and may represent an oxidized surface crust. Much unoxidized iron remains in the profile, particularly in the lower part, where it is contained in chamosite, magnetite, epidote and pyrite. The geochemical and mineralogical zoning in the palaeosaprolite suggests weathering by an alkaline, oxygen-deficient (but nevertheless oxygen-bearing) palaeogroundwater some 2200 m.y. ago. Groundwater of this nature may mark a transitional type to the more strongly oxidizing hydrosphere which had become established during Waterberg times, some 1800-1900 m.y. ago.

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I. INTRODUCTION

One of the major questions of Precambrian geology remains the character of the Earth's early atmosphere and hydrosphere. There is a considerable body of evidence which suggests that conditions were significantly different from those prevailing today (Button and Tyler, in press).

Palaeoweathering profiles are the direct product of the interaction of rocks with the ancient atmosphere-hydrosphere. A large number of such profiles have been recognized in the Precambrian areas of the world, particularly in southern Africa. In this paper a profile at the top of the 2200 m.y. old Hekpoort Basalt of the Pretoria Group, Transvaal Supergroup, is documented. The study adds some new facts which must be considered when theorizing on the nature of the Earth's early atmosphere.

II. GEOLOGICAL SETTING OF THE PALAEOWEATHERING PROFILE

The Hekpoort Basalt is a very widely developed volcanic formation in the Pretoria Group of the Transvaal Basin (Fig. 1). The unit covers an area of some 100 000 km^2 in the Transvaal. Its equivalent in the northwestern Cape, the Ongeluk Lava, covers a similar area.

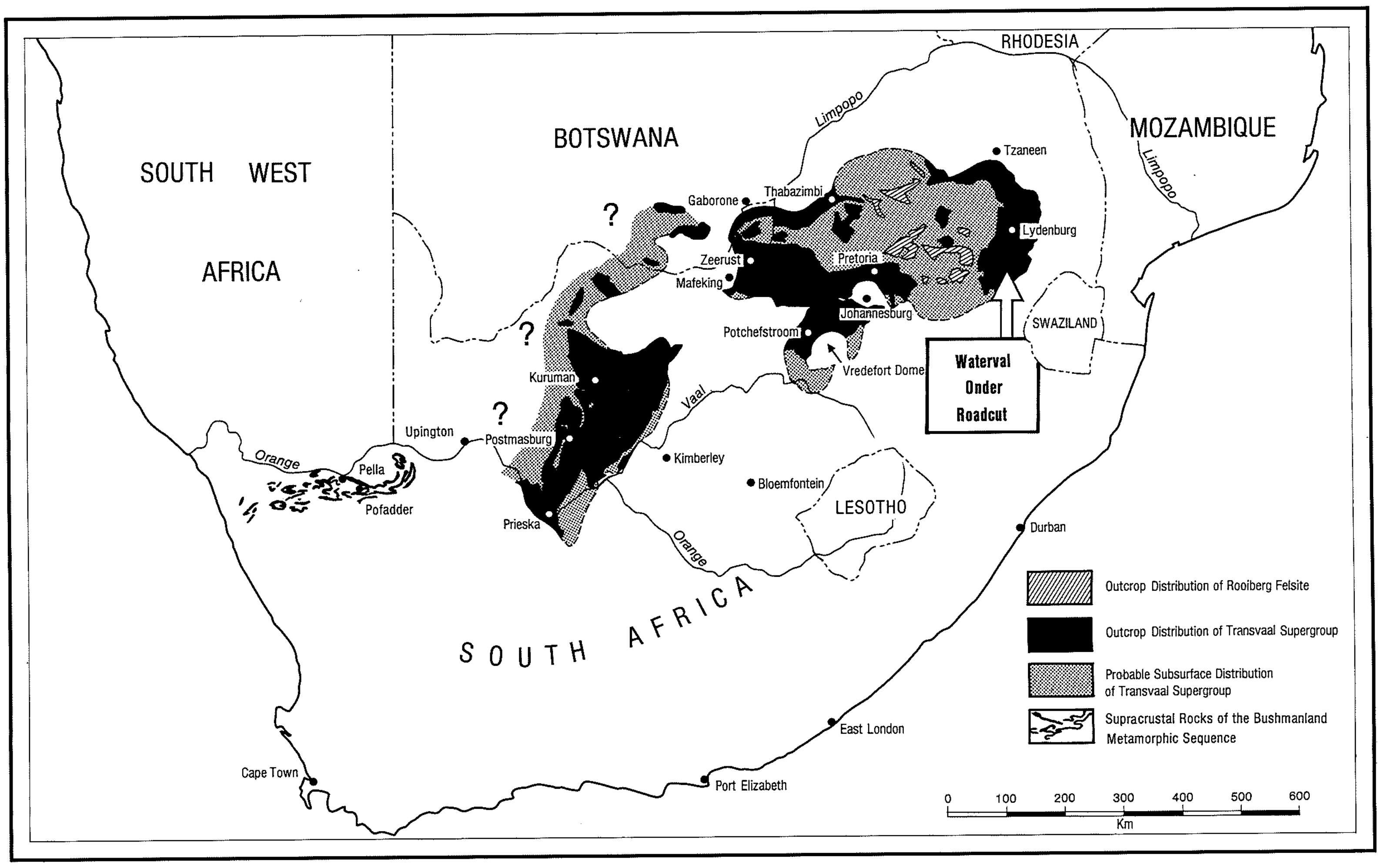

Figure 1 : Map showing location of the Waterval Onder roadcut in which the palaeosaprolite is exposed.

The Pretoria Group (up to 7 km thick) comprises mainly alternating shales and quartz arenites, deposited on a tide-dominated shelf and on fringing intertidal flats (Button, 1973). The Hekpoort Basalt, which ranges in thickness up to some 500 m, comprises subaerial flows with massive bases and highly amygdaloidal tops. Minor sedimentary and pyroclastic units are interstratified with the volcanics.

The Hekpoort Basalt is disconformably overlain by clastic sediments which vary in character across the basin. In the northern and eastern Transvaal, the basalt is overlain by coarse clastics (arenites, some conglomerates). In the western Transvaal, an oolitic ironstone covers the volcanic, while in the central and southern Transvaal, a thin iron-rich arenite, followed by shales with ironstone lenses, is developed at this level.

As far as can be determined, the uppermost few metres of the Hekpoort Basalt is altered over the entire sub-basin in the Transvaal. This very widespread alteration zone is thought to be a palaeoweathering profile, and is the subject of this paper.

III. GEOCHRONOLOGY

Shales in the Timeball Hill Formation below the Hekpoort Basalt, have been dated at 2263±85 m.y. by the Rb/Sr method (Hamilton, 1976). Hekpoort volcanic rocks have been dated by the same method, and have yielded an age of 2224±21 m.y. (D. Crampton, personal communication, 1972). The Pretoria Group is overlain and intruded by basic rocks of the Bushveld Complex, with a Rb/Sr whole rock age of 2095±24 m.y. (Hamilton, 1976). Available geochronology seems to be internally consistent, and indicates an age for the Hekpoort palaeoweathering event of a little over 2200 m.y.

IV. PREVIOUS WORK

An unpublished report of the South African Geological Survey, dated 1935, mentions the presence of "sericitic schists and shales" at the top of the Hekpoort Basalt (Liebenberg, 1961). These altered rocks were also mentioned in a report on the geology of the Long Tom Pass area (Visser and Verwoerd, 1960) and were thought to be "sub-aqueous decomposition products of the lava".

In the vicinity of Rustenburg, an alumina-rich zone containing large andalusite crystals is developed at the top of the Hekpoort Basalt (Von Backström, 1960). The alteration zone at the top of the formation was noted in a series of exploration drill holes in the Delmas area (Button, 1968).

In a regional study of the Transvaal Basin in the eastern Transvaal, the sericitic alteration zone was traced from near Carolina (in the south) to Potgietersrus (Button, 1973; 1975). It was thought to represent "an ancient residual clay soil, indicating that a period of weathering intervened after the volcanics were extruded and before deposition of the Dwaal Heuvel commenced".

In the Zeerust area of the western Transvaal, a 5 m layer of andalusite-muscovite rock is present at the top of the Hekpoort Basalt (Engelbrecht, 1976). The higher metamorphic grade is due to the intrusion of the basic rocks of the Bushveld Igneous Complex.

The alumina-rich altered zone, developed on the Hekpoort Basalt, has been identified over all but the northwestern and extreme southern parts of the basin in the Transvaal. Fieldwork would probably reveal its presence in these areas.

V. SCOPE OF THIS STUDY

The writer has examined the palaeosaprolite at some 200 locations, covering the entire eastern rim of the basin, as well as the southern rim, from Delmas, through Pretoria to the Botswana border. The metamorphic grade varies considerably through this area, as does the outcrop style. In the eastern and far western Transvaal, outcrops of the palaeoweathering profile are largely covered by scree shed from overlying arenites. An exceptionally good, essentially unmetamorphosed exposure is present in a cutting along the recently-completed national road between Waterval Onder and Waterval Boven, in the eastern Transvaal. As an initial investigation into the character of the palaeosaprolite, this set of exposures was studied in detail and sampled. The samples have been studied petrographically and by X-ray diffraction techniques,and have been analysed for major and some trace elements.

VI. STRUCTURE

The formations of the Pretoria Group are usually homoclinally tilted at angles of 5 to 30 degrees towards the Bushveld Complex. Intrastratal movements appear to have been preferentially accommodated in the sericitic rocks of the Hekpoort palaeosaprolite. Where dips are low, a weak cleavage has been impressed on the sericite rocks and is inclined at some 20 - 30 degrees steeper than the bedding. In areas of steeper dip, the palaeosaprolite is locally phyllitic to schistose, and is structured, in places, by small-scale crenulations.

In the Waterval Onder roadcut, the Pretoria Group sediments dip approximately 5 degrees to the west. A weakly-developed,non-penetrative,cleavage dips in the same direction at about 25 degrees.

VII. GENERAL CHARACTER OF THE PALAEOSAPROLITE

In general, accurate estimates of the thickness of the palaeosaprolite are hard to make since contacts are frequently scree-covered. In particular, the lower, iron-rich part of the palaeoweathering profile seldom outcrops, and is only completely seen in roadcuts and other man-made exposures.

The upper, sericite-rich phase of the palaeosaprolite ranges in thickness from less than 1 to over 5 m. Where exposed, the chlorite-rich zone is usually from 1 to 2 times thicker than the upper zone.

The clastic sediments which overlie the palaeosaprolite follow with a sharp, slightly undulating, contact (Plate 1A).

Rare disc-shaped clasts of the sericite-rich material are found in the basal parts of the arenite formation.

The contact of the sericitic and underlying chloritic zone is fairly sharp, a marked increase in iron content being noted over an interval of a few centimetres. In some exposures, vein-like downward projections of sericite-rich material into the chlorite-rich zone were noted. In others, sericitic material is developed in conformable zones well within the chloritic phase. These presumably represent joint-controlled regions of deeper penetration of weathering effects, such as are commonly seen in contemporary residual soil profiles.

In most exposures of the base of the chloritic zone the parent basalt has been weathered during the contemporary erosion cycle. It is usually seen as a red or orange clay with spheroidal remnants of fresh basalt. The amygdales and felted texture of the basalt can normally be seen in the residual clay soil.

VIII. VERTICAL ZONING OF THE PROFILE

In the Waterval Onder roadcut, four distinct stratigraphic zones can be recognized within the palaeoweathering profile.

A. Black Sericite

The uppermost zone is up to 0,5 m thick. Over the extent of the roadcut, it pinches out in places (Fig. 2). It is a dark grey to black, very fine-grained, sericite rock with a distinct fabric parallel to regional stratification. Near the base of this zone the black sericite carries ghost-like discs of lighter grey sericite, up to 10 cm long and 1 cm thick, with long axes oriented in the plane of regional stratification (Plate 1B). The discs have ragged outlines. At the basal contact of this zone the discs become lighter in colour, grading from grey to khaki over a stratigraphic thickness of 5 cm. This colour change is due to the progressively lower content of iron oxide dust stratigraphically downwards.

The black sericite zone is composed mainly of fine-grained sericite with a very heavy dusting of opaque specks. In thin section, some of the opaques form coatings around elliptical to disc-shaped clasts up to a few mm in size (Plate 1C). These iron oxide crusts (magnetite?) could be the analogues of the hematitic coatings commonly found around clasts in contemporary soils. The opaque dust could not be positively identified due to its very small grain size.

Small quantities of quartz and chamositic chlorite are present and decrease downwards in abundance (Fig. 3). Some of the chamosite is found in thin discs developed parallel to the regional stratification. Within the discs, individual chamosite plates are oriented at about 70 degrees to the regional fabric, suggesting that the discs,and their filling,developed as a result of intrastratal movements within the palaeosol after its burial.

Some leucoxene specks, a fraction of a millimetre in size, are developed in the black sericite. Laths of an opaque mineral, thought to be ilmenite, can be seen under the microscope.

B. Disc-Structured Zone

The second zone (Fig. 2) has gradational upper and lower contacts, and is from 10-20 cm thick. It comprises disc-like "clasts" with ragged edges measuring up to 10 cm long by 1 cm thick (Plate 1B). The clasts are oriented with their long axes in the plane of regional stratification. Seen in plan view, the discs have ragged polygonal outlines. They are composed of sericite ranging from cream to olive-yellow in colour. The discs are separated from one-another by vertical, subvertical and horizontal veinlets of darker, green-black sericitic material. The vertical and sub-vertical veinlets are strongly contorted, suggesting considerable compaction of the original clay minerals.

Symmetrical colour-zoning is seen on either side of the veinlets. The green-black veins are bounded by an olive selvedge, which grades to the yellowish shades of the clast. The veins can be traced upwards into the black sericite zone and it appears that they are filled by material leached downwards by palaeogroundwater. The olive selvedges of the veins suggest reaction of the sericite clasts with elements in the palaeogroundwater.

Microscopically, the downward transition from dark grey to olive-yellow clasts is seen to be due to a decrease in the proportion of opaque iron oxide dust. Leucoxene specks are particularly abundant in the dark vein material near the top of the zone.

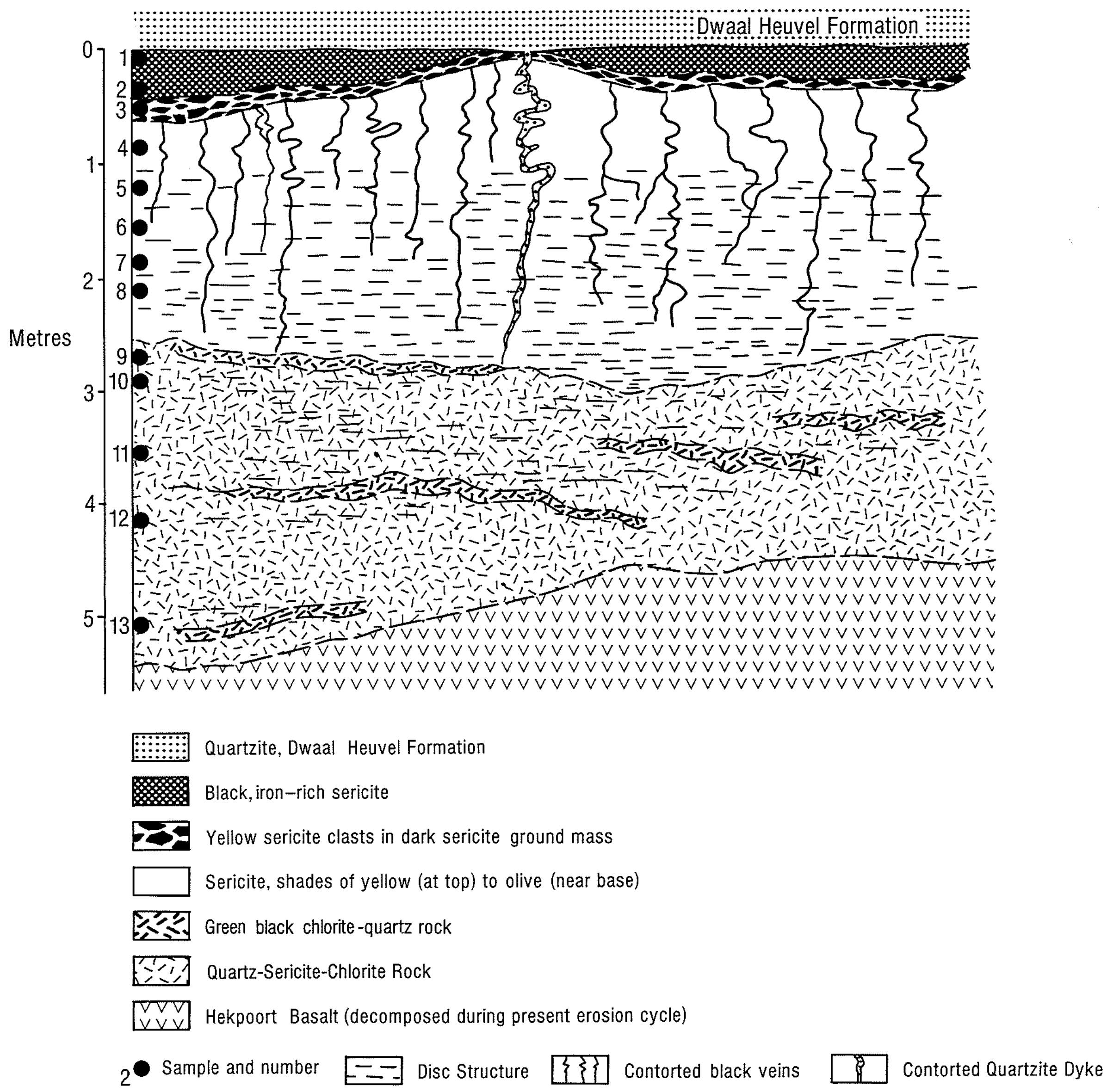

Figure 2 : Stratigraphic section of the Hekpoort palaeosaprolite showing structures, vertical zonation, and the positions of samples.

C. Yellow and Olive Sericite Zone

The third zone comprises a sericite which ranges in colour from yellow, at the top, to olive near the base. Its total thickness is from 2,0 to 2,7 m (Fig. 2). The uppermost 0,7 m comprises yellowish sericite with black veinlets, from 1-3 mm in width. The vertical and steeply-inclined veinlets are deformed due to compaction. They can be traced upwards to the overlying disc-structured zone. Spherical-to-elliptical orange-coloured leucoxene specks up to 1 mm in size are common in this phase. The veins become thinner and less conspicuous downwards.

Some 0,7 m below the top of this zone, a platy structure becomes prominent. It is comprised of very thin wafers of a green-black phyllosilicate. Where seen on surfaces parallel to regional stratification, the discs are usually circular, and measure about 1 cm across. Their intensity of development increases downward.

Mineralogically, this zone comprises very fine-grained sericite with opaques and, towards its base, increasing amounts of chamosite and quartz (Fig. 3). The yellowish colour of the upper parts is due to the pervasive leucoxene dusting in the sericite.

Thin sections of the contorted sub-vertical veinlets show that they are crowded with laths of chloritoid (see Appendix 2). The chloritoid was formed during low grade regional metamorphism of an iron-rich clay mineral which previously filled the contorted veinlets. The veinlets probably mark the pathways via which iron was leached downward in the palaeosol.

Chamosite blebs and discs become increasingly abundant towards the base of the zone. The discs appear to have formed fairly late in the history of the palaeosol since :-

(i) they cut cleanly through the subvertical contorted veinlets, and

(ii) they cut cleanly across mm-sized mottles of pure sericite in a leucoxene-rich sericite groundmass.

The discs are colour zoned, a green-black centre being surrounded by a diffuse green-grey rim (Plate 1D). The central zone comprises coarser chamosite flakes with some quartz, while the outer zone is composed of a mixture of sericite and finer chamosite flakes.

In one sample, a reverse microfault displaces the discs by 1 mm. Chamosite has replaced the sericite adjacent to the microfault and indicates the presence of iron-rich diagenetic fluids.

In places the discs are developed in an en echelon pattern when seen in vertical sections. Elsewhere, they branch and split at angles of 15 to 20 degrees. It was concluded that the discs formed during lithification of the palaeosol as the Dwaal Heuvel Formation slid out over the sericitic rocks during basin deformation. The sliding action is thought to have opened up small shear planes, into which iron-rich diagenetic water migrated over very short distances, and resulted in open space filling as well as partial replacement of the shear-plane walls.

The chloritic discs are often cut by spherical blebs of leucoxene. The preferential development of this mineral in these structures could be due to expulsion of the leucoxene dust from the sericite adjacent to the discs as it was replaced by chlorite.

Near the base of the zone a pleochroic mica, identified optically as stilpnomelane, makes its appearance. This mineral is usually intergrown with the chamosite, but is easily distinguished on account of its stronger pleochroism and higher birefringence.

D. Quartz-Sericite-Chlorite Zone

The top of the fourth zone is sharp and is marked by a colour change from olive to dark green-grey or green-black. As a whole, this zone is crudely stratified showing discontinuous, rather vague, 10-20 cm thick layers rich in a green-black chlorite (Fig. 2). The quartz-sericite-chlorite zone contains visible magnetite euhedra, some of which have been oxidized during the present erosion cycle to hematite and goethite.

In other exposures in the Transvaal Basin this zone is sometimes essentially sericite free. In yet other cases, magnetite has been found as a major constituent of the uppermost phase of the chloritic zone and has been martitized to varying degrees, presumably during the contemporary erosion cycle.

The chlorite-rich layers (for example, Sample 9, Fig. 2) are without fabric, and are composed mainly of chamosite and quartz, with some stilpnomelane and opaques (Fig. 3). The quartz is clouded with inclusions except along quartz-chamosite contacts (Plate 1E). The relations suggest that chlorite absorbed impurities out of the quartz.

FIG:3 VERTICAL DISTRIBUTION OF MINERAL PHASES

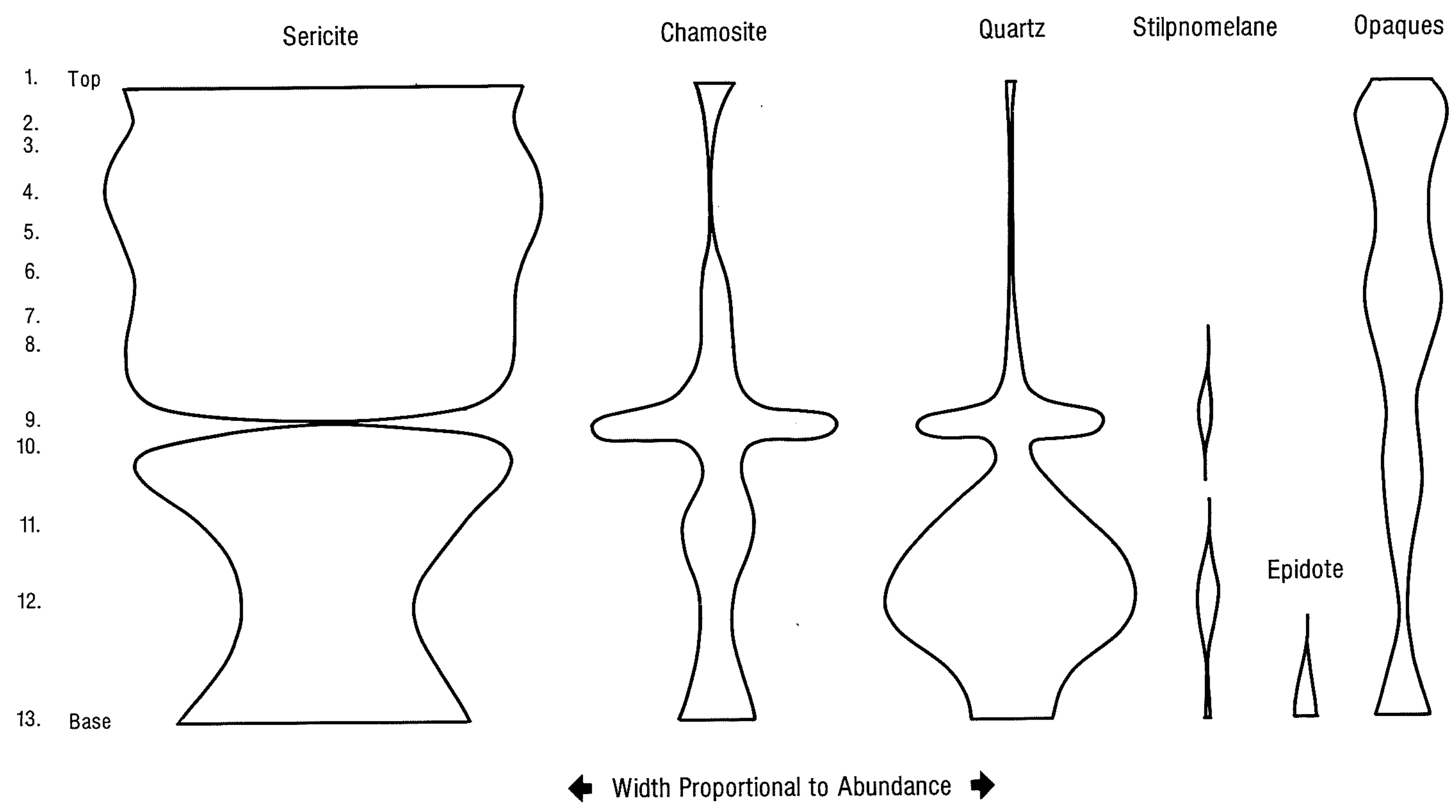

Figure 3 : Distribution diagram of major mineral phases in the palaeosaprolite (based on point counting of thin sections, see Appendix Table 1).

The remainder of this zone comprises a foliated rock composed largely of quartz, sericite, chlorite and opaques. Chamositic chlorite occurs in blebs and discs, the latter being essentially free of opaques as is the sericite around the discs. These observations appear to indicate that the chlorite incorporated many of the opaque minerals as it grew.

Small amounts of stilpnomelane are associated with the chlorite blebs and ragged-edged quartz is clouded with inclusions. Epidote is developed at the extreme base of the palaeosol (Plate 1F).

Opaque minerals are well-represented and include ilmenite laths, leucoxene specks (some concentrated along the chloritic discs) and magnetite euhedra (Plate 1F). The latter are particularly well-represented at the base of the section, where they make up at least four per cent of the rock.

IX. EVIDENCE OF COMPACTION

The sericite-rich upper zones show abundant evidence of compaction. Where steeply dipping, the thin chloritoid-bearing veins in the sericite zone are greatly shortened by compaction folding. A quartz-arenite-filled dykelet was found extending downwards from the Dwaal Heuvel Formation (Fig. 2). It is about 1 cm thick and can be traced downwards to the top of the quartz-sericite-chlorite zone. The dykelet represents a near-vertical crack in the clay minerals of the original weathering profile and may have formed by desiccation. After filling, it was strongly folded about near-horizontal fold axial planes. Folding was almost certainly due to compaction of the original clays.

An estimate of compaction was made by measuring the length of the sinuous quartzite dyke over a stratigraphic interval. The dyke is approximately four times longer than its stratigraphic height, suggesting compaction by this factor. If this is an accurate estimate, the original sericitic zone may have been some 10 m thick and must have had a very low density and high porosity.

X. CHEMISTRY OF THE PALAEOWEATHERING PROFILE

Chemical analyses were carried out on 13 samples selected from the Waterval Onder roadcuts. Their stratigraphic positions are shown on Fig. 2. The samples were also analyzed for 8 trace elements.

A. Basalt Geochemistry

In order to appreciate the geochemical changes brought about by palaeoweathering, the composition of the Hekpoort Basalt was determined (Table 1).

The basalts are of a high silica, high total iron type, very typical of the early Proterozoic basins of South Africa (Button, 1973; Wyatt, 1976). They average 0,73 per cent TiO_2 and 15,21 per cent Al_2O_3. There appear to be two sub-types, characterized by relatively high and relatively low alkalies. The alkali-rich sub-type is represented by basalts 1 and 2, from the eastern Transvaal, while the alkali-poor sub-types (analyses 3 and 4) are from the western Transvaal. They average, respectively, 1,61 and 1,1 per cent Na_2O and 1,15 and 0,28 per cent K_2O. The parent basalt for the palaeoweathering profile of the Waterval Onder outcrops is of the high-alkali sub-type.

B. Vertical Geochemical Zonation of the Palaeosaprolite

(i) SiO_2 - There is a distinct downward increase in the silica content of the palaeoweathering profile. Within the sericitic zone, there is a smooth increase from 44 to 48 per cent. Lower down, in the chloritic zone, the silica content is higher on average, but is erratic, and depends on the development of quartz and cherty silica. Relative to the parent basalt, the weathering profile is depleted in SiO_2. Apparently silica was leached from the profile, some of it being concentrated in the lower parts of the palaeosaprolite (Fig. 4 and Appendix Table 2).

(ii) TiO_2 - This phase is strongly concentrated in the sericitic phase at the 1,7 to 1,8 per cent level. Its concentration is erratic and somewhat lower in the underlying chloritic zone. By comparison with the parent basalt, the palaeosaprolite is enriched in TiO_2 by a factor of up to 2,5 times.

(iii) Al_2O_3 - There is a sympathetic distribution of TiO_2 and Al_2O_3 (Fig. 4). In the sericite zone, the alumina content ranges from 33 to 35 per cent - over twice its concentration in the parent basalt. Al_2O_3 varies from 14 to 30 per cent in the chloritic zone.

(iv) Total Iron (as Fe_2O_3) - The Hekpoort palaeoweathering profile is broadly divisible into an iron-poor upper zone, and an iron-enriched lower zone. Maximum iron concentration (some 24 per cent Fe_2O_3) occurs in the most chlorite rich samples. The uppermost 'black sericite zone' contains up to 6 times more iron than the sericitic interval as a whole. The dark colouration is almost certainly due to the presence of iron-rich minerals.

TABLE 1

Chemical Analyses of the Hekpoort Basalt

	1 ø AB 1236	2 ø AB 1235	3 ɵ Z19	4 ɵ Z21	5 ɵ Z29
SiO_2	57,28	55,06	55,6	55,2	59,0
TiO_2	0,67	0,67	0,74	0,84	0,42
Al_2O_3	15,41	14,43	15,9	15,1	9,1
Fe_2O_3	1,00	0,85	11,1*	12,3*	25,4*
FeO	8,00	7,96			
MnO	0,15	0,18	0,16	0,20	0,20
MgO	5,65	7,45	6,7	5,5	3,1
CaO	6,46	7,74	7,7	7,94	0,05
Na_2O	1,43	1,79	1,2	1,0	<0,2
K_2O	1,39	0,91	0,31	0,25	0,02
H_2O+	2,76	2,72	0,06#	1,35#	3,29#
H_2O^-	0,29	0,17			
P_2O_5	0,08	0,07	0,12	0,14	<0,02
CO_2	0,03	0,03	nd	nd	nd
TOTAL	100,60	100,03	99,59	99,82	100,58

Analysts : ø National Institute for Metallurgy, Johannesburg.
ɵ Bergström and Bakker, Johannesburg.

* Total iron as Fe_2O_3

Loss on ignition

nd. Not determined

Columns : 1. Hekpoort Basalt, from Kindergoed 332, Waterval Boven district (Button, 1973).

2. Hekpoort Basalt, from Sterkspruit 296, Nelspruit district (Button, 1973).

3. Hekpoort Basalt, from Waterval 386, Swartruggens district (Button, unpublished data).

4. Hekpoort Basalt, from Otterfontein 438, Koster district (Button, unpublished data).

5. Chlorite-quartz rock from basal zone of the Hekpoort palaeosaprolite from southern approach cutting to Daspoort Tunnel, Pretoria (Button, unpublished data).

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(v) Ferric Iron - The most striking feature of the distribution of ferric iron is its concentration, in the chloritic zone, at levels of up to 10 times its concentration in the parent basalt. The black sericite is also relatively rich in ferric iron. The effects of contemporary weathering on ferric iron distribution are minor. In the chloritic zone, a few iron oxide pseudomorphs after epidote clearly indicate some oxidation. However, the large change in oxidation state of iron from the parent basalt to the palaeosaprolite suggests oxidation during palaeoweathering.

(vi) Ferrous Iron - The sericitic zone as a whole is depleted in divalent iron, while the chloritic zone contains higher levels of FeO. The highest value (16,2 per cent) occurs in a sample exceptionally rich in chamositic chlorite. It is probable that soluble divalent iron was leached downward and fixed in chamosite, magnetite, epidote and, in some cases, pyrite.

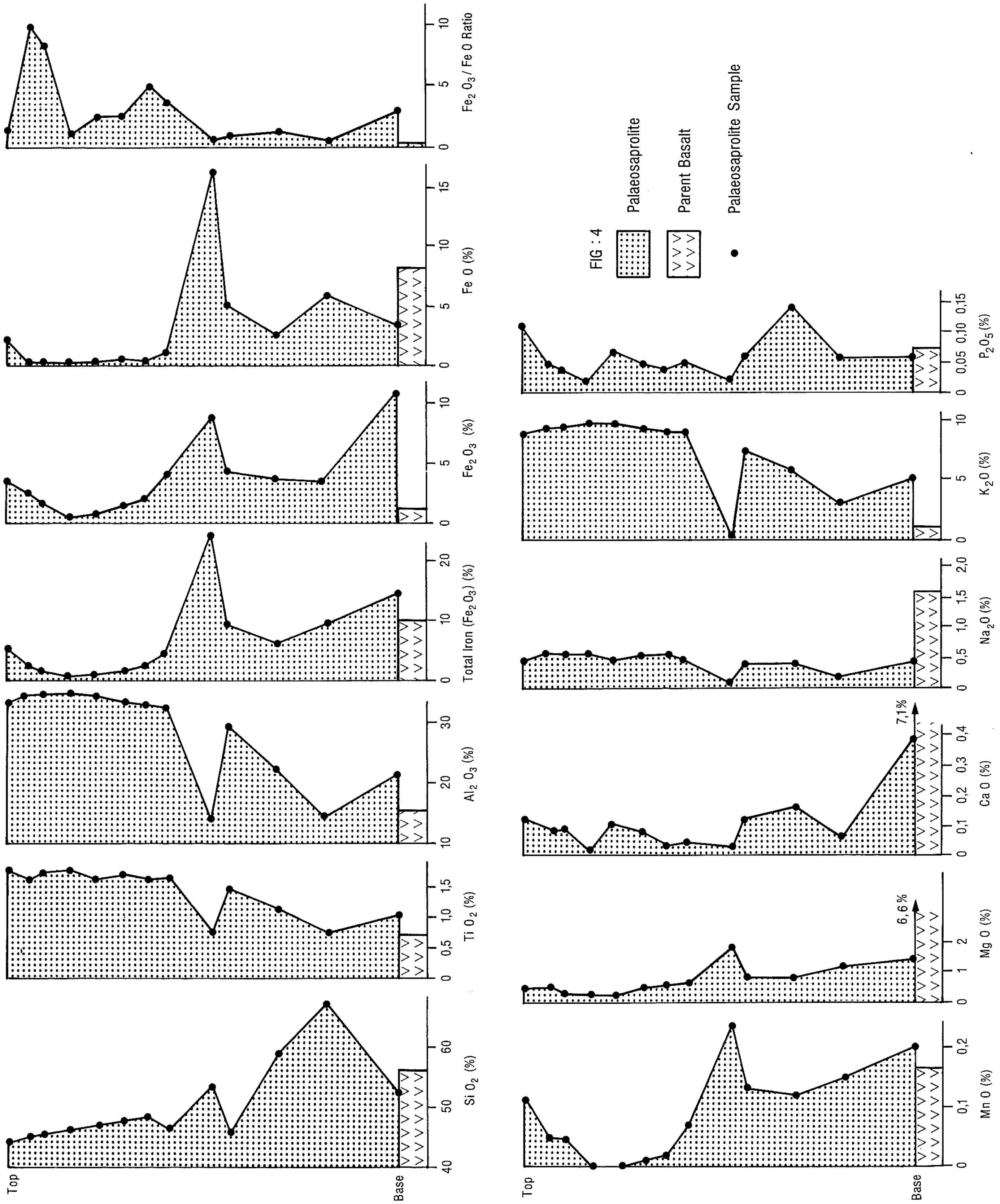

Figure 4 : Distribution of some of the major elements in the Hekpoort palaeosaprolite (based on analyses in Appendix Table 2).

(vii) <u>MnO</u> - The distribution pattern of MnO follows that of FeO and Fe_2O_3. It is concentrated in the black sericite at the top of the weathering profile and in the quartz-sericite-chlorite zone. It is depleted in the remainder of the sericitic zone. Like FeO, it is inferred to have leached downward in the soluble divalent state.

(viii) <u>MgO</u> - This oxide is depleted by a factor of 3 to 20 times relative to the parent basalt. Within the palaeoweathering profile MgO follows the FeO, Fe_2O_3 and MnO distributions, being richest in the chlorite-rich rocks, and being most strongly depleted in the sericitic phases.

(ix) <u>CaO</u> - Calcium has been more thoroughly leached from the profile than any other major element. Its concentration varies from 0,02 to 0,37 per cent in the palaeosaprolite, while it forms some 7 per cent of the parent basalt. The quartz-sericite-chlorite zone contains a higher level of CaO, on average, than the sericitic zone.

(x) <u>Na_2O</u> - Overall, Na_2O is depleted by a factor of 3 to 4 times relative to the parent basalt. Its distribution through the palaeosaprolite parallels that of K_2O and Al_2O_3, and suggests that the soda is tied up in sericite.

(xi) <u>K_2O</u> - Potassium is very strongly enriched in the upper parts of the palaeosaprolite, where it is present at the 9-10 per cent level. It is present in variable amounts in the quartz-sericite-chlorite zone. Chamosite-rich intervals (sample 9) carry less than 0,5 per cent K_2O. A chloritic sample from the equivalent zone north of Pretoria contains 0,02 per cent K_2O. (Table 1).

Relative to the parent basalt, K_2O has been enriched by a factor of up to 15 times.

(xii) <u>P_2O_5</u> - There appears to be no very clear P_2O_5 distribution through the palaeosaprolite. The concentration varies from 0,02 to 0,14 per cent, while that in the parent basalt is 0,07 to 0,08 per cent.

(xiii) <u>Fe_2O_3/FeO Ratio</u> - The palaeosaprolite is characterized by a Fe_2O_3/FeO ratio of 0,5 to over 10 (Fig. 3). The ratio in the parent basalt averages 0,12. Samples in the black sericite zone are the most strongly oxidized, while those in the quartz-sericite-chlorite zone are the least oxidized.

C. <u>Trace Element Patterns</u>

Eight trace elements were determined for the 13 palaeosaprolite samples (Appendix Table 2). It was anticipated that Zr would follow the TiO_2 and Al_2O_3 pattern, being a relatively inert element. This was found to be the case; a 300 to 340 ppm level in the sericitic zones decreases to the 120-250 ppm range in the lower part of the profile. The chamosite-rich sample contained the lowest quantity of Zr.

Rb, Sr and Ba follow the K_2O and Al_2O_3 distributions, which suggests that these elements are contained within the sericite lattice. The uppermost part of the profile is strongly enriched in Ba, which is present at the 500-1100 ppm level.

Cr shows a fairly even decrease downwards through the profile, from 250 to 100 ppm. Its behaviour is similar to that of Al_2O_3, TiO_2 and Zr.

Cu, Ni and Zn show distribution patterns similar to those for FeO, MgO and MnO. The former elements are probably contained in the iron-rich phases such as chlorite, magnetite and pyrite.

D. <u>Compaction - Corrected Geochemistry</u>

The presence of deformed veinlets in the weathering profile is good evidence of compaction of the original porous, clay-rich, saprolite. Compaction of this residual material would have resulted in decreased porosity and an increasing density. There must have been a sympathetic increase in the weight per cent of chemical constituents as volume was reduced. The chemical changes from parent basalt to the original uncompressed saprolite can be estimated if account is taken of compaction. A correction factor could be based on shortening of vertical veinlets or on compaction-induced enrichment of the original saprolite in elements known to be geochemically inert. The latter method has been used, analyses being normalized to the TiO_2 content of the parent basalt. The density of the samples was first determined, and their chemistry was then expressed in milligrams per cubic centimetre. Since the parent basalt contains 20 mg / cm^3 TiO_2, the palaeosaprolite analyses were recalculated to this norm (Appendix Table 3). The composition of pre-compaction saprolite can thus be compared directly with that of the basalt to determine the geochemical changes that took place during weathering.

The compaction-corrected analyses are plotted in Fig. 5 and show that SiO_2 has been strongly leached from the sericitic zones, and less strongly from the chlorite-rich zone. Only one sample contains more SiO_2 than the parent basalt. The normalized Al_2O_3 concentrations remain nearly constant at the 400 mg / cm^3 level, only slightly less than the 448 mg / cm^3 in the Hekpoort Basalt. Apparently very little alumina was leached from the saprolite. The 30 per cent Al_2O_3 concentration in the lithified saprolite must be due largely to the compaction of the original illite-rich profile.

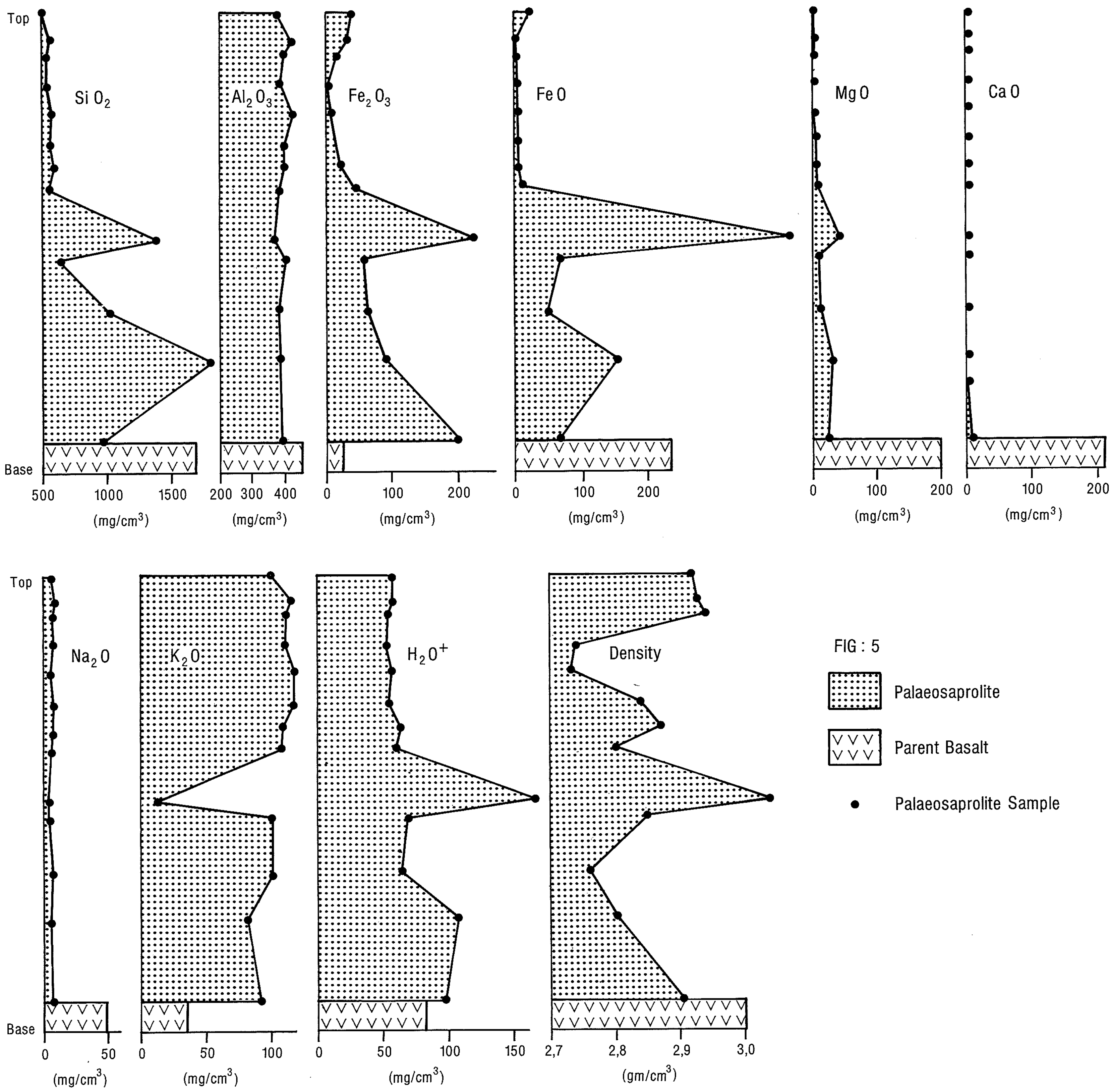

Figure 5 : Vertical distribution of some major elements in the Hekpoort palaeosaprolite. Elemental concentrations were corrected for compaction by normalizing to 0,20 mg / cm³ TiO_2 (based on analyses in Appendix Table 3).

Ferric iron is strongly enriched in parts of the quartz-sericite-chlorite zone (Fig. 5). Ferrous iron is almost completely leached from the sericitic zones, and is depleted in all but one of the samples in the chlorite-rich zone. When studied together, these curves suggest that iron was relatively soluble in the palaeogroundwater, and was leached downward to what may have been the water table. While some oxygen was obviously present to cause an enrichment in Fe_2O_3, the amount must have been limited, since much reduced iron remains in the quartz-sericite-chlorite zone.

The removal of MgO and CaO during palaeoweathering is very marked (Fig. 5). A modest amount of MgO remains in the lower parts of the profile where it is almost certainly contained in magnesian chamosite. CaO is present in above trace amounts in the lowest parts of the profile where it is found in epidote.

Only about one tenth of the original Na_2O remains in the saprolite, while K_2O has been enriched by a factor of about 3. The source of K_2O was probably the palaeogroundwater.

In summary, the strong silica leaching from the profile suggests the action of alkaline palaeogroundwater. Increasing silica concentrations downward may indicate a lower pH as the water table is approached. A high pH is also suggested by potassium fixation in the illitic precursor to sericite. The strong leaching (thus high solubilities) of FeO and MnO above what was probably the water table indicate oxygen deficient groundwaters. However, the uppermost parts of the profile are enriched in Fe_2O_3, which suggests that a low but significant quantity of oxygen was present. The amount of oxygen was certainly limited, since oxidation of ferrous iron did not proceed to completion. The relatively greater concentrations of FeO in the quartz-sericite-chlorite zone could be due to a lower Eh below the water table, such as is associated with the present day water table.

XI. DISCUSSION OF RESULTS

A. Vertical Zonation

The Hekpoort palaeosaprolite is texturally, mineralogically and chemically zoned. The uppermost unit (the black sericite zone) is layered in places and contains sericite clasts, some of which are slightly rounded. Aqueous transportation of clay-rich clasts on the palaeosurface is suggested. This zone contains a very heavy dust of opaque iron oxides, and has the highest Fe_2O_3 / FeO ratio in the entire profile. It is also (relatively) enriched in Fe_2O_3 as compared with the underlying sericite-rich zones and some clasts are coated by iron oxides (Plate 1C). The black sericite has the appearance of being a "proto-laterite", formed by oxidation of the surface layers by a weakly oxidizing atmosphere-hydrosphere.

The disc-structured zone marks the base of this"proto-laterite". Within this zone, sericite discs become progressively darker upwards due to the addition of the iron oxide dust (Plate 1B) and the cracking of the sericite may have resulted from near-surface desiccation.

The yellow sericite below the disc-structured horizon may represent the equivalent of the "pallid zone" frequently found below lateritic cappings. A major difference is the dominance of kaolinite in such pallid zones, whereas the equivalents in this palaeosaprolite were probably illites.

The downward increase in iron in the sericitic zone is indicated by a change in colour towards shades of olive due to increasing proportions of chamositic chlorite. The iron in the chamosite was probably leached from above, and moved downward via the steeply inclined black veinlets characteristic of this zone (Fig. 2). Thin sections of some of these veinlets showed that they are composed largely of chloritoid. Originally, the veinlets were probably steeply-inclined joints filled with an iron-rich clay mineral. Such structures are reminiscent of joints in the clay-rich phases of the B horizons of some contemporary soils.

The quartz-sericite-chlorite zone is, on average, richer in iron than overyling zones and has a lower Fe_2O_3 / FeO ratio. Conditions must have been more strongly reducing, as is indicated by the presence of chamosite, stilpnomelane, epidote and magnetite. In other exposures of this zone pyrite forms a major part of the rock. A lower oxidation potential is indicated and suggests that the chamosite-rich zone could lie within reach of a fluctuating water table.

The lowest Fe_2O_3 / FeO ratios of this zone coincide with the chlorite-quartz strata (Fig. 2). There are a number of such strata in the quartz-sericite-chlorite zone. They could mark stillstand positions of the upper surface of a fluctuating water table, where iron and silica, leached from above, were fixed by Eh and pH changes across this boundary.

B. Compaction

The upper units of the weathering profile have been strongly compacted. Steeply inclined veins and a quartzite-filled dykelet have been greatly shortened, which results in a contorted pattern (Fig. 2). The quartzite-filled dykelet is four times longer than its stratigraphic height, suggesting compaction by this factor.

C. Geochemistry

Considerable geochemical fractionation accompanied the palaeoweathering of the Hekpoort basalt. Relatively inert elements, such as Al, Ti and Zr, were concentrated by residual processes and by post-weathering compaction of the low density saprolite. Mobile elements, particularly Ca, Mg and Na, were leached from the profile and carried in solution to the Precambrian ocean. Silica was relatively soluble, suggesting an alkaline palaeogroundwater. This conclusion is supported by the enrichment of the original clays in potassium.

Iron (and manganese) distributions suggest vertical Eh zoning of the original saprolite. A slight concentration of iron (combined with a 10:1 Fe_2O_3 / FeO ratio) near the top of the profile indicates weak near-surface oxidation. Below this "proto-laterite" iron must have been relatively soluble, since the remainder of the sericitic zone is strongly leached of this element. It is suggested that the low levels of oxygen in the primitive hydrosphere were largely consumed by oxidation of near-surface materials, and that the groundwater that moved deeper into the saprolite had a relatively low Eh.

Further down in the profile (possibly below a palaeowater table) conditions were more strongly reducing and the pH may have been lower, since silica was precipitated along with minerals carrying considerable divalent iron.

D. Diagenetic Modification of the Palaeosaprolite

Some of the minerals presently seen in the palaeosol are probably the diagenetic products of the original clays. The sericite may have derived from an original illite whereas chamosite may be largely primary, since this mineral is found in contemporary lateritic clay deposits (Deer, Howie and Zussman, 1966). The pyrite (common in the lower parts of some exposures of the palaeosol) was probably a marcasite at the time of its formation. The quartz in the saprolite has been little affected and is largely primary. Recrystallization of chamosite adjacent to quartz resulted in clear quartz halos around dusty quartz interiors. Chamosite appears to have been able to accommodate some of the impurities in the quartz.

The extent of post-depositional reduction of trivalent iron is hard to assess. Younger Precambrian palaeosols contain abundant hematite or specularite (Kalliokoski, 1975; Elston and Scott, 1976). The abundance of divalent iron in the palaeosol probably represents the original condition, rather than a diagenetic modification.

E. Structural Modification of the Palaeosaprolite

In extreme cases, the sericitic saprolite is schistose and shows minor crenulations. More often it exhibits only a very weak non-penetrative cleavage, produced by intrastratal slip. In thin section, this weak foliation is seen as planes of slightly coarser sericite. Further evidence of deformation lies in the strained nature of the quartz.

The "disc structure" which occurs in the chamosite-rich, quartz-poor, parts of the palaeosol could also be due to the intrastratal slip. The discs cut compaction-deformed veinlets and are thus post-compaction in age. They are believed to have been minute openings which became filled by chamosite (and some quartz). The filling solutions are thought to have been very locally derived, since no chamositic discs are present in the iron-poor sericite phases. Successive movements are indicated since chamosite crystals, which grew in the discs, have been skewed by shear movements of opposite walls of the discs.

F. Metamorphic Modification of the Palaeosaprolite

The Hekpoort Basalt is known to have been overlain by some 7 km of Pretoria Group sediments (Button, 1973). To this figure can be added some 3 km of Rooiberg Felsite, 5 km of the Bushveld Layered Sequence and 1-2 km of mafic sills in the Pretoria Group. It is safe to assume a cover of at least 15 km. Using a low geothermal gradient of 20°C/km, a minimum burial temperature of 300°C can be estimated. Such a temperature explains the presence of chloritoid, stilpnomelane and epidote, which are typical of lower greenschist facies metamorphisn (Winkler, 1967).

G. Palaeoenvironmental Interpretation

The great lateral extent of the Hekpoort palaeosol, plus the fact that the basalt is frequently over- and underlain by marine sediments, indicates that weathering took place on a low-altitude peneplain, possibly only ten or twenty metres above sea level. Absence of carbonate nodules is indicative of weathering in a relatively humid climate (Birkeland, 1974).

Palaeogroundwaters were probably alkaline and oxygen deficient. Silica solution near surface, and its precipitation lower in the profile, suggest a surface pH of 9-10, decreasing to less than 9 near the palaeowater table. A high pH and high Si/Al ratio in the groundwater favours the formation of illite (Birkeland, 1974).

Quantification of Eh conditions is harder to make. Surface oxidation of iron resulted in a thin "proto-laterite". Below this, the Eh must have decreased rapidly, since iron was leached downward from the sericitic zone. A substantially lower Eh may have prevailed below the water table and may have favoured a base exchange of Fe^{++} for K^{+}, to convert illite to chamosite.

The Hekpoort palaeosol is probably unlike any soil forming today. The major difference is the presence of abundant vegetation in contemporary humid areas. Under such conditions acidic soils develop and kaolinite (rather than illite) is the dominant clay mineral.

H. Further Work

A significant contribution to the study of this and similar palaeosols may lie in the mineralogy of the very fine-grained opaque phases. Microprobe analyses would be the logical approach in the first instance.

Isotopic studies would assist in the interpretation of the conditions of formation of the palaeosols. Oxygen isotopes in the pedogenic silica phases might suggest groundwater palaeotemperatures, while Rb/Sr isotopic geochemistry should reveal much about the age and thermal history of the rocks.

Trace element fractionation, including the study of rare earths, would probably further elucidate the Eh and pH of the palaeogroundwater responsible for weathering.

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APPENDIX I - DESCRIPTION OF PALAEOSAPROLITE SAMPLES

Sample 1

Located just below the Dwaal Heuvel Formation. Comprises 81,6% sericite, 7,8% chlorite and 10,7% opaque minerals. The uppermost 1 cm comprises relatively coarse sericite with blebs of chlorite and quartz. The balance consists of a very fine-grained sericite ground mass with small blebs and discs of chlorite and a few quartz particles. The sericite is liberally dusted with opaques, including laths (ilmenite) and equant grains. A few relatively large leucoxene spots are developed. There has been slight oxidation adjacent to subhorizontal cracks in the sample, which has resulted in a small halo of yellow-stained sericite.

The well-defined coarser sericite layer may represent water-worked sericite, formed as the erosion surface was inundated during Dwaal Heuvel times.

Sample 2

Located 0,35 m from the base of the Dwaal Heuvel Formation. The sample is dark grey to black in colour and has a very distinct fabric due to elliptical pellets and discs of sericite oriented in the plane of stratification. The rock comprises very fine-grained sericite (77,4%) with a heavy dusting of opaques (22,3%) and a few discrete blebs and discs of chlorite (0,3%). The chlorite crystals in the discs are inclined to the disc bounding surface at an angle of about 70 degrees, rather like slip-fibre asbestos in a vein. These relationships suggest some movement along the discs, which are oriented in the plane of regional stratification. The sericite around the discs contains a heavy concentration of opaques.

In thin sections the fabric in the rock is seen to be due to elliptical pellets and small slabs (up to 2 x 5 mm) of opaque-free sericite in an opaque-rich sericite matrix. The opaques in the groundmass are sometimes concentrated in crude layers. Many of the "clean" sericite pellets have a dense coating of opaques. These coatings are likened to iron oxide coatings found around mineral grains in contemporary soils. The coatings and the opaque dust are probably magnetite, although this could not be firmly established due to their extremely fine grain size.

Sample 3

Located 0,50 m below the unconformity; spans the top contact of the disc-structured zone with the black sericite zone (see text). The upper half of the sample contains a heavy dusting of opaques and is similar to Sample 2. The opaque-poor lower half contains a few ilmenite blades and leucoxene specks. Overall, the sample contains 84,0% sericite, 14,9% opaques and 1,1% leucoxene. No quartz or chlorite were detected.

A crude layering is present in the rock. Within layers, sericite flakes are mainly in optical continuity. A shear was seen to cut across this fabric, and could be recognized due to coarser grained sericite.

Sample 4

Located 0,85 cm below the Dwaal Heuvel Formation. The rock is homogeneous, yellowish in colour and comprises a very fine-grained sericite groundmass (87,9%) with 12,1% of leucoxene-rich opaques. Traces of quartz are present. The cream to yellowish colour of the sample is due to the even dusting of leucoxene. A few larger blebs of orange-coloured leucoxene are present.

Sample 5

Located 1,20 m from the Dwaal Heuvel Formation. Comprises 87,0% sericite, 11,9% of leucoxene-rich dust, 1,2% chlorite and traces of quartz. The rock is weakly foliated and is yellowish in colour due to the even leucoxenic dusting. A few chloritic discs are present and are parallel to the regional foliation. One such disc is offset a few millimetres by a reverse fault. Along this microfault the sericite is slightly coarser grained. The coarser sericite vein has a selvedge of chlorite. A relatively large (0,5 mm) leucoxene bleb cuts the microfault and thus represents a very late-stage mineral.

Sample 6

Located 1,55 m below the Dwaal Heuvel Formation. Comprises 78,9% sericite, 5,1% chlorite, 0,3% quartz, 14,0% opaques and 1,5% of a mineral identified as chloritoid.

The rock is strongly foliated (in the plane of regional stratification) due to numerous chloritic discs. A mottled appearance is due to 1-2 mm diameter areas relatively free of opaques and with some quartz specks and laths of a mineral identified microscopically as chloritoid. The latter is pleochroic (pale yellowish to blue green), shows straight extinction, is length fast, exhibits moderate relief and what appears to be first order interference colours. Cross-sections have a hexagonal outline.

The surrounding lighter-coloured sericite is dusted with ill-defined blebs of cream-reflecting leucoxene and some larger orange-coloured spheres of this mineral.

The chloritic discs cut cleanly across the pre-existing mottles, which suggests a relatively late origin for the discs. The discs are zoned, with large chloritic flakes near the centre, and smaller, olive-coloured flakes along the margins. Some discs contain a few specks of quartz. The ends of some discs splay into two planes separated by angles of 15 to 20 degrees.

Sample 7

Located 1,85 m below the Dwaal Heuvel Formation. Resembles Sample 6 in most respects, including presence of a mottled texture with chloritic discs cutting the mottles. Discs are mineralogically zoned, with a transition zone of intermingled chlorite and sericite.

A somewhat higher proportion of quartz is present relative to Sample 6. Blebs of orange-reflecting leucoxene appear to be some of the youngest features in the rock, since they cut across the chloritic discs in places.

Sample 8

Located 2,10 m below unconformity. Sample is well-foliated due to presence of numerous chloritic discs. Under the microscope, the sericite groundmass (79,4%) has a yellowish colour relative to the clear quartz specks (4,2%). Chlorite makes up 6,3% of the sample, and is found in blebs as well as discs. Opaque minerals (10,1%) include lath-like ilmenites (some leucoxenized) and relatively large (0,5 mm) leucoxene specks which are younger than, and preferentially developed along, the chloritic discs. The chlorite blades in the discs are oriented at an angle to the disc margin suggesting intrastratal slip along these small planes. Traces of stilpnomelane are present, usually in association with chlorite.

Sample 9

This sample marks the boundary from the sericite-rich upper zone to the chlorite-rich lower zone and is located 2,70 m below the Dwaal Heuvel Formation. It shows no fabric and is composed mainly of quartz (37,3%) and chlorite (51,5%) with some stilpnomelane (5,1%) and opaques (6,0%). The chlorite is frequently lath-like and intimately mixed with quartz. The quartz is densely crowded with minute inclusions, which reflect a white to cream colour under reflected light. Along quartz-chlorite contacts the quartz is usually clear (Plate 1E). It appears as if the chlorite has absorbed some of the impurities out of the neighbouring quartz.

Opaques include some leucoxene grains. A few blades of relatively coarse-grained muscovite are developed in the rock.

Sample 10

Located 2,90 m below the Dwaal Heuvel Formation. The rock is foliated due to presence of chloritic discs. It comprises a very fine-grained sericite groundmass (77,6%) with some 10,1% chlorite, 4,5% quartz and 7,8% opaques. Chlorite discs frequently contain specks of quartz. Some of the discs swell to larger, irregular, elongate, blebs. Adjacent to the discs there is a selvedge of sericite relatively free of opaques. It appears as if the chlorite has had the capacity of absorbing impurities out of the neighbouring sericite. The chlorite discs themselves are relatively free of opaques, the latter including both equant specks and laths of ilmenite. Blebs of leucoxene are preferentially located along chlorite discs.

Sample 11

Located 3,70 m below the Dwaal Heuvel Formation. The rock is well-foliated due to the presence of wavy chloritic sheets. The sample comprises some 51,5% sericite (yellowish under plane-polarized light), 13,8% chlorite, 29,6% quartz (in ragged-outlined blebs), 4,4% opaques and 0,7% stilpnomelane. Some of the quartz is microcrystalline and most of it is clouded and exhibits undulose extinction. The clouded parts of the quartz grains reflect white to cream-coloured under incident light.

A small amount of stilpnomelane is associated with the chlorite. It is readily differentiated, being more strongly pleochroic and birefringent than chlorite.

Opaque phases include ilmenite laths and some euhedral magnetite crystals. Leucoxene blebs are strongly concentrated along chloritic discs.

Sample 12

Located 4,30 m below the Dwaal Heuvel Formation. The rock is essentially unfoliated, and is composed of quartz (52,3%), sericite (33,9%), chlorite (5,9%), stilpnomelane (5,4%) and opaques (2,6%). A microvein cuts the sample and has resulted in limonitic staining for a distance of a few millimetres on either side of it. The quartz is clouded with inclusions and shows undulose extinction. Chlorite occurs in wavy sheets and blebs. The latter are associated with stilpnomelane, the two minerals often being intimately intermingled. Opaques include ilmenite laths, leucoxene blebs and a few limonitic cubes, probably derived by oxidation of pyrite.

Sample 13

Located at the base of the profile, some 5,20 m below the Dwaal Heuvel Formation. The rock is structurally isotropic and comprises a very fine-grained sericitic groundmass (58,6%) with quartz (15,2%), chlorite (11,9%), epidote (3,8%), opaques (10,5%, at least 4,1% showing the euhedral outlines of magnetite) and traces of stilpnomelane. The quartz occurs in ragged edged, cloudy grains. Chlorite is found in blebs, associated with which are traces of stilpnomelane. Epidote forms high-relief laths, often associated with, and sometimes growing around, magnetite euhedra. Some of the laths are partly oxidized, which results in hematite specks and a ferruginous staining of the surrounding sericite. This oxidation is related to contemporary weathering and is quantitatively very minor.

Opaques include leucoxene blebs, some ilmenite laths and a rather high proportion of euhedral grains of magnetite. The magnetite was positively identified by passing a magnet over powdered rock. Some of these euhedra show a slight reddish tinge under incident light, which suggests martitization of the hematite.

APPENDIX II - IDENTIFICATION OF PROBLEMATIC MINERALS

Magnetite :

Opaque, cubic or octahedral outlines, black when the thin section is viewed under incident light. Magnet attracts minute particles in powdered rock.

Chloritoid :

Occurs in laths with hexagonal cross-sections. Moderate relief. Plechroic from pale yellowish (north-south) to green or bluish green (east-west). Parallel extinction. Length fast. First order interference colours.

Stilpnomelane :

Occurs in micaceous flakes, pleochroic in shades of yellow, dirty green and brown. Parallel extinction. Length slow. No birdseye extinction. Interference colours are rich oranges, yellows and browns.

Ilmenite :

Occurs in slender laths, often in clusters forming triangular shapes. Opaque. Strongly anisotropic on polished surfaces. Sometimes altered to leucoxene.

Magnesian Chamosite :

In thin section is seen to be of the chlorite family. Weakly pleochroic from deep green to yellowish green. Low relief. Very low birefringence. Length slow. Parallel extinction.

X-ray diffraction of the chloritic material shows a strong 7 Angström d spacing, as well as peaks at 4,69; 3,52; 2,82; 2,67; 2,61; 2,56; 2,46; 2,40; 2,27; 2,00; and 1,88 Angström units. All of these peaks coincide with those of magnesian chamosite.

APPENDIX TABLE I

Modal Analyses of Hekpoort Palaeoweathering Profile

Expressed as Percentages

Sample No.	Sericite	Chlorite	Quartz	Stilpnomelane	Epidote	Opaques	Number of Points Counted
1	81,6	7,8	0	0	0	10,7	385
2	77,4	0,3	0	0	0	22,3	726
3	84,0	0	0	0	0	16,0	362
4	87,9	0	0	0	0	12,1	420
5	87,0	1,2	0	0	0	11,9	345
6	80,4	5,1	0,3	0	0	14,2	393
7	77,8	5,9	1,0	0	0	15,2	388
8	79,4	6,3	4,2	0	0	10,1	378
9	0	51,5	37,3	5,1	0	6,0	332
10	77,6	10,1	4,5	0	0	7,8	515
11	51,5	13,8	29,6	0,7	0	4,4	297
12	33,9	5,9	52,3	5,4	0	2,6	354
13	58,6	11,9	15,2	0	3,8	10,5*	638

* At least 4,1 per cent showed cubic outlines.

APPENDIX TABLE II

Chemical Analyses of Hekpoort Palaeoweathering Profile

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	44,2	45,7	46,1	46,6	47,3	47,9	48,4	46,4	53,4	45,9	59,4	67,3	51,8
TiO_2	1,79	1,64	1,74	1,80	1,66	1,70	1,65	1,67	0,76	1,49	1,15	0,74	1,06
Al_2O_3	33,5	34,8	34,8	35,1	34,9	33,6	33,0	32,5	13,9	29,7	22,4	14,7	21,3
Fe_2O_3	3,66	2,60	1,77	0,49	0,85	1,50	2,12	3,89	8,80	4,39	3,65	3,45	10,80
FeO	2,30	0,25	0,20	0,35	0,30	0,55	0,40	1,00	16,20	5,04	2,75	5,87	3,60
MnO	0,117	0,05	0,05	<0,01	<0,01	0,01	0,02	0,07	0,24	0,13	0,12	0,15	0,20
MgO	0,5	0,5	0,3	0,3	0,3	0,5	0,6	0,6	1,8	0,9	0,8	1,2	1,4
CaO	0,13	0,09	0,09	0,02	0,11	0,08	0,04	0,05	0,03	0,13	0,17	0,06	0,37
Na_2O	0,5	0,6	0,6	0,6	0,5	0,6	0,6	0,5	0,1	0,4	0,4	0,2	0,4
K_2O	8,96	9,42	9,58	9,92	9,76	9,22	8,95	9,00	0,41	7,53	5,86	3,04	4,85
H_2O^+	5,2	4,8	4,8	4,7	4,8	4,6	5,3	4,99	6,45	5,28	3,88	3,99	5,20
H_2O^-	0,4	0,4	0,45	0,3	0,4	0,3	0,2	0,4	0,6	0,3	0,3	0,3	0,4
P_2O_5	0,11	0,05	0,04	0,02	0,07	0,05	0,04	0,05	0,02	0,06	0,14	0,06	0,06
CO_2	<0,1	<0,1	<0,1	0,1	0,1	<0,1	0,2	<0,1	0,1	<0,1	<0,1	0,2	<0,1
TOTAL	100,37	100,90	100,52	100,30	101,05	100,61	101,52	101,12	102,81	101,25	101,02	101,26	101,44
Zr*	290	340	340	320	290	300	290	270	120	250	210	130	175
Cr*	250	200	200	160	155	145	135	180	82	135	125	110	92
Rb*	330	340	330	360	360	350	350	370	49	340	280	170	260
Sr*	76	67	60	57	56	54	56	71	7	62	58	38	75
Ba*	1160	780	590	460	340	270	220	250	98	220	210	180	460
Ni*	137	104	95	65	89	124	147	153	226	132	190	264	258
Cu*	254	28	27	14	22	86	117	74	136	7	102	102	186
Zn*	11	<5	<5	<5	<5	<5	<5	<5	72	22	27	45	77

* ppm

Analysts : Bergström and Bakker, Johannesburg

APPENDIX TABLE III

Compaction - Corrected Analyses of Hekpoort Palaeoweathering Profile (normalized to 20 mg/cm^3 TiO_2)

Expressed as mg/cm^3 in compaction-corrected rocks

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	Parent Basalt
SiO_2	497	558	531	522	574	567	591	553	1411	623	1024	1794	967	1685
TiO_2	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Al_2O_3	376	425	401	393	424	398	399	387	368	403	386	391	397	448
Fe_2O_3	41	32	20	5	10	18	26	46	233	60	63	92	201	28
FeO	26	3	2	4	4	7	5	12	428	69	48	156	67	239
MnO	1	<1	<1	<1	<1	<1	<1	1	6	2	2	4	4	5
MgO	6	6	4	3	4	6	7	7	48	12	14	32	26	197
CaO	2	1	1	<1	1	1	<1	<1	1	2	3	2	7	213
Na_2O	6	8	7	7	6	7	7	6	3	5	7	6	7	48
K_2O	101	115	111	111	118	118	109	107	10	102	101	81	91	35
H_2O^+	58	59	55	53	58	55	65	60	170	71	67	107	97	82
H_2O^-	5	5	5	3	5	4	3	5	16	4	5	8	7	7
P_2O_5	1	1	<1	<1	1	<1	<1	<1	1	1	3	2	1	2
CO_2	<1	<1	<1	1	1	<1	3	<1	3	<1	<2	6	<2	1
Total Iron (Fe_2O_3)	67	35	23	9	14	24	31	58	660	128	111	249	269	(315)

EXPLANATION OF PLATE I

A. South face of Waterval Onder roadcut, showing Dwaal Heuvel Formation resting on sericitic (light-coloured) zone of the Hekpoort palaeosaprolite. The underlying darker zone is chlorite-rich. The lowest layer is the parent basalt. Subdivisions on scale are 10 cm.

B. Vertical slab of the disc-structured zone. Clasts "fade out" stratigraphically upwards (i.e. top left hand corner of photograph) due to increasing proportions of an iron oxide dust. Note colour-zoning and compaction-induced contortions in the black veinlets.

C. Thin section of sericite pellets coated by iron oxide dust (Sample No. 2, black sericite zone). Note fabric in the enclosing sericite iron oxide rock. Plane polarized light; larger pellet is 0,65 mm long.

D. Cross-section of a chamosite-filled disc. Note colour zoning. The disc is developed in a sericite rock with abundant opaques. Plane polarized light, disc is 0,3 mm wide.

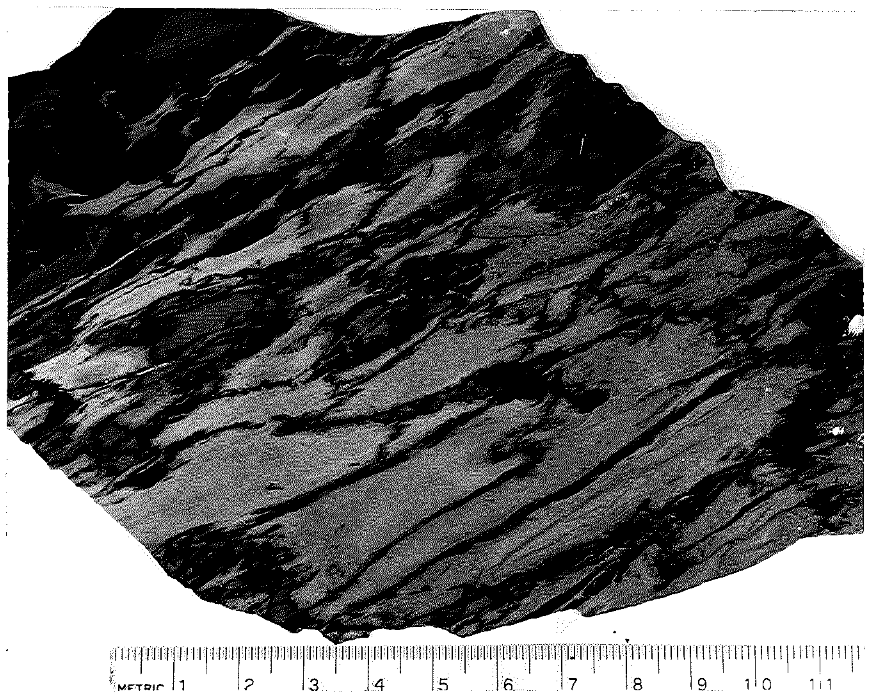
E. Chamosite (dark grey) and quartz (speckled lighter grey) in quartz-chlorite rock (Sample No. 9). Note clear quartz selvedges (white around chamosite laths. Plane polarized light, length of long chamosite lath near centre of photograph is 0,75 mm.

F. Magnetite (opaque, cubic outlines) and epidote (high relief) in a quartz and sericite groundmass, Sample 13 at base of palaeosaprolite. Plane polarized light, magnetite crystal on right hand edge of photograph measures 0,15 mm across.

PLATE 1

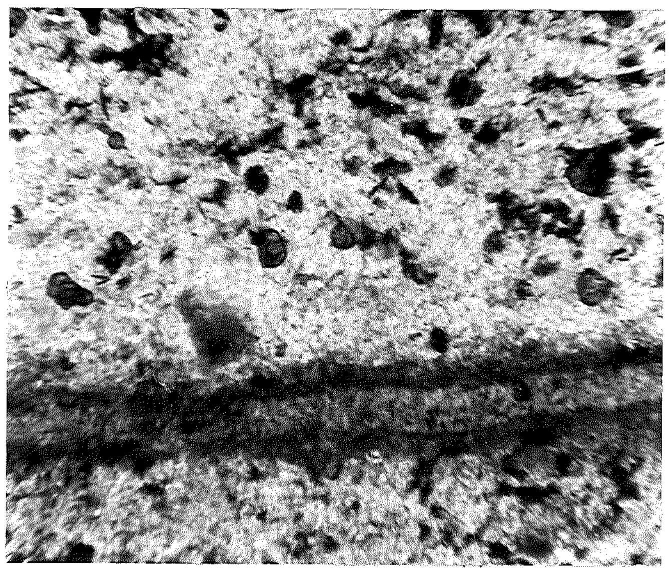
A

B

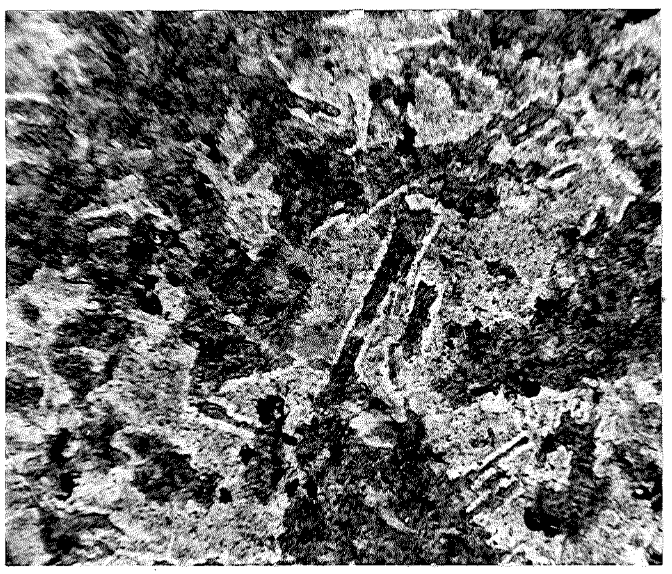


C

D



E



F