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POLYPHASE CRUSTAL EVOLUTION OF THE ARCHAEAN KRAAIPAN GRANITE-GREENSTONE TERRANE, KAAPVAAL CRATON, SOUTH AFRICA

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by

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ABSTRACT

Field, petrological, geochemical, isotopic and geophysical data has been assembled to determine the nature and extent of Archaean Kraaipan granite-greenstone rocks on the western edge of the Kaapvaal Craton, southern Africa.

The Kraaipan greenstone belts, consisting of metamorphosed mafic volcanic rocks and interlayered metasediments (mainly banded iron formations, jaspilites and ferruginous cherts), occur poorly exposed beneath cover sequences comprising mainly late Archaean Ventersdorp Supergroup volcanic rocks and a blanket of Tertiary- to-Recent Kalahari sediments. A variety of granitoid rocks intruded the Kraaipan greenstones which, on the basis of whole-rock Pb-Pb dating of banded iron formations, have yielded an age of 3410+61-64 Ma. The earliest granitic rocks, which comprise tonalites and trondhjemitic gneisses, were dated using the single-grain Pb-evaporation technique on zircons, and yielded minimum ages ranging from 3162±8 to 3070±7 Ma in the study area. This, coupled with 3250-3030 Ma ages reported for gneisses in the Kimberley and other areas on the western edge of the Kaapvaal Craton, suggests a prolongued evolution for the basement gneisses which were also disturbed between 2940 and 2816 Ma ago, probably during episodes of migmatization. Potassium-rich granitoids, also dated using the single-grain Pb-evaporation method, range in age from 2880±2 to 2846±22 Ma and extend from the Schweizer-Reneke area in the south to the Botswana border and beyond in the north. Geophysical evidence (aeromagnetic and Bouguer gravity data) suggests that this granitoid variety may be interconnected and might have been emplaced episodically across the study area. A close spatial relationship exists between these granodiorites and adamellites and known gold mineralization present in the Kraaipan-Madibe areas in the north and the Amalia area in the south. This suggests a possible genetic link which could be of significance in mineral exploration. Lastly, a late granitoid pluton, the Mosita adamellite, yielded a Pb-evaporation age of 2749±3 Ma and is the youngest intrusive body recorded in the Kraaipan granite-greenstone terrane. Its presence beneath Kalahari sand cover is defined by Bouguer gravity data. The Kraaipan granite-greenstone terrane, with a prominent north-south trend, appears to represent an Archaean crustal segment that may have accreted episodically on to the western edge of the Kaapvaal Craton. In a manner similar to the Murchison granite-greenstone terrane in the northeastern part of the Craton, the region may also have constituted an important potential source of placer gold mineralization found in the Witwatersrand Basin.

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INTRODUCTION

The Archaean granite-greenstone basement of the Kaapvaal Craton in southern Africa is, to a large extent, covered by mainly late Archaean and Proterozoic as well as younger cover sequences (Fig.1). Most of the available information on the basement rocks stems from studies in the eastern and northern sectors of the Craton extending from southern Swaziland and adjacent areas (Hunter, 1993 and references therein), northwards to the Barberton, Murchison, Sutherland and Pietersburg granite-greenstone terranes (see references in bibliographies compiled by Anhaeusser, 1976, 1986, 1992, 1996). Limited exposures in the central and western part of the Craton are found on the Johannesburg Dome (Anhaeusser, 1973) and the areas to the southwest where granitic basement inliers occur along the Rand Anticline, extending from west of Johannesburg (Fig.1) towards Schweizer-Reneke (Klemd, 1987; Robb and Meyer, 1987; Drennan, 1988; Drennan et al., 1990). Additional information relating to the granitic rocks of the basement beneath younger cover has been derived from boreholes drilled by various mining companies searching for extensions to the gold-bearing strata of the Witwatersrand Basin (Hallbauer, 1982; Klemd and Hallbauer, 1987; Robb and Meyer, 1987; Drennan et al., 1990; Robb et al., 1990, 1992).

To the west of the Rand Anticline, in the Mafikeng-Vryburg area, sporadic outcrops of granitoid rocks have been reported beneath a cover of late Archaean Ventersdorp Supergroup volcanic rocks and regionally extensive Tertiary to Recent sediments of the Kalahari Group (Von Backström et al., 1953; Von Backström, 1962; Van Eeden et al., 1963; Liebenberg, 1977; Michaluk and Moen, 1991; Keyser and Du Plessis, 1993; Schutte, 1994). Where exposed the granitoid rocks are generally weathered and poorly preserved. The earliest geological accounts of these r ocks were provided by Jorissen (1905) and Du Toit (1906,1908) who recognised the intrusive nature of the granites, the presence in them of inclusions derived from older formations, and the development of several varieties of granites and gneisses. More recently, studies in the Amalia - Schweizer-Reneke area (Drennan, 1988; Jones and Anhaeusser, 1991; Robb, 1991) and in the Vryburg - Mafikeng region (Zimmermann and Anhaeusser, 1991; Zimmermann, 1994) have added to the understanding of the granitic terrane, but no regional evaluation of the fragmentary database has ever been attempted.

Geochronological developments in recent years, involving the precise dating of single zircon grains, have led to a number of studies aimed at constraining the age of the Witwatersrand Supergroup, the latter succession being well known for its exceptional concentration of gold. These studies have included attempts at dating the basement granites in the hinterland of the Witwatersrand Basin (Anhaeusser and Burger, 1982; Robb and Meyer, 1987; Robb et al., 1990,1991,1992) and have even extended further afield to the Barberton and Murchison granite-greenstone terranes (Kamo and Davis, 1994; Poujol et al., 1996).

The picture that has emerged supports the view that the Kaapvaal Craton has undergone a prolonged history of crustal evolution and appears to consist of a mosaic of subdomains, now present in the form of small crustal blocks, that were accreted over a time span estimated at between 3.7 and 2.7 Ga years ago (De Wit et al., 1992).

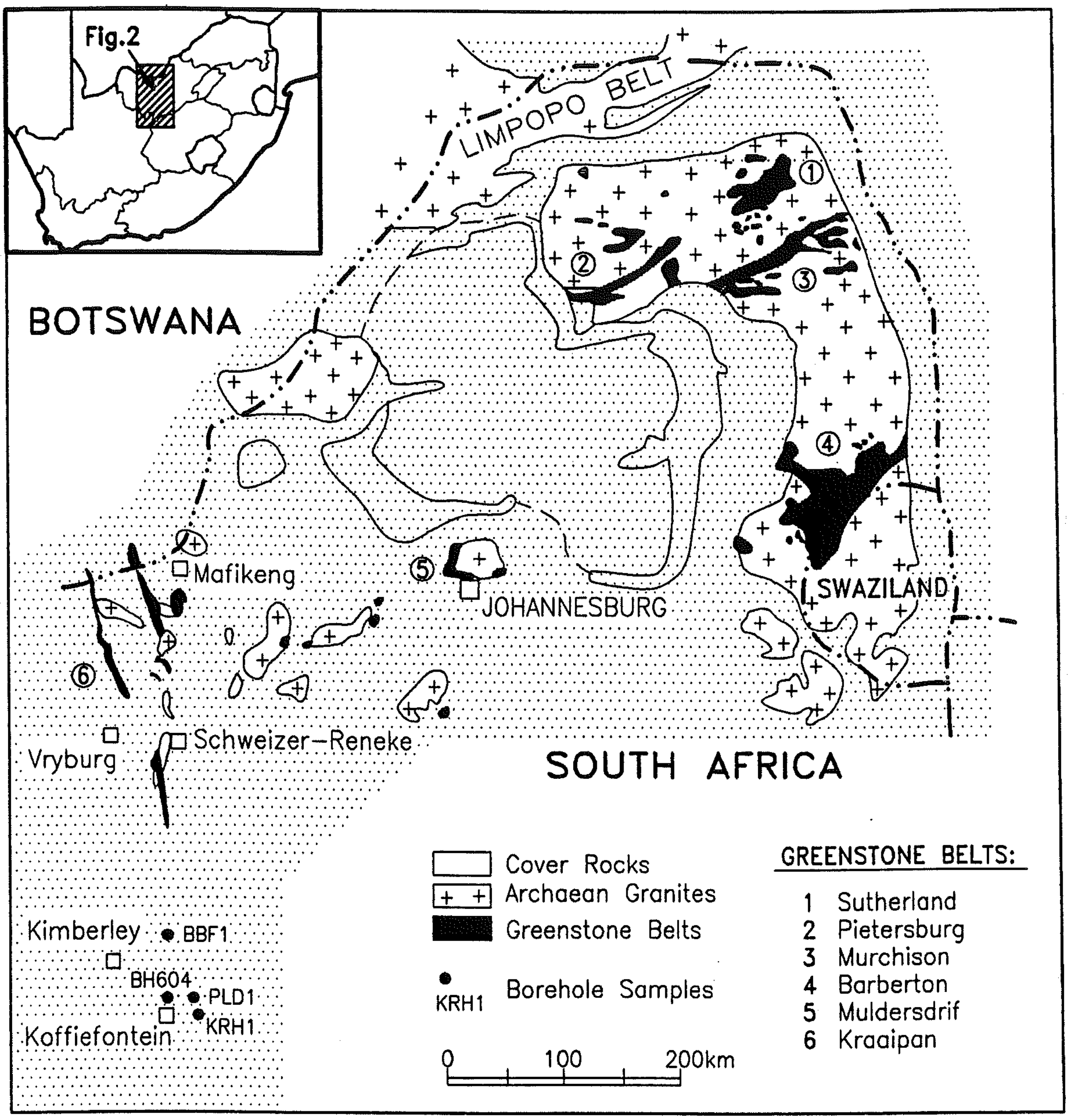


Figure1: Simplified geological map of the Kaapvaal Craton, South Africa, showing the distribution of the Archaean basement rocks in relation to the Kraaipan granite-greenstone terrane.

The present study relates to one of these continental fragments, that of the north-northwest trending Kraaipan granite-greenstone terrane (Fig.1), which is singled out for special attention involving a synthesis of the available field and geophysical evidence, coupled with preliminary isotopic studies. The object of this paper is to re-examine aspects of the granitic terrane, in particular to determine the possible nature and extent of the various granitoid components, their distribution beneath the blanketing cover sequences and their relative ages. A provisional model is proposed which demonstrates the episodic evolutionary development of the Archaean basement in the region. The Kraaipan granite-greenstone terrane, like the Murchison greenstone belt and surrounding granitoids in the northeastern part of the Kaapvaal Craton, remains a likely contributory provenance region for the gold mineralization presently in the Witwatersrand Basin. The gold mineralization potential of the Kraaipan granite-greenstone terrane has yet to be evaluated, but provisional indications are that the known gold occurrences in the region may have a spacial and genetic link with a specific stage of granite emplacement manifest in the area.

REGIONAL GEOLOGY

The Kraaipan Group of metamorphosed volcano-sedimentary and associated granitoid rocks crop out intermittently over a distance of approximately 250km from southern Botswana in the north, almost to the Vaal River near Christiana in the south (Fig.2). Because an extensive development of Ventersdorp Supergroup volcanic rocks blankets the basement formations for over 70km in the region between Amalia and Schweizer-Reneke in the south and Delareyville and Geysdorp in the north, the Kraaipan granite-greenstone terrane has, for the purposes of description, been separated into a northern and a southern domain.

The Kraaipan rocks in the northern domain occur in three narrow, approximately north-south-trending belts, separated by a variety of granitic, gneissic and migmatitic rocks. By contrast, the southern Kraaipan is represented by only one greenstone belt sliver, the latter also flanked by various granitoid rocks.

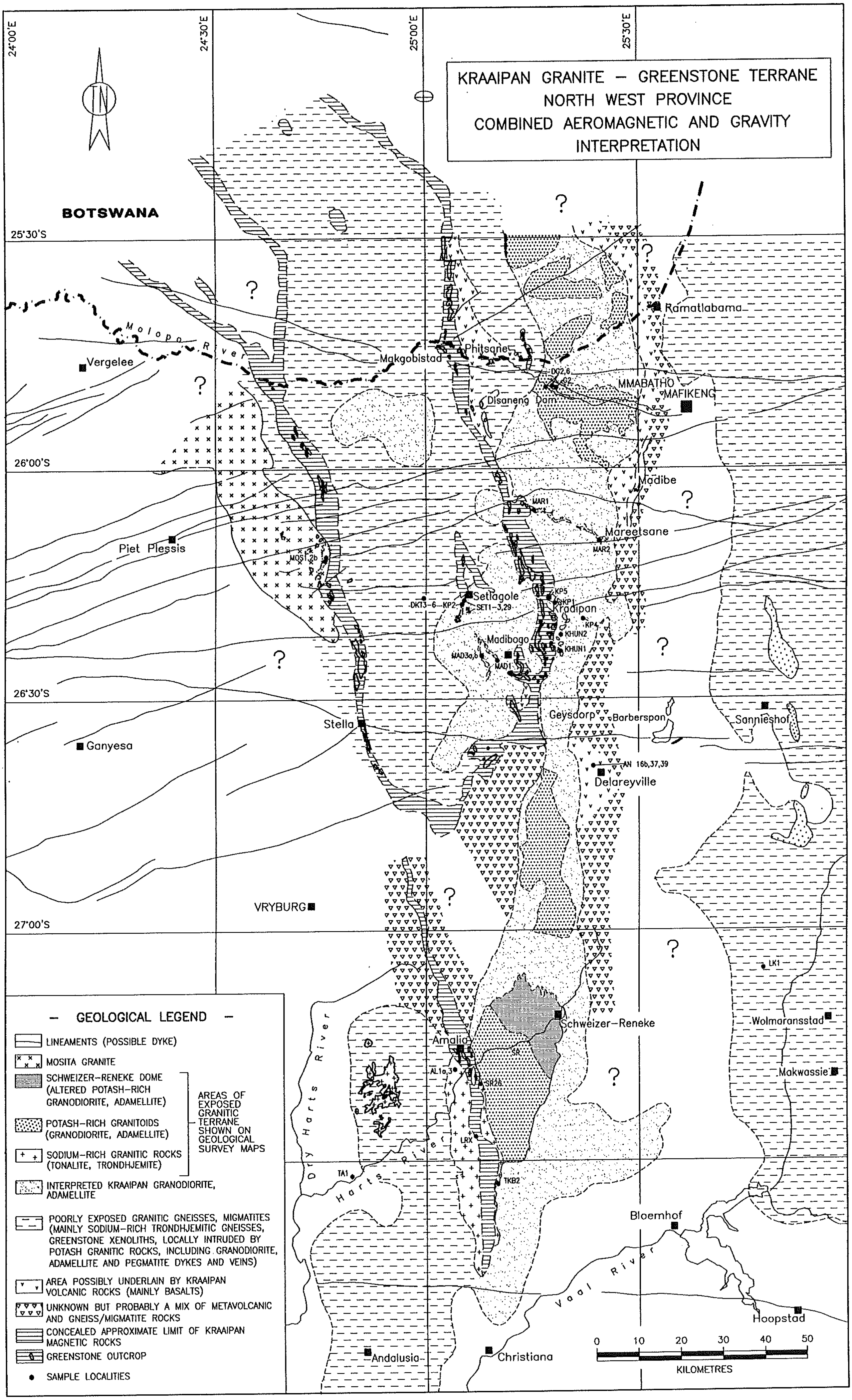
The most complete succession of Kraaipan rocks occurs north of the Kraaipan railway siding (SACS, 1980 ; Zimmermann, 1994). Even in this area the exposures are limited and poor outcrop continuity renders it difficult to confidently erect any stratigraphic column for the Kraaipan Group. In general, most of the exposed rocks occurring throughout the study region consist of various iron formation units (magnetite quartzites, banded ferruginous cherts, jaspilitic iron formations, iron formation breccias), the regional distribution of which is depicted in Figure 2. Volcanic rocks, consisting mainly of massive and pillowed tholeiitic lavas and mafic tuffs, and which have undergone various stages of deformation, metamorphism and hydrothermal alteration to amphibole-chlorite-epidote schists, occur with the iron formations, but are only rarely exposed. Other rock types encountered in the greenstone successions include rare occurrences of serpentinite, carbonates, accretionary lapilli tuffs, and phyllitic metasediments (Du Toit, 1906; Van Eeden et al., 1963; SACS, 1980; Jones and Anhaeusser, 1993; Zimmermann, 1994).

Despite the cover of Kalahari Group calcrete, silcrete, gravel and wind blown sand a variety of granitoid rocks have been recorded throughout the study area and are known from water storage pits and boreholes as well as larger whaleback exposures found in places. Nearly all the natural exposures are found in or close to river channels or poorly defined water courses. In southern Botswana Aldiss (1985) reported that most of the exposures of basement gneisses and migmatites were to be seen within the Molopo and Ramatlabama river channels. Further south in the Mafikeng/Mmabatho area granitoid rocks are found along the drainage channels leading to the Disaneng Dam (Fig.2). In the central part of the northern domain scattered exposures of granitic rocks occur in and adjacent to river courses in the Mareetsane, Kraaipan, Setlagole, Madibogo and Mosita areas (Fig.2).

In the southern domain Drennan (1988) described a number of granitoid exposures on the Schweizer-Reneke dome, but elsewhere in the region exposures are restricted to a few localities west of Amalia in the drainage system of the Harts River.

Still further south, in the vicinity of Kimberley and Koffiefontein (Fig.1), surface exposures of basement granites are again rare, but gneisses and migmatites and later cross-

Figure 2. *Regional geological map of the Kraaipan granite-greenstone terrane extending from southern Botswana into the North West Province, South Africa. The map shows the exposed Archaean basement, stripped of all younger cover, together with the combined aeromagnetic and gravity interpretation of the region. Samples used to characterize the granitoid rocks discussed in the paper are plotted on the map.*


KRAAIPAN GRANITE – GREENSTONE TERRANE
NORTH WEST PROVINCE
COMBINED AEROMAGNETIC AND GRAVITY INTERPRETATION
24°00'E
24°30'E
25°00'E
25°30'E
25°30'S
26°00'S
26°30'S
27°00'S
BOTSWANA
Molopo River
Vergelee
Makgobistad
Phitsane
Ramatlabama
MMABATHO
MAFIKENG
Disaneng Dam
Madibe
Mareetsane
Piet Plessis
Setlagole
Kraaipan
Madibogo
Stella
Ganyesa
Geysdorp
Barberspan
Sannieshof
Delareyville
VRYBURG
Schweizer–Reneke
Wolmaransstad
Makwassie
Amalia
Harts River
Dry Harts River
Bloemhof
Vaal River
Hoopstad
Andalusia
Christiana
0
10
20
30
40
50
KILOMETRES
– GEOLOGICAL LEGEND –
LINEAMENTS (POSSIBLE DYKE)
MOSITA GRANITE
SCHWEIZER–RENEKE DOME (ALTERED POTASH–RICH GRANODIORITE, ADAMELLITE)
POTASH–RICH GRANITOIDS (GRANODIORITE, ADAMELLITE)
SODIUM–RICH GRANITIC ROCKS (TONALITE, TRONDHJEMITE)
AREAS OF EXPOSED GRANITIC TERRANE SHOWN ON GEOLOGICAL SURVEY MAPS
INTERPRETED KRAAIPAN GRANODIORITE, ADAMELLITE
POORLY EXPOSED GRANITIC GNEISSES, MIGMATITES (MAINLY SODIUM–RICH TRONDHJEMITIC GNEISSES, GREENSTONE XENOLITHS, LOCALLY INTRUDED BY POTASH GRANITIC ROCKS, INCLUDING GRANODIORITE, ADAMELLITE AND PEGMATITE DYKES AND VEINS)
AREA POSSIBLY UNDERLAIN BY KRAAIPAN VOLCANIC ROCKS (MAINLY BASALTS)
UNKNOWN BUT PROBABLY A MIX OF METAVOLCANIC AND GNEISS/MIGMATITE ROCKS
CONCEALED APPROXIMATE LIMIT OF KRAAIPAN MAGNETIC ROCKS
GREENSTONE OUTCROP
SAMPLE LOCALITIES

cutting granitic phases are evident in undergroud workings of diamond mines located in this region (Drennan, 1988; Drennan et al., 1990).

Previous accounts of the granitoid rocks in the Kraaipan granite-greenstone terrane have, for the reasons set out above, been very generalized. Nevertheless, early workers, such as DuToit (1906,1908) and others associated with the Geological Surveys of South Africa and Botswana (SACS, 1980; Aldiss, 1985; Zimmermann,1994), recognized at least three granitoid varieties, but did not place them into any regional synthesis or scheme of crustal evolution. The granite types recorded include:

(1) foliated leucogneisses and migmatites containing remnants of Kraaipan amphibolites and banded iron formations like those seen in the Tlhakajeng River southeast of Kraaipan and in the Disaneng Dam spillway (Michaluk and Moen, 1991; Keyser and Du Plessis, 1993);
(2) fine-to-medium-grained grey or pink, homogeneous, or in places weakly foliated, massive granitoids as well as cross-cutting dykes and veins like those encountered on the Schweizer-Reneke dome and near Kraaipan railway siding (Drennan, 1988; Zimmermann, 1994); and
(3) coarse-to very-coarse-grained, homogeneous, pink granite of the type found in the Mosita area (Keyser and Du Plessis, 1993).

All the granitoid varieties contain xenoliths of Kraaipan rocks and hence appear to be younger than the greenstones developed in the area, but few reliable absolute ages for the different granitic phases, or the Kraaipan greenstones, were available prior to this study.

Apart from the Ventersdorp and Kalahari cover sequences the area is transgressed, particularly in the northern domain, by a set of east-northeast trending dykes (Fig.2) that are rarely exposed, but which show up clearly on the regional aeromagnetic maps published by the South African Council for Geoscience (see also Stettler et al., 1990 and Fig. 6).

KRAAIPAN GRANITOIDS

In an attempt to verify the threefold subdivision of the granitoid rocks mentioned earlier and to determine the regional extent of the different granitic components making up the Kraaipan crustal fragment, a study of the field relationships was combined with subsequent petrological, geochemical and isotopic investigations. The field investigations, from the Molopo River in the north to the area adjacent to Amalia and Schweizer-Reneke in the south, confirmed the broadly based characterization of the granitoids and led to the emergence of a cohesive distribution pattern of the various types.

Samples collected wherever unaltered material was available were studied petrologically and geochemically (Fig.2, and Tables 1-3). Details of this study will be provided elsewhere (Anhaeusser and Stevens, in preparation).

Tonalitic and trondhjemitic gneisses and migmatites

The earliest granitoids, which now form the ancient basement in the region, include tonalites and trondhjemites that invaded the Kraaipan volcano-sedimentary succession, prizing off variably sized fragments that have survived as refractory xenoliths of amphibolite and banded iron formation. These Na-rich granitoids are invariably foliated with a subvertical mineral fabric orientated parallel to the generally north-south trending Kraaipan greenstone successions. In places, the tonalitic and trondhjemitic gneisses are banded or display migmatitic textures. Intrusive leucocratic dykes and aplitic veins commonly occur parallel to the foliation, but sometimes display transgressive relationships suggesting a prolonged history of emplacement.

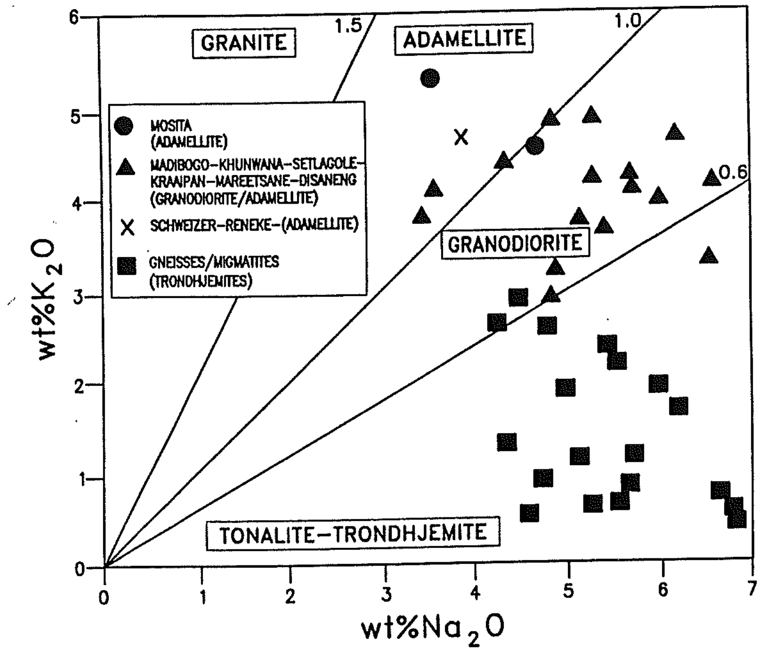


Figure 3: Plot of K_2O versus Na_2O for samples of the Archaean granitoid basement rocks listed in Tables 1-3 and located on Figure 2.

Geochemically, these rocks are characterized by their low Na_2O/K_2O ratios (Fig.3) and, as seen in Table 1, display variable SiO_2, total iron, MgO and CaO contents, reflecting the degree of contamination and assimilation of metabasaltic country rocks. Mineralogically, the tonalites differ from the leucocratic trondhjemites in possessing greater amounts of hornblende/actinolite/chlorite than their biotite-bearing counterparts. Where ferromagnesian minerals are prominent the rocks may be regarded as quartz-diorites. Plagioclase feldspar (albite-oligoclase) and quartz make up the bulk of the remaining components and accessory minerals generally include sphene, apatite, zircon, microcline and magnetite. The plagioclase commonly shows variable degrees of sericitization or alteration to epidote, the latter mineral also occurring as veins in the gneisses.

The tonalitic and trondhjemitic gneisses and migmatites occur extensively throughout the region, having been recorded by Joubert (1973) and Bosch (1993) as windows in Karoo cover rocks as far south as in the Kimberley-Boshof -Koffiefontein region and in underground workings in diamond mines in these areas (see also Fig.1, Table 1, columns 15-18, after Drennan, 1988). Surface exposures of these rocks as well as borehole intersections also occur in the southern domain flanking the Amalia greenstone belt (Fig.2, Table 1, columns 1-5 and 19), on the eastern edge of the Schweizer-Reneke dome on the outskirts of the town, and in borehole LK1 drilled 50km east of the town (Fig.2).

In the northern domain weathered trondhjemitic gneisses containing hornblende amphibolites and banded iron formation xenoliths occur in the Tlhakajeng River on the

Table 1. Tonalitic and trondhjemitic gneisses and migmatites, Kraaipan granite-greenstone terrane, North West Province (see Figure 2 for sample locations)

Column	1 *	2 *	3 *	4	5	6	7	8	9	10	11	12	13	14 *	15 *	16 *	17 *	18 *	19
Sample No	TKB2	TA1	LRX	AL1a	AL3	An16b	An37	An39	DKT3	DKT4	DKT5	DKT6	SET3	LK1	BBF1	PLD1	BH604	KRH1	SR26
SiO_2	75.33	64.45	74.20	69.36	71.80	71.65	74.07	74.12	63.85	61.71	69.23	71.62	76.56	69.23	66.88	64.78	63.54	61.29	70.42
TiO_2	0.08	0.56	0.11	0.27	0.19	0.21	0.20	0.31	0.32	0.58	0.37	0.02	0.05	0.31	0.46	0.67	0.47	0.58	0.19
Al_2O_3	15.03	16.00	14.63	16.85	15.98	15.75	14.62	13.90	15.97	14.74	15.24	16.11	14.20	15.17	15.55	16.11	17.32	16.40	14.69
Fe_2O_3	0.77	4.23	1.48	2.79	1.60	1.16	1.13	1.93	5.07	7.16	2.81	0.68	0.66	3.35	4.95	4.78	4.44	9.76	1.29
MnO	0.00	0.08	0.02	0.05	0.01	0.03	0.43	0.10	0.08	0.12	0.01	0.00	0.02	0.05	0.06	0.06	0.06	0.15	0.03
MgO	0.57	1.53	0.77	1.46	0.70	0.57	0.71	0.93	2.83	3.71	0.96	0.14	0.02	1.24	1.27	2.07	1.95	1.50	0.75
CaO	1.04	3.66	1.16	2.53	1.93	2.93	1.83	2.73	4.34	5.90	3.29	2.41	0.81	1.84	2.07	3.07	3.33	1.86	1.13
Na_2O	6.17	4.75	5.53	5.28	5.72	6.84	5.44	4.46	5.86	4.83	6.78	6.80	6.04	4.81	4.46	4.24	4.99	5.23	5.56
K_2O	1.67	0.88	0.77	1.13	1.14	0.54	2.32	1.32	0.83	0.54	0.71	0.42	1.92	2.61	2.94	2.62	1.88	0.61	2.20
P_2O_5	0.02	0.44	0.04	0.12	0.07	0.11	0.10	0.12	0.06	0.11	0.13	0.01	0.01	0.13	0.18	0.36	0.18	0.71	0.05
LOI	0.47	3.31	2.53	1.36	0.93	0.68	0.89	1.30	1.21	0.58	0.61	0.53	0.91	1.51	1.17	1.20	1.70	1.77	2.06
Total				101.21	99.76	100.48	101.36	101.23	100.41	99.98	100.12	98.74	101.18						99.37
$\bar{X}$	3	2	3											3	2	5	5	1	

* (after Drennan, 1988)

Table 2. Homogeneous, medium-to-coarse-grained, grey-to-pink granodiorites and adamellites from the northern Kraaipan domain between Madibogo and the Disaneng Dam, North West Province (see Figure 2 for sample localities)

Column	1	2	3	4	5	6	7	8	9 *	10	11	12	13	14	15	16	17	18
Sample No	KHUN1	KHUN2	MAD1	MAD3a	MAD3b	SET2	SET1	SET29	SR	KP1	KP2	KP4	KP5	MAR1	MAR2	DG1	DG6	G2
SiO_2	72.75	72.40	73.41	74.12	73.71	75.17	72.67	75.10	74.62	74.28	74.88	74.27	73.29	74.60	73.50	73.35	72.34	75.22
TiO_2	0.22	0.36	0.12	0.15	0.16	0.13	0.21	0.05	0.07	0.11	0.20	0.15	0.13	0.10	0.12	0.20	0.17	0.02
Al_2O_3	14.70	14.47	14.17	14.45	14.75	13.72	14.77	14.58	13.93	14.59	14.32	14.43	14.40	14.37	14.03	14.07	13.88	14.89
Fe_2O_3	1.42	1.98	1.20	1.04	1.01	1.04	1.21	0.71	1.14	1.40	1.75	1.08	1.30	0.87	1.07	1.22	1.25	0.49
MnO	0.02	0.01	0.01	0.02	0.01	0.01	0.00	0.00	0.02	0.03	0.03	0.01	0.03	0.01	0.00	0.01	0.01	0.03
MgO	0.39	0.82	0.30	0.24	0.14	0.13	0.39	0.16	0.24	0.20	0.32	0.20	0.25	0.12	0.23	0.33	0.27	0.06
CaO	1.05	1.26	0.37	0.97	1.33	0.80	1.08	0.77	0.66	0.47	0.97	0.22	0.50	0.75	1.09	0.58	0.83	0.43
Na_2O	5.26	4.92	6.11	5.51	6.62	5.85	4.90	4.59	3.81	5.43	3.55	5.85	6.77	3.47	4.41	5.38	6.23	4.99
K_2O	3.81	2.96	4.01	3.68	3.35	4.19	3.21	4.35	4.59	4.29	3.90	4.33	4.24	4.11	4.24	4.85	4.66	4.89
P_2O_5	0.06	0.12	0.04	0.05	0.04	0.03	0.05	0.02	0.02	0.02	0.97	0.03	0.03	0.03	0.02	0.06	0.97	0.03
LOI	0.62	0.77	0.87	0.44	0.29	0.35	0.64	0.64	0.47	0.48	0.49	0.41	0.60	0.50	0.49	0.59	0.68	0.23
Total	100.29	100.06	100.60	100.64	101.41	101.40	99.13	100.96	99.57	101.27	100.48	100.97	101.53	98.92	98.18	100.64	100.38	101.27
$\bar{X}$									14									

* (after Drennan, 1988)

eastern side of the Kraaipan granodiorite/adamellite intrusive body. Limited exposures of tonalite, trondhjemite and amphibolite also occur in the Setlagole area and were encountered in a borehole drilled by the Geological Survey approximately 10km to the west of Setlagole (Table 1, columns 9-13, Fig.2). Further north, exposures of these rocks are limited, but weathered gneisses, migmatites and greenstone xenoliths are exposed in excavations of the Disaneng Dam spillway (Anhaeusser, 1991; Michaluk and Moen, 1991) and in or near the Ramatlabama and Molopo river channels in southern Botswana (Aldiss, 1985).

Granodiorite -adamellite suite

Intruded into the earlier gneisses and migmatites described above are a variety of K_2O-rich granitoid rocks which also crop out erratically from south to north across the Kraaipan terrane. Drennan (1988) and Drennan et al. (1990) recorded potassic granitoid dykes and veins intruding the gneisses exposed in the Kimberley and Koffiefontein diamond mines, but the most extensive surface expression of these rocks was found on the Schweizer-Reneke dome (Fig.2). Drennan (1988) noted that the northeastern portion of the dome was made up of a distinctive green-to-pink adamellite in which the coloration reflects hydrothermal alteration of the feldspars and biotite. Microcline in the rocks is stained pink by microcrystalline hematite, whereas plagioclase is ubiquitously sericitized and epidotized. Biotite is partially altered to chlorite and minor carbonate alteration is also evident. Some intergranular fluorite was observed in places and accessory minerals are dominated by monazite, with zircon and apatite only rarely present. The southern part of the dome is underlain by greyish, occasionally porphyritic adamellite, which has the same mineralogical characteristics as rocks from the northeastern segment, except that pervasive sericitization, epidotization, hematitization and carbonate alteration is noticeably less evident.

The adamellite is generally massive, but Drennan (1988) recorded a north-south trending foliation in the central part of the dome which closely follows the trend of a major shear zone, increasing in intensity as the shear zone is approached.

Samples suitable for geochemical study were obtained from surface and borehole localities. In borehole TKB2 (Fig.2) both trondhjemitic gneisses and adamellites of the Schweizer-Reneke dome were encountered.

Table 2 (column 9 - sample numbered SR) provides an average composition of 14 samples from Drennan's (1988) study of the Schweizer-Reneke dome. Major elements, particularly a plot of K_2O vs Na_2O on a Harpum diagram (Fig.3), confirms the generally adamellitic composition of the rocks, which are also of a low CaO and marginally peraluminous variety.

In the northern domain rocks having similar characteristics to the unaltered granitoids in the Schweizer-Reneke area are found at a number of widely scattered localities. In the Kraaipan- Setlagole area and regions to the south (Madibogo - MAD and Khunwana - KHUN, Fig.2) homogeneous, pink and grey granodiorites-adamellites occur in many of the river channels present in the area. In places, as for example near Kraaipan railway siding, the granitic rocks are homogeneous, pink and fine-to-medium grained in texture. South of Setlagole similar pinkish fine-grained granitoids have a weakly developed foliation, while at Madibogo the rocks are pinkish-grey in colour and are again massive and homogeneous in texture. Near Khunwana, south of Kraaipan, the rocks are pinkish-grey, and have experienced brittle deformation and are variably jointed, brecciated and hydrothermally altered.

Table 2 (columns 1-8 and 10-13) provides major element geochemical data characterising these rocks which, mineralogically, are made up mainly of microcline, albitic plagioclase and quartz, with accessory and variable amounts of biotite, magnetite, apatite, fluorite, muscovite, epidote, chlorite, zircon and myrmekite. In places the plagioclase is partly altered to sericite and epidote, and reddish-brown hematitic staining is also sometimes evident suggesting partial hydrothermal reworking and alteration.

In the northern part of the study area further exposures of the homogeneous, K_2O-rich granitoids are evident in the Mareetsane river channelway where the rocks are medium-to-coarse grained and pinkish-grey in colour. Chemical analyses of these rocks are provided in Table 2 (columns 14-15). In the region west of Mafikeng and in the Disaneng Dam area the pinkish-grey granitoids again make an appearance. On the northeast shore of the dam unaltered, homogeneous, medium-grained granodiorite/adamellite is present and, in the dam spillway, dykes and veins of the same material have intruded the earlier-formed trondhjemitic gneisses, migmatites and amphibolite xenoliths. Also present are pegmatitic dykes that anastomose throughout the exposures. The intrusive granitoids are grey, white or reddish in colour and indications are that some hydrothermal alteration has also influenced these rocks.

None of the rocks in the dam spillway are suitable for geochemical analysis, but the finer-grained homogeneous granitoids on the east side of the dam have granodiorite-to-adamellite compositions (Table 2, columns 16-18 and Fig.3).

Leucocratic granodiorites or adamellites, with no visible fabric, extend across the border into southern Botswana where Aldiss (1985) reported irregular dykes of unfoliated granitoids intruding biotite gneisses and greenstone belt lithologies in various places north and east of Phitsane (Fig.2). Most of the granitoids vary from medium-grained to pegmatitic and are white or pale pink. The rocks consist mainly of plagioclase, microcline and quartz with small amounts of chloritised biotite, fine muscovite, perthite, apatite, zircon and opaque oxides. The plagioclase and the perthite is generally altered to sericite. The pegmatite dykes are similar to the unfoliated granitoids, except in grain size, but locally display graphic intergrowth textures and some carry muscovite. Pegmatites that intrude the gneisses contain biotite and garnet.

Aldiss (1985) recorded mylonitic leucocratic granitoids occurring along the Baralong Farms shear zone located approximately 6km west of Ramatlabama north of Mafikeng (Fig.2). Also in this area he noted that rocks of the Gaberone Granite Complex can be seen to post-date the basement complex granitoids.

Mosita adamellite

Between the central and western greenstone belts, which extend northwards from Kraaipan and Stella to the Botswana border (Fig.2), there are virtually no surface exposures of granitic rocks and their presence beneath the Kalahari sand cover is based mainly on boreholes drilled for water. The same applies to the terrane west of the Stella greenstone belt where Kalahari cover extends to Piet Plessis, Ganyesa and beyond. Only in the channelway of a north-trending water course on the farm Mosita, the latter located approximately midway between Setlagole and Piet Plessis, is some coarse-to-very-coarse-grained adamellite exposed sporadically for a distance of approximately 10km (Fig.2). The predominantly concealed granitoid body embays into the western margin of the Stella belt and large remnants of banded iron formation as well as smaller xenoliths of amphibolite occur enveloped within the granitic rocks.

The Mosita adamellite differs from all the granite-types described in the Kraaipan granite-greenstone terrane in that the rocks are much coarser-grained, consisting mainly of quartz, perthite, microcline and plagioclase (albite), together with accessory amounts of chlorite, zircon, magnetite, myrmekite (as vermicular forms in plagioclase) and carbonate (mainly in cross-cutting veins). The plagioclase is extensively altered to sericite or muscovite and the perthite consists of albitic feldspar intergrown in microcline.

Table 3. Homogeneous, very coarse-grained, pink adamellite from the Mosita pluton, North West Province (see Figure 2 for sample localities)

Column	1	2
Sample No	MOS2b	MOS1
SiO_2	73.90	72.55
TiO_2	0.29	0.28
Al_2O_3	12.96	14.22
Fe_2O_3	1.46	1.28
MnO	0.02	0.04
MgO	0.44	0.27
CaO	0.82	0.81
Na_2O	3.70	4.78
K_2O	5.37	4.54
P_2O_5	0.06	0.11
LOI	0.84	0.70
Total	99.85	99.57

The exposures of the Mosita granitoid are generally weathered and difficult to sample. Table 3 provides two analyses of the Mosita rocks which confirm the adamellitic composition of the body (Fig.3). The possibility exists that the Mosita granitoids might be genetically linked to the granites associated with the Gaberone Granite Complex in Botswana. However, as will be shown later, the latter granites appear to be older, based on recent Pb-Pb age determinations carried out on zircons from these granites sampled north of Mafikeng (Grobler and Walraven, 1993).

ISOTOPIC RESULTS

Previous work

The earliest studies of the ages of granitic rocks in the western sector of the Kaapvaal Craton date back more than three decades. The Schweizer-Reneke adamellite was one of the first rock units to have been dated by radiogenic isotopic means in South Africa. A Rb-Sr whole rock isochron was presented by Allsopp (1961,1964) for eight samples collected at various localities on the Schweizer-Reneke dome and yielded an age of 2700 ±55 Ma. Barton et al. (1986) re-examined the Schweizer-Reneke adamellite and produced whole-rock Rb-Sr and Pb-Pb isochron ages of 2767±110 Ma and 2780±70 Ma, respectively. More recently Drennan et al. (1990) and Robb et al. (1992), using precise single-grain U-Pb techniques on rutile and monazite, obtained concordant isotope ratios with $^{207}Pb/^{206}Pb$ ages of 2884±2 Ma and 2880± 2 Ma, respectively, for the Schweizer-Reneke granitoids. Early attempts at dating the Mosita adamellite were carried out by Burger and Walraven (1979) who reported an age of 2710±65Ma.

Further south, in the Kimberley area, samples from the gneisses and migmatites were collected by Drennan (1988) from the Bultfontein diamond mine for geochronological and isotopic studies. Zircons analysed by the U-Pb ion microprobe (SHRIMP) technique at the Australian National University, Canberra were found to be structurally complex, with well-defined cores rimmed by younger zircon overgrowths. The older cores defined a mean $^{207}Pb/^{206}Pb$ age of *ca* 3250 Ma, with no indication of any older ages in the population analysed. The younger rims yielded an age of *ca* 2940 Ma (Drennan et al., 1988,1990).

To the east of the Kraaipan granite-greenstone terrane Robb et al. (1992) reported various ages for the granitic rocks adjoining the Witwatersrand Basin, the closest to the study area being the 3031+11–10 Ma zircon ages for basement rocks in the Coligny-Ottosdal region, approximately 90km southeast of Mafikeng.

Lastly, Grobler and Walraven (1993) undertook Pb-Pb age determinations of single zircons, using the evaporation technique, of various granitic and rhyolitic phases of the Gaberone Granite Complex north of Mafikeng. These rocks, which yielded a mean date of 2780.6±1.8 Ma, post-date the Kraaipan granite-greenstone rocks in southern Botswana (Aldiss,1985).

This study

As part of the present investigation a number of additional isotopic studies were attempted with the aim of providing geochronological information for the Kraaipan Group and the granitoids in the region. Attempts were made to obtain zircons for evaporation age determination from volcanic rocks of the Kraaipan succession, but no suitable zircons were found in the material investigated.

Previous studies in South Africa and elsewhere have demonstrated the feasibility of using whole-rock Pb-Pb data for isotopic age determinations of chemical sediments, in particular banded iron formation (BIF), under certain circumstances. First among these was that of Moorbath et al. (1973) on BIF of the Isua Group where a whole-rock Pb-Pb date of 3710±10 Ma was interpreted as either the age of metamorphism or a minimum age of deposition. Sakko and Laajoki (1975) later reported a Pb-Pb isochron of 2080±45 Ma for BIF from the Pääkö Formation in Finland which they consider to represent the depositional age. Barton et al. (1986) recorded preservation of a *ca.* 3000 Ma Pb-Pb date for BIF of the Marydale Group under greenschist metamorphic conditions, while the Pb-isotope system was homogenised during amphibolite-grade metamorphism. Walraven (1993) obtained a 2000 Ma age for BIF from the Luiza Trough, Kasaï Craton, Zaïre, which is consistent with other geochronological information.

On this basis it was decided to attempt whole-rock Pb-Pb age dating of BIF from the Kraaipan Group in order to obtain a direct age for these rocks. Two sets of whole-rock samples were selected for analysis from the approximately 400 m thick Gold Ridge Formation and a third set of samples was collected from the immediately overlying Ferndale Formation of the Kraaipan Group described by SACS (1980) and Zimmermann (1994).

Whole-rock Rb-Sr and Pb-Pb age determinations were made of the Kraaipan and Mosita granitoids, but the isotope systematics of these rocks appear to have been severely disturbed with the result that no meaningful age interpretations can be made from these data. Single-grain Pb-evaporation age determinations of zircons from both these granites proved to be more successful. Similar Pb-evaporation age determinations were also made using zircons from two samples of basement gneiss obtained from the Geological Survey borehole (DKT) located west of Setlagole.

Techniques

All the isotopic studies were carried out at the Isotope Laboratory of the Council for Geoscience, Pretoria (formerly the Geological Survey of South Africa), following standard techniques. The whole-rock samples were totally dissolved in a mixture of HF and HNO_3 followed by conversion to chloride. Pb was separated from the sample using anion exchange columns followed by electrodeposition. Pb-isotopic compositions were measured on a Finnigan MAT261 mass spectrometer. Total method blank levels determined during the period of the analyses were less than 2 nanogram and external reproducibility of the determinations is better than 0.01, 0.01, and 0.02 for the $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios, respectively. NBS981 was used as a standard for the isotopic compositions and the results obtained were standardised to the recommended ratios for NBS981.

Data regression and age and error calculations were made following the methods of York (1969) and Ludwig (1980) as embodied in the GEODATE version 2.2 software (Eglington and Harmer, 1991). Initial Pb-isotopic compositions have been calculated relative to the two-stage crustal evolution model of Stacey and Kramers (1975). All uncertainties are quoted to 95% confidence limits.

The analytical techniques used for the single-grain zircon Pb-evaporation age determinations follow those of Kober (1986, 1987). Hand-picked zircon grains were selected for analysis and analysed using a Finnigan MAT261 thermal ionization mass spectrometer. Common-Pb corrections were applied to the measured ratios using the Stacey and Kramers (1975) Pb-isotopic compositions corresponding to the ages indicated by the $^{207}Pb/^{206}Pb$ ratios. In order to minimise the common-Pb corrections all data with $^{204}Pb/^{206}Pb$ ratios in excess of 0.0001 were rejected. Ages, errors, and weighted means were calculated using the GEODATE software referred to previously. The analytical uncertainties of the ages and the $^{207}Pb/^{206}Pb$ ratios are quoted at the 95% confidence level.

Results

The whole-rock Rb-Sr and Pb-Pb isotopic studies of the Kraaipan and Mosita granitic rocks resulted in errorchrons with exceedingly large uncertainties. These data are interpreted to reflect intense disturbance of the respective isotope systems and are considered to contain little or no geochronological information. As such they are not considered any further in this work.

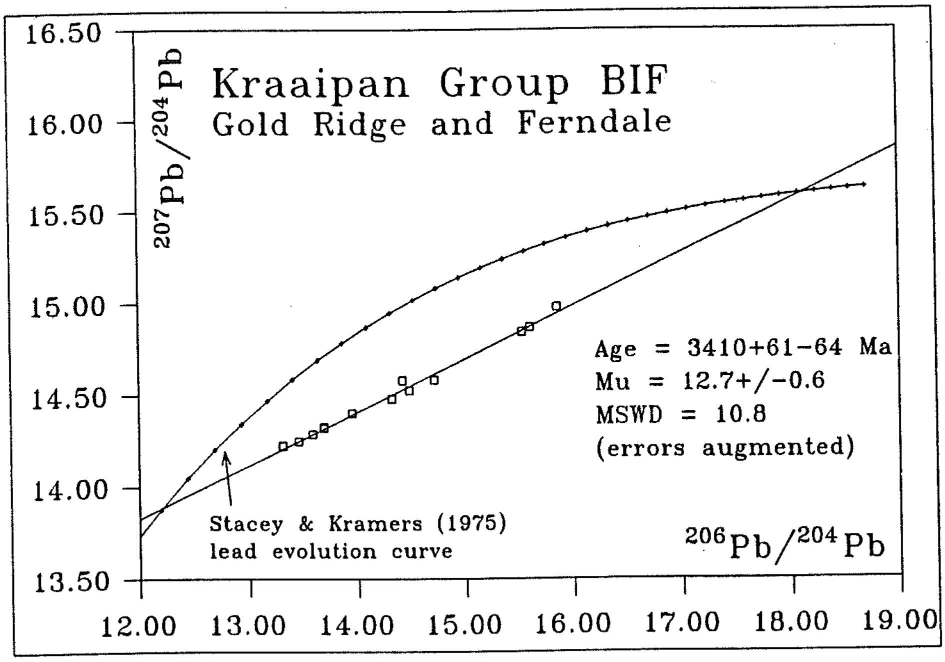


Figure 4: Whole-rock Pb-Pb diagram for samples of banded iron formation from the Gold Ridge and Ferndale Formations (SACS,1980) of the Kraaipan Group.

A totally different situation was encountered in the case of the whole-rock Pb-Pb isotopic studies of the Kraaipan Group (Fig. 4). Although the Pb from the Gold Ridge and Ferndale BIFs has a limited range of isotopic compositions, the data contain relatively little scatter. No significant distinction was found between the data from the three localities sampled and the data were therefore combined into one age calculation to obtain a somewhat larger spread of data points and a decrease in the uncertainty of the age determination. Regression of the combined data produced an errorchron of 3410+61-64 Ma (μ = 12.7±0.6; MSWD = 10.8 on 13 data points). Coincidence of the data from the two formations implies indistinguishable initial $^{238}U/^{204}Pb$ ratios and suggests the same or similar sources for the BIF in both formations.

The Pb-evaporation results obtained from the Mosita adamellite show the isotopic composition of the Pb in the analysed zircons to be comparatively homogeneous (sample FW92 105, Fig.5) both at different evaporation temperatures within individual grains as well as between different grains. Individual data blocks indicate model ages ranging from 2722±22 Ma (low-temperature block from one grain) to 2762±31 Ma (high-temperature block from another grain) and the weighted mean age for all the data from the Mosita zircons is 2749±3 Ma.

Somewhat older model ages and an increased range of model ages were found in the results obtained from zircons in the Kraaipan granitoids (sample FW88 409, Fig.5). Model ages for individual data blocks range from from 2790±2 Ma to 2846±22 Ma with a weighted mean age of 2805±9 Ma.

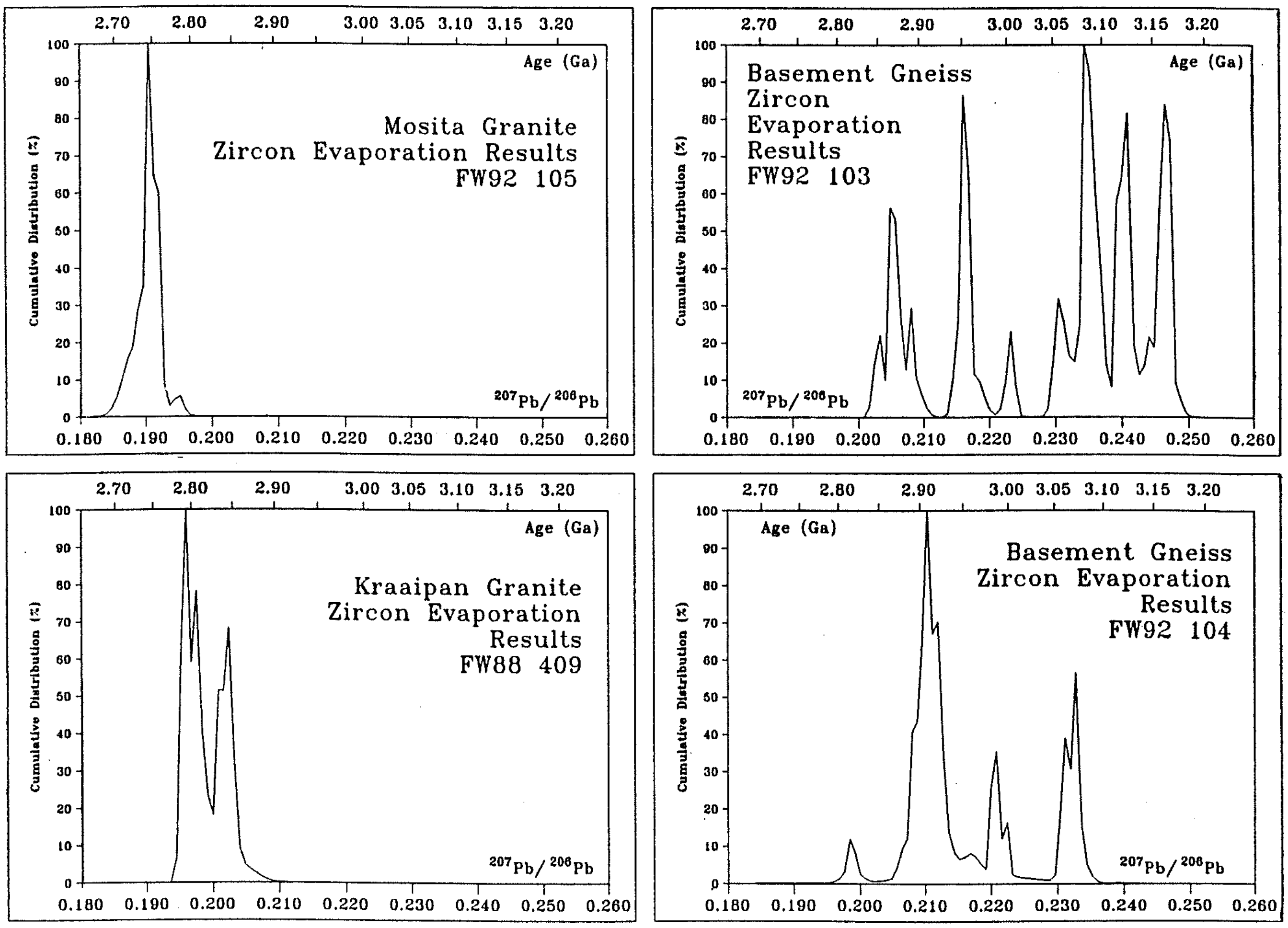


Figure 5: Cumulative age distribution diagrams for zircons from samples of Mosita adamellite (FW92 105), Kraaipan granodiorite-adamellite (FW88 409), and basement gneiss (samples FW92 103 and FW92 104).

Both samples of basement gneiss from the Setlagole borehole DKT, produced results differing significantly from those of the Kraaipan granitoids. In both cases large variations of Pb-isotopic composition were found (samples FW92 103 and FW92 104, Fig.5), both at different evaporation temperatures within zircon grains as well as between zircons. In the case of sample FW92 103, model ages for individual blocks range from a low of 2866+25-26 Ma in one grain to a high of 3162±8 Ma in another grain. Weighted mean calculations are considered to be without significance for data with such large variations and are, therefore, not reported. In the case of sample FW92 104 the lowest model age was found to be 2816±16 Ma and the highest 3070±7 Ma, both obtained from the same zircon grain. Model ages for the other four grains from this sample display a comparatively limited range (2908+32-33 Ma to 2945+149-167 Ma) and have a weighted mean of 2921+71-74 Ma.

A summary of the isotopic results and their interpretations is presented in Table 4.

Kraaipan Group

Two alternative interpretations of the age significance of the 3410+61-64 Ma date are possible. Firstly, the date can represent the age of deposition of the chemical sediments while secondly, it can represent the age of a metamorphic event which reset the Pb-isotope systematics of the BIFs. The relatively elevated initial ratio found for the BIFs could be taken

Table 4. Summary of isotopic results and interpretations

Rock Unit	Technique	Age (Ma)	Comments
Mosita adamellite	Zircon evaporation	2749±3	Age of crystallisation
Kraaipan granodiorite	Zircon evaporation	2846±22	Minimum age of crystallisation (? see text)
Basement gneiss 1	Zircon evaporation	2866+25-26 to 3162±8	Minimum and maximum for crystallisation and disturbance ages respectively
Basement gneiss 2	Zircon evaporation	2816±16 to 3070±7	Minimum and maximum for crystallisation and disturbance ages respectively
Kraaipan Group BIF	WR Pb-Pb	3410+61-64	Age of deposition or age of complete isotopic resetting during metamorphism

to support the second alternative although similarly elevated initial ratios have been observed in cases where the date obtained is considered to reflect the deposition age of the BIF.

The studies of Barton et al. (1986), Moorbath et al.. (1973), and others indicate that whole-rock Pb-isotope systems can remain undisturbed under low- to medium-grade metamorphic conditions, but can become reset under more intense metamorphic conditions. In the case of the Kraaipan Group the metamorphic conditions reached amphibolite grade in places and the possibility must be considered that the age obtained for the BIF does not represent the time of chemical sedimentation, but instead reflects a subsequent metamorphic event which caused almost complete resetting of the whole-rock Pb-Pb system of the BIF. In this case, the age of deposition of the BIF must be still greater than the 3410+61-64 Ma found for the BIF.

Mosita adamellite

The zircon Pb-evaporation data of the Mosita adamellite is consistent with a granitic intrusion that was emplaced at 2749±3 Ma and which was not significantly affected by isotopic disturbance during its subsequent history.

Kraaipan granodiorite-adamellite

The data from the Kraaipan granitoid body is slightly more complicated and could be interpreted in either of two ways—the higher ratios and greater model ages represent zircon grains incorporated as xenocrysts in the granitic magma during its emplacement, while the lower ratios and ages reflect the crystallisation of the magma itself. Alternatively, the data could be taken to indicate a crystallization age greater than 2846±22 Ma coupled with isotopic disturbance by an event at some later stage in the history of the Kraaipan granitoid. No clear distinction is possible on the basis of the available isotopic data.

Basement gneisses

The results obtained from the samples of basement gneiss are consistent with a situation where the zircons crystallised at some time before the maximum model age found in the data and were affected by isotopic disturbance at some time after their crystallization. In the case of sample FW92 103 the maximum model age is 3162±8 Ma and for sample FW92 104 this is 3070±7 Ma. Collectively, these results therefore suggest that the zircons in the basement gneiss crystallized at some time before 3162±8 Ma and that they were affected by severe isotopic disturbance at a later stage in their history.

Because Pb-loss could have continued from structurally damaged zircons for significant periods after closure of the event(s) that caused the isotopic disturbance, it is not possible to make categorical statements about the timing or the number of such events. Nevertheless, it must be noted that the distribution of the model ages displayed by the zircons analysed from both samples is consistent with isotopic disturbances at some time at or after 2816±16 Ma, the youngest model age found in the gneiss samples.

GEOPHYSICAL INVESTIGATIONS

Preliminary geophysical investigations of the Kraaipan granite-greenstone terrane were undertaken by the Geological Survey of South Africa in the region extending from the Botswana border, south through Stella and Kraaipan to Vryburg (Fig.2). Regional gravity as well as aeromagnetic surveys were undertaken and the results evaluated by Stettler et al. (1990). These authors found that in the north, near the Botswana border, the gravity contour map indicates the Kraaipan rocks correlate with two major gravity highs (Fig.6). These two highs coincide with the central and western greenstone belts and are believed to be caused by the magnetite quartzites, banded iron formations and metavolcanic rocks. Stettler et al. (1990) also noted that the two highs are interconnected with a gravity-high plateau, but were uncertain as to the cause of this plateau. They suggested that Kraaipan rocks were probably responsible and may be more extensively developed below the Kalahari sand cover than was previously believed. Another extensive development of Kraaipan rocks was postulated beneath the Ventersdorp lavas in the region approximately midway between Vryburg and Geysdorp (Fig.2).

Stettler et al. (1990) found, in addition, that the magnetic data also correlate well with the outcrop pattern of the banded iron formations. However, the palaeomagnetic samples collected in these iron formations showed a variable strong remanent magnetic component that hampered the interpretation of the magnetic data. Their preliminary interpretative results of the geophysical data led, nevertheless, to the suggestion that the Kraaipan rocks belong to a complex synclinal structure with a minor central anticline.

More extensive regional aeromagnetic and gravity coverage of the Kraaipan granite-greenstone terrane was made available for this study by Gold Fields of South Africa Limited. The aeromagnetic pattern shown in Figure 7 coincides with the map depicting the geological interpretation of the region (Fig.2) and extends from approximately 60km north of the

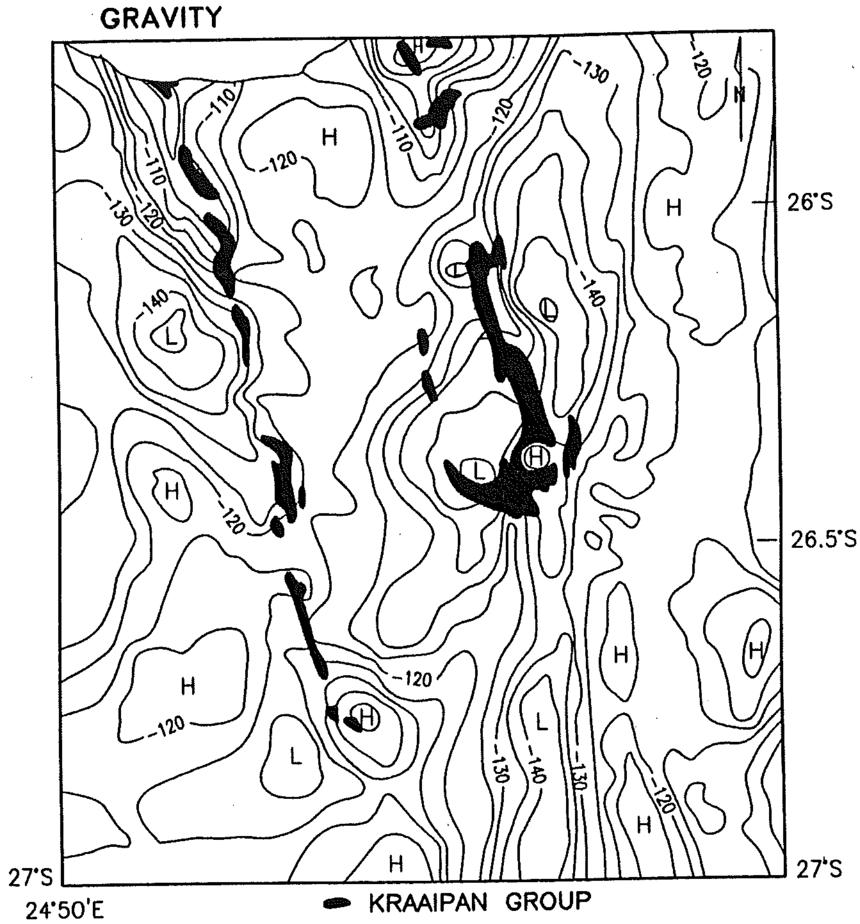


Figure 6: Regional gravity survey covering the Kraaipan granite-greenstone terrane of the western and central belts in the Stella-Kraaipan-Mafikeng area. The results are shown as Bouguer anomaly contours in milligals (after Stettler et al., 1990).

Botswana border to Christiana in the south, a distance of over 250km. At its widest, in the northern domain, the Kraaipan terrane reflected in Figure 7 is approximately 100km from west to east. Ventersdorp Supergroup volcanic rocks blanket most of the eastern and central sectors of the study area and north and west of Vryburg both Ventersdorp and early Proterozoic Griqualand West Supergroup volcano-sedimentary and dolomitic rocks influence the aeromagnetic pattern of rocks beneath the Kalahari cover. East-west and east-northest-trending dykes are particularly evident in the northern domain and cause local distortion of the regional magnetic pattern of the Kraaipan rocks.

The central and western Kraaipan belts have a strong magnetic signature and appear to outline a large fold structure beneath the Ventersdorp cover rocks between Vryburg and Delareyville (Fig.2). The eastern Kraaipan belt, extending from Mareetsane to Madibe and northwards to Mafikeng and beyond does not show up prominently on the aeromagnetic image. Likewise, in the southern domain, the Amalia greenstone belt, which has noteable developments of banded iron formation, also does not manifest itself clearly on the aeromagnetic image. However, what appears to be the southern extension of the Mafikeng-Madibe belt in the north projects southwards to Delareyville and then on to the Schweizer-Reneke area. Confirmation of this is seen in core from borehole BS1 drilled by Gold Fields on the farm Boschkopje, north of Delareyville (sample locality An, Fig.2), which intersected Kraaipan metatholeiitic volcanic rocks at a depth of approximately 520m beneath

Figure 7 : *Regional aeromagnetic map used in the interpretation of the Kraaipan granite-greenstone terrane shown in Figure 2 (aeromagnetic data supplied by Gold Fields of South Africa).*

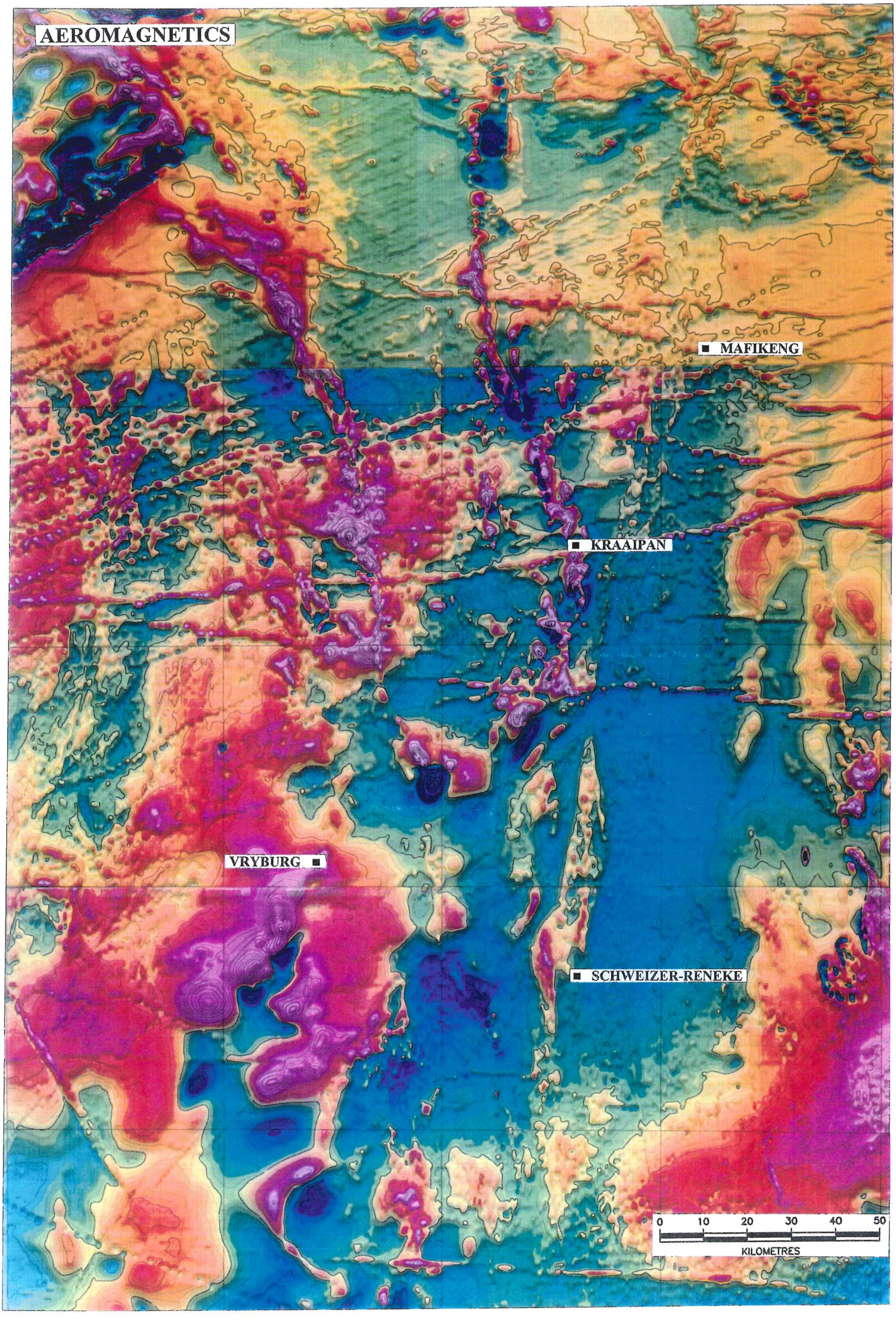
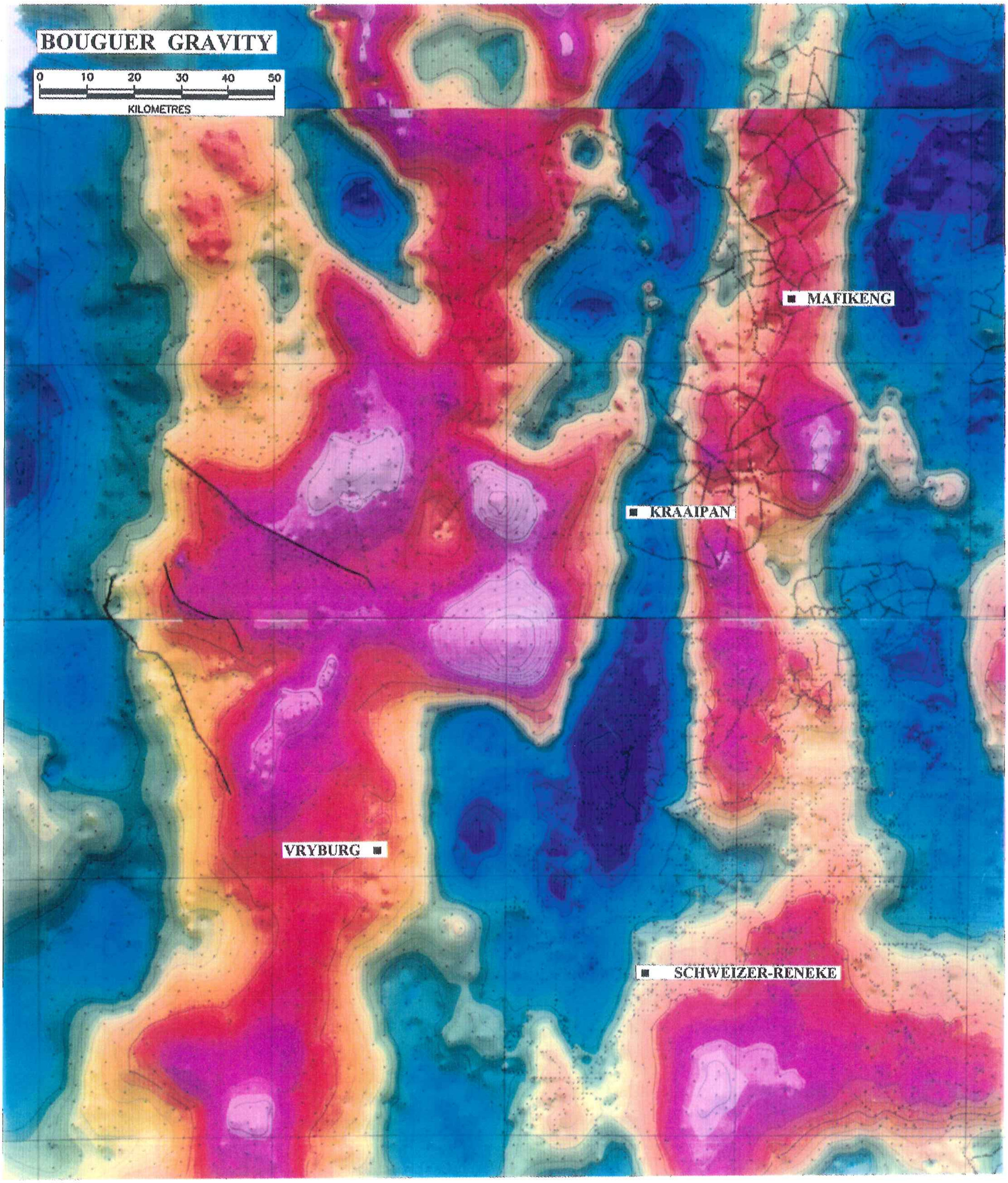

AEROMAGNETICS
MAFIKENG
KRAAIPAN
VRYBURG
SCHWEIZER-RENEKE
0 10 20 30 40 50
KILOMETRES

Figure 8: *Regional Bouguer gravity map used in the interpretation of the Archaean granite-greenstone terrane shown in Figure 2. The cold colours (shades of blue) coincide with the areas considered to be underlain by granitoid rocks. The warm colours (shades of red) may reflect north-south-trending regional crustal downwarps or graben structures, the latter occupied by Kraaipan greenstones and volcanic rocks of the Ventersdorp Supergroup (gravity data supplied by Gold Fields of South Africa).*


BOUGUER GRAVITY
0 10 20 30 40 50
KILOMETRES
MAFIKENG
KRAAIPAN
VRYBURG
SCHWEIZER-RENEKE

Ventersdorp lavas. The zone of high magnetic response extends to the west of Schweizer-Reneke, through the eastern portion of the Schweizer-Reneke dome where granitic rocks crop out on surface. This could mean that some hitherto unsuspected magnetic greenstone material occurs within the granitic terrane or at shallow depths beneath the dome.

The regional Bouguer gravity map shown in Figure 8, used in conjunction with the field observations as well as the geochemical and isotopic data presented elsewhere in this paper, provides additional information on the nature of the Archaean crust on the western margin of the Kaapvaal Craton. Clearly evident is the regional north-south trend manifest across the entire area by a series of gravity high and low areas (warm and cold colours, respectively, seen in Fig.8).

The gravity lows coincide with terrane where granitic rocks are exposed (Fig.2), or are known to be present from borehole information. What was not previously suspected, however, is the apparent continuity of the granitic rocks from the southern domain into the northern domain. In particular, the granitic rocks of the Schweizer-Reneke dome appear to merge with the Kraaipan-Mareetsane-Mafikeng granodiorites and adamellites. The gravity data also appears to define an oval-shaped, low-density body beneath the sparsely outcropping Mosita adamellite adjacent to the western Kraaipan belt (Figs.2 and 8).

What remains uncertain, due regard having been taken of all available information, is the fate of the Archaean basement as it projects into southern Botswana. North of the Molopo River, between Mafikeng and Phitsane, it seems likely that the eastern and central greenstone belts are represented to a variable degree and are separated by granitoids comprising basement gneisses and migmatites exceeding 3.0 Ga in age, the latter intruded by *ca* 2.8 Ga granodiorites and adamellites. Little is known of the terrane between the central and western belts, the latter appearing to curve away to the northwest before becoming obscured by Proterozoic cover rocks of the Kanye and Transvaal Supergroups. Clearly, more detailed geophysical investigations, coupled with selective drilling, is required to resolve the geology of these and other poorly exposed areas in southern Botswana and the North West Province of South Africa.

DISCUSSION AND CONCLUSIONS

This study emphasises the importance of integrating field and other supportive geochemical, isotopic and geophysical data in determining the geological character and evolutionary history of a poorly exposed segment of the Kaapvaal Craton. The field investigations determined the presence of a number of granitoid types, all seemingly later in age than the Kraaipan Group volcano-sedimentary successions.

Unsuccessful attempts at finding rocks containing zircons or other minerals suitable for precise dating of the Kraaipan formations led to an attempt at whole-rock Pb-Pb age dating of the banded iron formation and resulted in the attainment of an age of deposition or of complete isotopic resetting during metamorphism at 3410+61–64 Ma.

Intruded into this greenstone succession are a variety of tonalitic and trondhjemitic gneisses and migmatites that may be as old as the 3250 Ma zircons recorded in the basement gneisses in the Kimberley area. A range of ages for these gneisses in the Kraaipan granite-greenstone terrane and the adjacent areas to the east, in the hinterland of the Witwatersrand

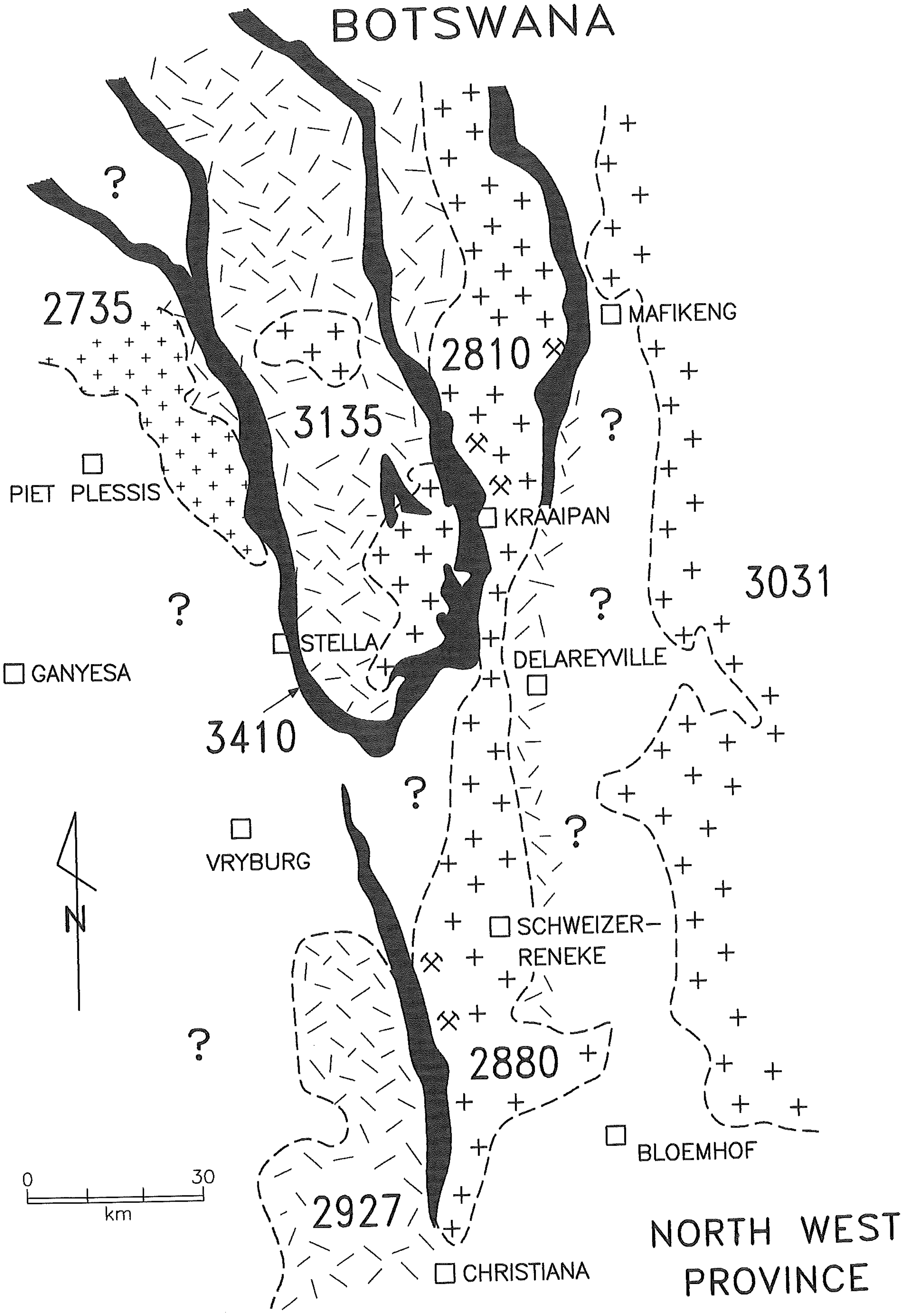


***Figure** 9: Simplified interpretative map showing the mean relative ages and regional distribution pattern of the Archaean volcano-sedimentary and granitoid rocks of the Kraaipan granite-greenstone terrane. Note the distribution of gold occurrences (crossed picks) in greenstones flanking the 2880-2810 Ma granodiorites and adamellites between Schweizer-Reneke and Mafikeng.*

Basin (3162±8 Ma; 3070±7 Ma; 3031+11–10 Ma) , as well as younger disturbance ages (ranging from 2927+23–6 Ma to 2816±16 Ma) possibly reflect stages of migmatization and crustal reworking. It therefore appears likely that the earliest granitoids forming the basement gneisses were added incrementally across a wide expanse of the western and central Kaapvaal Craton and did not result from a single magmatic episode.

The early Na-rich granitoids were succeeded by the emplacement, between 2884±2 Ma (Schweizer-Reneke adamellite) and 2846±22 Ma (Kraaipan granodiorite-adamellite), of a regionally extensive development of K-rich granitoids possessing distinctive petrological and geochemical characteristics as well as possibly having played a decisive role in the mineralization of the neighbouring Kraaipan greenstone successions.

In this regard, the granitic episodes involving the almost synchronous emplacement of the Schweizer-Reneke adamellites and the Kraaipan-Mareetsane-Mafikeng granodiorites-adamellites may be particularly significant. Known gold occurrences, some of which are currently being exploited, include those south of Amalia on the western flank of the Schweizer-Reneke dome (Goudplaats, Abelskop, Bothmansrust). In the northern domain, the Kalahari Goldridge Mine, and prospects north and south of Kraaipan railway siding, as well as the Madibe gold workings south of Mafikeng, occur in greenstones flanking the approximately 2810 Ma granodiorites and adamellites shown in Figures 2 and 9.

Further igneous and volcanic activity along the western sector of the Kaapvaal Craton took place north of Mafikeng and in Botswana, with the emplacement of the Gaberone Granite Complex at about 2780 Ma. In the study area the latest granitoid emplacement took place at 2749±3 Ma ago with the intrusion of the Mosita adamellite.

The geological information, supplemented by aeromagnetic and Bouguer gravity data helped constrain the nature and regional distribution of the Kraaipan greenstones and the invading, episodically emplaced granitoids. Follow-up studies, involving detailed geophysical and isotopic investigations, are required to place the Kraaipan granite-greenstone domain into the regional cratonic framework. Furthermore, the possible link between gold mineralization and selected granitoids could benefit the exploration and targeting of mineral deposits.

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