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GOLD DISTRIBUTION IN ARCHAEOAN GRANITOIDS AND  
SUPRACRUSTAL ROCKS FROM SOUTHERN AFRICA :  
A COMPARISON

RUDOLF SAAGER and MICHAEL MEYER

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• INFORMATION CIRCULAR NO. 165

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by

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ABSTRACT

Gold distributions in a suite of 190 samples from various granitoid bodies of the Eastern Transvaal Archaean basement and Johannesburg dome, South Africa, were determined and the data treated statistically. The Au values range from 0,3 to 7,8 ppb. The arithmetic mean was found to be 1,2 ppb and the geometric mean 1,0 ppb Au. The data exhibit a log-normal distribution with a weak positive skew. Partitioning of the bimodal cumulative probability curve for the Au data shows that 6 per cent of the values belong to an "excess population". Correlation and factor analyses of the geochemical data reveal an absence of relationships between Au and the major elements and, thus, with rock forming minerals. Mineralogical and geochemical considerations indicate that erratically distributed accessory pyrite is the main gold bearer in the granitoids whilst the rock forming minerals generally possess Au contents of less than 1 ppb. Furthermore, Au cannot be correlated with the differentiation trends evident in the granitoid suite of the Eastern Transvaal.

In contrast to the data from the granitoids, volcanic rocks from southern African greenstone belts show the following characteristics:

- (i) A more heterogeneous Au distribution (range: 0,1-372 ppb) and distinctly higher measures of central tendency ( $\bar{x}$ : 10,8 ppb; G: 2,1 ppb),
- (ii) a larger "excess Au value population" amounting to 19 per cent of the data set, and
- (iii) a higher content and greater variety of sulphide minerals which are more consistently and regularly distributed.

In the light of the metamorphic secretion theory for Au ore formation. It is suggested that the granitic rocks studied represent a less suitable source of gold than the adjacent greenstone volcanic assemblages. It is further suggested that the presence or absence of "excess" Au values in ultramafic to mafic volcanics could probably be used as an exploration guide. If, for example, the volcanic parent magma had achieved sulphur saturation prior to freezing (with the consequent formation of an immiscible sulphide phase possibly leading to a massive sulphide ore) then the *absence* of an "excess Au value population" might be indicative of this very process.

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## I. INTRODUCTION

Gold mineralization associated with Archaean granite-greenstone terranes is of considerable economic importance and occurs in most cratons. In southern Africa these gold deposits constitute the second most important source of gold in the area. According to Lightfoot (1934) gold has been produced from about 3800 mines in Zimbabwe and for the entire southern African subcontinent Anhaeusser (1976) has arrived at a figure of about 4000 gold mines or workings. Summers (1969) estimated that the amount of gold produced by the "ancients" (i.e. from the beginning of gold mining until the arrival of the early European explorers towards the end of last century) totalled about 700 tons. Modern gold production was about three times as large so that the total output from Archaean mineralization in southern Africa until the present time can be estimated at about 2800 tons of gold.

This figure is comparable with the production figures from other Archaean regions in the world which in the case of Western Australia has been over 2200 tons, for Brazil about 1400 tons, and for the Canadian Shield about 5400 tons of gold (Anhaeusser, 1976).

Four main types of Archaean gold deposits can be distinguished in the granite-greenstone terrane of South Africa, namely (i) gold-quartz veins, (ii) complex massive sulphide ores, (iii) gold bearing banded iron-formations, and (iv) placer occurrences in conglomerates (Viljoen *et al.*, 1969; Saager, 1973; Saager and Muff, in press). A similar classification was also proposed by Fripp (1976) for Archaean gold mineralization in Zimbabwe. Production figures for gold indicate that by far the most important type of mineralization is that associated with gold-quartz veins or *epigenetic* gold. These deposits account for more than half of the Archaean gold which has been produced.

A close spatial association between gold deposits and greenstone terranes has been described by a number of workers in southern Africa (Lightfoot, 1930; Macgregor, 1951; Viljoen *et al.*, 1969, 1970; Saager, 1973; Anhaeusser, 1976; Saager and Muff, in press). Similar observations were also made in other cratons by Weber and Stephenson (1973), Pyke (1975), Lavreau (1973), and Keays and Davidson (1976). In many instances the gold occurrences are situated in mafic or ultramafic metamorphosed volcanic rocks, although deposits may also occur in felsic metavolcanics, quartz porphyry stocks and associated sedimentary rocks. Anhaeusser (1976) has pointed out that only a few ore bodies occur within adjacent granitic batholiths and then are frequently marginal to or within greenstone xenoliths. The latter ores are generally located within a few kilometres of the main granite contact and never occur in the middle of the granite batholiths (Phaup, 1964).

Because much of the Archaean gold has occurred in epigenetic vein-type deposits, most discussions on the genesis of Archaean gold mineralization has centred around the formation of lode deposits. Early theories of ore generation suggested a direct link to the magma of granitic batholiths which intruded into the greenstone terranes (Emmons, 1937; Jones, 1948, De Villiers, 1957; George, 1967; and others). However, because of the preferred occurrence of lode deposits in greenstone belts, workers such as Boyle (1961), Viljoen *et al.* (1969), Ridler (1970), Saager (1973), Sawkins and Rye (1974), and Saager *et al.* (1982)

considered that these epigenetic-type deposits formed by metamorphic secretion and concentration of the gold in the host rock in suitable tectonic structures. Iron-formations (Ridler, 1970; Fripp, 1976), ultramafic to mafic "primitive" komatiitic volcanics (Viljoen *et al.*, 1969; Pyke, 1975; Keays, 1981), sulphide-bearing volcanics (Keays and Scott, 1976), and supracrustal rocks in general (Saager *et al.*, 1982) have been viewed as the source of the gold in Archaean lode deposits.

The close association between gold lodes and the supracrustal rocks of the greenstone belts, as well as the currently favoured metallogenetic concept (i.e. the metamorphic secretion theory) has led to a number of geochemical and mineralogical investigations on gold abundances in volcanic and sedimentary rocks associated with Archaean greenstone belts and also to studies on the mineralogical siting of gold within these rocks (Viljoen *et al.*, 1969; Anhaeusser *et al.*, 1975; Boyle, 1961, 1969, 1976; Keays and Davidson, 1976; Kwong and Crocket, 1978; Bavinton and Keays, 1978; Saager *et al.*, 1979; Saager *et al.*, 1982; and others). In contrast, investigations of gold abundances in Archaean granitic rocks are comparatively rare and certainly do not exist for samples from the cratonic areas of southern Africa. It is understandable, therefore, that on examining the available literature on gold distribution in igneous rocks, Boyle (1979) concluded that owing to "the diversity of findings and opinions the relationship between gold content of igneous rocks and the presence or absence of gold deposits is unresolved".

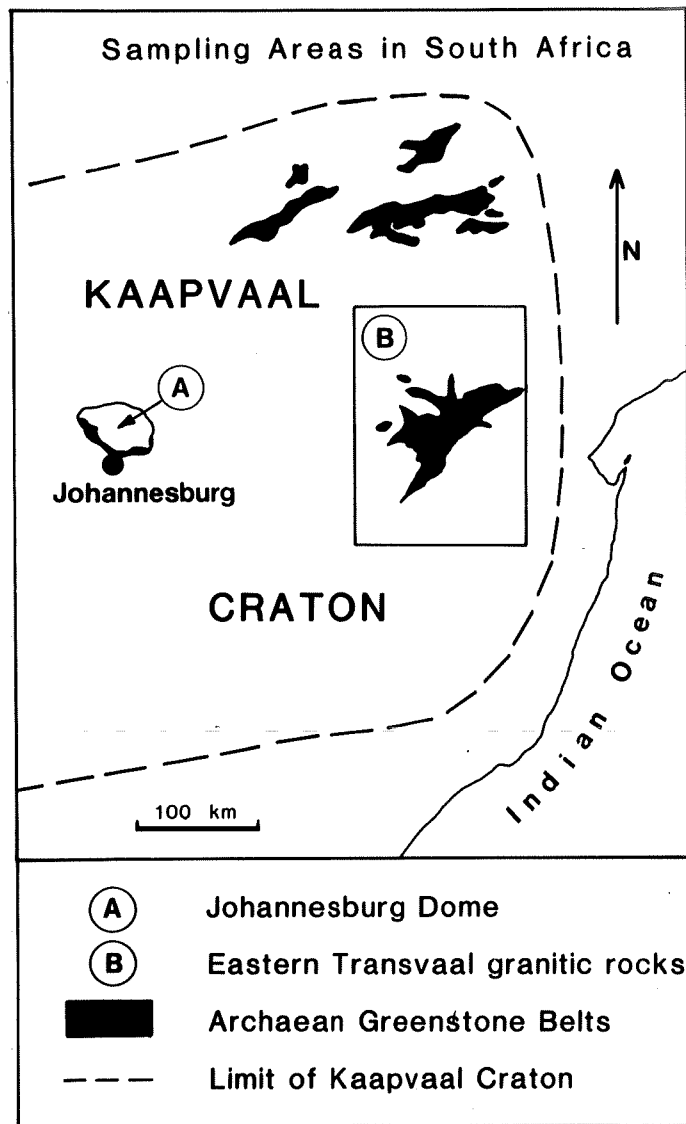
In this light the present investigation was undertaken, firstly, to gather data on the distribution of gold in early Precambrian granitic rocks of South Africa and, secondly, to learn more about the role of granitic intrusions in the genesis of epigenetic gold deposits in granite-greenstone terranes. For this study 23 samples from the Johannesburg granite dome (see Fig. 1) and 167 samples from the granitic terrane of the Eastern Transvaal (see Figs. 1 and 2) were investigated for their gold abundance. The results were then compared with those obtained in a recent study on the gold distribution within supracrustal rocks from Archaean greenstone belts of southern Africa (Saager *et al.*, 1982).

The geologic setting, petrology, petrogenesis and geochemistry of the investigated granitic plutons and batholiths are well studied and discussed in a number of papers (Anhaeusser, 1973, 1978, 1980; Anhaeusser and Robb, 1980, 1981, 1983a; Robb and Anhaeusser, 1983; Viljoen and Viljoen 1969; Tankard *et al.*, 1982; and others). The samples used for the present investigation were provided by C.R. Anhaeusser and L.J. Robb, Johannesburg, and are the same as those referred to by these two authors in their various publications.

## II. GEOLOGICAL SETTING OF THE AREAS SAMPLED

### A. Johannesburg Dome

The Archaean granites forming the Johannesburg dome (Fig. 1) are exposed between the cities of Johannesburg and Pretoria where they underlie an ovoid area some 700 km<sup>2</sup> in extent. These rocks constitute one of a number of domical windows of granite basement upon which a variety of sedimentary successions, ranging from the Pongola to the Karoo Supergroup, were laid down.



*Figure 1 : Sketch map of the granitic areas sampled on the Kaapvaal Craton.*

Age dating on one component of the Johannesburg dome, namely the tonalite gneisses, was carried out by Anhaeusser and Burger (1982) using the U-Pb method. This yielded an age of emplacement for the gneisses of  $3170 \pm 34$  Ma. Earlier, Allsopp (1961) had obtained a Rb-Sr age of  $3132 \pm 64$  Ma for granodiorites on the dome, the latter having been involved in a reheating episode which took place approximately 2075 Ma ago.

Anhaeusser (1973) recognized several types of granitic rocks on the dome the main varieties being: (i) mesocratic hornblende-biotite tonalitic gneisses, (ii) leucocratic biotite tonalitic gneisses and/or biotite trondhjemites, (iii) homogeneous and porphyritic granodiorites, and (iv) layered gneisses and migmatites. The latter varieties occupy practically the entire northern half of the dome, whereas the tonalitic gneisses are found along its southern, south-eastern and south-western margins. The granodiorites occur in the southern half of the dome with its central portions being occupied by adamellites and granites (*sensu stricto*) which effectively demarcate a transitional zone between the

granodiorites in the south and gneisses and migmatites to the north.

According to Anhaeusser (1973) the tonalitic gneisses of the Johannesburg dome have, in places, extensively stopped and assimilated pre-existing ultramafic and mafic greenstone assemblages. Variably sized xenoliths of amphibolite and serpentinite occur as remnants of this pre-existing greenstone terrane. Tonalite intrusion was then followed by metamorphic and paligenetic processes which gave rise to the layered gneisses and migmatites. Homogenization of the earlier granitic assemblages was considered to be a result of subsequent potash, silica and alumina metasomatism together with granite magmatism which produced the homogeneous and often porphyritic granodiorites, adamellites and granites.

The samples investigated were collected from all the major granite types of the dome. The main mineral phases in these rocks are quartz, sodic feldspar, and biotite with variable amounts of potash feldspar, hornblende and chlorite also being present. Rare magnetite and ilmenite both containing occasional inclusions of hematite, and even less abundant pyrite, were the only opaque minerals observed.

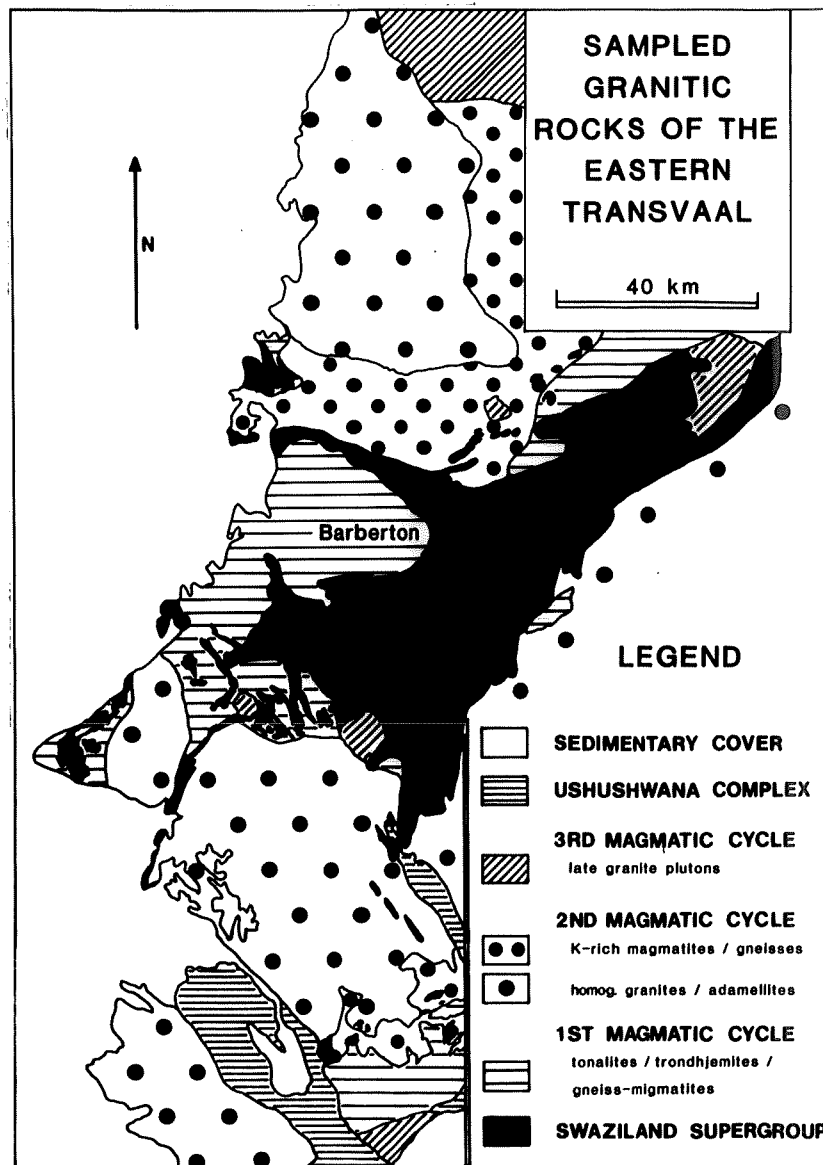
#### B. The Archaean Granitic Terrane of the Eastern Transvaal

The granitic basement of the Eastern Transvaal, which surrounds the Barberton greenstone belt (Fig. 2), has been the subject of intensive geological, geochemical, geochronological and structural studies. These have led to the recognition of a wide range of granitic rock types which, in turn, can be related to a number of tectono-magmatic events (Anhaeusser *et al.*, 1968; Hunter, 1957, 1970, 1973, 1979; Oosthuyzen, 1970; Viljoen and Viljoen, 1969; and others). In a recently published account, Anhaeusser and Robb (1981) attempted to subdivide this complex granitic terrane into three categories on the basis of similarities in field relationships, rock composition, geochemistry and isotopic ages. They referred to these categories as *magmatic cycles* which can be broadly identified as: (i) early tonalitic-trondhjemitic gneisses and/or migmatites, (ii) intermediate potassium-rich batholiths, and (iii) late granite (*senso lato*) plutons. The magmatic cycles are characterized by specific life-spans but encompass an array of events and granitic rock types bound by a set of unifying features.

The first cycle commenced about 3550 Ma ago and was terminated about 3200 Ma ago. It was characterized by the formation of soda-rich tonalites and trondhjemites and a complex series of bimodal gneisses and migmatites, the intrusion of which was responsible for the early stages of cratonization in this area of the subcontinent. The tonalitic/trondhjemitic magmas were considered to have been derived by melting of ensimatic crust, with the complex migmatites forming as a result of interaction between the early formed magmas (sial) and the pre-existing proto-crust (sima) (Anhaeusser and Robb, 1981).

The second magmatic cycle, which lasted from about 3200 Ma to about 3000 Ma ago, was responsible for the major processes of cratonization and stabilization of the Archaean basement. Large volumes of potassium-rich granitic magma were emplaced as batholiths which passively invaded the pre-existing crust by stopping, cauldron subsidence and assimilation. The batholiths were emplaced at relatively high crustal levels and occur as sheet-like masses which overlie the earlier-formed sialic crust of the first magmatic cycle (Anhaeusser and Robb, 1981).





*Figure 2 : Geological sketch map of the Eastern Transvaal basement showing the areal distribution of the three groups of granitic rocks sampled (after Anhaeusser and Robb, 1981).*

The third magmatic cycle covers the time span from 2900 Ma to about 2600 Ma ago and consists of a number of discrete, mainly granitic (*sensu stricto*) and syenitic bodies which were emplaced into an already consolidated and tectonically stable crust. Based on their isochron ages (Barton, 1981, Barton *et al.*, 1983) the plutons are classified into an old and a young category. The emplacement of these late granite (*sensu lato*) plutons is thought to be concomitant with the termination of cratonization in this area (Anhaeusser and Robb, 1981).

The samples investigated in this study are representative of all three magmatic cycles (see Table I).

TABLE I

SAMPLED PLUTONS AND BATHOLITHS IN THE GRANITIC  
BASEMENT OF THE EASTERN TRANSVAAL

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First Magmatic Cycle:  
tonalite/trondhjemite gneisses and migmatites

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Theespruit pluton (28)	
Brandybal pluton (8)	
Doornhoek pluton (4)	
Kaap Valley pluton (16)	
Batavia pluton (6)	
Steynsdorp pluton (9)	$\Sigma$ 95
Rooihoogte pluton (4)	
Nelshoogte pluton (2)	
Schapenberg pluton (7)	
Weergevonden pluton (9)	
Ofcolaco pluton (2)	

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Second Magmatic Cycle:  
granodiorites, adamellites, granites

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Heerenveen batholith (11)	
Nelspruit batholith (9)	$\Sigma$ 56
Mpuluzi batholith (36)	

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Third Magmatic Cycle:

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Mshishimala pluton (adamellite) (2)	
Dalmein pluton (granodiorite) (3)	
Cunning Moor pluton (tonalite) (2)	$\Sigma$ 16
Boesmanskop pluton (syeno-granite) (9)	

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Figures in brackets give number of samples

The mineralogical composition of the granitic rocks investigated varies considerably. The samples of the first magmatic cycle, mainly trondhjemites, have quartz, plagioclase (albite-oligoclase), and biotite as major constituents. Minor amounts of microcline occur together with chlorite, sphene and apatite. The Kaap Valley tonalite is an exception and may contain as much as 25 per cent hornblende, often without biotite. The rocks of the second magmatic cycle contain variable amounts of quartz, microcline and plagioclase as major constituents. Minor and accessory minerals are biotite, muscovite, chlorite, sphene, apatite and zircon. The mineralogical composition of the samples obtained from the third magmatic cycle (adamellites, granodiorites, tonalites and syenites) is extremely variable. Quartz, microcline, plagioclase and biotite are the major constituents but the relative proportions of these minerals vary from one pluton to another. Chlorite, epidote, sphene, apatite, allanite, and zircon occur as minor or accessory mineral phases.

Magnetite and ilmenite have been observed in most of the samples from all three magmatic cycles. Hematite and pyrite are rare and despite careful microscopic investigations, could not be detected. Pyrite, has in a few cases, been altered by supergenic processes to Fe-hydroxides which are occasionally pseudomorphous after the sulphide mineral.

### III. RESULTS

The major element data used in this study were made available to the authors by C.R. Anhaeusser and L.J. Robb of the Economic Geology Research Unit, University of the Witwatersrand, Johannesburg, who have published a number of these analyses in their various contributions to the Geodynamics programme (Anhaeusser and Robb, 1983b). Determination of the major elements was carried out by XRF, mainly utilizing the facilities in the Department of Geology, University of the Witwatersrand, Johannesburg. A few samples were analysed at the Council of Mineral Technology, Randburg, and at various commercial analytical laboratories in South Africa.

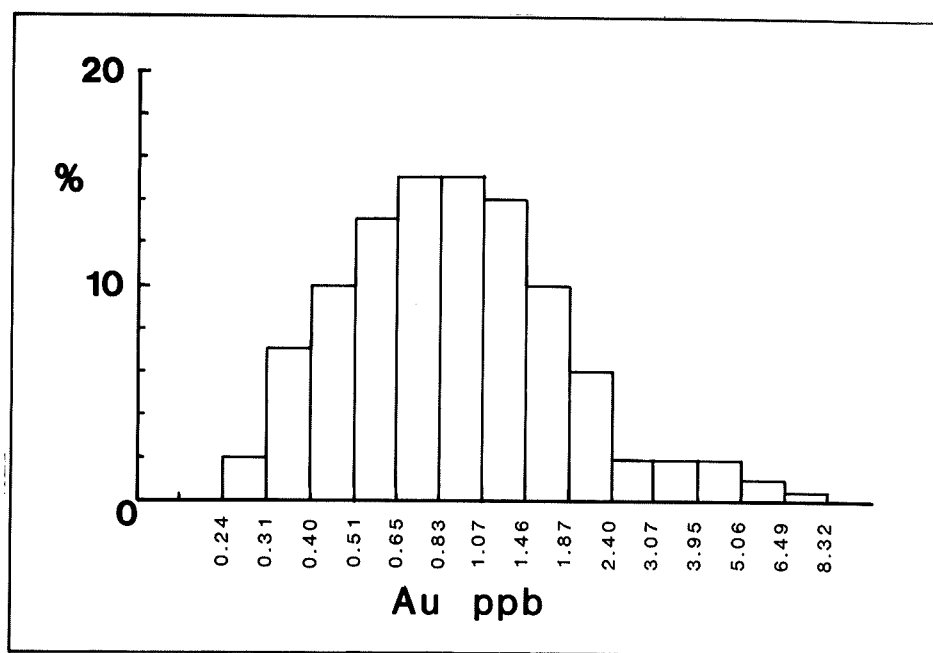
The abundances of Au and Ni were determined by instrumental epithermal neutron activation analysis (IENAA) using the facilities of the Kernforschungsanlage Jülich and the Institute of Nuclear Chemistry at the University of Cologne, West Germany. The analytical method employed and the accuracies and precisions obtained for the IENAA procedures are discussed by Saager *et al.* (1982).

The raw data for the Au concentrations of all granitic rocks are positively skewed and Fig. 3 shows that when logarithmically transformed, the data exhibit an almost perfect normal distribution(\*). The 190 analysed samples show an arithmetic mean ( $\bar{x}$ ) Au content of 1,2 ppb ( $s = 1,1$  ppb Au) and range from 0,3 to 7,8 ppb Au. The geometric mean (G), which in this case is a better measure of central tendency than the arithmetic mean, has a value of 1,0 ppb Au (Table II).

Using the method described by Sinclair (1978) the cumulative frequency distribution of the logarithmically transformed gold data has been partitioned into a "background value population" termed A and an "excess value population" termed B (Lepeltier, 1969; Saager *et al.*, 1982). It was found that the "excess value population" ( $\bar{x}_B = 4,1$  ppb Au,  $\bar{x}_B + 2s_1 = 9,9$  ppb Au,  $\bar{x}_B - 2s_1 = 1,6$  ppb Au) comprises 6 per cent of all the gold values with the "background value population" ( $\bar{x}_A = 0,9$  ppb Au, Au,  $\bar{x}_A + 2s_1 = 2,4$  ppb Au,  $\bar{x}_A - 2s_1 = 0,4$  ppb Au) comprising the remaining

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(\*) Tables of the analytical data used are given in Saager and Meyer (in prep.).



*Figure 3 : Gold distribution in the granitic rocks studied.*

94 per cent. This result is a reflection of the near perfect lognormal distribution of the gold data possessing only a weak skew (Fig. 3). It is further indicated in Fig. 4 where the threshold value between the background and excess populations is set at  $\bar{x}_A + 2s_1 = 2.35$  ppb Au, the value obtained by partitioning of the bimodal logarithmic probability curve of the gold data.

This pattern of Au data (Fig. 4), namely where numerous samples have low (background) Au concentrations and only a few samples have high (excess) Au concentrations, has previously been observed and discussed by Fritze and Robertson (1969) and Saager *et al.* (1982) who suggested that gold occurs in two components in the rocks studied by them; firstly, in rock-forming minerals of low Au contents and, secondly, as inter-granular gold particles or in accessory, erratically distributed, sulphides of higher Au contents.

To study the correlations of Au with  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{CaO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ , and Ni a product moment correlation coefficient matrix has been erected (Table III). For the calculation of this matrix, and subsequent statistical tests, the Au and Ni data were logarithmically transformed - based on chi square statistics - whilst for the major elements the raw data were used.

The correlation matrix depicted in Table III indicates that, in all cases, the correlations between Au and the other elements studied

TABLE II  
ARITHMETIC MEANS, STANDARD DEVIATIONS, GEOMETRIC  
MEANS AND RANGES OF AU CONTENTS IN THE GRANITIC  
ROCK TYPES STUDIED

Rock group	N ppb	$\bar{x}$ ppb	s ppb	G ppb	range ppb
1st magmatic cycle	95	1,2	1,1	0,9	0,4-7,8
2nd magmatic cycle	56	1,0	0,7	0,9	0,4-5,2
3rd magmatic cycle	16	1,7	1,4	1,3	0,4-5,5
Johannesburg dome	23	1,2	0,5	1,0	0,3-2,4
Total	190	1,2	1,1	1,0	0,3-7,8

N: number of samples;  $\bar{x}$ : arithmetic mean;  
s: standard deviation; G: geometric mean

are not significantly different from zero at the one per cent level. Lack of correlation between Au and Si, Ca, Mg and K is also indicated in Fig. 4, in which the Au values are plotted against the modified Larsen factor (Nockolds and Allen, 1953).

The geochemical data was also investigated by an R-mode factor analysis and the varimax rotated factor values, together with the communalities, are presented in Table IV. The extracted three-factor model accounts for 76,7 per cent of the total variance in the original data set (9 variables). The communality values indicate that, with the exception of  $Al_2O_3$  (approximately 38%) and  $Ni_{log}$  (approx. 62%), all other variables are explained by the three-factor model to more than 73 per cent. The highest communality value is achieved by  $Au_{log}$ , which is explained to more than 99 per cent by the model.

*Factor 1* possesses a high negative loading of  $SiO_2$  and high positive loadings of  $Fe_2O_3$ ,  $MgO$ , and  $CaO$ . This element configuration is typical for the mafic rock-forming mineral phases present in the rock types studied. Factor 1 was, therefore, named *mafic mineral factor*. *Factor 2* exhibits a high positive loading of  $Na_2O$  and a high negative loading of  $K_2O$ . This is a reflection of the preponderance of either plagioclase or K-feldspar in the suite of rock samples studied (see also Fig. 5), and this factor is consequently termed the *alkali or feldspar factor*. *Factor 3* is almost exclusively loaded by  $Au_{log}$ , and is, therefore, called the *gold factor*. The latter indicates the complete separation of gold from any other geochemical variable investigated by the statistical analysis. The lack of a fundamental relationship between  $Au_{log}$  and the  $K_2O$  and  $Na_2O$  contents of the samples studied is furthermore displayed in Fig. 5 which shows the absence of clustering of high Au values in any one of the four delineated granitic rock types (i.e. tonalite, granodiorite, adamellite, granite).

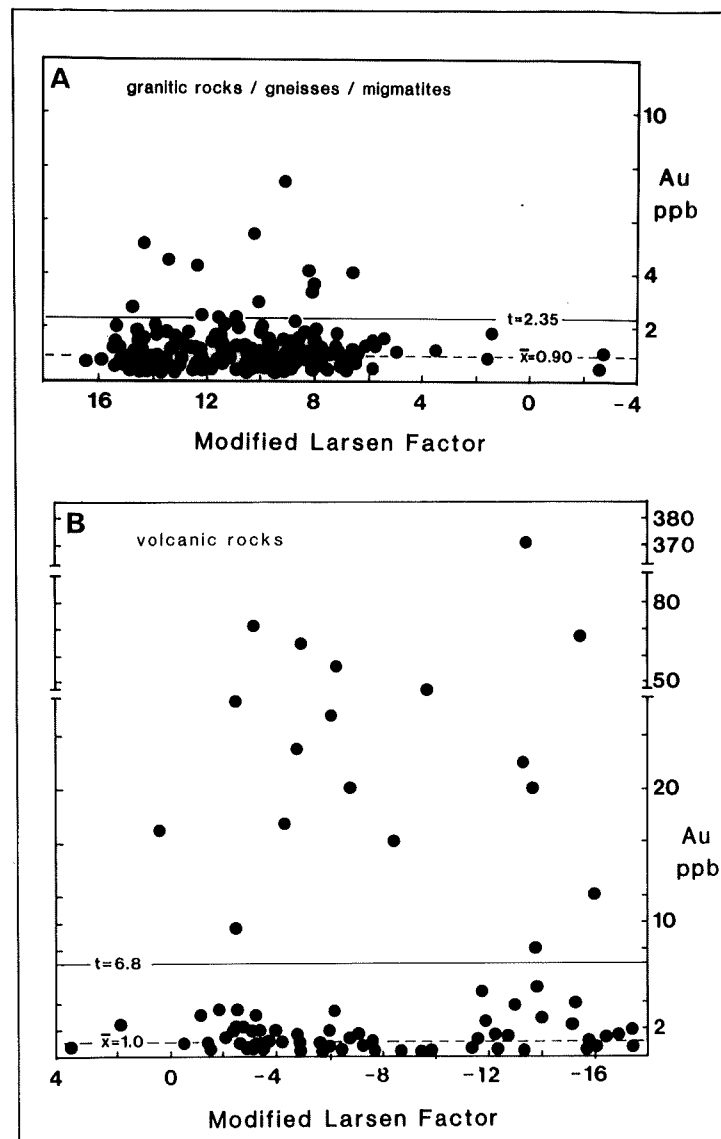


Figure 4 : A. Plot of modified Larsen factor versus Au contents of the granitic rocks

B. Plot of modified Larsen factor versus Au contents of metavolcanic rocks (after Saager et al., 1982)  $t$  = threshold values separating the background from the excess populations;  $\bar{x}$  = mean values of the background populations. For further information see text.

TABLE III  
PRODUCT MOMENT CORRELATION MATRIX FOR  
GEOCHEMICAL DATA

	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	Ni <sub>log.</sub>
Al <sub>2</sub> O <sub>3</sub>	-0,407							
Fe <sub>2</sub> O <sub>3</sub>	-0,883	0,165						
MgO	-0,805	0,066	0,807					
CaO	-0,791	0,263	0,784	0,810				
Na <sub>2</sub> O	0,072	0,209	-0,198	-0,194	-0,178			
K <sub>2</sub> O	0,309	-0,357	-0,301	-0,399	-0,598	-0,398		
Ni <sub>log.</sub>	-0,511	0,167	0,531	0,614	0,657	0,092	-0,604	
Au <sub>log.</sub>	-0,126	0,009	0,133	0,067	0,094	-0,005	-0,066	0,070

N: 180;  $r_{0,99} = 0,192$

TABLE IV  
R-MODE FACTOR MATRIX FOR THE GEOCHEMICAL DATA

	Factor 1	Factor 2	Factor 3	Communality
SiO <sub>2</sub>	-0,89102	-0,13014	-0,07206	0,81604
Al <sub>2</sub> O <sub>3</sub>	0,19032	0,58685	-0,02680	0,38134
Fe <sub>2</sub> O <sub>3</sub>	0,91897	-0,02540	0,08341	0,85210
MgO	0,92440	0,00464	-0,00094	0,85454
CaO	0,91636	0,19301	0,01809	0,87730
Na <sub>2</sub> O	-0,29949	0,80124	0,03808	0,73313
K <sub>2</sub> O	-0,40710	-0,77434	-0,02115	0,76578
Ni <sub>log.</sub>	0,67131	0,40771	0,00694	0,61694
Au <sub>log.</sub>	0,07390	0,00772	0,99549	0,99652
Sum of squares	4,08041	1,80714	1,00614	
Explained variability	47,9%	17,7%	11,0%	
Cumulative variability	47,9%	65,6%	76,6%	

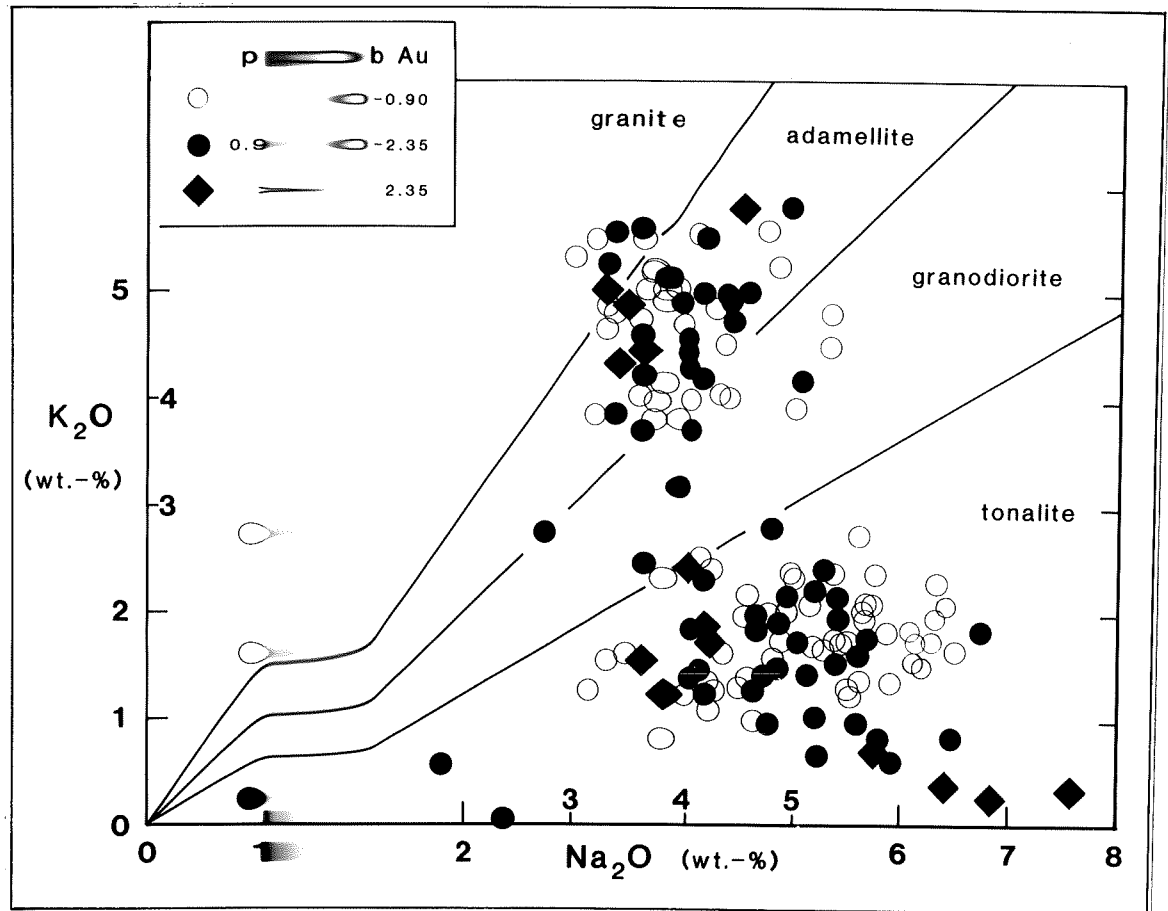


Figure 5 :  $K_2O$  versus  $Na_2O$  diagram of data from the granitic rocks.

The Au values obtained for the samples of the Eastern Transvaal granitic basement were grouped according to the scheme outlined by Anhaeusser and Robb (1981) with each Au value being assigned to one of the three magmatic cycles. The mean values (geometric mean and arithmetic mean), standard deviations, and ranges of the Au data for each of the three cycles, as well as those of the samples obtained from the Johannesburg dome, are provided in Table I.

The arithmetic and geometric mean values found for the rocks of the first and second magmatic cycles and the Johannesburg dome are almost identical, while the samples of the third magmatic cycle possess higher values for these measures of central tendency. Non parametric Kolmogorov-Smirnov two-sample tests (Miller and Kahn, 1965; Siegel, 1956) show, however, that the Au values of all the investigated paired sample populations (Johannesburg dome/first magmatic cycle, Johannesburg dome/second magmatic cycle, first magmatic cycle/third magmatic cycle, etc.) have been drawn from the same population at a 0,05 level of significance.



#### IV. GOLD DISTRIBUTION IN SUPRACRUSTAL ROCKS FROM SOUTHERN AFRICAN ARCHAEOAN GREENSTONE BELTS

Saager *et al.* (1982) investigated Mg, Cr, Fe, Co, Ni, and Au abundances in 98 samples of ultramafic and mafic metavolcanic rocks of (i) the upper greenstone assemblage of the Belingwe belt, Zimbabwe, (ii) the Tjakastad Subgroup of the Barberton greenstone belt, Eastern Transvaal, and (iii) the Mathiba and Eersteling Formations of the Pietersburg greenstone belt, Northern Transvaal. In addition, these authors determined Cr, Co, Ni, Au, Th, and U abundances in 32 samples of ferruginous cherts and oxide facies banded iron-formations of the major South African greenstone belts and also of the Pongola (Mozaan Group) and Witwatersrand (West Rand Group) basins. The mean Au values found by Saager *et al.* (1982) are given in Table V.

TABLE V  
ARITHMETIC MEANS, STANDARD DEVIATIONS, GEOMETRIC MEANS  
AND RANGES OF AU CONTENTS IN VARIOUS SOUTHERN AFRICAN  
GREENSTONE BELTS AND IN FERRUGINOUS CHEMICAL SEDIMENTS  
(from Saager *et al.*, 1982)

Sample area	N	$\bar{x}$ ppb	s ppb	G ppb	range ppb
Southern African greenstone belts (Belingwe belt, Pietersburg belt, Barberton Mountain Land)	98	10,8	39,6	2,1	0,1-372
South African greenstone belts (Pietersburg belt, Barberton Mountain Land)	47	2,4	3,8	1,3	0,4-20,2
Barberton Mountain Land (type locality of Komati Formation)	12	1,0	0,5	0,9	0,4-2,1
Pietersburg belt (Eersteling area)	35	2,8	4,4	1,5	0,3-20,2
Belingwe belt (Ngesi River area)	51	18,6	53,8	3,1	0,1-372
Chemical Sediments (South Africa)	32	129,9	165,2	35,7	0,5-667

N: Number of samples;  $\bar{x}$ : arithmetic mean; s: standard deviation;  
G: geometric mean

When grouped geographically, these values also indicate regional differences of Au abundance in geologically, geochemically and petrographically similar volcanic rocks. Such regional differences are probably due to (i) heterogeneous Au concentrations in the upper mantle, (ii) differences in crustal development and mantle differentiation, and/or (iii) metamorphic and hydrothermal processes obscuring primary gold distribution patterns (Saager *et al.*, 1982).

For the metavolcanic rocks no correlation between Au and Mg, Fe, Cr, Co, and Ni could be found. According to Saager *et al.* (1982) this is an indication of the lack of a relationship between gold and the rock-forming minerals within these rocks. Factor analysis corroborated this observation and revealed the distinctly independent behaviour of gold.

As in the case of the granitic rocks, Saager *et al.* (1982) recognized the presence of "background" and "excess" Au values in the mafic and ultramafic metavolcanic rocks (Fig. 4). They also noted that the Au values in the metavolcanics showed no correlation with the modified Larsen factor (Fig. 4).

With respect to the Au values in the chemical ferruginous sediments analysed by Saager *et al.* (1982), a much wider range and distinctly higher mean values ( $\bar{x}$ , G) than those in either the granitic or metavolcanic rocks investigated were reported (Tables II and V).

Despite a careful microscopic examination of polished sections during this study and earlier (Saager *et al.*, 1982), the authors were not able to detect gold in the rock samples. Thus, the mineralogical siting of gold in rocks remains a matter of dispute and many workers, such as Boyle (1979), Keays (1981), and Saager *et al.* (1982), hold that accessory sulphide minerals are the most important carriers of gold and that some native, submicroscopic, grains of gold may also occur as intergranular particles. The presence of gold-bearing accessory sulphides and probably also of intergranular gold particles is indicated by the occurrence of the "excess" Au values and the distribution curves exhibiting a positive skew, both in the study by Saager *et al.* (1982) and the present investigation (see Figs. 3 and 4). A single normal distribution of Au values in a particular rock type can thus be used to indicate that its gold is solely hosted in rock-forming minerals. From their study of the Au distribution in phlogopite-peridotite samples of the Finero ultramafic complex in Switzerland/Italy, Saager *et al.* (1982) suggested that rock-forming and oxide-minerals contribute less than 0,5 ppb to the total Au content of these igneous rocks.

#### V. COMPARISON OF DATA FROM SOUTHERN AFRICAN GRANITIC AND SUPRACRUSTAL ROCKS

A comparison of some of the *geochemical data* obtained for the supracrustal rocks studied by Saager *et al.* (1982) with those for the presently investigated granitic rocks shows:

- (1) distinct differences in the measures of central tendency ( $\bar{x}$ , G) and also in the ranges of the Au values. Kolmogorov-Smirnov two-sample statistical tests indicate that the Au

values of the chemical sediments, metavolcanics and granitic rocks were drawn from different populations at an 0,05 level of significance. The chemical sediments were found to have the highest, and the granitic rocks the lowest mean values ( $\bar{x}$ , G),

- (2) a bimodal distribution for the chemical sediments, with the Algoma-type ferruginous sediments containing more gold than those of the Superior type. In contrast, the Au distribution in granitic rocks has a lognormal nature (Fig. 3) whilst that in the metavolcanic rocks is also lognormal but with a more pronounced positive skew. This latter observation explains the much larger proportion of "excess values" found in the metavolcanic rocks compared to the granitic rocks,
- (3) that the threshold value separating the "background value population" from the "excess value population" is about three times higher for the metavolcanic rocks than for the granitic rocks (Fig. 4). This indicates a more homogeneous distribution of Au values in the granitic than in the metavolcanic rocks. In spite of this difference in the threshold value it is interesting to note that for both rock groups the arithmetic mean Au values of the "background value populations" are almost identical, i.e. 1,0 ppb Au for the metavolcanic rocks and 0,9 ppb Au for the granitic rocks. From a statistical point of view this may allow the conclusion to be drawn that the Au content of rock-forming silicate minerals in the presently investigated granitic rocks does not exceed 1 ppb - a value somewhat higher than the one suggested by Saager *et al.* (1982) which was deduced from a study of sulphide-free phlogopite-peridotites,
- (4) that both the metavolcanic and granitic rocks exhibit a lack of correlation between gold and major and trace elements. Furthermore, factor analyses revealed a complete absence of any interrelationships between gold and other analyzed elements. This rules out that Au is systematically related to the rock-forming silicates in which, if present, Au probably occurs in defect structures of the crystal lattices,
- (5) that the Au values of both the granitic and metavolcanic rocks cannot be correlated with differentiation trends (Fig. 4), and
- (6) that the metavolcanic rocks exhibit regional differences in Au abundances which cannot be detected in the granitic rocks.

A comparison of the *mineralogy* of the two groups of rocks shows:

that the granitic rocks have a distinctly lower sulphide content than the supracrustal rocks. Rare particles of pyrite, generally forming inclusions in markedly more abundant magnetite and ilmenite, were found in only a few samples from the granitic rocks. On the other hand, the supracrustal rocks, in addition to ubiquitous pyrite and pyrrhotite, carry arsenopyrite, chalcopyrite and pentlandite.

## VI. DISCUSSION AND CONCLUSIONS

Gold abundance data obtained both from granitic as well as associated metavolcanic and metasedimentary rocks comprising a typical Archaean granite-greenstone gold province are rare. The present investigation, coupled with that of Saager *et al.* (1982), provides an unique opportunity to compare and contrast southern African granitic rocks and greenstone assemblages as potential sources of gold for epigenetic gold deposits formed by metamorphic secretion processes (Boyle, 1979). These findings might also help to explain why Archaean gold mineralization is preferentially located in greenstone assemblages within these provinces.

The Au distributions in the investigated granitoids and in the mafic and ultramafic metavolcanics studied by Saager *et al.* (1982) are of a lognormal nature and exhibit varying degrees of positive skew, the latter feature indicating the presence of excess gold values in the data set. For the analyzed granitic rocks the "excess value population" was shown to contain only 6 per cent of all gold values (Fig. 4). This is small when compared with the "excess value population" found in the metavolcanic rocks from greenstone belts which accounts for 19 per cent of the data (Saager *et al.*, 1982). These authors suggested that gold, occurring as inclusions and in solid solution in erratically distributed sulphides, and as intergranular submicroscopic native gold, is responsible for the "excess value population".

Of the accessory mineral phases present within the granitic rocks studied only pyrite - a known gold carrier - was found to be erratically distributed. All other accessories (i.e. magnetite, ilmenite, hematite, apatite, zircon, sphene, etc.) are more consistently and regularly distributed and are less likely to act as gold-bearers than pyrite or other sulphide phases. Thus, it is proposed that most of the gold in the granitic rocks studied is contained in pyrite. Similarly, whilst investigating precious metals in volcanic peridotite-associated nickel sulphide deposits in Western Australia Keays and Davidson (1976) also concluded that chalcopyrite and pyrite are the most important hosts of Au.

High gold contents in rock-forming minerals such as hornblende, biotite, or even feldspars, are reported from the Marysville quartz diorite stock, Montana, by Mantai and Brownlow (1967) and from various intrusive rocks in the USSR by Davletov and Dzhakshibayev (1970). Such a distribution is not in agreement with the positively skewed Au distribution patterns found in the present study and also in the investigations of Saager *et al.* (1982). Furthermore, high gold contents within major rock-forming silicates are also unlikely because of the absence of any relationship between Au and the analyzed major elements, as exhibited by statistical factor analyses.

Detailed microscopic studies have shown that by comparison with the granitic rocks, the metavolcanics contain many more and varied sulphide minerals. The latter rocks, thus, exhibit a less homogeneous Au distribution with a larger proportion of excess values and distinctly higher measures of central tendency ( $\bar{x}$  and G) (Tables II and V). This substantiates the previous statement that within the granitoids, as with

the greenstones, sulphide minerals - notably pyrite - are the principal carriers of gold. Furthermore, this casts some doubt on the supposed existence of intergranular particles of native gold contributing to the Au content of a rock.

Keays and Scott (1976) proposed that the suitability of a rock as a source for vein-type gold mineralization is largely dependent on the presence of gold which is readily accessible to migrating hydrothermal solutions (i.e. gold in sulphide minerals and intergranular native gold). If this is the case, and if our suggestion is correct, that pyrite and other sulphide minerals form the principal gold hosts within granite-greenstone assemblages, the conclusion can be drawn that granitic rocks are less suitable sources for gold than associated supracrustal rocks because the latter rock types can be shown to contain more sulphides than the granitoids. This conclusion coincides with field observations which reveal that Archaean gold mineralization is predominantly located within greenstone assemblages and not within the granitic rocks.

The granitic rocks from the Eastern Transvaal formed in response to three magmatic cycles inter-related by successive reworking of older material (Anhaeusser and Robb, 1981). This evolutionary process apparently did not affect the Au distribution within these rocks in a systematic way (Fig. 5). Similarly, the absence of a differentiation trend for Au (Fig. 4) is also apparent in the mafic-to-ultramafic range of metavolcanic rocks (Saager *et al.*, 1982). In addition, both the granitic rocks (made up essentially of felsic silicates) and the meta-volcanics (comprising largely mafic silicates) possess almost identical mean Au contents with respect to their "background value populations" (Fig. 4). This observation provides a further indication that Au apparently has an inert behaviour during differentiation processes (see also Gottfried and Greenland, 1972; Gottfried *et al.*, 1972; and others). It also indicates that both mafic and felsic minerals show no systematic differences of their Au contents which are similar and probably do not exceed one ppb. This differs markedly from the view expressed by many Russian workers (Davletov, 1970; Davletov and Dzhakshibayev, 1970; Zvereva and Gavrilenko, 1971; Shcherbakov, 1967; Shcherbakov and Perezhogni, 1964 and also by Gottfried *et al.* (1972) who observed that gold tends to be higher in the mafic minerals. Because gold is preferentially hosted in sulphide minerals it is proposed that the precipitation of gold from a crystallizing magma is essentially determined by its sulphur fugacity. Systematic trends in Au contents reported from differentiated rock suites are, therefore, rather influenced by different sulphide contents of these rocks and do not indicate a differentiation trend of Au (*per se*) during magma crystallization.

In concluding, it is pertinent to comment on a paper by Keays (1981) in which it was proposed that within a crystallizing magma early sulphur saturation, occurring before the extrusion of magma, appears to lead to the formation of an immiscible sulphide melt which depletes the coexisting silicate melt in gold. In the light of both the present investigation and Keays' (1981) suggestion one may speculate that the presence or absence of gold-hosting sulphides in ultramafic-to-mafic volcanics might be of importance from the exploration point of view. For example, the presence of such phases which would be indicated by the existence of a distinct "excess Au value population" - exceeding 10 to 15 per cent of the total data set - could be used as an indication

whether the parent magma of the volcanic rocks studied had achieved sulphur saturation or not before its extrusion. A large "excess Au value population" would, accordingly, suggest that no immiscible sulphide phase had formed and that the likelihood of forming a massive sulphide ore was reduced.

Applying this hypothesis to the Au data from the unmineralized upper volcanics of the Belingwe greenstone belt - a succession which displays a pronounced "excess Au value population" (Saager *et al.*, 1982) - it appears that no immiscible sulphide melt formed during the freezing of this magma. This accords with results reported by Leshner *et al.* (1981) who compared the Ni and Co content of Belingwe volcanics with theoretical curves for sulphide undersaturated olivine fractionation given by Duke (1979). From this Leshner *et al.* (1981) concluded that the rock suites at Belingwe had not been depleted in chalcophile elements by a scavenging immiscible sulphide liquid. Consequently, sulphur saturation, and the consequent processes of massive sulphide mineralization, may not have been applicable at Belingwe.

As another example, Au data as well as the Ni, Co and MgO concentrations given by Saager *et al.* (1982) for komatiitic samples of the Pietersburg greenstone belt, indicate that the parental magma of these rocks was similarly not depleted in chalcophile elements and gold by a scavenging sulphide phase. Thus, the occurrence of massive sulphide mineralization in the volcanic rocks of the area investigated also seems unlikely.

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