Chapter 4

Precise SHRIMP U-Pb Ages for Quartz Porphyritic Lavas Near the Base of the Waterberg Group

4.1 Introduction

Voluminous late Paleoproterozoic red bed successions cover an extensive area of the Kaapvaal craton and part of the Limpopo metamorphic belt in geographically separated outcrop areas. These successions include the Waterberg, Soutpansberg, Palapye and Olifanshoek Groups and the Blouberg Formation (Fig 4.1). However, true depositional ages for these successions are ill defined. There is only one reliable single zircon U-Pb age available from lava interbedded with these early red beds, a 1928±4Ma single zircon U-Pb age for the Hartley lava of the Olifantshoek Supergroup (Cornell et al., 1998).

The lack of well-defined radiometric ages for these successions, has resulted in uncertainty concerning the correlation and relative ages of the different Paleoproterozoic red bed successions, especially the Waterberg, Olifantshoek and Soutpansberg Groups (Jansen, 1976; Meinster, 1977; Key, 1983; Cheney et al., 1990; Carney et al., 1994; Bumby, 2000, Bumby et al., 2001) on the Kaapvaal craton. One of the keys to decipher the stratigraphical relationships between these successions, is to obtain further radiometric ages from them. Acquiring a radiometric age for the lower part of the Waterberg Group would determine when deposition of the succession commenced and perhaps help resolve the question of relative ages of the Waterberg, Soutpansberg and Olifantshoek Groups.

Quartz porphyritic lava flows are present near the base of the Waterberg Group in the Nylstroom and Rust de Winter areas (Fig 4.2). This paper provides precise SHRIMP zircon U/Pb ages for these lava flows. They represent the first precise depositional ages for the lower part of the Waterberg red bed succession.

4.2 Geological Setting

4.2.1 Regional Overview

The Waterberg Group is a virtually undeformed succession of red beds that is preserved in two main areas, in total covering an area of approximately 60000km^2 on the Kaapvaal craton (Fig 4.1). The larger of the two areas, known as the Nylstroom area (Fig 4.1) is located in the northwestern Transvaal and eastern Botswana.

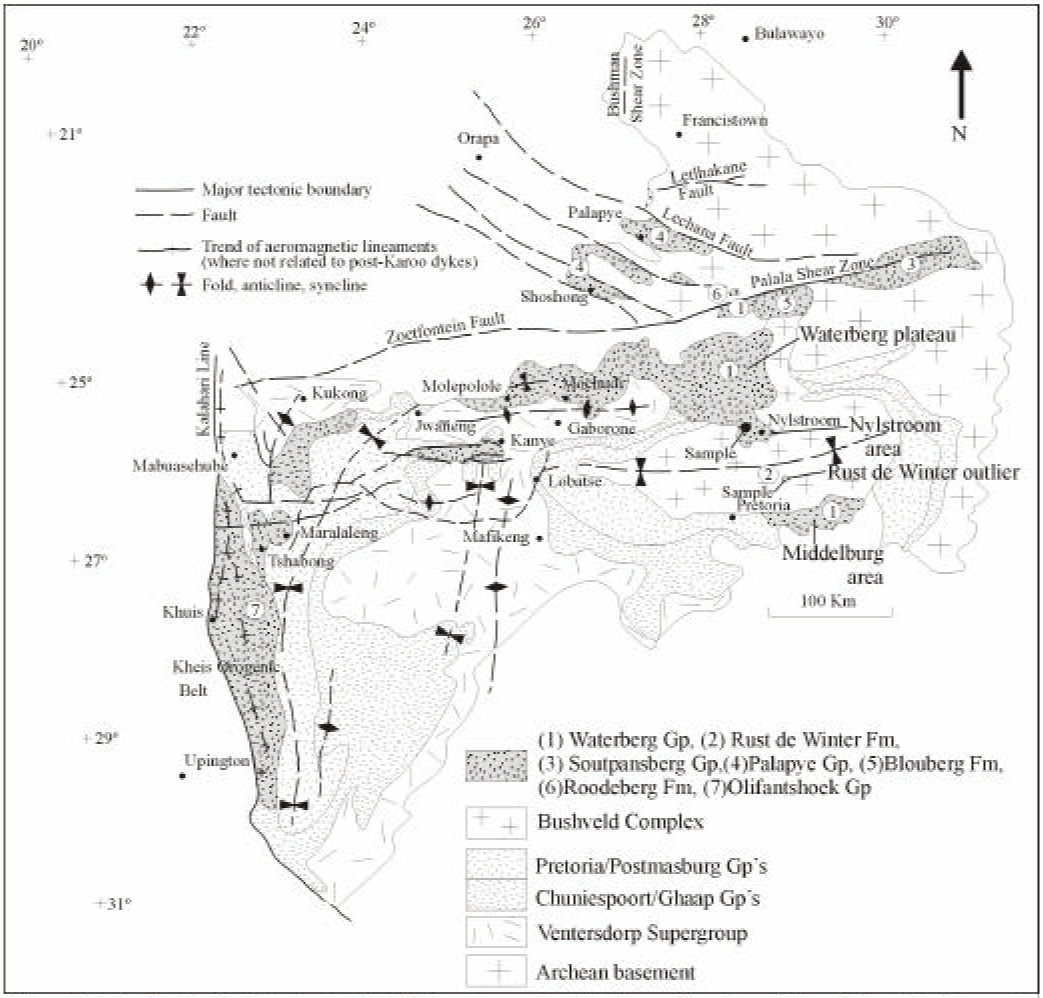

Figure 4.1 Map indicating the extent of late Paleoproterozoic red bed successions in southern Africa (after Carney et al., 1994). Important to note is that most of the structural lines are related to structures older than the Paleoproterozoic red bed successions, and generally do not affect the outcrop pattern of these red beds.

In this area the Waterberg Group is subdivided into the Nylstroom, Matlabas and Kransberg Subgroups (SACS, 1980). In parts of this outcrop area the Waterberg Group unconformably overlies the Rooiberg Group. The Rooiberg Group, in turn, is intruded by the Bushveld Complex and has a radiometric age of 2061±2Ma

(Walraven, 1997), which represent the maximum age for the lower part of the Waterberg Group.

The second major outcrop area of the Waterberg Group is located around Middelburg (Fig 4.1) (Eriksson et al., 1997, Van der Neut et al., 1991, Callaghan et al., 1991). Here, the Waterberg Group consists of the Wilgerivier Formation that is correlated with the Nylstroom Subgroup (SACS, 1980; Callaghan et al., 1991). It is underlain by the Loskop Formation that unconformably overlies the Schrikkloof Formation of the Rooiberg Group (SACS, 1980; Martini, 1998).

In addition, there is also a small erosional outlier that is regarded as part of the Waterberg Group preserved at Rust de Winter, between the Nylstroom and Middelburg areas (Fig 4.1). Here, the succession of the Waterberg Group comprises of conglomerate, quartzite and a quartz porphyritic lava known as the Rust de Winter Formation (Walraven, 1981). The succession overlies rhyolite of the Rooiberg Group and granite of the Bushveld Complex unconformably (Fig 4.2).

Quartz porphyry lava flow samples for zircon SHRIMP analyses were collected from the lower part of the Waterberg Group in the Nylstroom area as well as from the Rust de Winter Formation in the Rust de Winter outlier (Fig 4.1).

4.2.2 Nylstroom area

Quartz porphyry lava flows are present in the Swaershoek Formation of the Nylstroom outcrop area (Fig 4.2). The Swaershoek Formation forms the basal unit of the Nylstroom Subgroup in the Nylstroom syncline (Figs 4.2 and 4.3). There are two exposures of quartz porphyry in the Nylstroom area of the Waterberg Group. The first exposure is on the farm Rhenosterpoort 402 KR west of Nylstroom and the second in the eastern Swaershoek Mountains (Jansen, 1970). The quartz porphyry that was sampled comes from the farm Rhenosterpoort 402, west of Nylstroom at S24°39’18.7” and E28°10’28.3” (Fig 4.2). In this area the Swaershoek Formation overlies rhyolite of the Schrikkloof Formation of the Rooiberg Group (Walraven, 1997; SACS, 1980; Martini, 1998)(Fig 4.2) with an erosional contact.

The basal part of the Swaershoek Formation that overlies rhyolites of the Schrikkloof Formation with an erosional contact, is composed of conglomerate, granulestone and quartzite (Figs 4.2 and 4.3).

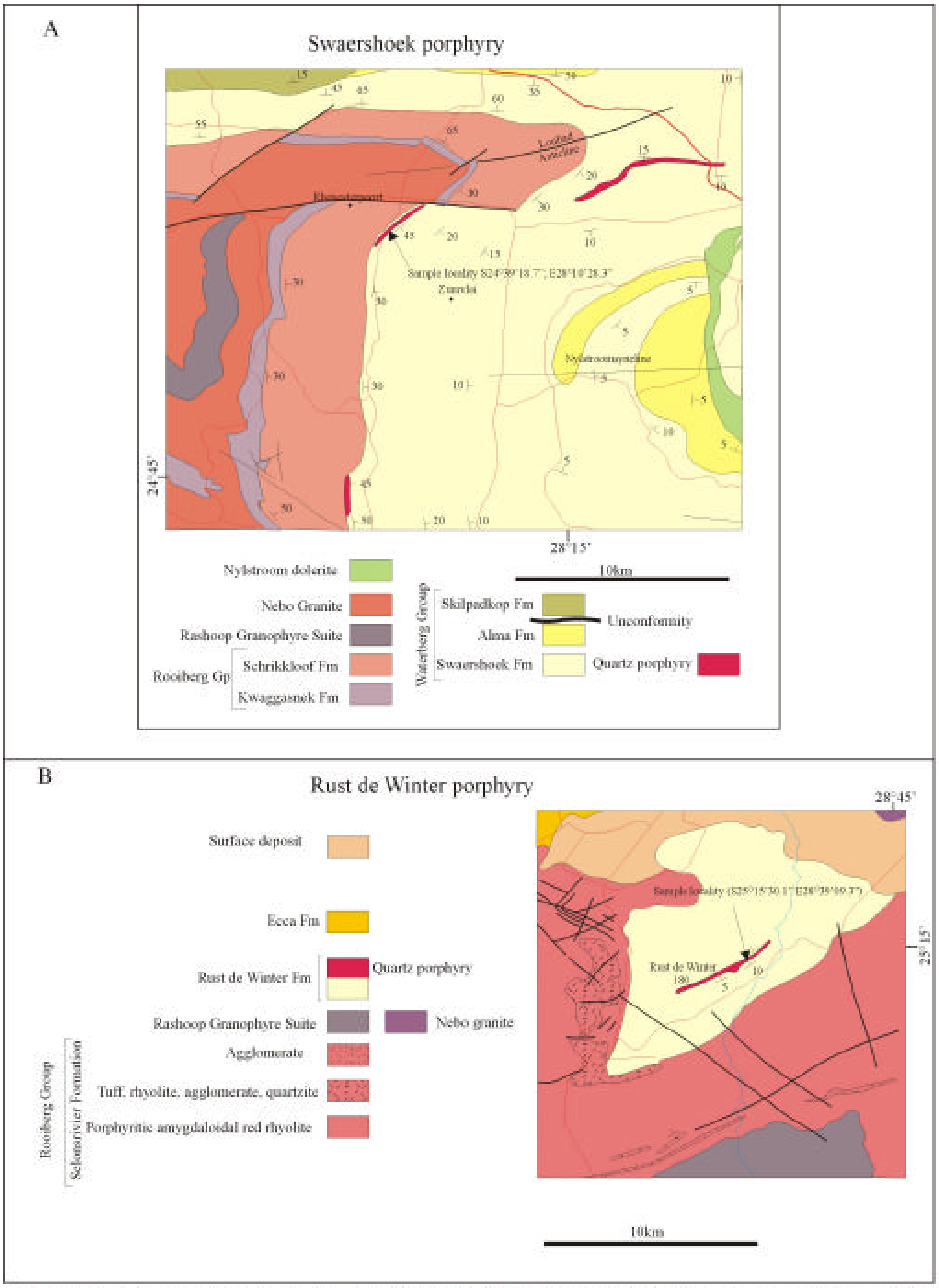

Figure 4.2 Geological maps indicating sample localities for the Swaershoek (A) and Rust de Winter (B) quartz porphyries. (1:250000 Pretoria and Nylstroom maps, Council of Geoscience, Pretoria).

Quartz porphyry is occurs as lenticular lava flows in this succession (Fig 4.3)(Jansen, 1970).

The quartz porphyry is a hard, pinkish to greyish rock in which quartz phenocrysts are visible with the naked eye. The matrix is extremely fine grained and strongly sericitised. Some of the quartz phenocrysts are euhedral but display a rounded form when sericitised. The rounded quartz phenocrysts frequently display undulose extinction, cracks and resorption bays (Jansen, 1970).

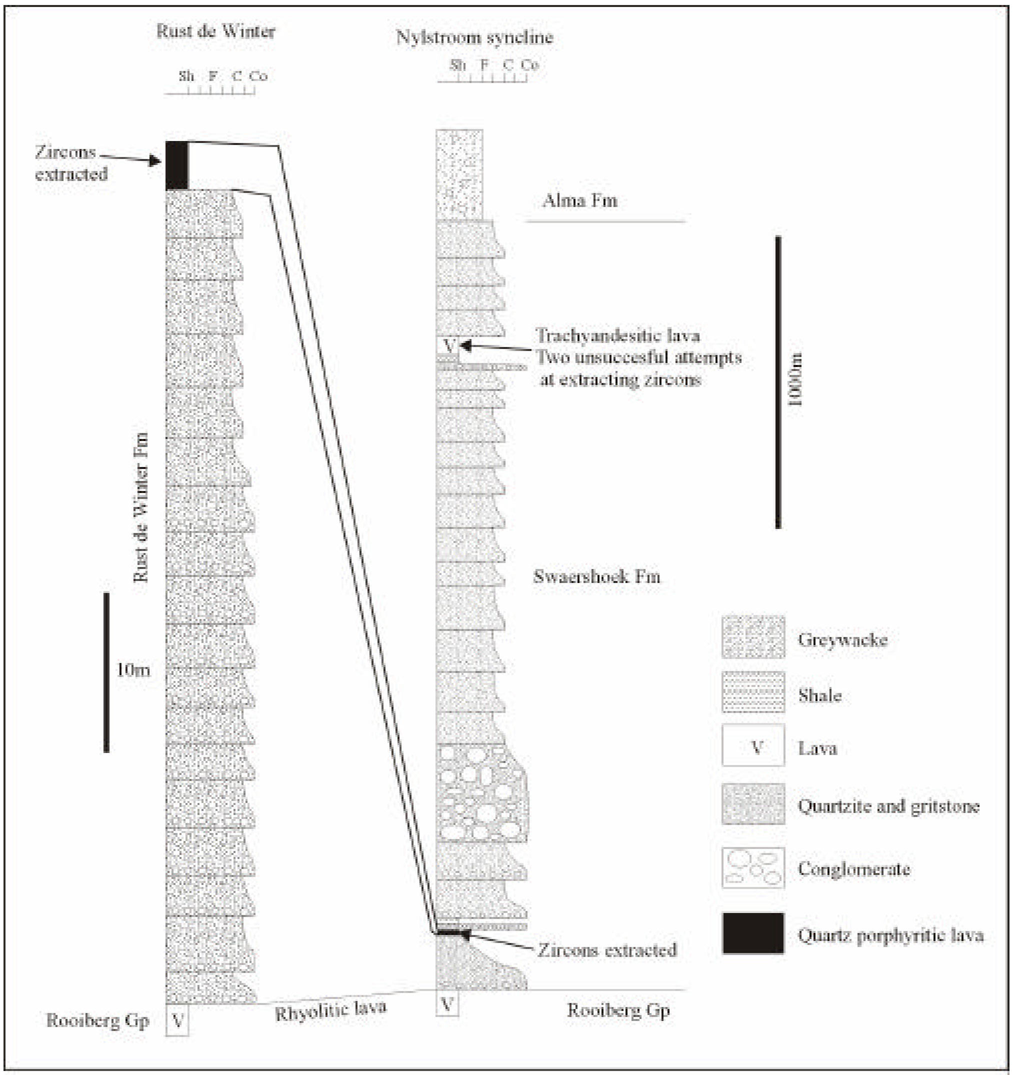

Figure 4.3 Stratigraphic position of quartz porphyritic lavas in the Rust de Winter Formation and Swaershoek Formation. Note the difference in vertical scale between the two columns.

A brick red shale overlies the quartz porphyritic lava (Fig 4.3). Several hundred meters of conglomerate and quartzite overlies the brick red shale, and represent the upper part of the Swaershoek Formation in the area (Fig 4.3). Trachytic lava flows are present in this upper part of the Swaershoek Formation (Fig 4.3) on the farm Driefontein 378 to the north of Nylstroom. Two attempts were made to separate zircons from these trachyandesitic lavas of the Swaershoek Formation without any success. This despite the fact that the lavas contain up to 535ppm Zr (Table 4.1). It is possible that Zr may be present in baddeleyite, and it is suggested that in future attempts could be made to extract this mineral from the lavas for radiometric age dating purposes.

Table 4.1 Geochemistry of Trachytic lava , Swaershoek Formation (Weight percent). All samples are from the same locality. Analysed by XRF at Africa Geological Services.

	SWD101	SWD102	SWD103	SWD104	SWD105
Major elements, data in wt%					
SiO_2	55.2	55.1	53.3	51.9	54.8
Al_2O_3	14.4	14.7	14.3	14.7	14.7
Fe_2O_3	17.3	17.4	14.7	18.2	14.1
MnO	0.18	0.16	0.52	0.38	0.07
MgO	0.58	0.69	0.95	0.87	0.46
CaO	1.14	1.15	4.6	1.68	2.07
Na_2O	0.50	0.10	3.73	3.30	3.50
K_2O	8.00	7.84	5.4	5.83	7.18
TiO_2	1.64	1.71	1.60	1.92	1.86
P_2O_5	0.81	0.83	0.81	1.02	1.00
L.O.I.	2.55	2.41	3.7	1.5	0.82
Total	99.7	99.6	100	99.7	99.7
Trace elements, data in ppm					
Nb	26	27.5	22.8	24.0	24.6
Y	94.2	55.4	53.2	53.3	59.5
Rb	363.7	402.5	174.6	267.6	261.5
Zr	537.3	555.6	506.9	515.6	503.4
Sr	77.0	51.0	179.1	149.0	276.4
U	4.4	2.4	5.8	0.3	3.5
Th	22.1	21.9	21.4	17.9	19.3
S	128	28	8	10	19
Ba	2840.6	2355.9	2215.3	2463.3	3244.5
Sc	27.2	27.8	24.2	36.2	29.4
Cr	2.1	0.1	0.0	1.6	0.0
V	17.3	20.5	24.9	33.5	28.7
La	170.4	194.7	128.2	142.6	119.0
Zn	162.3	419.8	486.3	411.1	128.8
Cu	8.3	9.0	4.3	5.6	3.9
Ni	3.2	0.5	0.7	0.1	0.9
Pb	31.9	112.6	29.5	37.2	66.7
Ga	17.6	20.8	17.8	19.1	14.7
Co	7.2	9.9	13.1	12.0	2.8
Ce	253.3	255.8	216.7	239.5	211.8
Nd	133.2	125.0	93.8	112.7	111.8

4.2.3 Rust de Winter Outlier

In the Rust de Winter outlier, quartzite and granulestone of the Rust de Winter Formation (Walraven, 1981), a correlative of the Wilgerivier Formation of the Middelburg area (1:250 000 Pretoria map, Council of Geoscience), overlies rhyolite of the Selonsrivier Formation, the stratigraphic equivalent of the Schrikkloof Formation (SACS, 1980) of the Rooiberg Group (Fig 4.2).

The basal part of the Rust de Winter Formation is composed of approximately 80m of conglomerate and quartzite (Fig 4.3). A quartz porphyry lava overlies this basal conglomerate and quartzite unit (Figs 4.2 and 4.3). It occurs as a sheet-like body interbedded with the quartzite. There are virtually no contact metamorphic effects on the quartzite at the base of the quartz porphyry lava. The lowermost 5-10cm of the quartz porphyry is very fine-grained and may represent devitrified volcanic glass (Glatthaar, 1956). Spherulites are developed in the groundmass of the quartz porphyry, suggesting that the porphyry is extrusive rather than intrusive in origin (De Bruiyn and Andrew, 1972).

The sample of quartz porphyry for radiometric age dating was collected on the farm Rust de Winter 180 at S25°15’30.1”; E28°39’09.3”. This quartz porphyry has previously yielded whole rock U-Pb ages of 1790±90 Ma (Oosthuizen,(1964) and discordant U-Pb zircon ages of between 1965 – 2060Ma (Walraven, 1981).

4.3 Geochronology

Zircons were extracted and mounted using methods described in Appendix 1. Analyses of zircons of the Swaershoek quartz porphyry were performed by SHRIMP at Curtin University, while zircons of the Rust de Winter Formation quartz porphyry were analysed by SHRIMP at the Australian National University. Zircons were photographed and studied by cathodoluminescence before analyses to aid the selection process.

4.3.1 Swaershoek Quartz Porphyry

The zircon grains extracted from the Swaershoek quartz porphyry on the farm Rhenosterpoort are on average 150μm in length, euhedral, prismatic and oscillatory zoned (Fig 4.4), typical in appearance of zircons in acid igneous rocks. None of the grains showed any signs of rounding or reworking. Forty two grains were analysed for the quartz porphyry of the Swaershoek Formation (Table 4.2). Thirty nine of these grains were nearly concordant (within 10% discordancy)(Fig 4.5). In combination, they give a $^{207}Pb/^{206}Pb$ age of 2054±4Ma for the quartz porphyry (Fig 4.5). This age is thought to represent the best estimate for the extrusion of the porphyry of the Swaershoek Formation.

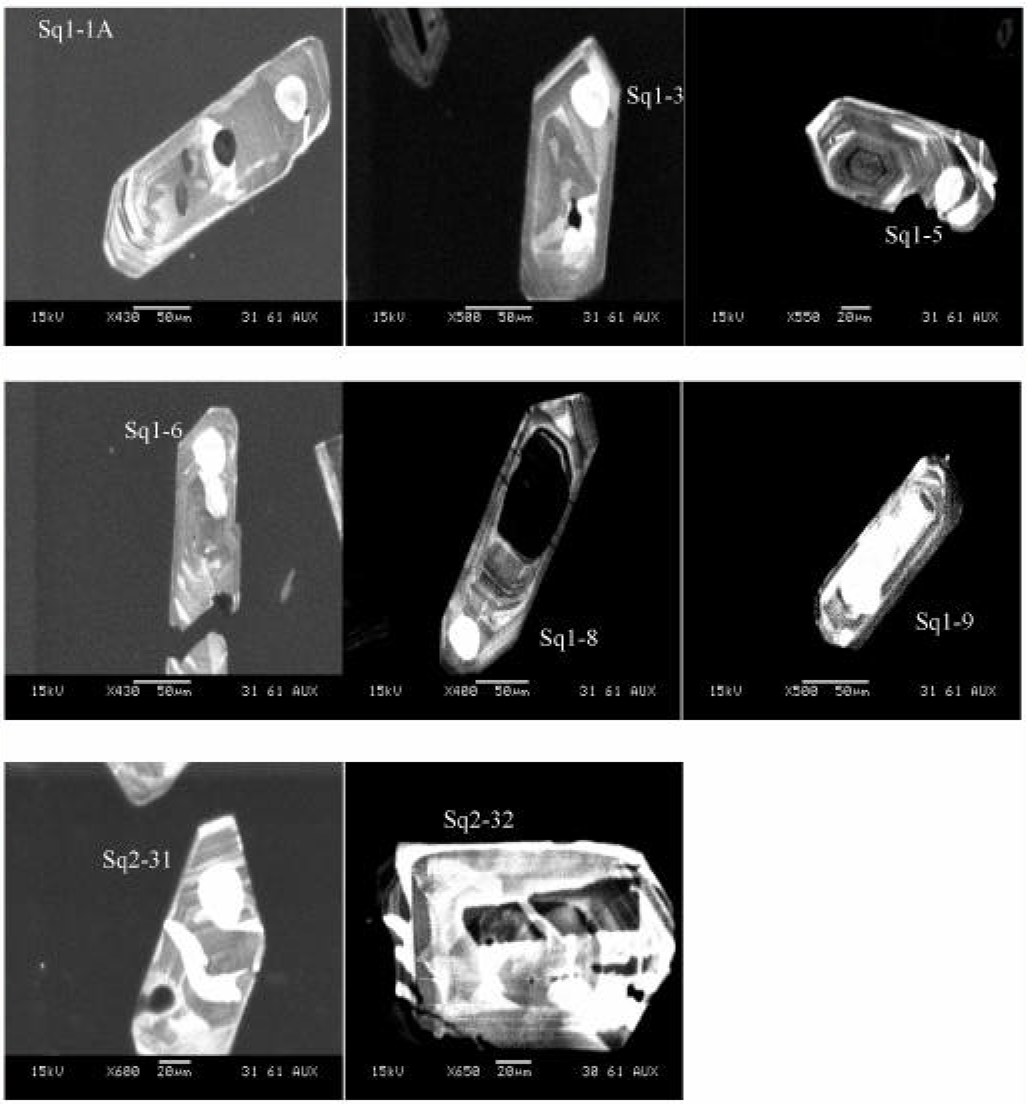

Figure 4.4 Cathodoluminescence images of selected zircons from the quartz porphyry of the Swaershoek Formation.

4.3.2 Rust de Winter Quartz Porphyry

The zircon grains extracted from the Rust de Winter quartz porphyry sample are on average 200µm in length, euhedral and prismatic in form, and oscillatory zoned (Fig

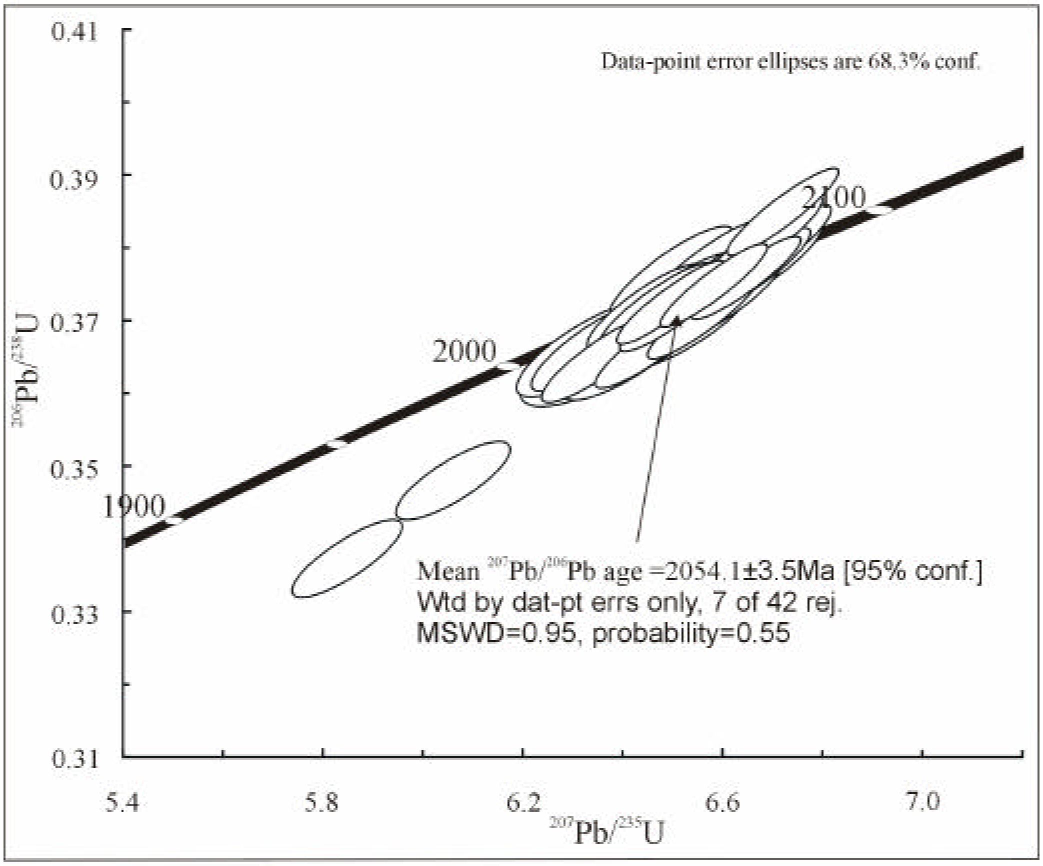

Figure 4.5 Concordia plot of magmatic zircons from the Swaershoek quartz porphyry.

4.6). None of the grains showed any signs of rounding or reworking. Seventeen zircon grains from the Rust de Winter porphyry were analysed. Eleven of these grains yielded nearly concordant to concordant results (discordant within 10%, Table 4.3, Fig 4.7). The six most concordant grains (within 2% discordancy) were used to determine a concordia age of 2051±8Ma (Fig 4.7). This age is thought to represent the best estimate for the extrusion of the Rust de Winter porphyry.

4.4 Discussion

Radiometric ages for the Bushveld Complex suggest emplacement at 2058Ma (Walraven et al., 1990, Walraven, 1997; Buick et al., 2001). Radiometric ages of 2054±4Ma and 2051±8Ma for the Swaershoek and Rust de Winter quartz porphyries

Table 4.2 Summary of SHRIMP U-Pb data for zircons from the Swaershoek quartz porphyry.

Grain.Spot	(1) % $^{206}Pb_c$	Ppm U	ppm Th	$^{232}Th/^{238}U$	ppm $^{206}Pb^*$	(1) $^{206}Pb/^{238}U$ Age		(1) $^{207}Pb/^{206}Pb$ Age		% Discorant	(1) $^{207}Pb^*/^{206}Pb^*$	±%	(1) $^{207}Pb^*/^{235}U$	±%	(1) $^{206}Pb^*/^{238}U$	±%	errcorr
11.1	0.02	99	40	0.41	31.2	2,018	±19	2,039	± 13	1	0.12574	0.74	6.375	1.3	0.3677	1.1	.833
22.1	0.03	89	34	0.40	27.9	2,008	±20	2,060	± 14	3	0.12722	0.78	6.412	1.4	0.3655	1.2	.829
23.1	0.10	79	41	0.53	25.0	2,011	±20	2,033	± 15	1	0.1253	0.87	6.324	1.5	0.3661	1.2	.803
24.1	0.09	163	90	0.57	51.0	2,004	±18	2,047	± 10	2	0.12628	0.57	6.349	1.2	0.3646	1.0	.879
25.1	0.08	164	84	0.53	52.4	2,038	±18	2,038	± 11	0	0.12568	0.61	6.444	1.2	0.3719	1.0	.863
26.1	--	124	72	0.60	39.3	2,031	±19	2,070	± 11	2	0.12798	0.64	6.535	1.3	0.3704	1.1	.861
27.1	0.13	125	48	0.40	39.4	2,013	±19	2,035	± 12	1	0.12544	0.68	6.339	1.3	0.3665	1.1	.849
28.1	--	176	76	0.44	55.4	2,014	±18	2,066.4	± 9.3	3	0.12769	0.53	6.455	1.2	0.3666	1.0	.892
29.1	--	217	101	0.48	69.5	2,041	±18	2,048.6	± 8.0	0	0.12641	0.45	6.493	1.1	0.3725	1.0	.914
210.1	0.02	111	47	0.44	35.1	2,026	±19	2,041	± 12	1	0.12586	0.70	6.409	1.3	0.3693	1.1	.845
211.1	0.00	69	26	0.39	22.2	2,046	±21	2,056	± 15	0	0.1269	0.87	6.536	1.5	0.3735	1.2	.811
212.1	--	249	97	0.40	80.3	2,052	±18	2,061.0	± 7.7	0	0.12730	0.43	6.579	1.1	0.3749	1.0	.918
213.1	--	170	80	0.49	54.5	2,048	±18	2,057.1	± 9.6	0	0.12701	0.55	6.551	1.2	0.3740	1.0	.887
214.1	0.05	134	54	0.42	43.0	2,043	±19	2,065	± 11	1	0.12761	0.62	6.563	1.2	0.3730	1.1	.867
215.1	0.05	88	28	0.33	28.1	2,027	±20	2,069	± 15	2	0.1279	0.85	6.514	1.4	0.3695	1.1	.804
216.1	0.01	266	117	0.45	87.8	2,099	±18	2,051.3	± 7.7	-2	0.12660	0.44	6.718	1.1	0.3848	1.0	.919
217.1	0.35	180	89	0.51	52.3	1,875	±17	2,037	± 12	8	0.12559	0.70	5.845	1.2	0.3376	1.0	.829
218.1	--	116	48	0.43	36.6	2,019	±19	2,067	± 11	2	0.12776	0.62	6.479	1.3	0.3678	1.1	.871
219.1	0.04	192	79	0.42	61.5	2,039	±18	2,043.8	± 9.8	0	0.12606	0.55	6.467	1.2	0.3720	1.0	.881
220.1	0.08	161	78	0.50	51.2	2,024	±18	2,061	± 14	2	0.12733	0.77	6.475	1.3	0.3688	1.1	.808
221.1	0.11	159	68	0.44	51.0	2,045	±19	2,048	± 10	0	0.12636	0.57	6.504	1.2	0.3733	1.1	.885
222.1	--	228	86	0.39	72.4	2,032	±18	2,075.8	± 8.3	2	0.12837	0.47	6.559	1.1	0.3706	1.0	.908
223.1	0.01	124	52	0.43	40.3	2,061	±19	2,029	± 11	-2	0.12505	0.63	6.495	1.3	0.3767	1.1	.866
224.1	3.54	599	680	1.17	133	1,426	±13	2,120	± 42	33	0.1317	2.4	4.49	2.6	0.2476	1.0	.385
225.1	0.06	130	52	0.42	42.1	2,064	±19	2,055	± 15	0	0.1268	0.83	6.601	1.4	0.3774	1.1	.801

Table 4.2 (continued)

Grain.Spot	(1) % $^{206}Pb_c$	Ppm U	ppm Th	$^{232}Th/^{238}U$	ppm $^{206}Pb^*$	(1) $^{206}Pb/^{238}U$ Age		(1) $^{207}Pb/^{206}Pb$ Age		% Discorant	(1) $^{207}Pb^*/^{206}Pb^*$	±%	(1) $^{207}Pb^*/^{235}U$	±%	(1) $^{206}Pb^*/^{238}U$	±%	errcorr
226.1	0.09	196	91	0.48	62.8	2,040	±19	2,050.8	± 9.2	1	0.12657	0.52	6.497	1.2	0.3723	1.1	.897
227.1	0.10	127	54	0.44	41.4	2,070	±19	2,053	± 11	-1	0.12671	0.65	6.615	1.3	0.3786	1.1	.859
228.1	0.14	174	77	0.46	56.4	2,066	±18	2,044.7	± 9.7	-1	0.12613	0.55	6.569	1.2	0.3777	1.0	.885
229.1	0.08	173	78	0.47	55.6	2,045	±18	2,047	± 10	0	0.12633	0.59	6.502	1.2	0.3733	1.0	.872
230.1	0.23	92	40	0.45	28.8	2,008	±22	2,045	± 20	2	0.1262	1.1	6.36	1.7	0.3654	1.3	.744
231.1	0.05	104	47	0.46	33.7	2,065	±20	2,070	± 13	0	0.12799	0.73	6.662	1.4	0.3775	1.2	.847
232.1	--	152	63	0.43	48.5	2,042	±19	2,075.9	± 10.0	2	0.12838	0.57	6.598	1.2	0.3728	1.1	.882
11A.1	0.00	249	108	0.45	80.5	2,057	±18	2,074.0	± 7.7	1	0.12824	0.43	6.646	1.1	0.3759	1.0	.917
12.1	--	164	68	0.43	52.9	2,058	±18	2,058.0	± 9.3	0	0.12708	0.53	6.592	1.2	0.3762	1.0	.892
13.1	0.00	176	70	0.41	56.9	2,061	±18	2,072.4	± 9.2	1	0.12812	0.52	6.655	1.2	0.3767	1.0	.895
14.1	--	138	70	0.52	45.1	2,075	±19	2,068	± 10	0	0.12779	0.59	6.690	1.2	0.3797	1.1	.876
15.1	--	254	138	0.56	81.0	2,037	±18	2,055.3	± 8.5	1	0.12689	0.48	6.501	1.1	0.3716	1.0	.903
16.1	--	198	87	0.46	64.8	2,081	±18	2,059.0	± 8.6	-1	0.12715	0.49	6.681	1.1	0.3811	1.0	.903
17.1	9.57	1574	1030	0.68	148	596	±22	2,060	±140	71	0.1273	7.7	1.70	8.8	0.0968	3.8	.431
18.1	0.13	157	65	0.43	50.9	2,063	±19	2,049	± 11	-1	0.12644	0.61	6.575	1.2	0.3771	1.1	.865
19.1	0.64	243	157	0.67	73.4	1,926	±17	2,045	± 13	6	0.12616	0.73	6.057	1.2	0.3482	1.0	.807
110.1	11.89	988	255	0.27	160	968	±18	1,843	±250	47	0.113	14	2.52	14	0.1620	2.3	.164

Errors are 1-sigma; Pb_c and Pb^* indicate the common and radiogenic portions, respectively. Error in Standard calibration was 0.28% (not included in above errors but required when comparing data from different mounts). (1) Common Pb corrected using measured ^{204}Pb.

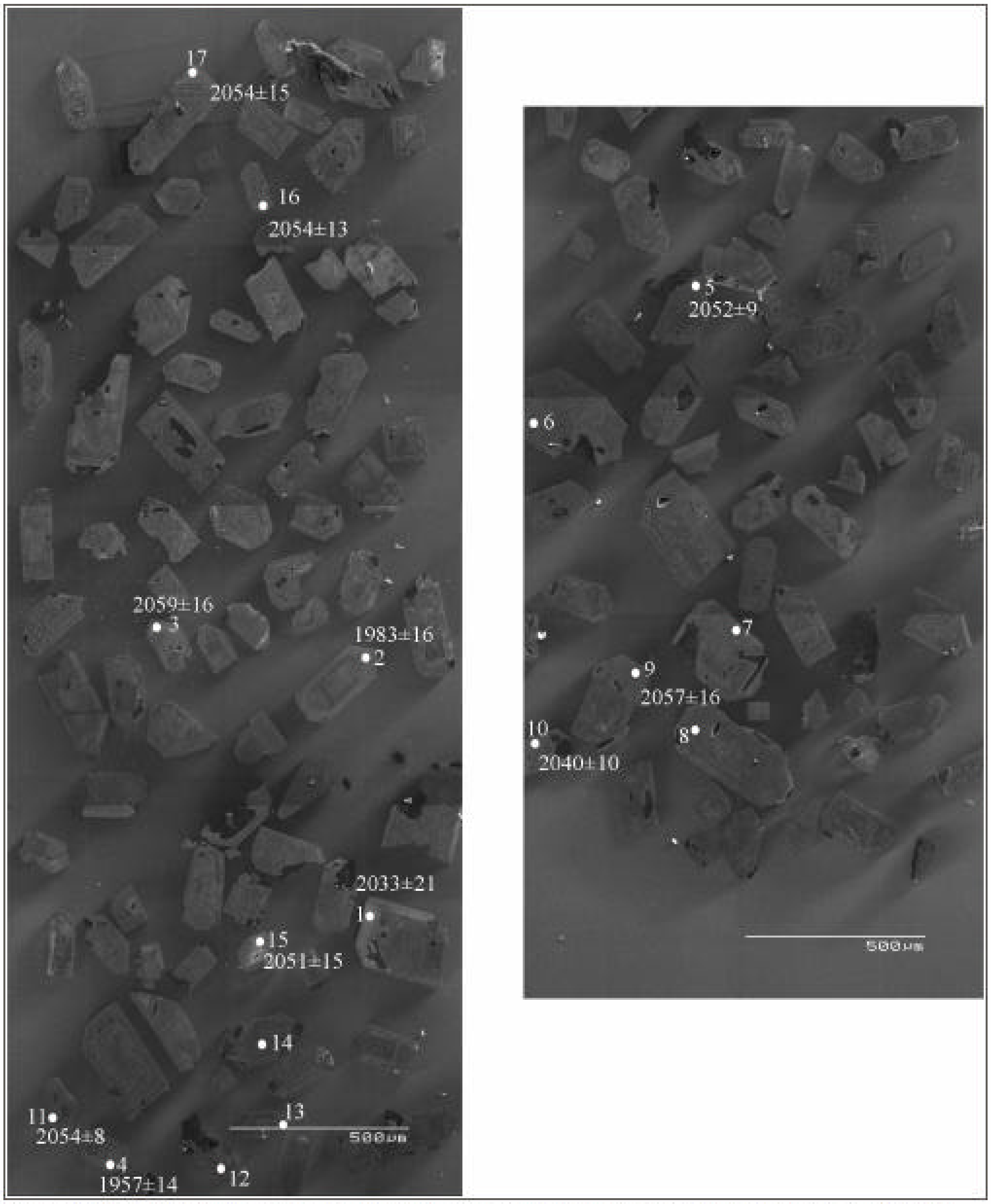

Figure 4.6 Cathodoluminescence images of zircons from the quartz porphyry of the Rust de Winter Formation. Spots selected for analyses and their ages are indicated.

are within error of an age of 2054±2 obtained for the Nebo granite (zircon Pb/Pb, Walraven and Hattingh, 1993). These results, in combination with field geological relationships lead to the conclusion that deposition of the lower Waterberg Group was initiated immediately after the emplacement of the Bushveld Complex. Taking into account the zircon $^{207}Pb/^{206}Pb$ age of 1928±4Ma for the Hartley lava (Cornell et al., 1998) of the Olifantshoek Group (SACS, 1980), it is suggested that the lower part of the Waterberg Group (specifically the Swaershoek Formation and correlative Rust de

Winter Formation) were deposited approximately 120Ma earlier than the Volop Subgroup of the Olifantshoek Supergroup that overlies the Hartley lava (Fig 4.8). This implies that the lower part of the Waterberg Group is not laterally equivalent to the Volop Subgroup (Fig 4.8).

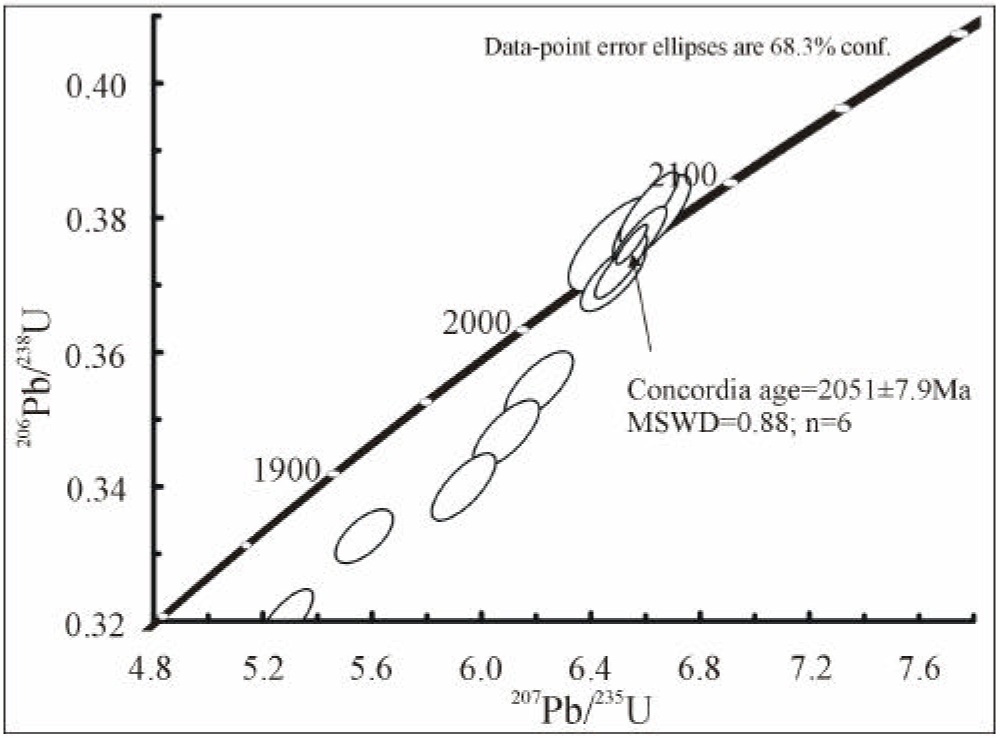

Figure 4.7 Concordia plot of magmatic zircons from the Rust de Winter quartz porphyry.

The new age for the lower part of the Waterberg Group also has implications for chronostratigraphical correlation between the Soutpansberg and Waterberg Groups. The Sibasa lavas at the base of the Soutpansberg Group unconformably overlies the Entabeni granite that has an age of 2021±5Ma (SHRIMP zircon $^{207}Pb/^{206}Pb$ age, chapter 5). This implies that the Soutpansberg Group is at least 25-30Ma younger than the lower part of the Waterberg Group. This conclusion is in good agreement with the observation by Bumby (2000) that the Waterberg Group underlies the Soutpansberg Group at Blouberg in the Limpopo Province.

The above strongly suggests that there were at least two major episodes of Late Paleoproterozoic red bed deposition in southern Africa. One at around 2050Ma, immediately after emplacement of the Bushveld Complex, and the second after 2021

Table 4.3 Summary of SHRIMP U-Pb data for zircons from the Rust de Winter quartz porphyry.

Grain.Spot	(1) % $^{206}Pb_c$	ppm U	ppm Th	$^{232}Th/^{238}U$	ppm $^{206}Pb^*$	(1) $^{206}Pb/^{238}U$ Age		(1) $^{207}Pb/^{206}Pb$ Age		% Discordant	Total $^{238}U/^{206}Pb$	±%	Total $^{207}Pb/^{206}Pb$	±%	(1) $^{238}U/^{206}Pb^*$	±%	(1) $^{207}Pb^*/^{206}Pb^*$	±%	(1) $^{207}Pb^{*235}U$	±%	(1) $^{206}Pb^*/^{238}U$	±%	errcorr
1.1	0.34	156	67	0.44	50.7	2,059	±21	2,033	±21	-1	2.649	1.2	0.1283	0.85	2.658	1.2	0.1253	1.2	6.50	1.7	0.3762	1.2	.715
2.1	0.77	863	331	0.40	249	1,856	±12	1,983	±16	6	2.974	0.76	0.12855	0.49	2.997	0.77	0.1218	0.92	5.605	1.2	0.3337	0.77	.642
3.1	0.61	348	205	0.61	105	1,928	±15	2,059	±16	6	2.851	0.92	0.13255	0.58	2.869	0.93	0.1271	0.88	6.111	1.3	0.3486	0.93	.723
4.1	1.07	882	449	0.53	246	1,797	±14	1,957	±14	8	3.076	0.91	0.12950	0.43	3.110	0.92	0.12008	0.77	5.324	1.2	0.3216	0.92	.765
5.1	0.00	411	199	0.50	133	2,060	±16	2,052.8	± 9.2	0	2.655	0.88	0.12671	0.52	2.655	0.88	0.12671	0.52	6.579	1.0	0.3766	0.88	.860
6.1	2.95	521	286	0.57	134	1,639	±12	2,029	±26	19	3.352	0.84	0.15100	0.49	3.454	0.86	0.1250	1.5	4.990	1.7	0.2895	0.86	.508
7.1	2.03	1177	523	0.46	190	1,088.7	± 7.5	1,708	±22	36	5.325	0.74	0.12227	0.43	5.435	0.75	0.1046	1.2	2.654	1.4	0.1840	0.75	.536
8.1	1.93	1899	410	0.22	139	517.3	± 3.6	1,750	±25	70	11.738	0.72	0.12385	0.71	11.969	0.73	0.1071	1.4	1.233	1.6	0.08355	0.73	.470
9.1	0.32	351	180	0.53	108	1,961	±16	2,057	±16	5	2.803	0.92	0.12981	0.63	2.812	0.92	0.1270	0.92	6.227	1.3	0.3556	0.92	.710
10.1	0.03	395	277	0.72	129	2,083	±16	2,040.7	± 9.7	-2	2.620	0.89	0.12613	0.54	2.621	0.89	0.12585	0.55	6.620	1.0	0.3815	0.89	.852
11.1	0.07	596	331	0.57	191	2,043	±14	2,054.0	± 8.2	1	2.680	0.81	0.12737	0.44	2.682	0.81	0.12679	0.46	6.519	0.93	0.3729	0.81	.868
12.1	0.59	1337	743	0.57	129	682.8	± 5.0	1,898	±15	64	8.898	0.76	0.12135	0.53	8.951	0.77	0.11619	0.86	1.790	1.2	0.11172	0.77	.668
13.1	11.36	2171	3256	1.55	175	514.7	± 4.8	1,438	±85	64	10.665	0.84	0.18792	0.38	12.03	0.96	0.0906	4.4	1.038	4.5	0.08311	0.96	.211
14.1	10.21	1346	1391	1.07	159	749.4	± 5.8	1,558	±60	52	7.284	0.74	0.18451	0.41	8.112	0.82	0.0965	3.2	1.641	3.3	0.1233	0.82	.248
15.1	0.16	208	99	0.49	68.1	2,076	±19	2,051	±15	-1	2.628	1.1	0.12799	0.74	2.632	1.1	0.1266	0.86	6.631	1.4	0.3800	1.1	.781
16.1	0.61	456	228	0.52	146	2,036	±15	2,054	±13	1	2.677	0.87	0.13218	0.51	2.693	0.87	0.12680	0.76	6.492	1.2	0.3713	0.87	.752
17.1	0.32	302	162	0.55	88.7	1,891	±16	2,054	±15	8	2.924	0.95	0.12963	0.63	2.934	0.95	0.1268	0.85	5.960	1.3	0.3409	0.95	.748

Errors are 1-sigma; Pb_c and Pb^* indicate the common and radiogenic portions, respectively. Error in Standard calibration was 0.33% (not included in above errors but required when comparing data from different mounts). (1) Common Pb corrected using measured ^{204}Pb.

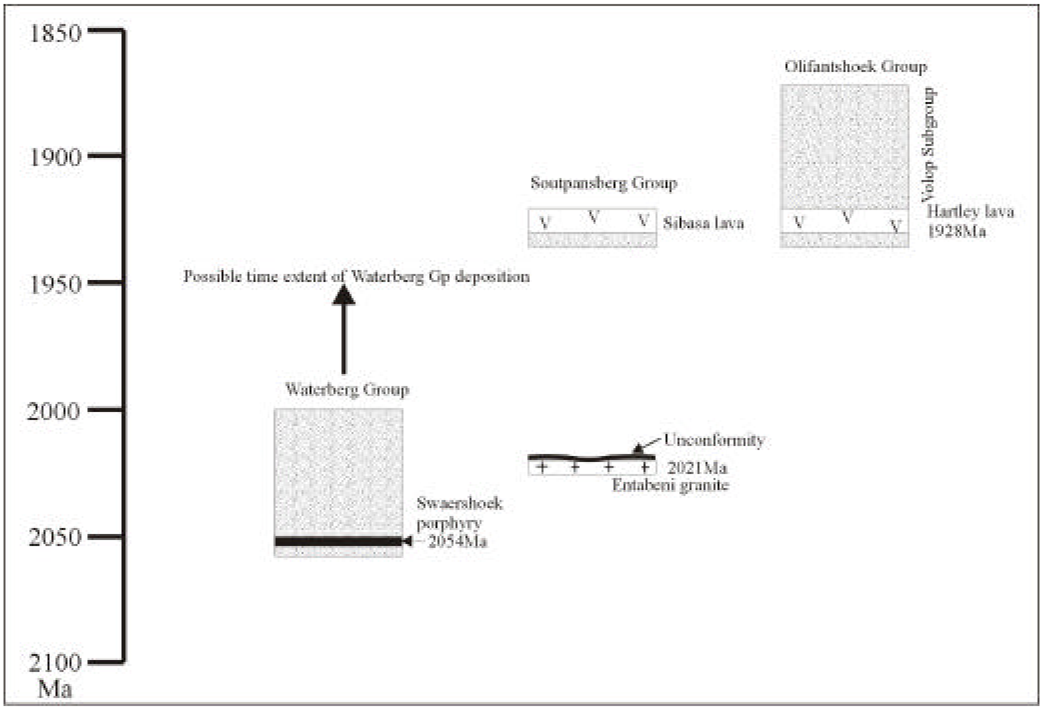

Figure 4.8 Time-stratigraphy plot indicating the ages of Waterberg and Soutpansberg Groups and the Volop Subgroup of the Ollifantshoek Supergroup.

and/or 1928Ma, following the intrusion of the Entabeni granite, and outflow of the Hartley lava, respectively (Fig 4.8).

4.5 Conclusion

The most important conclusion that may be drawn from the SHRIMP U-Pb ~2053Ma zircon ages acquired for the Swaershoek and Rust de Winter Formation quartz porphyries, is that they extruded almost immediately after intrusion of the Bushveld Complex. Secondly, it is quite clear that the lower part of the Waterberg Group (specifically the Swaershoek and correlative Rust de Winter Formations) is older than both the Volop Subgroup of the Olifantshoek Group and the Soutpansberg Group.

4.6 References

Buick, I.S., Maas, R. and Gibson, R. (2001). Precise U-Pb titanite age constraints on the emplacement of the Bushveld Complex, South Africa. Journal of the Geological Society, London, 158, 3-6.

Bumby, A.J. (2000). The geology of the Blouberg Formation, Waterberg and Soutpansberg Groups in the area of the Blouberg mountain, Northern Province, South Africa. PhD thesis (unpublished), University of Pretoria, South Africa, 323pp.

Bumby, A.J., Eriksson, P.G., Van Der Merwe, R. and Maier. W.D. (2001). The Stratigraphic relationship between the Waterberg Group and the Soutpansberg Group (Northern Province, South Africa): Evidence from the Blouberg area. South African Journal of Geology, 104, 3, 205-216.

Callaghan, C.C., Eriksson, P.G., and Snyman, C.P. (1991). The sedimentology of the Waterberg Group in the Transvaal, South Africa: an overview. Journal of African Earth Sciences, 13(1), 121-139.

Carney, J.N., Aldiss, D.T. and Lock, N.P. (1994). The Geology of Botswana, Bulletin 37, 113pp.

Cheney, E.S., Barton, J.M., and Brandl, G. (1990). Extent and age of the Soutpansberg sequences of southern Africa. South African Journal of Geology, 93, 664-675.

Cornell, D.H., Armstrong, R.A., and Walraven, F. (1998). Geochronology of the Proterozoic Hartley Basalt Formation, South Africa: constraints on the Kheis tectogenesis and the Kaapvaal Craton's earliest Wilson cycle. Journal of African Earth Sciences, 26, 5-27.

De Bruiyn, H. and Andrew, G.F. (1972). Syn-Waterberg volcanism in the vicinity of Rust de Winter dam. Annals of the Geological Survey of South Africa, 9, 89-90.

Eriksson, P.G., Reczko, B.F.F. and Callaghan, C.C. (1997). The economic mineral potential of the mid-Proterozoic Waterberg Group, northwestern Kaapvaal craton, South Africa. Mineralium Deposita, 32, 401-409.

Glatthaar, C.W. (1956). Die verysterde piroklaste en 'n na-Waterbergse granite, suidoos van die dam Rust der Winter. M.Sc. thesis (unpublished), University of Pretoria, 80pp.

Jansen, H. (1970). Volcanic rocks and associated sediments in the southern portion of the Waterberg basin. Annals of the Geological Survey of South Africa, 8, 53-62.

Jansen, H. (1976). The Waterberg and Soutpansberg Groups in the Blouberg area, northern Transvaal. Transactions of the Geological Society of South Africa, 79, 281-291.

Key, R.M. (1983). The geology of the area around Gaborone and Lobatse. District memoir Geological Survey of Botswana, 5, 230pp.

Martini, J.E.J. (1998). The Loskop Formation and its relationship to the Bushveld Complex, South Africa. Journal of African Earth Sciences, 27(2), 193-222.

Meinster, B. (1977). Discussion on H. Jansen: The Waterberg and Soutpansberg Groups in the Blouberg area, northern Transvaal. Transactions of the Geological Society of South Africa, 80. 289-296.

Oosthuizen, E.J. (1964). 'n Geochronologiese studie van sekere stollingsgesteentes net ouer en jonger as die Sisteem Waterberg. M.Sc thesis(unpublished), University of Pretoria, 80pp.

SACS (The South African Committee for Stratigraphy) (1980). Stratigraphy of South Africa, Part 1 (Compiler: Kent, L.E.). Lithostratigraphy of South Africa, South West Africa/Namibia and the Republics of Bophuthatswana, Transkei and Venda. Handbook. Geological Survey of South Africa, 8, 690pp.

Van der Neut, M, Eriksson, P.G. and Callaghan, C.C. (1991). Distal alluvial fan sediments in early Proterozoic red beds of the Wilgerivier Formation, Waterberg Group, South Africa. Journal of African Earth Sciences, 12, 537-547.

Walraven, F. (1981). The Stratigraphic position of the post-Rooiberg sediments at Rust de Winter. Annals of the Geological Survey of South Africa, 15(2), 37-41.

Walraven, F. (1997). Geochronology of the Rooiberg Group, Transvaal Supergroup, South Africa. University of the Witwatersrand, Johannesburg, Economic Geology Research Unit Information Circular, 316, 21pp.

Walraven, F., Armstrong, R.A., and Kruger, F.J. (1990). A chronostratigraphic framework for the north-central Kaapvaal craton, Bushveld Complex and the Vredefort structure. Tectonophysics, 171, 23-48.

Walraven, F. and E. Hattingh (1993). Geochronology of the Nebo Granite, Bushveld Complex. South African Journal of Geology, 96(1/2), 31-41.