CHAPTER 6

GEOCHRONOLGY OF THE UMKONDO DOLERITES AND POSSIBLE MESOPROTEROZOIC DYKES

6.0 Introduction

Two Umkondo sills that are at least 100 km apart have yielded U-Pb zircon/baddeleyite ages of 1105 ± 2 Ma (Hanson *et al.*, 1998) and 1105 ± 5 Ma (Wingate, 2001). The widespread sills that intruded the Umkondo group in eastern Zimbabwe may either belong to one magmatic event or may reflect multiple injections of magma at various ages. The age constraints of the Mutare dykes of Wilson *et al.* (1987) that intrude Archean basement granites and the Umkondo group to the south of Mutare are poor. The relationship between the Mutare dyke swarm of Wilson *et al.* (1987) and Umkondo sills has not been directly ascertained in the field due to lack of exposures in areas where they intersect. The dykes intrude rocks of the Umkondo Group and appear to be feeders to Umkondo sills. Watson (1969) mapped the dykes as being continuous with Umkondo sills to the south of Chimanimani. Based on these facts, it is possible to interpret the dykes and sills to belong to a single magmatic event.

In this chapter, additional isotopic data for two sills and a dyke that intrude the Zimbabwe facies of the Umkondo group are presented. The extent of the Umkondo Igneous event in Zimbabwe is revisited and the regional significance of the new age data for a dyke that is part of the Mutare dyke swarm of Wilson *et al.* (1987), are discussed in the light of new geochronological results. The relationship between Umkondo sills and dykes is also discussed.

6.1 Sampling Procedure

In order to explore the extent of Umkondo magmatism in Zimbabwe, twenty-six samples were collected for U-Pb zircon/baddeleyite dating from Umkondo sills and three dyke

swarms of Wilson *et al.* (1987), namely the Guruve, Mutare and Kamativi dykes (Fig. 2.2). The three dyke swarms were chosen in this study because previous workers (Wilson *et al.*, 1987) have correlated these swarms with Umkondo dolerites on the basis of scant geochronological and palaeomagnetic data (chapter 2). Sampling sites for the three swarms and Umkondo sills were chosen after careful study of the available 1:100 000 geological maps for the respective areas of study that were prepared by the Geological Survey of Zimbabwe (Appendix 6.1; Figs. 1.2-1.9). Sampling sites were chosen in accessible areas in a manner that is representative of the entire dyke swarm population. The samples that each weighed about 20 kilograms on average were fresh and devoid of veins. Weathered material was removed in the field. Dykes/sills that are undeformed and show little or no alteration and metamorphism were sampled in order to avoid metamict zircon/baddeleyite that may have suffered Pb loss. Samples in eastern Zimbabwe were therefore collected some tens of kilometres west of the highly metamorphosed Mozambique facies since the metamorphic grade decreases from east to west (Stocklmayer, 1978; Payne, 1984; Munyanyiwa, 1999). Granophyres with pegmatitic segregations are preferred for sampling as there appears to be a higher chance of finding zircons in these units (R. Hanson, personal communication, 2001). However, samples were collected from the coarsest material of the sills/dykes where the granophyres could not be found.

Sampling of Umkondo sills in Nyanga and the Chimanimani-Chipinge area was done in sills that are located in different stratigraphic settings of the Umkondo Group in order to establish whether all these sills belong to a single intrusive event or not. South of Mutare town, dykes belonging to each of the two near-perpendicular sets (Fig. 7.2) were sampled in order to establish the age relationships. Dykes that appeared to transit into Umkondo sills were also targeted for sampling in order to establish if these dykes acted as feeders to Umkondo sills. Fresh samples of the Guruve and Kamativi swarms were sampled, while the highly metamorphosed schistose dykes of similar trends in the same vicinity were considered to be much older than the Guruve swarm and were therefore avoided.

6.2 Sample Preparation

Only 19 samples were processed due to time constraints. Sample preparation and conventional U-Pb zircon/baddeleyite geochronology was, done in an M.I.T., laboratory, Boston, U.S.A. Standard crushing, heavy liquid and magnetic mineral separation techniques were used to separate zircon/baddeleyite grains from dolerite samples.

About 5–15 kg of sample was crushed, pulverised and run over a wet Wifley table to obtain a heavy mineral concentrate. Magnetic separation was performed using a hand magnet and then a Frantz Isodynamic magnetic separator. Heavy mineral separation was done by density separations using bromoform. Paramagnetic minerals were further removed with the Frantz Isodynamic separator by increasing the current and reducing the tilt. A final Frantz separation was performed to isolate baddeleyite and zircon based on a slight difference in paramagnetism. Best zircon grains devoid of fractures, inclusions, alterations and other imperfections were found in the least magnetic Frantz separation.

Three samples; namely JM0104 (Fig. 1.3), JM0109 (Fig. 1.6) and JM 0125 (Fig. 1.3), yielded usable baddeleyite grains while a fourth sample, JM0138 (Fig. 1.7), yielded metamict zircons (Appendix 6.1). Sample JM0125 was collected from a mesocratic granophyre capping the Tandaai dolerite sill some 8 km south southeast of Cashel (Fig. 1.3; Grid Ref.: 480387; 7832272). The sill intruded the upper arkose unit of the upper part of the Umkondo group. Sample JM0109 (Fig. 1.6) was taken from pegmatitic segregations some 15 metres below the sill top. The sill intruded the lower Umkondo group and occurs about 31 km north northeast of Birchenough Bridge (Fig. 1.6; Grid Ref.: 444620; 7781753). Sample JM0138 (Fig. 1.7) was collected from approximately, the same locality as Wingate (2001), i.e. on a sill-top north northeast of Nyanga town (Fig. Grid Ref.: 482155; 7997149). Note that the grid reference for this sample given in Wingate (2001) does not correspond to location details supplied by Prof. D. Jones. The sill intrudes the Archean basement granites as well as the metasedimentary rocks of the lower Zimbabwe facies. Sample JM0104 was collected from the eastern most of three-north northwest trending; sub-vertical dykes that intruded the upper arkoses of the

Zimbabwe facies south of Chimanimani town (Grid Ref.: 490120; 7794842). The petrography of these sills and the dyke are described in chapter 3.

Metamict zircons from sample JM0138 (Fig. 1.7) were considered unsuitable for dating since they may have suffered radiogenic lead loss through their disintegrated crystal lattices. Metamict zircons may occur as a result of pressure relaxation during a short episode of uplift and associated erosion and circulation of hydrothermal fluid circulation (Goldich and Mudrey, 1972).

The baddeleyite grains from samples JM0104, JM0109 and JM0125 are light to dark brown coloured, thin and elongate plates that have a typical aspect ratios of 10:5:1. Grains in samples JM0104 and JM0125 constitute small populations and are small in size, ranging from 50 to 100 μm, while those in sample JM0109 are abundant and relatively large with a size range from 100 to 300 μm.

Analysis of these samples was carried out in an Isotope Geochemistry Laboratory at the Massachusetts Institute of Technology laboratory, Boston, U.S.A. U-Pb baddeleyite dating was done by Jim Crowley in the same laboratory.

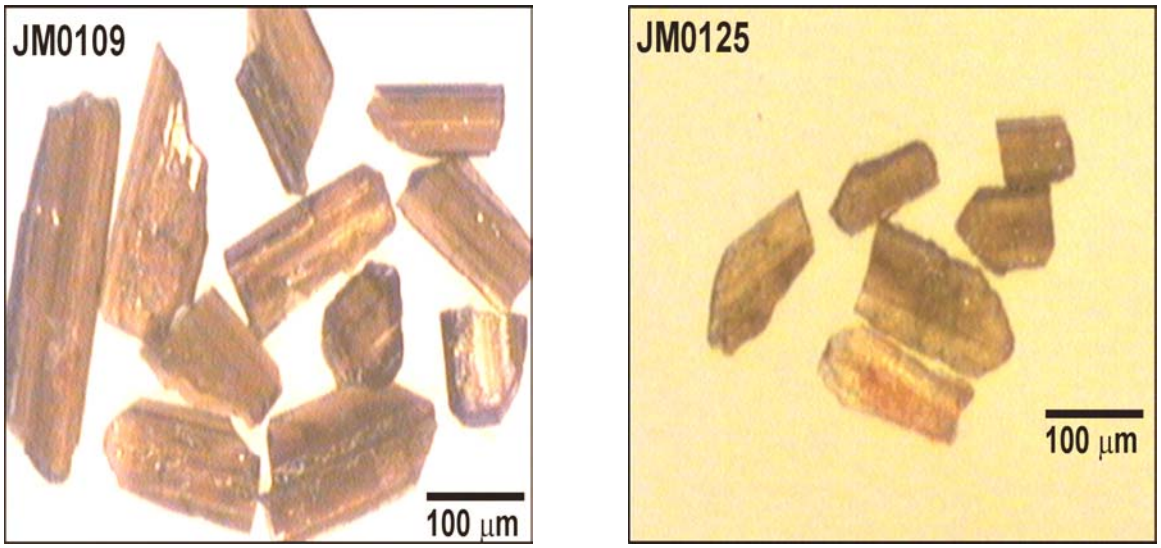

Fig. 6.1 Microphotographs showing baddeleyite grains from samples JM0109 and JM0125. The grains are light to dark brown in colour, thin and elongate plates with typical aspect ratios of about 10:5:1

6.3 Analytical Methods

The high precision isotope dilution thermal ionization mass spectrometry method was used, following procedures similar to those for zircon as outlined by Bowring *et al.* (1998). Age calculations followed those of Ludwig (1980) and are based on the decay constant of Steiger and Jäger (1977). Initial common Pb composition was taken from the model of Stacey and Kramers (1975). The error ellipses in the concordia diagrams are given at 95 % confidence level and errors are 2 sigma, propagated using the algorithms of Ludwig (1980). The discordia line calculated for sample JM0125 and the age uncertainties on the intercepts were calculated using a modified York (1969) regression. Analytical data and results are presented in Table 6.1.

Table 6.1 Isotopic data for baddeleyite grains from three dolerite samples. B_1-B_{10} represent grain fractions that correspond to labels on the concordia diagrams and the number of multi-grains are shown in brackets. Sample weights are measured to within 40% using measured dimensions and density. Percentage discordance = 100 – (100 x [$^{206}Pb/^{238}U$ age] / [$^{207}Pb/^{206}Pb$])

		Concentrations				Isotopic ratios									Ages (Ma)			
Sample	Weight (µg)	U (ppm)	Pb (ppm)	Th/U	Pb_c (pg)	$^{206}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	% err	$^{207}Pb/^{235}U$	% err	$^{207}Pb/^{206}Pb$	% err	corr. coef.	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	% disc.
(a)	(b)			(c)	(d)	(e)	(f)	(f)	(g)	(f)	(g)	(f)	(g)		(h)	(h)	(h)	(i)
JM0104																		
B1	0.9	69	8	0.05	1.2	408	0.015	0.11863	1.02	1.04015	1.10	0.06359	0.40	0.93	722.6	726.0	728.2 ± 8.4	0.8
B2	1.3	82	9	0.03	1.0	863	0.009	0.11852	0.25	1.03611	0.36	0.06341	0.25	0.71	722.0	722.0	721.9 ± 5.4	0.0
B4	0.6	122	13	0.06	1.0	561	0.018	0.11847	0.87	1.03694	0.91	0.06348	0.26	0.96	721.8	722.4	726.4 ± 5.6	0.4
B5 (2)	1.3	85	9	0.04	1.1	812	0.012	0.11786	0.58	1.03193	0.64	0.06350	0.26	0.92	718.2	719.9	725.0 ± 5.5	0.9
B6 (3)	1.2	117	13	0.11	0.8	1341	0.035	0.11768	0.16	1.02992	0.21	0.06347	0.14	0.77	717.2	718.9	726.2 ± 2.9	1.0
JM0109																		
B1	8.1	319	57	0.08	2.6	11740	0.023	0.18760	0.08	1.97886	0.10	0.07650	0.06	0.80	1108.4	1108.3	1108.3 ± 1.3	0.0
B2	6.0	614	109	0.07	2.3	12405	0.021	0.18726	0.10	1.97597	0.13	0.07653	0.09	0.75	1106.5	1107.3	1109.0 ± 1.7	0.2
B3	2.6	385	68	0.06	1.9	6043	0.020	0.18713	0.09	1.97375	0.14	0.07650	0.11	0.62	1105.8	1106.6	1108.1 ± 2.2	0.2
B4	2.9	287	51	0.08	1.1	9074	0.024	0.18735	0.06	1.97633	0.10	0.07651	0.08	0.59	1107.0	1107.5	1108.4 ± 1.6	0.1
B5	2.4	600	106	0.05	2.3	7337	0.016	0.18780	0.05	1.98150	0.10	0.07652	0.08	0.55	1109.5	1109.2	1108.7 ± 1.7	-0.1
JM0125																		
B1	0.9	452	76	0.10	1.2	3728	0.031	0.17613	0.12	1.85751	0.16	0.07649	0.11	0.74	1045.8	1066.1	1107.9 ± 2.2	5.6
B2	0.8	305	55	0.08	2.5	1140	0.023	0.18275	0.18	1.92416	0.26	0.07636	0.18	0.73	1082.0	1089.5	1106.6 ± 3.6	2.0
B3	0.8	138	23	0.04	0.8	1540	0.011	0.18129	0.17	1.91029	0.27	0.07642	0.21	0.65	1076.0	1086.7	1106.2 ± 6.1	2.9
B4	0.8	283	46	0.08	1.1	2274	0.025	0.17112	0.20	1.79268	0.22	0.07598	0.09	0.92	1018.3	1042.8	1096.6 ± 1.7	7.0
B5	0.7	542	82	0.14	2.2	1665	0.050	0.15345	0.14	1.60710	0.16	0.07596	0.07	0.89	920.3	973.0	1096.0 ± 1.4	15.9
B6	0.4	245	42	0.05	0.9	1294	0.015	0.18408	0.17	1.94004	0.21	0.07644	0.12	0.82	1089.2	1095.0	1106.5 ± 2.6	1.6
B8	1.1	160	29	0.04	2.8	718	0.011	0.17959	0.25	1.88917	0.30	0.07629	0.16	0.86	1066.7	1077.3	1102.8 ± 3.1	3.5
B9	0.9	385	66	0.06	2.8	1381	0.018	0.17757	0.13	1.86228	0.18	0.07606	0.12	0.75	1053.7	1067.8	1096.8 ± 2.4	3.9
B10	0.6	339	59	0.03	1.5	1552	0.010	0.18227	0.26	1.91816	0.28	0.07632	0.10	0.94	1079.4	1087.4	1103.6 ± 1.9	2.2

6.4 Results

Mapping and geochronological work from this project have been partly a basis for publication of 2 conference papers and a journal paper (appendices 6.2-6.4)

6.4.1 Age of the Dolerite Sills (JM0125 and JM0109)

Analysis of nine single baddeleyite grains fractions from sample JM0125 yielded varying degrees of moderately discordant dates that are mostly between 2 and 7% discordant. The discordance indicates that the grains have suffered a moderate amount of Pb loss. True Pb loss is related to the crystal size, U-concentration and to the radiation damage in the crystal (Faure, 1986). Baddeleyite grains in a sample of igneous rock may lose varying

proportions of their radiogenic Pb although they have experienced similar conditions and the baddeleyite fractions plot as series of points on a discordia line (Jelsma, 1993). Six analyses from sample JM0125 are colinear (Fig. 6.2), and a York (1969) regression through these analyses yields an upper intercept of 1109.0 ± 2.2 Ma and lower intercept of 211 ± 41 Ma (MSWD = 0.6). The upper intercept of 1109.0 ± 2.2 Ma is interpreted as the crystallization age, and hence the emplacement age of the sill. The lower intercept age of 211 ± 41 Ma may be indicative of episodic Pb loss event, e.g. during a metamorphic event (Wetherill, 1956) possibly associated with Karoo reheating throughout the Zimbabwe craton (Tilton, 1960; Wetherill, 1963) or may have no geological meaning as a result of continuous Pb loss. The three analyses that lie slightly above or below the discordia had a different Pb loss history than the analyses that define the discordia.

Analysis of five single grain fractions from sample JM0109 yielded concordant data (Fig. 6.3). The interpreted crystallization age of 1108.5 ± 0.4 Ma (MSWD = 0.6) is the weighted mean of the $^{207}Pb/^{206}Pb$ dates. Geochronology results from both samples indicate an Umkondo crystallisation age for both sills.

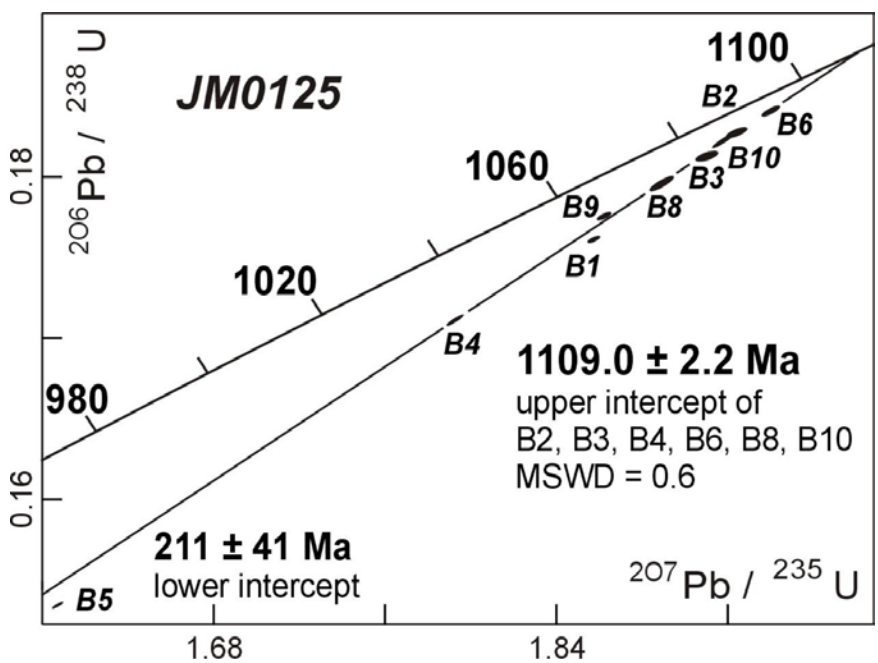

Fig. 6.2. U-Pb Concordia diagram of baddeleyite fractions from an Umkondo sill (sample JM0125) that intruded the upper arkose unit of the Zimbabwe facies south southeast of Cashel (Grid Ref.: 480387; 7832272). Linear regression is through 6 of the 9 discordant data points and gives an upper intercept age of 1109.0 ± 2.2 Ma that is interpreted to be the emplacement age of the sill, and a lower intercept age of 211 ± 41 Ma.

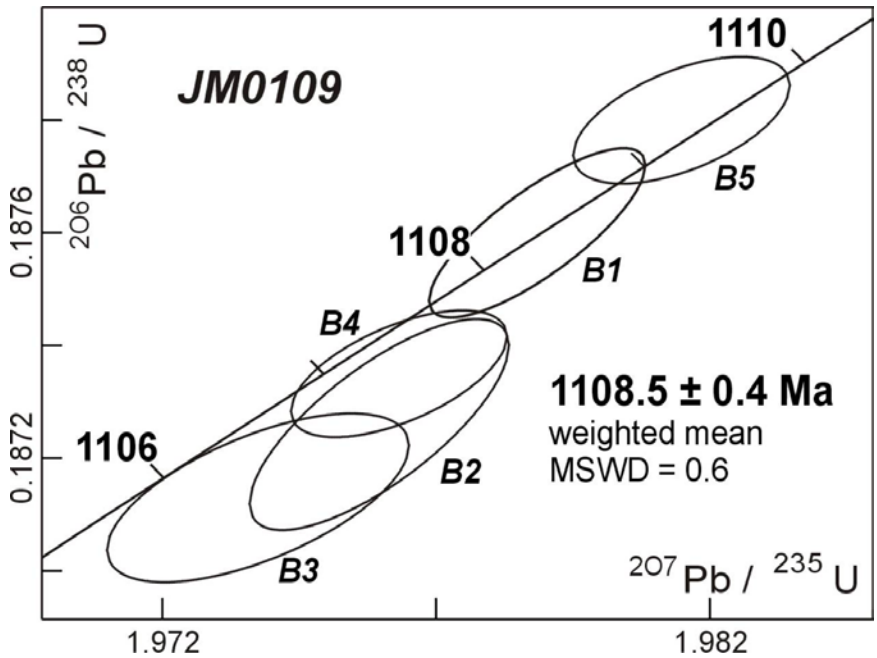

Fig. 6.3. U-Pb Concordia diagram for an Umkondo sill (JM0109). The weighted mean of the analyses gives an age of 1108.5 for the sill that intrudes metasedimaentary rocks the lower Zimbabwe facies.

6.4.2 Age of a Dolerite Dyke (JM0104)

Analysis of three fractions of single baddeleyite grains and two multi-grain fractions from sample JM0104 are concordant to slightly discordant when plotted on a concordia diagram (Fig. 6.4). Four least discordant analyses yield a Pan-African age of 724 ± 2.1 Ma (MSWD = 0.3), which is the weighted mean of the $^{207}Pb/^{206}Pb$ dates from the four analyses. The age is interpreted to reflect the crystallization age, and hence the emplacement age of the dyke.

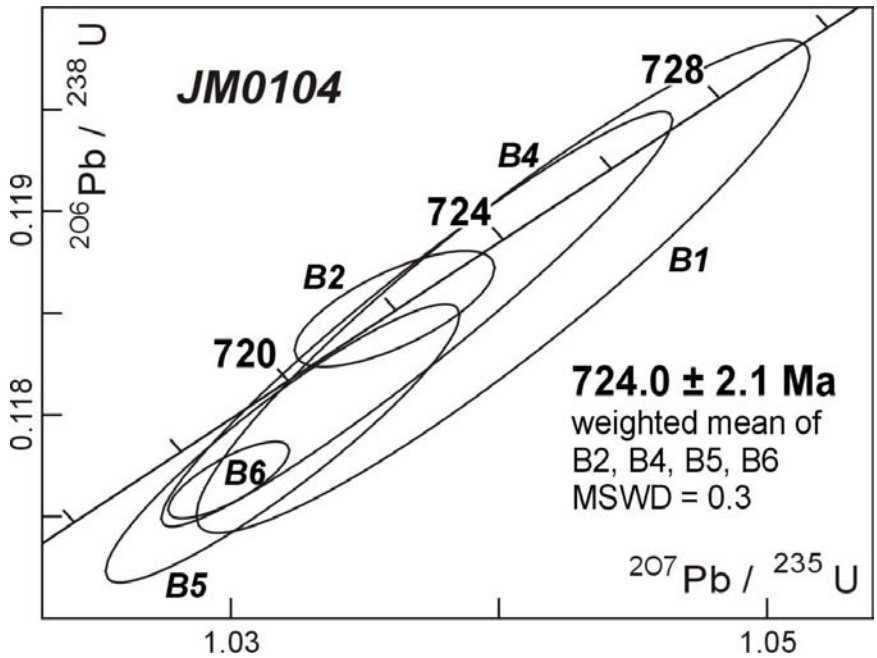

Fig. 6.4 Concordia diagram of baddeleyite fractions from a north northwest trending dyke (sample JM0104) that occurs to the south of Chimanimani town. The four least discordant analyses yield a Pan-African age of 724 ± 2.1 Ma that is interpreted as the emplacement of the dyke, and hence the Mutare dyke swarm.

6.5 Discussion and Conclusions

The significance of the new and published isotopic data for Umkondo dolerites and the Mutare swarm are discussed below. The ages of the Deweras and Kamativi dykes remain speculative because no baddeleyite/zircon grains were recovered from these dykes using the sample preparation procedures described above (section 6.2).

6.5.1 Significance of New Ages for Dolerite Sills

The isotopic ages for two sills in eastern Zimbabwe of 1108.5 ± 0.4 Ma and 1109.0 ± 2.2 Ma obtained from this study are within the margin of errors of each other suggesting that both sills were emplaced contemporaneously and are of Umkondo age (Hanson *et al.*, 1998). The U-Pb zircon age of 1105 ± 2 Ma obtained by Hanson *et al.* (1998) is within the margin of errors of the age of baddeleyite grains in JM0125 (1109.0 ± 2.2 Ma), but does not overlap with the age of baddeleyite grains in sample JM0109 (1108.5 ± 0.4 Ma). However, the difference is very small and therefore may not be significant. The two

samples, i.e. JM0125 (Fig. 1.3) and JM0109 (Fig. 1.6) were collected from sills that were emplaced at or near the top and bottom of the Umkondo group stratigraphy respectively. Hanson's sampling site is located in a sill that intruded the middle Umkondo group. The Umkondo ages for these three sills are highly significant in that they show that at least some top most sills were emplaced at the same time (within error) as those emplaced at the base of the Zimbabwe facies stratigraphy. These results permit the inference that the voluminous sills that were emplaced in different stratigraphic levels of the Zimbabwe facies in eastern Zimbabwe may be part of a single igneous event.

The published mean age of 1105 ± 5 Ma (Wingate, 2000) for Umkondo dolerites overlaps with the margin of errors of the age of baddeleyite grains from both samples, JM0109 and JM0125. However, a sample (JM0138) collected from the same locality as Wingate (2001) yielded metamict zircons (section 6.2). Wingate (2001) also found that the zircons are dark brown to opaque and are variably cracked. These facts render the isotopic ages from this sill unreliable since the zircons have suffered variable Pb-loss. Farther more, Wingate used an unreliable method (chapter 2) to ascertain the mean age, and the ages may have no geological significance.

In conclusion, available geochronological data show that Umkondo magmatism in eastern Zimbabwe occurred between c. 1105 Ma and c. 1109 Ma. These ages show that Umkondo magmatism took place within a short period of time. The regional and global significance of the Umkondo dolerites has been discussed in sections 2.7 and 2.8.

6.5.2 Significance of the Age of the North Northwest Trending Dyke

North to northeast trending dykes have been interpreted to be either of Umkondo or Mashonaland age through palaeomagnetic studies. Geochronological results from this study show that a north northwest trending dyke (JM0104) that was inferred to be contemporaneous with Umkondo sills (Watson, 1969), has in fact a Pan-African age of 724 ± 2.1 Ma and is nearly 400 Ma younger than the Umkondo sills. It is therefore concluded that at least three generations of dykes exist within the Mutare swarm of

Wilson et al (1987) and the term swarm cannot be used for these dykes (section 2.10). Petrographic and textural similarities cannot be used to correlate dykes of similar trend, or to correlate dykes and sills. The dated dyke (JM0104), for example, is coarse grained and has a mineralogical composition and granophyric texture that is similar to that of Umkondo sills. It may be tempting to suggest that the dykes and sills are contemporaneous since dolerites that have petrological similarities with the sills appear to be continuous. Rigorous isotopic dating and palaeomagnetic studies of more dykes in eastern Zimbabwe need to be done in order to constrain the ages of the dykes and their relevance to continental drift.

The 724 ± 2.1 Ma age for the north northwest trending dyke in eastern Zimbabwe does not correspond to any major documented igneous event within the Zimbabwe craton. However, SHRIMP U-Pb analyses of zircons from the Great Dyke gave a lower intercept age of 708 ± 62 Ma (Wingate, 2000), which is interpreted to reflect perturbation on the isotopic system that resulted in loss of radiogenic Pb. The Pb loss at approximately 700 Ma has been interpreted to reflect the onset of the Pan-African tectonothermal event in the Zimbabwe craton (Mukasa *et al.*, 1998). Pan African K-Ar whole rock and pyroxene ages that are close to or within the margin of error of the age of the north northwest trending dyke have been obtained for some Umkondo sills that intrude the Zimbabwe facies in eastern Zimbabwe (table 2.1; Snelling *et al.*, 1964; Vail and Dodson, 1969). These K-Ar ages are interpreted to reflect Ar-loss due to perturbations to the K-Ar system associated with the tectonothermal event, during which the north northwest trending dyke was emplaced.

Emplacement of the north northwest trending dyke and possible associated dykes was probably not contemporaneous with the east-west compressional deformation in the Mozambique belt (Fig. 5.22) since the dykes trend at a small angle to that of the Mozambique belt. The orientation of the north northwest dyke emplaced at 724 ± 2.1 Ma suggests that the maximum principal stress (σ_1) during their emplacement was north northwest-south southeast. A single-zircon evaporation age of 737 ± 0.4 Ma (Dirks *et al.*, 1997) and a U-Pb zircon age of 748 ± 3 Ma (Hanson *et al.*, 1998a), obtained from the

Zambezi belt, have been interpreted as crystallisation ages. The orientation of σ_1 during dyke emplacement is consistent with the contractional deformation in the Zambezi belt at the time of dyke emplacement. Pan African deformation in the Zambezi belt reflects intraplate accommodation of collision along the Mozambique belt (Hanson *et al.*, 1994). These facts suggest that emplacement of some north trending dykes on the Zimbabwe craton was probably contemporaneous with the Zambezi orogeny. However, farther geochronological work on the dykes needs to be done to support this assertion.

The age of the dyke dated in this study is within the error of margins of the Pan-African Mbodzi complex in the Congo craton dated at c. 743 ± 30 Ma (Meert *et al.*, 1995) and Gannakouriep mafic dyke swarm in Namibia dated at 717 ± 11 Ma (Reid *et al.*, 1991). Maboko *et al.* (1985) obtained a zircon U-Pb upper intercept of ~715 Ma for the Wami River granulites in Tanzania, which they interpreted as the age for the granulite facies metamorphism within the entire Mozambique belt. The age has been re-interpreted as the emplacement age of the protoliths to the granulites (Hanson *et al.*, 2004). These emplacement ages suggest that magmatism in the two cratons, i.e. the Kalahari and the Congo cratons between 750 and 720 Ma was synchronous. The orogenesis and magmatism at ~ 720 Ma relate to the break-up of Rodinia that was initiated at ~ 750 Ma and began with the separation of East Gondwana from the western margin of Laurentia (Weil *et al.*, 1998; Dalziel *et al.*, 2000), and subsequent assembly of Gondwana by ~ 550 Ma. The Mozambique belt that extends along the eastern margin of Africa (Fig. 5.22) has been interpreted as a suture that resulted from the collision of East and West Gondwana between 800 and 650 Ma (Maboko *et al.*, 1985, 1990, 1995; Stern, 1994; Meert and Van der Voo, 1997; Maboko and Nakamura, 1995). Deformation in the transcontinental Damara-Lufilian–Zambezi belts (Fig. 5.22) was not caused by a single collisional event between the Congo and the Kalahari cratons since deformation is diachronous along strike of the transcontinental system (Hanson *et al.*, 1994).