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Archean Metallogeny in Southern Africa

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Abstract

The Archean granite-greenstone terrain of southern Africa possesses a number of unique characteristics. Not only is the shield area one of the smallest in the world but it is also one of the oldest crustal fragments still preserved. Estimates of lithic proportions show that, in the southern African Archean, the granitic rocks outnumber those of the volcanic belts (greenstone belts) by approximately 6:1—in marked contrast to the situation on the Canadian Shield where granite: greenstone ratios have been estimated to be approximately 1:2.

In order to establish further details of the lithological proportions, the southern African Archean greenstone belts are described in terms of a three-stage stratigraphic model involving a Lower Ultramafic Unit at the base, followed by a Mafic-to-Felsic Unit and a terminal Sedimentary Unit. Planimeter studies demonstrate that on average the southern African greenstone belts possess a relatively high proportion of ultramafic and mafic volcanic and plutonic rock types and a correspondingly lower proportion of rocks of intermediate to felsic composition. The relative abundances of the various volcanic components of the lower two stratigraphic units are tabulated, and the lithic proportions are compared with similar data available from greenstone belts of the Superior Province in Canada. Geochemical data illustrating the nature of Archean volcanism in southern Africa and elsewhere are made available for purposes of comparison.

The distribution patterns of a wide variety of Archean mineralization types, including the deposits associated with the ancient granites and pegmatites, are illustrated by means of mineral distribution maps. A close genetic relationship exists between the various lithological subdivisions of the Archean greenstone belts and the mineralization. Important deposits of chrome, nickel-copper, gold, and chrysotile asbestos are associated with the ultramafic-mafic component of the volcanic pile, whereas antimony, gold, and lesser amounts of mercury, barite, corundum, copper-lead-zinc, and massive sulfide iron-formations occur throughout the greenstone piles and commonly occur as chemical sediments terminating cycles of volcanism. These well-banded rocks, which probably formed by fumarolic-exhalative processes, also contain significant stratiform gold mineralization.

The Archean mineralization of southern Africa is briefly compared and contrasted with that of the Canadian Shield and elsewhere. It is concluded that the disparity of lithological types and proportions between the Canadian and southern African shields is, together with differences in age, the underlying cause of the variability in the mineralization thus far encountered in the two regions.

Introduction

The early Precambrian (Archean) granite-greenstone terrain that forms part of the southern African Shield constitutes one of the oldest known fragments on the earth's surface. Underlying the eastern part of Botswana, the northeastern segment of South Africa, and Rhodesia, the shield consists of two cratons—the Kaapvaal and the Rhodesian Cratons—separated by the Limpopo high-grade metamorphic belt. Ranging in age from 2,700 to 3,500 m.y. (or even older), the region acts as basement to a unique series of cratonic basins which formed under continental conditions as far back in time as 3,000 m.y. ago (Anhaeusser, 1973a; Pretorius, 1974a). Although the bulk of the mineral wealth of the African subcontinent has largely come from these basins (Pretorius, 1973; 1974a, b), the older Archean granite-greenstone terrain has the distinction of having been the principal source of much of this mineralization (which includes gold and uranium), as well as of currently contributing the most diversified range of mineral types and products exploited in southern Africa.

The purposes of this paper are, briefly, to consider the nature and distribution of Archean mineralization in southern Africa and to relate the mineral deposits to one another and to the geological environments in which they occur. Furthermore, it has become apparent that, despite the many similarities that exist between the Archean shield areas of the world (Anhaeusser et al., 1969) there are also significant differences, the latter reflected in the variable geochemical nature of the volcanic sequences (Wilson et al., 1965; Baragar and Goodwin, 1969; Viljoen

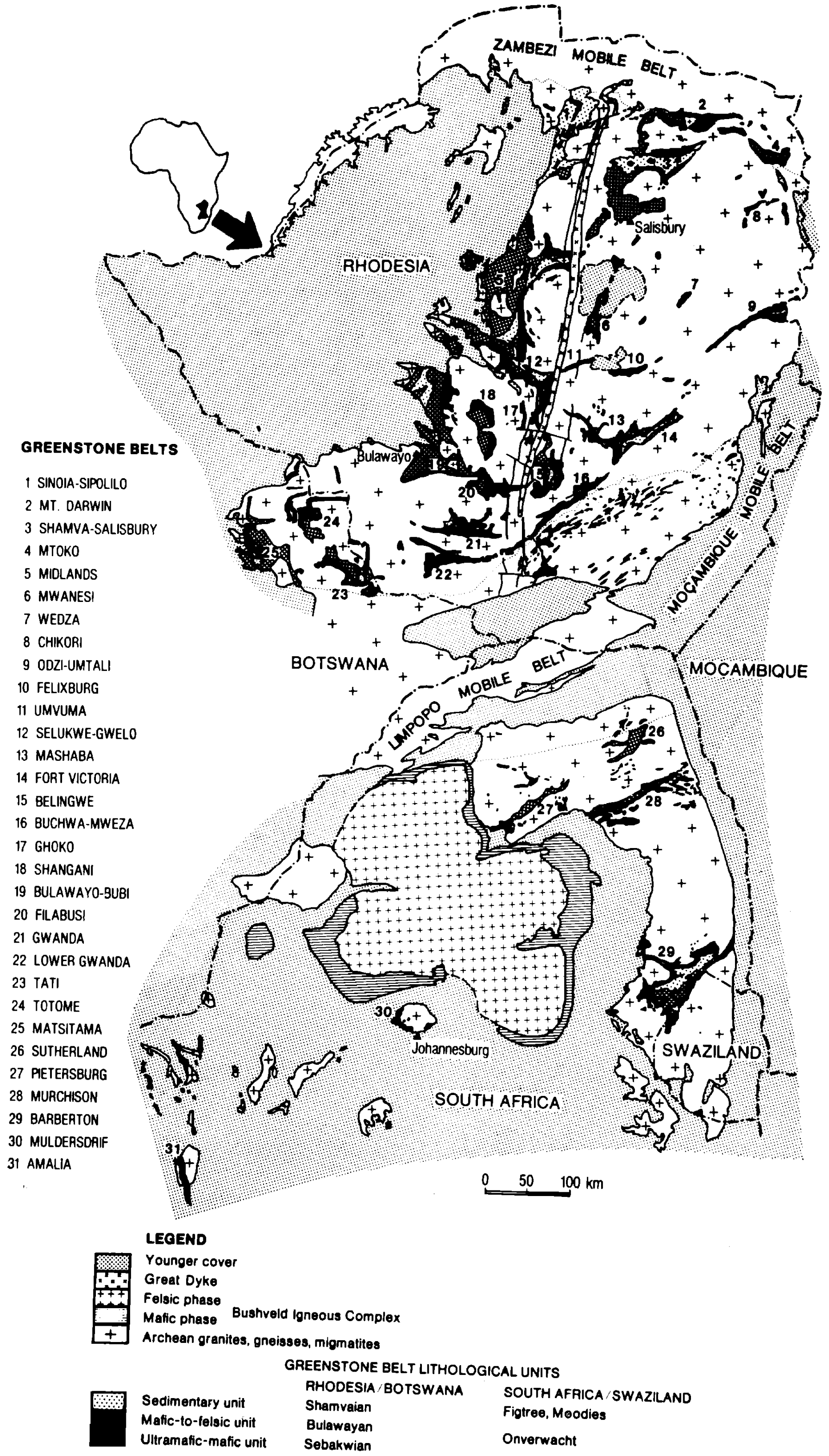

FIG. 1. Map illustrating the exposed Archean granite-greenstone terrain of the Rhodesian and Kaapvaal Cratons, southern Africa.

TABLE 1. Areal Extent and Relative Proportions of Archean and Younger Sequences Developed on the Rhodesian and Kaapvaal Cratons

Crustal Fragment	Area (km²)	Exposed Archean (km²)	Exposed Granites (km²)	Exposed Greenstone Belts (km²)	Younger Cover (km²)	Exposed Archean (%)	Exposed Granites (%)	Exposed Greenstone Belts (%)	Younger Cover (%)
Rhodesian Craton	312,000	195,762	162,027	33,735	116,238	62.7	51.9	10.8	37.3
Kaapvaal Craton	585,000	80,662	73,778	6,884	504,338	13.8	12.6	1.2	86.2
Combined Rhodesian and Kaapvaal Cratons	897,000	276,424	235,805	40,619	620,576	30.8	26.2	4.6	69.2

and Viljoen, 1969a, b; Hallberg, 1972) and in the nature of the mineralization.

In the sections which follow, selected metallogenic data are used to illustrate the close genetic relationship of mineralization to specific stages in the evolutionary development of the granite-greenstone terrain in southern Africa. Comparisons and contrasts are drawn between this mineralization and that developed in Archean successions elsewhere in the world, particularly in the Canadian Shield.

The Archean Granite-Greenstone Terrain of Southern Africa

Nature and distribution

A great variety of volcanic, sedimentary, and granitic elements make up the Rhodesian and Kaapvaal Cratons. Scattered within the expanse of granitic rocks are numerous volcanic (greenstone) belts, the present-day configurations of which are shown in Figure 1. Much of the southern African Archean is covered by younger formations which obscure approximately 70 percent of the cratonic crustal area. The exposed Archean consists predominantly of granitic rock types with the greenstone belt relics constituting a relatively low proportion of the preserved basement. The areal extent and relative proportions of Archean and younger successions developed on the Rhodesian and Kaapvaal Cratons are shown in Table 1. By comparison with Archean crustal fragments in Canada and Western Australia (Table 2), the southern African fragments are generally smaller, a feature that may be linked to the latter area's apparently greater antiquity.

TABLE 2. Areal Extent of Archean Crustal Fragments in Canada and Western Australia

Locality	Area (km²)
Superior Province, Canada	2,000,000
Slave Province, Canada	195,000
Yilgarn Block, Western Australia	700,000
Pilbara Block, Western Australia	500,000

Both the Rhodesian and Kaapvaal Cratons are bounded by high-grade, polymetamorphic, mobile belts which are considered to represent reworked Archean cratonic material, with or without infolded, younger, supracrustal rocks (Anhaeusser et al., 1969; Anhaeusser, 1973a; Mason, 1973). As these areas represent separate geotectonic domains they will not be described further except where pertinent to the metallogenic history of the regions discussed in this paper.

Stratigraphy

The volcanic and sedimentary piles that comprise the greenstone belts of the Rhodesian basement complex have been grouped into three major subdivisions, referred to as the Sebakwian, Bulawayan, and Shamvaian groups, respectively (Macgregor, 1951; Bliss and Stidolph, 1969; Wilson, 1973). At the base, the Sebakwian stratigraphy consists of a variety of mafic and ultramafic rocks with sedimentary interlayers, and is characterized by the presence of intrusive masses of ultramafic rocks which have, in the past, been classed into the so-called Magnesian Series—a name reserved by Macgregor (1951) for a suite of late Sebakwian intrusive ultramafic rocks. In many places the Sebakwian Group has been extensively invaded, fragmented, and often apparently granitized by the intrusion of a wide variety of granitic rock types. Mafic lavas, often pillowed, together with andesites, felsic lavas, and pyroclasts, and local sedimentary intercalations (usually of the banded iron-formation-phyllite association), constitute the overlying Bulawayan Group. The latter assemblage is in turn overlain by the Shamvaian Group which is comprised predominantly of quartzites, conglomerates, graywackes, and shales, together with subordinate volcanic rocks, the latter consisting of andesites, and felsic lavas and pyroclasts.

On the Kaapvaal Craton, rocks of an essentially similar character to those of the Rhodesian greenstone belts are collectively referred to as remnants of the Swaziland Sequence (Supergroup) the latter being particularly well developed in the Barberton Mountain Land. The Onverwacht Group, developed at the base of the sequence, has been subdivided into six formations (Fig. 2). The lower three formations are referred to collectively as the *Lower Ultramafic Unit,* being characterized by a relative abundance of ultramafic and mafic volcanic rocks. These assemblages are not comparable with any well-established class of ultramafic or basaltic rock types and have been assigned the name "komatiite" (Viljoen and Viljoen, 1969a).

A persistent sedimentary horizon termed the *Middle Marker* is developed at the top of the Lower Ultramafic Unit and heralds an abrupt change in the type of volcanicity that occurs in the upper three formations of the Onverwacht stratigraphy (Viljoen and Viljoen, 1969b). Referred to collectively as the *Mafic-to-Felsic Unit,* the upper formations consist of cyclically alternating mafic and intermediate to acid volcanic rocks, together with a wide variety of pyroclastic and chemical sedimentary rocks (tholeiitic basalts, dacites, rhyodacites, rhyolites, and cherts). Ultramafic bands and lenses occur sporadically throughout the succession but are volumetrically of minor importance.

In a number of localities within the Lower Ultramafic Unit, layered differentiated ultramafic pods and sills are developed, the latter consisting of dunites, harzburgites, peridotites, pyroxenites, gabbros, norites, and anorthosites (Anhaeusser, 1969, 1972; Viljoen and Viljoen, 1969g; see also paper on chrysotile asbestos by Anhaeusser (1976–this volume).

Overlying the predominantly volcanic successions of the Onverwacht Group is an asemblage of rocks consisting mainly of detrital sediments with subordinate volcanic and pyroclastic members. This succession has been subdivided into an argillaceous and an arenaceous sedimentary unit, the former known as the Fig Tree Group, the latter as the Moodies Group. The Fig Tree assemblages consist mainly of pelitic sediments (graywackes, shales) with siliceous chemical precipitates (banded ferruginous cherts) and minor trachyandesitic lavas, agglomerates, and tuffs. The Moodies Group represents a cyclically repetitive assemblage composed predominantly of conglomerates, quartzites, subgraywackes, sandstones and shales, together with subordinate mafic lavas, jaspilitic chert, and banded iron-formation.

No general agreement exists as to the precise correlation of the Archean stratigraphic subdivisions of

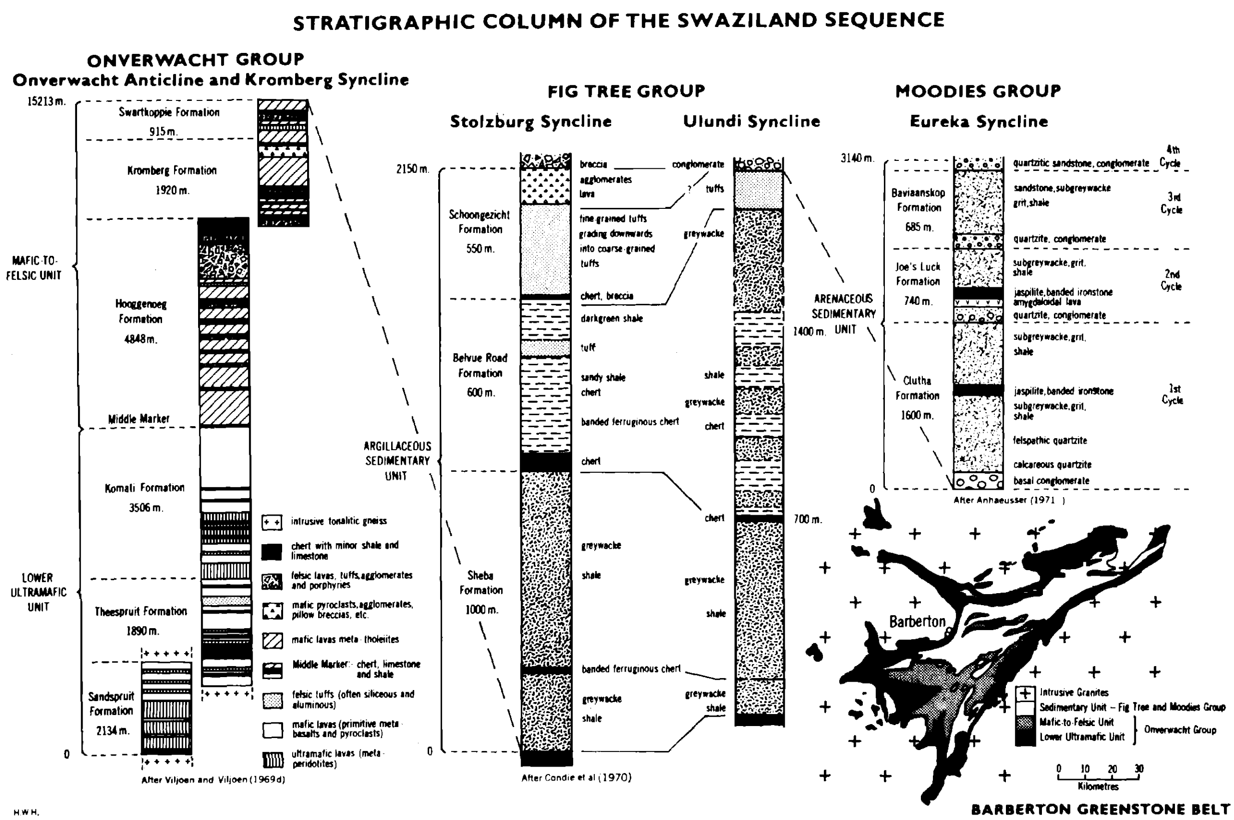

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FIG. 2. Stratigraphic column of the Swaziland succession in the Barberton Mountain Land, South Africa. The distribution of the Lower Ultramafic Unit, the Mafic-to-Felsic Unit, and the Sedimentary Unit is shown in the inset general geological map of the Barberton greenstone belt. (after Anhaeusser, 1973a).

TABLE 3. Suggested Lithostratigraphic Correlation of Rhodesian and Swaziland Archean Rocks with the Barberton Stratigraphic Model

<table>
<tr><th colspan="2">SOUTH AFRICA
Barberton Belt</th><th>SWAZILAND</th><th>RHODESIA</th><th colspan="2">UNIT</th></tr>
<tr><td colspan="2">MOODIES</td><td>MOODIES</td><td rowspan="2">SHAMVAIAN</td><td>arenaceous</td><td rowspan="2">SEDIMENTARY
UNIT</td></tr>
<tr><td colspan="2">FIGTREE</td><td>FIGTREE</td><td>argillaceous</td></tr>
<tr><td rowspan="3">UPPER
ONVERWACHT
Middle Marker</td><td>Swartkoppie</td><td rowspan="3">UPPER
ONVERWACHT</td><td rowspan="3">BULAWAYAN</td><td colspan="2" rowspan="3">MAFIC-TO-FELSIC
UNIT</td></tr>
<tr><td>Kromberg</td></tr>
<tr><td>Hooggenoeg</td></tr>
<tr><td rowspan="3">LOWER
ONVERWACHT</td><td>Komati</td><td rowspan="2">LOWER
ONVERWACHT</td><td rowspan="2">SEBAKWIAN</td><td colspan="2" rowspan="3">LOWER ULTRAMAFIC
UNIT</td></tr>
<tr><td>Theespruit</td></tr>
<tr><td>Sandspruit</td><td>Ancient Gneiss Complex</td><td>Pre-Sebakwian</td></tr>
</table>

Rhodesia, Swaziland, and South Africa. The main areas of contention center about the suggestions, proposed by Stowe (1968a, b) and Hunter (1970), that successions older than the greenstone belts exist both in Rhodesia (the Pre-Sebakwian) and in Swaziland (the Ancient Gneiss Complex). Viljoen and Viljoen (1969e, f) and Anhaeusser (1973a) regard these areas as metamorphosed xenolithic equivalents of the Lower Ultramafic Unit.

As no extensive lithostratigraphic subdivision of the Rhodesian Archean has yet been attempted, efforts at a precise correlation of the stratigraphy with the Barberton model are not possible. A simplified scheme of correlation across the southern African Archean is shown in Table 3. In the writer's opinion, the granitic rocks (including those grouped with the Ancient Gneiss Complex and the Pre-Sebakwian) postdate the assemblages grouped within the Lower Ultramafic Unit.

Lithic proportions

A planimeter survey of the geologic map (Fig. 1 provides an assessment of the lithic compositions of the southern African Archean. Due to the lesser degree of exposure of the granite-greenstone basement of the Kaapvaal Craton (Table 1), the Rhodesian Craton was selected to illustrate the varying proportions of the more important elements making up this ancient terrain. As can be seen in Table 4, granitic rocks make up over 80 percent of the exposed Rhodesian basement complex, the remainder consisting of the Great Dyke and the greenstone belt relics. In an attempt to further refine the lithic proportions of the latter volcanic belts, it was considered necessary to attempt a geological reinterpretation of the Rhodesian granite-greenstone terrain based on the Barberton model. The resulting map (Fig. 1) was compiled from all the existing Rhodesian Geological Survey bulletins, as well as from the 1 : 1,000,000 geological map of Rhodesia (1971 edition). In addition, use was made of the reinterpretive geological map of the region compiled by Viljoen and Viljoen (1969f, p. 252).

TABLE 4. Lithological Proportions in the Exposed Granite-Greenstone Terrain of the Rhodesian Craton

Rock Type	Area (km²)	Percent
Granitic Rocks*	162,027	81.2
Greenstone Belts*	33,735	16.9
Great Dyke	3,800	1.9
Total	199,562	100.0
Ultramafic-Mafic Rocks*	2,823	8.4
Volcanic Rocks* (mafic and felsic)	25,894	76.7
Sediments*	5,018	14.9
Total	33,735	100.0

* Includes granite-greenstone terrain of northeastern Botswana.

The principal objective of the exercise was to subdivide the greenstone belts into component parts, the latter reflecting the broad-scale subdivision of the stratigraphy into a Lower Ultramafic Unit, a Mafic-to-Felsic Unit, and a Sedimentary Unit, respectively. The results of the planimeter survey are given in Table 4, which shows that the greenstone belts are dominated by mafic to felsic volcanic rocks, the latter accounting for more than 75 percent of the greenstone remnants.

A similar planimeter study was undertaken over the Barberton greenstone belt on the Kaapvaal Craton. This area was selected for analysis as it represents one of the better known southern African greenstone belts, having been the subject of numerous detailed investigations both recently and in the past. The region, furthermore, acts as the type locality for greenstone belts on the Kaapvaal Craton.

TABLE 5. Lithological Proportions in the Barberton Mountain Land, South Africa

	Area (km^2)	Percent
Ultramafic-Mafic Rocks	540	16.2
Volcanic Rocks (mafic to felsic)	1,682	50.5
Sediments	1,108	33.3
Total	3,330	100.0

The lithic proportions of the Barberton Mountain Land are shown in Table 5. As was the case with the Rhodesian greenstone belts, the volcanic rocks of mafic to felsic composition constitute the largest proportion (50.5 percent) of the Barberton stratigraphy. Comparison of Tables 4 and 5 shows, however, that the Barberton greenstone belt contains approximately twice the Rhodesian average of rocks of (1) ultramafic-mafic, and (2) sedimentary, affinity.

Further refinement of the data relating to the proportions of the various lithologic types in the Barberton greenstone belt is possible. The threefold subdivision of the stratigraphy described earlier provides a useful separation of lithologic assemblages, as is shown in the first part of Table 6. In the Onverwacht Group, the Lower Ultramafic Unit is most prominently represented, accounting for approximately 80 percent of the volcanic succession (second part of Table 6).

The proportions of the various component rock types predominating in each of the three main stratigraphic units of the Barberton greenstone belt are shown in the third part of Table 6. Basalts and peridotites, particularly of the komatiitic variety, make up the bulk of the Lower Ultramafic Unit. The amount, which approaches close to 53 percent, includes the contributions made by the layered differentiated ultramafic complexes to the total. Furthermore, it is evident from Table 6 that felsic volcanic rocks are, volumetrically, insignificant in the Lower Ultramafic Unit, a feature that might not have been fully appreciated due to the prominence these rocks receive following their usefulness as stratigraphic marker beds. Similarly, ultramafic-mafic rocks of the type found in the Lower Ultramafic Unit are subordinate components of the Mafic-to-Felsic Unit, the latter being dominated by cyclically developed volcanic rock types possessing calc-alkaline chemical affinities.

The lithic proportions of the Barberton greenstone belt, when compared with the average Rhodesian values, demonstrate that this region is anomalously well endowed with rocks of mafic and ultramafic composition. This fact is further strengthened by comparison of the data with those made available from selected areas on the Canadian Shield. In

TABLE 6. Lithological Proportions in the Barberton Greenstone Belt, Detail of Table 5

	Area (km^2)	Percent
Onverwacht Group		
Lower Ultramafic Unit	1,768	53.1
Mafic-to-Felsic Unit	454	13.6
Fig Tree and Moodies Groups		
Sediments	1,108	33.3
Total	3,330	100.0
Onverwacht Group		
Lower Ultramafic Unit	1,768	79.6
Mafic-to-Felsic Unit	454	20.4
Total	2,222	100.0
Onverwacht Group		
Lower Ultramafic Unit		
Ultramafic-Mafic Rocks	523	15.71
Basalts	1,230	36.94
Felsic Volcanics	15	0.45
Mafic-to-Felsic Unit		
Ultramafic-Mafic Rocks	17	0.50
Mafic to Felsic Volcanics	437	13.10
Fig Tree and Moodies Groups		
Sediments	1,108	33.30
Total	3,330	100.0

Table 7 the lithic proportions of the rocks in the Slave Province and parts of the Superior Province are shown. Compared with southern African green-

TABLE 7. Lithological Proportions of Selected Areas in the Superior and Slave Provinces of the Canadian Shield

Locality	Area (km^2)	Total Greenstone Belt (km^2)	Granite (km^2)	Total Greenstone Belt (%)	Granite (%)
Abitibi Belt*	95,573	64,723	30,850	67.7	32.3
Wabigoon Belt*	15,496	7,655	7,841	49.4	50.6
Slave Province†	195,000	120,000	75,000	61.5	38.5

Locality and Rock Type	Area (km^2)	Percent
Abitibi Ultramafic-Mafic Rocks	2,389	3.7
Abitibi Volcanic Rocks (mafic and felsic)	47,021	72.6
Abitibi Sediments	15,316	23.7
Total	64,726	100.0
Wabigoon Ultramafic-Mafic Rocks	248	3.2
Wabigoon Volcanic Rocks (mafic and felsic)	6,214	81.2
Wabigoon Sediments	1,193	15.6
Total	7,655	100.0
Slave Province Volcanic Rocks	24,000	20.0
Slave Sediments	96,000	80.0
Total	120,000	100.0

* After Goodwin et al., 1972.
† After McGlynn and Henderson, 1972.

TABLE 8. Proportions of Rock Types in Greenstone Belts of the Superior Province, Canada, the Rhodesian Craton, and the Barberton Mountain Land, South Africa

Locality	Proportions (km)²				
	Ultra-mafic-Mafic	Basalts	Andesite	Felsic Volcanics	Total
Abitibi Belt*	2,389	28,213	14,106	4,702	49,410
Wabigoon Belt*	248	3,728	1,864	622	6,462
Rhodesian Craton	2,823	17,279	6,461	2,154	28,717
Barberton Belt	540	1,600	—	82	2,222
	Proportions (percent)				
Abitibi Belt	4.8	57.0	28.5	9.7	100.0
Wabigoon Belt	3.8	57.7	28.9	9.6	100.0
Rhodesian Craton	9.8	60.2	22.5	7.5	100.0
Barberton Belt	24.3	72.0	—	3.7	100.0

* After Goodwin et al., 1972.

stone belts the Canadian occurrences are generally very much more extensive, the Abitibi belt alone being approximately twice the area of all the Rhodesian greenstone belts combined. Similarly the Wabigoon belt is areally greater than all the exposed greenstone remnants on the Kaapvaal Craton (cf. Tables 1 and 7).

TABLE 9. Ratios of Various Rock Types and Lithological Combinations in the Superior Province, Canada, the Rhodesian Craton, and the Barberton Mountain Land, South Africa

Locality	Ultramafic/Mafic	:	Basalts + Andesites + Felsic Volcanics
Wabigoon Belt*	1	:	25.3
Abitibi Belt*	1	:	19.8
Average Rhodesian Craton	1	:	9.2
Barberton Belt	1	:	3.1
Locality	**Ultramafic/Mafic + Basalts**	**:**	**Andesites + Felsic Volcanics**
Wabigoon Belt*	1.6	:	1
Abitibi Belt*	1.6	:	1
Average Rhodesian Craton	2.3	:	1
Barberton Belt	26.1	:	1
Locality	**Ultramafic/Mafic + Basalts + Andesites**	**:**	**Felsic Volcanics**
Wabigoon Belt*	9.4	:	1
Abitibi Belt*	9.3	:	1
Average Rhodesian Craton	12.3	:	1
Barberton Belt	26.1	:	1

Average Superior Province, Canada*

	Basalt	:	Andesite	:	Felsic Volcanics
	6	:	3	:	1
or	Mafic	:	Felsic		
	9	:	1		

Barberton Belt, South Africa

	Ultramafic/Mafic	:	Basalt	:	Felsic Volcanics
	6.6	:	19.5	:	1
or	Ultramafic/Mafic	:	Felsic		
	26	:	1		

* After Goodwin et al., 1972.

Canadian greenstone belts are dominated by calc-alkaline volcanic sequences (Wilson et al., 1965; Baragar and Goodwin, 1969; Goodwin, 1971; Goodwin et al., 1972, and Table 7), whereas rocks of ultramafic-mafic composition play a subordinate role, the average for the Abitibi and Wabigoon belts, combined, being less than half the average value for the Rhodesian belts, and less than one-quarter the value of similar rocks in the Barberton greenstone belt (cf. Tables 4, 6, and 7).

The proportions of the various volcanic rock types in greenstone belts of Canada, Rhodesia, and South Africa can be compared in a variety of ways, probably the most informative of which are shown in Tables 8 and 9. In the first of these tables (Table 8) the relative proportions of specific rock types are compared. Basaltic rocks clearly form the major portion of Archean greenstone belts, wherever the latter may occur. Andesitic volcanic rocks are prominent in Canadian greenstone belts and are developed in some Rhodesian belts, but are virtually absent in the Barberton Mountain Land. Ultramafic-mafic rocks, including extrusive peridotitic lavas and the differentiated ultramafic complexes, are well represented in southern Africa, whereas the felsic volcanic component in this region is poorly represented relative to the Canadian examples.

The second table (Table 9) shows the ratios of various rock types, and combinations thereof, in the Canadian and southern African Archean greenstone belts. The ratios of all the combinations demonstrate clearly that the southern African greenstone belts (and the Barberton Mountain Land, in particular) have a greater ultramafic-mafic component and a lower intermediate to felsic component than their Canadian counterparts. This relationship, it will be shown later, has important implications in terms of the metallogenic potential of the areas discussed.

Geochemistry of Archean Volcanic Rocks

The sequential development of Archean volcanic-sedimentary piles is now well established (Goodwin, 1968, 1971; Anhaeusser et al., 1969; Anhaeusser 1971; Baragar and Goodwin, 1969; Viljoen and Viljoen, 1969a, b, 1971). Average chemical compositions of Archean volcanic rocks, arranged in generalized ascending stratigraphic order, have been presented for the volcanic assemblages of the Canadian Shield by Goodwin (1968), and for southern Africa and the Archean in general by Anhaeusser (1971, 1973a) and Viljoen and Viljoen (1969a, b, 1971). This, and supplementary data, are provided Tables 10 and 11.

In Table 10 the average chemical compositions of the more important volcanic components of the Onverwacht Group on the Kaapvaal Craton are

TABLE 10. Chemical Composition of Archean Volcanic Rocks on the Kaapvaal Craton, South Africa

	Ultramafic-Mafic Unit													Mafic-Felsic Unit					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SiO_2	44.72	41.61	47.37	49.19	52.22	52.73	78.91	41.22	47.40	51.36	51.99	41.78	50.79	49.95	49.86	50.07	56.54	64.38	73.66
Al_2O_3	3.25	2.70	6.76	3.76	5.42	9.83	15.14	3.30	4.87	4.38	12.67	5.06	14.23	13.48	14.25	13.34	14.19	10.24	11.57
Fe_2O_3	6.02	5.63	1.18	11.80	0.98	1.23	0.25	4.31	3.48	2.33	1.61	5.28	1.12	1.82	2.65	2.31	0.0	1.40	0.93
FeO	5.52	4.35	8.08		8.88	9.70	0.69	6.54	6.32	8.47	6.45	4.53	7.11	7.89	7.67	9.10	14.24	12.76	0.62
MgO	25.35	30.35	20.39	20.03	15.25	10.10	0.38	30.65	23.62	16.00	10.33	29.69	9.48	9.68	7.32	6.10	4.20	2.80	1.29
CaO	6.97	4.28	8.31	9.51	12.83	9.99	0.29	2.94	8.55	13.86	8.18	3.95	12.07	9.52	10.69	9.47	0.19	2.09	3.98
Na_2O	0.49	0.15	0.39	0.10	1.21	2.65	0.40	0.10	0.23	0.49	2.25	0.12	1.65	2.38	2.54	3.34	0.29	0.05	5.03
K_2O	0.05	0.03	0.06	0.02	0.09	0.46	2.67	0.01	0.06	0.14	2.48	0.03	0.13	0.77	0.16	0.54	1.02	3.72	3.50
TiO_2	0.52	0.31	0.46	0.43	0.56	0.85	0.54	0.27	0.43	0.46	0.47	0.22	0.41	0.69	0.70	1.22	2.03	1.13	0.02
P_2O_5	—	0.02	—	—	—	—	0.15	0.04	0.07	0.08	0.30	0.03	0.08	0.09	0.05	—	—	—	0.31
MnO	0.19	0.17	0.19	0.17	0.22	0.22	0.01	0.19	0.16	0.23	0.16	0.13	0.19	0.18	0.17	0.19	0.07	0.04	0.06
CO_2	—	—	—	—	—	—	—	0.00	0.09	0.08	0.40	0.05	0.14	0.13	0.48	0.23	0.08	1.56	1.73
H_2O	5.58	8.81	5.26	—	2.05	1.87	1.31	9.50	4.29	2.24	2.63	8.65	2.09	3.07	2.81	3.01	5.84	2.50	2.68
No. of Analyses	3	8	4	2	5	3	4	9	4	8	1	1	7	5	5	2	1	1	1

Onverwacht Group Type Locality, Barberton Mountain Land

1. Average peridotitic komatiite, Sandspruit Formation.
2. Average peridotitic komatiite, Komati Formation.
3. Average high-alumina basaltic komatiite (Geluk type).
4. Average low-alumina basaltic komatiite (Geluk type).
5. Average basaltic komatiite (Badplaas type).
6. Average basaltic komatiite (Barberton type).

Jamestown Schist Belt, Barberton Mountain Land

7. Average felsic volcanic rocks (Theespruit Formation).

Nelshoogte Schist Belt, Barberton Mountain Land

8. Average peridotitic komatiite.
9. Average basaltic komatiite (Geluk type).
10. Average basaltic komatiite (Badplaas type).
11. Tholeiitic basalt.

Muldersdrif Greenstone Belt, NW of Johannesburg

12. Peridotitic komatiite.
13. Average tholeiitic basalt.

Onverwacht Group Type Locality, Barberton Mountain Land

14. Average magnesian-rich basalt (Hooggenoeg Formation).
15. Average tholeiite basalt (Hooggenoeg Formation).
16. Average tholeiite basalt (Kromberg Formation).
17. Pillowed intermediate lava (Hooggenoeg Formation).
18. Pillowed intermediate lava (Hooggenoeg Formation).
19. Pillowed acid lava (Kromberg Formation).

Analyses: 1–6 and 14–19 (Viljoen and Viljoen, 1969a, b), 7 (Anhaeusser, 1972), 8–13 (Anhaeusser, manuscript in preparation).
Analysts: 8–13 National Institute for Metallurgy, Johannesburg, and Durham University, Durham, England.

shown. Columns 1 to 13 list the geochemistry of the basaltic and peridotitic komatiite lavas, tholeiitic basalts, and subordinate felsic volcanic interlayers encountered in the Lower Ultramafic Unit, whereas columns 14 to 19 show the geochemistry of the mafic, intermediate, and felsic lavas of the Mafic-to-Felsic

TABLE 11. Comparative Geochemistry of Archean Volcanic Rocks of the Superior Province, Canada, the Yilgarn Block, Australia, and the Rhodesian Craton

	Superior Province-Canadian Shield						Yilgarn Block Western Australia			Rhodesian Craton				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	48.85	48.9	54.7	61.5	67.3	74.3	41.20	48.82	51.4	45.54	50.47	53.30	55.59	61.48
Al_2O_3	7.55	14.5	15.0	15.7	14.8	12.9	5.31	11.90	14.8	9.19	15.45	54.42	15.83	14.52
Fe_2O_3	2.02	2.14	2.00	1.83	1.17	0.74	3.89	1.17	1.5	2.40	1.63	1.49	1.47	1.44
FeO	11.09	9.03	7.64	4.49	3.44	2.22	5.13	9.24	9.1	8.53	9.62	9.71	5.73	4.25
MgO	16.73	6.27	4.50	2.38	1.55	0.85	29.87	12.81	6.7	20.65	6.05	3.97	5.51	4.33
CaO	11.43	8.74	6.39	4.41	3.13	1.48	4.66	12.70	10.7	6.07	11.76	11.36	7.50	5.64
Na_2O	0.81	2.51	2.79	3.15	3.07	2.47	0.24	1.33	2.7	0.93	1.68	1.63	2.80	3.69
K_2O	0.07	0.45	0.55	1.16	1.40	2.10	0.03	0.11	0.18	0.21	0.57	0.95	1.02	0.65
TiO_2	1.14	1.06	0.99	0.63	0.51	0.26	0.23	0.42	0.92	0.55	0.89	0.99	0.64	0.61
P_2O_5	0.30	0.07	0.12	0.12	0.07	0.07	—	0.06	0.13	0.08	0.26	0.12	0.15	0.15
MnO	0.02	0.21	0.28	0.16	0.08	0.10	0.17	0.27	0.21	0.19	0.15	0.19	0.10	0.08
CO_2	0.79	1.93	1.93	2.18	0.98	0.86	—	—	0.1	0.01	0.20	0.32	0.34	0.11
H_2O	3.5	3.34	2.92	2.27	1.56	1.17	8.54	1.05	1.0	4.48	1.22	1.11	4.19	2.95
No. of Analyses	1	162	119	272	177	85	3	1	123	4	11	3	4	2

1. Basaltic komatiite, Wawa volcanic belt, Ontario.
2. Average basalt.
3. Average andesite.
4. Average dacite.
5. Average rhyodacite.
6. Average rhyolite.
7. Average peridotite (peridotitic komatiite, Mt. Ida and Scotia, W.A.).
8. Magnesian basalt (basaltic komatiite).
9. Average tholeiitic basalt (Kalgoorlie-Norseman area, W.A.).
10. Average olivine basalt (basaltic komatiite, Geluk type).
11. Average tholeiitic basalt, Bulawayan Group.
12. Average "andesite," Bulawayan Group.
13. Average andesite, Maliami River Formation.
14. Average dacite, Maliami River Formation and Umniati Group.

1 (Brooks and Hart, 1972), 2–6 (Goodwin, 1968), 7 (Nesbitt, 1971), 8 (McCall, 1973), 9 (Hallberg, 1972), 10–14 (Bliss and Stidolph, 1969).

Unit in the Barberton greenstone belt. Table 11 provides a comparative set of data reflecting the geochemistry of some of the rock types encountered in the Archean greenstone belts of Canada, Western Australia, and Rhodesia. Although basaltic and peridotitic komatiites occur in all three areas, they nowhere appear as abundantly as in the Barberton Mountain Land. As was discussed previously, the Canadian volcanic sequences are characterized by calc-alkaline assemblages similar to those listed in Table 11, columns 2 to 6. In Western Australia, analyses available from only a few selected areas suggest that the predominant volcanic rock types are tholeiitic basalts (column 9), like those described by Hallberg (1972). Peridotitic lavas and magnesian-rich basaltic lavas are also represented in places and have komatiitic affinities (columns 7 and 8).

Very little geochemical information is available from the Rhodesian greenstone belts. Some examples, listed in Table 11, columns 10 to 14, show a spread from basaltic komatiites to rock of the calc-alkaline volcanic class. Assemblages, correlated with the Lower Ultramafic Unit, are widespread in this country (Fig. 1) and will doubtless be found to be geochemically comparable to rocks of similar character in the Barberton belt (Table 10). Unlike the latter area, however, the Rhodesian greenstone belts contain prominent developments of andesitic pillow lavas, the latter forming part of the Bulawayan succession. Intermediate to felsic lavas and pyroclasts (andesite to dacite) occur in greenstone belts located along the western edge of the exposed Archean basement of the Rhodesian Craton. Extending from the Matsitama belt in eastern Botswana, through the Bulawayo-Bubi belt into the Midlands belt (Fig. 1), these successions are referred to synonomously as the Maliami River Formation or the Umniati Group (Bliss and Stidolph, 1969). Doubt has been expressed (Bliss, 1970) as to whether these rocks form part of the greenstone belt successions or whether they represent some younger sequence. Unquestionably the assemblage, which consists predominantly of extensive sheets of pyroclastic rocks and fresh, pyroxene-bearing lavas, is unlike the Bulawayan succession encountered elsewhere on the Rhodesian Craton. This is further borne out by the distinctive metallogenic characteristics of the successions in the areas in which these rocks occur, and which will be discussed later.

Archean Mineralization

Types

Virtually all the known Archean mineral occurrences in the world are associated with the volcanic-rich sequences of greenstone belts, the exceptions being the deposits linked with sedimentary rocks and granites and pegmatites. Mineral distribution patterns and metallogenic studies in Archean terrains are generally lacking, the only noteworthy contributions in this context coming from the Canadian Shield (Goodwin, 1965, 1966, 1971; Hutchinson et al., 1971; Hutchinson, 1973) and, to a lesser extent, Western Australia (Prider, 1965).

From these and numerous other, more local, studies, it has become obvious that certain mineral types and associations have a relationship both to one another and to their host rocks. Hutchinson et al. (1971) recognized four families of mineral deposits, believed to be of primary origin, in Archean rocks. Broadly, these may be modified to include: (1) Ores of nickel, with minor copper and associated platinum-group metals, asbestos and magnesite deposits, and chromite and magnetite deposits. These are invariably associated with ultramafic to mafic igneous bodies (as well as ultramafic volcanic rocks). (2) Pyritic, massive base metal sulfide deposits of copper, zinc, silver, lead, and gold, as well as antimony and mercury, all of which are invariably associated with well-differentiated, mafic to felsic extrusive and pyroclastic rocks of calc-alkaline character. Many of these deposits are considered to be of volcanic exhalative origin. Also included in this category are certain gold and copper deposits in porphyritic, subvolcanic intrusions of felsic composition. (3) Diverse varieties of iron-formation, with or without associated sediments, that occur in well-differentiated volcanic complexes. These well-banded rocks are widely considered to be chemical sediments probably formed by fumarolic-exhalative processes. Included in this category are certain gold ores, the latter associated with oxide iron-formations. (4) Iron-formations, particularly the oxide and some silicate species, the latter generally lacking the gold association of the exhalite variety. These iron-formations occur with immature clastic sediments (graywackes and argillites). Included in this group also are certain gold deposits occurring in quartzitic and conglomeratic clastic sedimentary rocks.

To the four general families outlined above may be added two additional categories. These include: (5) Mineral deposits associated with granites and pegmatites, including occurrences of beryllium, lithium, tin, tungsten, tantalum-columbium, bismuth, molybdenum, corundum, mica, quartz (silica), and felspar, as well as the precious and semiprecious minerals, emerald, ruby, and sapphire, and (6) the stratiform deposits other than the iron-formations and including limestone, barite, corundum, graphite, and a variety of slates. The latter products have diverse origins ranging from sedimentary to metamorphic and volcanic exhalative or volcanogenic pyroclastic.

The Nature and Distribution of Archean Mineralization in Southern Africa

In order to simplify description of the Archean mineralization of southern Africa, the threefold subdivision of the stratigraphy of the greenstone belts described earlier will be used as a basis for classification. This deviates little from the classification scheme outlined initially by Hutchinson et al. (1971) and modified by the writer in the previous section. Fundamentally, both approaches center around mineral types and host rock associations, as well as an underlying stratigraphic evolutionary control.

Ideally, Archean greenstone belts commence with an ultramafic-mafic group of rocks at the base and pass upward into mafic, intermediate, and felsic volcanic rocks higher in the successions, the latter overlain and terminated by a variety of sedimentary assemblages (Anhaeusser et al., 1969; Anhaeusser, 1971). Most greenstone belts, however, display only parts of the total idealized column, being aborted at varying stages due to one or other causes, the most destructive of which appears to have been the intrusion of a wide variety of granitic rock types.

The southern African greenstone belts are no exception, and, apart from the Barberton Mountain Land which probably approaches closest to the theoretical model, virtually all the Archean remnants have sections of their stratigraphy either missing or attenuated. Rocks of the Lower Ultramafic Unit, being at the base of the synclinally folded greenstone belts are usually more prone to metamorphic alteration, fragmentation, and assimilation by the granites than rocks higher in the succession. Despite this, however, it is evident from Figure 1 and Tables 4 and 8 that much of this rock assemblage is preserved in southern Africa.

Mineralization Associated with Ultramafic to Mafic Volcanic and Plutonic Rocks

The distribution of mineralization associated with rocks of the ultramafic-mafic succession is shown in Figure 3. The mineral occurrences include deposits of nickel (plus copper), chrome, chrysotile asbestos, magnesite, talc, and the ornamental products verdite and buddstone. The greatest density of mineralization occurs in greenstone belts located in the southern part of Rhodesia and in the Barberton Mountain Land, both regions possessing abundant ultramafic rocks.

Nickel-copper

Despite the abundance of seemingly favorable host rocks, noteworthy deposits of nickel are relatively rare in southern Africa and for the present are restricted to three major deposits including the Shangani, Trojan, and Empress orebodies (Fig. 3). The Trojan deposit, north of Salisbury, is described by le Roex (1964) as consisting of finely disseminated nickeliferous (pentlandite, millerite) and other sulfides (pyrite, pyrrhotite, chalcopyrite) occurring in dunite, serpentinite, and serpentine-talc-carbonate rocks. Nickel also occurs as a nickeloan magnetite.

The Shangani deposit, the most recent nickel discovery, is to be described in detail (Viljoen et al., 1976). The ore deposit, which occurs in serpentinized peridotite, overlies a siliceous footwall tuff unit and consists of massive and disseminated sulfides (mainly pyrrhotite and pentlandite).

The Empress nickel-copper deposit, which has been described by Sharpe (1964) and Eales (1964), differs from both the Trojan and Shangani deposits in that the mineralization occurs in a differentiated sill-like, predominantly meta-gabbroic body, containing subordinate picrite, amphibolites (orginally pyroxenites), norite, and diorite. The ore minerals present in the body, in order of abundance, include pyrrhotite and pentlandite, chalcopyrite, pyrite, violarite, and some sphalerite and chalcocite. Minor amounts of gold, silver, and platinoids are also present in the ore. The Empress deposit, furthermore, does not occur in rocks of the Lower Ultramafic Unit and should in effect be considered separately. It is located, instead, in the contentious Umniati Group described by Bliss (1970) and referred to earlier.

Other noteworthy occurrences of nickel-copper occur in the Tati greenstone belt of eastern Botswana. Two prospects, the Selkirk and the "Mound Struck", occur in a host rock setting consisting of quartz and felspar porphyritic volcanic rocks, all with dacitic affinity (Mason, 1970). The mineralization consists mainly of chalcopyrite, pyrite, pyrrhotite, and pentlandite. Little is known of the deposits but the mineralization appears to be related to troctolitic gabbroic intrusions and is thus more closely akin to the Empress deposit.

Promising nickel prospects, in rocks of the ultramafic-mafic clan, occur in the Damba area, west of the Shangani mine, and in greenstone remnants in the Madziwa batholith, north of the Trojan deposit (Fig. 3). Signs of nickel-copper mineralization occur in virtually all areas where ultramafic rocks are developed. This is true for the Barberton greenstone belt where, despite the showings of millerite and nickeloan magnetites and trevorite, as well as the great abundances of ultramafic extrusive and intrusive rock types, no nickel orebodies have yet been located.

Chrysotile asbestos

Rocks of the Lower Ultramafic Unit are particularly favorable host rocks to chrysotile asbestos in southern Africa. As can be seen in Figure 3, there

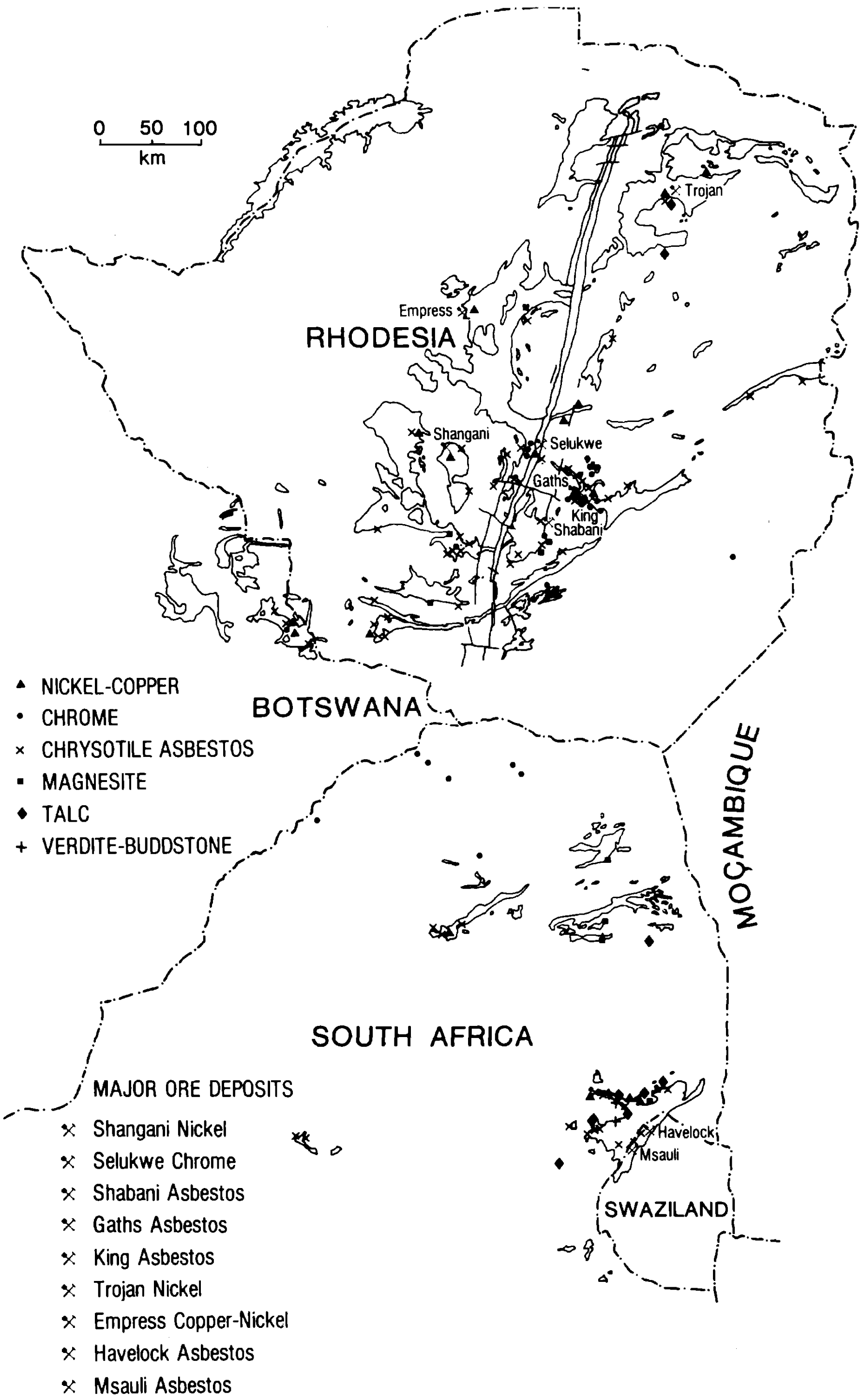

FIG. 3. Map showing the distribution of nickel-copper, chrome, chrysotile asbestos, talc, verdite-buddstone, and magnesite in the Archean greenstone belts of southern Africa.

is a widespread distribution of this mineral, coinciding mainly with areas containing abundant serpentinized ultramafic rocks (cf. Fig. 1). Areas of particular importance are the Filabusi-Belingwe-Fort Victoria regions in the south and southeastern parts of the Rhodesian Craton and the Barberton greenstone belt, on the Kaapvaal Craton.

As a more comprehensive account of southern

African chrysotile asbestos mineralization is given elsewhere (Anhaeusser, 1976), few details will be given here. The asbestos is not confined to rocks of the Lower Ultamafic Unit but occurs also in sill-like bodies of ultramafic rocks developed less frequently in stratigraphy of the Mafic-to-Felsic Unit (e.g., the Havelock and Msauli mines). In addition, it occurs in differentiated ultramafic complexes in Rhodesia (e.g., Mashaba Igneous Complex, Shabani ultramafic body) considered by Wilson (1968, 1973) to be younger than the greenstone belts but older than the latest intrusive granitic events in the area.

Magnesite

Almost all the occurrences of magnesite in the Archean rocks of southern Africa are the alteration products of ultramafic rocks, the exception being the Barton Farm magnesite deposit near Gatooma in Rhodesia (located in the Midlands greenstone belt, halfway between the Great Dyke and the Empress Mine, Fig. 3). This deposit, described by MacGregor and Bliss (1968), occurs in dolomitic argillites and arkoses of the Shamvaian Group, but these authors were unable to determine whether this magnesite is a primary sediment or a replacement body.

Of the remaining magnesite occurrences, the distribution of which again coincides with the regional development of ultramafic rocks, the most important orebodies have been those located along the northeastern margin of the Barberton Mountain Land. Descriptions of these and other magnesite deposits in South Africa were given by van Zyl et al. (1942). More recently, Viljoen and Viljoen (1969c) showed that the important magnesite deposits in the Kaapmuiden-Malelane area of the Barberton greenstone belt occurred mainly as stockworks and, more rarely, as tabular bodies in altered layered ultramafic bodies. A number of sill-like bodies of ultramafic type have, in this area, undergone magmatic segregation yielding extensive dunite or peridotitic dunite zones, the latter followed sequentially by pyroxenites, gabbros, anorthositic gabbros, and norites. It is in the dunite zones, with cumulus olivine crystals (Fo 93 to Fo 100) constituting 70 to 90 percent of the rock, that magnesite has formed within depth zones influenced by the circulation of meteoric water. This process of alteration has been assisted locally by faulting and fracturing of the successions in the area.

Talc

Talc deposits are prevalent in all greenstone belts possessing ultramafic rocks or magnesian-rich basalts. Individual deposits vary in size and grade of talc produced. Most deposits occur in areas where deformation has affected the ultramafic rocks. The combined influence of structure and proximity to a heat source appears to have been an important factor in talc formation. Numerous deposits have been worked in the Barberton Mountain Land, the most important occurrences being those developed along the northern margin of the greenstone belt (Fig. 3), in the Jamestown Schist Belt, and areas to the east (Anhaeusser, 1969, 1972).

The talc deposits occur as follows: (1) rimming intrusive porphyritic granite bodies intruded into the ultramafic lavas or layered ultramafic complexes; (2) in fault zones associated, in places, with gold-quartz veins, e.g., the Albion gold-talc deposit in the Jamestown Schist Belt; (3) in areas where ultramafic rocks have been folded, serpentinized, and steatized to form mainly talc-carbonate rocks in which pods of quality talc develop by lateral secretion from the wall rocks; (4) in ultramafic rocks influenced by metasomatizing hydrothermal solutions derived from intrusive granites. The Scotia Talc Mine in the Barberton belt has, for example, numerous tourmaline needles in the talc, indicating that boron metasomatism probably accompanied the talc formation.

Verdite-buddstone

Several occurrences of verdite, which is a dark green semiprecious variety of serpentine used mainly as an ornamental stone, are known to occur only in the Barberton region (Fig. 3). The mineral is frequently associated with a gray-to-white silica and talc assemblage giving rise to an attractive, banded, and invariably contorted rock known locally as buddstone.

The verdite occurrences, which are small podlike deposits, are confined to the layered differentiated bodies and appear to have formed in zones of shearing and differential movement between pyroxene peridotite layers and adjacent, more massive and structurally competent, meta-gabbroic layers (Anhaeusser, 1969, 1972).

Chromite mineralization in Archean greenstone belts

Important occurrences of chromite are located in the Archean rocks of southern Africa. Most outstanding are the very high grade chromite deposits in the Selukwe area, in south-central Rhodesia (Fig. 3). These deposits, which have been described in detail by Stowe (1968a) and Cotterill (1969), occur in a structurally complex succession that forms part of the Sebakwian Group of rocks. Lenticular sheets of differentiated ultramafic to mafic material, containing chromite bodies, occur together with metabasaltic lavas, interbedded quartzites (altered cherts), banded iron-formation, and a variety of argillaceous sediments (tuffs, graywackes) and arkosic graywackes.

TABLE 12. Comparison of Cr_2O_3 and Cr/Fe in Southern African Chromite Deposits

Geological Setting	Area and Reference	Cr_2O_3 (percent) Range	Cr_2O_3 (percent) Mean	Cr/Fe Range	Cr/Fe Mean	No. of Analyses
Sebakwian Group, Rhodesia (~3.4 b.y. old)	Selukwe					
	Selukwe Peak Mine	52.32–58.41	55.59	1.9–3.9	2.9	6
	Railway Block, Priority 1	57.89–60.65	60.23	3.2–4.26	3.9	10
	Magazine Hill	58.41–59.41	58.82	3.68–3.9	3.8	3
	Railway Block, Priority 1	58.45–61.60	59.70	3.33–4.19	3.8	10
	Mount Claims (Cotterill, 1969)	52.98–55.47	54.54	1.36–1.65	1.5	7
	Mashaba (Wilson, 1968)		41.5		2.7	1
Mashaba Igneous Complex, Rhodesia (post-Shamvian age—~3.0 b.y. old)	Mashaba (Wilson, 1968)	56.61–60.29	55.87	3.51–4.56	3.91	18
Messina Formation, Limpopo Mobile Belt (~3.0 b.y. old)	Soutpansberg-Messina (van Eeden et al., 1955)	29.6–30.0	29.80	1.2–1.4	1.3	2
Great Dyke, Rhodesia (~2.5 b.y. old)	Musengezi Complex	53.82–61.85	53.90	1.8–3.97	2.15	8
	Selukwe Complex	51.17–56.81	54.80	2.28–3.18	2.72	5
	Wedza Complex	50.04–56.37	53.31	1.94–3.05	2.52	4
	Hartley Complex (Worst, 1960)	51.02–59.16	56.00	1.93–4.20	2.90	20
	Motoroshanga (Cotterill, 1969)	58.81–59.03	58.98	3.48–3.75	3.6	5
Bushveld Igneous Complex, South Africa (~1.95 b.y. old)	Eastern Bushveld					
	Central Sector	38.9–49.84	~46.0	0.7–1.92	~1.55	20
	Southern Sector (Cameron, 1964)	43.35–48.17	~45.0	1.2–1.59	~1.45	14
	Western Bushveld					
	Data from 15 chromite seams (Cousins and Feringa, 1964)	38.0–53.0	~47.0	0.85–2.4	~1.5	64
Turkish Ultramafic and Related Gabbroic Complexes (~300 m.y. old)	Fethiye-Marmaris Complex (van der Kaaden, 1970)	30.41–59.28	~45.0	2.1–4.3	~3.0	56

The structural reconstruction of the area suggests that the Lower Ultramafic Unit rocks of the Sebakwian sequence were involved in folding, thrusting, metamorphism, silicification, and erosion prior to the deposition of the Bulawayan succession. In support of this it can be shown that the Bulawayan conglomerates contain pebbles and boulders of Sebakwian sedimentary and ultramafic rocks, including chromite pebbles and boulders.

The chromite deposits in the Selukwe area formed by magmatic segregation as cumulate layers at varying intervals in the differentiating ultrabasic intrusion, the thickest layers accumulating in downwarps on the chamber floor (Cotterill, 1969). Primary magmatic textures and structures occur in the chromite layers, despite the intense alteration of the rocks in the area. Cotterill indicated that, at least twice after accumulation, metasomatism of the sheared chromite and peridotite has modified the chemical constitution of the chrome ores and the ultramafic rocks. Typical chromites are rich in Cr and Mg and poor in Fe, Al, and Mn. In Table 12 average ore grades of the Selukwe chrome deposits are listed. The orebodies are among the richest in the world in terms of grade and Cr/Fe ratios and are prized as metallurgical-grade ores.

The Sebakwian chromite deposits have not been specifically dated but are considered to be approximately 3,400 m.y. old. Further deposits of this nature occur scattered about the southern regions of Rhodesia (Fig. 3), particularly in the Sebakwian remnants west of the Fort Victoria greenstone belt (Wilson, 1968) and in the region south of the Buhwa-Mweza belt (Worst, 1926b). In the latter area the chromite orebodies, which include the Rhonda, Hmardick, United, and Mlimo mines, occur in greenstone remnants caught up in the northern marginal zone of the Limpopo high-grade metamorphic belt.

The chemical composition of the chromite from the Rhonda group of mines ranges from 32 to 53 percent Cr_2O_3, the Cr/Fe ratio varying between 1.23 and 3.03 (Worst, 1962b). Some of the ore is metallurgical grade but most is hard lumpy and of chemical grade.

Chromite of a younger Archean age (approximately 3,000 m.y. old) occurs in significant quantities in the Mashaba Igneous Complex at the western end of the Fort Victoria greenstone belt. Here the bulk of the chrome orebodies are found in ultramafic rocks (serpentinized dunites and peridotites) centered about the Prince Mine situated near the King asbestos mine (Fig. 3). Most of these deposits are intensely deformed, but in the Prince orebody there is a chromite-rich zone over 30 m thick in which chromite seams, varying from less than 5 mm up to 50 mm, occur as density separated layers in serpentinite. The chromite deposits of the Mashaba Igneous Complex contain high-grade metallurgical ores, the latter contrasting with the lower grade mineralization found in Sebakwian rocks in this region (Table 12).

On the Kaapvaal Craton chromite is not present in any great quantities in rocks of Archean age. It is of interest to note, however, that in the area south of the Limpopo metamorphic belt xenolithic remnants of Swaziland Supergroup ultramafic material containing chromite have been reported. Willemse (1948) investigated a chromite occurrence on the farm Lemoenfontein, west of Bandelierkop, and although the ore reserves were estimated to be only approximately 60,000 tons of ore containing only 33 percent chromite, the grade was found to be exceptionally high (58 to 60 percent Cr_2O_3).

Other chromite occurrences in southern Africa

While not intending to describe in any detail the remaining chromite occurrences in southern Africa, it is nevertheless of interest to note certain features relating to this mineral's distribution in time and space.

The first, and oldest, of these remaining chromite-bearing environments is located in the Limpopo metamorphic belt. Developed in this region are rocks of the Messina Formation, the latter considered to be approximately 3,000 m.y. old (van Breemen and Dodson, 1972). Anorthosite complexes which appear to be semiconcordant intrusions within the Messina Formation are found in the area and are distinctly layered and folded with the latter successions. Both Söhnge (1945) and van Eeden et al. (1955) recorded chromitite layers in serpentinites, hornblende gneisses, and anorthositic hornblende gneisses in the area around Messina. The chromite occurrences, which have been included in Figure 3, are small, of low grade (Table 12), and have not been mined.

The second, and considerably more important, chromite-bearing region is that associated with the Great Dyke of Rhodesia (Worst, 1960, 1964). The Dyke, which exceeds 500 km in length, is approximately 2,500 m.y. old (Davies et al., 1969) and is made up of four aligned lopolithic complexes, each possessing similar characteristics. Consisting mainly of a variety of ultramafic to gabbroic rock types, the Dyke also contains a total of 14 proved chrome seams, the latter traceable over much of the length of the complex. Tremendous tonnages of intermediate- to high-grade chromite exists in the Dyke (Table 12) but at present mining is being carried out only on a small scale.

The third, and largest, chromite occurrences in southern Africa are those located in the Bushveld Igneous Complex, the latter body occupying the central region of the Kaapvaal Craton (Fig. 1). Estimates by Cousins and Feringa (1964) place the chrome ore reserves at approximately 18,000 million tons, making the Bushveld Complex the largest repository of chrome in the world.

The Bushveld chrome is, on average, lower grade than chrome ores in the Archean greenstone belts, the Great Dyke, and the Turkish ultramafic and related gabbroic complexes (Table 12). The ore has mainly been used for the production of chromium chemicals, but increasing metallurgical applications are being found as supplies of the world's higher grade chrome ores diminish.

Chromite distribution in southern Africa

The principal areas of chromite development in southern Africa are illustrated in Figure 4. Several features of significance emerge from studies of the chromite distribution. These include the following: (1) The main chromite occurrences are developed on the cratonic portions of the shield and are symmetrically disposed on either side of the Limpopo mobile belt. (2) The chromite is developed in geological formations ranging in age from the Sebakwian ($\sim$3.5 b.y. ago) to the Bushveld Complex ($\sim$2.0 b.y. ago). (3) The chromite occurs in Archean greenstone belts immediately flanking the Limpopo mobile belt and not in those far removed from this region. A significant case in point is the Barberton greenstone belt which has virtually no known chrome mineralization despite the great abundance of favorable ultramafic rock types. (4) The richest chromite ores

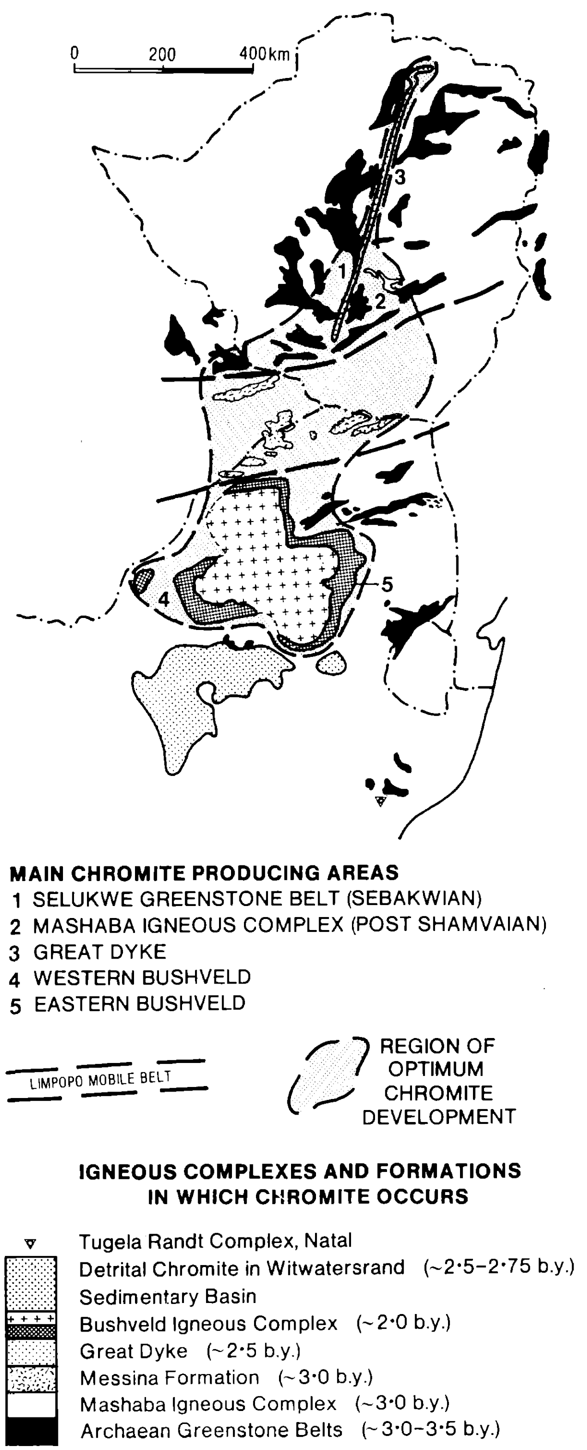

FIG. 4. Distribution of chrome in southern Africa. The chrome ores are developed in formations spanning approximately 1,500 m.y. of geologic time.

are those of the Rhodesian Archean and the Great Dyke, whereas the greatest chromite ore reserves occur on the Kaapvaal Craton. Thus the high-grade chromite appears to be developed in the older geologic environments, whereas the lower grade ores are found in the younger geological settings. (5) Chromite is not known to occur in large amounts anywhere in the Archean greenstone belts preserved on the Kaapvaal Craton. Indirect evidence suggesting the former presence of such chromite-rich greenstone belts lies in the fact that the Witwatersrand Goldfield, which formed approximately 2.50 to 2.75 b.y. ago, contains abundant detrital chromite, the latter occurring within the auriferous conglomerates. The available evidence suggests that the Witwatersrand sediments, including the gold and chromite grains, were derived from the erosion of pre-2.75 b.y.-old greenstone belts formerly located to the north and northwest of the Witwatersrand sedimentary basin (Viljoen et al., 1970; Pretorius, 1974b). These belts probably occurred in the region now largely occupied by the Bushveld Complex. (6) Small chromite occurrences are located in the Tugela Randt Complex in Natal but are of minor importance. It may be significant that this chromite occurrence is close to the Tugela fault zone, the latter representing the boundary between the Kaapvaal Craton and the Natal high-grade metamorphic belt to the south.

The various chromite occurrences in southern Africa combine to form the largest concentration of this mineral known on the earth's surface. The full implications of the symmetrical distribution of the chromite on either side of the Limpopo belt remain to be determined. The fact that chromite has been contributed to a variety of geotectonic regimes (in the area shown in Fig. 4) over a time span approaching 1,500 m.y. does, however, suggest that the mantle, centered about the region of the Limpopo mobile belt, must have been particularly chromium enriched.

Gold

The distribution of 289 of the more important gold occurrences in the Archean greenstone belts of southern Africa is shown in Figure 5. Of this number, 57 ore deposits have each yielded in excess of 100,000 ounces of gold. A total of over 4,000 different gold deposits occur scattered throughout virtually all the greenstone belt remnants, the latter often being referred to locally as "gold belts". The majority of these deposits have been small with the output of just over 50 million ounces of gold and approximately 14 million ounces of silver coming from about 20 large mines. Phaup (1964) showed, for example, that in the area around Gatooma, which is located in the northern part of the Midlands greenstone belt (Fig. 1), there were 359 mines that had been worked prior to 1951. The total production from this area had been over 4.5 million ounces

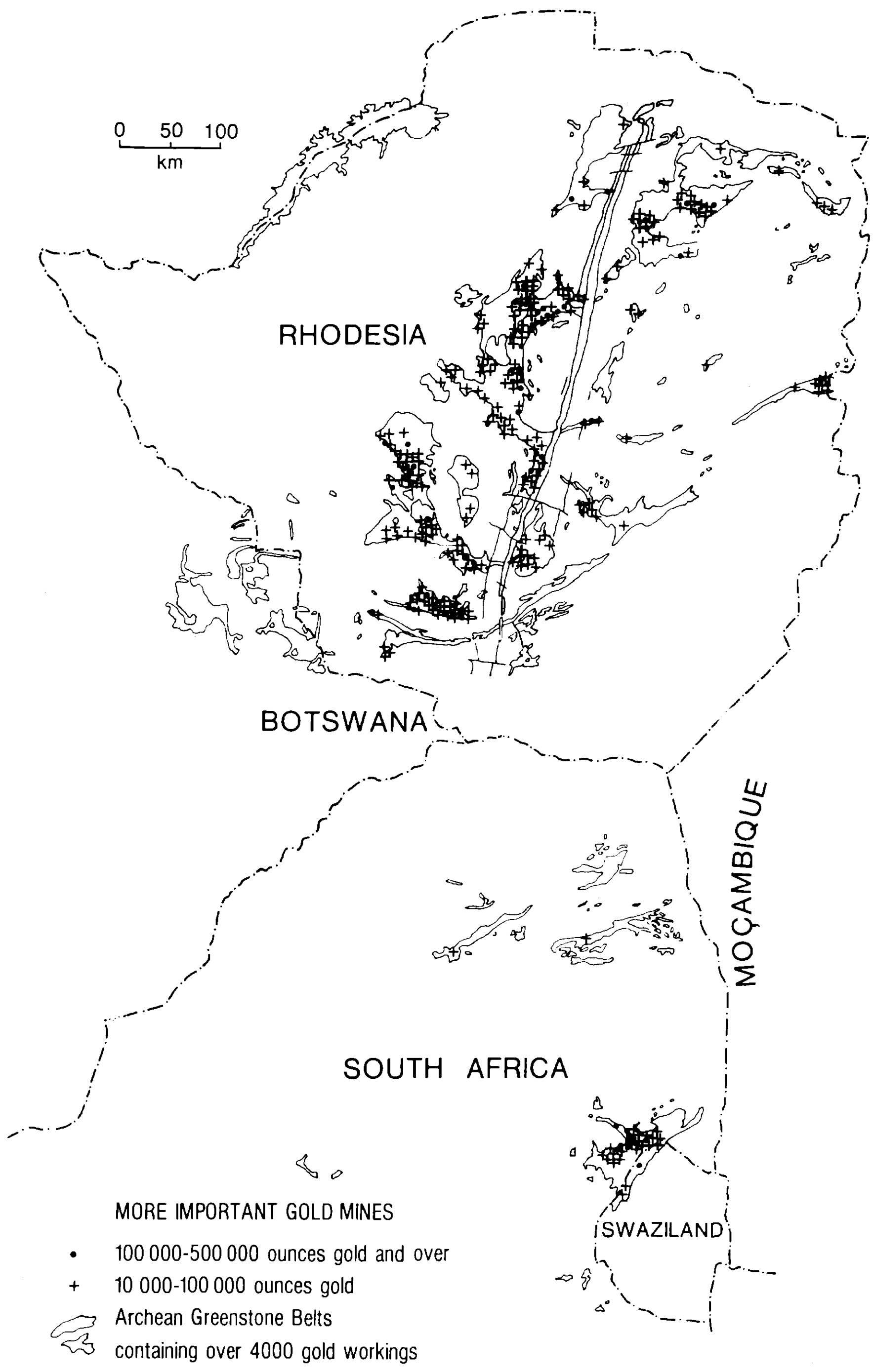

FIG. 5. Map of southern Africa showing the distribution of the more important gold occurrences in the Archean greenstone (metavolcanic) belts.

of gold of which 64 percent came from the Cam and Motor Mine, 8.6 percent from the Giant Mine, 4.4 percent from the Thistle Etna Mine, and 23 percent from the remainder. Less than 1 percent of the total came from 165 mines or prospects.

Similarly, for the Barberton greenstone belt, it was shown (Anhaeusser, 1969) that up to the end of 1963, a total of 5.65 million ounces of gold had been produced from 274 recorded deposits in the area. Of this total, 62 percent of the gold came from three mines (Sheba, Consort, Fairview), whereas 99.3 percent of the total came from 45 mines (the balance of 0.7 percent thus coming from the remaining 229 deposits).

Gold mineralization occurs throughout the Archean stratigraphic column but is preferentially developed in the volcanic-rich units and in banded iron-formation, cherts, and, to a lesser extent, in argillites and quartzites. Some gold also occurs in the granitic rocks, particularly where these occur adjacent to greenstone belts or their xenolithic remnants. The ultimate source of the gold appears to be genetically related to volcanogenic activity of one sort or another within the volcanic-rich belts. Although no quantitative supporting data are available, it is the writer's opinion (Anhaeusser, 1969), as well as that of Viljoen et al. (1969, 1970), that the basaltic and peridotitic rocks of the Lower Ultramafic Unit were the primary host rocks of much of the gold mineralization found in the southern African greenstone belts. Gold and associated sulfides are, however, widespread in volcanogenic rocks of the Mafic-to-Felsic Unit (e.g., Bulawayan succession, Rhodesia, and Swartkoppie Formation, Barberton Mountain Land). These rocks are generally further removed from intrusive granite bodies than the stratigraphically lower basaltic and peridotitic assemblages and have, therefore, been less affected by metamorphism than the latter successions. The concentration of the mineralization in the areas rimming the granite bodies (particularly evident along the contact zone between the Midlands greenstone belt and the Rhodesdale batholith, c.f. Figs. 1 and 5) may therefore be linked with the heat effects consequent on granite intrusion, rather than reflect initially higher gold content of these rocks.

Descriptions of many of the southern African Archean gold deposits are available. Information on the mines (with varying degrees of attention given to detail) is available in most of the bulletins of the Geological Survey of Rhodesia, in numerous dissertations, and in publications of the Geological Society of South Africa (particularly Haughton, 1964, and Visser, 1968). Several attempts have been made to summarize what is known of the deposits, their distribution, and the controls to mineralization, and further details may be obtained in the references cited (Davies and Hunter, 1964; Goldberg, 1964; Phaup, 1964; Anhaeusser, 1965, 1969; Pretorius and Hempkins, 1968a, b; Anhaeusser et al., 1968; Viljoen et al., 1969).

As mentioned previously, most of the gold is now considered to be genetically associated with rocks of volcanic origin. The superimposed effects of granite intrusion, metamorphism, and deformation have been largely responsible for the migration of much of this gold from its original source into dilationary (tensional) zones produced by folding and faulting. Added support for this derives from trace element patterns observed in pyrites from gold-sulfide deposits of the Barberton Mountain Land. This, as well as lead isotopic data showing the age of the mineralization in the Barberton greenstone belt to be between 3,450 to 3,800 m.y. old, is described by Saager and Köppel in this volume (1976).

Although many of the Archean gold deposits are clearly related to hydrothermal processes, there is growing evidence to suggest that some of the gold-pyrite-arsenopyrite mineralization is also stratiform in character. The association between gold and various types of iron-formation (both oxide and sulfide facies) and banded cherts has long been recognized. The association has only recently been interpreted as being of volcanic exhalative origin. Examples of this type are known in the Barberton greenstone belt and in many areas of Rhodesia, including specifically the Vubachikwe-Blanket mine areas of the Gwanda greenstone belt (Fig. 1) and the Neardy mine area in the Odzi-Umtali belt. Further details of these, and other occurrences like them, are discussed elsewhere in this volume (Fripp, 1976). Many of the deposits in this category occur in jaspilitic iron-formations terminating volcanic cycles of mafic to felsic lava and acid tuffs and pyroclasts.

Regional distribution of Archean gold mineralization

It can be seen in Figure 5 that the greatest concentration of gold deposits occurs in the more centrally situated greenstone belts on the Rhodesian Craton, as well as in the Barberton Mountain Land. As mentioned earlier, there is a tendency for most deposits to be located around the periphery of the greenstone belts, not on the contacts with the main granite batholiths but, as pointed out by Phaup (1964), usually a few kilometers in from the margins of the belts. Exceptions occur where some gold deposits flank small stocks or granite cupolas and even extended into the granite itself. There thus appears to be an "optimum thermal zone" in greenstone terrains wherein the gold and associated sulfide mineralization tends to concentrate preferentially. No quantitative data are yet available to define more precisely the thermal regime most conducive to gold accumulation, but evidence from metamorphic mineral assemblages suggests that conditions akin to middle or upper greenschist facies of regional metamorphism were probably most favorable (450° to 550°C).

Additional support for an optimum thermal zone for gold mineralization follows from the studies of Pretorius and Hempkins (1968a), who investigated data concerning gold production in Rhodesia. Analyses of the general statistics of population frequency distributions indicated a pattern of more favorable intensity of gold mineralization associated with ores containing the lower temperature minerals chalcopyrite, stibnite, and galena than from ore characterized by the presence of the higher temperature minerals pyrrhotite, arsenopyrite, and sphalerite.

On a regional scale it can be shown schematically (Fig. 6) that the high-grade metamorphic belts are not only virtually barren of gold mineralization but have influenced (mainly thermally) the greenstone belts in their immediate vicinity—only very minor quantities of gold having been located in areas flanking the mobile belts.

Mineralization of the type discussed was unstable in the high temperature/pressure regimes of the mobile belts and consequently moved away from these areas, and the craton margins, toward the craton interiors. Some of the mineralization in the thermally affected regions may also have been dissipated (as opposed to being concentrated) throughout many rocks in the heat-affected regions. In addition, some of the migratory gold mineralization may have eventually ended up in the Witwatersrand sedimentary basin (or other interior basins), together with gold and sulfides derived from the erosion of Archean greenstone belts.

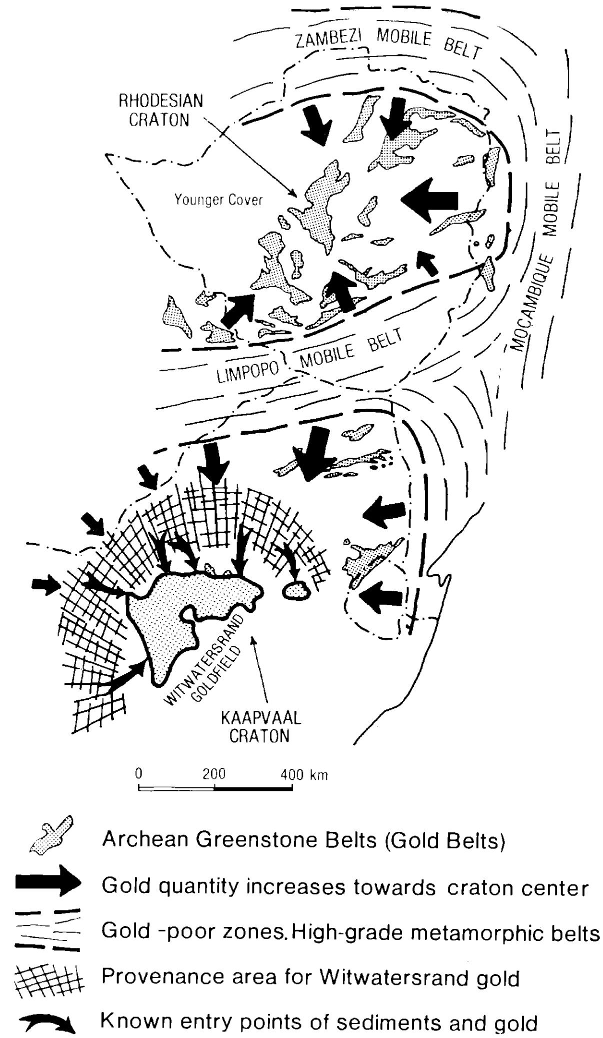

FIG. 6. Schematic map of the southern African Shield showing the distribution of gold mineralization in relationship to the circum-cratonic high-grade metamorphic mobile belts. The provenance area of the Witwatersrand Goldfield is now largely covered by younger formations, including the Bushveld Complex.

Mineralization Associated with Mafic to Felsic Volcanic Rocks

Under this heading, mineral types associated with volcanic rocks of intermediate to acid composition are described. Most of the mineralization occurs in successions grouped within the Mafic-to-Felsic Unit outlined earlier. Exceptions include mineral deposits related to felsic volcanic and pyroclastic rocks of the Lower Ultramafic Unit. The latter include mainly small deposits of barite, corundum, and kyanite, and, unlike the rocks of the Mafic-to-Felsic Unit, have not yielded signs of any noteworthy sulfide mineralization.

The distribution of the mineral occurrences, which include deposits and prospects of antimony, gold, mercury, copper, lead, zinc, tungsten, and massive pyrite-pyrrhotite, are shown in Figures 7 and 8.

Antimony and mercury

One of the most important single occurrences of antimony mineralization in the world, and certainly the largest deposit of its kind anywhere in the Archean, is the Consolidated Murchison mine located in the Murchison greenstone belt on the Kaapvaal Craton (Figs. 1 and 7). A number of orebodies occur in lenses strung out along approximately 50 km of the so-called "Antimony Line" (van Eeden et al., 1939) where the host rocks consist mainly of sheared and, in places, intensely carbonated (green and gray dolomite) intermediate to felsic volcanic rocks of greenschist metamorphic grade. The mineralization consists mainly of the sulfides stibnite, berthierite, tetrahedrite, and chalcostibite and includes the antimony oxides stibiconite and kermesite. Gold, pyrite, arsenopyrite, and cinnabar occur locally, the mercury having been mined in the past, whereas gold is still recovered as a by-product of the antimony mining. Descriptions of the orebodies (Mendelssohn, 1938; Hausmann, 1959; Sahli, 1961; Boese, 1964) suggest that the mineralization is epigenetic (hydrothermal) in origin, but these views are now being challenged in favor of a volcanogenic origin (volcanic exhalative, fumarolic). It is suggested that processes involving the remobilization of the ores by hydrothermal activity caused local concentrations of mineralization in structurally favorable areas.

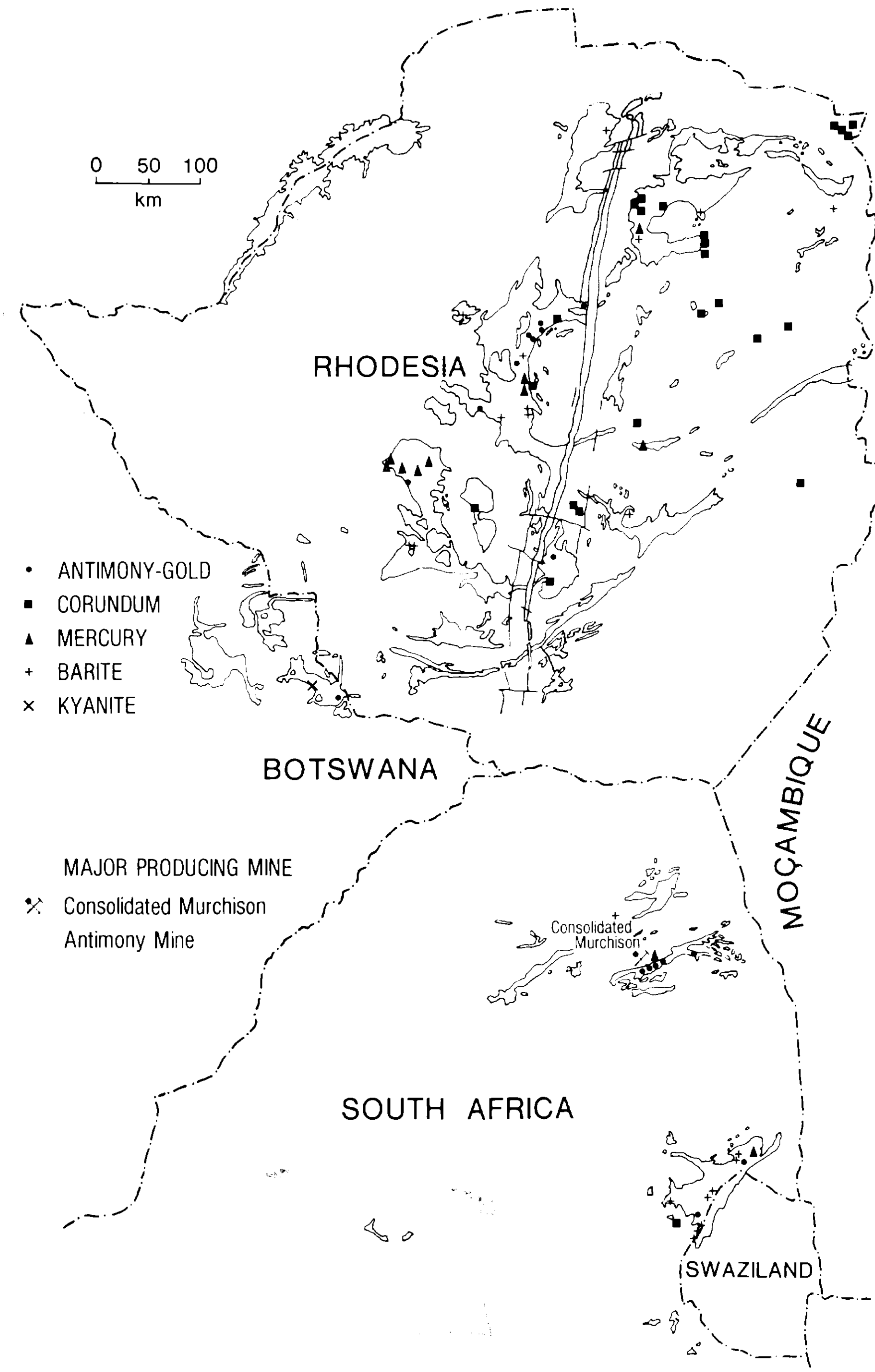

FIG. 7. Map showing the distribution of antimony, barite, mercury, corundum, and kyanite associated with felsic volcanic rocks in Archean greenstone belts of the Rhodesian and Kaapvaal Cratons.

The reconcentration of the stibnite was probably accompanied by silicification and dolomitization of the volcanic rocks in the structurally disturbed areas, although the association of stibnite mineralization with green dolomitic rocks in the mines has led to an alternative suggestion that the carbonate rocks originally constituted a stratigraphic unit interlayered with the volcanic successions (M. J. Viljoen, pers. commun., 1974).

Antimony mineralization is also known in the Barberton greenstone belt as well as in the centrally situated greenstone belts of the Rhodesian Craton.

These deposits are generally small, the antimony frequently being recovered as a by-product of gold mining (e.g., the Indarama gold-antimony deposit in the Midlands greenstone belt near Que Que, Rhodesia, described by Mehliss, 1968). The distribution of mercury mineralization (cinnabar) follows closely the pattern outlined for the antimony (Fig. 7), with most of the production again representing a by-product of gold mining. The small Rhodesian occurrences have been described by Robertson (1972) who noted that the more significant deposits are located in weakly metamorphosed carbonated andesitic lavas. The main occurrence on the Kaapvaal Craton is the Monarch cinnabar deposit located in the Murchison greenstone belt, close to the antimony workings of the Consolidated Murchison mine. Hausmann (1959) described the cinnabar-rich lodes as occurring in siliceous carbonate rocks together with minor amounts of chlorite and associated low-temperature ore minerals, the latter including pyrite, chalcopyrite, stibnite, tetrahedrite, digenite, and covellite.

The mercury occurrences, like those of the antimony deposits, have generally been described as hydrothermal in origin. However, the close association of the mineralization with rocks of intermediate to felsic volcanic origin suggests an alternative genetic history linking these deposits to the late stages of an exhalative sedimentary environment (fumarolic mineral springs depositing siliceous sinters).

Barite

Small, generally subeconomic, and usually strati-form deposits of barite occur scattered throughout many greenstone belts in southern Africa (Fig. 7). Investigations in the Barberton Mountain Land by Viljeon and Viljeon (1969c) and Reimer and Heinrichs (in press) suggest that the mineralization occurs in both the Onverwacht and overlying Fig Tree groups. In both these settings the barite is considered to be of volcanogenic origin, probably forming from volcanic exhalations associated with explosive volcanicity, as witnessed by the presence of tuffs in the surrounding strata. Previous hydrothermal postulates appear untenable as it can be demonstrated that the barite generally has a marked stratigraphic control, being confined to the terminal phases of volcanic cycles in which mafic lavas, followed by felsic lavas or pyroclasts, are overlain by persistent cherty layers containing both massive and banded barite.

A similar origin is suggested for many of the barite occurrences in the Rhodesian greenstone belts despite the conclusions by Morrison (1970) that the majority of the deposits occur as vein fillings associated with faults traversing Archean granites, greenstones, and metasediments. Mineralization of this type is easily remobilized, transported, and redeposited by secondary processes making its origins appear divergent and obscure.

Corundum and kyanite

Rhodesia has for many years been the world's principal supplier of corundum, followed by South Africa, India, Kenya, and Tanzania. Two commercial varieties are known, crystal corundum and boulder corundum. The crystal corundum deposits, the distribution of which is shown in Figure 9, owe their origin to a number of processes which, according to Morrison (1972), include: (1) the metamorphism of sedimentary rocks; (2) the desilication of pegmatites intrusive into hornblende and tremolite schists, respectively (cf. Hall, 1920); (3) the metasomatism of amphibolites, biotite schists, serpentinites, and fuchsitic mica schists during granitizaton; (4) the effects of granulite facies metamorphism on ultramafic rocks, on anorthosites, and on biotite schist relics in leuco-paragneisses.

The absence of pegmatites in the development of (3) and (4) above is noteworthy. These deposits fall largely in the areas of influence of the Limpopo, Zambezi, and Mocambique high-grade metamorphic belts.

The boulder corundum is, economically, more important, particularly in Rhodesia. To the end of 1965, Morrison (1972) showed that boulder corundum had accounted for 97.8 percent of the 40,297 tons of corundum produced in that country. The distribution of this variety is shown in Figure 7. All these deposits are situated in rocks of the greenstone belts and, like the barite deposits, appear to occur at various stratigraphic levels within the volcanic sequences.

Morrison (1972), who investigated the boulder corundum deposits of Rhodesia, found the main features of the occurrences to be as follows: (1) Most deposits are situated near greenstone-granite contacts or near intrusive mafic complexes or dikes, all of which provided a source of heat for the development of the corundum. (2) The corundum deposits form part of the lithological sequence and show no crosscutting relationships with the country rocks. (3) The corundum commonly occurs as lenses within aluminous mica schists containing one or more of the following minerals: andalusite, chiastolite, sillimanite, and kyanite. Fuchsite, sericite, rutile, diaspore, and margarite frequently accompany the corundum. (4) The deposits occur with wall rocks that include ultramafic rocks (talc schists, serpentinites), banded iron-formation, phyllites and argillaceous metasediments (mafic tuffs), aluminous micaceous schists, and hornblende schists or gneisses.

Morrison (1972) concluded that the boulder corundum deposits of Rhodesia were formed as a result of metamorphism of alumina-rich sediments, presumably pre-existing bauxites. These findings have been confirmed in the Barberton area where the corundum host rocks consist of felsic volcanic rocks (mainly pyroclasts and tuffs—see chemical analysis, Table 10, column 7), the latter occurring as members of volcanic cycles within the greenstone belts.

In addition to the corundum mineralization, precious and semiprecious sapphires and rubies have been obtained from some of the crystal corundum deposits in northeastern Rhodesia. Furthermore, kyanite has been mined in some localities, including the Halfway Kop deposit in the Tati greenstone belt of Botswana (cf. Figs. 1 and 7). Here lenses and pods of kyanite occur in quartz-kyanite-sericite-pyrophyllite-schists (Boocock, 1965). These rocks represent altered felsic pyroclasts and tuffs (Mason, 1970).

Copper-lead-zinc-gold

The distribution of copper, lead, and zinc mineralization is shown in Figure 8. Unlike the Canadian Archean, there are no known major massive base metal sulfide deposits in the greenstone belts of southern Africa. Most of the locations shown in Figure 8 are prospects or small workings. Only in a few cases (e.g., the Cactus mine, south of Que Que in the Midlands greenstone belt) are deposits of this type being mined, and then only on a small scale.

On the Kaapvaal Craton occurrences of this type are virtually absent with the exception of small stratiform deposits (probably totalling less than 1 million tons) located along the "Letaba copper-zinc line" in the Murchison greenstone belt. The deposits, with the ore minerals pyrite, marcasite, chalcopyrite, cubanite, sphalerite, pyrrhotite, digenite, covellite, and galena (Hausmann, 1959), occur in quartz-mica and quartz-chlorite schists (low to intermediate metamorphic grades), now considered to be altered equivalents of felsic volcanic rocks.

On the Rhodesian Craton the Cactus mine is one of the few deposits being worked. The Cu-Pb-Zn ores, which also contain appreciable amounts of Sb, Au, and Ag, occur in structurally disturbed felsic volcanic rocks (quartz-feldspar porphyries and felsic tuffs). The ore deposit is associated with fractures and appears to be of hydrothermal origin. It is possible that the ore deposit represents mineralization remobilized from volcanogenic source rocks.

Copper has also been recovered as a by-product of gold mining at the Falcon mine (Fig. 8) in the Umvuma greenstone belt, and is a common associate of gold in the small mines of the Felixburg, Odzi-Umtali, Midlands, and Filabusi greenstone belts (cf. Figs. 1 and 8). Indications of copper mineralization are also prevalent in many of the greenstone belts along the northwest margin of the exposed Archean terrain of the Rhodesian Craton, extending from the Matsitama belt in Botswana through the western portions of the Bulawayo-Bubi and Midlands belts. The copper showings along this zone coincide with the major differences in metallogenic association reported by Bliss (1970), who maintained that the line of demarcation of an essentially gold-rich province (including scheelite) and a copper-nickel province (with minor gold and no recorded scheelite) corresponded with the lithological variation recorded between rocks of the Bulawayan Group and those of the Umniati and Maliami River formations.

Massive sulfide iron-formations

Massive sulfide deposits of pyrite and pyrrhotite are known to occur in several areas on the Rhodesian Craton as well as in the Limpopo mobile belt (Fig. 8). North of Salisbury, the Iron Duke mine represents one of the few sulfide facies stratiform ore occurrences to have been mined essentially for its massive pyrite (Ferguson and Wilson, 1937). This, and other deposits in the Shamva-Salisbury greenstone belt (Fig. 8) represent the product of exhalative volcanogenic activity during the deposition of the Shamvaian Group.

Further massive pyrite-pyrrhotite deposits are known in the Bulawayo, Gwanda, and Tati greenstone belts. In the latter greenstone belt Ryan (1970) reported the presence of a major pyrite-pyrrhotite deposit in the Mphoengs schist belt, which extends from Botswana into Rhodesia. The mineralization, which can be traced intermittently for over 18 km, occurs in association with a thin but persistent limestone unit that occurs in a succession of altered basalt-andesite-dacite-rhyolite volcanic and pyroclastic rocks. The sequence also contains banded iron-formations and is correlated with the Mafic-to-Felsic Unit.

Silver-tungsten-arsenic

Silver, tungsten, and arsenic mineralization occur widespread throughout the southern African greenstone belts but are invariably by-products of gold mining. The silver occurs alloyed with gold, whereas the tungsten (mainly scheelite) and arsenic (arsenopyrite) are found associated with the gold ores. The main tungsten-rich gold deposits are shown in Figure 8. The distribution of the silver and arsenic follows closely the pattern of gold distribution shown in Figure 5.

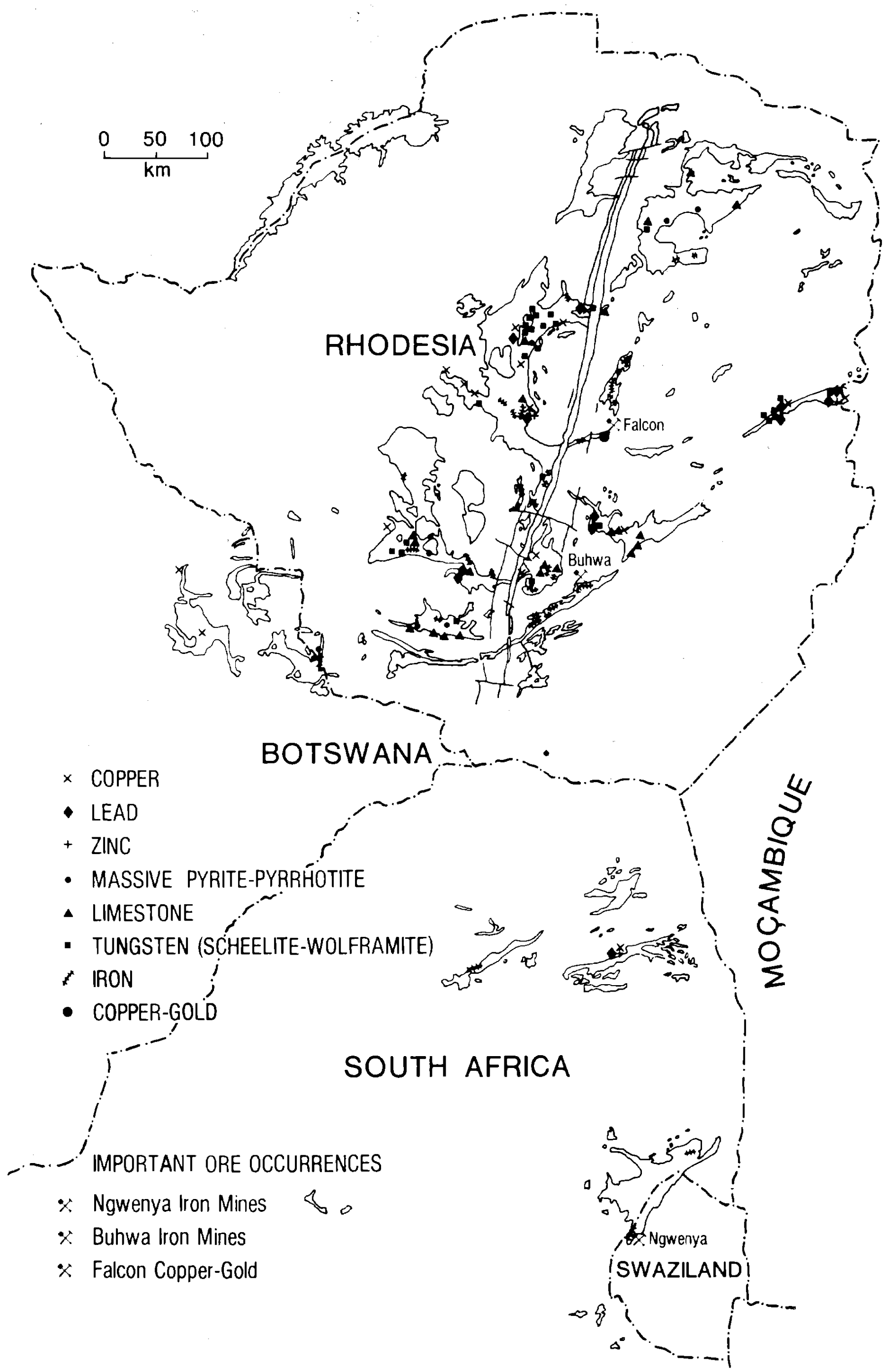

FIG. 8. Distribution of copper, lead, zinc, copper-gold, tungsten, iron, limestone, and iron sulfide mineralization in Archean greenstone belts of southern Africa.

Archean Sedimentary Deposits

Under this heading may be grouped the ancient placer gold-pyrite deposits that occur in conglomerate-quartzite formations of the Archean greenstone belts. These have been worked in a small way in the Uitkyk Formation of the Pietersburg greenstone belt (Fig. 1) and in Shamvaian successions in parts of Rhodesia. Other sedimentary mineral occurrences of note include the Archean iron-formations and the limestone deposits, the latter confined to the Rhodesian greenstone belts (Fig. 8).

The iron-formations in the greenstone belts are almost invariably associated with volcanic rocks. They are developed at various stratigraphic positions from the base to the top of the greenstone piles but are more commonly located in the lower, essentially volcanic environment as opposed to the terminal sedimentary parts of the stratigraphic column (Beukes, 1973). Detailed mineralogical data on the iron-formations are not available, but qualitative estimates suggest that the order of abundance of iron compounds deviates little from the findings of James (1966) and Stanton (1972) who reviewed the chemistry of iron-formations of Archean age throughout the world. The iron oxides appear to be most abundant, followed by carbonate, silicate, and sulfide facies iron-formations.

Almost without exception the greenstone belts in southern Africa have iron-formations that may be grouped into one or more of the four above-mentioned categories. Most important are the finely laminated, alternating, iron- and silica-rich beds referred to locally as jaspilites or "banded ironstones". The general tenor of iron in these rocks varies from 30 to 40 percent Fe, although in the Mwanesi greenstone belt in Rhodesia (Fig. 1) up to 50 percent Fe has been recorded (Worst, 1962a). Processes of enrichment of the protore give rise locally to deposits with 60 to 65 percent Fe, examples of which are given later.

The banded iron-formations occur in two environments. In the volcanic environment they are associated with mafic and felsic volcanics and are often members of a three-part cycle consisting of mafic lava, felsic lava, and chert or iron-formation. Examples of this type are found commonly in the Sebakwian and Bulawayan groups in Rhodesia (Bliss and Stidolph, 1969) and within the Onverwacht assemblages of the Barberton and Pietersburg greenstone belts. Iron-formations also occur in an essentially sedimentary environment where they are associated with shales, phyllites, limestones, graywackes, quartzites, and minor lava units. As pointed out by Anhaeusser and Button (1974), the role of volcanism and iron deposition in such settings is not easy to assess, and inferences have to be drawn largely from associated rock types. A close and probable genetic relationship to volcanism appears reasonable for some of the iron-formations in the Shamvaian Group in Rhodesia and in the Moodies Group in the Barberton Mountain Land. In the latter case, banded jaspilitic iron-formations occur stratigraphically above a minor basaltic lava unit (Anhaeusser, 1971), whereas in the underlying Fig Tree Group, iron-formations occur in a predominantly sedimentary assemblage which, however, includes lava and pyroclastic members with sodatrachytic affinities (Visser et al., 1956).

Subordinate carbonate and silicate iron-formations are known, as well as the sulfide facies varieties described earlier. Some iron-formations, linked with those of the Archean, have been subjected to intermediate to high grades of metamorphism and have undergone recrystallization to magnetite quartzites. These changes have taken place mainly in the mobile belts encircling the cratons. Many of the magnetite quartzite occurrences along the southern and southeastern margins of the Rhodesian Craton (Fig. 1) appear to belong to this category (Worst, 1962b). In addition, bands of resistant iron-formation and magnetite quartzites also occur as xenoliths in the granites on the cratons.

Deposits of iron ore that are being mined include the enriched high-grade hematite orebodies near Que Que in the Midlands greenstone belt, the deposits in the Buhwa belt (Worst, 1962b), and the enriched Fig Tree iron-formations in the Ngwenya mine area in Swaziland (Bursill et al., 1964). Large reserves of lower grade iron ore occurs in the Mwanesi Ranges (Worst, 1962a).

Limestone occurrences are found as stratigraphic interlayers within the volcanic successions. The deposits are mined for the manufacture of cement (e.g., Colleen Bawn mine, Gwanda belt) and for the steel industry. It is of interest to note that the oldest stromatolites yet recorded have come from the Archean limestones in the Huntsman quarry north of Bulawayo (Macgregor, 1940).

Mineralization Associated with Granites and Pegmatites

A wide variety of minerals occurs scattered throughout the Archean granitic terrain of southern Africa (Fig. 9). With the exception of tin, molybdenum, and tantalum-columbium, the mineralization consists mainly of nonmetallic deposits of beryllium, lithium, bismuth, mica, corundum, and emeralds as well as felspar, silica, and graphite. Most of the deposits are associated with pegmatites located close to the margins of greenstone belts or in areas where there are numerous xenolithic greenstone remnants.

Although the deposits occur widespread throughout the region depicted in Figure 9, there are two prominent areas of pegmatite development from which the bulk of the mineralization has so far been recovered. The most important pegmatite area is that known as the Bikita Tinfield, located at the eastern extremity of the Fort Victoria greenstone belt in Rhodesia (Martin, 1964). Situated in this region is the Bikita pegmatite, one of the largest deposits of lithium, caesium, and beryllium in the world. The Bikita deposit, which is approximately 2,650 m.y. old (Cooper, 1964), contains numerous minerals of economic importance. In order of abundance these

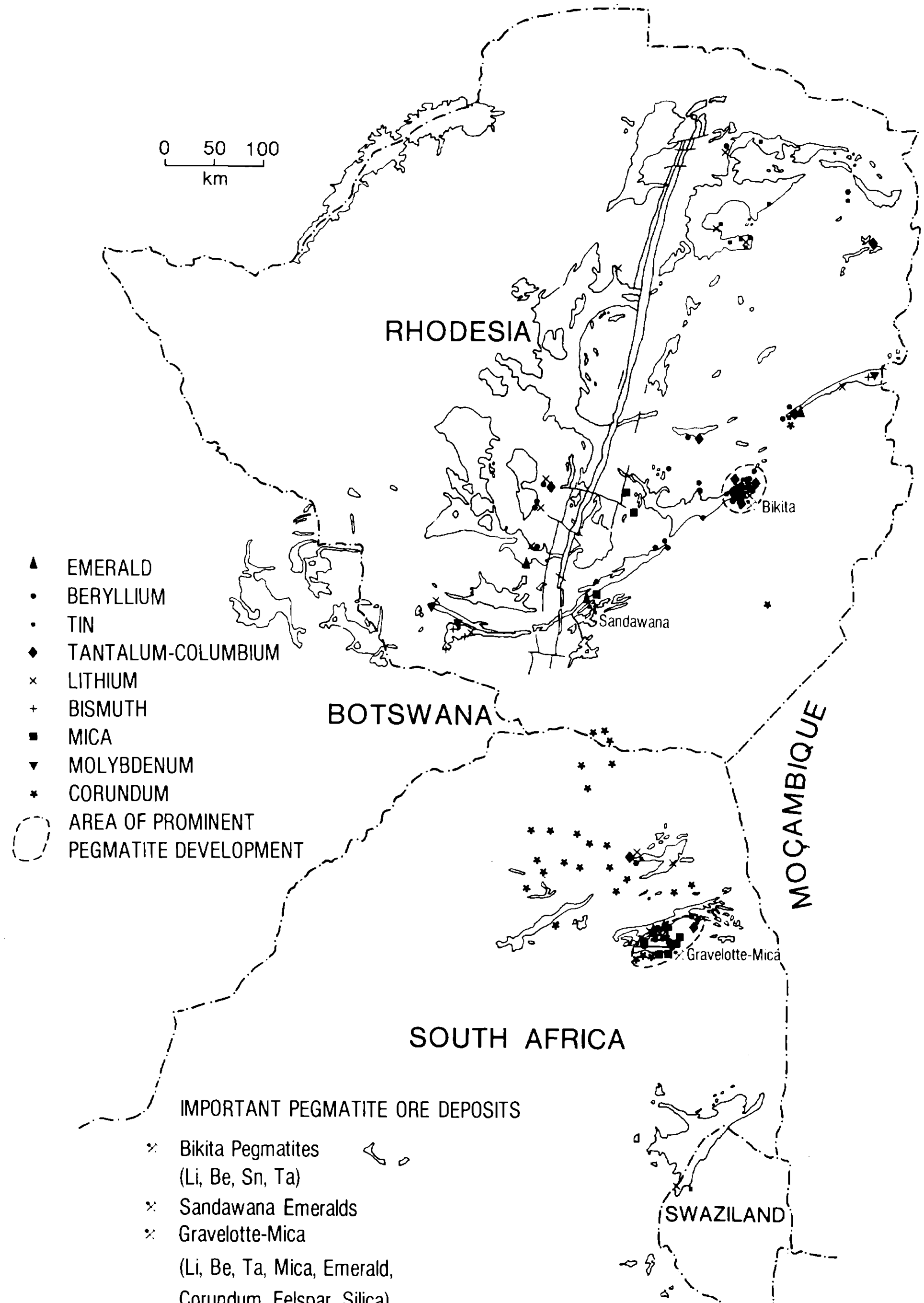

FIG. 9. Map showing the distribution of mineral occurrences associated with Archean granites and pegmatites in southern Africa.

are: petalite, lepidolite, spodumene, pollucite, beryl, eucryptite, and amblygonite. The cassiterite, tantalite, and microlite deposits have been mined out.

The second prominent pegmatite area is referred to as the Gravelotte-Mica pegmatite field, located in and adjacent to remnants of the Murchison greenstone belt on the Kaapvaal Craton. Important deposits of mica occur in the region, which also supplies quantities of beryllium, lithium, tantalum and columbium, corundum, felspar, and silica. Emeralds, together with beryl, are mined from pegmatites intruded into biotite schists. The pegmatites are associated with a late potassic granite body (the Mashishimala Pluton), which was intruded into the area south of the main remnant of the Murchison schist belt.

Deposits of corundum, associated with pegmatites, show a clustering in the region north of the Pietersburg and Murchison greenstone belts. These deposits, which have been described by Hall (1920), yielded large quantities of corundum and made South Africa one of the world's leading producers of this mineral during the first quarter of this century.

Important deposits of emeralds occur not only in the Gravelotte-Mica area but also in the Rhodesian greenstone belts flanking the Limpopo metamorphic belt. The most valuable deposits are those associated with pegmatites in the Sandawana Emerald mine area, adjacent to the Buhwa-Mweza greenstone belt. Emeralds have also been recovered in the Bikita area, the Odzi-Umtali area, and the Filabusi greenstone belt (Fig. 9).

Tin has been recovered from a number of pegmatites throughout the Archean regions discussed in this paper. The most important deposits, which are now largely mined out, occur in the Bikita area (Martin, 1964), in the Salisbury greenstone belt, and in Swaziland, the last deposits being associated with granites and pegmatites southeast of the Barberton greenstone belt (Davies, 1964).

Small graphite deposits occur in metamorphosed carbonaceous shale xenoliths in the Archean granites and gneisses. Most of these deposits are located in the Limpopo mobile belt and in the areas flanking this region in Rhodesia and South Africa.

Discussion

Petrogenetic, tectonic, and stratigraphic processes in Archean rocks appear very similar throughout the world (Goodwin, 1968, 1971; Anhaeusser et al., 1969; Glikson, 1970). Furthermore, as pointed out by Hutchinson et al (1971), the rock types, stratigraphic relationships, and contained mineral deposits are similar in most shield areas, including Canada, Australia, Brazil, Fennoscandia, and Africa. Despite these similarities, which support suggestions that the Archean was a time of unique crustal development, increasing evidence is being made available demonstrating that appreciable differences do exist from one shield area to another.

The most significant differences are reflected in the variable geochronological and geochemical data emanating from studies of Archean rocks around the world. Although geological processes and responses appear to have been similar in all these ancient terrains, variations in geochemical characteristics of the Archean volcanic sequences probably reflect contrasting stages in crustal development, the latter also being time dependent.

Consequent on the geochemical changes that have been recorded are variations relating to the nature and relative abundances of Archean mineral deposits throughout the world. In the preceding pages, attempts have been made to briefly describe and illustrate the nature and distribution of Archean mineralization in southern Africa. By comparing this mineralization with that reported in the Archean terrains of Canada, Western Australia, and elsewhere, a number of important features emerge. These include the following: (1) The range in the types of mineralization found in Archean successions is everywhere extensive, although the relative abundances of the mineralization is variable. (2) Certain types of mineralization appear to be equally well represented in greenstone terrains around the world. These include deposits of gold (and associated silver), as well as the various facies of iron-formation. (3) Chromite is most abundantly developed in the Archean successions of the Rhodesian Craton. (4) Nickel-copper ores are particularly well represented in the Yilgarn Province of the Western Australian Shield (Woodall and Travis, 1969; Fardon, 1971), and to a lesser extent on the Rhodesian Craton. Deposits of nickel-copper ores also occur in Canadian greenstone belts but, as pointed out by Naldrett and Gasparrini (1971), the orebodies tend to be small. (5) Massive base metal sulfide orebodies containing copper, lead, and zinc are exceptionally well developed in the Canadian greenstone belts. Prominent silver-gold mineralization is associated with these deposits (Goodwin, 1965; Hutchinson et al., 1971; Hutchinson, 1973). By contrast, Cu-Pb-Zn deposits of this type are rare in Western Australia and southern Africa, and virtually all the silver produced in these regions is alloyed with the gold mineralization. Absent are deposits of silver (and cobalt) like those at Cobalt, Ontario, in Canada. Although the latter deposits are closely related spatially to the Nipissing diabase sill of Preterozoic age, the silver-cobalt veins are also close to the unconformity between Archean (Keewatin volcanics and Timiskaming sediments) and younger rocks (Gowganda Formation). In the opinion of Boyle (1968) and Hutchinson et al. (1971), the silver and other elements in the Cobalt area may have been derived from the underlying Archean volcano-sedimentary rocks by thermal remobilization due to the diabase intrusion. (6) The Archean granite-greenstone terrain in southern Africa has important deposits of chrysotile asbestos and antimony and, in addition, has been a principal world-supplier of certain nonmetallic minerals associated with granites and pegmatites (particularly lithium, beryllium, and corundum).

What reasons can be offered to explain the unequal concentration of mineralization types in the Archean successions of the world? There is always a danger in speculations of this kind, as vast areas of the shields still remain to be mapped and geologically prospected. However, bearing these limitations in mind and considering the available data, it is possible to demonstrate a worldwide association of certain mineral types with particular host rock stratigraphy.

As was demonstrated earlier, the southern African greenstone belts, relative to their Canadian counterparts, contain a greater proportion of ultramafic and mafic rocks and are deficient in rocks of intermediate to felsic character. It is concluded that this disparity of lithological proportions between the Canadian and southern African shields is the underlying cause of the variability in the mineralization thus far encountered in the two regions.

The more prominent development in southern Africa of rocks of the type classified with the Lower Ultramafic Unit probably represents a function of the greater age of the latter rock assemblages. Greater abundances of the siderophile elements (e.g., Au, Ni, Fe, and the platinum-group metals) as well as chromium are thus to be expected in rocks of this character. By contrast, the younger, well-differentiated, intermediate to felsic volcanic sequences of calc-alkaline affinity, like those so well represented on the Canadian Shield, are the host rocks of the chalcophile elements (e.g., Cu, Pb, Zn), and represent more favorable target areas for Archean base metal exploration. It is suspected that mineralization of this type may yet be encountered in southern Africa, but the greater age of the rocks and their proportionately smaller areal (volumetric) extent will probably provide constraints on the number and size of possible ore deposits that might be encountered.

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