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# THE ORIGIN OF GOLD IN ARCHAEAN EPIGENETIC GOLD DEPOSITS

by

M. MEYER and R. SAAGER

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## ABSTRACT

Gold deposits in Archaean granite-greenstone environments, especially gold-quartz veins, contribute materially to the world's gold production. The formation of epigenetic gold mineralization in greenstone belts is generally explained by the metamorphic secretion theory which assumes that the source of the gold may be komatiitic or tholeiitic lavas, pyritic chemical or clastic sediments, and even granitic rocks. This gold is believed to have been extracted and concentrated in suitable structures as a result of regional metamorphism.

It has been shown that in potential source rocks gold is predominantly associated with sulphide minerals and thus, relatively more accessible to secretion and reconstitution processes.

A large number and variety of rock types originating from granite-greenstone terranes of the Kaapvaal and Rhodesian cratons were geochemically investigated and the following ranges for gold determined:

| | | |
|---|---|---|
| volcanic rocks (komatiitic and tholeiitic) | : | 0,1 - 372 ppb |
| granitic rocks of the basement | : | 0,3 - 7,8 ppb |
| iron-rich chemical sediments | : | 1,0 - 667 ppb |

Statistical treatment of the data reveals that volcanic rocks, as well as iron-rich chemical sediments, are favourable sources for epigenetic gold mineralization formed by metamorphic secretion, whereas granitic rocks are less favourable primary gold sources. The close spatial relationship linking gold-quartz veins and greenstone belts is explained by these findings. The prevalence of epigenetic gold deposits in the Archaean is, however, attributed to the unique geologic and metamorphic history of the granite-greenstone terranes.


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# THE ORIGIN OF GOLD IN ARCHAEAN EPIGENETIC GOLD DEPOSITS

## I. INTRODUCTION

Gold occurrences in Archaean granite-greenstone terranes contribute about 200 t of gold to the world's annual gold production which presently amounts to approximately 1300 t.

The Archaean gold occurrences include massive sulphide-hosted ores, fossil placers, and banded iron-formations. An additional important class comprises the epigenetic gold deposits associated with quartz veins. Gold-quartz veins with a close spatial link to Archaean greenstones are known to occur on a world-wide scale, for instance in the Barberton Mountain Land, South Africa, in the Golden Mile of the Kalgoorlie District, Western Australia, and in the Abitibi greenstone belt of the Superior structural province, Canada.

Prior to 1960 the metallogenetic concept that was favoured to explain the formation of gold lodes was the magmatic hydrothermal theory. This associated ore formation with granitoid intrusions from which the gold-bearing solutions were derived. The formation of vein-type deposits, based on the lateral secretion concept, had previously been suggested by Sandberger (1882). Adopting this approach Knight (1957) proposed the so-called source bed concept and stated "... that all sulphide ore bodies in the majority of fields are derived from sulphides that were deposited syngenetically at one particular horizon in the sedimentary basin constituting the field and that sulphides subsequently migrated in varying degree under the influence of rise in temperature of the rock environment".

Boyle (1955, 1959) and Wanless *et al.* (1960) adopted the source bed concept to explain the formation of gold-quartz veins in the Yellowknife greenstone belt, Canada. These authors, employing the metamorphic secretion hypothesis, assumed that the gold, silver, and gangue minerals initially present in the country rocks were mobilized and concentrated in suitable tectonic structures and chemical traps during metamorphism. This metallogenic concept was subsequently used by a number of authors to explain many Archaean gold lodes. In Southern Africa, Viljoen *et al.* (1969) suggested that the ultimate source of the gold in vein deposits of the Barberton Mountain Land was the "gold enriched" primitive komatiitic lava of the Tjakastad Subgroup. From this source it was mobilized and concentrated in dilatant zones as a result of the influence of granitoid intrusions. According to Viljoen *et al.* (1969) a number of succeeding, in part, sedimentary, but predominantly metamorphic, concentration processes were necessary to form the economic deposits.

Ridler (1970) postulated a syngenetic-metamorphic origin for the gold deposits of the Kirkland Lake-Larder Lake deposits in Ontario, Canada. According to Ridler the gold was mainly derived from banded iron-formations where it was originally present as "exhalite" mineralization of extremely low grade. Similarly, Lavreau (1984), investigating gold deposits in northern Zaire, proposed a two-stage model for the formation of gold lodes whereby primary, sub-economic, gold concentrations occurred in banded iron-formations as a result of fumarolic activity and secondary economic concentration was produced by magmatic-induced thermal effects and metamorphic overprinting.

By contrast, Anoshin and Potapyev (1966), proposed granitoids as the primary source of gold for deposits in the Altai and Transbaikalian regions of the USSR. These authors describe metamorphosed and hydrothermally altered granitoids from which gold was released and concentrated in quartz veins. A third possible source for epigenetic gold mineralization was shown by Glasson (1975) to be associated with black shales.

Because of these contrasting views on the source of gold Tilling *et al.* (1973) concluded that "the difference in gold content among common rock types (igneous and other) are simply too small, relative to the more than thousand fold gold concentration needed to produce ore grade material, for any particular rock to be considered a more favourable source than another".

In any metallogenic concept, based on metamorphic secretion, the availability and, therefore, the siting of gold in potential source rocks is of great importance. For this reason the mineralogical siting of gold in various types of potential source rocks has been discussed by a number of workers (Boyle, 1979; Gottfried *et al.*, 1972; Tilling *et al.*, 1973; Crocket, 1974; Ramdohr, 1975; Keays and Scott, 1976; Saager *et al.*, 1982; and others). In most papers a preferential association of gold with sulphides is suggested, but it is still unclear whether gold occurs in solid solution or as submicroscopic inclusions in sulphides. The presence of gold in sulphide minerals is of great importance as the gold hosted in these minerals can easily be leached by migrating solutions and is thus available to metamorphic secretion processes, whereas gold hosted in silicates or oxides is not readily accessible to leaching fluids.

Another important consideration is a knowledge of the behaviour of gold during magmatic differentiation. Some workers have proposed a general decrease of the precious metal from mafic to felsic rocks (Shcherbakov, 1967; Tilling *et al.*, 1973), whereas others (Vincent and Crocket, 1960; Gottfried and Greenland, 1972; Saager *et al.*, 1982) concluded that gold behaves inertly during differentiation.

Keays (1981) related the behaviour of gold during differentiation of a silicate melt to the formation of an immiscible sulphide melt. According to this model, the gold content of a differentiated silicate melt increases until sulphur saturation is reached after which the melt is depleted of gold by segregation of immiscible sulphide droplets. Saager and Meyer (1984) stated that "... systematic trends in gold contents reported from differentiated rock suites are (rather) influenced by different sulphide contents of these rocks and do not indicate a differentiation trend of gold *per se* during magma crystallization".

The present study is aimed at resolving the relationship between the occurrence of gold lodes and their surrounding country rocks in Archaean greenstone terranes. For this purpose a large number and variety of rock types originating from Southern African greenstone belts and basement granitoids (Fig. 1) were geochemically and mineralogically investigated.

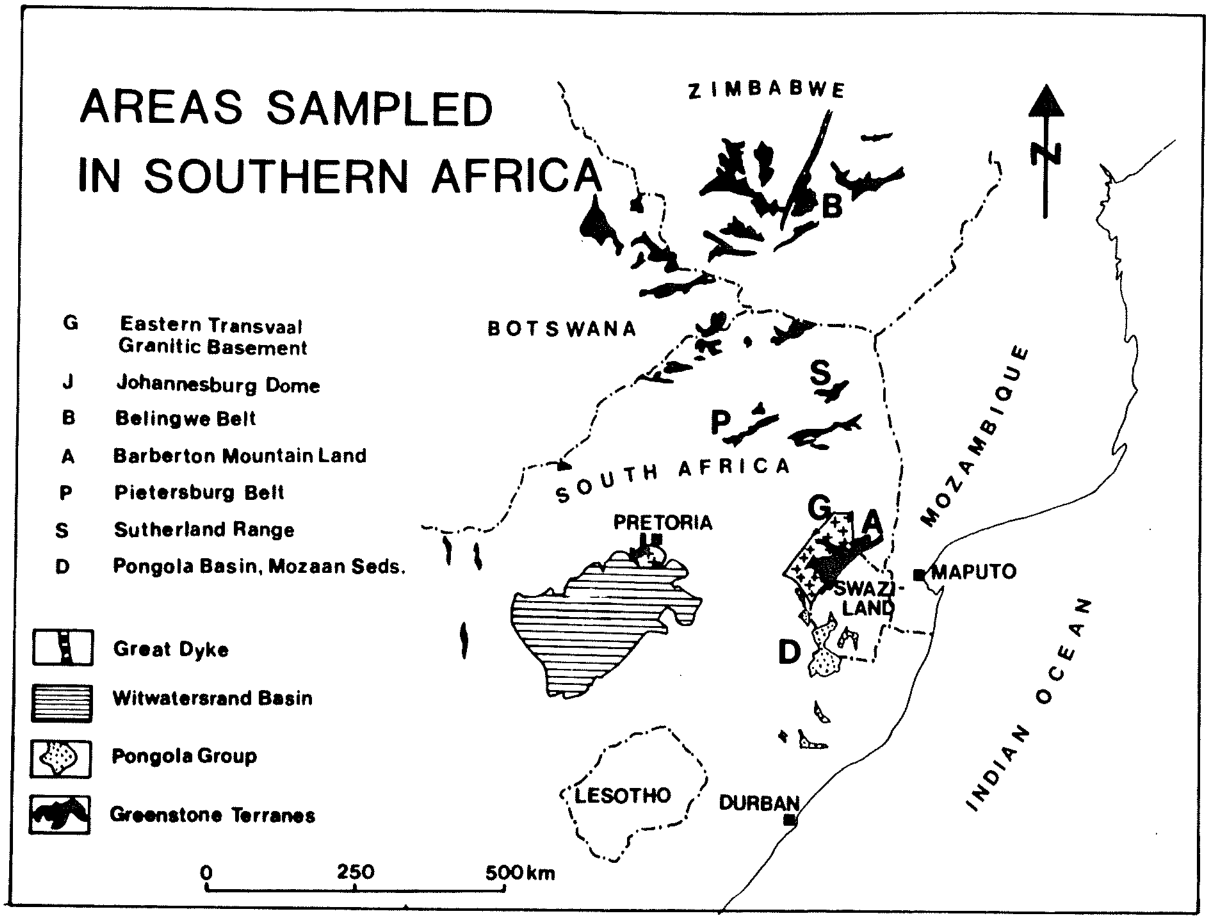



*Figure 1* : *Geologic sketch map of Southern Africa showing areas sampled for this study.*

## II. SAMPLE DESCRIPTION

The 98 samples of *volcanic rocks* investigated in this study include peridotitic and basaltic komatiites and tholeiitic lavas collected from the Reliance and Zeederberg formations of the Belingwe greenstone belt, Zimbabwe, the Eersteling Formation of the Pietersburg greenstone belt South Africa, and the Tjakastad Subgroup of the Barberton greenstone belt also in South Africa. The various sampling areas are shown in Fig. 1. More detailed petrographic and geochemical descriptions of the samples are given in Viljoen and Viljoen (1969), Nisbet *et al.* (1977), Saager and Muff (1978), and Saager *et al.* (1982).

Two hundred and twelve samples of *granitoid rocks* were also collected from the Archaean granitic basement of the Eastern Transvaal and from the Johannesburg Dome (Fig. 1). The geologic setting of the sampling areas, as well as the petrology and geochemistry of the granitoids, are described by Anhaeusser (1973), Robb and Anhaeusser (1983), and Saager and Meyer (1984). The granitic basement of the Eastern Transvaal which evolved in three tectono-magmatic cycles genetically inter-related by successive reworking of older material, is made up *inter alia* of tonalite/ trondhjemite gneisses and migmatites, granodiorites, adamellites, syeno-granites, and granites.

Twenty-four samples of *banded ferruginous chert and banded iron-formation* were collected from the Ysterberg and Eersteling formations of the Pietersburg greenstone belt, the Moodies and Fig Tree groups of the Barberton greenstone belt, the Sutherland greenstone belt, and the Mozaan Group of the Pongola Supergroup (Fig. 1). Details of the geology of these areas and sample descriptions are given in Saager and Muff (1978), Saager *et al.* (1979), and Saager *et al.* (1982). These iron-rich chemical sediments are considered to be similar to Algoma-type banded iron-formations.

All the sedimentary and volcanic rocks investigated have been subjected to a weak regional metamorphism corresponding to the lower greenschist facies.

## III. RESULTS

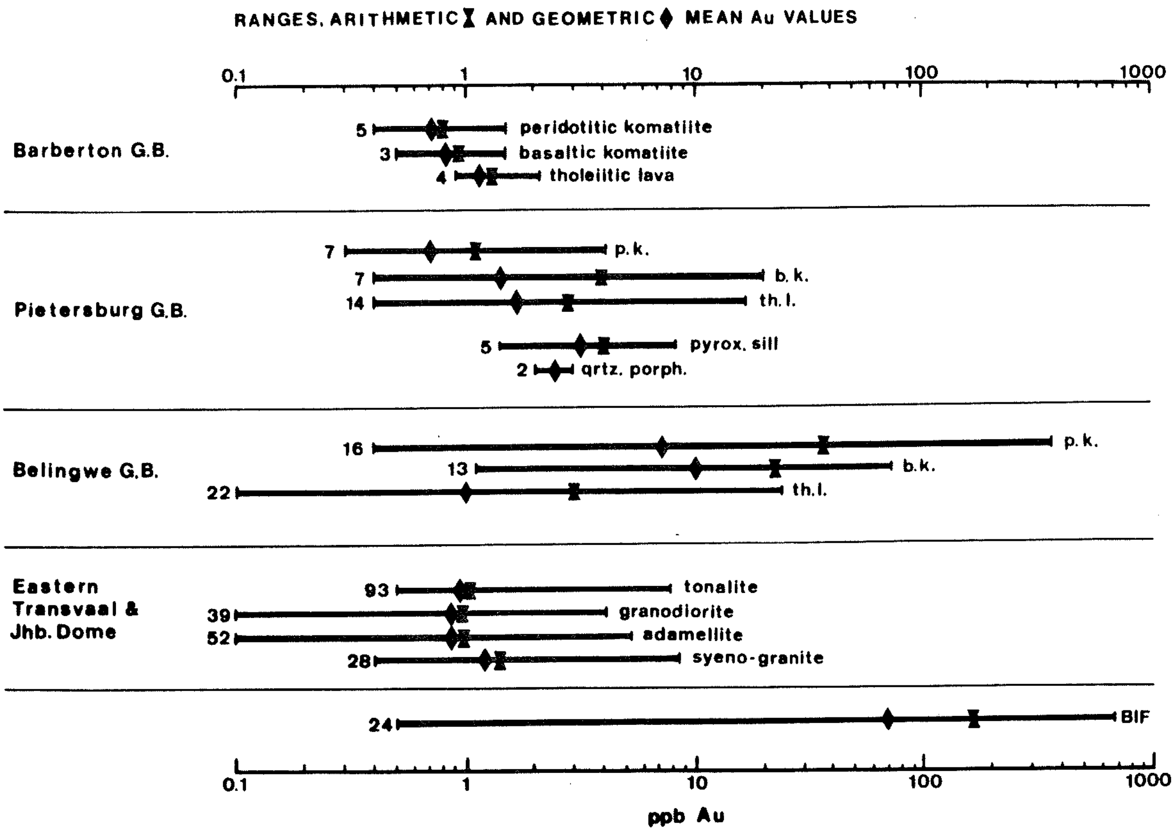
The abundances of gold, nickel, and cobalt were determined by instrumental epithermal neutron activation analyses (IENAA). To analyse the nickel and copper contained in sulphide minerals a sulphide selective leach (Olade and Fletcher, 1974) was employed and the two elements determined by means of conventional atomic absorption spectrometry (AAS).

In addition, pyrite concentrates, recovered by hydrofluoric acid treatment (Neuerburg, 1975) of hand specimens and/or hand picking from gently crushed samples were analysed for their gold contents by IENAA. The samples containing pyrite were obtained from various gold mines in the Barberton and Murchison greenstone belts and from a serpentinite (Msauli area) and a basaltic komatiite (type locality of the Tjakastad Subgroup), both in the Barberton greenstone belt.

Ranges and arithmetic and geometric mean values of the gold data obtained for the various rock types and/or sampling areas studied are given in Fig. 2. This data reveals that, among the volcanic rocks, the samples from the Barberton Mountain Land possess the lowest mean values and smallest ranges, whereas the volcanic rocks from the Belingwe greenstone belt have the largest range and highest mean gold values. The Pietersburg volcanic rocks occupy an intermediate position. Saager *et al.* (1982) showed that the relatively higher gold tenor obtained for the Belingwe samples is statistically significant. They interpreted this regional enrichment to reflect an inhomogeneity of gold abundance in the upper mantle from which the rocks were derived.

If the volcanic rocks are grouped into peridotitic and basaltic komatiites and tholeiithic lavas, non-parametric Kolmogorov-Smirnov statistics indicate that the rocks are drawn from the same population.

As indicated by the bar-diagram (Fig. 2) the granitic rocks possess low mean gold values which, in a general way, can be compared with those found in the volcanics of the Barberton greenstone belt. However, the granites show markedly larger variations in their gold values. Saager and Meyer (1984) have already pointed out that the gold distributions in the various types of granitic rocks do not differ systematically. The largest variation in gold content and the highest mean values of all investigated rock types occur in the ferruginous chemical sediments.




<u>*Figure 2*</u> *: Bar-diagram showing number of samples analysed, ranges, arithmetic, and geometric mean gold values for the various rock types and/or sampling areas.*

Comparison by Kolmogorov-Smirnov statistics of the gold abundance data obtained for the three groups of rocks studied (i.e. volcanics, granitoids, and sediments) shows that the gold distributions of these rock types belong to three different populations (Fig. 3).

The sulphide content of the rocks studied was inferred by measuring the amount of nickel and copper in the sulphide leach ($Ni_{sul.}$ and $Cu_{sul.}$). This procedure is permissible as nickel and copper in the rocks studied are chiefly contained in sulphide minerals. The scattergrams of Au versus $Ni_{sul.}$ and Au versus $Cu_{sul.}$ (Fig. 4) do not indicate obvious correlations between the variables. However, when evaluating the scattergrams it must be realized that the analysis of $Ni_{sul.}$ and $Cu_{sul.}$ on the one hand, and Au on the other, was carried out using two methods (AAS and IENAA) and two sets of aliquants. The lack of obvious correlation may, furthermore, be caused by the presence of rare particulate gold in certain aliquants, as discussed by Saager *et al.* (1982).

The suggestion that sulpdide minerals are important gold carriers is emphasized by the analyses of two pyrite concentrates obtained from rocks of the Barberton greenstone belt (Table I). The analyses indicate

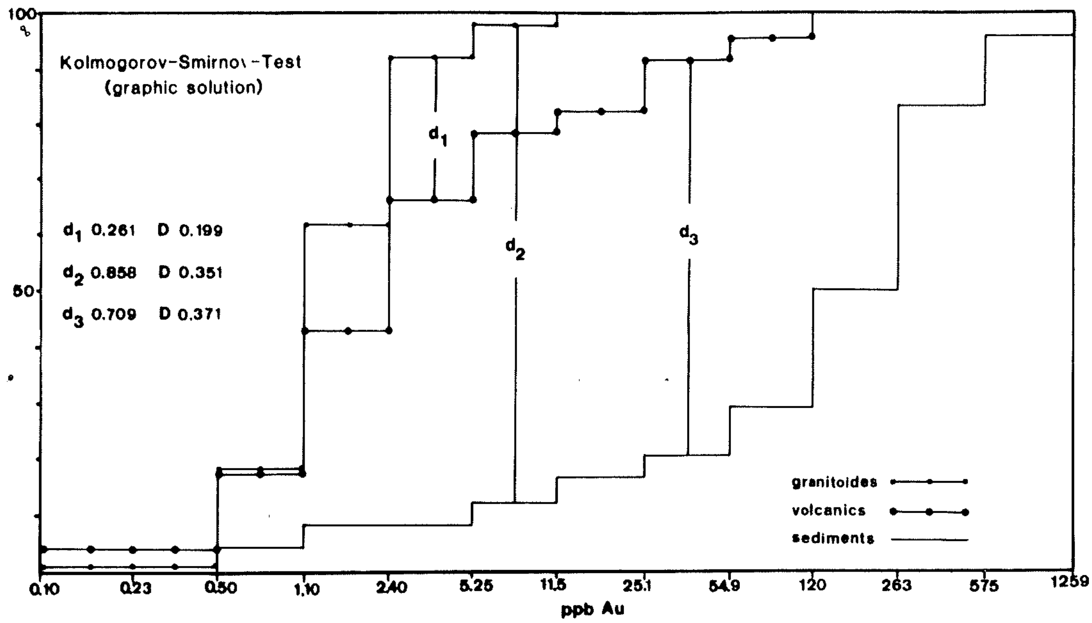



*Figure 3* : *Graphical Kolmogorov-Smirnov test of gold distributions in the granitic, volcanic, and sedimentary rocks investigated. Note that for the three sample pairs the calculated d-values exceed the critical values of D.*

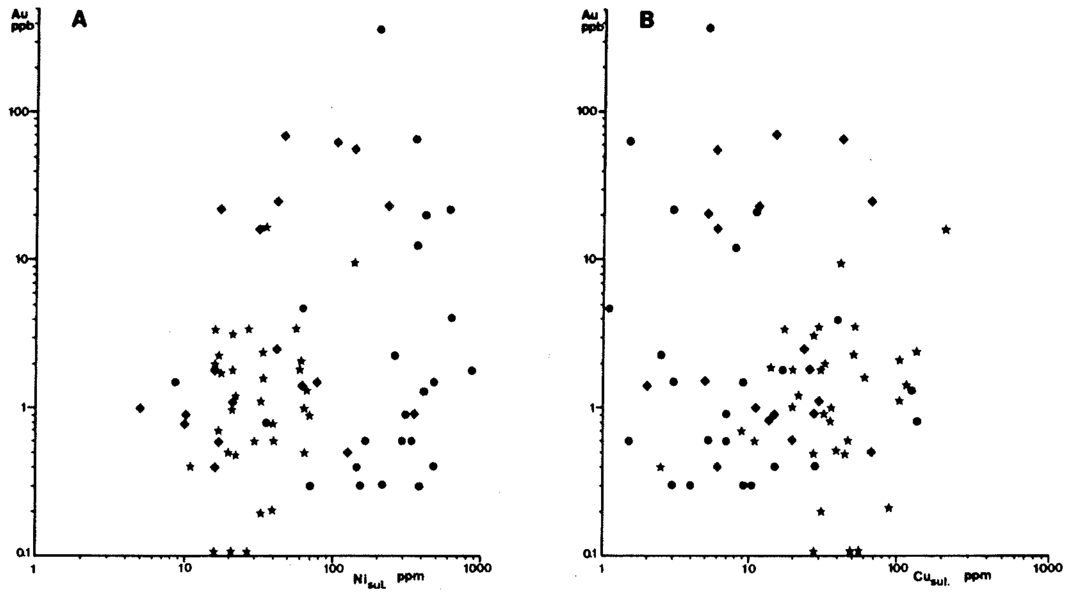



*Figure 4* : *A: Plot of $Ni_{sul.}$ versus Au contents of peridotitic and basaltic komatiites and tholeiitic lavas.*

*B: Plot of $Cu_{sul.}$ versus Au contents of peridotitic and basaltic komatiites and tholeiitic lavas.*

- ● *periodotitic komatiites*
- ♦ *basaltic komatiites*
- ⋆ *tholeiitic lavas*

that the mean gold value found for the komatiites of the Barberton greenstone belt ($\bar{x}$=0,8 ppb) could be explained by a pyrite content of as little as only 0,3 per cent in these volcanics. This estimation assumes that gold is solely hosted in various sulphide minerals and that their gold content approximates that found in the pyrite concentrates of volcanic rocks ($\bar{x}$=260 ppb).

TABLE I

Arithmetic Means, Standard Deviations, Geometric Means, and Ranges of Gold contents in Pyrite Concentrates from Gold Mines of the Barberton and Murchison Greenstone Belts and from a Serpentinite and a Basaltic Komatiite from the Barberton Mountain Land.

| pyrite concentrates from: | N | $\bar{x}$ (ppm) | s | G | range |
|---|---|---|---|---|---|
| Barberton gold mines | 17 | 20,9 | 25,7 | 6,73 | 0,01-96,2 |
| Murchison gold mines | 5 | 8,7 | 18,9 | 0,27 | 0,01-42,5 |
| rocks of the Barberton greenstone belt | 2 | 0,3 | 0,1 | 0,26 | 0,20-0,33 |

## IV. DISCUSSION

When discussing the source of gold in Archaean epigenetic gold deposits formed by metamorphic secretion processes, the following points are commonly considered: (i) gold abundances of the potential source rocks; (ii) availability of the gold, i.e. its mineralogical siting in the source rocks; and (iii) metamorphic overprint of the source rocks and element transport by hydrothermal solutions, i.e. the metamorphic secretion.

Examination of Fig. 2 is, therefore, of interest as it reveals that for the Barberton and the Pietersburg greenstone belts no statistically significant differences in gold abundances are observable, at least with respect to the volcanic rocks. In both terranes the rocks are affected by greenschist facies metamorphism and by structural disturbances that were possibly somewhat more intense in the Pietersburg belt than in the Barberton belt.

Gold abundances in the komatiites from the little altered Belingwe belt, as pointed out earlier, is higher than that of equivalent volcanics from the South African greenstone belts. The gold abundances of the tholeiites of the Belingwe belt, on the other hand, do not differ from those of the other tholeiites studied.

Saager *et al.* (1982) investigated the siting of gold in komatiitic and tholeiitic volcanics and observed an "excess population" of higher gold values which they attributed to the presence of gold in sulphide minerals. Such gold, according to Keays and Scott (1976), can readily be leached by hydrothermal solutions and is, therefore, available to metamorphic secretion processes. In spite of the lower gold levels in the volcanics of the Barberton and Pietersburg greenstone belts, these terranes nevertheless contain a number of epigenetic gold deposits which have been, or still are, economically exploited. Such deposits, however, are unknown from the Belingwe greenstone belt. This indicates that the specialization of gold abundances on a regional scale, in addition to being a result of upper mantle inhomogeneities, may also be influenced by varying degrees of metamorphic alteration, especially in the case where genetically related epeigenetic gold mineralization is present. In other words, the lower gold levels observed in the Barberton and Pietersburg greenstone belts may be a result of gold depletion by metamorphic processes.

Gold abundances in the granitoids surrounding and intruding the greenstones of the Barberton Mountain Land do not differ from those of the latter rocks. Noteworthy, however, is the fact that no gold mineralization is known to occur in the granitic terrane. This suggests that the gold in the granites may not be hosted in leachable phases and, therefore, could not be transported and enriched by secretion processes. Alternatively, it could also mean that no metamorphic secretion processes occurred within the granitoids. Saager and Meyer (1984), who studied the mineralogical siting of gold in the granitoids, found that these rocks exhibited a much smaller "excess population" of gold values than the volcanic rocks. They concluded that readily leachable gold in sulphide minerals is much scarcer in granitoids than in volcanics and, consequently, suggested that granitoids are a "less suitable source of gold than the adjacent greenstone volcanic assemblage".

Among all the rock types investigated the oxide facies ferruginous cherts and banded iron-formations possess the largest range of gold values and, by far, the highest geometric mean gold value. The siting of the gold in these chemical sediments, which are probably of volcanogenic origin, is unknown. The occurrence of quartz veins carrying gold within, or adjacent to, strongly deformed banded iron-formation is, however, an indication that metamorphic secretion took place and that the gold in the source rock was present in a readily leachable form. The rather impermeable nature of the chert-rich sediments may be an explanation for the small size of the gold-bearing veins in banded iron-formation of the area studied and, to a certain extent, might also explain the absence of pronounced regional gold depletion in these rocks.

Many authors (Anhaeusser *et al.*, 1969; Anhaeusser, 1975, 1983; Groves *et al.*, 1978; Windley, 1981; and others) have emphasized the unique tectonic evolution of granite-greenstone terranes. This may be the main reason for the conspicuous abundance of epigenetic gold mineralization in Archaean greenstone belts. Intrusion of diapiric granitoids into a thin, unstable early crust was mainly responsible for the thermo-dynamic metamorphism in Archaean greenstones. According to Anhaeusser (1975), the intrusion of tonaltic and trondhjemitic diapirs was accompanied by gravity-induced downsagging of adjacent greenstones resulting in a preferential development of synclines, with adjacent anticlines being faulted out by high-angle slides. Compressional tectonics, large-scale low-angle thrusts accompanied by nappe-development, and intense metamorphism typical of alpine-type orogenies, are not regarded as being of dominant importance in terms of Archaean tectonic evolution.

The tectonic style outlined above resulted, at least within certain spatially restricted areas, in the unique preservation of weakly metamorphosed zones juxtaposed with strongly-deformed greenstones adjacent to intrusive granitoids. In competent greenstones structural deformation may have led to the development of dilatant zones (faults, shears, fractures, etc.) which acted as sinks of gold and other elements transported by migrating metamorphic secretions. In such a model the adjacent intrusive granites acted solely as a heat source generating the secretion processes, and did not contribute directly to the ore forming elements. The latter, together with the transporting aqueous fluids, must have been derived from the greenstones in which the epigenetic deposits now occur.

In more recent alpine-type mountain ranges the nature of tectonism may often have resulted in a spatial separation between the source rock, the heat anomaly causing metamorphic secretion (e.g. granite intrusions), and the host rocks. Such separation will have hindered the formation of epigenetic gold mineralization formed by metamorphic secretion, and might be the main reason that areas of post-Archaean orogenesis represent less important gold provinces than equivalent geologic terranes of Archaean age.

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