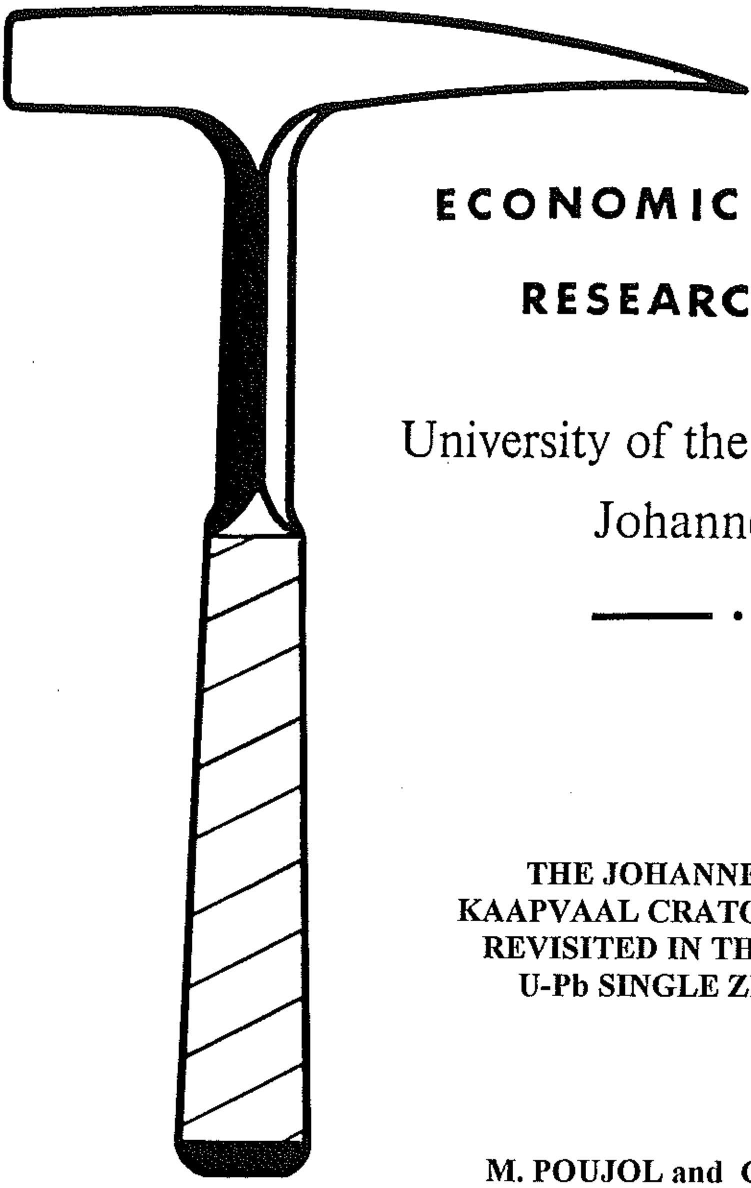

ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

THE JOHANNESBURG DOME, KAAPVAAL CRATON, SOUTH AFRICA, REVISITED IN THE LIGHT OF NEW U-Pb SINGLE ZIRCON DATING

M. POUJOL and C.R.ANHAEUSSER

INFORMATION CIRCULAR No.339

UNIVERSITY OF THE WITWATERSRAND
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by

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ABSTRACT

The Johannesburg Dome, located in the central part of the Kaapvaal Craton constitutes one of the key areas for determining the Archaean crustal evolution of this part of the craton. The 700km^2 dome consists of a mosaic of different granitic rocks intruded into an earlier-formed Archaean greenstone crust. This study presents new precise U-Pb single zircon ages for 7 samples collected from different granitoid phases identified on the Johannesburg Dome. A trondhjemitic gneiss sample from the northwestern part of the dome represents the oldest granitoid rock recognized so far and has been dated at 3340 ± 3.3 Ma. This result has important implications with regard to the age of the mafic and ultramafic greenstone remnants that occur scattered throughout the dome. It has been demonstrated for the Barberton and Murchison greenstone belts, which are located on the eastern and northeastern side of the Kaapvaal Craton, that their volcanic and magmatic events are genetically linked. Consequently, if such reasoning is applied to the rocks on the Johannesburg Dome this would imply that the greenstone remnants found in the area are at least 3.34 billion years old. The initial magmatic episode, involving early greenstone and TTG granitoid development was followed by the emplacement, at 3201 ± 5 Ma ago, of a hornblende-biotite-tonalite gneiss exposed on the southern edge of the dome. Following the trondhjemite-tonalite events a further period of mafic plutonism occurred resulting in the intrusion of tholeiitic dykes that were subsequently metamorphosed to hornblende amphibolites. The age of these dykes has yet to be determined quantitatively, but they fall within the time constraints imposed by the age of the trondhjemitic gneisses (3340 - 3200 Ma) and the crosscutting, homogeneous granodiorites (3121 - 3114 Ma) discussed below. A third magmatic event, consisting mainly of potassic granitoids, has been dated at 3121 ± 5 Ma for a medium-grained granodiorite phase and 3114 ± 2.3 Ma for its porphyritic granodiorite equivalent. Late-stage pegmatites crosscutting all the earlier granitoid events were found to be younger than 3120 Ma, with some possibly being approximately 3.0 billion years old. Finally, the new age data presented in this study provides further confirmation that the sediments of the Witwatersrand Basin were deposited unconformably on an Archaean granite-greenstone basement that was as young as 3120 Ma.

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INTRODUCTION

Unconformably overlain by the sedimentary successions of the world-class auriferous Witwatersrand Basin, the Johannesburg Dome (also referred as the Johannesburg-Pretoria Dome) constitutes one of the few Archaean granite-greenstone inliers exposed in the southern part of the Kaapvaal Craton. With a total extent of approximately 700km^2, it provides a unique opportunity to examine Archaean basement rocks in this part of the craton.

Anhaeusser (1973) provided the first comprehensive geological map of the dome. This work described the Johannesburg Dome as a mosaic of different granitic rocks intrusive into Archaean greenstone remants. The granitic rocks display distinctive field characteristics and variable geochemical, mineralogical and textural properties. The oldest granitic rocks comprise a suite of tonalitic and trondhjemitic gneisses and migmatites that occupy most of the northern half of the dome (Fig.1). The south-central portion consists mainly of a variety of homogeneous, medium-grained granodioritic rocks which, in the west, are somewhat coarser grained and are commonly porphyritic in texture. Pegmatitic dykes and veins are also common.

Despite the fact that the Johannesburg Dome constitutes an almost unique opportunity to better understand the Archaean history of this part of the Kaapvaal Craton, very few geochronological data are presently available. The purpose of this information circular is, therefore, to present new U-Pb single zircon dating for the Johannesburg Dome. A total of 7 samples representative of the different granitic rocks have been collected: 3 trondhjemitic gneisses from the northern part of the dome, 1 tonalitic gneiss from the south and 3 homogeneous granodioritic rocks from other localities shown in Figure 1.

GEOLOGICAL AND CHRONOLOGICAL SETTINGS

General geology

A variety of mafic and ultramafic rocks, many displaying affinities with komatiites, high- magnesian basalts, and tholeiites constitute the earliest recognized rocks exposed on the Johannesburg Dome (Anhaeusser, 1977,1978,1992). These primitive greenstone belt remnants, which have been equated with similar rocks found elsewhere on the Kaapvaal Craton (e.g. rocks of the ~3500 Ma Barberton greenstone belt), have been intruded, metamorphosed and migmatized by successive granitoid events.

Regional mapping, coupled with selected detailed studies of key outcrops, such as the Nooitgedacht migmatite platform seen in a river exposure in the northwestern sector of the dome, led to the establishment of a field-based chronology of granitic emplacement events (Anhaeusser, 1973,1998). The earliest granitoid rocks include a suite of trondhjemitic and tonalitic gneisses (TTG's), most of which occupy the northern half of the Johannesburg Dome

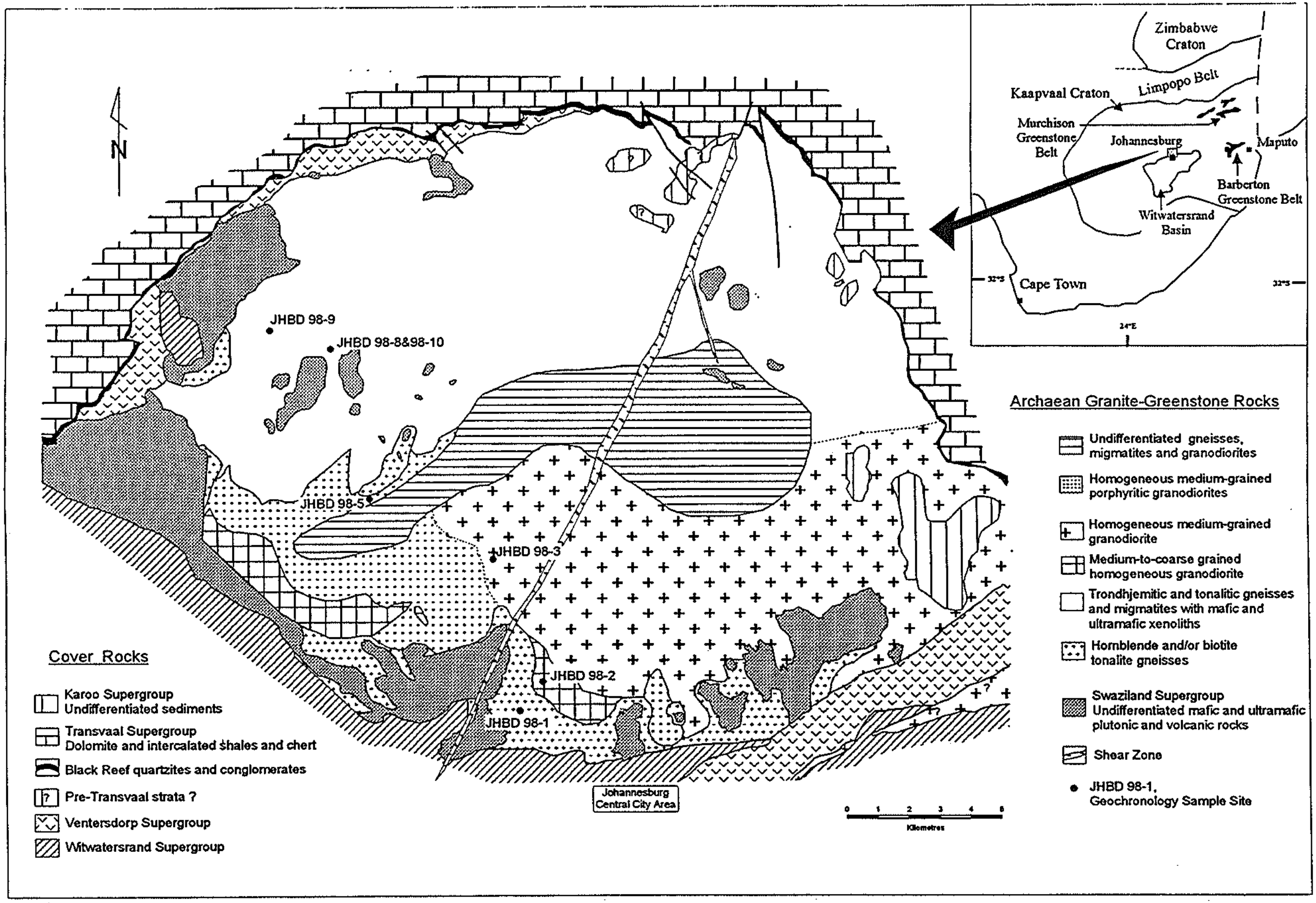

Figure 1: Simplified geological map of the Johannesburg Dome (after Anhaeusser, 1973) showing the location of the samples. Inset map shows the location of the dome within the Kaapvaal Craton.

(e. g. samples JHBD 98-8, 98-9, 98-10, Fig. 1). Exposures of similar rocks also occur on the southern edge of the dome (represented by hornblende-tonalite gneiss sample JHBD 98-1, Fig.1) and underlie the Witwatersrand Supergroup sediments that dip to the south. Field relations suggested that the sodium-enriched TTG granitoid suite, which includes dioritic, tonalitic and trondhjemitic gneisses and migmatites, may have been emplaced at different stages; hence it became important to establish the isotopic ages of the various granitic phases distinguishable on the basis of their mineralogical, geochemical and textural differences.

Following the emplacement of the TTG suite, an early mafic dyke event can be recognised on the dome (e.g. on the Nooitgedacht platform, Fig. 2). These mafic dykes, now represented by hornblende amphibolites, preceded the intrusion of the potassic granite suite that occupies most of the southern half of the dome (Fig. 1).

The potassic granitoids consist of a variety of homogeneous granodiorites that differ texturally across the dome. Homogeneous, grey, medium-grained granodiorites occur in the south-central and southeastern sectors (sample JHBD 98-3, Fig. 1) whereas coarser-grained, homogeneous, porphyritic granodiorites occupy the southwestern sector (sample JHBD 98-5, Fig. 1). A further textural variation of the homogeneous granodiorite suite is developed along the southern contact of the main potassic massif, adjacent to the hornblende-tonalite gneisses. These medium-to-coarse-grained, pinkish granodiorites are represented in this study by sample JHBD 98-2 (Fig. 1).

Fine-grained, homogeneous granodiorite dykes, considered to be genetically related to the potassic granitoids described above, transgress the trondhjemite gneiss-migmatite terrane on the northern half of the dome. Also transgressing these gneiss-migmatite exposures are coarse-textured pinkish pegmatite dykes that probably represent the final stages of granitoid emplacement on the dome. The pegmatites, which are also encountered in the homogeneous granodiorites, were sampled for isotopic dating, but the few zircons found in these rocks proved to be unsuitable for this purpose.

The Johannesburg Dome has also participated in various episodes of epeirogenic uplift beginning in the early Archaean and extending to post-Transvaal Supergroup times (~2250 Ma). Shear zones, like the prominent north-northeast-trending structure shown in Figure 1, were reactivated by successive periods of uplift and tectonic disturbance on the Kaapvaal Craton (Anhaeusser, 1973; Hilliard, 1994). The dome was also intruded in Ventersdorp and Transvaal times (~ 2700 - 2224 Ma, Walraven et al., 1990) by numerous dykes. These include post-Transvaal mafic dykes which preceded and accompanied the emplacement of the ~2060 Ma Bushveld Complex. Later intrusive events included the subalkaline and mafic dykes associated with the ~1300 Ma Pilanesberg Alkaline Complex, and mafic dykes linked to the early Mesozoic Karoo igneous activity that occurred between 190-170 Ma ago.

Previous geochronological studies

Allsopp (1961) carried out the first geochronological investigations involving Rb-Sr ages on granitic rocks. He examined both whole-rock and separated mineral fractions from samples collected exclusively from the granodioritic phases developed in the central portion of the dome. A whole-rock Rb-Sr age (recalculated with $\lambda=1.42\times10^{-11}$ years^{-1}) was found to be 3132 ± 65 Ma (Allsopp, 1961) with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7060 ± 0.0030 (Allsopp, 1964). Widely differing apparent ages were obtained for the separated mineral fractions and

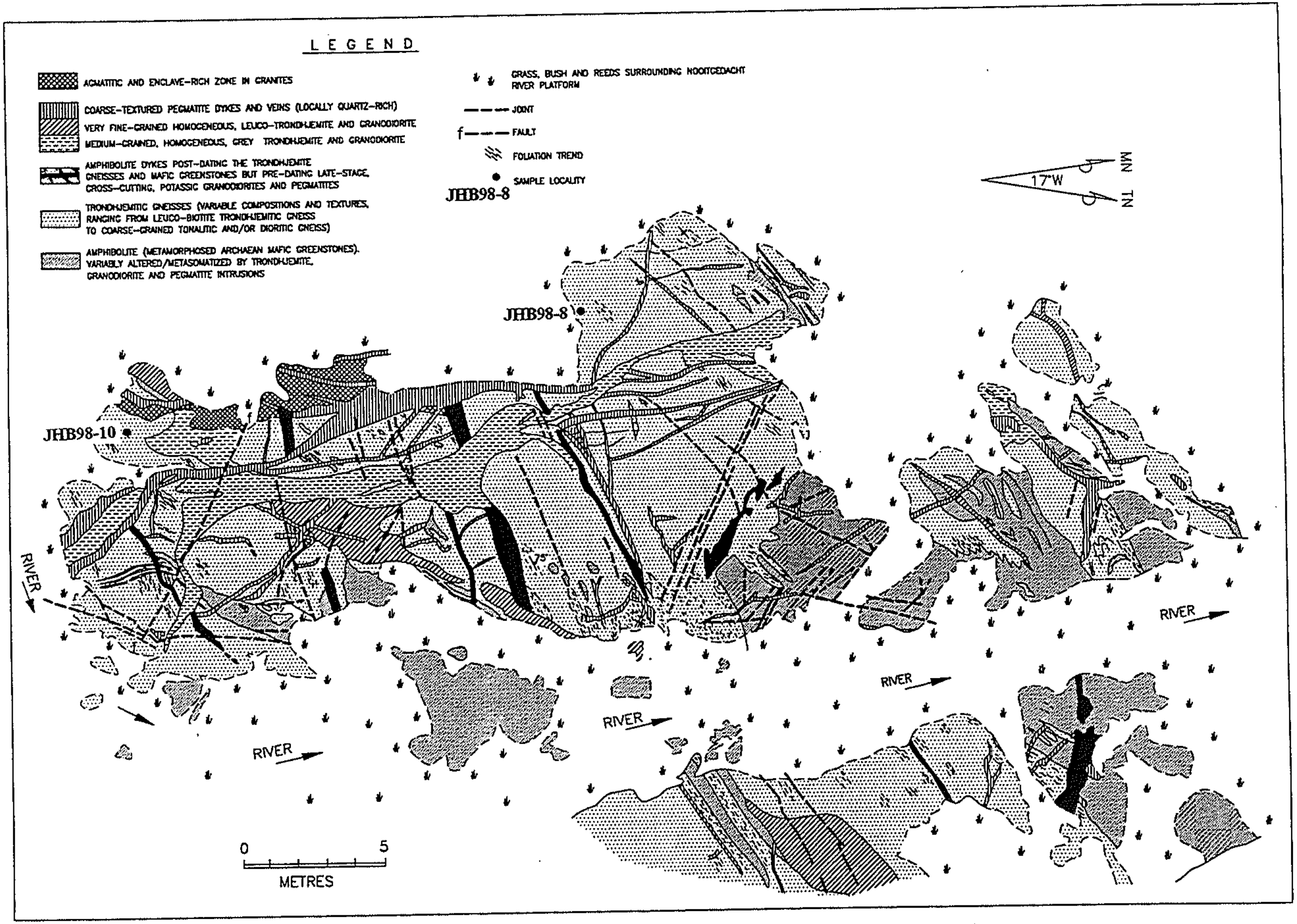

Figure 2: Geological map of the Nooitgedacht migmatite platform (after Anhaeusser, 1998).

Allsopp concluded that the discordance of the mineral ages was the result of the diffusion of radiogenic strontium from mineral to mineral. Contrasting with this whole-rock Rb-Sr age is a $^{207}Pb/^{206}Pb$ zircon age of 2585 ± 65 Ma (Burger and Walraven, 1979) obtained from one of the granodiorite samples analyzed by Allsopp. More recently, Barton et al. (1999) conducted a Rb-Sr, Pb-Pb and Sm-Nd study on granitoid rocks from the Johannesburg Dome. The whole-rock Rb-Sr data on the granodiorites define ages at 3158 ± 179 Ma and 3081 ± 33 Ma respectively. The Pb-isotope data for the same units define ages at 3062 ± 26 Ma and 3112 ± 14 Ma, while zircon evaporation data define an age of 3093 ± 3.2 Ma. These authors concluded that the granodiorites were emplaced ~3090 Ma ago and were derived from a source between ~3300 and 3500 Ma old.

Very few data are available for the tonalitic-trondhjemitic gneisses. An U-Pb age of 3170 ± 34 Ma (Anhaeusser and Burger, 1982) was determined from multiple zircons obtained from a tonalite cropping out on the southern edge of the Johannesburg Dome. The least discordant isotopic data were found to closely conform to a 3200 Ma Wasserburg-type diffusion curve. More recently, Barton et al. (1999) obtained a whole-rock Pb age of 3001 +132/-146 Ma for tonalite from the same sample locality. In addition, this tonalite yielded a whole-rock Rb-Sr age of 2385 ± 127 Ma and a biotite Rb-Sr age of 2321 ± 23 Ma.

Sampling

A total of 7 samples representative of the different granitic phases were collected from various localities on the Johannesburg Dome (Fig. 1). The tonalitic-trondhjemitic gneisses (TTG) were sampled at three different locations; JHBD 98-1 is a hornblende-biotite-tonalitic gneiss cropping out along the southern margin of the dome, whereas JHBD 98-9 represents a sample of leuco-biotite trondhjemitic gneiss from the northwestern sector of the dome (Fig. 1). Samples JHBD 98-8 and JHBD 98-10 consist of leuco-biotite trondhjemitic gneisses from the Nooitgedacht migmatite platform (Fig. 2) described recently by Anhaeusser (1998). This exposure also occurs on the northwestern side of the dome and is situated approximately 2km east of locality JHBD 98-9.

The homogeneous potassium-rich granitoid suite was sampled at four separate localities. Sample JHBD 98-2 is a relatively coarse-grained homogeneous granodiorite from the southern half of the dome; sample JHBD 98-3 is a medium-fine-grained granodiorite from the south-central part of the dome and sample JHBD 98-5 is a coarse-grained porphyritic granodiorite from the west-central part (Fig. 1).

Methodology

All the samples were prepared and analyzed at the Hugh Allsopp Laboratory, University of the Witwatersrand. Rock samples were pulverized using a heavy-duty hydraulic rock splitter, jaw crusher and swing mill. Mineral separation involved the use of a Wilfley Table, heavy liquids (bromoform and methylene iodide) and a Frantz Isodynamic Separator. Zircons were examined with a binocular microscope in order to assess grain quality, degree of fracturing and the possible existence of inherited cores. Handpicked zircons were abraded using the techniques of Krogh (1982) and washed in ultra-pure acetone, diluted nitric acid and hydrochloric acid. Single grains or small populations of zircons were then placed into 0.35 ml Teflon vials together with 30 μl HF and a mixed ^{205}Pb-^{235}U spike. Eight of these Teflon vials were then placed in a Parr Container for 2 days at 220°C. The samples were chemically processed without separating U and Pb (Lancelot et al., 1976) and loaded on a rhenium filament together with a 0.25N phosphoric acid - silica-gel mixture. The analyses were performed on an automated single collector VG54E mass spectrometer, corrected by 0.002 (± 0.05%) for mass fractionation. Data were reduced using PbDat (Ludwig, 1993a). Analytical uncertainties are listed at 2σ and age determinations were processed using Isoplot (Ludwig, 1993b).

Results

Tonalitic and trondhjemitic gneisses

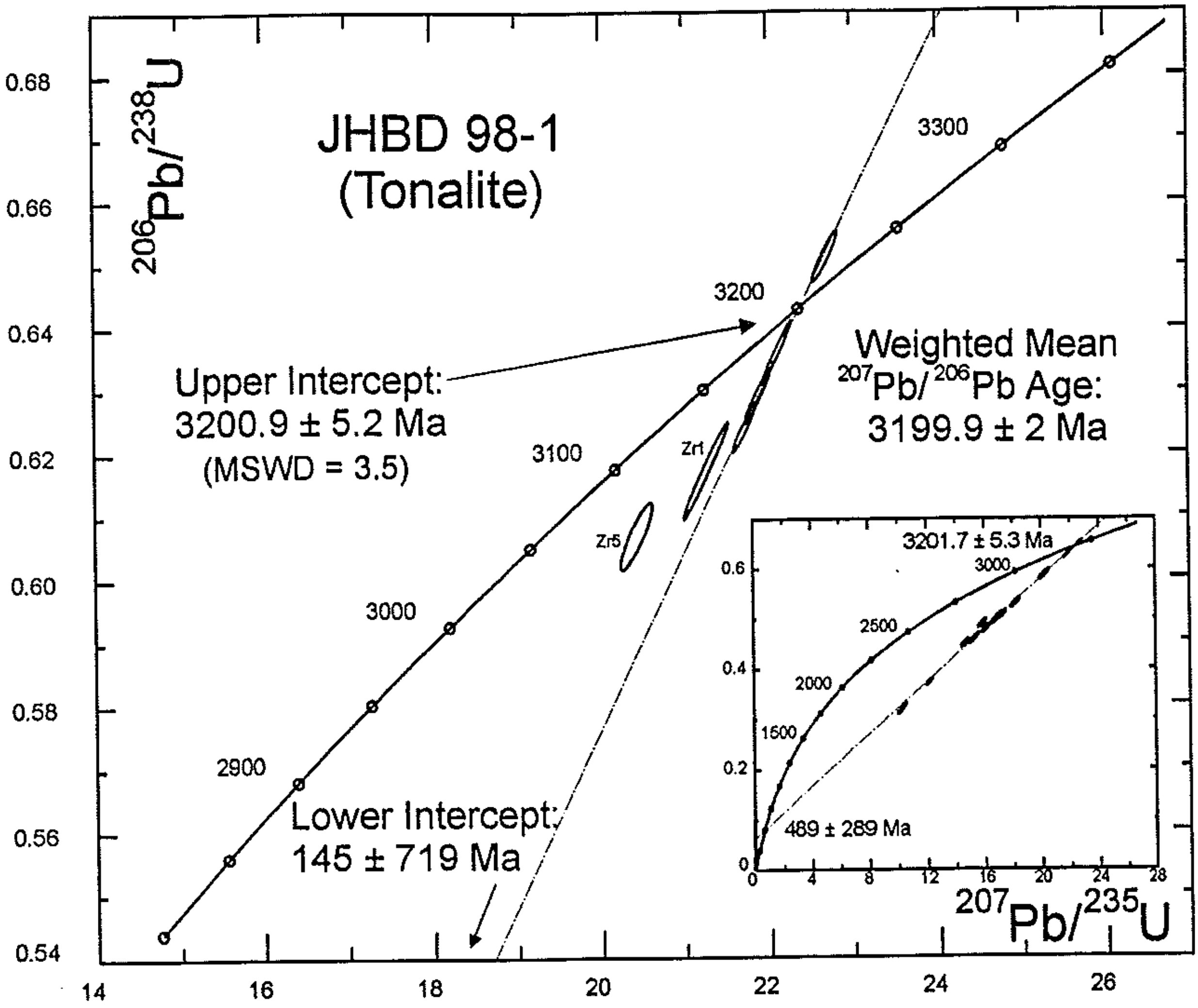

Figure 3: Concordia diagram for hornblende-biotite-tonalite sample JHBD 98-1. Inset diagram shows these data together with that from Anhaeusser and Burger (1982).

The hornblende-biotite-tonalitic gneiss (JHBD 98-1; equivalent to sample RP7 of Anhaeusser, 1971,1973) consists mainly of quartz, sodic-plagioclase, hornblende and biotite. Accessory minerals include sphene, apatite, magnetite, zircon and microcline. The plagioclase (albite-oligoclase) is generally saussuritized or sericitized, whereas the hornblende is partly or totally altered to chlorite. The tonalitic gneisses have a distinctive chemical composition characterized by high Na_2O (4.23wt%) and low K_2O (2.24wt%) contents. As mentioned earlier this tonalitic gneiss was found to be approximately 3170 Ma by Anhaeusser and Burger (1982) using multiple zircon populations. In the present study all the zircons extracted from sample JHBD 98-1 were found to be translucent and pink in colour. Six grains were analyzed (Table 1) and the results plotted in a concordia diagram (Fig. 3). Four sub-concordant points define an upper intercept age of 3200.9 ± 5.2 Ma (MSWD=3.5) with a weighted mean $^{207}Pb/^{206}Pb$ age of 3199.9 ± 2 Ma. This new data, together with that from Anhaeusser and Burger (Fig. 3 inset) define a similar age of 3201.7 ± 5.3 Ma. Consequently, we consider that the emplacement age of this tonalite was ~3200 Ma. Zircons 1 and 5 (Table 1), although identical in shape and colour, but smaller in size, are slightly discordant and plot well to the left of the discordia defined by the other four grains. It is possible that the smaller grain size rendered these zircons more suitable for complex lead loss. Alternatively, they may have been modified during the alteration event affecting the gneisses. The presence of such grains within the zircon population of the tonalite gneiss may also explain the slightly younger age (3170 Ma) recorded by Anhaeusser and Burger (1982). This younger age might reflect an artificial rejuvenation caused by mixing older and younger $^{207}Pb/^{206}Pb$ signatures.

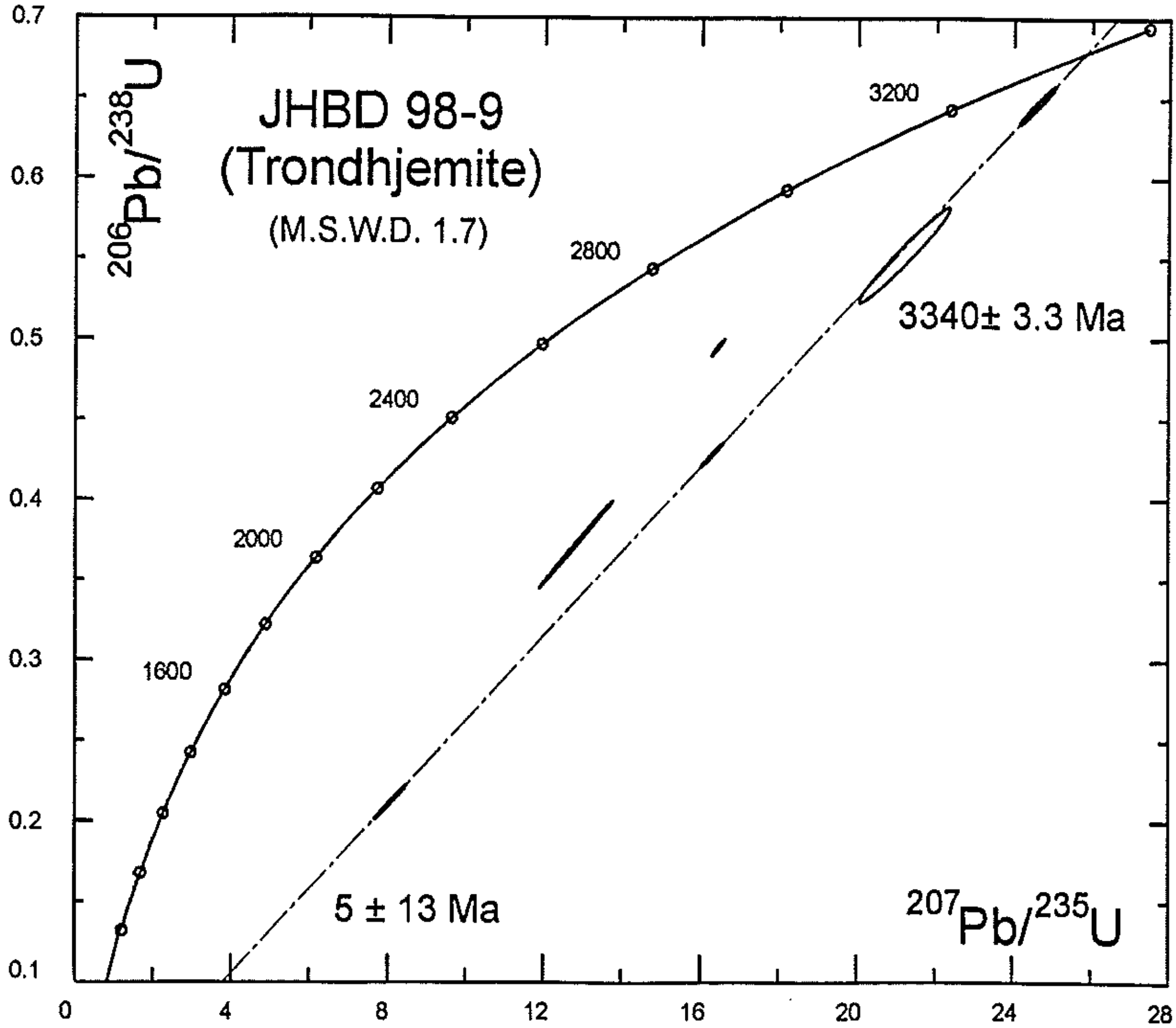

Figure 4: Concordia diagram for the trondhjemitic gneiss sample JHBD 98-9 from the northwestern part of the Johannesburg Dome (Fig. 1).

Table 1: U-Pb data for granitoid samples from the Johannesburg Dome

Sample	U/ Pb	^{206}P/ ^{204}Pb	^{206}Pb/ ^{238}U^{C}	+/- %	^{207}Pb/ ^{235}U^{C}	+/- %	^{208}Pb/ ^{206}Pb^{C}	+/- %	^{207}Pb/ ^{206}Pb^{C}	+/- %	^{207}Pb/^{206}Pb age(Ma)	Cor. Coef.
JHBD 98-1												
Zr 1	1.3	810	0.6170	1.0	21.257	1.0	0.1935	0.3	0.2450	0.2	3184 ± 3	0.986
Zr 2	1.3	582	0.6240	0.5	21.727	0.5	0.1924	0.2	0.2526	0.1	3201 ± 2	0.967
Zr 3	1.2	1102	0.6243	0.6	21.708	0.7	0.2704	0.2	0.2522	0.1	3199 ± 2	0.986
Zr 4	1.3	985	0.6393	0.5	22.282	0.5	0.1669	0.3	0.2528	0.2	3202 ± 3	0.947
Zr 5	0.7	272	0.6066	0.7	20.421	0.8	0.1732	0.5	0.2442	0.4	3147 ± 6	0.887
Zr 6	0.8	597	0.6290	0.6	21.882	0.6	0.1980	0.3	0.2523	0.1	3200 ± 2	0.972
JHBD 98-2												
Zr 1	3.9	331	0.2080	1.4	6.066	1.9	0.1531	1.2	0.2115	1.2	2917 ± 20	0.773
Zr 2	4.3	271	0.2064	0.9	6.021	0.9	0.1021	0.9	0.2116	0.4	2918 ± 6.5	0.905
Zr 3	14.1	224	0.0603	8.5	1.665	8.5	0.0961	0.6	0.2004	0.5	2830 ± 9	0.998
Zr 4	8.6	255	0.0946	3.6	2.614	3.7	0.1018	0.7	0.2004	0.7	2829 ± 11	0.983
JHBD 98-3												
Zr 1	1.8	234	0.4201	4	14.872	4	0.1963	1.2	0.2568	1.3	3227 ± 21	0.949
Zr 2	1.4	355	0.5735	0.6	18.747	0.7	0.1566	0.2	0.2371	0.3	3101 ± 5.1	0.889
Zr 3	2.0	365	0.4024	1.9	12.253	2.1	0.1575	0.6	0.2208	0.8	2987 ± 13	0.927
Zr 4	2.5	1767	0.3366	0.6	9.967	0.7	0.1256	0.3	0.2147	0.3	2942 ± 5	0.898
Zr 5	1.6	379	0.5288	0.9	17.045	0.9	0.1509	0.2	0.2337	0.2	3078 ± 3	0.975
Zr 6	1.9	590	0.4430	0.8	13.829	1.0	0.1415	0.4	0.2264	0.5	3027 ± 7	0.878
Zr 7	2.7	366	0.3296	0.7	9.274	0.8	0.0963	0.4	0.2040	0.4	2859 ± 6	0.879
Zr 8	2.1	2151	0.4089	0.7	12.478	0.7	0.1291	0.2	0.2213	0.1	2991 ± 2	0.977
JHBD 98-5												
Zr 1	1.1	648	0.6198	0.7	20.408	0.8	0.3003	0.5	0.2388	0.5	3112 ± 7	0.803
Zr 2	1.5	2122	0.5593	0.9	18.290	0.9	0.1337	0.3	0.2372	0.2	3101 ± 3	0.986
Zr 3	1.1	694	0.6316	4.1	20.699	4.4	0.1572	1.8	0.2377	1.7	3105 ± 27	0.926
Zr 4	1.6	1200	0.5245	0.9	17.037	0.9	0.0955	0.3	0.2356	0.2	3091 ± 3	0.973
Zr 5	4.0	438	0.2249	1.6	6.386	1.6	0.0795	0.3	0.2060	0.3	2874 ± 5	0.981
JHBD 98-8												
Zr 1	1.4	354	0.6289	1.0	20.371	1.6	0.0505	1.0	0.2349	1.0	3086 ± 16	0.800
Zr 2	1.7	511	0.5134	0.5	16.823	0.5	0.0721	0.2	0.2376	0.1	3105 ± 2	0.973
Zr 3	1.9	601	0.4614	0.6	15.184	0.7	0.0737	0.3	0.2386	0.2	3111 ± 3.6	0.942
Zr 4	1.6	1051	0.5589	0.6	18.473	0.7	0.0611	0.2	0.2397	0.2	3118 ± 3	0.959
Zr 5	2.3	700	0.3797	7.7	12.570	7.7	0.0554	0.4	0.2401	0.2	3121 ± 3.8	0.999
Zr 6	1.7	448	0.5173	0.6	17.304	0.6	0.0832	0.3	0.2426	0.2	3137 ± 4	0.919
Zr 7	1.2	1066	0.7355	4.4	24.900	4.5	0.1040	0.5	0.2455	0.4	3156 ± 7	0.995
Zr 8	1.7	1565	0.5946	9	18.222	9.0	0.0711	0.5	0.2222	0.4	2997 ± 7	0.996
Zr 9 (4)	1.5	409	0.5961	1.8	20.438	2.0	0.0873	0.7	0.2487	0.7	3176 ± 11	0.936
Zr 10	1.7	612	0.5140	1.6	17.050	1.8	0.0979	0.6	0.2406	0.6	3124 ± 9	0.947
Zr 11 (2)	1.9	272	0.4681	0.7	14.738	0.9	0.0574	0.6	0.2284	0.6	3041 ± 9	0.794
JHBD 98-9												
Zr 1	1.5	683	0.5525	4.4	21.198	4.5	0.1166	1	0.2782	0.9	3353 ± 15	0.977
Zr 2	1.2	969	0.6466	3.6	24.613	3.9	0.1800	1.4	0.2761	1.4	3341 ± 4.6	0.982
Zr 3	1.8	644	0.4283	1.5	16.280	1.6	0.1958	0.3	0.2757	0.3	3339 ± 3.2	0.990
Zr 4	3.8	901	0.2123	1.4	8.070	1.5	0.1619	0.3	0.2756	0.2	3338 ± 7.1	0.994
Zr 5	2.3	405	0.3723	4.3	12.817	1.3	0.0531	0.5	0.2496	0.4	3183 ± 4.7	0.999

Table 1 (continued):

Sample	U/ Pb	^{206}P/ ^{204}Pb	^{206}Pb/ ^{238}U^{C}	+/- %	^{207}Pb/ ^{235}U^{C}	+/- %	^{208}Pb/ ^{206}Pb^{C}	+/- %	^{207}Pb/ ^{206}Pb^{C}	+/- %	^{207}Pb/^{206}Pb age(Ma)	Cor. Coef.
Zr 6	1.8	474	0.4945	6	16.415	6	0.0616	0.3	0.2407	0.3	3125 ± 2.5	0.974
JHBD 98-10												
Zr 1	1.8	1434	0.5073	1.0	15.504	1.0	0.0506	0.3	0.2217	0.1	2993 ± 1.7	0.995
Zr 2	1.4	655	0.6099	1.2	21.397	1.4	0.1366	0.7	0.2544	0.6	3213 ± 10	0.885

Sample JHBD 98-9 is a trondhjemitic gneiss (equivalent to sample SK7 of Anhaeusser, 1971, with 6.25wt% Na_2O and 0.97wt% K_2O) from the northwestern part of the dome (Fig. 1). Zircons extracted from this sample were typically pink in colour and most often translucent. However, some of the zircons were darker and metamict. Six grains in total were analyzed from this rock (Table 1). Plotted in a concordia diagram (Fig. 4) they are slightly to highly discordant. All the translucent grains define a discordia pointing to a well-defined upper intercept age of 3340 ± 3.3 Ma (MSWD=1.7) with a lower intercept age of 5 ± 13 Ma. This ~3340 Ma age is considered to be the best estimate for the emplacement of the trondhjemite. Two metamict zircons are discordant (Fig. 4) and, relative to the others, are characterized by younger $^{207}Pb/^{206}Pb$ ages as well as very low $^{208}Pb/^{206}Pb$ ratios (Table 1). These grains can, therefore, be interpreted as a reflection of a post-crystallization (migmatization or gneiss-forming ?) event leading to a complex lead loss and/or partial recrystallization.

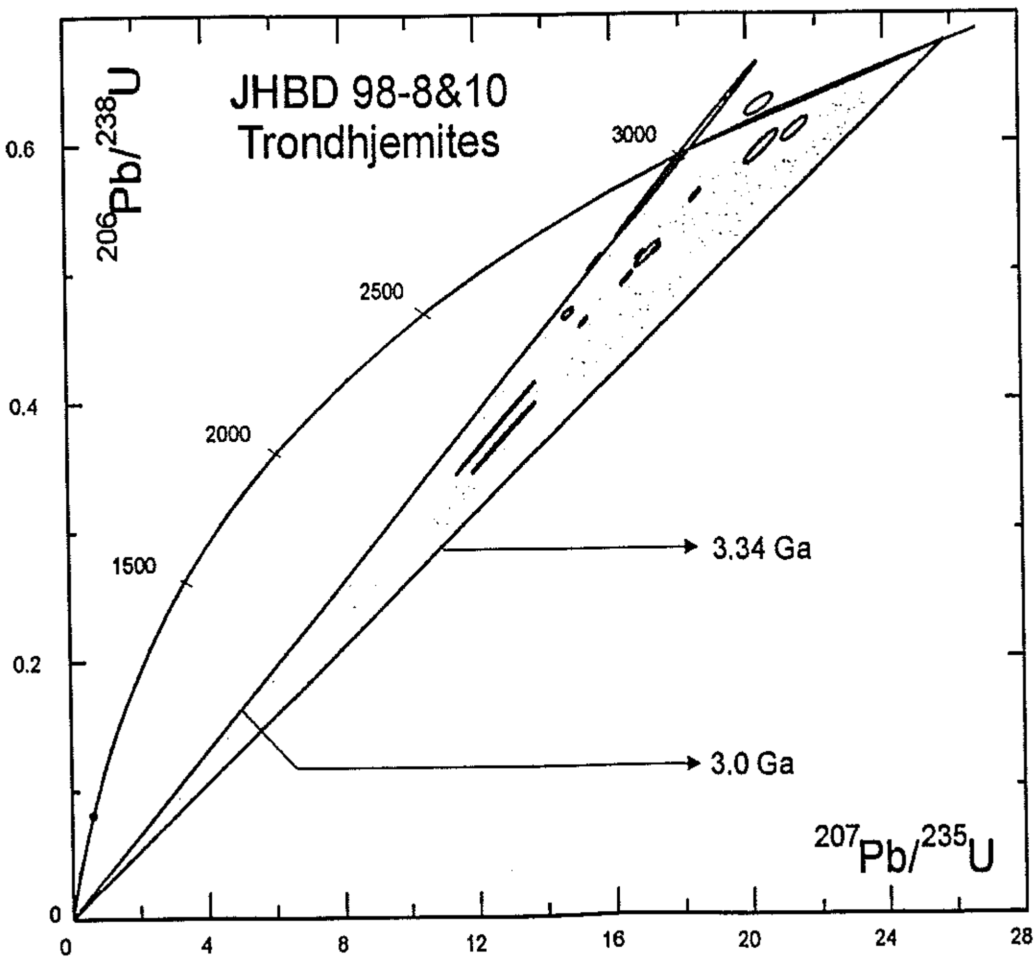

Figure 5: Concordia diagram for trondhjemite gneiss samples JHBD 98-8 and 98-10 from the Nooitgedacht river platform shown in Figure 2.

Samples JHBD 98-8 and 98-10 are additional trondhjemitic gneisses (equivalent to samples N14 and N2 of Anhaeusser, 1998, and which average 6.08wt% Na_2O and 0.95wt% K_2O) that crop out on the Nooitgedacht migmatite platform (Fig. 2). Zircons from these samples are generally pink in colour and display different degrees of metamictisation. Eleven grains from sample JHBD 98-8 and 2 grains from sample JHBD 98-10 were analyzed (Table 1) and plotted in a concordia diagram (Fig. 5). They are concordant to discordant and occur scattered in the diagram. The youngest point (JHBD 98-8, Zr 8, Fig. 5) is perfectly concordant with a $^{207}Pb/^{206}Pb$ age of 2997 ± 7 Ma, whereas the oldest (JHBD 98-10, Zr 2, Fig. 5) is 4.6% discordant with a $^{207}Pb/^{206}Pb$ age of 3213 ± 10 Ma. As displayed in Figure 2, the Nooitgedacht migmatite platform is a very complex exposure showing most of the igneous phases recognized on the dome. The scatter of the data could therefore be a consequence of the complex history of this platform, which has been influenced by a succession of different fluid injections. The trondhjemite data positions from the northwestern part of the dome can therefore be best explained in term of a crisis polygon (grey triangle, Fig.5) defined by 3 apices at 3400 Ma, 3000 Ma and zero respectively. The first apex at 3400 Ma (defined by sample JHBD 98-9) represents the age of the trondhjemite emplacement; the second at ca. 3000 Ma (defined by the youngest concordant point) could represent the youngest significant event to have influenced the platform (emplacement of the pegmatitic dykes?) and the third,at zero, representing recent lead loss.

Potassic granitoids

Sample JHBD 98-2 (equivalent to sample VP2 of Anhaeusser, 1973, with 4.12wt% Na_2O and 3.97wt% K_2O) is described as a coarse-grained, homogeneous granodiorite (Fig. 1). The zircons from this rock are generally pink in colour (some are yellowish) with different degrees of metamictisation. Their U/Pb concentration ratios are very high (4 -11) emphasizing the high uranium content of these zircons. Four zircons were analyzed (Table 1) and, when plotted in a concordia diagram (Fig. 6), display high degrees of discordance. They point to a relatively poorly defined upper intercept age of 2947 ± 57 Ma (MSWD=22) and a lower intercept age of 49 ± 56 Ma. This age of ~2950 Ma is therefore considered to be a minimum age for the emplacement of this potassic granitoid.

Sample JHBD 98-3 (similar to sample FD2 of Anhaeusser, 1973, with 3.98wt% Na_2O and 4.30wt% K_2O) is a medium-grained granodiorite cropping out in the central part of the dome (Fig. 1). All the zircons extracted from this sample were translucent to dark-pink in colour. Eight zircons were analyzed (Table 1) and have been plotted in a concordia diagram (Fig. 7). They are sub-concordant to very discordant. Six of the seven zircons analyzed define a relatively well-constrained upper intercept age of 3121.2 ± 5 Ma (MSWD=0.8) with a lower intercept age of 636 ± 25 Ma. This age of ~3120 Ma is regarded as the age of the emplacement of this granodiorite in the south-central part of the dome. The seventh zircon (Zr 1, Table 1) is slightly discordant and is defined by a $^{207}Pb/^{206}Pb$ age of 3227 Ma. This zircon is interpreted as a xenocryst probably extracted from the earlier TTG granitoid suite.

Lastly, sample JHBD 98-5 (similar to sample HD30 of Anhaeusser, 1971, with 4.14wt% Na_2O and 4.45wt% K_2O) is representative of the porphyritic granodiorites that crop out in the western part of the dome. Most of the zircons from this sample are pink and translucent

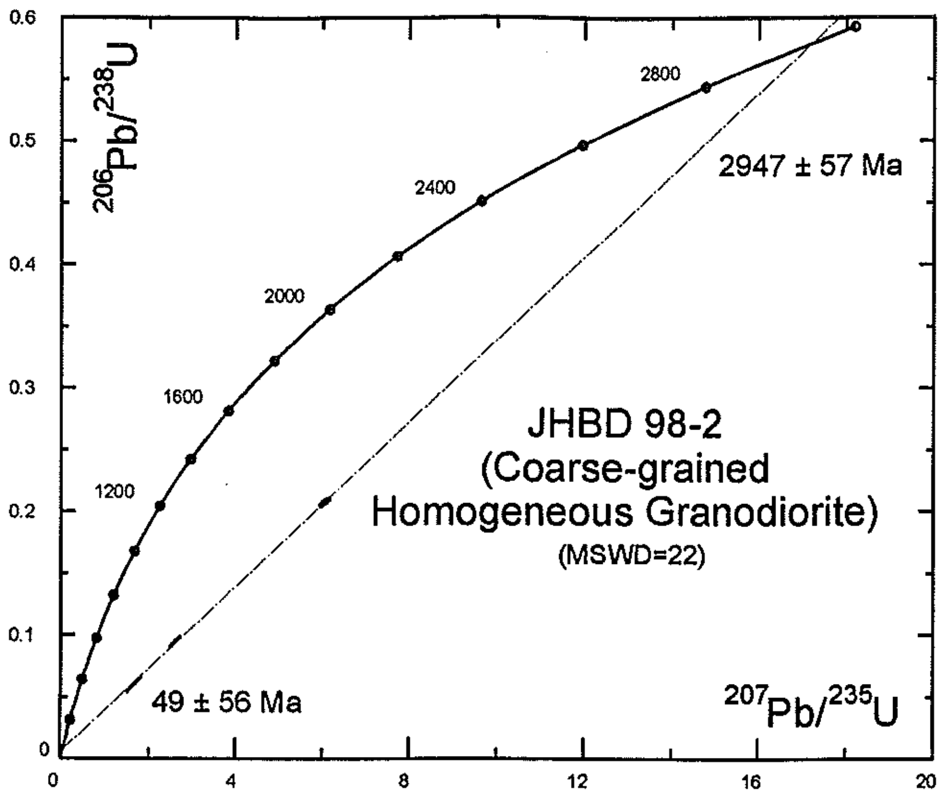

Figure 6: Concordia diagram for the medium-to-coarse-grained pinkish granodiorite sample JHBD 98-2 located approximately 5km north of central Johannesburg (Fig. 1).

and occur together with some darker-pink grains. Five zircons were analyzed (Table 1) - two of them being perfectly concordant and the remaining three presenting different degrees of discordance. They define a well-constrained upper intercept age of 3114.2 ± 2.3 Ma (MSWD=0.47) with a lower intercept age of 358 ± 11 Ma, the latter without any apparent geological meaning. The age of ~3120 Ma is once again considered to be the age of emplacement of the porphyritic granodiorite within this portion of the dome.

DISCUSSION

The first part of this study focused on the trondhjemitic and tonalitic gneisses occurring mainly on the northern half of the Johannesburg Dome, but which are also represented on the southern margin of the dome where they intrude the mafic and ultramafic igneous and volcanic rocks of the Swaziland Supergroup. The most interesting result derives from sample JHBD 98-9, which gives an age of 3340 ± 3.3 Ma. The two trondhjemitic gneiss samples studied from the nearby Nooitgedacht migmatite platform yielded very scattered data (Fig. 5) that does not provide any direct geochronological constraints. This is interpreted as reflecting the complex multi-stage history that this granitoid platform had undergone, including a late-stage event, possibly linked to the emplacement of pegmatites at approximately 3000 Ma.

The Johannesburg Dome, which was previously considered to be approximately 3170 Ma old (Anhaeusser and Burger, 1982) has now been shown to contain an older granitoid phase. The ~3340 Ma age determined for the trondhjemites gneisses represents the oldest magmatic phase described from the granitoid rocks of the dome. This result may also have important implications with regard to the age of the mafic and ultramafic greenstone remnants that occur scattered throughout the dome and which have not yet been dated because of the absence of material suitable for this purpose. It has been demonstrated elsewhere (e.g. in the Barberton and Murchison greenstone belts in South Africa) that the volcanic and magmatic events are genetically linked (Armstrong et al., 1990; Poujol and Robb, 1999). Consequently, if such reasoning can be applied to rocks on the Johannesburg Dome, it implies that the greenstone remnants, which were considered by Anhaeusser (1998) to have formed in an Archaean oceanic or volcanic arc-like geotectonic setting, may be at least 3.34 billion years old.

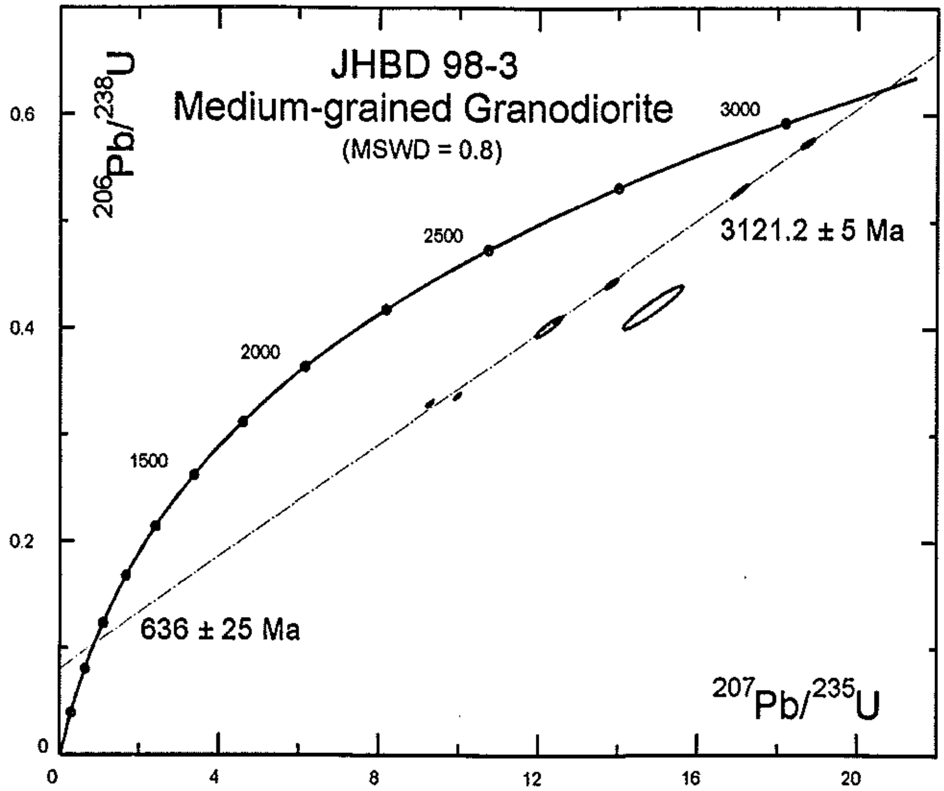

Figure 7: Concordia diagram for the medium-grained granodiorite sample JHBD 98-3 from the central part of the Johannesburg Dome (Fig.1).

This initial magmatic episode involving early greenstone and TTG granitoid development on the northern half of the dome was then followed by the emplacement of the hornblende-biotite-tonalite in the south at ~3200 Ma as has been demonstrated by the data from sample JHBD 98-1(Fig.3).

Following the trondhjemite-tonalite event there appears to have been a further period of mafic plutonism manifest in the form of the amphibolite dykes displayed on the Nooitgedacht migmatite platform and shown in Figure 2. Geochemical evidence, in the form of distinctly differing REE abundances, led Anhaeusser (1998) to suggest that more than one dyke event may have occurred. It was argued that if only a single stage of dyke emplacement had been involved the magmas would probably have formed from different sources. The age of these dykes has yet to be determined quantitatively, but they fall within the time constraints imposed by the age of the trondhjemitic gneisses (3340 – 3200Ma) and the crosscutting homogeneous granodiorites (3121 – 3114 Ma) discussed below.

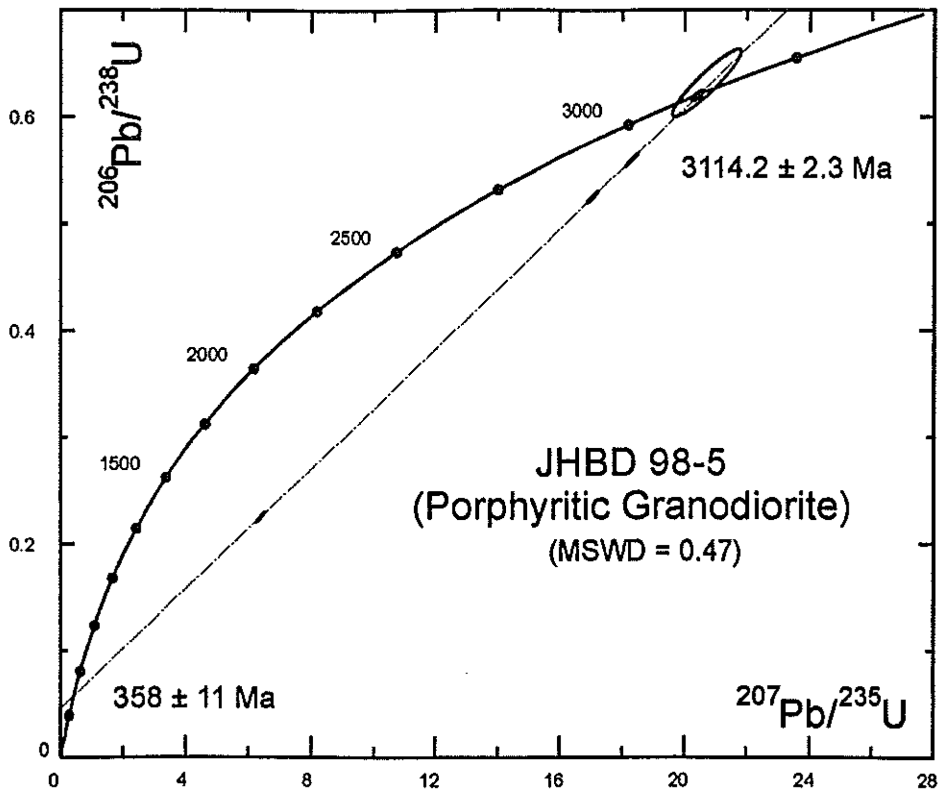

Figure 8: Concordia diagram for the porphyritic granodiorite sample JHBD 98-5 from the west-central part of the Johannesburg Dome (Fig.1).

The final stages of Archaean crustal evolution evident on the Johannesburg Dome coincided with the emplacement of an aerially extensive homogeneous granodiorite-porphyritic granodiorite batholith or massif, the latter seen occupying most of the southern half of the dome(Fig.1). Manifestations of this event are also seen on the northern half of the dome in the form of the granodiorite and pegmatite dykes that intrude the earlier-formed greenstones, gneisses and migmatites (Fig.2).

Two samples representative of the medium-grained and porphyritic potassic granitoids have been dated in this study at 3121 ± 5 Ma and 3114 ± 2 Ma respectively. A third sample of coarse-grained granodiorite yielded a poorly constrained minimum age of 2947 ± 57 Ma. Consequently, we consider that the potassic granitoid suite within the Johannesburg Dome was emplaced approximately 3121 – 3114 Ma ago. This age is in a good agreement with the 3132 ± 65 Ma age determined by Allsopp (1961), but contradicts the zircon evaporation age of 3090 Ma published recently by Barton et al.(1999). One of the problems of the zircon evaporation technique lies with the difficulty in controlling the concordance of the zircons. The data presented in this study show that very few zircons are concordant, some of them giving apparent $^{207}Pb/^{206}Pb$ ages at around 3.09 Ga (sample JHBD 98-3: Zr 2 3101Ma, Zr 5 3078Ma; sample JHBD 98-5: Zr 2 3101 Ma; Zr 4 3091 Ma). It is therefore possible to conclude that Barton et al. (1999) were dealing with sub-concordant zircons which yielded younger $^{207}Pb/^{206}Pb$ ages.

CONCLUSIONS

The Johannesburg Dome consists of a complex mosaic of granitoid rocks manifest by differences in composition, texture, volume and age. The present geochronological study has demonstrated some of the difficulties that can be encountered in dating Archaean granite-gneiss-migmatite terranes.

Three main magmatic events have been defined. The first involved the emplacement of trondhjemitic rocks at 3340 Ma in the northern part of the dome, followed by a tonalitic phase at 3200 Ma in the south. The greenstone remnants occurring widespread on the dome predate the earliest trondhjemitic gneisses and are therefore at least 3.34 billion years old. The mafic dykes that intruded the TTG suite were emplaced between 3340 and 3140 Ma. The third event, namely the emplacement of the potassic granodiorite suite, is shown to have taken place at 3120 - 3114 Ma, followed by a pegmatite dyke episode possibly as young as 3.0 billion years.

A similar age of 3120 ± 5 Ma was obtained from the granitoid basement that pre-dates the 3074 ± 6 Ma Dominion Group lavas underlying Witwatersrand successions southwest of Klerksdorp in the North West Province (Armstrong et al., 1991). Consequently, the new data from the Johannesburg Dome, situated approximately 150km to the northeast, provide confirmation that the Witwatersrand Basin was deposited unconformably on an Archaean basement as young as 3120 Ma.

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