ECONOMIC GEOLOGY

RESEARCH UNIT

University of the Witwatersrand

Johannesburg

U-Pb ZIRCON DATES FROM AN ARCHAEAN RAPAKIVI GRANITE-ANORTHOSITE-RHYOLITE COMPLEX IN THE WITWATERSRAND HINTERLAND, SOUTHERN AFRICA

M. MOORE, L.J. ROBB, D.W. DAVIS,
D.F. GROBLER AND M.C. JACKSON

INFORMATION CIRCULAR No. 260

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

U-Pb ZIRCON DATES FROM AN ARCHAEAN RAPAKIVI GRANITE-ANORTHOSITE-RHYOLITE COMPLEX IN THE WITWATERSRAND BASIN HINTERLAND, SOUTHERN AFRICA

by

M. MOORE[1], L.J. ROBB[2], D.W. DAVIS[1], D.F. GROBLER[2,3] and M.C. JACKSON[4]

*([1]Jack Satterly Geochronology Laboratory,
Royal Ontario Museum, Toronto, Ontario M5S 2C6,
Canada
[2]Department of Geology, University of the Witwatersrand,
P.O. Wits 2050, Johannesburg, R.S.A.
[3]Geological Survey of South Africa,
Private Bag X112, Pretoria 0001, R.S.A.
[4]Economic Geology Research Unit, Department of Geology,
University of the Witwatersrand, P.O. Wits 2050,
Johannesburg, R.S.A.)*

ECONOMIC GEOLOGY RESEARCH UNIT
<u>INFORMATION CIRCULAR No. 260</u>

December, 1992

U-Pb ZIRCON DATES FROM AN ARCHAEAN RAPAKIVI GRANITE-ANORTHOSITE-RHYOLITE COMPLEX IN THE WITWATERSRAND BASIN HINTERLAND, SOUTHERN AFRICA

ABSTRACT

The Gaborone Granite Suite underlies an area of $>6000km^2$ in the northwestern portion of the Kaapvaal Craton and comprises A-type rapakivi granite, leucogranite, granophyric microgranites and minor anorthosite. It is partially surrounded by a c.1000m-thick pile of pyroclastic and flow-banded rhyolitic lavas known as the Kanye Formation. The relationship between the Gaborone Granite Suite and the Kanye Formation, the ages of the two units, and their correlation with other magmatic suites of the Kaapvaal Craton has been a long-standing enigma. Precise U-Pb dating of granitic and granophyric components of the Gaborone Granite Suite and rhyolite of the Kanye Formation has indicated that all three rock types are the same age within error (2783-2785 Ma). The Gaborone Granite Suite and the Kanye Formation, therefore, represent a single magmatic event and may be the oldest rapakivi granite-anorthosite-rhyolite suite in the world. Emplaced in the immediate source area **during** upper Witwatersrand Supergroup sedimentation the Gaborone Granite-Kanye event may have played a key role in the development of the adjacent auriferous quartz-pebble conglomerates.

oOo

U-Pb ZIRCON DATES FROM AN ARCHAEAN RAPAKIVI GRANITE-ANORTHOSITE-RHYOLITE COMPLEX IN THE WITWATERSRAND BASIN HINTERLAND, SOUTHERN AFRICA

CONTENTS

_____oOo_____

Published by the Economic Geology Research Unit,
Department of Geology,
University of the Witwatersrand,
1 Jan Smuts Avenue,
Johannesburg 2001,
Republic of South Africa

ISBN 1 86838 048 3

U-Pb ZIRCON DATES FROM AN ARCHAEAN RAPAKIVI GRANITE-ANORTHOSITE-RHYOLITE COMPLEX IN THE WITWATERSRAND BASIN HINTERLAND, SOUTHERN AFRICA

INTRODUCTION

Large, cogenetic magmatic complexes comprising rapakivi granite, gabbro-anorthosite and rhyolite extrusives are a characteristic feature of the mid-Proterozoic North Atlantic Shield orogenic belt extending from the USA and Canada, through Greenland and Scandinavia, into Karelia and the Ukraine. These complexes typically formed between 1100-1900 Ma, but sporadic occurrences were intruded as early as 2400 Ma (O. Tapani Rämö, pers. comm.). Although rapakivi granite-anorthosite-rhyolite suites are spatially associated with major orogenic belts they are generally post-tectonic in age and the granitic component often has an A-type character (alkaline, anhydrous, anorogenic). The granitic component is believed to have been formed by anatexis of water-deficient crustal material forming, therefore, at relatively high temperatures. The anorthositic and gabbroic components are not necessarily strictly co-magmatic and are derived from crustally contaminated, mantle-derived magma, the intrusion of which into the lower crust, may have been responsible for the associated crustal anatexis (Rämö, 1991). Windley (1977) has suggested that the specific development of rapakivi granite-anorthosite-rhyolite suites in space and time may reflect a landmark in global crustal evolution, possibly related to the generation of an early-Proterozoic supercontinent (Hoffman, 1989).

In southern Africa recent work by Sibiya (1988) has identified an association of rapakivi granite and anorthosite in the Archaean Gaborone Granite Suite of southeastern Botswana and northwestern Transvaal, South Africa. The Gaborone Granite Suite is also spatially associated with a thick sequence of rhyolites known as the Kanye Formation. The ages of, and relationship between, these two units has long been a controversial and enigmatic problem in understanding the evolution of the Kaapvaal Craton. The Gaborone Granite Suite comprises rapakivi feldspar-bearing granites, leucogranites, granophyric microgranites and massif-type anorthosites exposed over an area of at least 6 000 km^2, mainly in SE Botswana (Key and Wright, 1982; Sibiya, 1988; Aldiss *et al.*, 1989). Considerable expanses of the complex occur beneath the Kalahari Basin, and rocks identified as Kanye Formation rhyolite have been found as far west as Kokong in southern Botswana (Fig. 1). If this correlation is correct the complex may be 2 - 3 times bigger than the exposed portion. A small section of the Gaborone Granite Suite and Kanye Formation is exposed in South Africa, just north of Mafikeng (D.F. Grobler, in prep.). The Kanye Formation comprises a sequence of generally massive K-feldspar phyric rhyolites with occasional fragmental and flow-banded units, which almost entirely surrounds the Gaborone Granite Suite (Fig. 1). The thickness of the volcanic pile is unknown due to incomplete exposure, and estimates range from 500 - 1300 m (Aldiss *et al.*, 1989). A well-developed suite of granophyric micrograntes, known locally and in Botswana, as the Ntantlhe Microgranite, generally outcrops between the Gaborone Granite Suite and the Kanye Formation.

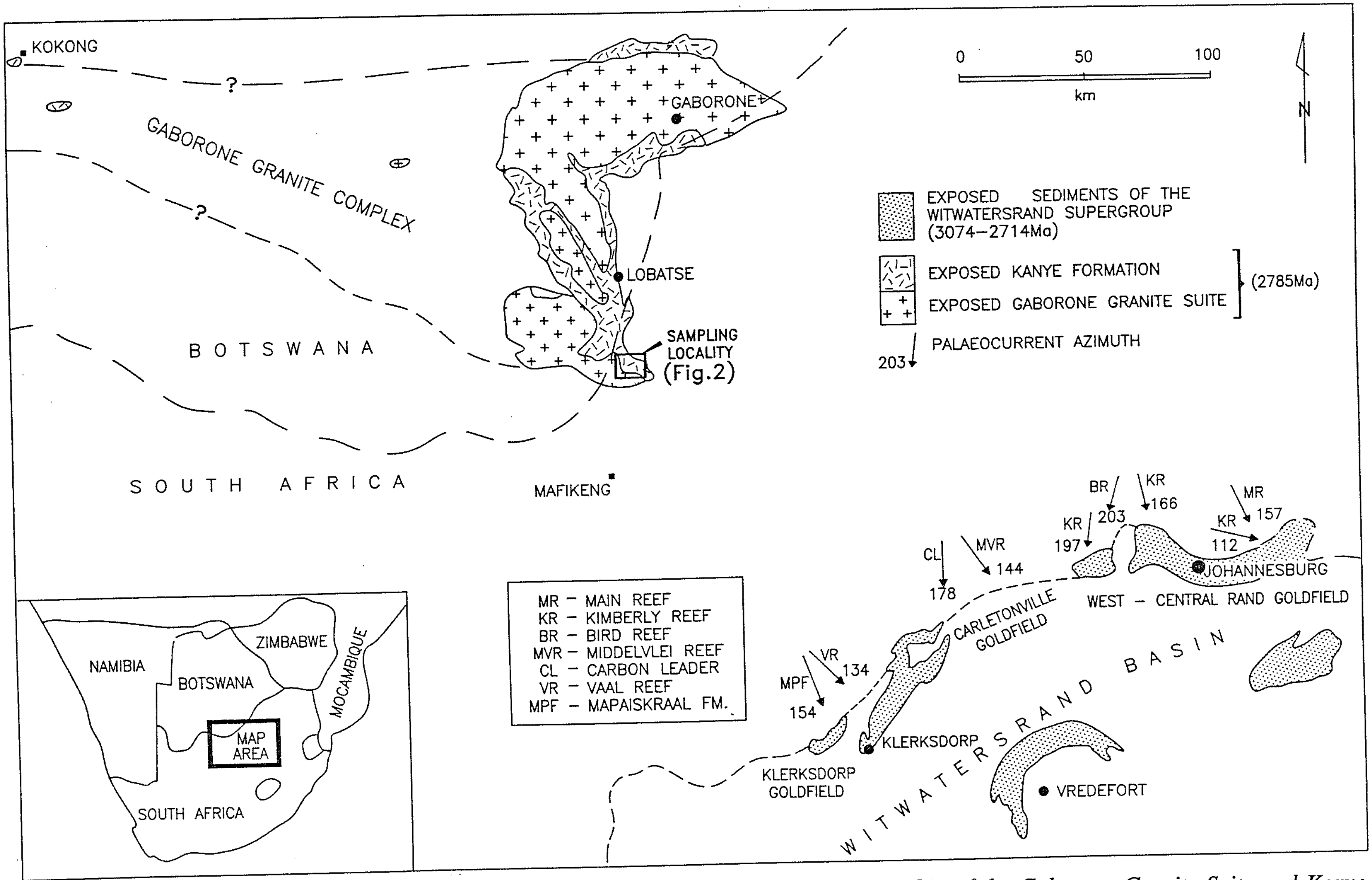

Figure 1: Generalized geologic map of the northern Kaapvaal Craton showing the relationship of the Gaborone Granite Suite and Kanye Formation to the Witwatersrand Basin; the location of the study area is also shown. Palaeocurrent data after Minter and Loen (1991).

Prior to this work there were no satisfactory age determinations for either the Gaborone nor the Kanye rock sequences since most previous attempts involved imprecise whole-rock Rb-Sr determinations. Whole-rock Rb-Sr dating of Gaborone Granite Suite components and the Ntantlhe Microgranite, or both units combined, have yielded a wide range of ages: 2290 ± 44 Ma (McElhinny, 1966), 2318 ± 17 Ma (Burger, 1974), 2328 ± 44 Ma and 2685 ± 70 Ma (Harding *et al.*, 1974), 2394 ± 26 Ma and 2428 ± 55 Ma (Key and Wright, 1982), 2616 ± 18 Ma (Cahen *et al.*, 1984) and 2341 ± 289 Ma (Grobler, in prep.). In contrast, U-Pb isotope determinations on multiple zircon fractions indicated a much older age of 2830 ± 10 Ma (Sibiya, 1988). These data suggest that the Gaborone Granite Suite may be around 2 800 Ma, with the Rb-Sr isotope system in the rocks having been reset some 400-500 Ma later. In a companion study, where zircons from the same set of samples have been analyzed by the Kober or "evaporation" method (Grobler and Walraven, in press), U-Pb zircon evaporation ages have yielded ages of 2780 Ma for both the Gaborone Granite Suite and the Kanye Formation. The object of the present study is to determine the ages of the Gaborone and Kanye sequences using the high-precision, single or small-population, U-Pb zircon dating methods of Krogh (1973; 1982) and to speculate on the significance of the ages in terms of crustal evolution on the Kaapvaal Craton.

CORRELATION OF THE GABORONE GRANITE SUITE AND KANYE FORMATION

One of the major problems which remains unresolved, despite regional and detailed mapping as well as geochemical studies, is the relationship between the Gaborone Granite Suite and its associated granophyric phases, and the Kanye Formation. Two hypotheses have been proposed; the first considers the various components of the Gaborone, Ntantlhe and the Kanye successions to be co-magmatic, all derived by differentiation and extrusion from a single, high-level magma chamber (Wright, 1958; Key and Wright, 1982; Aldiss in prep.). The opposing hypothesis is that the granitoids of the Gaborone Granite Suite intruded into an older Kanye Formation causing widespread remelting and/or recrystallization of the latter to form the Ntantlhe Microgranite and other granophyric textured microgranites (Truter, 1949; Poldervaart, 1954; Crockett, 1969).

Understanding the significance of the Gaborone and Kanye successions in terms of tectonic setting and crustal evolution of the Kaapvaal Craton depends on correctly interpreting the relationships between the two units. Furthermore, the recent recognition in the central portion of the Gaborone Granite Suite of a rapakivi granite - massif anorthosite association occurring together with a mafic-felsic dyke swarm (Sibiya, 1988) is a feature which needs to be incorporated into existing models for the formation of the Kaapvaal Craton during the late Archaean. The large size of the intrusion, its suggested association with an equally sizeable extrusive component, and the tectonomagmatic framework which gave rise to this event are all questions which will remain unanswered until substantially more detailed work has been carried out. However, a major contribution could be made if it were known with certainty whether the three assemblages of rocks were similar in age, or not. This paper presents a set of high-precision U-Pb isotope analyses of carefully selected, abraded zircons, and demonstrates the cogenetic nature of all three units. The data appear to substantiate the possibility that the Gaborone Granite Suite and the Kanye Formation may represent the oldest rapakivi granite-anorthosite-rhyolite suite known.

SAMPLING AND GEOLOGICAL RELATIONSHIPS

Samples were collected from a reasonably well exposed area in South Africa adjacent to the Botswana border north of Mafikeng (Figs. 1 and 2) where units of all three rock sequences are exposed. In this area the Gaborone Granite Suite occurs as a coarse-grained leucocratic granite which is correlated with the marginal phase of the suite known in Botswana as the Kgale Granite. The centrally disposed, more voluminous, rapakivi-textured granite, known as the Thamaga Granite or the Main Felsic Suite (Sibiya, 1988), does not occur in the study area. The Kanye Formation consists of massive, grey-black, K-feldspar-phyric rhyolite with occasional banded and pyroclastic units. The granophyric rocks have been correlated with the Ntantlhe Microgranite (Key, 1983) in Botswana (also called the Masopa Microgranite; Aldiss *et al.*, 1989), but detailed mapping (Grobler, in prep.) has revealed at least four textural varieties, namely, granophyric granite, porphyritic granophyre, medium-grained microgranite and spherulitic porphyritic microgranophyre. Nowhere in the study area have the contact relationships between any of the four granophyric units, nor between the Kgale Granite, the granophyres and the volcanics been directly observed.

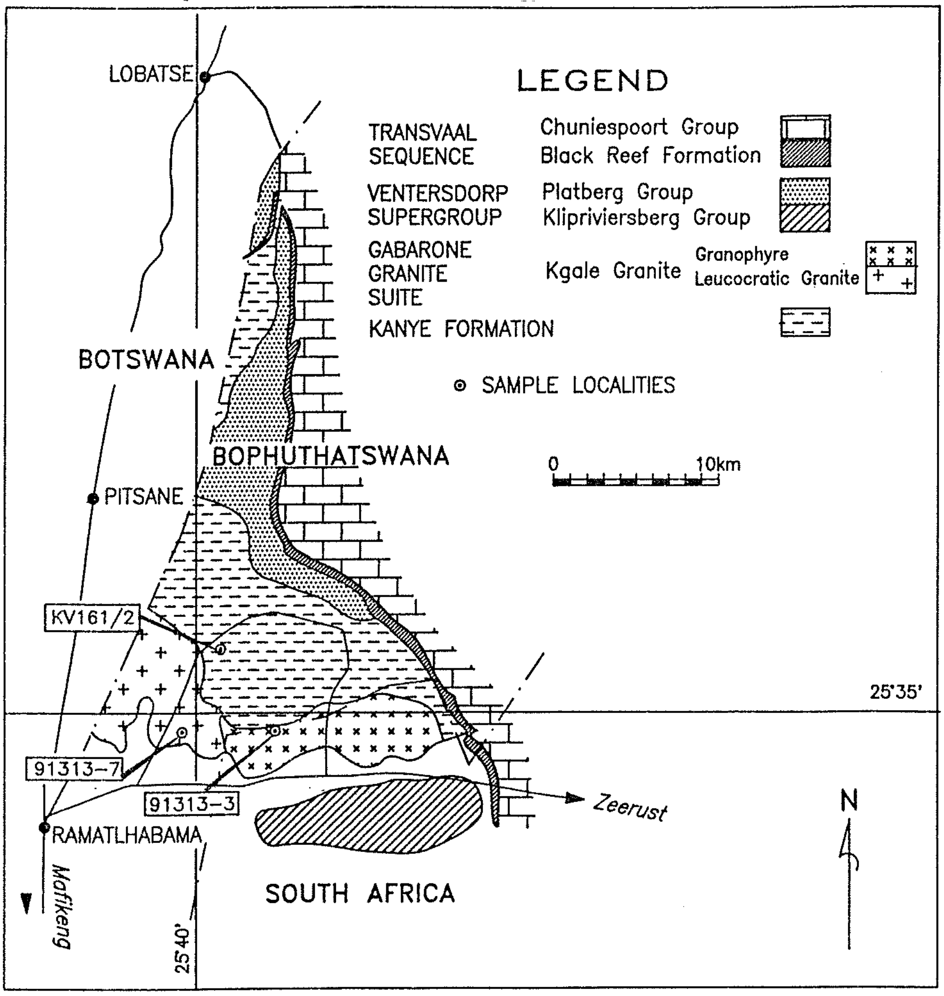

Figure 2: Map showing the distribution of the Gaborone Granite Suite and the Kanye Formation and sample locations in the area north of Mafikeng.

From a total of eight samples collected initially for zircon separation two samples (granophyre 91313-3 and granite 91313-7) with abundant and homogeneous zircon populations were selected for dating. Not all the rhyolite samples yielded good zircon populations and two samples (KV16-1/2) were chosen once microscopic observation had revealed zircon, and high Zr contents had been detected chemically.

PETROGRAPHY AND GEOCHEMISTRY OF DATED SAMPLES

The dated volcanic samples (KV16-1/2) both come from an outcrop of black, vitreous rhyolite exhibiting contorted flow banding, located about 1 km from the contact with the Gaborone Granite Suite (Fig. 2). In thin section the rock contains phenocrysts of perthitic potassium feldspar up to 5 mm in size. Some phenocrysts appear to be broken and others are well rounded. Small clusters of magnetite and chlorite, and accessory apatite and zircon, occur in a felsitic matrix. The presence of flow banding and broken-to-rounded phenocrysts suggest that this is a high-temperature rhyolite lava flow or rheomorphic welded tuff.

Sample 91313-3 is a spherulitic porphyritic microgranophyre. It contains a few percent of euhedral to subhedral potassium feldspar phenocrysts (1-5 mm in size) in a fine-grained groundmass composed of dark spherulitic zones and lighter-coloured areas between spherulites of quartz-feldspar of granular to granophyric texture. Elongate needles of green pleochroic pyroxene (aegirine?) radiate out from feldspar cores in feldspathic spherulites about 1-10 mm in diameter. Larger pyroxene crystals crosscut the spherulites. Zircon and apatite occur as accessory minerals.

Granite sample 91313-7 is from the main phase of the Kgale Granite. It is a medium- to coarse-grained, subequigranular, leucocratic granite composed almost entirely (>95%) of anhedral subrounded bluish quartz grains and pinkish potassium feldspar showing string perthite texture. Clusters of green hornblende, magnetite, zircon and apatite occur as accessory minerals.

The bulk-rock chemical compositions (XRF) of the various rock types dated in this study are presented in Table 1. The dated volcanic samples are high-K rhyolites which plot at the high-Si and high-alkali end of the spectrum of known Kanye volcanic compositions (Fig. 3). Samples of this composition also have the highest Zr and zircon contents and were found to be the most suitable for dating. The granophyre has a similar SiO_2 and slightly lower total alkali content to the volcanic samples and a similar K_2O/Na_2O to KV16-1, and is nearly identical in major, and most trace elements to the composition of the Kgale Granite (Table 1). Two analyses of rhyolites from the Kokong area (Fig. 1) are also plotted on Figure 3 and fall well within the field of the Kanye Formation rhyolites, which supports the suggestion that the rapakivi granite-anorthosite-rhyolite suite extends for a considerable distance westwards under the Kalahari sand.

All rock types are marginally peraluminous and plot in the rhyolite field on the total alkalies vs. SiO_2 diagram (Fig. 3). They have high contents of Rb, Nb, Y and Zr. Variations in Ba and Sr may be due to variable amounts of potassium feldspar and plagioclase fractionation. Zr also shows a wide range, the content of Zr in the volcanic

Table 1: Major and Trace Element Data for Dated Samples From the Gaborone Granite Suite and Kanye Formation.

		1	2	3	4
		KV16-1	KV16-2	91313-3	91313-7
	SiO_2	75.68	74.57	74.80	74.39
	TiO_2	0.43	0.42	0.33	0.41
	Al_2O_3	11.68	11.79	11.40	11.83
	Fe_2O_3	2.64	3.12	3.91	3.18
wt. %	MnO	0.03	0.04	0.07	0.06
	MgO	0.20	0.26	0.24	0.20
	CaO	0.50	0.25	0.52	0.59
	Na_2O	3.86	2.79	3.25	3.55
	K_2O	5.56	7.40	5.31	5.12
	P_2O_5	0.11	0.10	0.05	0.08
	L.O.I.	0.45	0.45	0.09	0.42
	TOTALS	101.15	101.19	100.04	99.83
	Rb	215	269	264	309
	Sr	32	27	16	22
ppm	Ba	590	590	276	365
	Y	93	97	114	119
	Nb	30	30	37	41
	Zr	771	764	948	476
	Ga	20	20	-	25

Columns 1 and 2 - Rhyolite, Kanye Formation
3 - Ntantlhe Granophyre
4 - Kgale Granite

samples is intermediate between the granophyre and the granite. The A-type classification of the suite is based on high SiO_2, alkalies, FeO*/MgO, Ga/Al_2O_3, and high field strength element contents (Table 1 and Aldiss, in prep.) compared to I-type granites (Collins *et al.*, 1982).

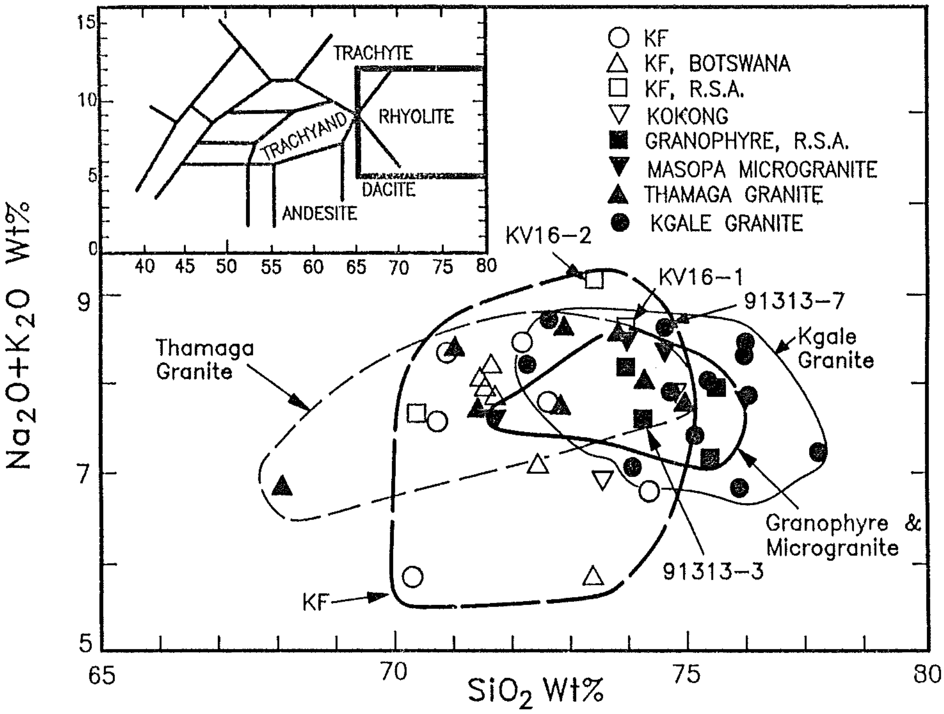

Figure 3: Na_2O+ K_2O vs SiO_2 (TAS) diagram showing compositional range of Kanye Formation, microgranite and granophyre, and Kgale and Thamaga granites in Botswana and South Africa, as well as the specific compositions of dated samples. Data are compiled from several sources (Aldiss et al., 1989; Aldiss in prep; Key, 1983; Key and Wright, 1982; Sibiya, 1988; Tyler, 1979a). Inset shows the area of the expanded TAS classification diagram of Cox et al. (1979).

ANALYTICAL METHODS

Crushing and mineral separation were carried out using standard procedures involving a Wilfley table, heavy liquids and a Frantz magnetic separator. Zircons were hand-sorted to be as free of cracks and visible alteration as possible. Most of the picked fractions were abraded (Krogh, 1982) to remove the outer surface and improve concordancy. Zircon grains, and small fractions were weighed (accurate to 30%) and then dissolved in small teflon bombs in the presence of mixed ^{205}Pb-^{235}U spike. Pb and U were extracted using small ion exchange columns (Krogh, 1973) and isotopic ratios determined using a VG354 mass spectrometer equipped with a Daly collector. Zircon morphologies are described by Grobler and Walraven (in press).

RESULTS

The results of isotopic analyses are given in Table 2 and plotted on Figures 4a and b. Data regressions were calculated using the program of Davis (1982) and are given in Table 3. Age errors are quoted at 95% confidence levels but the error ellipses on Figures 4a and b are plotted at 1 sigma to facilitate visual recognition of the data points.

Since no significantly discordant points were measured from the two volcanic samples their ages were calculated by forcing regression lines through the concordia origin (i.e the same as averaging the $^{207}Pb/^{206}Pb$ ages). Data points from sample KV16-1 are tightly clustered and give an age of 2784.7 $\pm$ 1.7 Ma. Data points from the other volcanic sample, KV16-2, show greater scatter (26% probability of fit) but yield the same age of 2784.8 $\pm$ 1.8 Ma. The lower probability of fit (50% is the expected average probability of fit) may indicate that analytical errors for this sample have been slightly underestimated.

Unabraded zircon fractions were analyzed from both the granophyre and the granite, yielding isotope ratios that were sufficiently discordant to define a Pb loss line with the more concordant data points from the abraded fractions. Four data points from the granophyre define an age of 2784.9 $\pm$ 1.9 Ma with a lower concordia intercept of 150 Ma. The granite sample provides an age of 2783.1 $\pm$ 2.0 Ma with a lower concordia intercept of 103 Ma, based on four data points. The probability of fit for both samples is high (Table 3).

DISCUSSION AND CONCLUSIONS

Ages from the two volcanic samples and the granophyre are identical within error (Table 3). The granite appears to be slightly younger but the age difference is just unresolved at the 95% confidence level. Average Th/U ratios of the volcanic zircons are distinctly higher than those of zircons in the granite (Table 2). The granophyre zircons have intermediate Th/U but are closer to the volcanics than the granite. Thus, the U-Pb systematics and the zircon Th/U suggest that the volcanics and granophyres are comagmatic. If this is the case then the 10 data points from these samples may be regressed together to give an age of 2785.1 $\pm$ 1.1 Ma. The granite may be 1-2 Ma younger than its extrusive counterparts, a feature which is consistent with the fact that the granite is observed in some places to crosscut the volcanics.

The isotope data presented above, together with marked similarities in mineralogy and chemical composition and gradational field relationships, suggest that the Gaborone, Ntantlhe and Kanye phases are the products of a single igneous event as previously proposed by Key and Wright (1982) and Aldiss (in prep.). Although the Kanye Formation is largely massive and lacks definitive evidence of extrusive origin (at least in Botswana), leading Key and Wright (1982) to propose that it was a shallow-level chilled phase of the granite, previous work by Tyler (1979a, b) and detailed mapping by one of the authors (D.F. Grobler, in prep.) has shown that most of the Kanye succession in South Africa at least, is volcanic in origin, and is characterized by flow-banding and pyroclastic textures in many outcrops. The distinctive highly fractionated composition of the Kanye Formation (i.e. high Ba, Rb, Nb, Y, Zr; low Ti, P, Sr), along with the new age data presented here, preclude proposed

Table 2: Isotopic data for zircon from the Kanye Formation and Gaborone Granite Suite

Sample	Weight (mg)	U (ppm)	Pb_{COM} (pg)	MEASURED $^{207}Pb/^{204}Pb$	CORRECTED Th/U	CORRECTED $^{206}Pb/^{238}U$	CORRECTED $^{207}Pb/^{235}U$	% DISC	$^{207}Pb/^{206}Pb$ Age (Ma)
KV16-1 Kanye Formation									
1. Ab, 1 gr	0.004	80	2	1065	0.60	0.53685	14.438	0.7±1.0	2785.1±3.3
2. Ab, 6 gr	0.040	80	7	2979	0.61	0.53659	14.425	0.7±1.0	2784.5±3.2
3. Ab, 19 gr	0.109	60	10	4456	0.61	0.53425	14.360	1.1±1.2	2784.2±3.2
KV16-2 Kanye Formation									
4. Ab, 6 gr	0.027	60	4	2490	0.63	0.53789	14.472	0.5±1.0	2786.0±3.2
5. Ab, 1 gr	0.004	90	3	996	0.61	0.53624	14.426	0.8±1.0	2785.6±3.2
6. Ab, 5 gr	0.007	80	4	933	0.64	0.53718	14.423	0.5±1.0	2782.4±3.5
91313-3 Granophyre									
7. Ab, 4 gr	0.005	80	2	1061	0.58	0.54085	14.543	-0.1±1.0	2785.0±3.4
8. Ab, 14 gr	0.020	60	5	1656	0.58	0.53826	14.473	0.4±1.0	2785.0±3.2
9. Ab, 12 gr	0.018	60	10	786	0.58	0.53912	14.492	0.2±0.8	2784.3±3.2
10. 28 gr	0.065	110	141	286	0.60	0.43239	11.527	19.5±1.0	2771.0±3.2
91313-7 Granite									
11. Ab, 11 gr	0.020	70	5	1687	0.52	0.53930	14.494	0.2±0.8	2784.0±3.2
12. Ab, 11 gr	0.017	130	5	2768	0.53	0.53850	14.459	0.2±1.8	2782.5±3.9
13. Ab, 15 gr	0.040	110	4	6684	0.50	0.53706	14.416	0.5±0.8	2782.0±3.2
14. 30 gr	0.292	120	460	437	0.50	0.46281	12.383	14.1±1.0	2777.0±3.2

Ab - abraded. Pb_{COM} - common Pb, assuming all is blank. Common Pb in excess of 8 pg is assigned an isotopic composition from the Stacey and Kramers (1975) growth curve

Th/U calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{207}Pb/^{206}Pb$ age assuming concordance

% DISC - per cent discordance for the given $^{207}Pb/^{206}Pb$ age

Table 3: Summary of age data from the Kanye Formation and Gaborone Granite Suite

Sample	Age (Ma)	Lower Intercept (Ma)	Probability of fit (%)	Number of points
KV16-1 Volcanic	2784.7 ± 1.7	-	92	3
KV16-2 Volcanic	2784.8 ± 1.8	-	26	3
91313-3 Granophyre	2784.9 ± 1.9	150	97	4
Volcanics and Granophyre	2785.1 ± 1.1	152	96	10
91313-7 Granite	2783.1 ± 2.0	103	71	4

correlations with the 3074 Ma felsic volcanics of the Dominion Group at the base of the Witwatersrand triad (Jackson, 1991) or other felsic members of the Witwatersrand or Ventersdorp Supergroups. The Gaborone and Kanye rocks are clearly representative of a distinct magmatic episode without known correlatives on the Kaapvaal Craton.

The Gaborone Granite Suite comprises a complex, multi-component intrusive suite which is made up of rapakivi-feldspar granitoids, anorthosites and gabbro-norites, and fine-grained granophyric rocks (Ntantlhe Microgranite). This suite is almost entirely surrounded by the Kanye Formation which is made up dominantly of a pile of porphyritic rhyolite several hundred metres thick. The observed intrusive nature of the Gaborone-Kanye contact can thus no longer be regarded as evidence for temporally discrete magmatic episodes, but suggests a comagmatic association between large volumes of silicic ash-flow tuffs (± lavas) and a high-level resurgent-caldera granitoid body intruding its own volcanic carapace, such as have often been identified in the Cordillera of western North America (e.g. Lipman, 1984; Du Bray and Pallister, 1991).

The assemblage of rapakivi granite - anorthosite (plus gabbro) - rhyolite is one which typifies, *inter alia*, the sequence of rocks that has developed in mid-Proterozoic orogenic belts of the North Atlantic Shield (Windley, 1977). These complexes, particularly those of Finland and Greenland are generally 1700-1800 Ma old, and none have been described from the Archaean, although anorthosites *per se* (i.e. without high-level rapakivi granites and felsic volcanics) have been documented in several old (> 2700 Ma) orogenic belts (Bridgwater and Windley, 1973). Consequently, the existence of a very well preserved rapakivi granite - anorthosite - rhyolite complex that is close to 2 800 Ma in age is highly unusual and could have major implications for the tectono-magmatic evolution of the northern part of the Kaapvaal Craton and adjoining Limpopo orogenic belt. It is possible that the processes of anatexis that prevailed beneath thickened crust during mid-Proterozoic orogenesis also

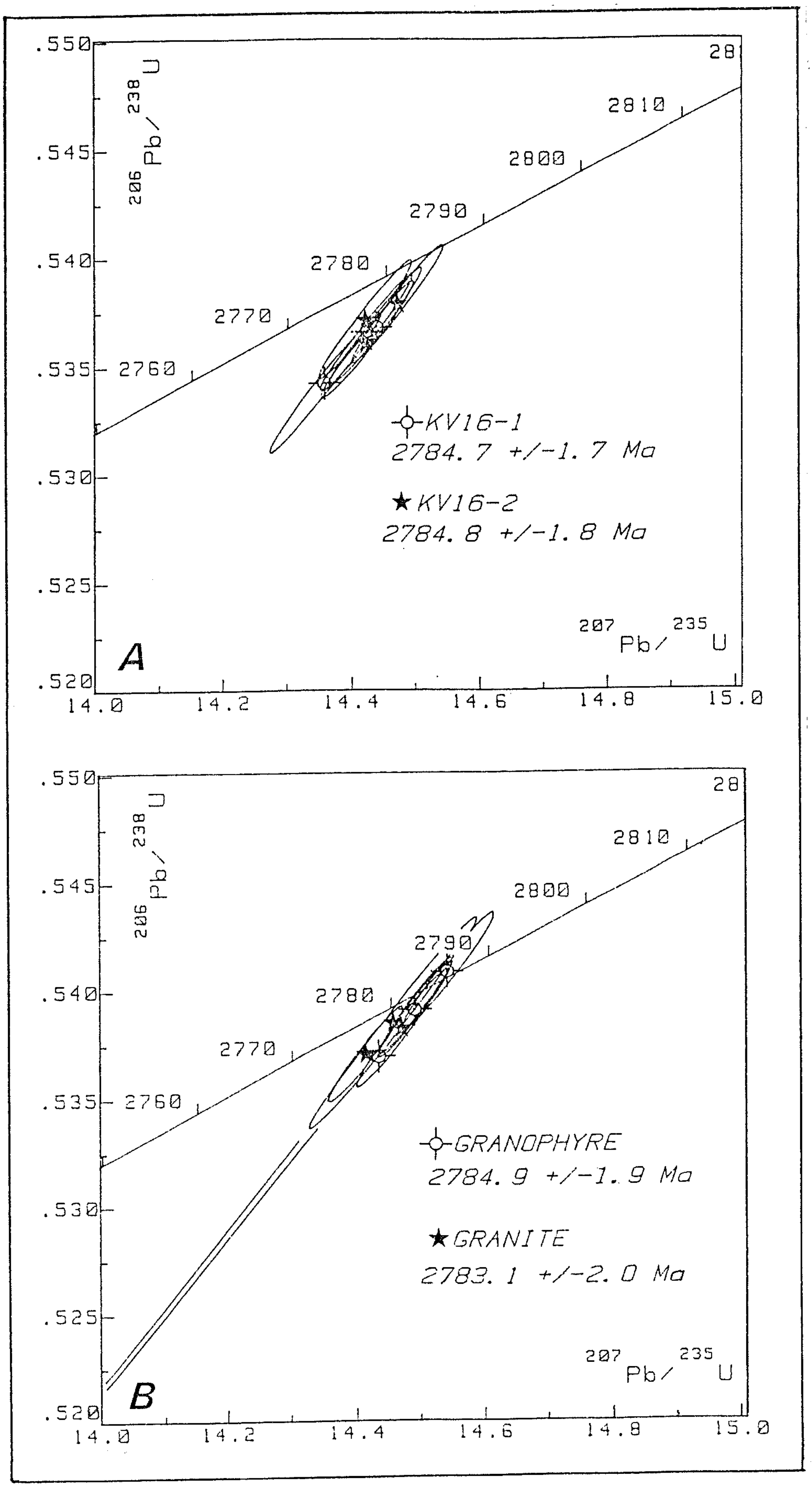

Figure 4: a. U-Pb isotopic analyses for the Kanye Formation. Ellipses are drawn at 1 sigma, but age errors are quoted at 95% confidence.

b. U-Pb isotopic analyses for granophyre and granite samples of the Gaborone Granite Suite. Ellipses are drawn at 1 sigma, but age errors are quoted at 95% confidence. The lines represent best fit lines to the concordant data points and one discordant data point (off scale) from each sample.

characterized marginal portions of the Kaapvaal Craton at c. 2 800 Ma. It is pertinent to note that the Limpopo orogeny may have been undergoing continent-continent collision (i.e. collision of the Zimbabwe and Kaapvaal cratonic blocks) as early as c. 2 800 Ma (Robb *et al.*, 1991) and even earlier if it is accepted that some form of subduction process prevailed prior to this time (Burke *et al.*, 1986). Consequently, early crustal thickening may have been followed by rifting which gave rise, at c. 2 800 Ma, to major plutonic - volcanic complexes such as the Gaborone Granite Suite and the Kanye Formation. The emplacement ages of 2785 Ma for the latter may, in fact, be providing information on the minimum age for continent collision during the Limpopo orogeny.

It is also pertinent to note that the Gaborone and Kanye successions were emplaced at the same time as the deposition of the upper (Central Rand Group) part of the Witwatersrand Supergroup, which is now constrained in age between 2840-2714 Ma (Armstrong *et al.*, 1991; Robb *et al.*, 1991). This has important implications for the origin of detrital gold in the Witwatersrand Basin since it provides a means whereby primary gold mineralization in the basin hinterland might have taken place. The presence of a major felsic volcanic province in the source area of the Witwatersrand Basin raises the possibility that an extensive period of epithermal gold mineralization might have been associated with the formation of the Gaborone Granite Suite and the Kanye Formation. The Gaborone Granite Suite itself contains known occurrences of Pb-, Au-, Ag- and F-bearing quartz veins (Key, 1983; Aldiss *et al.*, 1989) and the authors have also seen zones of intense silicification and brecciation in the Kanye Formation, although the extent of this type of alteration and the presence of mineralization is unknown at this stage. Elsewhere in the Witwatersrand hinterland many pre- to syn-Witwatersrand granitoids are characterized by hydrothermal alteration and veining, and contain anomalous enrichments of Au and U (Robb and Meyer, 1990; Robb *et al.*, 1992). These granites are regarded as the root zones of high-level hydrothermal systems that mineralized the upper portions of the crust in the Witwatersrand hinterland, although direct evidence of such systems has largely been removed by erosion. The preservation of the Kanye Formation indicates that certain of the syn-Witwatersrand magmatic events did contain high-level/extrusive components.

In summary, the significance of the Gaborone Granite Suite and the Kanye Formation lies in the fact that it represents a major magmatic episode characterized by an unusually old, atypical (for the region) rapakivi granite-anorthosite-rhyolite suite. It also has indications of attendant hydrothermal mineralization, is located well within the confines of the Witwatersrand Basin source area, and has an age that coincides with deposition of the upper, auriferous, section of the Witwatersrand Supergroup. Thus, the Gaborone/Kanye event at 2785 Ma may have played an important role in the tectonic evolution of the northwestern Kaapvaal Craton and in the formation of the Witwatersrand Basin.

ACKNOWLEDGEMENTS

Don Aldiss and David Piper of the British Geological Survey are gratefully acknowledged for the use of unpublished chemical data, logistical support, and many helpful comments which improved the quality of the manuscript. The authors also thank Victor Sibiya and Norman Lock for introducing them to some of the many fascinating aspects of Botswanan geology and Janet Long for secretarial assistance.

REFERENCES

Aldiss, D.T., Tombale, A.R., Mapeo, R.M.B. and **Chiepe, M.** 1989. The geology of the Kanye area. Bull. **33**, Geol. Surv. Botswana, 170pp.

Armstrong, R.A., Compston, W., Retief, E.A., Williams, I.S. and **Welke, H.J.** 1991. Zircon ion microprobe studies bearing on the age and evolution of the Witwatersrand triad. Precambrian Res. **53**: 243-266.

Bridgwater, D. and **Windley, B.F.** 1973. Anorthosites, post-orogenic granites, acid volcanic rocks, and crustal development in the North Atlantic Shield during Mid-Proterozic. *In*: L.A. Lister (ed.), Symp. on Granites and Related Rocks. Geol. Soc. S. Afr. Spec. Publ. **3**: 307-318.

Burger, A.J. and **Coertze, F.J.** 1976. Summary of age determinations carried out during the period April, 1974 to March, 1976. Annals Geol. Surv. S. Afr., **11**, 317-329.

Burke, K., Kidd, W. S. and **Kusky, T. M.** 1986. Archean basin foreland tectonics in the Witwatersrand, South Africa. Tectonics, V. **5**/3, 439-456.

Cahen, L., Snelling, N.J., Delhal, J. and **Vail, J.R.** 1984. The Geochronology and Evolution of Africa. Clarendon Press, Oxford, 512 pp.

Collins, W.J., Beams, S.D., White, A.J.R. and **Chappell, B.W.** 1982. Nature and origin of A-type granites with particular reference to southeastern Australia. Contrib. Mineral. Petrol. **80**: 189-200.

Cox, K.G., Bell, J.D. and **Pankhurst, R.J.** 1979. The Interpetation of the Igneous Rocks. George Allen & Unwin, London, 450 pp.

Crockett, R.N. 1969. The geological significance of the margin of the Bushveld Basin in Botswana. Ph.D. thesis, Univ. London, 273 pp. (unpubl.).

Davis, D.W. 1982. Optimum linear regression and error estimation applied to U-Pb data. Can. J. Earth Sci. **19**: 2141-2149.

Du Bray, E.A. and **Pallister, J.S.** 1991. An ash-flow caldera in cross-section: ongoing field and geochemical studies of the mid-Tertiary Turkey Creek caldera, Chiricahua Montains, SE Arizona. J Geophys. Res. **96**: 13435-13457.

Grobler, D.F. and **Walraven F.** 1993. Geochronology of Gaborone Granite Complex extensions in the area north of Mafikeng, South Africa. Isot. Geoscience, (in press).

Harding, R.R., Crockett, R.N. and **Snelling, N.J.** 1974. The Gaborone Granite, Kanye Volcanics and Ventersdorp plantation porphyry, Botswana; geochronology and review. Rep. Inst. Geol. Sci. **74**/5, 26 pp.

Hoffman, P.F. 1989. Speculations on Laurentias first giga Year (2.0 to 1.0 Ga). Geology, **17**, 135-138.

Jackson, M.C. 1991. The Dominion Group: a review of the late Achaean volcano-sedimentary sequence and implications for the tectonic setting of the Witwatersrand Supergroup, South Africa. Econ. Geol. Res. Unit, Info. Circ. **240**, University Witwatersrand, Johannesburg, 40 pp.

Key, R.M. 1983. The geology of the area around Gaborone and Lobatse, Kweneng, Kgatleng, Southern and Southeast districts. Dist. Mem. **5**, Geol. Surv. Botswana, 230 pp.

Key, R.M. and **Wright, E.P.** 1982. The genesis of the Gaborone rapakivi granite complex in southern Africa. J. geol. Soc. London **139**: 109-126.

Krogh, T.E. 1973. A low contamination method for the hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations. Geochim. Cosmochim. Acta **37:** 485-494.

Krogh, T.E. 1982. Improved accuracy of U-Pb zircon ages by creation of more concordant systems using an air abrasion technique. Geochim. Cosmochim. Acta **46**: 637-649.

Krogh, T.E. and **Davis, G.L.** 1974. Alteration in zircons with discordant U-Pb ages. Carnegie Inst. Yearbook **73**: 560-567.

Lipman, P.W. 1984. The roots of ash-flow calderas in western North America: windows into the tops of granitic batholiths. J. Geophys. Res. **89**: 8801-8844.

McElhinny, M.W. 1966. Rb-Sr and K-Ar age measurements on the Modibe gabbro of Bechuanaland and South Africa. Earth Planet Sci. Lett., **1**: 439-442.

Minter, W.E.L. and **Loen, J.S.** 1991. Palaeocurrent dispersal patterns of Witwatersrand gold placers. S. Afr. J. Geol. **94**: 70-85.

Poldervaart, A. 1954. The Gaborones granite (South Africa). Comptes Rendus, XIX Congress Geol. Int., Alger 1952, Assoc. Service Geol. Africaine **20**: 315-333.

Rämö, O.T. 1991. Petrogenesis of the Proterozoic rapakivi granites and related basic rocks of SE Fennoscandia: Nd and Pb isotopic and general geochemical constraints. Bull. Geol. Surv. Finland, **355**: 260pp.

Robb, L.J. and **Meyer, F.M.** 1990. The nature of the Witwatersrand hinterland: conjectures on the source area problem. Econ. Geol. **85**: 511-536.

Robb, L.J., Davis, D.W. and **Kamo, S.L.** 1991. Chronological framework for the Witwatersrand Basin and environs: towards a time-constrained depositional model. S. Afr. J. Geol. **94**: 86-95.

Robb, L. J., Davis, D. W., Kamo, S.L. and **Meyer, F.M.** 1992. Ages of altered granites adjoining the Witwatersrand Basin, with implications for the origin of gold and uranium. Nature, **357**, 677-680.

Sibiya, V.B.B. 1988. The Gaborone Granite Complex, Botswana, southern Africa: an atypical rapakivi granite-massif anorthosite association. Ph. D. thesis, Free Univ., Amsterdam, Free University Press, 449 pp.

Stacey, J.S. and **Kramers J.D.** 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. Earth Planet. Sci. Lett. **26**: 207-221.

Truter, F.C. 1949. A review of volcanism in the geological history of South Africa. Proc. Geol. Soc. S. Afr. **52**: 29-88.

Tyler, N. 1979a. Stratigraphy, origin and correlation of the Kanye Volcanic Group in the west-central Transvaal. Econ. Geol. Res. Unit, Info. Circ. **130**, University Witwatersrand, Johannesburg, 15 pp.

Tyler, N. 1979b. Correlation, stratigraphic relations and geochemistry of the Ventersdorp Supergroup in the Derdepoort area, west-central Transvaal. Econ. Geol. Res. Unit, Info. Circ. **131**, University Witwatersrand, Johannesburg, 23 pp.

Windley, B.F. 1977. The Evolving Continents. John Wiley & Sons, N.Y., 385 pp.

Wright, E.P. 1958. Geology of the Gaborone District. Records Geol. Surv. Bechuanaland Protectorate, 1956: 12-20.

-----oOo-----