ECONOMIC GEOLOGY RESEARCH UNIT

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Johannesburg

THE APPLICATION OF DISCRIMINATORY AND CLUSTER ANALYSIS AS AN AID TO THE UNDERSTANDING OF THE ACID PHASE OF THE BUSHVELD COMPLEX

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INFORMATION CIRCULAR No. 72

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ABSTRACT

The Acid Phase of the Bushveld Complex has hitherto been subdivided into an earlier Epicrustal Phase and a Later Plutonic Phase which respectively predate and postdate the mafic and ultramafic suite of the Main Plutonic Phase. Rooiberg felsites, granophyres, leptites and associated sedimentary rocks have been included in the Epicrustal Phase while the Late Plutonic Phase is composed solely of granites. Apparently contradictory evidence has been reported regarding the time sequence of certain of the components of the Acid Phase notably leptites and granophyres. Much of the difficulty in interpreting their age relations stems from the fact that the term leptite has been inconsistently used, and that granophyres have formed through a variety of processes within the Complex. In an attempt to systematize the descriptive nomenclature a number of granophyre types are defined depending upon the stratigraphic position they occupy within the framework of the Complex.

Multivariate analysis of the available full-silicate data pertaining to the Acid Phase of the Complex reveals a significant homogeneity displayed by all its components and as such places a serious limit on their value in aiding the definition of, and discrimination between the various components of the Acid Phase of the Bushveld Complex.

Multivariate analysis of trace and minor element data from the Zaaiplaats tin-mining area reveals significant differences in the chemistries of the Rooiberg felsites, textural varieties of unmineralized Bushveld granites including certain different granophyre types, and the mineralized Bobbejaankop granites.

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INTRODUCTION

Although the Bushveld Complex has been investigated for approximately one hundred years, controversy still reigns in the literature as to the origin and time-sequence of emplacement of its various components.

Willemse (1964), basically following the ideas of Hall (1932), summarised the events leading up to and those actually constituting the emplacement of the Bushveld Complex as follows :

(i) Deposition of the Transvaal Sequence including contemporaneous volcanicity which heralds the magmatic event.

(ii) Sill Phase of diabase sheets injected into the Pretoria Group of the Transvaal Sequence.

(iii) Epicrustal Phase represented by the Rooiberg felsites, granophyres, leptites and interbedded sedimentary rocks.

(iv) Main Plutonic Phase which produced granodiorite, diorite, mafic and ultramafic rocks.

(v) The Late Plutonic Phase represented by the Bushveld granites.

Willemse included in the Epicrustal Phase the Rooiberg felsites, leptites, granophyres, and interbedded sedimentary rocks. Leptite is the name given to fine-grained quartzo-felspathic rocks of uncertain parentage, which, however in some localities, are reported to grade into granophyres. Gradation from leptite to quartzite is also frequently seen.

Granophyre is the term applied to all rocks displaying characteristic intergrowths of quartz and potash feldspar within the Bushveld Complex irrespective of parentage and mode of formation.

The felsites are cryptocrystalline rocks which range in colour from black through various shades of green to brown or red. Lombaard (1932) suggested that typical extrusive felsites carry albite phenocrysts and that the microperthite-bearing felsites represent the fine-grained chilled facies of the granophyre. The felsites usually overlie either leptite, granophyre, Bushveld granite or rocks of the Main Plutonic Phase. In a few localities the Rooiberg felsites rest conformably upon sediments of the Smelterskop strata of the Pretoria Group. Argillaceous and tuffaceous sediments are developed in the middle and upper part of the felsite succession. Von Gruenewaldt (1966) and Coetzee (1970) report thicknesses of between 3 500 and 5 000 metres for the felsites.

Although the Bushveld Granite, or Late Plutonic Phase, underlies the largest area of any of the components of Bushveld Complex it has received least attention. The Bushveld granite has generally been regarded as a sheet-like layer overlying the Main Plutonic Phase. Nowhere is the contact between the main body of the granite and the Main Plutonic Phase clearly exposed. Daly (1928) suggested that the main mass of granite could predate the Main Plutonic Phase and that only the granites exposed at Magnet Heights and Steelpoort Park etc. are younger. Strauss (1954) stated, however, that the Magnet Heights granite can be correlated with the first phase of granite emplacement in the Zaaiplaats area. This granite is concluded to be younger than the Main Plutonic Phase on the grounds that the second phase of granitic activity cuts both this granite and the underlying noritic rocks.

Strauss and Truter (1944) and Strauss (1954) recognised three phases of granite emplacement at Zaaiplaats, viz.

(3) Bobbejaankop granite with a hood of Lease microgranite

(2) Foothills granite

(1) Main granite.

The Main granite is considered to be a crudely stratiform sheet intruded more or less concordantly between overlying Rooiberg felsites and underlying metasediments and norites of the Mafic Phase of the Complex. Lithologically distinct varieties grade into one another almost imperceptibly, resulting in a pseudostratification which conforms to the roof and the floor of the sheet. The granites are chemically and mineralogically uniform. They are composed of quartz, perthitic feldspar (frequently red in colour), hornblende and biotite, the last two usually displaying varying degrees of alteration to chlorite and generally subordinate. Texturally, however, the granites display a wide range from those in which grain size is nearly as fine as the felsites to those which are coarse-grained and porphyritic. Granophyric varieties are also quite prominently developed.

In the Stavoren area Wagner (1921) recognised a number of textural varieties of Bushveld granites which included coarse red granites, finer red granophyric granites, granophyre and a narrow zone of medium-grained granite occurring between the granophyre and overlying Rooiberg sedimentary rocks.

In the Stavoren area dykes of quartz porphyry cut the granites and irregularly shaped bodies of pegmatite, generally lying horizontally, which are found in the granite, granophyric granite and granophyre. Although Wagner (1921) finds most of the granite in this area to be red in colour, he does report the existence of grey granite. The granitic and granophyric rocks are considered to form a stratiform sheet dipping to the south. Wagner (1927) subsequently recognised a dome-shaped pluton of miarolitic granite on the farm Mutue Fides which intrudes the composite sheet.

In both the Zaaiplaats and Stavoren areas mineralization is associated with the youngest granites.

PROBLEMS OF THE EPICRUSTAL AND LATE PLUTONIC PHASES

A. *The Problem of Stratigraphic Position of the Rooiberg Felsites*

The stratigraphic position occupied by the Rooiberg felsites has been, and still remains a controversial subject. Mellor (1906) first described the Rooiberg felsites in the Middelburg area where they are conformably overlain by, and gradational into the sediments of the Waterberg Sequence. He concluded that the Rooiberg felsites represented the volcanic assemblage of the lower division of the Waterberg Sequence.

Humphrey (1908), working in the Rooiberg area, coined the term 'Rooiberg Series' for the felsites and underlying sediments and included this succession in the lower division of the Waterberg Sequence.

On the evidence of a local unconformity between the Rooiberg felsites and overlying Waterberg Sequence and the fact that the Bushveld granite is not intrusive into the Waterberg Sequence, the Shaler Memorial Expedition separated the Rooiberg felsites and underlying sediments from the Waterberg Sequence and included them in the Transvaal Sequence at the top of the Pretoria Group, (Daly and Malengraaff, 1924). The sediments which underlie the Rooiberg felsites were subsequently assigned to a new "Smelterskop Stage" [Strauss (1954) and Coertze (1961)], while the name Rooiberg was retained for the felsites. Truter (1955) regarded the Rooiberg felsites as the extrusive phase of the Bushveld Complex on the grounds that the felsites "occur irrespective of whether the higher stages of the Transvaal System are present or not", an observation subsequently shown to be incorrect (Coertze, 1961; von Gruenewaldt, 1966).

The question of the stratigraphic position of the Rooiberg felsites remains open.

B. *The Problem of the Nomenclature Used for the Acid Phase of the Bushveld Complex*

Much of the confusion that reigns in the literature regarding the Acid Phase of the Bushveld Complex stems from an inadequate nomenclature system. The problem of nomenclature

arises primarily through the use of petrographic textures for rock names disregarding the fact that identical petrographic textures may result through more than one process.

(a) Leptite

The term leptite has its origin in the Fennoscandian countries where it is used as a sack-name for fine-grained quartz-feldspar rocks of uncertain origin. In Bushveld terminology the term has been inconsistently used. In certain instances leptite may refer to recrystallized felsites while in others, recrystallized sedimentary rocks (cf. von Gruenewaldt, 1966; Strauss, 1947; 1954; Visser and others 1961; and Watson, 1967). In the opinion of the author the term leptite is an unnecessary complication and should be dropped.

(b) Granophyre

In his subdivision of the Acid Phase of the Bushveld Complex Willemse (1964) included granophyres in the Epicrustal Phase. It is well established that the Bushveld granites are intrusive into the Rooiberg felsites. Relationships between the granites and granophyres, and the granophyres and felsites are more confused. The contradictory evidence which has been reported in the literature and much of the difficulty in interpreting the age relations between these rocks stems from the fact that the granophyres have formed within the Bushveld Complex through a variety of processes and are therefore not all genetically related.

Both Hall (1932) and Lombaard (1932) regard the granophyres in the vicinity of Paardekop, Tautes Heights, as being genetically related to the Rooiberg felsites representing the more slowly cooled portion of a felsite flow. Where the granophyre intrudes felsites it is considered by Hall to represent either an intrusion of granophyre into its own roof or alternately the intrusion of a granophyre related to a later flow.

Boshoff (1942) and van der Westhuizen (1945) concluded that fine-grained, acid rocks overlying the dioritic layers of the Upper Zone of the Main Plutonic Phase represent the final differentiation product of the basic magma. Boshoff considered that the Bushveld granophyre at Tautes Heights was emplaced after differentiation in depth had resulted in the attainment of the composition of the postulated residual magma.

Strauss (1947; 1954) and Iannello (1971) have demonstrated the existence of at least two, and possibly three granophyres of distinctly different origin;

(i) granophyres that have crystallized directly from and acid magma;

(ii) granophyres formed by the reconstitution of Rooiberg felsite, and

(iii) granophyres formed by the reconstitution of quartzofelspathic sediments.

The granophyres formed by direct crystallization from acid magma Strauss (1954) designated Bushveld granophyre and those formed by the reconstitution of sedimentary material - pseudogranophyre. Iannello (1971), on the other hand designated granophyres formed by the reconstitution of quartzo-felspathic sediments Bushveld granophyre and those representing palingenetic products of the Rooiberg felsites, Rooiberg granophyre.

Von Gruenewaldt (1968) recognised the existence of the three varieties of granophyres similar to those described by Strauss (1947, 1954) and Iannello (1971) :

(i) The palingenetic product of the Rooiberg felsite he designated the Rooiberg granophyre.

(ii) The granophyric granite and granophyre, co-genetic with the Bushveld granites, he left un-named.

(iii) The granophyre developed between the Bushveld granite and roof-forming quartzite, from Boshoffsberg in the Rooiberg area and the Mutue Fides-Stavoren area, he designated the Stavoren granophyre.

The origin of the Stavoren granophyre is uncertain. Strauss (1947), and Iannello (1971), are of the opinion that the Stavoren granophyre represents metasomatically altered sediments in the Boshoffsberg area. Steyn (1962) on the other hand prefers a magmatic origin for this rock and is of the opinion that it is genetically related to the Bushveld granite. Willemse (1964) states that the Bushveld granite is intrusive into the Stavoren granophyre and that the transition between the granite and granophyre is often characterized by a fine-grained chill facies which suggests the chilling of the former. The different terminologies used by Strauss (1947; 1954), von Gruenewaldt (1968) and Iannello (1970) are summarized in Table 1.

TABLE 1

Terminology Applied to Granophyres in the Bushveld Complex

Origin	Terminology as used by : Strauss 1947, 1954	von Gruenewaldt 1968	Iannello 1970
1. Direct crystallization product of magma	Bushveld granophyre	-	-
2. Reconstitution of felsites	-	Rooiberg granophyre	Rooiberg granophyre
3. Reconstitution of quartzo-feldspathic sedimentary rocks	Pseudo-granophyre	-	Bushveld granophyre
4. Granophyre developed between Bushveld granite and its roof of quartzite	-	Stavoren granophyre	Bushveld granophyre

During the present study four genetically distinct varieties of granophyre were identified in the Potgietersrust-Zaaiplaats area, and will be referred to in a subsequent section of this paper. They are ;

(i) a granophyre genetically related to the Bushveld granite which occurs along the contact with the overlying Rooiberg felsites,

(ii) a granophyre formed by the complete reconstitution of the Transvaal Sequence sediments (≡ pseudogranophyre of Strauss, 1954),

(iii) a granophyre developed in the Main granite as a metamorphic halo to the intrusive plugs of Stanniferous Bobbejaankop granite, and

(iv) a granophyre developed in the Main granite as a metamorphic halo to the post-Waterberg diabase sheets that intrude the Bushveld granites.

In an attempt to systematize the descriptive nomenclature regarding the granophyres developed within the Bushveld Complex in accordance with the principles laid down in the South African Code of Stratigraphic Terminology and Nomenclature the following names for the different granophyres are proposed :

(i) Waterval granophyre, for granophyres developed along the contact of the underlying Mafic Phase and the overlying Rooiberg felsites, from the type-area on the farm Waterval east of Loskop Dam. The term Rooiberg granophyre should be dropped as it has been used on previous occasions for different granophyre types.

(ii) The Paardekop granophyre, for granophyres developed as lenses and cross-cutting bodies in the Rooiberg felsites, from the type area near the trigonometrical beacon Paardekop, Tautes Heights.

(iii) The Sterk River granophyre, for granophyres developed along the contacts of underlying Bushveld granites and overlying Rooiberg felsites, from the type-area near the Sterk River in the Zaaiplaats tin-mining area northwest of Potgietersrust.

(iv) The Blinkwater granophyre, for granophyres developed at the base of the Bushveld granites along the contact with rocks of the Mafic Phase of the Bushveld Complex in association with metamorphosed sedimentary material, from the type-area on the farm Blinkwater in the Zaaiplaats tin-mining area.

(v) The Groenfontein granophyre, for granophyres developed in the Main granite adjacent to plugs of younger stanniferous Bushveld granite, from the type-area on the farm Groenfontein in the Zaaiplaats tin-mining area.

(vi) The Welgevonden granophyre, for granophyres developed in Bushveld granites, adjacent to dykes and sheets of diabase, dolerite etc., from the type-area on the farm Welgevonden in the Zaaiplaats tin-mining area.

(vii) The Stavoren granophyre, for granophyres developed along the contacts of Bushveld granites and sedimentary roof rocks, from the type-area on the farm Stavoren to the north of Marble Hall.

The proposed new classification of granophyre types developed in the Bushveld Complex is summarized in Table 2.

PREVIOUS GEOCHEMICAL STUDIES OF THE ACID PHASE

A. *Major Element Chemistry*

Detailed geochemical studies of the Acid Phase of the Bushveld Complex have only been undertaken by Liebenberg (1961) and Fourie (1969).

A relatively detailed literature survey yielded two hundred and seventeen published and unpublished full silicate analyses directly or indirectly pertaining to the Acid Phase of the Bushveld Complex. These include analyses of Bushveld granites, granophyres, leptites, metasediments, Rooiberg felsites, post-Waterberg granites and felsites and acid to intermediate lavas of Transvaal and Bushveld age.

Analyses of the available major element data of the components of the Acid Phase of the Bushveld Complex sensu stricto by standard two and three variable variation diagrams reveals a remarkable homogeneity. Where small numbers of samples from individual localities are studied separately subtle differences exist between the different components of the Acid Phase. However, when the number of samples is increased to statistically significant levels the apparent differences are obliterated by large population overlaps that result from the enlarged data spread.

B. *Trace Element Chemistry*

The bulk of the available trace element data pertaining to the Acid Phase of the Bushveld Complex is from the studies of Liebenberg (1961) and Fourie (1969). Apart from these data only a few isolated trace element determinations are scattered through the literature.

Liebenberg (1961) concluded from his studies that the Bushveld granites plot on generalized fractionation curves which support the view that an original magma differentiated to give the various fractions seen today. However the number of his analyses in respect of the Acid Phase of the Complex is limited and he admits that certain inconsistencies were apparent, particularly in respect of Zr, Mn, Sr, and Ba.

Fourie (1969), on the basis of a widespread chemical study of the Acid Phase of the Bushveld Complex, found that the concentration limits of major and trace elements in the granophyre, leptite and felsite differ from granite and therefore concluded that the granites were formed from a genetically different and more differentiated magma than in the case of granophyres, leptites and felsites.

TABLE 2

Proposed Classification of Granophyres Developed Within the Bushveld Complex

Nature of Granophyre	Proposed Name	Type Area	Previous Name
(i) Developed along the contact of the Mafic Phase with the overlying felsites	Waterval granophyre	The farm Waterval, east of Loskop Dam	Rooiberg granophyre
(ii) Developed as lenses and cross-cutting bodies in felsites	Paardekop granophyre	Near the trigonometrical beacon Paardekop, Tautes Heights	-
(iii) Developed along the contacts of Bushvend granites and overlying felsites	Sterk River granophyre	Sterk River, Zaaiplaats tin-mining area	Bushveld granophyre
(iv) Developed along the base of the Bushveld granites along the contact with the Mafic Phase	Blinkwater granophyre	The farm Blinkwater, Zaaiplaats tin-mining area	Pseudo-granophyre, Bushveld granophyre
(v) Developed in the Bushveld granites adjacent to plugs of stanniferous granite	Groenfontein granophyre	The farm Groenfontein, Zaaiplaats tin-mining area	-
(vi) Developed in the Bushveld granites adjacent to dykes and sheets of diabase, dolerite etc.	Welgevonden granophyre	The farm, Welgevonden, Zaaiplaats tin-mining area	-
(vii) Developed along the contacts of Bushveld granites and sedimentary roof rocks	Stavoren granophyre	The farm Stavoren, Mutue Fides - Stavoren tin-mining area	Stavoren granophyre, Bushveld granophyre

Unfortunately Fourie's sampling reveals a marked bias towards acid rocks collected from the Zaaiplaats and Bronkhorstspruit areas. Within the Zaaiplaats area there is a heavy bias on samples collected from the mineralized Bobbejaankop granite and the Main granite in the immediate vicinity of the former. Consequently some reservation must be expressed about Fourie's results, but in spite of these criticisms the results are important in that they indicate that such studies may prove fruitful and provide clues to the evolution of the Acid Phase of the Bushveld Complex.

OBJECTS AND METHODS

The object of this paper is to attempt to establish on the basis of multivariate statistical analysis of both major and trace element geochemistry, whether any distinct difference between the various components of the Acid Phase of the Bushveld Complex, defined under the present nomenclature system, exists, or, alternately to define on the basis of these results an alternate subdivision of the Acid Phase of the Complex.

The initial phase of the study involved the multivariate analysis of available geochemical data. During the second phase of the study a detailed systematic mapping and geochemical program was undertaken in the Zaaiplaats tin-mining area (Figure 1) to establish a systematic data matrix for analysis. The resulting geological map is presented in Figure 2.

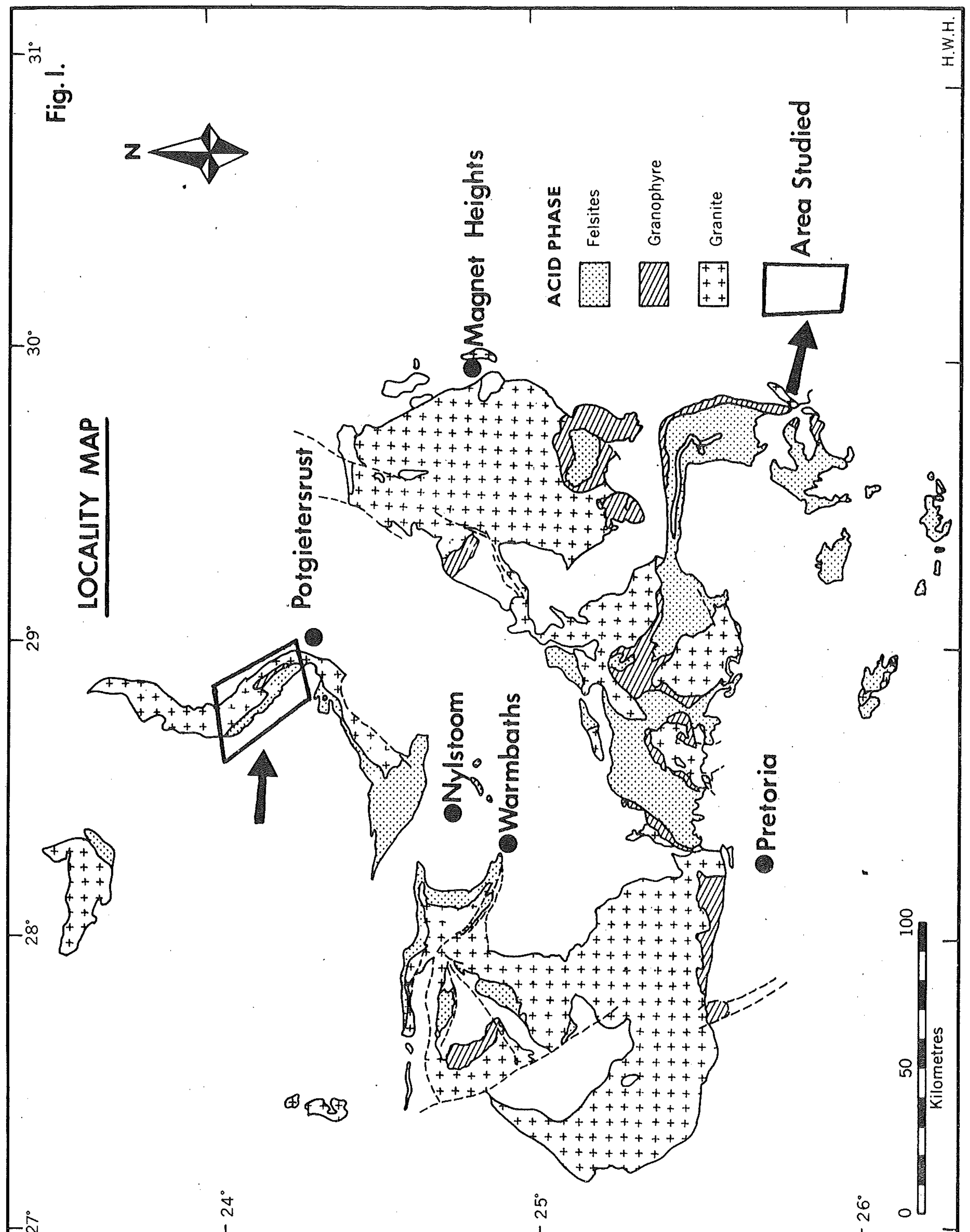
On the basis of the results of field mapping the Acid Phase of the Bushveld Complex was subdivided into ten units which include

(x) Rooiberg felsites
(ix) Feldspar porphyry
(viii) Sterk River granophyre
(vii) Granophyric granite
(vi) Welgevonden granophyre
(v) Groenfontein granophyre
(iv) Bobbejaankop granite including its fine-grained hood facies
(iii) Aplite and porphyritic granite
(ii) Coarse grey granite
(i) Meta-sediments and Blinkwater granophyre

During the geochemical program a total of 269 samples of Bushveld granite, Rooiberg felsite, granophyres of various parentage, feldspar porphyry and metamorphosed Transvaal Sequence sediments were collected on a regular grid to obviate any bias that may arise through sampling (Figure 3). Microscopic investigations revealed that without exception all samples displayed varying degrees of alteration. Only the best-preserved, least-weathered and most representative rock material was used for analysis. Samples weighing between 4 and 6 kilograms were collected at each sample station, care being taken to remove any weathered surfaces. Primary crushing was carried out in a jaw crusher and was followed by fine grinding to <200 mesh of each sample in four stages using a Siebtechniek pulverizer with an agate-lined vessel and rings.

The samples were analysed for Zr, Ba, Zn, Co, Ti, Sc, Sn, La, Ca and Li by General Superintendence Company (Pty.) Limited. Na_2O determinations were carried out by the National Institute of Metallurgy and finally the author analysed the samples for K_2O, Rb and Sr. During the sampling program the total gamma flux density was measured at each sample station with a portable scintillometer Model Type NE 148A. The average grain-size of the feldspars was measured by means of a calibrated transparent grid. For simplicity the grain-size of the feldspars is expressed in square millimetres. Aphanitic felsites were arbitrarily accorded a grain-size of an order of magnitude less than the finest crystalline rock.

Duplicate samples were taken at six stations not only to check analytical precision but also subsequent statistical analysis. The total number of samples treated therefore amounted to 275. At each sample station the measurement of 16 purely quantitative variables provides the raw data which was analysed by multivariate analyses.


LOCALITY MAP
Fig. I.
Potgietersrust
Magnet Heights
Nylstroom
Warmbaths
Pretoria
ACID PHASE
Felsites
Granophyre
Granite
Area Studied
N
0
50
100
Kilometres
27°
28°
29°
30°
31°
24°
25°
26°
H.W.H.

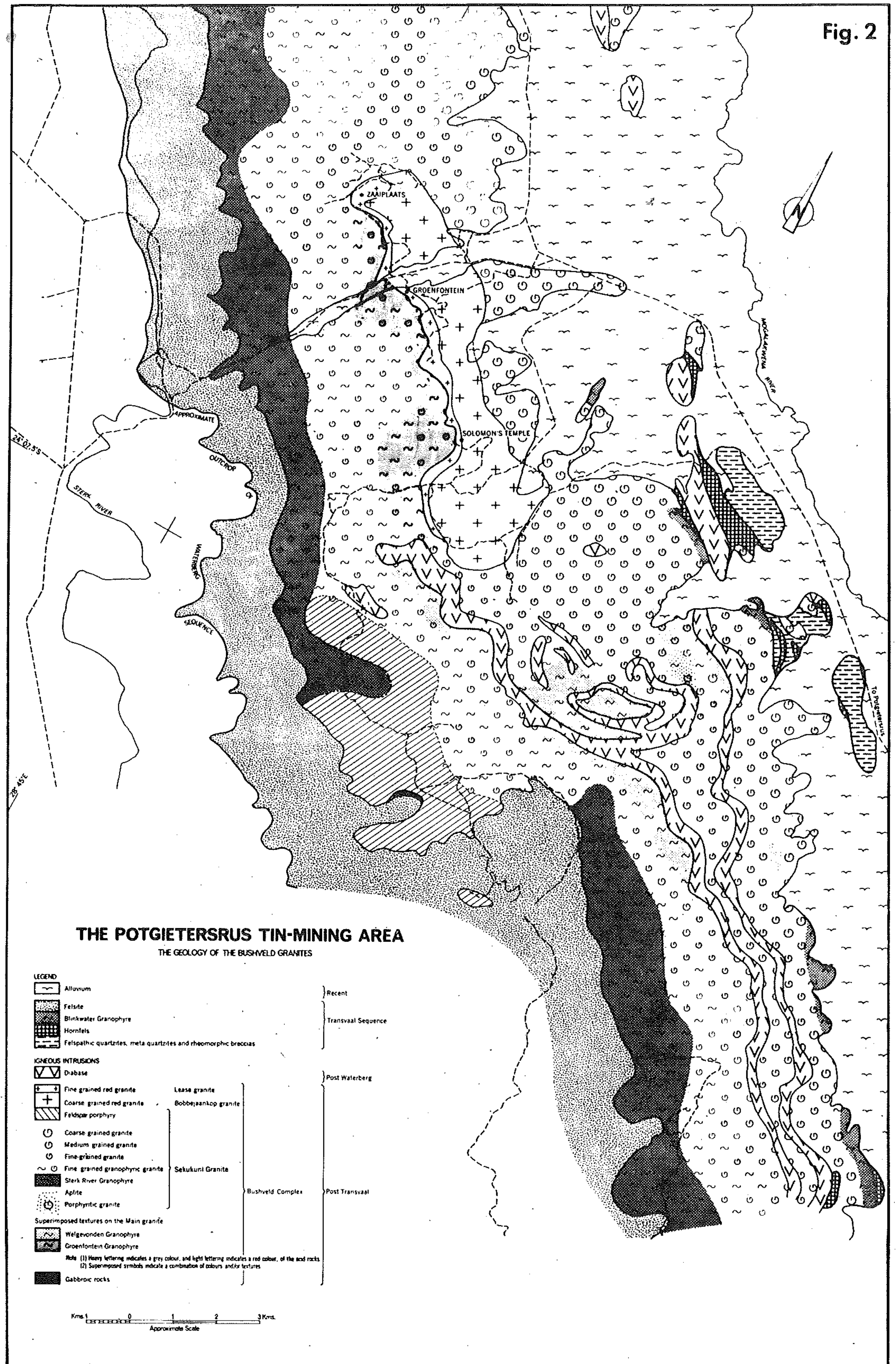
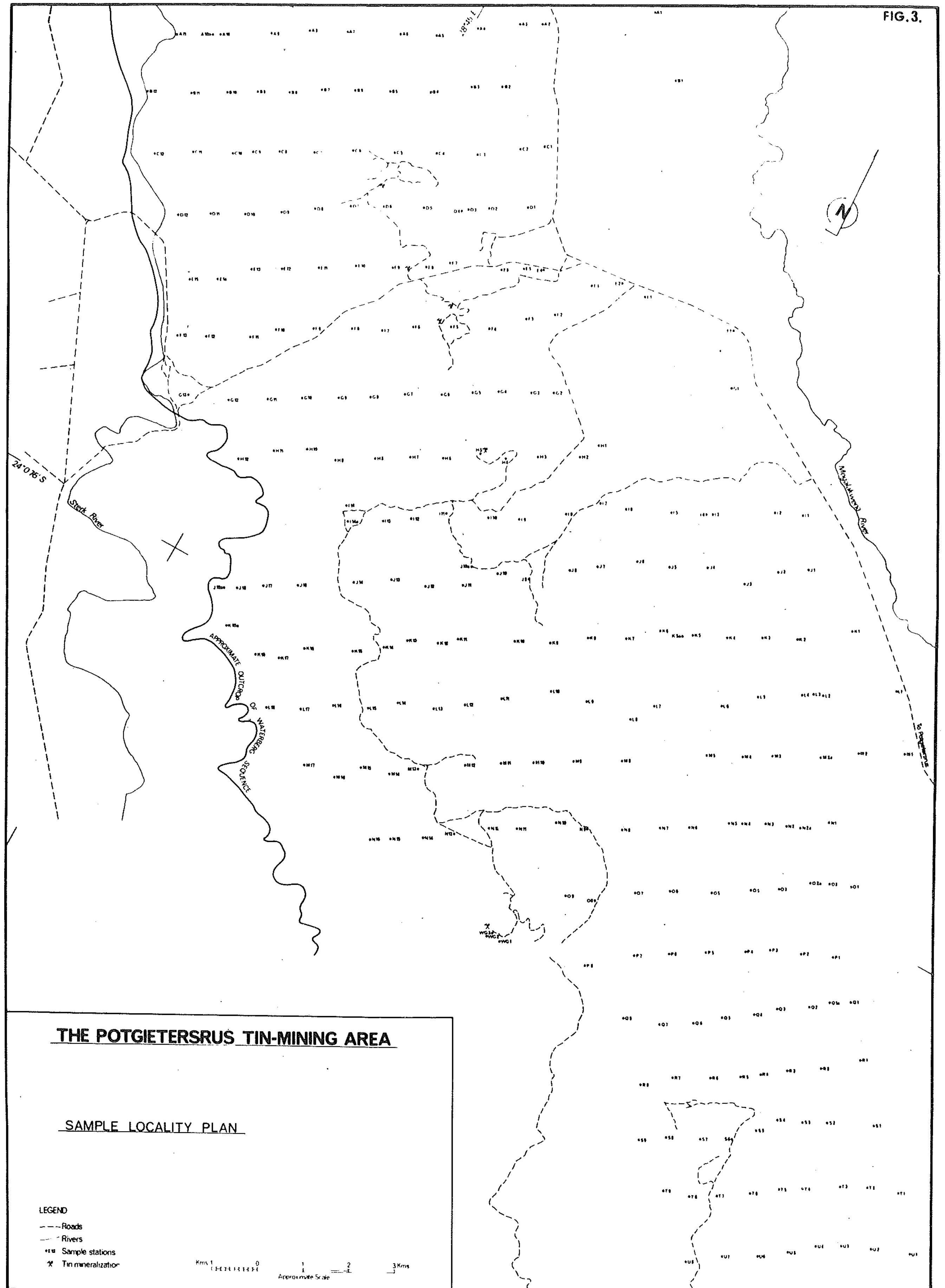


Fig. 2
ZAAIPLAATS
GROENFONTEIN
SOLOMON'S TEMPLE
THE POTGIETERSRUS TIN-MINING AREA
THE GEOLOGY OF THE BUSHVELD GRANITES
LEGEND
Alluvium
Recent
Felsite
Blinkwater Granophyre
Hornfels
Felspathic quartzites, meta quartzites and rheomorphic breccias
Transvaal Sequence
IGNEOUS INTRUSIONS
Diabase
Post Waterberg
Fine grained red granite
Coarse grained red granite
Lease granite
Bobbejaankop granite
Feldspar porphyry
Coarse grained granite
Medium grained granite
Fine-grained granite
Fine grained granophyric granite
Sterk River Granophyre
Aplite
Porphyritic granite
Sekukuni Granite
Bushveld Complex
Post Transvaal
Superimposed textures on the Main granite
Welgevonden Granophyre
Groenfontein Granophyre
Note (1) Heavy lettering indicates a grey colour, and light lettering indicates a red colour, of the acid rocks.
(2) Superimposed symbols indicate a combination of colours and/or textures
Gabbroic rocks
Kms. 1
0
1
2
3 Kms.
Approximate Scale



STATISTICAL METHODS

A. *General*

The appraisal and interpretation of large quantities of data can be assisted by use of a variety of statistical methods.

Whitten and his co-workers [Whitten (1961); Dawson and Whitten (1962); Whitten (1963); and Whitten and Boyer (1964)] have approached this problem using quantitative data to study the areal variation of granitic rocks by trend surface analysis. An alternative is to use numerical classification procedures such as cluster and discriminatory analysis. In cluster analysis, the samples are first compared for similarity, and then subdivided into an unknown number of distinct groups in which the samples in each group are more or less similar to one another than to those in other groups. Discriminatory analysis is used to test the significance between already established groups, and also to assign unknown samples to an appropriate group.

Field mapping procedures may be described as the comparison of each outcrop with an integrated concept of the character of the rock-mass, and dividing the rock-mass into areas of similar rock-types. Numerical and field procedures are basically similar and one may therefore compliment the largely subjective field procedures with the more reproduceable procedures based upon quantitative data.

B. *Cluster Analysis*

Various methods are available for determining the similarity between two samples. They may be subdivided into two categories,

(i) those using numerical data, such as correlation coefficients, distance coefficients or cos Θ coefficients, and

(ii) those using non-numerical data coded into two- or multi-state form, such as matching and association coefficients. Details of computational procedures to determine these coefficients are discussed by Skokal and Sneath (1963), Williams and others (1966), and Harbaugh and Merriam (1968).

In this study the similarity matrix was calculated using the simple distance coefficients given by the formula :

$$D_{ik}^2 = \frac{1}{N} \sum_{i=1}^{N} (X_{ij} - X_{ik})^2$$

Where X_{ij} and X_{ik} are standardized values for the i th variable in samples j and k, and D_{jk}^2 is the squared Euclidian distance between the two samples in N- dimensional space. The data are standardized by the method of standard scores prior to the calculation of the similarity coefficients. If continuous data is not standardized then similarity coefficients will be biased towards those variables that have the largest variances. The shorter the "distance" between two samples, the greater the degree of similarity and vice versa. Distance coefficients are calculated for all the N (N-1)/2 possible pairs of samples and tabulated in a triangular similarity matrix.

Where only a few samples are involved it is easy to inspect the similarity matrix visually to find groups or clusters of samples that show a high degree of similarity to one another. However, where the similarity matrix is too large for a direct interpretation, it is necessary to determine the interrelationships and natural groupings within the similarity matrix by some clustering method and represent the groupings in a two-dimensional hierarchial diagram or dendogram in which the groupings are more obvious.

Numerous criteria for grouping of data have been advanced but essentially fall into two main categories :

(i) divisive, and

(ii) agglomerative.

Divisive methods involve the splitting of the similarity matrix into two dissimilar groups each of which is in turn split into a further two groups, the process continuing until

(i) all samples within a single unit are identical, or

(ii) to some specified limit.

The second method of clustering operates in the opposite direction to the first. In agglomerative methods, similar samples are combined into subgroups which in turn are linked into larger groups. Divisive methods of clustering have been fully discussed by Edwards and Cavalli-Sforza (1965), and agglomerative methods are dealt with by Skokal and Sneath (1963).

Under both divisive and agglomerative clustering techniques numerous individual methods of clustering exist, each based upon a separate criterion for fusing individual samples or groups. Ward's method of clustering (Ward, 1963) was selected and used throughout this study.

Ward's method of clustering is based upon the premise that the greatest amount of information in a data set is available when the N members of the set are ungrouped. Grouping then proceeds by selecting two of the subsets, which, when grouped reduce the number of subsets by one and produce the least impairment of the optimal value of the "objective function".

The "objective function" is that function which provides some "value-of-information" reflecting-number of the amount of information in a set of data. In general, an objective function may be any functional relation that an investigator selects to reflect the relative desirability of groupings. The criterion selected as the "objective function" is the error sum of squares, defined as :

$$E.S.S. = \sum_{i=1}^{N} X_i^2 - \frac{1}{N} \left(\sum_{i=1}^{N} X_i \right)^2$$

Where X_i is the value of the i th individual. The most desirable level of this objective function is its minimum value 0.

The (N-1) resulting subsets are then examined to determine whether a third member should be united with the first pair or another pairing made in order to secure the optimal value for the objective function for (N-2) groups. The procedure is then repeated until all N members of the original array are in a single group. By Ward's clustering method all the hierarchial groups are mutually exclusive.

The resulting pattern of grouping into the various clusters is then diagrammatically displayed in the form of a dendogram. Dendograms are two-dimensional simplifications of multi-dimensional relationships. Consequently it is inevitable that some distortions of similarities will occur particularly at low levels of similarity. However a measure of the distortion can be obtained by calculating a correlation coefficient between the distance functions of the similarity matrix, and those derived from the dendogram. Individual discrepancies can be identified by computing the difference between the distance functions of the similarity matrix and the dendogram, and representing the results in a deviation matrix. Large deviations, that is those that are larger than the normal level of deviation, can then be identified by inspection.

C. *Discriminatory Analysis*

Examples illustrating the application of discriminatory analysis to geological problems are given by Krumbein and Graybill (1965), Davies and Sampson (1966) and Harbaugh and Merrian (1968). All examples, including the present study, deal with the simple discrimination between two groups. The more general form of the discriminant problem, involving more than two groups, is described by Cooley and Lohnes (1962) and has been applied to geological problems by Middleton (1962).

In general terms discriminatory analysis is the calculation of some linear combination of N variables that most effectively separates two sample populations in N-dimensional space so that the ratio of the between-group variance to the within-group variance is maximized. This linear function is defined as :

$$D = \sum_{i=1}^{N} K_i X_i$$

Where D is the discriminant function, K_i the constant for the X_i variable.

The values of the constants (K), are obtained by solving a series of n simultaneous equations

$$\begin{array}{lcl}
K_1W_{11} + K_2W_{12} + \ldots\ldots\ldots K_nW_{1n} & = & \Delta\bar{X}_1 \\
K_1W_{21} + K_2W_{22} + \ldots\ldots\ldots K_nW_{2n} & = & \Delta\bar{X}_2 \\
\quad " \qquad\quad " \qquad\qquad\qquad\quad " & & \\
\quad " \qquad\quad " \qquad\qquad\qquad\quad " & & \\
\quad " \qquad\quad " \qquad\qquad\qquad\quad " & & \\
K_1W_{n1} + K_2W_{n2} + \ldots\ldots\ldots K_nW_{nn} & = & \Delta\bar{X}_n
\end{array}$$

In the simultaneous equations $\Delta\bar{X}_i$ is the difference between the variable means X_{i1} and X_{i2} for the two groups and W_{ij} is an unbiased estimate of the pooled covariance of variables X_i and X_j. The pooled covariance can be calculated by the formula :

$$W_{ij} = \frac{1}{N_1+N_2-2} \left[\sum_{c=1}^{N_1} (X_{i1c} - \bar{X}_{i1})(X_{j1c} - \bar{X}_{j1}) + \sum_{c=1}^{N_2} (X_{i2c} - \bar{X}_{i2})(X_{j2c} - \bar{X}_{j2}) \right]$$

The first subscript denotes the variable, the second the group and the third the individual within a group.

The significance of the discrimination between the different units was not tested because tests of significance are without exception based upon normal distributions of data, a condition that could not be satisfied with the data available. The only test of significance used, was to ascertain whether the solution was geologically meaningful.

MULTIVARIATE ANALYSIS OF THE MAJOR ELEMENT CHEMISTRY OF THE ACID PHASE OF THE BUSHVELD COMPLEX

The statistical analysis of the major element chemistry of the Acid Phase of the Bushveld Complex was carried out in two separate runs. Fourie's (1969) data was treated separately as all his full silicate analyses are expressed in the anhydrous form.

A. *Discriminatory Analysis*

The full silicate data were not subjected to a discriminatory analysis for the following reason. Discriminatory analysis, as stated previously, is a method for testing the significance

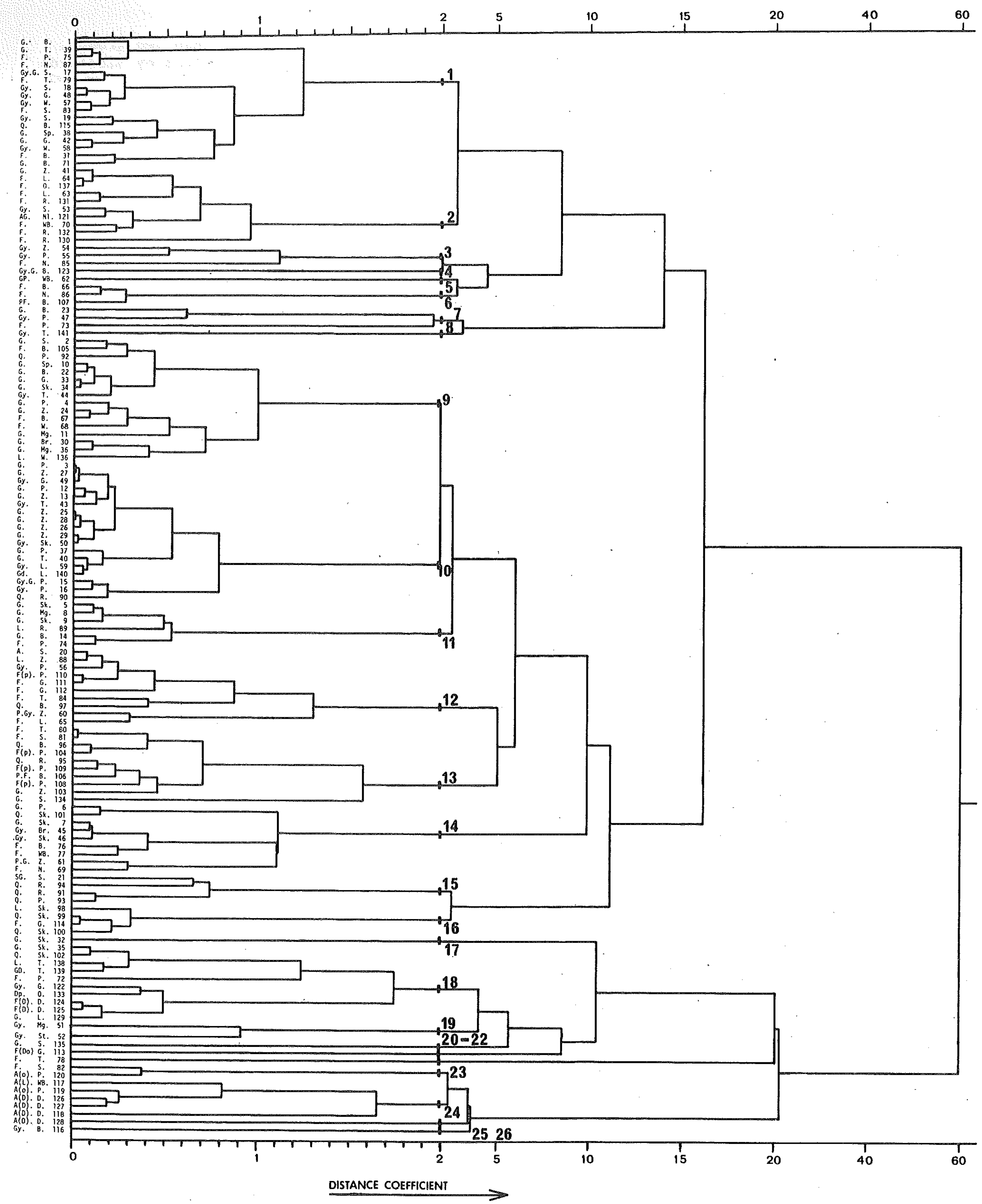
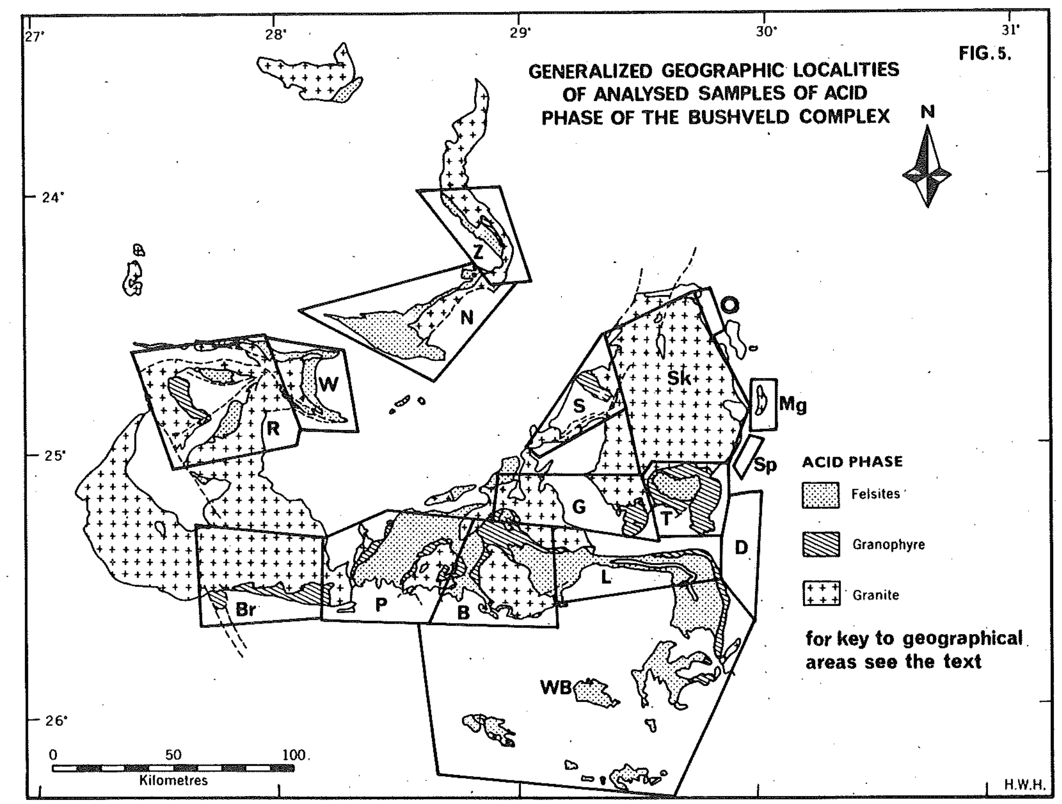


Figure 4 : Dendogram for all published and unpublished full silicate analyses of samples directly or indirectly related to the Acid Phase of the Bushveld Complex.

of already existing groups, or to assign unknown samples to an appropriate group. In the general discussion it has been shown that the system of nomenclature applied to the Acid Phase of the Bushveld Complex is inadequate. The application of discriminatory analysis in such circumstances would not be meaningful.

B. *Cluster Analysis*

Figure 4 summarizes the cluster analysis of one-hundred and fourty-one analyses, excluding the data of Fourie (1969). In the extreme left-hand column the individual rock-type, according to the original author, is identified, the second column indicates the broad geographical location of each sample, (Figure 5), and the third column lists the sample identification used in the analysis. The key to the code system for identification of rock types and geographic locality is presented in Table 3.



The dendogram shows the resulting major clusters. Clusters or groups of clusters may be taken at any desired level of similarity, but it is necessary to establish objectively at what level of similarity clusters or groups of clusters should be taken. In the present study an empirical technique was used to determine the level of similarity at which groups were taken for each cluster analysis. The point was determined below which the fusion of essentially similar samples or groups of samples produced a minimal decrease in the level of similarity (i.e. minimal increase in distance coefficient), and above which the fusion of essentially dissimilar groups produced large decreases in the level of similarity, (i.e. large increases in the distance coefficient).

TABLE 3

Identification Code for Rock Type and General Geographic Locality of Published and Unpublished Full Silicate Analyses

Code	Rock Type	Code	Area
A.	Aplite	B.	Bronkhorstspruit
AG.	Andesite (Godwan Formation)	Br.	Brits
A(o).	Andesite (Ongeluk Lavas)	D.	Dullstroom
A(L).	Andesite (Loskop System)	G.	Groblersdal
Dp.	Dacite porphyry	L.	Loskop Dam
F.	Rooiberg felsite	Mg.	Magnet Heights
F(D).	Felsite (Dullstroom Lavas)	N.	Nylstroom
F(Do).	Felsite (correlated with the Dominion Reef System)	Nl.	Nelspruit
F(p)	Premier Mine felsite	O.	Olifants River
G.	Bushveld granite	P.	Pretoria
Gd.	Granodiorite	R.	Rooiberg
Gp.	Granite porphyry	S.	Stavoren
Gy.	Granophyre	Sk.	Sekukuniland
Gy.G.	Granophyric granite	Sp.	Steelpoort Park
L.	Leptite	T.	Tauteshoogte
P.F.	Pseudofelsite	W.	Warmbaths
P.Gy.	Pseudogranophyre	WB.	Witbank
Q.	Metaquartzite	Z.	Zaaiplaats
S.G.	Stanniferous Greisen		

In clustering the one-hundred and forty-one full silicate analyses the level of similarity at which groups were taken was established at a distance coefficient of 2. The clusters are numbered on the diagram. A cursory inspection of clusters at this level indicates that neither individual rock-types nor samples from individual localities tend to form well defined groups. Two exceptions exist.

(i) Felsites from widely-spaced geographical localities cluster in group 2.

(ii) Andesites essentially from the Dullstroom volcanics cluster in the second- and third-last groups. For the remainder, samples of leptite, granophyre, felsite, metaquartzite and granophyric granite are randomly distributed through the different clusters.

There is a tendency for samples or groups of samples analysed during particular studies to form small clusters at relatively high levels of similarity, separate from samples from the same area but analysed during different studies presumably at different laboratories or in the same laboratory at different times. Such an example is the cluster of Bushveld granites from the Zaaiplaats tin-mining area, samples 25, 26, 28 and 29 from the publication of Strauss (1954). These analyses are of different varieties of Bushveld granite which tend to cluster with each other rather than with similar varieties from different studies. (cf. samples 24, 41 and 103).

The results of the initial cluster analyses proved disappointing but do confirm the chemical homogeneity of the Acid Phase, the conclusion arrived at on the basis of analysis using standard variation diagrams.

The samples of bona fide Bushveld Acid Phase were then subdivided under three very broad headings, granites, granophyre and felsite and each group in turn was subjected to a separate cluster analysis. The general geographic locality code is the same as that used in the initial cluster analysis and the samples retain their original identification numbers for comparison.

(a) Felsites

The results of the cluster analyses of the felsite samples are summarized in the dendogram in Figure 6. The empirically determined level of significance at which groups are taken is established at a distance coefficient of 5, and at this level of similarity six groups exist. The first three account for the bulk of the analyses while the last three contain two, one and one samples respectively.

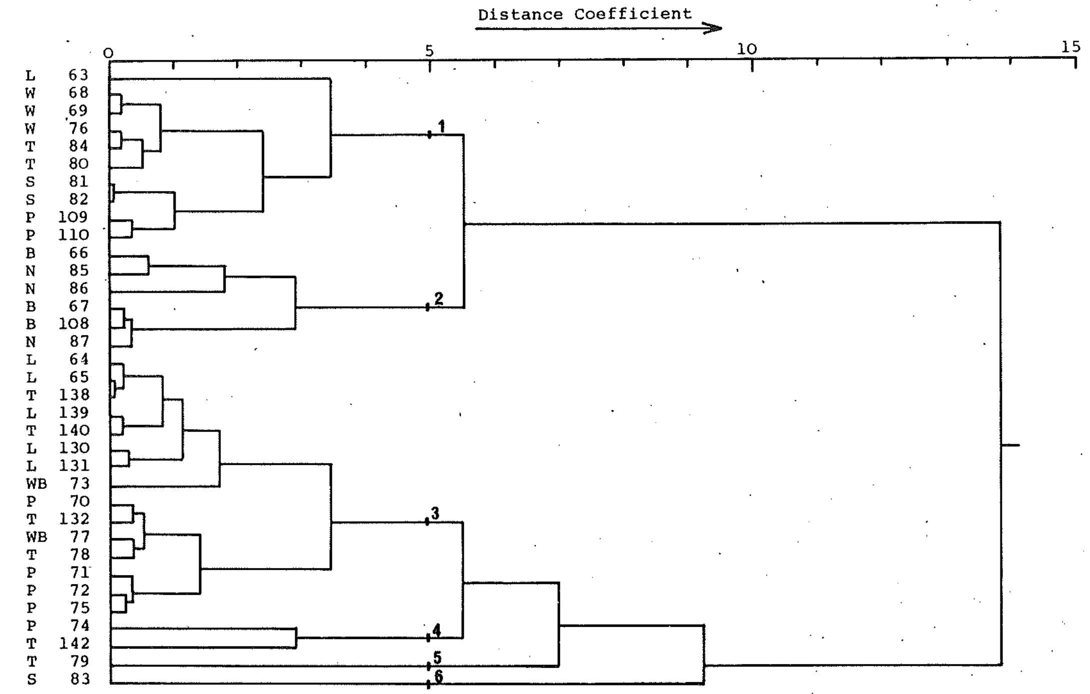


Figure 6. Dendogram for Rooiberg Felsites.

Group 3, numerically the largest contains a heterogeneous cross-section of samples from a wide range of geographic localities, across the Complex. Group 1 contains examples more or less restricted to the southeastern section of the Complex and Group 2 samples from Bronkhorstspruit and Nylstroom.

On the basis of cluster analysis using major element chemistry the felsites appear to be relatively homogeneous and no distant varieties are characteristic of individual geographic areas.

(b) Granophyres

In this analysis all samples designated granophyre by the original author irrespective of their stratigraphic position or origin were used. The results of the cluster analysis of the granophyre samples are summarized in the dendogram in Figure 7. The level of similarity at which groups are taken is established at a distance coefficient of 3, and at this level six groups exist. The bulk of the granophyres are clustered into two groups, seven samples constituting the remaining four groups.

Significantly the cluster analysis has identified as completely different sample 52, an albitized granophyre from Stavoren.

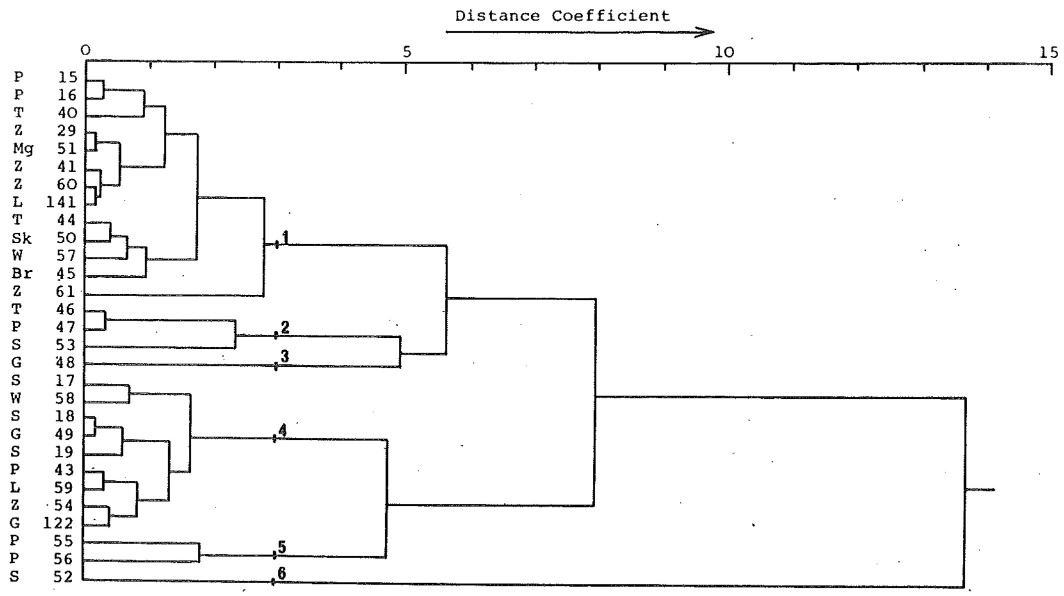


Figure 7. Dendogram of all granophyres associated with the Bushveld Complex.

The most important groups, one and four, are both composed of a heterogeneous assortment of granophyres from a wide variety of geographic localities.

(c) Granites

The results of the cluster analysis of the granite samples are summarized in the dendogram in Figure 8. The level of similarity at which groups are taken is established at a distance coefficient of 5, and at this level six groups exist.

Group 1 contains twenty-one of the thirty-six granite samples and these include samples from each of the broad geographic localities covering the Complex. Group 2, numerically the next most important of the clusters also contains samples from different geographic localities within the Complex. The remaining groups comprise only a few samples each.

The fact that the major portion of the granite samples are contained in only two groups suggests a high degree of chemical homogeneity in the granite of the Bushveld Complex.

The dendogram in Figure 9 summarizes the cluster analyses of the Acid Phase of the Bushveld Complex based upon Fourie's (1969) full silicate analytical data. The first column lists the original sample identification, the second the rock type, the third the broad geographic locality as given by Fourie, and the fourth the sample identification used in the cluster analysis. The key to the rock-type and geographic locality is presented in Table 4. (Note that the geographical localities given by Fourie (1969) do not correspond in all cases to those defined in Figure 5 of this paper).

The empirically determined level of similarity of which samples are taken is established at a distance coefficient of 2.1, and at this level twelve groups exist.

Samples within individual groups or clusters have in all cases fused at extremely high levels of similarity, generally below a distance coefficient of 1.0, while the bulk of the groups are fused into six composite clusters at a relatively low distance coefficient of 6.0. The fusion of the samples at these high levels of similarity emphasises the marked chemical homogeneity of the components of the Acid Phase of the Bushveld Complex.

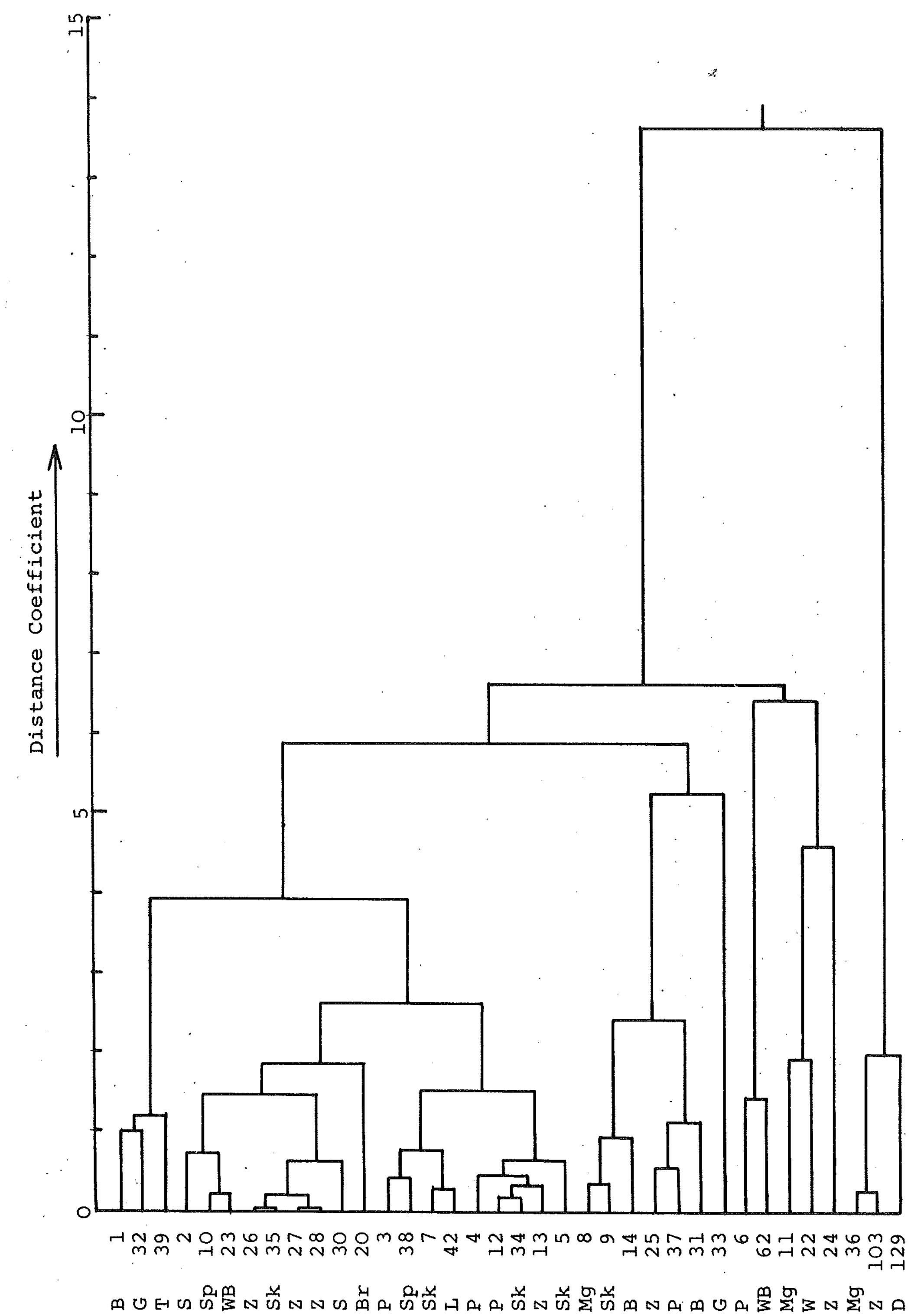


Figure 8. Dendogram of Bushveld Granites.

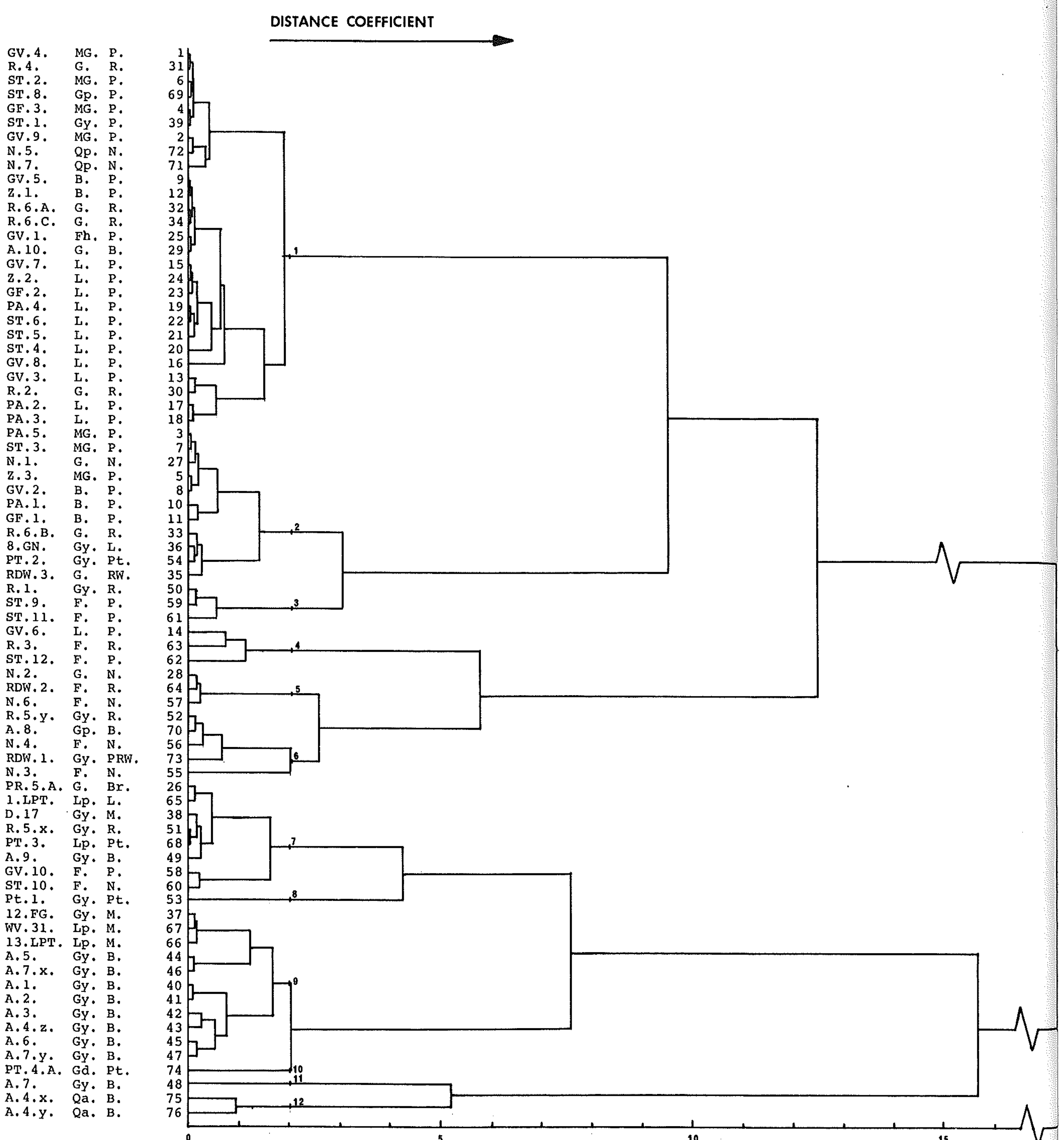


Fig. 9. Dendogram of Fourie's (1969) Full Silicate Analyses of the Acid Phase of the Bushveld Complex.

TABLE 4

Identification Code for Rock Type and General Geographic Locality for Fourie's (1969) Analyses

Rock Type			Locality		
MG.	-	Main Granite	B.	-	Bronkhorstspruit
B.	-	Bobbejaankop granite	Br.	-	Brits
L.	-	Lease granite	L.	-	Lydenburg
Fh.	-	Foothills granite	M.	-	Middelburg
G.	-	Bushveld granite	N.	-	Nylstroom
Gy.	-	Granophyre	P.	-	Potgietersrust
F.	-	Felsite	Pt.	-	Pretoria
Lp.	-	Leptite	R.	-	Rooiberg
Gp.	-	Granite porphyry	RW.	-	Rust de Winter
Qp.	-	Quartz porphyry			
Gy.P.	-	Granophyric granite porphyry			
Gd.	-	Granodiorite			
Qa.	-	Quartz andesite			

Group 1, numerically the largest, is formed by the fusion of two relatively large subgroups at a distance coefficient of 1.96. The first of these subgroups is composed essentially of coarse Bushveld granites from Potgietersrust and Rooiberg, samples of porphyry and a single granophyre from the Potgietersrust area. The second of the subgroups is almost exclusively made up of stanniferous Lease and Bobbejaankop granites plus a few granite samples from the Rooiberg area. Significantly, the granite sample R.2 is closely associated with tin mineralization in the Rooiberg area.

The second group includes Bushveld granites from Potgietersrust and Nylstroom, including three of the five samples of mineralized Bobbejaankop granite, and a few granophyre samples from Rooiberg, Pretoria and Rust de Winter.

The third to the eighth groups, all numerically small, are composed of felsites, granophyres and leptites with an occasional granite sample. No one rock-type dominates in any of these groups.

Granophyres west and southwest of Bronkhorstspruit appear to have a characteristic geochemistry and cluster separately in the ninth group.

The remaining clusters are composed of one to two samples only.

C. *Discussion*

The disappointing results of the cluster analysis of the Acid Phase of the Bushveld Complex based on major element data excluding that of Fourie (1969) may well be a direct result of the variability of analytical precision over the years that this information has been gathered. The tendency for samples of different rock-types, analysed together, to cluster with one another rather than with similar rock-types analysed at different times or in different laboratories (e.g. the samples from Strauss 1954) argues strongly in favour of this possibility.

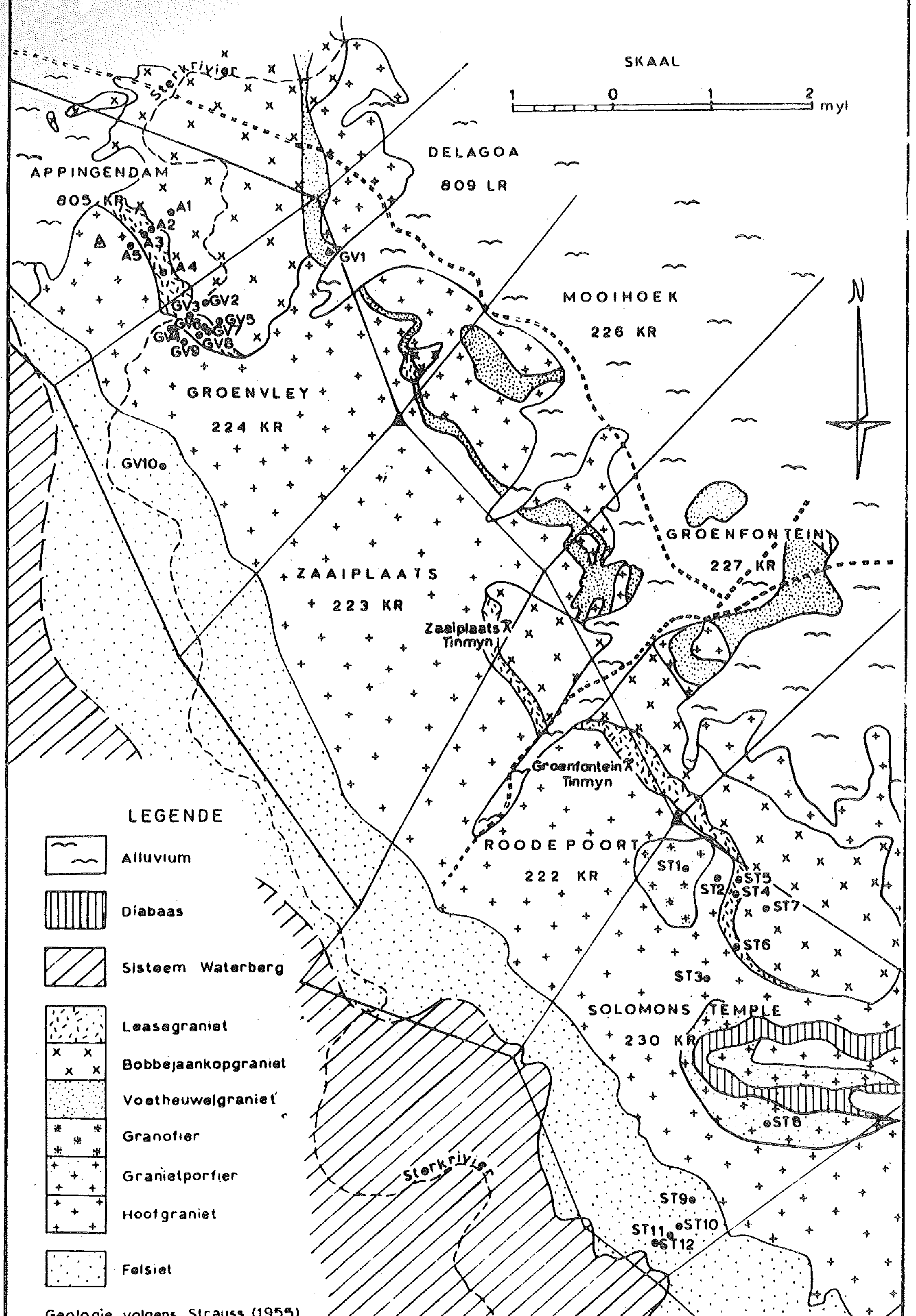
The apparently better results of the cluster analysis using Fourie's (1969) major element data suggests on first appraisal that with more precise analytical techniques distinction and discrimination between the various components of the Acid Phase of the Bushveld Complex may be possible. However the sampling bias in Fourie's data and its effect on the conclusions which may be drawn must be discussed.

(a) Samples from the Potgietersrust Area

Fourie's (1969) original sample locality map for the Potgietersrust area is reproduced in Figure 10. Without exception samples of the Main granite are taken within the immediate vicinity of the two plugs of Bobbejaankop granite. Further all the samples are of the same

FIG. 10.

LOKALITEITSKAART VAN MONSTERS VERSAMEL IN DIE POTGIETERSRUS - TINVELD



textural variety, namely medium- to fine-grained red granophyric granites. The remaining textural varieties of the Main granite, which include coarse- to medium-grained leucocratic and mesocratic granites, locally rapakivic, are not represented. The stanniferous Bobbejaankop granite, including its fine roof facies - the Lease granite, has only been sampled along its upper contact in close proximity to known and worked mineralization within the bodies.

The single sample of Foothills granite from the Zaaiplaats area is taken almost adjacent to the Appingendam plug. Work in progress has shown that the trace element chemistry of unmineralized Bushveld granites is highly affected in the immediate vicinity of Bobbejaankop granite, and the same may be true for the major element chemistry.

(b) Samples from the Bronkhorstspruit Area

The granophyre samples from the Bronkhorstspruit area which group in a well defined cluster, are all taken from a small exposure to the north of Argent. On Figure 5 this locality would plot in the Witbank area. Samples A4 and A5 are from the same borehole and samples A7X, Y, Z are taken within 45 metres of one another.

If the Potgietersrust and Bronkhorstspruit samples referred to are excluded from the dendogram the resulting distribution of the rock-types is similar to that obtained in the cluster analysis based on the 141 silicate analyses in which granophyre, granite, leptite, felsite and porphyry samples are randomly distributed throughout the clusters.

The basic conclusion drawn from all the cluster analyses based upon full silicate data is that an overriding chemical homogeneity in all components of the Acid Phase of the Bushveld Complex is manifest.

It is noted that the Lease granite, probably the Bobbejaankop granite, and the granophyre in the Bronkhorstspruit area may possess distinctive major element geochemistries, as suggested by the data of Fourie (1969) but until this is verified by more systematically selected samples the conclusion of chemical homogeneity remains the only one tenable.

MULTIVARIATE ANALYSIS OF THE TRACE ELEMENT CHEMISTRY OF THE ACID PHASE OF THE BUSHVELD COMPLEX

The multivariate analysis of the trace element chemistry of the Acid Phase of the Bushveld Complex was carried out in two separate runs. Fourie's (1969) data was treated separately primarily because the data matrices were not composed of the same elements and secondly the concentrations of certain of the common elements are not directly comparable. Liebenberg's (1961) data contained only a few elements common to the data matrix of Fourie (1969) or that of the present study and as the number of samples analysed is numerically small a separate statistical analysis is not feasible.

A. *Discriminatory Analysis*

Fourie's (1969) data was not subjected to a discriminatory analysis for the same reason as in the case of major element chemistry.

On the basis of systematic mapping the samples collected in the Zaaiplaats tin-mining area, were subdivided into ten field mapping units :

1. coarse grey granite
2. the mineralized Bobbejaankop granite with its associated fine-grained roof facies (Lease microgranite of Strauss 1954)
3. Rooiberg felsites
4. aplites and porphyritic granites

5. granophyric granites
6. Sterk River granophyre
7. Groenfontein granophyre
8. Feldspar porphyry
9. Welgevonden granophyre, and
10. Metasediments and Blinkwater granophyre.

The data matrix for the samples was used in a discriminatory analysis to determine whether, in fact, the ten field map units are distinct.

All fourteen chemical elements, the gamma flux density and the grain-size were used to create the discriminant functions for each of the map units, and on the basis of discriminant functions, so generated, each sample was reclassified into one of the ten units. Good correspondence between the original field classification and the reclassification based upon the discriminant functions is regarded as a measure of the uniqueness of the unit.

The results for each of the units are summarized below in the form of simple 2 x 2 matrices in which columns relate to the field classification and rows the classification based upon the discriminant function.

In the case of unit 1, 88 samples were classified as being of unit 1 type in the field, the total of column 1, and 187 samples, the remainder not in unit 1, the total of column 2. On the basis of the discriminant functions 42 samples were ascribed to unit 1, the total of row 1, and the remaining 233 samples, the sum of row 2, not in unit 1. In 35 cases there was agreement in classification of samples being of unit 1 type and in 180 cases, agreement in classification of samples as not being of unit 1 type. The probability of a correct affirmative classification on the basis of discriminatory analysis is $^{35}/_{88}$ or 0.40, while the probability of a correct negative classification is $^{180}/_{187}$ or 0.96.

Coarse grey granite

		Field Classification: In unit 1	Field Classification: Not in unit 1
Computer Classification	In unit 1	35	7
	Not in unit 1	53	180

Probability of a correct affirmative classification = 0.40
Probability of a correct negative classification = 0.96

Bobbejaankop granite

		Field Classification: In unit 2	Field Classification: Not in unit 2
Computer Classification	In unit 2	16	2
	Not in unit 2	1	256

Probability of a correct affirmative classification = 0.94
Probability of a correct negative classification = 0.99

Rooiberg felsites

		Field Classification: In unit 3	Field Classification: Not in unit 3
Computer Classification	In unit 3	35	3
	Not in unit 3	2	253

Probability of a correct affirmative classification = 0.95
Probability of a correct negative classification = 0.99

Aplites and porphyritic granites

		Field Classification: In unit 4	Field Classification: Not in unit 4
Computer Classification	In unit 4	6	26
	Not in unit 4	11	232

Probability of a correct affirmative classification = 0.35
Probability of a correct negative classification = 0.90

Granophyric granites

		Field Classification: In unit 5	Field Classification: Not in unit 5
Computer Classification	In unit 5	24	28
	Not in unit 5	19	204

Probability of a correct affirmative classification = 0.56
Probability of a correct negative classification = 0.88

Sterk River granophyre

		Field Classification: In unit 6	Field Classification: Not in unit 6
Computer Classification	In unit 6	10	11
	Not in unit 6	24	230

Probability of a correct affirmative classification = 0.29
Probability of a correct negative classification = 0.95

Groenfontein granophyre

		Field Classification: In unit 7	Field Classification: Not in unit 7
Computer Classification	In unit 7	3	11
	Not in unit 7	4	257

Probability of a correct affirmative classification = 0.43
Probability of a correct negative classification = 0.96

Feldspar porphyry

		Field Classification	
		In unit 8	Not in unit 8
Computer	In unit 8	7	15
Classification	Not in unit 8	5	248

Probability of a correct affirmative classification = 0.58

Probability of a correct negative classification = 0.94

Welgevonden granophyre

		Field Classification	
		In unit 9	Not in unit 9
Computer	In unit 9	6	25
Classification	Not in unit 9	2	242

Probability of a correct affirmative classification = 0.75

Probability of a correct negative classification = 0.91

Metasediments and Blinkwater granophyre

		Field Classification	
		In unit 10	Not in unit 10
Computer	In unit 10	4	1
Classification	Not in unit 10	8	262

Probability of a correct affirmative classification = 0.33

Probability of a correct negative classification = 0.99

Discriminatory analysis, on the basis of the present data set and field classification suggests that only units 2 and 3 may represent distinctly different families. There is a suggestion that the feldspar porphyry, unit 8, and the Welgevonden granophyre, unit 9, may be distinct, however as a large number of samples not belonging to either of these units are incorrectly classified with them, and as the number of samples in each unit on which the discriminant function is calculated is relatively small, their uniqueness is suspect. The inability of the analysis to discriminate effectively between the remainder of the map units may be due to one of two possible reasons :

(i) that families are inherently so similar that large population overlaps preclude the possible discrimination between them, or

(ii) the map units are artificial and transgress real family boundaries.

If the first reason is true then no further information can be gained by this technique, but, if the second case holds, then an analysis of incorrectly classified samples in each unit may suggest regrouping of individual field units into distinct families. Table 5 represents such an analysis.

The samples of field units, in rows, incorrectly classified by discriminatory analysis are broken down into the different units for which they were mistaken under the different columns. The results of the analysis of incorrectly classified samples show that disagreement between field and computer classification occurred 129 out of a possible 275 times. Fifty-three samples in field unit 1 were incorrectly classified, two samples for unit 2, 21 for unit 4, 16 for unit 5, etc.

TABLE 5

Analysis of Samples in Field Units, Incorrectly Classified by Discriminatory Analysis, See Text for Explanation

Units	1	2	3	4	5	6	7	8	9	10	Total
1	–	2	–	21	16	4	1	1	8	–	53
2	–	–	–	–	–	–	–	1	–	–	1
3	–	–	–	–	1	–	–	1	–	–	2
4	6	–	–	–	2	1	–	–	1	1	11
5	1	–	–	4	–	2	3	5	4	–	19
6	–	–	1	–	4	–	4	6	9	–	24
7	–	–	–	–	2	1	–	1	–	–	4
8	–	–	–	–	2	1	2	–	–	–	5
9	–	–	–	–	1	1	–	–	–	–	2
10	–	–	2	1	–	1	1	–	3	–	8
Total	7	2	3	26	28	11	11	15	25	1	129

Inspection of Table 5 shows that the coarse grey granites, unit 1, were frequently confused with the aplites and porphyritic granites and the granophyric granites, units 4 and 5 respectively. The aplites and porphyritic granites, unit 4, were primarily confused with the coarse grey granites, unit 1, and to a lesser degree with the granophyric granites, unit 5.

The granophyric granites, unit 5, were confused with the aplites and porphyritic granites, unit 4, to a slight degree but more frequently with the feldspar porphyry and the Welgevonden granophyre, units 8 and 9 respectively. The remaining incorrect classifications appear to be relatively random and non-reciprocal, for this reason, only units 1, 4, and 5 were grouped together as a composite unit for a second discriminatory analysis.

The results of the discriminatory analysis based on the full data set, but with field map units 1, 4 and 5 combined are listed below :

Coarse gray granite, aplite and porphyritic granite and granophyric granite

		Field Classification	
		In unit 1	Not in unit 1
Computer	In unit 1	93	5
Classification	Not in unit 1	55	122

Probability of a correct affirmative classification = 0.63

Probability of a correct negative classification = 0.96

Bobbejaankop granite

Computer Classification		Field Classification: In unit 2	Not in unit 2
	In unit 2	16	3
	Not in unit 2	1	255

Probability of a correct affirmative classification = 0.94
Probability of a correct negative classification = 0.99

Rooiberg felsite

Computer Classification		Field Classification: In unit 3	Not in unit 3
	In unit 3	35	3
	Not in unit 3	2	235

Probability of a correct affirmative classification = 0.95
Probability of a correct negative classification = 0.99

Sterk River granophyre

Computer Classification		Field Classification: In unit 4	Not in unit 4
	In unit 4	10	23
	Not in unit 4	24	218

Probability of a correct affirmative classification = 0.29
Probability of a correct negative classification = 0.91

Groenfontein granophyre

Computer Classification		Field Classification: In unit 5	Not in unit 5
	In unit 5	4	20
	Not in unit 5	3	248

Probability of a correct affirmative classification = 0.57
Probability of a correct negative classification = 0.93

Feldspar porphyry

Computer Classification		Field Classification: In unit 6	Not in unit 6
	In unit 6	9	17
	Not in unit 6	3	246

Probability of a correct affirmative classification = 0.75
Probability of a correct negative classification = 0.94

Welgevonden granophyre

Computer Classification		Field Classification: In unit 7	Not in unit 7
	In unit 7	7	25
	Not in unit 7	1	242

Probability of a correct affirmative classification = 0.88
Probability of a correct negative classification = 0.91

Metasediments and Blinkwater granophyre

Computer Classification		Field Classification: In unit 8	Not in unit 8
	In unit 8	4	1
	Not in unit 8	8	262

Probability of a correct affirmative classification = 0.33
Probability of a correct negative classification = 0.99

By combining field map units 1, 4 and 5 (coarse grey granite, aplites and porphyritic granites, and granophyric granites) the efficiency of discrimination between the various units is generally improved, particularly in the case of the Welgevonden granophyre and feldspar porphyry. However the number of samples incorrectly classified as either Welgevonden granophyre or feldspar porphyry remains relatively large. The improvement in efficiency of discrimination by combining certain of the original map units suggests that the map units are artificial boundaries delineating textural variations in a single homogeneous unit (excluding the mineralized Bobbejaankop granite and the Rooiberg felsites).

Implicit in this discriminatory analysis is the consanguinity of the aplites and porphyritic granites and the Main granite, i.e. essentially the composite of field map units 1, 4 and 5. The separation of the aplites and porphyritic granites as a distinct episode in the emplacement of the Bushveld granites as the Foothills granite by Strauss (1954), appears to be unjustified on the basis of the present evidence.

It is of economic importance to be able to positively identify the stanniferous phase of the Bushveld granite, viz. the Bobbejaankop granite and for economic reasons the number of criteria necessary for identification should be minimized. Inspection of the discriminant functions for the Bobbejaankop granite shows that Ba, Zn, Ti, Rb, Sr and gamma flux density are the most important contributing factors in the identification of the Bobbejaankop granite. These variables together with Co, added to maintain the discrimination efficiency of the Rooiberg felsites, were used in a final discriminant analysis to assess the possible potential of this technique for exploration purposes. Discriminant functions were generated, using the listed variables, for the original ten map units and the results of the analysis are listed below.

Coarse grey granite

Computer Classification		Field Classification: In unit 1	Not in unit 1
	In unit 1	28	12
	Not in unit 1	60	175

Probability of a correct affirmative classification = 0.32
Probability of a correct negative classification = 0.94

Bobbejaankop granite

		Field Classification: In unit 2	Field Classification: Not in unit 2
Computer Classification	In unit 2	17	3
	Not in unit 2	0	255

Probability of a correct affirmative classification = 1.0
Probability of a correct negative classification = 0.99

Rooiberg felsite

		Field Classification: In unit 3	Field Classification: Not in unit 3
Computer Classification	In unit 3	32	5
	Not in unit 3	5	283

Probability of a correct affirmative classification = 0.86
Probability of a correct negative classification = 0.98

Aplites and porphyritic granites

		Field Classification: In unit 4	Field Classification: Not in unit 4
Computer Classification	In unit 4	4	19
	Not in unit 4	13	239

Probability of a correct affirmative classification = 0.24
Probability of a correct negative classification = 0.93

Granophyric granite

		Field Classification: In unit 5	Field Classification: Not in unit 5
Computer Classification	In unit 5	16	29
	Not in unit 5	27	203

Probability of a correct affirmative classification = 0.37
Probability of a correct negative classification = 0.88

Sterk River granophyre

		Field Classification: In unit 6	Field Classification: Not in unit 6
Computer Classification	In unit 6	5	12
	Not in unit 6	29	229

Probability of a correct affirmative classification = 0.15
Probability of a correct negative classification = 0.95

Groenfontein granophyre

		Field Classification: In unit 7	Field Classification: Not in unit 7
Computer Classification	In unit 7	1	11
	Not in unit 7	6	257

Probability of a correct affirmative classification = 0.14
Probability of a correct negative classification = 0.96

Feldspar porphyry

		Field Classification: In unit 8	Field Classification: Not in unit 8
Computer Classification	In unit 8	8	15
	Not in unit 8	4	248

Probability of a correct affirmative classification = 0.67
Probability of a correct negative classification = 0.94

Welgevonden granophyre

		Field Classification: In unit 9	Field Classification: Not in unit 9
Computer Classification	In unit 9	8	42
	Not in unit 9	0	225

Probability of a correct affirmative classification = 1.00
Probability of a correct negative classification = 0.80

Metasediments and Blinkwater granophyre

		Field Classification: In unit 10	Field Classification: Not in unit 10
Computer Classification	In unit 10	5	3
	Not in unit 10	7	260

Probability of a correct affirmative classification = 0.42
Probability of a correct negative classification = 0.99

On the basis of six chemical elements, Ba, Zn, Co, Ti, Rb, Sr, and gamma flux density, the efficiency of discriminant analysis to positively identify Bobbejaankop granites is 100 per cent, further only three samples were incorrectly identified as Bobbejaankop granites. On the basis of the discriminant functions derived from the seven variables there is perfect positive identification of the Welgevonden granophyre, however the number of samples incorrectly identified as Welgevonden granophyre is drastically increased. The efficiency in discrimination of the Rooiberg felsites is only slightly impaired in the "reduced variable base" on which the discriminant functions were calculated.

It must be pointed out that until the discriminant functions are tested in other mineralized areas in the Bushveld Complex the conclusions drawn only hold for the Zaaiplaats area.

B. *Cluster Analysis*

The results of the cluster analysis based upon Fourie's (1969) trace element data are summarized in the dendogram in Figure 11. The empirically determined level similarity at which groups or clusters are taken is established at a distance coefficient of 2.1 and at this level twelve groups exist.

Individual samples in the clusters are fused at extremely high levels of similarity. The clusters are in turn fused into six major super groups at the relatively low distance coefficient of 5. The means and standard deviations of each of the variables in the twelve clusters are summarized in Table 6. Except for the last five clusters which contain the bulk of the mineralized granites, variations in the mean values of the individual elements appear to vary in a relatively random fashion in the remaining clusters.

Cluster five composed essentially of the granophyre suite from Bronkhorstspruit differs from the remaining clusters, excluding those containing mineralized granites, by low Ce, La, Rb, Sm, Th and Yb concentrations.

The mineralized Bobbejaankop and Lease granites are distributed through the last five clusters which fuse to a composite at a distance coefficient of 7.07. In addition to the Lease and Bobbejaankop granites a single Foothills granite, two quartz porphyries plus a granite sample from Nylstroom and a granite from Rooiberg are included in the last four groups. Significantly each of the samples, excluding the Foothills granite, are taken in relatively close proximity to known mineralization suggesting that the trace element geochemistry of mineralized granites in the Bushveld Complex may be uniformly distinctive.

The mineralized granites, including the samples from Nylstroom and Rooiberg, are distinguished on average from the non-mineralized components of the Acid Phase of the Bushveld Complex by :

(i) significantly higher Ce, ~~Co~~, Lu, Rb, Sm, Sn, Th, and Yb concentrations,

(ii) significantly lower Ba, Co, Cu, Sc and Sr concentrations, and

(iii) less erratic variations in the Ba, Eu, Sm and Zr concentrations.

On the basis of the cluster analysis of Fourie's (1969) trace element data the following facts have been established :

1. Non-mineralized granites of the Bushveld Complex (essentially cluster 1) apparently have a distinctive chemistry from granophyres, leptites, felsites and mineralized granites,

2. Granophyres, excluding the suite from Bronkhorstspruit, felsites and certain of the leptites grouped in cluster 2 have a different chemistry from mineralized and unmineralized granites. However there appear to be subtle differences in the chemistries of the granophyres and leptites and the felsites which are separated in two distinct sub-clusters in cluster 2.

3. The granophyre suite from Bronkhorstspruit together with leptites and granophyres from Middelburg and granodiorite from Pretoria display totally unique geochemistries.

4. Mineralized granites, essentially from the Zaaiplaats area, have distinctive geochemistries from all other components of the Acid Phase of the Bushveld Complex and within themselves display a high degree of chemical variability suggestive of a strong chemical zonation, in so far as trace and minor elements are concerned, within the individual bosses of stanniferous granite. Assuming that a relationship can be established between the chemistry of granite within ore-zones and mineralization, then a useful technique will be

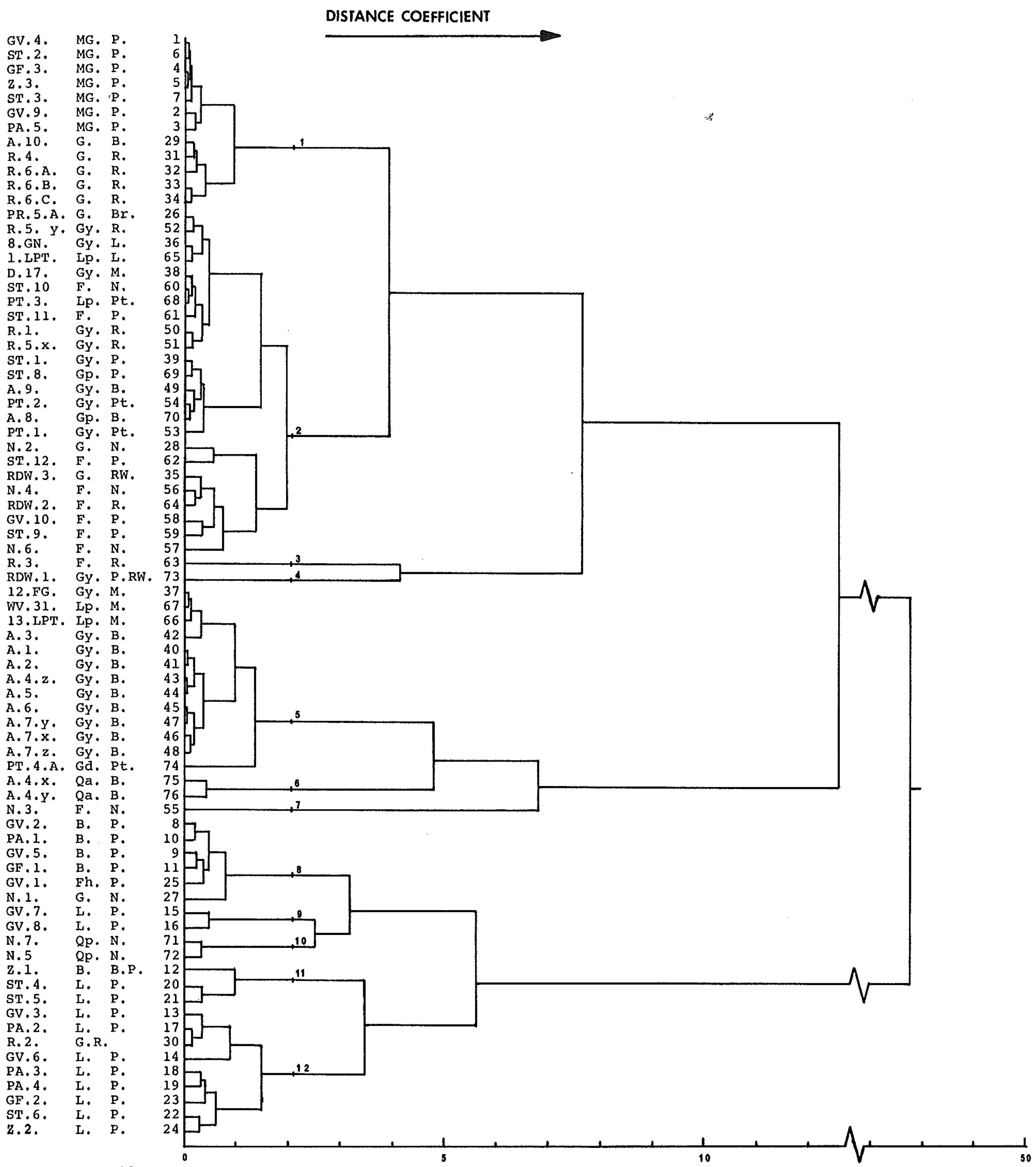


Fig. 11. Dendogram of Fourie's (1969) Trace Element chemical data of the Acid Phase of the Bushveld Complex.

TABLE 6

Means and Standard Deviations of Measured Variables in Clustered Families of Samples of the Acid Phase of the Bushveld Complex. Based on the Data of Fourie, 1969
(Size = Number of Samples in the Cluster)

MEANS

Cluster	Ba	Ce	Co	Cs	Dy	Eu	Hf	La	Lu	Mn	Nb	Rb	Sc	Sm	Sn	Sr	Th	Yb	Zn	Zr	Size
1	752.8	137.8	2.2	2.5	7.0	1.7	5.9	92.1	.7	353.7	23.3	265.5	1.1	15.6	13.3	20.8	23.0	2.9	82.8	332.5	12
2	1090.9	108.9	3.2	4.2	5.3	1.9	6.0	61.1	.6	728.3	19.5	218.3	4.7	11.2	8.3	69.8	16.9	2.6	145.5	395.7	24
3	1261.0	361.0	7.7	1.1	11.0	7.3	4.7	180.0	.8	204.0	17.0	272.0	6.0	37.5	9.0	9.0	22.5	3.8	35.0	355.0	1
4	1108.0	308.0	6.7	5.6	9.0	.2	8.9	145.0	.8	5397.0	33.0	234.0	1.3	22.2	3.0	18.0	71.0	3.6	27.0	401.0	1
5	869.5	78.2	8.3	1.9	3.8	2.6	4.8	52.9	.4	996.5	20.3	113.3	9.4	9.6	2.9	195.6	10.4	1.7	106.4	346.8	13
6	698.0	44.5	31.6	2.3	1.8	1.3	3.0	32.7	.2	1012.5	16.0	81.0	17.9	5.0	8.0	292.0	8.2	1.0	116.0	187.0	2
7	1293.0	92.0	3.7	2.4	2.0	2.4	4.6	50.0	.4	4112.0	14.0	309.0	9.5	9.0	0.0	23.0	18.0	1.4	1671.0	345.0	1
8	424.2	175.0	1.6	3.9	11.9	.4	6.8	104.7	1.1	258.0	32.5	413.7	1.3	19.5	23.2	9.5	37.5	5.1	63.7	216.5	6
9	432.0	199.5	1.0	15.3	11.4	.3	10.0	137.0	1.1	709.0	55.0	601.0	1.7	25.6	16.5	2.5	53.0	5.0	110.5	292.5	2
10	541.0	247.0	1.1	6.9	7.0	.1	5.8	138.5	.6	196.0	36.5	578.0	2.1	21.1	11.5	38.5	101.8	2.9	46.5	221.0	2
11	351.0	107.7	1.4	5.8	8.7	.3	8.9	89.7	1.0	243.7	51.0	556.0	1.4	11.2	129.0	10.3	43.8	4.3	39.0	266.7	3
12	257.6	122.2	.7	5.3	7.7	.2	8.5	72.3	.7	325.1	51.7	519.7	1.6	10.5	18.4	4.6	54.1	3.3	43.7	284.1	9

STANDARD DEVIATIONS

Cluster	Ba	Ce	Co	Cs	Dy	Eu	Hf	La	Lu	Mn	Nb	Rb	Sc	Sm	Sn	Sr	Th	Yb	Zn	Zr	Size
1	126.1	17.0	1.5	1.1	1.0	.4	.9	20.4	.2	116.4	1.6	35.3	.3	2.5	11.4	8.3	4.8	.9	37.7	29.0	12
2	166.2	20.2	1.2	3.3	1.4	.5	1.0	11.8	.1	373.8	2.3	92.9	2.5	3.5	12.0	33.1	4.7	.7	115.0	50.4	24
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
5	166.8	4.5	2.5	1.1	1.1	1.2	.8	9.8	.1	336.5	2.4	25.6	1.9	2.7	2.1	43.7	2.6	.4	61.7	40.1	13
6	56.0	3.5	3.8	.6	.4	.1	0.0	.5	.0	32.5	1.0	18.0	3.8	1.4	4.0	77.0	.8	.0	26.0	22.0	2
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
8	108.5	38.6	.6	1.1	1.3	.3	1.8	14.7	.2	85.3	4.1	72.5	.5	3.6	10.9	9.5	5.3	.8	30.0	22.7	6
9	43.0	15.5	.3	1.8	1.6	.1	0.0	4.0	.3	18.0	9.0	88.0	0.0	2.6	1.5	1.5	3.0	.0	8.5	13.5	2
10	35.0	4.0	.2	.7	2.0	.1	.7	.5	.1	53.0	1.5	101.0	.1	1.1	2.5	2.5	3.2	.9	5.5	7.0	2
11	47.4	9.0	.8	2.8	.4	.2	.7	14.2	.2	92.7	8.5	61.4	.4	1.5	36.9	2.6	4.5	1.5	15.0	40.9	3
12	76.1	16.6	.2	2.9	2.4	.2	1.5	21.6	.2	178.3	6.1	119.6	.3	3.1	16.4	2.9	9.6	1.0	30.1	34.9	9

available to assist in the delineation and exploitation of economic tin mineralization within individual bodies of mineralized granite.

These conclusions can for the present only be regarded as tentative, their validity will of necessity have to be established by more systematic sampling in the Acid Phase of the Bushveld Complex.

The results of the cluster analysis of the trace element data of the present study are summarized in the dendogram in Figure 12. The number in the left hand column refers to the field map unit in which the sample is classified and the number in the second column is the sequential sample identification number for the analysis. The key to the field map units is listed below :

Map Unit	Rock Type
1.	Coarse grey granite
2.	Bobbejaankop granite
3.	Rooiberg felsite
4.	Aplite and porphyritic granite
5.	Granophyric granite
6.	Sterk River granophyre
7.	Groenfontein granophyre
8.	Feldspar porphyry
9.	Welgevonden granophyre
10.	Metasediments and Blinkwater granophyre

The empirically determined level of similarity at which the clusters or groups are taken was established at a distance coefficient of 10, and at this level fourteen clusters exist. The means and standard deviations of each variable in the clusters were calculated and summarized in Table 7. The data of the metamorphosed sediments and Blinkwater granophyre were excluded from the calculations thereby reducing the number of clusters to 13 and the number of samples in the thirteenth cluster is reduced to one, a single felsite sample.

The Bushveld granites, excluding the mineralized Bobbejaankop granite, have been essentially subdivided into six clusters, (Clusters 1 - 4, 8, 12) the latter two containing four and two samples respectively.

The Bobbejaankop granite together with five additional samples has been split up into three groups, clusters five, six and seven.

The Rooiberg felsites are subdivided into four distinct varieties, clusters nine, ten, eleven and thirteen, cluster thirteen containing only one sample excluding the two samples of metasediment and Blinkwater granophyre.

The differences between the means of the individual variables in the different clusters are frequently subtle. Standard deviations show large population overlaps of individual variables in the different clusters when each is considered separately, however, as multivariate means in sixteen-dimensional space, the differences between the individual variable means are significant.

Clusters 1-4, 8 and 12 (non-mineralized Bushveld granite)

Clusters 8 and 12 contain only four and two samples respectively and are distinguished from the remainder of the non-mineralized granites as follows :

(i) Cluster 8 is characterized by higher concentrations of Zr, Ba, Co, Ti, Sc, Ca, Li and Sr, and lower concentrations of La and Rb than clusters 1-4 on average, and

Fig. 12 : Dendogram of Trace and Minor Element data of the Acid Phase of the Bushveld Complex in the Zaaiplaats Tin-mining area.

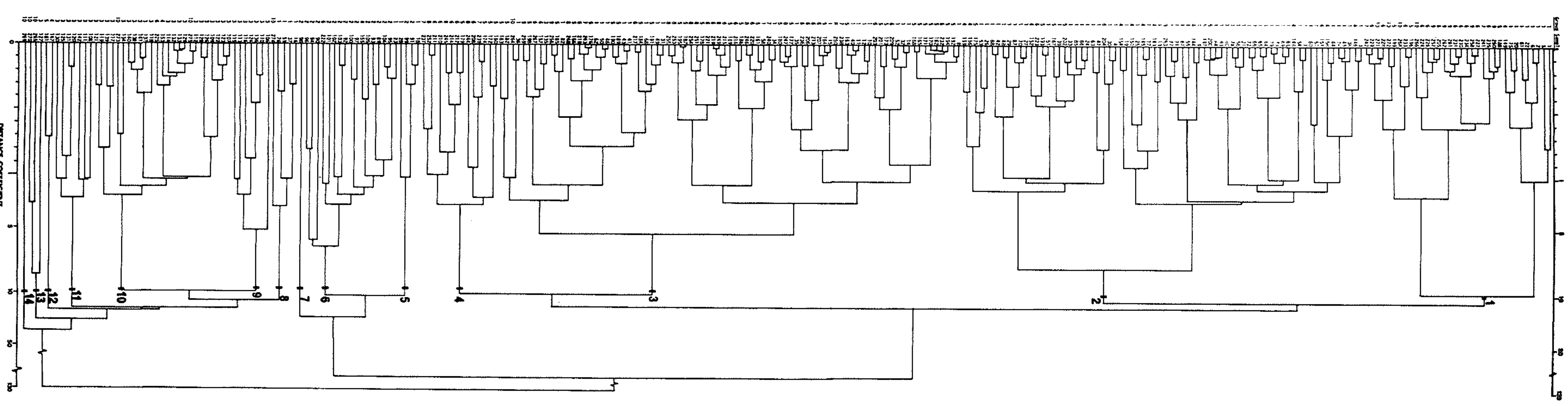


TABLE 7

Means and Standard Deviations of Measured Variables in Clustered Families of Samples of the Acid Phase of the Bushveld Complex from the Potgietersrust Tin-mining Area
(Grn. = Grain-size, Gam. = Gamma flux density, Size = Number of samples in the cluster)

MEANS

	Zr	Ba	Zn	Co	Ti	Sc	Sn	La	Ca	Li	Rb	Sr	K_2O	Na_2O	Grn.	Gam.	Size
Cluster 1	510.9	1539.3	96.5	12.1	1399.3	3.5	7.5	88.3	5117.1	34.8	197.5	54.9	4.8	3.2	13.8	26.0	31
Cluster 2	417.9	1079.8	89.6	10.5	1089.2	2.8	6.9	91.7	4949.6	36.4	211.6	34.1	4.9	3.2	20.2	31.6	72
Cluster 3	421.2	1105.5	82.4	11.1	1113.1	2.7	9.5	103.7	4998.5	29.6	231.4	25.7	4.9	2.9	5.1	31.4	81
Cluster 4	404.8	1149.2	150.3	13.5	1105.3	1.9	15.5	156.1	3702.1	38.9	267.9	16.4	4.9	2.3	2.7	31.4	14
Cluster 5	325.3	909.5	41.0	9.0	560.5	2.8	6.5	325.8	6470.3	35.8	358.0	6.8	4.9	3.1	42.0	46.5	4
Cluster 6	326.9	414.7	29.2	8.9	435.0	3.1	50.6	104.8	7315.3	35.4	423.8	6.9	4.8	3.0	29.6	48.8	17
Cluster 7	405.0	298.0	23.0	6.0	121.0	4.0	1242.0	3.0	20705.0	35.0	430.0	15.0	4.9	1.7	4.0	60.0	1
Cluster 8	626.8	2520.8	132.0	20.8	2538.0	9.0	6.5	50.0	12428.0	41.5	168.5	107.5	4.9	3.5	23.5	22.5	4
Cluster 9	377.6	1424.4	314.9	31.1	2420.1	12.0	6.3	70.9	9683.7	44.1	173.7	48.9	4.1	3.1	.1	23.7	7
Cluster 10	410.5	1468.5	119.3	23.9	2290.9	10.4	3.4	73.2	8824.0	39.9	180.5	95.0	4.8	3.1	.4	24.2	23
Cluster 11	369.4	1361.1	159.6	37.7	2585.0	8.1	18.7	69.1	2268.0	41.9	176.1	23.0	4.7	.3	.1	21.7	7
Cluster 12	385.5	843.0	93.5	8.0	987.0	3.0	5.0	95.5	6437.5	37.0	225.5	499.0	5.0	2.6	12.0	35.0	2
Cluster 13	357.0	561.0	460.0	5.0	2557.0	8.0	20.0	48.0	2101.0	44.0	16.0	90.0	0.3	0.6	0.1	20.0	1

STANDARD DEVIATIONS

Cluster 1	46.0	181.2	30.4	2.4	209.0	1.8	11.7	22.0	2152.1	7.3	23.3	20.5	.2	.2	13.9	4.2	31
Cluster 2	51.6	221.8	26.3	2.0	181.4	.8	4.6	26.3	1356.8	6.8	28.0	12.1	.2	.2	11.1	4.1	72
Cluster 3	34.0	127.0	35.3	2.4	135.6	1.0	9.2	20.7	1959.7	4.6	34.0	12.2	.1	.4	4.2	3.4	81
Cluster 4	38.3	210.4	84.0	2.8	83.4	1.0	15.5	45.2	2238.6	6.8	52.7	6.7	.2	.6	1.7	2.8	14
Cluster 5	22.8	200.0	3.7	2.4	119.8	1.3	2.6	49.7	3597.4	5.4	17.3	2.2	.1	.1	3.1	2.1	4
Cluster 6	47.5	195.3	21.2	3.7	174.5	2.2	136.0	47.2	6718.9	7.4	76.7	2.2	.2	.6	17.2	8.5	17
Cluster 7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Cluster 8	41.2	205.0	39.8	3.8	457.5	2.2	3.8	10.8	2376.7	5.7	21.0	39.1	.1	.3	2.1	3.4	4
Cluster 9	14.2	141.3	155.5	4.4	99.4	2.0	7.3	8.2	4859.0	8.0	41.0	24.3	.9	.6	0.0	2.0	7
Cluster 10	20.4	129.5	42.5	2.4	168.6	1.9	1.1	12.7	4140.7	5.6	17.9	30.5	.4	.4	1.2	1.6	23
Cluster 11	36.5	264.0	63.1	8.2	279.4	1.7	29.6	18.6	3972.6	13.4	84.5	12.8	.2	.4	0.0	2.0	7
Cluster 12	22.5	187.0	6.5	1.0	139.0	1.0	0.0	2.5	2683.5	6.0	24.5	46.0	.1	.2	8.0	3.0	2
Cluster 13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

(ii) Cluster 12 has somewhat lower concentrations of Zr, Ba, Co and Ti, and higher concentration of Sr and (Ca?) than clusters 1-4 on average.

Samples in cluster 8 are generally from the base of the Bushveld granite, close to the contact with the Mafic Phase of the Complex and their distinctive geochemistry suggests contamination from the latter.

The two samples in cluster 12 have a trace element geochemistry intermediate between mineralized Bobbejaankop granite and non-mineralized Bushveld granites but are precluded from being grouped with the former because of their higher Zn, Ti, (Li?) and Sr concentrations and lower La and Rb concentrations as well as lower gamma flux density.

The differences between the means of the individual variables in clusters 1-4 are complex. The more obvious differences between clusters 1-4 are listed below :

(i) in general there are sympathetic decreases in the Zr, Sc, Sr and Ca concentrations, and antipathetic increases in the Sn, La and Rb concentrations from clusters 1-4,

(ii) Ba and Ti are significantly enriched in cluster 1 relative to clusters 2, 3 and 4,

(iii) Zn has a significantly higher concentration in cluster 4 and decreases more gradually through clusters 1 to 3,

(iv) Li and Co decrease in concentration through clusters 4, 2, 1 and 3, and 4, 1, 3 and 2 respectively,

(v) the K_2O concentration is virtually constant in all four clusters,

(vi) the Na_2O concentration is equal in clusters 1 and 2 and from cluster 2 decreases through clusters 3 and 4,

(vii) the grain-size of samples decreases markedly through clusters 2, 1, 3 and 4 respectively, and

(viii) the gamma flux density is slightly lower in cluster 1 than in the remaining three clusters.

Clusters 5-7 (the Bobbejaankop granite and five additional samples)

Clusters 5 and 6 contain the bulk of the samples, cluster 7 contains only one sample.

There are significant, sympathetic decreases in the Ba, Zn, Co, Ti and La concentrations coupled with a decrease in grain-size, and antipathetic increases in the concentration of Sc, Sn, Ca, (Rb?), (Sr?) and gamma flux density in clusters 5 to 7.

The subdivision of the Bobbejaankop granite into three distinct varieties lends support to the tentative suggestion of strong chemical zonation within the plug as implied in the trace and minor element data of Fourie (1969). On the basis of the few data available a close positive correlation between Ca, Sc, (Rb?) and (Sr?), and a negative correlation between Ba, Zn, Co, Ti and La, and tin is suggested. These variables or any selected combination of them, which tend to be less erratically distributed in the granite, may therefore prove useful in the location and delineation of distinct ore bodies within the Bobbejaankop granite plug. This suggestion, however, remains to be verified.

Clusters 9-11 and 13 (Rooiberg felsites and one additional sample)

Cluster 10 contains 23 samples, clusters 9 and 11 contain 7 each and cluster 13 contains only 1 sample.

The single sample in cluster 13, sample K18, is completely anomalous when compared with the remaining Rooiberg felsites. Both K_2O and Na_2O concentrations are less than one per cent. In addition sample K18 is distinctly impoverished in Ba, Co, La and Rb, and enriched in Sn and Zn relative to the remainder of the Rooiberg felsites.

The variation in elemental concentrations in clusters 9 to 11 are complex, the more obvious are :

(i) Sc and Co vary antipathetically in clusters 9 to 11 with Sc becoming progressively impoverished,

(ii) Zn and Li concentrations decrease sympathetically through clusters 9, 11 and 10 respectively,

(iii) Zr, Ba, La, Sr concentrations, as well as gamma flux density, decrease sympathetically through clusters 10, 9 and 11 respectively,

(iv) Rb concentration decreases through clusters 10, 11 and 9 respectively, and

(v) Ti, Co and Sn concentrations sympathetically decrease through clusters 11, 9 and 10 respectively.

In order to ascertain whether any geographical coherence and geological significance exists in the different cluster, groups of contiguous samples belonging to the same cluster are outlined in Figure 13. A certain degree of similarity exists between the geological map in Figure 2 and the cluster map in Figure 13.

The Bobbejaankop granite consisting of clusters 5, 6 and 7 is distinctly outlined and is more-or-less located along the common boundary of clusters 2 and 3 of the non-mineralized granite.

Samples belonging to cluster 1, characterized mainly by an abnormally high Ti concentration, are distributed in ten separate groups in the map area. In the south two groups of cluster 1 substitute in part for cluster 3, immediately beneath the felsites and correspond broadly to a combination of Welgevonden and Sterk River granophyres. The remaining eight groups of samples of cluster 1 are small, composed of a maximum of two samples the larger two occurring at the base of the Makapaansberg near the contact of the Acid and Mafic Phases of the Bushveld Complex.

Samples from cluster 2 generally correspond to the coarse grey meso- to leucocratic granites and aplites and porphyritic granites along the escarpment of the Makapaansberg. Small bodies of cluster 2 at the southern tip of the Bobbejaankop granite plug are from a deeply incised valley. The remaining groups of cluster 2 consists of individual samples, probably erratics, and therefore are not significant.

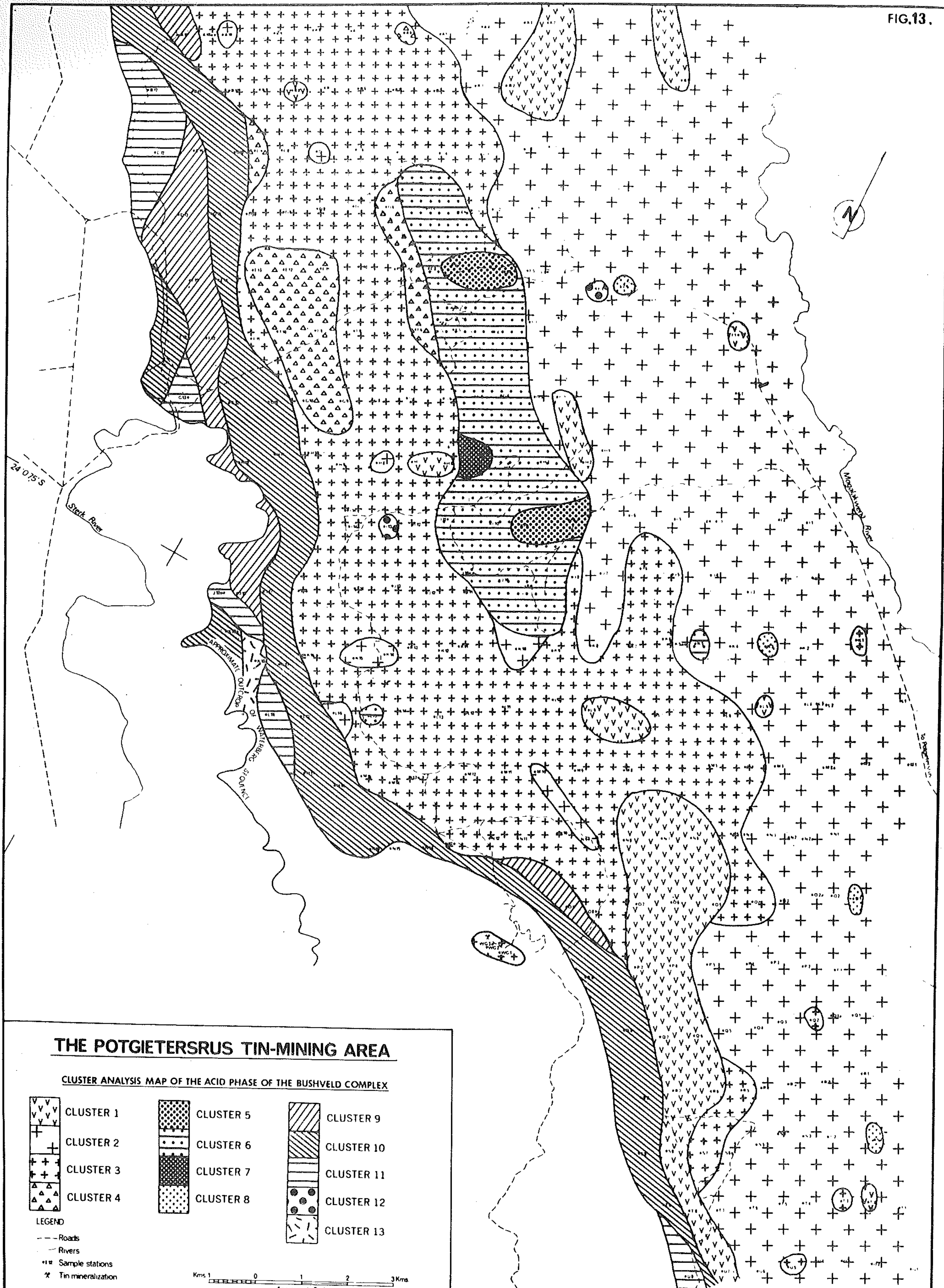
Samples from cluster 3 generally correspond to the granophyric granite, Groenfontein granophyre, Sterk River granophyre and feldspar porphyry. Cluster 3 together with cluster 4 forms a broad but relatively shallow fine-grained chill facies of the Bushveld granites beneath the Rooiberg felsites. On this basis the position of the Bobbejaankop is apparent, emplaced immediately beneath the marginal chill zone of the Bushveld granites.

The Rooiberg felsites, clusters 9, 10, 11 and 13 form a composite band along the western margins of the Bushveld granites. Cluster 10 containing the largest number of samples forms a continuous mass stretching the full length of the map area, as well as two isolated groups immediately beneath the cover of Waterberg Sequence sediments. Samples belonging to cluster 11 form four distinct geographically separate groups and those of cluster 9 form five distinct geographically separate groups.

The samples of clusters 8 and 12 always occur as individuals and can therefore be confidently regarded as erratics.

On the basis of the cluster analysis using the trace element data of the present study the following is established for the Zaaiplaats area only :

FIG.13.



1. The components of the Acid Phase of the Bushveld Complex are subdivided into three major categories viz. Rooiberg felsites, non-mineralized granites, and mineralized granites each of which is in turn subdivided into a number of chemical varieties.

2. The Rooiberg felsites are subdivided into four distinct chemical varieties.

3. The non-mineralized Bushveld granites form six distinct varieties which suggest a broad chemical fractionation from base to roof within the body.

4. The mineralized Bushveld granites are subdivided into three groups. On the limited number of samples a chemical zonation within the plug is tentatively suggested.

5. The various granophyre types identified in the field appear to be chemically indistinguishable from the unmineralized granites which corroborates the conclusions drawn from the discriminatory analysis carried out on the same data.

6. The aplites and porphyritic granites distinguished by Strauss (1954) as constituting a separate episode in the emplacement of the Bushveld granites, the Foothills granite, appear to be genetically related to the Main granite and are regarded as an auto-injection of Main granite magma into early consolidated zones.

CONCLUSIONS

The imprecisely defined and inadequate nomenclature hitherto used to subdivide the Acid Phase of the Bushveld Complex has precipitated a state of confusion in the literature primarily where granophyres are concerned. On the basis of their stratigraphic position seven granophyre types have been defined in order to systematize the nomenclature and to provide a broad framework for future work.

A pronounced chemical homogeneity, with respect to the major oxides, in all the components of the Acid Phase of the Complex is manifest. The more accurate analytical data of Fourie (1969) implies differences in the major element geochemistry between the mineralized and non-mineralized components of the Acid Phase, however this can only be regarded as a tentative conclusion until verified by more systematic data.

On the basis of trace and minor element composition the Acid Phase of the Bushveld Complex, in the Zaaiplaats area, may be subdivided into three broad components :

(i) Rooiberg felsites

(ii) non-mineralized granites and associated granophyres

(iii) mineralized granites with associated microgranite roof facies.

All the granophyres within Potgietersrust area, excluding those formed through the complete reconstitution of sediments, appear on trace element composition genetically related to the non-mineralized granites. Similarly the aplites and porphyritic granites appear to be co-genetic with the non-mineralized granites and in the light of the information now available their separation as a distinct episode in the emplacement of the Bushveld granite as the Foothills granite by Strauss (1954) appears to be unjustified. To avoid further confusion it is proposed that the term "Main", already overworked in Bushveld terminology, be replaced by Sekukuni in the designation of all non-mineralized Bushveld granites and their textural variations, while the term "Bobbejaankop" be retained for all younger, intrusive mineralized Bushveld granites.

Finally the classificatory statistical techniques of cluster and discriminatory analysis appear to have potential in the location and delimitation of mineralized granites within the framework of the Bushveld Complex and the subsequent delineation of ore zones within the mineralized granite bodies.

* * * * * * * * * * *

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APPENDIX I

Key to Source of the Published and Unpublished Full-Silicate Analyses of the Acid Phase of the Bushveld Complex presented in Appendix II
(Excluding the Data of Fourie, 1969)

	Year	Sample Number (Refer to Appendix II)
Baring Horwood, C.	1910	22.
Berning, J.	1941	103.
Bond, G.W.	1946	31, 37.
Coetzee, G.L.	1970	85-87.
Fockema, R.A.P.	1952	30.
Glatthaar, C.W.	1957	66, 67, A123.
Groeneveld, D.	1970	123-132.
Grout, F.F.	1935	11.
Hall, A.L.	1932	1, 3-9, 44, 45, 47, 76-80, 82, 118, 119.
Hammerbeck, E.C.I.	1970	38.
Liebenberg, C.J.	1961	33-35, 40, 49, 50, 63, 111, 112, 142.
Lombaard, B.V.	1931	113.
Lombaard, B.V.	1932	12-16, 71-75, 104, 105.
Lombaard, B.V.	1934	10, 39, 43, 46, 84.
Schwellnus, J.S.I.	1956	99-101, 133.
Snyman, C.P.	1958	114, 122.
Steyn, J.G.D.	1962	52, 53, 53A.
Strauss, G.A.	1947	89-91, 94, 95.
Strauss, C.A. and Truter, F.C.	1950	32, 48.
Strauss, C.A.	1954	24-29, 41, 60.
van Biljon, S.	1949	55, 56, 92, 93, 102, 108-110.
van Rooyen, D.P.	1950	61, 88.
Visser, H.N. et al	1961	23, 96, 97, 106, 107, 115-117.
von Gruenewaldt, G.	1966	42, 59, 64, 65.
von Gruenewaldt, G.	1971	138-141.
Wagner, P.A.	1927	2, 17-21, 81, 83, 134, 135.
Watson, M.D.	1967	136.
Wolhuter, L.E.	1954	70.
Handbook No. 5. Geol. Surv. S. Afr.	1964	Unpublished analyses ; 36, 51, 54, 57, 58, 62, 68, 69, 98, 120, 121.

APPENDIX 2

PUBLISHED AND UNPUBLISHED FULL SILICATE ANALYSES OF THE ACID PHASE OF THE BUSHVELD COMPLEX (EXCLUDING THE DATA OF FOURIE 1969).

KEY

BUSHVELD GRANITES
- UNDIFFERENTIATED 1-13,22,23,30-39,42,103
- GRANOPHYRIC 15,17,40,A123
- PORPHYRITIC 14
- BOBBEJAANKOP AND LEASE GRANITES 24,25
- MAIN GRANITE 27-29
- FOOTHILLS GRANITE 26
- APLITE 20
- GRANITE PORPHYRY 62
- STANNIFEROUS GREISEN 21

GRANOPHYRES
- GRANOPHYRE 16,18,19,41,43-58,53A,116,141
- MICROGRANOPHYRE 59
- PSEUDOGRANOPHYRE 60,61

FELSITES
- ROOIBERG FELSITE 63-82,84-87,108-110,130-132
- POST-WATERBERG FELSITE 104,105
- PSEUDOFELSITE 106,107
- PRE-TRANSVAAL FELSITES 111-114
- TRANSVAAL SEQUENCE FELSITES 123-125

LEPTITES
- LEPTITE 88,89,96-98,136,138,142

META-SEDIMENTS
- META-QUARTZITES 90-95,99-102,115

ANDESITES
- TRANSVAAL SEQUENCE ANDESITES 117-121,126-128

GRANOPHYRE OR GNEISS 122

DACITE PORPHYRY 133

SODA-TRACHY-ANDESITE 83

GRANODIORITE 139,140

HORNBLENDE AKERITE 134,135

HORNBLENDE MICROGRANITE(TRANSVAAL SEQUENCE) 129

SP. NO. SAMPLE NUMBER

APPENDIX 2 CONTINUED

SP. NO.	SIO2	AL2O3	FE2O3	FEO	MNO	MGO	CAO	NA2O	K2O	TIO2	P2O5	H2O	CO2	SNO2
1	75.84	11.14	4.68	0.01		0.27	1.04	2.69	3.92			0.66		
2	75.70	14.30	0.90			0.75	1.20	1.70	4.30	0.05	0.00	0.65		
3	74.10	13.25	1.75	0.75		0.15	1.10	3.40	5.00	0.20	0.00	0.60		
4	74.00	11.85		3.00	0.05	0.35	1.50	3.20	5.25	0.10	0.20	0.95		
5	76.00	11.00	0.65	3.15	0.05	0.15	1.05	3.70	3.30	0.30	0.05	0.85		
6	74.06	12.62	0.96	1.88	0.45	0.02	1.11	2.44	5.36	0.24	0.14	0.81		
7	71.80	12.94	1.25	2.96	0.26	0.06	1.64	3.28	4.28	0.39	0.08	0.75		
8	71.90	14.00		3.45	0.05	0.20	1.15	4.60	3.40	0.20	0.05	0.90		
9	71.25	12.30	0.70	4.70	0.10	0.20	1.50	4.35	3.25	0.45	0.10	1.00		
10	75.80	13.30	0.50	1.60		0.20	1.30	2.40	3.90	0.15	0.05	0.85		
11	79.58	8.91	0.52	2.26	0.05	0.17	0.69	2.48	3.89	0.23	0.29	0.41	0.04	
12	75.76	11.50	1.28	1.01	0.02	0.12	1.12	3.40	4.81	0.34	0.09	0.86		
13	75.69	10.75	1.31	1.54	0.02	0.20	1.25	3.55	5.12	0.17	0.12	0.61		
14	71.97	13.56	0.38	1.92	0.05	0.72	0.74	4.75	4.30	0.60	0.07	0.84		
15	74.00	11.39	1.99	1.26	0.04	0.15	0.91	3.48	5.45	0.47	0.13	0.59	0.25	
16	75.54	11.24	2.31	0.77	0.01	0.04	0.19	2.75	6.47	0.47	0.15	0.74		
17	70.65	10.40	3.65	3.45		0.40	2.15	2.40	5.20	0.20		0.62		
18	70.40	12.50	2.75	3.75		0.05	1.45	2.73	4.78	0.35		1.02		
19	69.20	12.30	3.30	3.60		0.20	1.30	3.25	4.95	0.65		1.00		
20	75.50	11.55	1.85	0.55		0.12	0.25	2.00	6.60	0.35	0.00	0.80		
21	31.20	6.65				0.60	0.65	0.25	1.40			1.29		54.65
22	80.00	10.87	2.57	0.00	0.00	0.79	1.05	2.51	2.05		0.00			
23	75.04	12.76	1.16	0.79	0.02	0.40	1.32	2.40	4.70	0.20	0.01	1.06		
24	72.56	13.36	0.95	1.87	0.05	0.61	1.63	3.22	5.05	0.00	0.89			
25	72.67	13.16	0.80	1.44	0.05	0.79	2.13	3.09	4.37	0.00	0.00	0.94		
26	75.42	11.80	1.27	1.44	0.06	0.53	0.84	3.08	4.80	0.24	0.03	0.79	0.13	
27	73.30	12.18	1.75	1.87	0.06	0.51	1.57	3.14	5.00	0.21		0.70	0.02	
28	73.48	12.36	1.75	1.58		0.56	1.18	3.22	5.09	0.21	0.00	0.60	0.10	
29	73.68	12.92	1.59	1.44	0.06	0.69	0.90	3.00	5.00	0.25	0.03	0.88	0.10	
30	72.06	12.90	1.91	1.65	0.02	0.72	0.58	3.11	4.98	0.25	0.06	1.18	0.36	
31	73.00	13.78		3.52	0.00	0.40	0.96	3.91	3.09	0.10		0.15	0.52	
32	71.40	12.38	3.83	1.15	0.08	0.16	0.77	4.46	4.28	0.25	0.05	0.74		
33	72.80	12.57	1.29	3.18		0.26	1.67	3.20	4.40	0.40		0.40		
34	75.60	11.54	0.85	1.85		0.30	1.13	3.20	4.50	0.24		1.08		
35	74.36	12.21	1.08	1.62		0.55	0.83	3.20	4.88	0.18		0.77		
36	63.33	14.55	2.77	6.28	0.18	0.45	3.16	3.80	3.92	0.77	0.09	0.83		
37	72.40	14.40		2.40	0.00	0.72	2.00	3.30	4.00	0.16		0.38		

APPENDIX 2 CONTINUED

SP. NO.	SIO2	AL2O3	FE2O3	FEO	MNO	MGO	CAO	NA2O	K2O	TIO2	P2O5	H2O	CO2	SNO2
38	73.70	11.63	1.59	3.45	0.09	0.18	1.12	2.80	4.40	0.35	0.10	0.44		
39	67.83	11.10	5.24	4.20	0.08	0.30	1.83	2.80	4.90	0.45	0.10	0.85		
40	75.00	12.10	3.75	0.10		0.15	0.27	2.81	5.03	0.25		0.74		
41	73.45	11.92	2.39	1.01	0.08	0.52	0.62	3.17	4.81	0.43	0.00	0.85	0.39	
42	70.46	12.51	1.85	3.92	0.10	0.10	1.88	3.42	4.18	0.37		0.76		
43	70.12	11.50	3.90	3.64	0.07	0.20	1.60	3.70	3.74	0.45	0.10	0.90		
44	74.20	11.35	2.05	1.85		0.20	1.65	3.00	5.15	0.15	0.20	0.80	0.05	
45	73.70	12.15	1.30	3.45		0.35	0.55	2.70	3.80	0.20	0.10	1.40		
46	74.15	12.61	0.90	2.39	0.32	0.03	0.82	2.87	4.86	0.37	0.14	0.57		
47	74.31	12.30	0.58	2.45	0.35	0.16	1.67	3.13	3.87	0.34	0.07	0.90		
48	72.50	12.10	2.60	0.00	0.09	0.30	2.10	4.60	4.20	0.10	0.60	0.46		
49	72.50	11.62	2.12	3.26		0.27	1.27	3.19	4.38	0.39		0.80		
50	75.30	10.81	1.70	2.21		0.08	1.15	3.28	4.83	0.21		0.56		
51	74.21	12.15	2.15	1.37	0.04	0.39	1.04	2.95	4.75	0.26	0.06	1.05		
52	59.83	17.81	2.10	5.68	0.19	0.19	2.36	7.40	0.48	0.49	0.11	2.69	0.77	
53A	34.19	19.89	7.90	24.81	0.41	0.56	0.20	0.18	3.40	0.38	0.05	8.36		
53	74.21	11.11	1.21	3.59	0.17	0.14	1.32	4.70	0.42	0.36	0.08	1.90	0.67	
54	70.50	12.60	2.80	2.60	0.20	0.60	1.70	3.10	4.80	0.30		0.90		
55	68.85	11.99	5.05	2.24	0.25	0.43	0.66	2.94	4.67	0.44	0.10	2.01		
56	67.66	11.89	4.52	4.07	0.06	1.64	0.60	3.27	3.39	0.60	0.17	2.00		
57	73.07	11.24	1.75	2.08	0.03	0.69	1.28	1.99	6.81	0.21	0.08	0.76		
58	72.03	9.96	2.87	2.36	0.01	0.98	1.93	3.63	4.72	0.34	0.12	0.86		
59	68.34	12.52	3.74	3.49	0.14	0.42	2.24	3.51	3.92	0.45		0.75	0.15	
60	72.83	12.01	1.43	2.16	0.07	0.40	0.95	3.04	5.01	0.43	0.00	0.87	0.35	
61	78.70	9.20	2.20	0.60	0.06	0.80	0.70	0.50	4.60	0.50	0.00	1.65		
62	72.68	10.11	1.76	3.02	0.38	0.36	2.50	2.04	4.60	0.40	0.44	1.20	0.18	
63	68.00	10.87	2.41	2.71		0.42	3.86	2.47	4.03	0.40		4.28		
64	68.21	12.63	3.14	3.97	0.13	0.40	2.92	3.03	4.33	0.53	0.18	0.30		
65	69.58	12.41	2.22	4.31	0.11	0.34	2.58	3.23	3.78	0.48		0.47		
66	72.80	11.84	1.93	0.57	0.12	0.13	2.46	1.00	5.40	0.35	0.05	2.24	1.56	
67	77.24	11.86	4.44	0.57	0.00	0.13	0.44	0.35	2.95	0.30	0.05	2.14	0.00	
68	74.35	11.23	0.72	2.50	0.02	0.78	1.26	3.38	4.40	0.09	0.10	0.99		
69	72.44	11.72	1.83	1.93	0.04	0.96	1.40	4.11	4.00	0.00	0.20	0.83		
70	73.84	9.56	2.06	2.87	0.23	0.47	2.02	2.03	4.70	0.35	0.25	1.18	0.01	
71	72.81	11.97	2.79	2.63	0.17	0.00	0.06	3.34	5.31	0.68	0.15	0.73		
72	74.58	11.11	2.55	1.69	0.10	0.00	0.06	4.46	4.76	0.50	0.00	0.61		
73	67.77	12.60	4.44	3.00	0.14	0.12	1.72	5.16	3.82	1.15	0.12	0.44		

APPENDIX 2 CONTINUED

SP. NO.	SIO2	AL2O3	FE2O3	FEO	MNO	MGO	CAO	NA2O	K2O	TIO2	P2O5	H2O	CO2	SNO2
74	70.19	12.05	3.65	3.20	0.13	0.12	4.07	5.02	0.70	0.13	0.36			
75	72.03	11.30	1.37	3.78	0.09	0.05	0.81	5.09	4.50	0.63	0.08	0.74		
76	72.50	12.40	3.35	2.15		0.25	0.50	2.80	4.70	0.20	0.10	0.95		
77	71.33	13.26	0.24	4.62	0.19	0.05	1.45	3.26	3.88	0.39	0.13	1.32		
78	74.00	12.45	0.47	1.88	0.17	0.37	0.99	3.09	4.93	0.48	0.09	0.52		
79	68.25	11.15	1.95	6.50		0.50	3.40	3.00	4.05	0.50	0.35	0.10	0.00	
80	71.35	10.15	3.10	4.70		0.30	2.90	3.20	3.90	0.30		0.60	0.00	
81	73.85	11.85	1.20	2.60		2.35	1.00	2.80	2.10	0.25	0.10	1.55	0.50	
82	74.05	11.70	0.80	2.70		1.95	1.05	2.45	2.55	0.25	0.10	1.50	0.60	
83	56.85	14.20	1.90	7.35	0.15	6.09	3.50	6.00	0.50	0.75	0.05	2.35		
84	72.60	11.90	3.05	2.30		0.40	1.60	3.05	3.65	0.30	0.10	0.80		
85	75.17	12.83	2.32		0.10	0.79	0.40	0.44	6.31	0.08	0.00	1.56		
86	69.16	11.75	7.17		0.16	0.64	1.31	1.81	6.31	0.32	0.03	1.35		
87	77.71	11.33	4.64		0.08	0.65	0.02	0.03	3.63	0.25	0.00	1.68		
88	71.72	10.27	4.15	1.30	0.05	0.94	0.95	2.87	5.00	0.16	0.07	1.12	0.69	
89	76.14	12.36	1.32	0.43		0.49	0.23	1.59	5.67	0.27	0.00	0.67	0.53	
90	68.80	16.47	1.33	0.85		0.69	0.82	4.48	3.78	0.34	0.24	1.39	0.53	
91	73.08	14.29	0.82	0.28		0.30	0.60	3.46	5.73	0.48	0.23	0.55	0.35	
92	92.73	4.16	0.12	0.30		0.02	0.27	1.54	0.74			0.39		
93	79.25	10.97	0.40	1.05		0.23	0.09	1.90	5.80			0.55		
94	89.01	6.22	0.56	0.07		0.50	0.39	2.73	0.25			0.25		
95	81.89	10.64	0.56	0.07		0.64	0.39	4.81	0.37			0.43		
96	70.94	11.23	1.76	2.87	0.09	2.32	2.36	2.35	3.91	0.32	0.04	1.38	0.35	
97	74.90	10.94	1.75	1.15	0.04	1.92	0.52	2.04	4.31	0.25	0.04	1.74	0.07	
98	78.32	10.11	2.11	0.50	0.02	0.45		0.40	6.94	0.20	0.10	0.35		
99	93.34	3.23	1.04	0.50	0.01	0.25		0.35	0.91	0.20	0.07	0.54		
100	89.06	4.75	1.09	0.50	0.01	0.33		0.35	2.52	0.20	0.08	0.61		
101	86.50	5.82	1.35	0.50	0.01	0.36	0.06	0.36	3.22	0.50	0.10	0.72		
102	77.04	12.59	0.03	0.39	0.39	0.03	0.51	2.43	5.83	0.09	0.12	0.64		
103	62.70	13.35	2.25	7.70	0.10	0.35	3.60	3.65	3.65	0.75	0.15	0.95		
104	77.78	8.81	1.12	1.26	0.06	2.78	0.37	2.57	3.48	0.52	0.29	1.19		
105	75.13	9.96	1.14	1.72	0.08	2.20	1.08	1.89	3.57	0.20	0.12	2.03	1.22	
106	78.88	9.74	1.51	0.79	0.04	1.06	0.20	2.05	4.00	0.22	0.03	1.02	0.07	
107	73.51	11.26	1.28	2.59	0.08	1.58	1.94	2.02	3.89	0.28	0.28	1.26	0.07	
108	77.00	10.50	4.20	0.30	0.03	1.20	0.50	0.20	1.80	0.26	0.06	2.60		
109	77.05	10.12	0.64	1.44	0.07	2.17	1.74	1.12	3.97	0.55		1.07	0.29	
110	72.66	10.20	0.80	2.73	0.07	2.53	3.03	1.76	3.45	0.45	0.12	1.28	0.54	

APPENDIX 2 CONTINUED

SP. NO.	SIO2	AL2O3	FE2O3	FEO	MNO	MGO	CAO	NA2O	K2O	TIO2	P2O5	H2O	CO2	SNO2
111	74.00	12.08	0.68	1.97		0.47	1.05	2.66	5.78	0.44		0.91		
112	75.50	11.35	0.88	2.07		0.38	0.68	1.90	6.05	0.43		0.71		
113	72.75	11.45	0.80	3.60	0.05	0.40	0.70	1.50	6.90	0.35	0.10	1.65	0.30	
114	70.92	12.41	1.27	2.44	0.17	0.59	1.94	3.15	4.60	0.55	0.05	1.02	0.75	
115	87.99	5.63	0.72	0.36	0.03	0.29	0.04	0.30	3.25	0.15	0.04	0.82	0.14	
116	70.62	11.75	2.80	2.80	0.08	1.19	2.00	2.41	4.00	0.60	0.04	0.99	0.42	
117	54.13	13.15	4.24	6.18	0.47	5.43	6.76	2.40	1.75	0.88	0.41	2.98	1.15	
118	59.15	14.80	0.40	8.30		4.25	6.75	2.65	0.85	0.65	0.20	1.65	0.20	
119	52.40	16.35	0.65	8.95		5.45	8.25	2.05	1.00	0.60	0.15	4.00	0.30	
120	54.35	14.38	0.88	9.14	0.19	6.40	7.53	2.31	2.12	0.59		2.33		
121	55.96	12.55	1.08	9.75	0.14	5.54	4.78	4.30	0.88	0.92		2.73	1.18	
122	71.25	12.31	2.39	2.16	0.17	0.69	1.83	3.15	4.90	0.55	0.07	0.44	0.13	
A123	72.44	11.76	5.60	0.14	0.52	0.04	1.30	2.55	4.85	0.08	0.17	1.16		
123	65.17	13.18	2.15	4.63	0.14	2.17	4.00	3.02	2.64	0.65	0.12	2.00		
124	66.36	11.43	2.20	7.33	0.06	1.53	2.88	3.00	2.94	0.64	0.19	1.46		
125	66.75	11.82	2.54	6.38	0.06	1.29	3.26	2.84	2.88	0.80	0.19	1.22		
126	56.78	14.81	1.73	7.35	0.16	5.09	7.29	2.77	1.88	0.57	0.13	1.67		
127	54.78	14.61	1.59	7.90	0.15	6.88	8.17	2.70	1.05	0.63	0.11	1.86		
128	50.52	15.60	2.70	7.73	0.22	7.41	12.41	2.41	0.28	0.42	0.02	0.49		
129	65.11	11.00	2.37	8.24	0.08	1.06	3.79	3.05	3.00	0.92	0.29	1.12		
130	66.13	10.69	2.52	8.69	0.09	0.35	2.10	0.92	4.58	0.60	0.18	0.70		
131	67.93	10.73	3.01	7.09	0.09	0.45	2.20	2.97	4.14	0.62	0.15	0.61		
132	69.20	11.79	2.35	3.79	0.18	0.71	1.71	2.94	4.95	0.60	0.14	1.40		
133	64.41	13.59	0.97	6.68	0.13	2.18	2.06	3.86	2.51	0.85	0.13	1.34		
134	62.60	17.95	0.65	3.45	0.10	1.10	3.40	0.20	1.65	0.26	0.20	0.60		
135	53.45	16.80	2.25	7.65	0.10	2.35	5.70	6.20	1.75	1.60	0.80	1.25		
136	72.54	12.69	0.96	0.43	0.02	0.96	2.91	3.50	3.02	0.39	0.12	0.44	1.04	
138	70.49	11.96	1.91	4.54	0.13	0.10	2.24	2.69	4.14	0.55		0.51		
139	68.22	12.50	1.41	5.98	0.17	0.13	2.90	3.84	3.74	0.66		0.56		
140	66.43	13.17	1.70	5.74	0.22	0.15	2.45	4.04	3.92	0.90		1.15		
141	74.09	11.64	1.65	2.02	0.14	0.06	0.80	3.05	5.07	0.39		0.81		
142	69.00	12.17	3.35	3.80	0.11	0.68	2.11	3.53	4.30	0.40	1.39	0.83		

APPENDIX 3

FULL SILICATE ANALYSES OF THE ACID PHASE OF THE BUSHVELD COMPLEX

(DATA OF FOURIE 1969).

KEY

BUSHVELD GRANITES
- MAIN GRANITE 1-7
- BOBBEJAANKOP GRANITE 8-12
- LEASE GRANITE 13-24
- FOOTHILLS GRANITE 25
- BUSHVELD GRANITE (BRITS) 26
- BUSHVELD GRANITE (NYLSTROOM) 27,28
- BUSHVELD GRANITE (BRONKHORSTSPRUIT) 29
- BUSHVELD GRANITE (ROOIBERG) 30-34
- BUSHVELD GRANITE (RUST DER WINTER) 35

GRANOPHYRES
- GRANOPHYRE (LYDENBERG) 36
- GRANOPHYRE (MIDDELBURG) 37,38
- GRANOPHYRE (POTGIETERSRUST) 39
- GRANOPHYRE (BRONKHORSTSPRUIT) 40-49
- GRANOPHYRE (ROOIBERG) 50-52
- GRANOPHYRE (PRETORIA) 53,54

ROOIBERG FELSITES
- ROOIBERG FELSITE (NYLSTROOM) 55-57
- ROOIBERG FELSITE (POTGIETERSRUST) 58-62
- ROOIBERG FELSITE (ROOIBERG) 63
- ROOIBERG FELSITE (RUST DER WINTER) 64

LEPTITES
- LEPTITE (LYDENBERG) 65
- LEPTITE (MIDDELBERG) 66,67
- LEPTITE (PRETORIA) 68

PORPHYRIES
- GRANITE PORPHYRY (POTGIETERSRUST) 69
- GRANITE PORPHYRY (BRONKHORSTSPRUIT) 70
- QUARTZ PORPHYRY (NYLSTROOM) 71,72
- GRANOPHYRIC GRANITE PORPHYRY (RUST DER WINTER) 73

GRANODIORITE
- GRANODIORITE (PRETORIA) 74

QUARTZ ANDESITES
- QUARTZ ANDESITE (BRONKHORSTSPRUIT) 75,76

SP NO = SAMPLE NUMBER

SP NA = SAMPLE NAME

APPENDIX 3 CONTINUED

SP NO	SP NA	SIO2	AL2O3	FE2O3	FEO	MGO	CAO	NA2O	K2O	TIO2	P2O5
1	GV4	76.0	12.2	2.3	1.7	.2	.4	2.7	4.9	.1	.0
2	GV9	75.8	12.5	2.6	.5	.2	.1	2.6	5.3	.2	.0
3	PA5	75.9	11.1	2.4	1.2	.1	.4	2.7	4.7	.2	.0
4	GF3	75.9	12.5	1.5	.7	.2	.7	3.3	4.9	.1	.0
5	Z3	75.8	11.2	1.5	1.2	.2	.9	3.1	4.7	.1	.0
6	ST2	75.9	12.3	1.5	1.2	.0	.7	2.7	4.9	.1	.0
7	ST3	76.2	11.1	2.0	1.2	.2	.7	2.4	5.2	.1	.0
8	GV2	76.7	11.3	1.4	1.4	.1	.8	2.8	4.8	.0	.0
9	GV5	75.7	12.5	.7	1.6	.1	1.2	2.7	5.0	.1	.0
10	PA1	76.0	12.0	2.7	.7	.2	1.2	3.0	4.9	.0	.0
11	GF1	77.4	11.5	1.9	.3	.1	1.1	3.5	4.9	.0	.0
12	Z1	75.9	12.5	.6	1.5	.2	1.0	3.2	4.9	.0	.0
13	GV3	75.8	13.6	1.1	.1	.1	.8	2.7	5.2	.0	.0
14	GV6	74.2	12.4	4.9	1.8	.2	.6	1.4	4.9	.0	.0
15	GV7	75.5	12.7	1.3	1.1	.2	1.1	2.9	4.8	.0	.0
16	GV8	74.3	12.5	1.2	2.0	.3	2.1	3.7	3.8	.0	.0
17	PA2	79.0	12.9	.1	.1	.0	.2	2.8	4.7	.0	.0
18	PA3	76.9	13.0	.6	.2	.0	.1	3.4	4.8	.0	.0
19	PA4	75.4	12.7	1.4	.7	.2	1.6	2.5	4.6	.0	.0
20	ST4	75.8	12.9	.0	.1	.3	2.2	3.0	4.7	.0	.0
21	ST5	77.0	12.6	.9	.1	.2	1.1	2.8	4.9	.0	.0
22	ST6	75.6	12.4	1.5	1.0	.1	1.3	2.9	4.8	.0	.0
23	GF2	76.8	12.8	1.0	.8	.2	.5	2.4	4.9	.0	.0
24	Z2	76.0	12.9	.8	1.2	.2	1.0	2.7	5.0	.0	.0
25	GV1	76.2	12.5	1.3	1.2	.1	.7	3.2	4.9	.1	.0
26	PRET5A	72.7	12.8	1.1	2.9	.2	1.4	3.6	4.9	.4	.0
27	N1	76.9	11.3	1.5	.7	.1	.5	2.5	5.4	.1	.0
28	N2	77.1	12.3	2.4	.7	.4	.0	.1	6.8	.1	.0
29	A10	76.9	12.3	.9	1.2	.0	.5	3.1	4.7	.1	.0
30	R2	74.7	13.2	1.5	.1	.1	.7	3.2	5.9	.0	.0
31	R4	75.6	12.6	2.0	1.6	.1	.3	2.8	4.6	.1	.0
32	R6A	75.9	12.2	.9	1.5	.2	.5	2.7	5.2	.1	.0
33	R6B	75.6	12.0	.8	1.6	.2	.7	3.4	5.2	.1	.0
34	R6C	75.7	12.5	.9	1.5	.1	.5	2.8	5.1	.1	.0
35	RDEW3	75.9	11.7	2.1	1.6	.1	.4	3.5	5.0	.2	.0
36	8GRAN	74.7	12.1	1.2	2.5	.1	1.0	3.2	4.7	.2	.0
37	12FYNGRAN	69.9	12.3	3.5	3.2	.5	2.0	3.0	4.0	.5	.1
38	D17	70.0	12.6	2.6	3.8	.3	1.9	3.0	4.2	.3	.0

APPENDIX 3 CONTINUED

SP NO	SP NA	SIO2	AL2O3	FE2O3	FEO	MGO	CAO	NA2O	K2O	TIO2	P2O5
39	ST1	75.5	12.5	2.2	1.2	.1	.3	3.4	5.0	.2	.0
40	A1	68.5	12.9	2.8	4.0	.5	2.0	4.6	2.9	.7	.1
41	A2	68.6	12.8	2.7	3.2	.5	2.2	4.7	3.1	.7	.1
42	A3	71.0	12.5	2.1	2.6	.5	2.1	4.0	3.2	.7	.1
43	A4Z	71.4	12.5	2.3	2.4	.5	1.8	5.1	3.3	.6	.1
44	A5	71.1	11.4	2.6	2.7	.7	2.5	3.8	3.2	.6	.1
45	A6	69.8	12.7	2.2	3.8	.7	2.6	3.5	3.1	.6	.1
46	A7X	70.1	11.4	2.5	3.1	.5	2.7	4.2	3.3	.5	.1
47	A7Y	70.4	12.7	1.1	3.5	.5	2.0	3.5	3.2	.5	.1
48	A7Z	69.5	11.4	1.9	4.0	4.5	2.8	4.0	2.7	.6	.1
49	A9	72.3	12.6	2.5	2.2	.1	1.2	3.7	4.1	.4	.0
50	R1	73.4	11.1	2.1	3.2	.3	1.4	3.2	5.0	.3	.0
51	R5X	71.9	12.4	2.4	3.1	.3	1.5	2.9	4.7	.3	.0
52	R5Y	73.8	12.3	.9	2.7	.2	1.1	1.6	5.3	.2	.0
53	PRET1	74.3	12.6	1.6	1.9	.1	.6	3.9	5.2	.0	.3
54	PRET2	74.3	12.0	.9	2.2	.1	.8	4.2	4.8	.2	.0
55	N3	71.6	12.2	1.5	5.7	.4	.2	.1	6.4	.5	.0
56	N4	75.8	12.6	1.4	2.6	.2	.0	1.4	5.0	.3	.0
57	N6	76.9	12.5	2.4	.7	.3	.0	.0	5.7	.3	.0
58	GV10	71.9	12.5	4.0	2.6	.5	.3	3.4	3.5	.3	.0
59	ST9	72.2	11.2	2.5	3.8	.2	1.8	3.8	4.4	.3	.0
60	ST10	71.4	12.5	4.7	1.9	.2	1.0	3.9	4.2	.3	.0
61	ST11	71.9	10.9	4.1	2.7	.4	.7	2.8	4.4	.3	.0
62	ST12	74.5	12.8	6.3	.5	.3	.0	.0	4.1	.3	.0
63	R3	70.8	12.0	5.9	3.8	.4	.1	.2	5.4	.2	.0
64	RDEW2	76.0	12.7	2.3	1.9	.3	.1	.1	6.6	.2	.0
65	1LEPTIET	73.6	12.4	1.0	3.0	.2	1.6	3.8	4.4	.2	.0
66	13LEPTIET	68.2	12.4	4.0	3.5	.4	2.5	3.7	4.0	.5	.1
67	WV31	69.6	12.3	3.6	3.3	.5	2.4	3.8	3.3	.5	.1
68	PRET3	72.6	12.5	2.3	3.1	.2	1.5	3.5	4.6	.3	.0
69	ST8	76.4	12.4	1.9	1.0	.2	.3	2.8	4.7	.2	.0
70	A8	74.8	12.7	1.0	2.1	.2	1.6	2.1	4.9	.3	.0
71	N7	76.3	12.4	2.7	.1	.2	.4	3.0	4.0	.1	.0
72	N5	76.7	12.5	1.9	.3	.2	.1	1.9	5.2	.0	.0
73	RDEW1	73.8	12.1	.8	2.7	.2	.3	2.0	6.0	.1	.0
74	PRET4A	64.0	12.4	3.6	6.3	.4	2.8	3.8	3.3	.8	.1
75	A4X	64.0	13.3	3.8	3.8	2.4	6.2	4.0	1.9	.7	.1
76	A4Y	68.7	13.2	3.3	3.3	1.7	5.1	2.2	2.7	.7	.1

APPENDIX 4

TRACE AND MINOR ELEMENT ANALYSES OF THE ACID PHASE OF THE BUSHVELD COMPLEX (DATA OF FOURIE 1969).

KEY

BUSHVELD GRANITES
- MAIN GRANITE 1-7
- BOBBEJAANKOP GRANITE 8-12
- LEASE GRANITE 13-24.
- FOOTHILLS GRANITE 25
- BUSHVELD GRANITE (BRITS) 26
- BUSHVELD GRANITE (NYLSTROOM) 27,28
- BUSHVELD GRANITE (BRONKHORSTSPRUIT) 29
- BUSHVELD GRANITE (ROOIBERG) 30-34
- BUSHVELD GRANITE (RUST DER WINTER) 35

GRANOPHYRES
- GRANOPHYRE (LYDENBERG) 36
- GRANOPHYRE (MIDDELBURG) 37,38
- GRANOPHYRE (POTGIETERSRUST) 39
- GRANOPHYRE (BRONKHORSTSPRUIT) 40-49
- GRANOPHYRE (ROOIBERG) 50-52
- GRANOPHYRE (PRETORIA) 53,54

ROOIBERG FELSITES
- ROOIBERG FELSITE (NYLSTROOM) 55-57
- ROOIBERG FELSITE (POTGIETERSRUST) 58-62
- ROOIBERG FELSITE (ROOIBERG) 63
- ROOIBERG FELSITE (RUST DER WINTER) 64

LEPTITES
- LEPTITE (LYDENBERG) 65
- LEPTITE (MIDDELBERG) 66,67
- LEPTITE (PRETORIA) 68

PORPHYRIES
- GRANITE PORPHYRY (POTGIETERSRUST) 69
- GRANITE PORPHYRY (BRONKHORSTSPRUIT) 70
- QUARTZ PORPHYRY (NYLSTROOM) 71,72
- GRANOPHYRIC GRANITE PORPHYRY (RUST DER WINTER) 73

GRANODIORITE
- GRANODIORITE (PRETORIA) 74

QUARTZ ANDESITES
- QUARTZ ANDESITE (BRONKHORSTSPRUIT) 75,76

SP NO = SAMPLE NUMBER

SP NA = SAMPLE NAME

APPENDIX 4 CONTINUED

SP NO	SP NA	BA	CE	CO	CS	DY	EU	HF	LA	LU	MN	NB	RB	SC	SM	SN	SR	TH	YB	ZN	ZR
1	GV4	653.0	141.0	1.6	2.0	6.8	2.3	7.3	81.0	.6	610.0	25.	311.	1.3	13.3	32.0	15.0	24.3	3.0	139.	361.
2	GV9	889.0	154.0	1.7	1.5	7.6	2.1	5.1	75.0	.7	229.0	22.	313.	1.4	20.4	18.0	14.0	22.3	1.6	80.	339.
3	PA5	553.0	174.0	1.1	5.7	6.0	1.4	4.5	99.0	.7	427.0	21.	304.	1.3	15.1	18.0	15.0	24.0	2.0	149.	332.
4	GF3	676.0	120.0	1.1	1.5	5.6	1.3	6.3	85.0	.5	461.0	23.	307.	.7	13.5	32.0	22.0	16.8	2.4	68.	336.
5	Z3	654.0	115.0	1.6	3.2	6.8	1.7	5.9	85.0	.5	396.0	21.	242.	.7	11.6	14.0	18.0	16.1	2.5	78.	328.
6	ST2	775.0	139.0	1.1	2.1	7.8	1.7	6.0	75.0	.6	366.0	24.	281.	1.0	15.7	18.0	22.0	27.4	3.0	73.	348.
7	ST3	851.0	131.0	1.8	2.9	5.2	2.1	7.6	83.0	.4	341.0	22.	272.	1.5	12.9	21.0	24.0	26.3	2.0	131.	383.
8	GV2	379.0	189.0	1.5	5.1	9.7	.2	10.1	96.0	1.0	290.0	39.	433.	1.3	18.0	40.0	6.0	41.8	4.5	84.	224.
9	GV5	503.0	164.0	.7	2.4	11.0	.3	6.0	133.0	1.1	284.0	33.	513.	1.1	20.5	25.0	5.0	37.4	5.0	80.	195.
10	PA1	542.0	224.0	2.5	5.3	11.9	.2	7.8	110.0	1.2	238.0	33.	413.	1.1	17.8	29.0	4.0	41.8	5.5	62.	217.
11	GF1	210.0	103.0	2.0	3.3	13.2	.5	7.0	96.0	1.0	143.0	33.	477.	.9	16.3	22.0		43.0	5.0	37.	200.
12	Z1	319.0	119.0	1.1	9.6	9.0	.1	9.3	70.0	1.2	265.0	39.	609.	.9	12.9	94.0	9.0	39.3	6.3	60.	215.
13	GV3	278.0	130.0	.7	5.2	6.0	.0	9.0	85.0	.5	.0	60.	603.	1.6	9.4	15.0	1.0	58.5	3.0	49.	224.
14	GV6	190.0	120.0	1.0	12.0	3.6	.0	6.2	70.0	.4	568.0	41.	781.	1.2	15.1	7.0	4.0	56.0	2.0	88.	308.
15	GV7	475.0	215.0	1.3	13.5	13.1	.5	10.0	133.0	1.4	691.0	46.	689.	1.7	23.0	18.0	1.0	50.0	5.1	102.	306.
16	GV8	389.0	184.0	.7	17.0	9.8	.2	10.0	141.0	.8	727.0	64.	513.	1.7	28.3	15.0	4.0	56.0	5.0	119.	279.
17	PA2	174.0	100.0	.6	3.3	6.6	.1	8.0	44.0	.6	400.0	51.	363.	1.3	8.5	5.0	6.0	59.0	2.5	21.	268.
18	PA3	275.0	120.0	.7	2.4	9.3	.2	8.0	46.0	1.0	107.0	58.	382.	1.6	8.0	12.0	6.0	69.8	4.2		304.
19	PA4	361.0	120.0	.5	3.4	9.4	.0	8.5	55.0	.9	502.0	54.	433.	2.1	9.9	55.0	11.0	38.9	4.0	68.	234.
20	ST4	418.0	97.0	.6	2.9	9.0	.5	8.0	96.0	1.0	345.0	57.	470.	1.6	9.2	180.0	14.0	42.1	3.0	31.	270.
21	ST5	316.0	107.0	2.4	4.8	8.2	.3	9.5	103.0	.8	121.0	57.	589.	1.8	11.4	113.0	8.0	50.0	3.5	25.	315.
22	ST6	274.0	157.0	.3	3.8	11.6	.5	9.2	94.0	1.0	236.0	42.	555.	1.5	15.9	13.0	5.0	45.0	4.0	80.	340.
23	GF2	317.0	117.0	.5	8.9	9.9	.7	7.0	87.0	.8	357.0	52.	538.	1.5	10.8	37.0	3.0	48.0	3.0	43.	283.
24	Z2	332.0	136.0	.8	4.9	7.7	.1	11.7	110.0	1.0	272.0	53.	531.	1.5	11.0	22.0	4.0	65.2	5.0	43.	306.
25	GV1	470.0	166.0	.9	4.2	13.5	1.0	5.8	87.0	.9	410.0	25.	302.	1.1	17.4	19.0	13.0	30.9	4.0	104.	252.
26	PRET5A	1346.0	103.0	3.3	1.1	4.4	2.7	6.3	59.0	.5	536.0	15.	129.	4.0	10.5		96.0	14.3	2.0	71.	413.
27	N1	441.0	206.0	1.9	3.0	12.2	.3	4.4	106.0	1.5	186.0	32.	344.	2.4	27.0	4.0	29.0	30.0	6.5	15.	201.
28	N2	727.0	99.0	1.8	4.0	3.8	.4	5.2	43.0	.5	517.0	22.	502.	.9	6.0	19.0	16.0	29.2	2.3	73.	282.
29	A10	590.0	115.0	.1	2.7	7.9	1.1	5.6	80.0	.7	434.0	26.	230.	.8	16.1	7.0	43.0	16.7	3.0	103.	296.
30	R2	117.0	100.0	.9	4.0	5.2	.0	9.0	60.0	.5	484.0	54.	491.	1.9	5.5		1.0	46.5	2.0	1.	290.
31	R4	713.0	133.0	3.4	3.1	7.7	1.8	6.0	74.0	1.0	193.0	22.	254.	1.3	14.8		30.0	30.4	4.0	33.	295.
32	R6A	825.0	158.0	3.8	1.9	6.9	1.2	6.2	100.0	.6	264.0	24.	221.	1.2	17.7		13.0	18.2	4.4	45.	277.
33	R6B	893.0	142.0	3.6	1.9	8.9	1.3	5.5	136.0	.9	311.0	24.	229.	1.3	18.2		14.0	28.2	4.5	49.	355.
34	R6C	962.0	131.0	5.8	1.6	7.2	2.1	5.0	132.0	.7	212.0	25.	222.	1.2	17.8		20.0	25.9	3.0	46.	340.
35	RDEW3	991.0	129.0	1.5	3.9	5.0	1.8	7.0	84.0	.8	1695.0	23.	207.	2.0	10.0		50.0	20.1	3.7	112.	408.
36	8GRAN	1018.0	79.0	2.2	1.3	3.1	1.8	6.0	46.0	.4	484.0	16.	172.	2.7	7.3		71.0	7.7	1.5	123.	377.
37	12FYNGRAN	894.0	76.0	11.2	2.9	2.5	1.7	3.9	45.0	.4	947.0	17.	147.	13.2	6.5	6.0	140.0	17.6	2.0	109.	329.
38	D17	931.0	116.0	4.4	.9	5.8	2.2	5.8	47.0	.7	911.0	17.	151.	8.2	8.8	5.0	102.0	12.4	2.7	99.	372.

APPENDIX 4 CONTINUED

SP NO	SP NA	BA	CE	CO	CS	DY	EU	HF	LA	LU	MN	NB	RB	SC	SM	SN	SR	TH	YB	ZN	ZR
39	ST1	1126.0	113.0	1.7	1.7	7.2	2.0	6.7	75.0	.7	718.0	20.	206.	1.6	13.1	18.0	82.0	14.6	3.6	176.	486.
40	A1	803.0	78.0	9.9	.8	3.0	2.8	5.0	51.0	.5	1013.0	20.	122.	8.5	12.4	3.0	277.0	7.4	2.0	132.	352.
41	A2	704.0	81.0	9.5	1.7	4.3	2.9	6.0	63.0	.4	1258.0	21.	121.	6.9	10.4	5.0	268.0	8.5	1.8	194.	341.
42	A3	812.0	77.0	9.2	3.8	3.4	.0	5.0	52.0	.3	926.0	14.	117.	9.1	9.9		203.0	10.3	1.5	55.	368.
43	A4Z	786.0	77.0	6.6	1.3	5.0	2.1	5.2	44.0	.4	1012.0	21.	129.	7.4	9.2	2.0	216.0	12.1	1.5	100.	388.
44	A5	700.0	82.0	9.7	1.4	3.3	2.3	4.6	44.0	.3	832.0	23.	114.	9.2	9.4		234.0	11.2	1.3	57.	361.
45	A6	836.0	85.0	7.3	1.2	2.6	2.7	5.6	50.0	.3	770.0	22.	79.	8.9	12.1	5.0	179.0	8.2	1.4	89.	394.
46	A7X	795.0	71.0	5.9	2.3	4.5	3.2	5.5	60.0	.5	782.0	22.	95.	11.0	10.0	4.0	206.0	12.8	2.2	95.	372.
47	A7Y	873.0	70.0	5.3	.8	2.7	2.7	4.7	66.0	.2	812.0	20.	78.	6.4	12.3		162.0	10.5	1.4	61.	379.
48	A7Z	1072.0	78.0	5.9	.4	3.7	3.6	5.8	65.0	.3	824.0	22.	67.	8.1	9.4	1.0	202.0	10.0	1.6	156.	353.
49	A9	972.0	141.0	2.3	3.9	7.3	3.0	5.2	64.2	.6	765.0	23.	159.	3.5	14.5	12.0	121.0	17.0	2.5	59.	504.
50	R1	1112.0	123.0	6.9	3.8	5.7	2.3	6.3	60.0	.5	386.0	19.	173.	6.8	9.1	7.0	54.0	19.3	3.0	98.	313.
51	R5X	1168.0	127.0	4.4	2.4	5.3	2.3	3.8	66.0	.6	483.0	20.	173.	7.6	12.0	3.0	68.0	16.0	2.9	31.	346.
52	R5Y	1226.0	87.0	3.3	1.6	3.9	1.8	4.5	82.0	.3	303.0	19.	217.	2.8	8.5	12.0	43.0	15.9	1.8	30.	418.
53	PRET1	1162.0	129.0	1.2	6.5	8.3	1.6	8.8	68.0	.5	329.0	22.	244.	2.0	11.7	10.0	39.0	20.2	2.4	65.	459.
54	PRET2	1111.0	121.0	1.7	3.8	6.9	2.4	6.2	78.0	.5	279.0	24.	194.	1.6	14.3	9.0	46.0	17.6	2.0	56.	439.
55	N3	1293.0	92.0	3.7	2.4	2.0	2.4	4.6	50.0	.4	4112.0	14.	309.	9.5	9.0		23.0	18.0	1.4	1671.	345.
56	N4	1224.0	114.0	3.2	4.7	4.5	1.6	6.0	62.0	.7	693.0	18.	224.	4.9	11.5	7.0	48.0	19.7	3.0	179.	408.
57	N6	1119.0	109.0	2.6	12.0	5.6	1.4	6.8	75.0	.9	551.0	19.	421.	5.3	23.3		27.0	18.2	3.5	374.	422.
58	GV10	1043.0	103.0	3.6	5.1	5.9	1.6	6.9	61.0	.8	1429.0	17.	130.	8.3	10.2	9.0	62.0	16.4	3.4	542.	376.
59	ST9	1038.0	98.0	4.1	12.0	6.5	1.5	6.5	53.0	.8	1198.0	20.	177.	8.0	10.3	4.0	106.0	15.5	3.0	151.	369.
60	ST10	1073.0	82.0	3.8	3.2	4.1	2.1	7.2	57.0	.6	1177.0	19.	166.	7.6	11.1	3.0	101.0	14.4	2.5	206.	380.
61	ST11	1164.0	98.0	3.6	1.1	3.6	1.9	4.5	43.0	.5	922.0	18.	191.	7.8	9.9	7.0	57.0	17.5	2.0	298.	375.
62	ST12	884.0	93.0	4.1	12.0	4.2	1.6	6.3	56.0	.5	349.0	18.	331.	5.0	8.5	59.0	41.0	15.4	2.1	190.	364.
63	R3	1261.0	361.0	7.7	1.1	11.0	7.3	4.7	180.0	.8	204.0	17.	272.	6.0	37.5	9.0	9.0	22.5	3.8	35.	355.
64	RDEW2	1622.0	160.0	3.4	5.4	6.2	2.1	6.4	69.0	.7	946.0	18.	363.	4.6	14.7	2.0	9.0	19.3	3.5	152.	423.
65	1LEPTIET	960.0	70.0	4.0	2.9	2.3	2.0	4.9	45.0	.5	652.0	19.	134.	6.3	5.9		107.0	5.8	1.9	78.	322.
66	13LEPTIET	864.0	85.0	11.6	2.6	5.4	1.9	4.4	40.0	.6	984.0	20.	155.	11.1	5.1	3.0	141.0	8.4	2.5	89.	334.
67	WV31	807.0	75.0	12.0	1.6	3.6	1.8	3.7	40.0	.3	732.0	19.	131.	11.3	4.6	4.0	142.0	9.0	1.6		272.
68	PRET3	1006.0	103.0	3.4	2.7	5.0	1.3	6.2	54.0	.6	1196.0	18.	155.	7.3	9.8		89.0	16.9	1.9	131.	400.
69	ST8	1071.0	121.0	3.8	1.0	6.6	1.6	5.4	66.0	.7	489.0	23.	254.	1.1	12.5	13.0	117.0	26.1	3.3	136.	416.
70	A8	1087.0	96.0	1.8	3.9	6.0	2.8	6.1	54.0	.5	470.0	21.	166.	2.9	14.2		122.0	16.7	2.0	62.	424.
71	N7	506.0	243.0	1.4	7.6	5.0	.0	6.6	138.0	.5	249.0	35.	477.	2.2	20.0	14.0	36.0	98.6	2.0	41.	228.
72	N5	576.0	251.0	.9	6.2	9.0	.2	5.1	139.0	.7	143.0	38.	679.	2.0	22.3	9.0	41.0	105.0	3.8	52.	214.
73	RDEW1	1108.0	308.0	6.7	5.6	9.0	.2	8.9	145.0	.8	5397.0	33.	234.	1.3	22.2	3.0	18.0	71.0	3.6	27.	401.
74	PRET4A	1358.0	81.0	4.4	4.0	6.0	5.7	3.4	67.6	.4	2063.0	23.	118.	11.2	14.1	5.0	173.0	9.8	1.4	246.	256.
75	A4X	542.0	48.0	35.4	1.8	2.2	1.3	3.0	32.3	.3	1045.0	15.	63.	21.7	3.6	4.0	369.0	7.4	1.0	142.	165.
76	A4Y	654.0	41.0	27.9	2.9	1.4	1.4	3.0	33.2	.2	980.0	17.	99.	14.1	6.4	12.0	215.0	9.1	1.1	90.	209.

APPENDIX 5

TRACE AND MINOR ELEMENT GEOCHEMISTRY OF THE ACID PHASE OF THE

BUSHVELD COMPLEX IN THE ZAAIPLAATS TIN MINING AREA

KEY

COARSE GREY GRANITE 1-88

BOBBEJAANKOP GRANITE 89-105

ROOIBERG FELSITES 106-142

APLITES AND PORPHYRITIC GRANITES 143-159

GRANOPHYRIC GRANITES 159-202

STERK RIVER GRANOPHYRE 203-236

GROENFONTEIN GRANOPHYRE 237-243

FELDSPAR PORPHYRY 244-255

WELGEVONDEN GRANOPHYRE 256-263

BLINKWATER GRANOPHYRE AND METASEDIMENTS 264-275

SP NO = SAMPLE NUMBER

SP NA = SAMPLE NAME

GRAIN = GRAIN SIZE IN SQUARE MILLIMETRES

GAMMA = GAMMA FLUX DENSITY

APPENDIX 5 CONTINUED

SP NO	SP NA	ZR	BA	ZN	CO	TI	SC	SN	LA	CA	LI	RB	SR	K2O	NA2O	GRAIN	GAMMA
1	A1	399	2250	102	12	1465	6	3	126	7873	36	130	110	4.67	3.38	37.00	17
2	A2	462	1635	90	17	1507	6	10	62	7998	45	159	75	4.82	3.04	38.00	21
3	A4	385	1191	114	10	1125	3	5	92	5120	30	205	37	4.67	3.17	36.00	34
4	A5	478	985	112	8	1034	3	3	73	5411	38	206	45	5.20	3.32	10.00	31
5	B1	417	1337	69	19	2284	10	3	67	11330	34	151	100	4.76	3.52	37.00	21
6	B2	451	1604	72	14	1386	4	3	82	6120	45	172	65	4.98	3.10	40.00	27
7	B3	355	623	68	9	785	2	3	83	3656	29	222	27	4.73	3.13	20.00	37
8	B4	425	1254	89	10	1132	2	3	131	3650	28	195	44	4.82	3.23	6.00	37
9	C2	482	1261	92	13	1229	3	5	95	4069	31	203	40	4.96	3.45	40.00	36
10	C3	492	1176	137	11	1132	4	3	122	6905	35	181	42	4.98	3.33	8.00	33
11	C4	430	1162	92	12	1041	3	3	116	3706	32	205	52	5.02	3.31	4.00	32
12	C6	452	1118	121	10	1102	3	3	103	5416	37	236	28	4.84	3.43	3.00	30
13	D2	369	967	100	14	1357	2	11	52	2423	28	232	25	5.01	3.14	40.00	31
14	D3	409	1040	117	9	1006	3	12	107	4779	26	227	34	4.90	3.22	6.00	34
15	D8	436	1102	153	11	1123	3	12	79	4911	35	241	27	4.83	2.72	3.00	32
16	E2	683	2585	106	25	3211	12	12	43	16076	49	153	137	4.81	3.94	24.00	28
17	E5	417	1116	93	9	1015	3	10	103	5199	48	230	29	5.02	3.23	38.00	35
18	E6	354	866	37	7	536	2	5	330	5379	31	350	7	4.90	3.22	38.00	47
19	F2	329	1797	97	9	967	3	5	37	3984	40	212	63	4.92	3.56	30.00	27
20	G2	555	1947	94	15	1659	5	3	64	8028	40	196	88	4.83	3.35	28.00	25
21	H1	443	1005	85	8	945	3	3	87	5216	38	215	41	4.72	2.81	18.00	34
22	H2	438	1552	114	13	1255	5	14	46	6905	51	225	63	4.98	3.44	37.00	22
23	H3	293	399	37	6	376	3	20	130	5181	45	410	7	4.53	2.94	35.00	43
24	H8	409	1124	65	10	1009	2	6	97	4674	40	175	29	4.86	3.40	4.00	32
25	I5	395	1133	117	11	1123	4	3	87	6408	39	180	57	4.82	3.20	50.00	36
26	I6	371	657	67	8	803	3	6	104	5660	46	203	48	4.83	2.99	20.00	43
27	I7	365	1077	76	10	1187	4	6	104	5542	46	245	42	5.07	3.50	20.00	33
28	I8	300	1224	47	13	763	2	11	405	3153	45	379	10	4.92	2.97	40.00	43
29	J2	379	1066	35	6	1069	3	3	65	6420	46	198	56	4.98	3.56	9.00	26
30	J4	504	1205	123	11	1271	3	5	66	4473	42	221	39	4.87	3.15	9.00	32
31	J5	391	1180	106	11	1130	3	3	127	5510	22	206	36	4.98	3.28	9.00	29
32	J6	408	1083	135	10	1015	3	3	106	5611	25	252	23	4.92	3.32	12.00	30
33	J7	387	1134	131	12	1087	2	8	83	2968	44	213	38	5.02	3.09	9.00	26
34	J8	441	1168	83	12	1121	2	6	117	4249	31	214	37	4.55	2.43	9.00	30
35	J11	409	1165	63	8	957	3	3	96	5069	35	219	50	4.96	2.38	4.00	34
36	K1	311	741	21	4	746	4	3	52	7783	34	184	75	4.73	3.06	4.00	27

APPENDIX 5 CONTINUED

SP NO	SP NA	ZR	BA	ZN	CO	TI	SC	SN	LA	CA	LI	RB	SR	K2O	NA2O	GRAIN	GAMMA
37	K3	649	2823	158	24	2708	10	3	62	12956	45	153	138	4.87	3.25	20.00	21
38	K4	410	1175	129	11	1058	2	3	92	4921	35	198	40	5.14	3.21	25.00	30
39	K5A	420	1183	111	9	1015	3	6	84	5498	48	248	48	4.48	3.30	9.00	35
40	K6	424	1111	92	12	997	3	3	98	5916	31	207	37	4.93	3.30	6.00	34
41	K7	405	981	83	7	1005	4	5	96	6645	23	201	28	5.08	3.46	9.00	32
42	K8	420	966	123	9	974	3	3	61	5340	36	214	36	4.82	3.30	20.00	28
43	K9	409	1092	71	9	949	4	3	87	5640	26	196	44	5.00	3.23	10.00	34
44	K10	398	1159	70	9	906	4	3	126	6330	32	126	33	4.75	3.49	9.00	24
45	L4	406	1125	134	10	928	4	3	113	5836	28	197	43	4.88	3.08	20.00	28
46	L7	405	1141	62	11	1128	3	9	85	5790	26	241	25	5.02	3.12	12.00	30
47	M2A	491	1254	91	9	1121	5	5	113	7574	49	230	43	4.98	3.21	25.00	40
48	M3	419	1037	73	10	1016	3	5	75	5573	45	208	39	5.08	3.41	10.00	28
49	M4	392	1103	50	10	989	3	7	122	5226	24	221	29	5.16	3.22	8.00	32
50	M5	418	1136	53	12	1057	2	13	82	4801	28	218	31	4.92	3.16	8.00	29
51	M10	403	1117	90	11	1053	3	7	86	5165	37	248	30	4.95	3.10	3.00	33
52	M12	443	1184	178	9	1060	3	11	97	4700	24	220	37	5.00	3.22	2.00	28
53	N1	258	1024	81	9	894	3	10	103	5536	41	218	36	4.81	3.42	15.00	38
54	N2	404	637	75	8	831	2	3	66	5011	30	233	44	4.76	3.43	25.00	33
55	N2A	504	1198	103	11	1235	3	3	64	4538	33	248	19	4.36	3.32	25.00	34
56	N3	416	999	80	10	992	2	8	91	3583	32	218	34	4.45	3.04	25.00	34
57	N4	395	1180	100	15	1006	2	8	136	3635	27	231	32	5.86	3.18	30.00	37
58	N5	421	1287	91	12	1197	2	17	160	3949	30	260	22	5.04	3.09	15.00	35
59	O1	583	2285	82	16	2111	6	8	59	9960	36	164	113	5.02	3.56	25.00	22
60	O2	476	1515	59	12	1333	3	3	183	4795	32	206	52	4.96	3.38	38.00	28
61	O3	406	1020	84	10	962	3	5	83	4521	26	231	38	4.72	3.25	15.00	33
62	O4	385	1075	40	12	1009	2	12	87	4579	21	218	27	5.08	3.01	8.00	29
63	P1	524	1377	71	11	1362	4	5	91	6603	44	212	56	5.36	3.32	25.00	32
64	P2	432	972	80	10	985	3	3	63	5201	27	224	37	4.92	3.22	26.00	29
65	P3	445	1068	80	10	1204	3	9	94	5144	25	197	36	4.92	3.13	30.00	27
66	P4	451	1036	21	11	1249	2	23	83	3328	31	176	36	5.19	3.21	25.00	29
67	Q1A	542	1101	89	10	1122	3	3	76	5229	23	192	43	4.65	3.43	20.00	30
68	Q2	389	1278	35	11	988	3	3	131	5288	24	189	45	4.82	3.24	25.00	34
69	Q3	389	1012	44	12	1036	3	9	81	5422	26	205	36	4.98	3.15	20.00	34
70	Q4	401	992	62	9	1028	3	14	81	4843	42	235	22	4.92	3.29	20.00	32
71	Q9	431	1278	116	15	1401	4	9	67	6695	29	214	40	4.82	3.11	25.00	25
72	R2	426	958	54	8	986	3	5	78	5193	31	171	37	4.98	3.23	25.00	27

APPENDIX 5 CONTINUED

SP NO	SP NA	ZR	BA	ZN	CO	TI	SC	SN	LA	CA	LI	RB	SR	K2O	NA2O	GRAIN	GAMMA
73	R3	432	1010	83	11	982	3	15	75	5785	28	193	29	5.04	3.23	20.00	33
74	R4	389	1094	72	10	1206	2	10	115	4151	34	219	23	4.59	2.99	18.00	32
75	R9	523	1623	90	13	1498	6	3	64	7895	38	156	75	5.04	3.11	38.00	21
76	S1	592	2390	182	18	2122	8	3	36	10720	36	204	42	4.75	3.21	25.00	19
77	S2	508	1251	115	14	1378	4	8	50	6586	33	217	39	4.96	3.12	25.00	25
78	S3	381	1101	89	8	944	3	10	99	5666	32	196	36	4.90	3.28	20.00	30
79	S4	426	980	60	11	1236	3	18	64	6115	31	201	24	4.90	3.03	18.00	33
80	S5	417	1100	91	13	1243	1	7	110	2379	32	200	20	5.55	2.98	9.00	33
81	T2	512	1750	174	13	1444	5	3	45	7393	45	199	76	4.98	3.32	26.00	23
82	T3	424	1063	49	7	894	3	5	73	5738	26	203	50	4.95	2.23	15.00	30
83	T4	428	1140	98	11	1102	3	12	115	5401	33	235	27	4.98	3.27	16.00	31
84	T5	428	1110	109	11	1152	2	13	88	2785	35	242	24	4.81	3.01	20.00	33
85	T6	354	1041	121	10	1196	2	9	86	4489	39	231	26	4.83	3.08	15.00	33
86	T7	397	1092	83	11	1333	3	9	112	5005	39	220	28	4.80	3.38	12.00	28
87	U3	406	1039	87	9	887	2	7	96	5651	49	231	34	4.83	3.23	25.00	28
88	U4	445	872	83	10	1045	2	15	49	4668	38	235	27	4.93	3.35	20.00	28
89	D4	274	570	9	20	472	2	19	120	3268	27	397	5	4.95	2.21	35.00	45
90	D5	215	461	51	12	450	4	588	124	12830	34	394	5	4.98	2.60	40.00	43
91	E7	341	668	40	7	472	2	5	277	4811	33	334	6	4.76	2.90	45.00	48
92	E8	279	207	28	10	395	2	30	38	4809	28	359	6	4.80	3.34	38.00	52
93	F4	288	545	5	12	387	1	3	111	666	34	400	6	4.71	2.97	30.00	52
94	F5	365	300	15	7	200	8	3	81	20893	48	429	9	4.83	2.61	38.00	62
95	G4	358	329	14	9	476	3	3	98	7771	43	320	5	4.83	3.31	30.00	47
96	G5	370	181	10	4	164	9	62	47	25938	42	526	9	4.73	1.94	4.00	65
97	H4	325	616	32	8	407	4	77	175	8709	38	331	6	4.88	3.51	55.00	53
98	H5	405	298	23	6	121	4	1242	3	20705	35	430	15	4.86	1.74	4.00	60
99	I9	306	880	40	9	471	5	5	291	12538	34	369	4	4.88	3.22	45.00	48
100	I10	317	491	23	4	429	4	3	182	8836	45	393	6	4.72	3.77	40.00	55
101	I11	421	275	10	6	300	1	6	163	1988	42	556	6	5.24	3.53	4.00	62
102	J9	341	155	55	9	447	1	3	19	1688	25	523	7	4.96	1.74	56.00	43
103	J10	311	285	24	7	421	1	6	56	639	25	368	5	4.72	3.51	48.00	47
104	J10A	324	416	54	9	467	4	13	105	7738	36	391	7	4.87	2.99	30.00	45
105	M6	337	618	11	9	601	2	14	118	3834	32	410	6	4.95	2.87	4.00	45
106	A11	379	1627	672	27	2291	10	3	68	9144	33	196	98	5.10	2.78	.10	23
107	B11	408	1493	179	26	2399	10	3	73	6256	33	166	103	4.36	3.46	.10	26
108	B12	302	1438	100	49	2323	11	3	54	11985	48	179	14	4.60	.17	.10	21

APPENDIX 5 CONTINUED

SP NO	SP NA	ZR	BA	ZN	CO	TI	SC	SN	LA	CA	LI	RB	SR	K2O	NA2O	GRAIN	GAMMA
109	C10	412	1824	110	27	2521	10	5	74	4719	32	196	120	4.52	2.83	.10	23
110	C11	382	1493	286	29	2376	13	3	81	9969	39	169	61	4.61	2.89	.10	24
111	C12	354	1592	218	43	2714	8	3	82	845	68	165	14	4.36	1.20	.10	24
112	D11	397	1367	120	24	2271	13	3	65	11914	38	165	101	4.81	3.69	.10	22
113	D12	392	1309	224	33	2380	16	3	62	20463	51	120	52	2.78	2.66	.10	20
114	E14	387	1474	120	25	2423	13	6	71	13028	40	205	96	4.87	2.48	.10	22
115	E15	388	1212	138	38	2626	11	3	81	5331	45	134	20	2.93	4.39	.10	27
116	F12	389	1427	286	25	2358	13	3	63	10879	58	193	51	5.04	2.42	.10	25
117	F13	377	1718	72	26	2219	8	3	79	3444	41	201	15	4.90	2.23	.10	27
118	G11	447	1474	142	22	2539	8	3	81	2043	44	156	120	4.83	3.04	.10	23
119	G12	406	1500	223	25	2530	10	3	74	4055	30	159	71	4.69	3.13	.10	23
120	G13	403	1157	149	32	2586	9	3	76	548	38	182	22	4.45	.04	.10	19
121	H11	448	1603	208	24	2651	8	3	125	1931	36	206	45	5.37	3.03	.10	24
122	H12	395	1440	178	26	2237	11	3	66	10709	40	168	135	4.51	3.26	.10	24
123	J17	406	1443	118	26	2284	11	3	70	8050	34	159	102	4.55	3.06	.10	25
124	J18	362	1582	302	36	2445	10	24	63	6771	46	153	32	3.75	2.89	.10	24
125	J18A	374	1049	279	39	2686	7	88	38	312	30	307	12	4.95	.02	.10	24
126	K17	411	1440	117	27	2199	12	3	74	11388	44	184	108	4.11	3.34	.10	25
127	K18	357	561	460	50	2557	8	20	48	2101	44	16	90	.33	.61	.10	20
128	K18A	408	1376	155	25	2351	12	3	74	10185	44	161	61	3.89	3.21	.10	27
129	L17	420	1431	88	25	2142	11	3	69	12678	37	158	114	4.73	3.29	.10	24
130	L18	410	1305	82	36	3063	8	28	98	988	25	.0001	26	4.93	.03	.10	22
131	M7	401	1139	151	43	2609	9	3	77	722	35	183	21	4.80	.05	.10	19
132	M16	395	1490	107	25	2191	12	7	65	13090	41	178	120	4.69	3.07	.10	24
133	M17	403	1421	83	23	2137	12	3	67	12008	36	203	119	4.83	3.09	.10	25
134	N16	396	1352	115	24	2295	14	3	63	19603	50	189	69	5.72	2.23	.10	23
135	O8	363	1073	115	8	969	3	3	93	4750	31	208	47	4.73	3.23	.10	28
136	O9	351	1321	296	30	2465	11	5	78	5229	37	251	28	4.51	3.34	.10	23
137	P8	430	1379	112	20	2054	8	3	80	7488	47	195	70	5.00	3.38	.10	25
138	Q8	439	1361	53	20	2163	9	3	75	7630	41	198	114	4.73	2.93	.10	24
139	R8	428	1470	86	20	2066	7	3	79	4763	31	205	44	4.90	3.02	.10	25
140	S9	435	1306	77	21	2165	9	3	63	7823	49	185	103	4.27	3.20	.10	27
141	T9	428	1322	100	19	2075	10	3	55	9223	47	190	121	5.01	3.35	.10	24
142	U8	342	1848	138	22	2114	5	3	59	476	49	217	52	4.83	.45	.10	23
143	A3	406	990	95	13	1339	5	5	26	9181	33	176	29	4.76	3.25	38.00	32
144	C1	548	1230	90	13	1369	3	9	91	4583	30	201	40	5.00	3.33	40.00	29

APPENDIX 5 CONTINUED

SP NO	SP NA	ZR	BA	ZN	CO	TI	SC	SN	LA	CA	LI	RB	SR	K2O	NA2O	GRAIN	GAMMA
145	D1	366	1052	103	7	1051	3	3	94	6713	42	212	27	4.92	3.24	38.00	34
146	E1	369	1249	104	11	1095	4	3	113	6075	32	189	48	4.73	3.42	35.00	27
147	E3	363	656	87	9	848	2	5	98	3754	43	250	453	5.08	2.45	20.00	38
148	E4	427	495	119	10	751	3	3	105	5518	32	267	14	4.96	3.43	30.00	42
149	F1	469	1600	101	11	1561	5	3	50	7594	33	194	60	4.73	3.24	28.00	14
150	F3	394	1206	116	12	1335	2	14	98	1596	37	83	22	4.75	3.36	30.00	37
151	G1	418	1310	76	12	1299	4	3	111	6119	34	167	55	4.40	3.19	20.00	23
152	I2	343	1110	27	7	836	3	3	132	6254	44	222	43	5.18	3.20	3.00	28
153	I3	373	1718	88	23	2534	9	3	74	10858	42	164	111	4.69	3.19	6.00	22
154	I4	385	1452	98	10	1196	4	5	59	5945	39	194	60	4.90	3.09	25.00	28
155	K5	352	265	33	7	404	2	7	62	5158	30	400	8	4.67	3.85	10.00	37
156	L3	315	592	100	6	517	2	3	87	4000	48	221	13	4.98	3.86	2.00	38
157	L6	433	1119	84	9	1099	3	3	81	4831	25	189	50	4.61	3.11	2.00	24
158	M2	384	1342	98	9	1119	4	3	126	7313	27	180	49	5.01	3.45	12.00	24
159	O2A	437	471	62	10	729	3	3	67	4598	40	242	19	4.81	3.58	2.00	35
160	A6	302	1239	299	14	1165	1	17	123	2341	32	230	12	4.87	3.12	6.00	32
161	A7	404	1209	98	10	1188	1	10	160	2249	25	246	22	4.92	2.82	3.00	32
162	A8	407	1101	120	12	1259	3	5	93	4563	31	241	21	4.76	2.72	3.00	35
163	B5	411	1123	100	11	1143	4	6	125	7139	31	220	20	4.92	3.24	4.00	32
164	B6	429	1013	132	11	1286	2	16	86	5168	31	238	15	5.04	2.85	3.00	32
165	B7	442	1200	113	12	1109	1	7	119	2416	32	239	23	5.04	2.81	3.00	35
166	C5	437	845	64	7	1158	3	13	102	6968	27	219	17	4.98	3.11	3.00	28
167	C7	401	1039	140	10	1044	3	3	103	5204	45	241	22	4.81	2.42	2.00	33
168	C8	456	1128	104	13	1115	1	11	126	1308	28	266	15	5.08	2.76	1.00	37
169	D7	430	989	93	11	1199	3	58	104	6443	39	273	13	4.83	2.17	4.00	34
170	D9	415	1157	97	12	1238	2	12	92	2419	31	256	15	4.92	2.86	3.00	36
171	E10	388	1071	113	13	1301	2	22	103	4969	29	235	12	5.00	3.00	4.00	37
172	E11	420	1231	350	13	1199	2	3	125	3378	39	230	34	4.98	2.94	3.00	27
173	F8	341	1035	107	11	1186	2	7	87	1885	25	244	25	4.93	2.99	3.00	32
174	F9	384	1361	183	10	1061	1	5	168	2681	28	217	19	4.87	1.95	3.00	31
175	G3	391	640	57	9	805	1	5	163	2728	43	244	8	4.73	3.22	30.00	35
176	G6	396	1061	76	11	1039	3	6	93	5931	30	221	20	4.86	3.08	4.00	30
177	G7	423	1060	85	12	1048	4	6	107	9430	32	232	18	4.69	2.78	4.00	33
178	G8	385	1296	102	14	1353	1	8	127	1718	38	243	16	4.92	2.23	3.00	30
179	G9	387	966	137	13	1022	3	3	175	8348	37	265	13	4.86	2.18	3.00	32
180	H9	450	1146	120	11	1277	4	10	90	7266	32	238	16	4.93	2.33	3.00	33

APPENDIX 5 CONTINUED

SP NO	SP NA	ZR	BA	ZN	CO	TI	SC	SN	LA	CA	LI	RB	SR	K2O	NA2O	GRAIN	GAMMA
181	I13	408	1030	100	7	1126	4	5	93	9121	31	201	545	4.98	2.75	4.00	32
182	I14	340	1145	105	13	1006	3	12	102	7259	31	172	9	4.75	1.71	3.00	24
183	I14A	377	779	62	14	993	7	3	85	13928	29	245	10	4.81	2.38	3.00	26
184	J12	438	1217	45	9	1144	2	8	127	4983	22	182	30	4.82	2.81	3.00	30
185	J13	451	1249	43	13	1123	3	5	86	5650	24	205	39	4.95	2.74	3.00	28
186	J14	381	987	14	15	900	2	19	136	5281	26	260	11	4.80	2.48	2.00	32
187	J15	414	997	37	15	1170	2	6	82	3233	34	285	12	4.80	2.77	3.00	32
188	L5	483	1385	46	14	1230	2	15	115	3324	27	218	65	4.72	3.05	4.00	27
189	L10	442	982	65	8	1066	4	6	80	7110	24	184	27	4.80	3.79	10.00	35
190	L11	445	1053	61	8	899	3	3	75	5530	20	217	30	4.86	3.45	12.00	30
191	M9	373	938	48	7	733	3	29	101	6031	25	202	28	4.84	3.30	6.00	27
192	M11	450	1129	93	12	1301	2	8	108	3998	24	220	34	4.86	3.11	3.00	34
193	N9	412	1043	55	12	1144	3	25	86	4988	41	233	16	4.98	2.85	3.00	34
194	N10	464	1142	65	9	1109	2	11	101	4265	31	222	29	4.86	3.11	3.00	35
195	N11	402	995	36	17	1271	2	7	87	3365	33	280	12	4.98	2.78	3.00	32
196	O6	514	1539	97	10	1247	3	5	103	4125	43	226	53	4.86	3.04	3.00	27
197	Q5	433	1190	117	15	1247	1	7	121	3308	35	248	23	5.02	2.93	15.00	32
198	R5	431	995	58	10	1187	3	17	83	5413	34	191	19	4.98	3.12	9.00	23
199	R6	543	1511	66	11	1351	3	5	78	3906	40	203	49	4.92	3.19	10.00	28
200	S6	438	1071	86	11	1338	2	6	94	3137	36	219	18	5.10	3.11	10.00	33
201	U5	385	1080	91	12	1151	1	7	91	2464	28	240	18	4.98	2.81	20.00	30
202	U6	432	1156	96	13	1203	2	6	116	3499	46	201	20	4.96	3.16	12.00	30
203	A9	371	1136	153	7	1052	2	5	149	2795	28	233	18	5.55	2.78	3.00	33
204	A10	476	1297	158	12	1279	1	3	98	1420	45	197	19	4.64	3.05	2.00	30
205	B8	498	1281	103	9	1099	3	5	92	4626	25	210	31	4.96	3.17	3.00	29
206	B9	501	1338	118	11	1350	3	3	93	5670	39	238	18	5.20	2.68	1.00	27
207	B10	470	1030	135	13	1117	2	5	88	6101	34	217	16	4.80	3.07	1.00	33
208	C9	440	1199	95	12	1108	1	6	219	2013	28	229	12	4.82	3.09	1.00	32
209	D10	426	1221	131	10	1134	2	8	86	3734	29	243	29	5.19	3.39	3.00	31
210	E12	418	1236	243	17	1196	1	3	112	2035	44	286	17	4.86	1.48	2.00	26
211	E13	435	836	110	15	1177	3	11	103	5863	46	251	13	4.82	2.23	1.00	32
212	F10	402	1126	109	13	1017	1	9	180	1807	45	262	21	4.87	2.13	2.00	34
213	F11	481	848	181	11	1229	3	5	94	4546	32	226	18	4.94	3.13	1.00	28
214	G10	390	928	101	17	1070	1	28	138	2426	34	309	13	5.61	1.51	2.00	36
215	H10	402	863	68	13	1013	2	3	128	4372	36	275	16	4.95	2.09	4.00	37
216	J16	426	1124	20	11	888	3	13	139	5260	25	262	13	5.01	2.77	1.00	38

APPENDIX 5 CONTINUED

SP NO	SP NA	ZR	BA	ZN	CO	TI	SC	SN	LA	CA	LI	RB	SR	K2O	NA2O	GRAIN	GAMMA
217	K12	451	1263	36	9	1080	2	12	136	3649	23	222	22	5.01	3.12	4.00	32
218	K13	435	1214	56	13	1160	2	12	103	3828	28	199	24	4.75	3.10	3.00	28
219	K16	412	746	55	12	950	1	6	102	2111	38	325	10	4.98	2.58	1.00	35
220	L12	422	1188	78	11	1160	2	5	120	3393	25	268	16	4.72	2.73	8.00	32
221	L14	398	1063	93	18	1270	2	34	111	5051	31	313	13	4.93	2.40	8.00	38
222	L15	388	937	86	12	1009	2	3	152	4414	28	598	14	5.01	2.60	6.00	33
223	L16	421	791	53	11	1009	2	11	137	3966	42	229	12	4.98	3.19	4.00	33
224	N8	526	1452	169	11	1229	3	5	105	5280	34	229	38	4.71	3.31	4.00	32
225	N14	393	1374	94	26	2244	12	3	67	10065	40	161	124	5.58	3.33	1.00	22
226	O7	497	1468	161	11	1312	2	5	85	3874	27	217	45	4.92	3.03	3.00	28
227	P6	547	1461	70	12	1469	2	3	93	3993	25	187	38	5.02	3.11	10.00	28
228	P7	541	1518	91	15	1388	2	3	106	3881	38	212	39	4.96	3.09	3.00	27
229	Q6	498	1517	104	10	1457	2	3	127	2844	39	197	42	4.87	3.23	8.00	26
230	Q7	576	1393	92	11	1330	3	3	90	6200	35	182	51	4.72	3.31	3.00	28
231	R7	566	1509	67	11	1308	3	3	90	3980	31	202	47	5.00	3.25	4.00	28
232	S7	464	1199	97	9	1229	3	7	111	4924	31	191	27	5.01	3.06	4.00	36
233	S8	519	1542	94	13	1326	3	9	100	4480	47	204	43	5.02	2.63	1.00	27
234	T8	550	1466	82	12	1214	3	65	86	4298	25	210	51	4.82	3.28	8.00	28
235	U7	527	1537	75	9	1262	3	3	84	4405	28	206	76	4.84	3.11	3.00	21
236	U9	516	1283	118	11	1359	3	6	93	5516	28	237	19	4.82	2.58	1.00	27
237	D6	415	1112	64	11	1243	2	35	113	2745	47	397	5	4.98	2.73	6.00	32
238	E9	430	923	61	8	785	4	24	84	7251	32	240	27	4.73	3.45	6.00	32
239	F6	422	1311	140	11	1160	1	20	198	1698	33	249	15	4.88	2.07	4.00	34
240	F7	415	1224	99	14	1212	2	13	150	4154	33	222	15	4.75	2.61	3.00	33
241	H6	516	1452	37	7	1329	2	3	116	2379	29	198	32	4.49	3.36	4.00	29
242	H7	525	1621	106	11	1572	2	3	125	2156	39	216	41	4.93	3.01	3.00	29
243	I12	419	1118	58	11	1156	3	18	95	5679	30	201	20	4.96	3.22	4.00	30
244	K14	470	1647	89	9	1054	3	7	262	4478	42	199	25	4.98	3.19	3.00	27
245	K15	365	1030	94	19	940	2	10	153	3374	41	356	15	4.98	1.91	2.00	34
246	L13	446	1249	41	15	1278	1	5	137	2730	27	272	19	4.88	2.81	6.00	32
247	M13	436	1161	51	13	1317	4	5	94	6743	35	230	20	4.98	2.76	4.00	32
248	M14	473	1101	47	12	1256	4	5	108	7681	27	220	22	4.98	2.90	3.00	32
249	M15	398	960	66	11	975	2	6	99	5423	33	284	24	5.01	2.40	2.00	34
250	N12	422	1147	68	16	1238	4	49	98	7354	34	262	28	4.65	3.23	2.00	29
251	N13	442	1122	69	11	1193	1	5	100	530	36	270	17	4.96	2.14	2.00	31
252	N15	417	867	90	15	1062	4	60	116	8643	49	270	15	4.82	2.00	.10	30

APPENDIX 5 CONTINUED

SP NO	SP NA	ZR	BA	ZN	CO	TI	SC	SN	LA	CA	LI	RB	SR	K2O	NA2O	GRAIN	GAMMA
253	WG1	415	1118	59	15	1160	3	6	94	5633	29	296	16	4.99	2.76	4.00	33
254	WG2	440	1136	71	14	1223	1	7	115	1050	36	302	17	4.72	2.98	4.00	33
255	WG3	414	1110	52	13	1058	3	8	93	6150	33	305	18	4.60	2.69	4.00	28
256	K11	434	1382	52	9	1273	3	3	87	6225	25	164	45	4.95	2.47	4.00	32
257	L8	520	1479	119	9	1206	2	24	88	3284	27	228	33	4.96	3.32	9.00	33
258	L9	525	1465	99	13	1463	3	3	97	4331	28	195	34	4.98	3.31	6.00	31
259	M8	440	1325	75	12	1245	2	7	86	3503	36	176	37	4.92	3.46	4.00	20
260	N6	465	1484	92	11	1204	3	3	90	4343	34	202	58	4.55	3.00	6.00	27
261	N7	570	1405	114	13	1498	1	3	89	1594	31	199	30	4.84	3.22	4.00	28
262	O5	595	1395	106	12	1426	3	8	84	5074	26	201	38	4.42	3.04	6.00	27
263	P5	545	1466	116	14	1307	3	7	99	4806	33	207	35	5.01	3.06	20.00	27
264	I1	282	621	9	5	529	4	3	85	6999	31	179	49	4.95	2.74	3.00	25
265	J1	426	324	8	3	2038	6	3	44	9429	31	11	144	.41	4.28	3.00	26
266	J3	504	1737	113	11	1334	4	3	144	6108	28	196	69	4.98	3.34	12.00	32
267	K2	465	1229	96	10	1392	4	3	27	4943	30	177	62	4.83	2.82	4.00	20
268	L1	460	1545	37	13	1448	4	3	85	3034	47	178	69	4.98	3.02	1.00	20
269	L2	310	737	11	15	6173	49	3	45	63522	68	26	239	5.24	5.60	1.00	13
270	M1	144	60	9	9	532	4	3	3	6894	47	8	61	.20	1.77	1.00	7
271	Q1	504	1470	73	14	1388	3	3	134	4881	38	193	46	4.70	3.25	2.00	28
272	R1	525	1384	59	8	1279	4	3	102	6489	36	177	45	4.95	3.64	4.00	26
273	T1	346	1454	65	21	2677	15	3	65	13858	52	218	30	4.69	3.50	2.00	22
274	U1	870	2741	117	33	4827	15	7	55	20007	41	206	68	4.77	3.07	6.00	19
275	U2	395	1327	95	22	2224	12	3	69	12074	42	182	97	4.95	3.34	2.00	23