CHAPTER 8

DISCUSSION AND CONCLUSIONS

8.1 Pre-Umkondo Deformation – D_1 and D_2

The Zimbabwe craton was affected by two major deformations prior to deposition of the Umkondo group at ~ c. 1100 Ma in eastern Zimbabwe (Table 8.1). The first deformation, D_1, resulted in folding of the Cronley Schist belt about an east northeast trending axis prior to the emplacement of the Chibi granites at c. 2650 Ma. Chenjerai (1995) also documented this deformation in the Mutare greenstone belt. The deformation was possibly associated with north northwest-south southeast regional compressive stresses.

The second major deformation, D_2, in eastern Zimbabwe is related to the north northwest-south southeast directed maximum compressive stresses that were associated with the north-directed thrusting of the North Marginal Zone of the Limpopo belt onto the Zimbabwe craton. D_2 structures include dextral strike-slip, northeast to east trending shear zones in eastern Zimbabwe. North northwest to north northeast trending faults that cut the Zimbabwe craton are probably related to the Popoteke set of faults, which were propagated during the Limpopo orogeny in response to the north northwest-south southeast directed maximum compressive stresses. These faults exerted a strong structural control on the subsequent emplacement of mafic dykes in the Zimbabwe craton. The similarity of the orientation of the Great Dyke emplaced at 2575 ± 0.7 Ma (Oberthür *et al.*, 2002) and a north northwest trending dyke emplaced at 724 ± 2.1 Ma dated in this study, with the Popoteke fault set show the significance of the Popoteke set of faults in controlling emplacement of mafic dykes at various ages of the geological time scale.

Table 8.1. A summary of the major metamorphic, deformation and magmatic events in eastern Zimbabwe.

Age	**Metamorphism**	**Deformation**	**Magmatism**
≥ c. 2.65 Ga	M_1	D_1	
c. 2.62-2.58 Ga	M_2	D_2 Limpopo orogeny	
c. 1.8 Ga			Mashonaland sills/dykes
c. 1105 - 1109 Ma			Umkondo sills/dykes
c. 724 Ma			Pan African dykes
c. 550 Ga	M_3	D_3 Mozambique orogeny	

8.2. Evolution of the Umkondo group and its Significance

The structural and lithological similarities (section 5.9) exhibited by rocks of the Zimbabwe and Mozambique facies probably indicate that rocks of the Mozambique facies are the strongly deformed and highly metamorphosed equivalent of the Zimbabwe facies. The Zimbabwe facies shales and slates are possibly equivalent to the pelitic schists and mylonites of the Mozambique facies and the arkoses are equivalent to the Mozambique facies psammites. Small-scale structures that occur in the Zimbabwe facies, i.e. west-verging folds and thrusts are equivalent to the large scale folds and thrusts that occur in the Zimbabwe facies. The Zimbabwe facies of the Umkondo group consists of pebbly basal arkoses that are succeeded by shallow-marine stromatolitic limestones, cherts and the cross-bedded upper arkose unit. These rocks record deposition in fluvial to shallow-water deltaic environments with episodic input of distal bimodal pyroclastic debris. The Umkondo group was deposited in an epicontinental basin on a flat, peneplained surface developed on the Zimbabwe Archean craton. Lateral continuity of the main stratigraphic units suggests a single depositional basin with a north-south dimension of at least 400 km.

8.3 Pan African Deformation – D_3

Rocks of the Mozambique facies of the Umkondo group were intensely and penetratively deformed and metamorphosed during the D_3 Pan African Mozambique orogeny, dated at ~ 550 Ma (Munyanyiwa, 1999). The Mozambique facies is definitely allochtonous and thrust to the west during D_3. D_3 structures such as a subhorizontal lineation, west verging folds with sub-horizontal north-south fold axes, S-C fabrics and sigma clasts are consistent with west directed thrusting. The north trending Mozambique belt represents a suture zone involved in Gondwana assembly and records a 500 Ma history of accretion culminating in collision of East Africa and Antarctica at ~ c. 550 Ma (Dirks *et al.*, 1998).

In contrast to the Mozambique facies, the structural evolution of the Zimbabwe facies has been a subject of controversy since there is evidence for some allochtoneity in some places but autochtoneity in others. The Zimbabwe facies is interpreted to be underlain by a thrust to the east of Chimanimani since the Zimbabwe facies overlies the Mozambique facies, which is intensely deformed and was thrust to the west (Dirks, personal communication, 1999). Small-scale west-verging folds and thrusts that occur in places in the Zimbabwe facies clearly indicate that the Zimbabwe facies was locally affected by the Mozambique orogeny. These facts permit the suggestion that the Zimbabwe facies may be allochtonous.

However, lack of discontinuity at the Archean basement granites/Zimbabwe facies contact in many exposures observed in Chipinge and Chimanimani districts indicates that the contact is locally a nonconformity to the west. In one locality (Grid Ref.: 446960, 7818693), the basal pebbly arkose unit overlies a matrix of weathered granite suggesting that the contact is at least locally a nonconformity. Moreover, some sills pass without break from the Archean basement granites into the Zimbabwe facies. These facts clearly suggest that the Zimbabwe facies is not wholly underlain by a thrust. The thrust that is inferred to underlie the Zimbabwe facies (Dirks, personal communication, 1999) possibly dies out in the east and the effects of thrusting and deformation in the Zimbabwe facies progressively diminishes towards west. The occurrence of small-scale, west-verging

structures on a scale of a few metres to tens of metres in the Zimbabwe facies permit an inference that some parts of the Zimbabwe facies were locally thrust to the west, but these structures have not accommodated movement on the scale of more than hundreds of metres. The Zimbabwe facies of the Umkondo group is therefore autochthonous on a large scale.

8.4. Magmatism in Eastern Zimbabwe

Pre-existing faults exerted a strong structural control on the emplacement of dykes in eastern Zimbabwe. Faults that cut the Umkondo group were probably reactivated after deposition and lithification of the Umkondo strata. Consequently, dykes of different ages occur in close spatial association and share a common trend. At least three generations of dykes occur in eastern Zimbabwe. These are of Mashonaland, Umkondo and Pan African ages. The Mashonaland and Umkondo igneous events dated at ~ 1.8 and 1.1 Ga have affected the Zimbabwe craton in eastern Zimbabwe. There is however, a possibility of yet an additional Pan African igneous event at about 0.7 Ga. The probable occurrence of three generations of dykes is consistent with geochemical results obtained from these dykes (Mutare dykes) by Ward (2002). Ward (2002) identified three possible magma sources for the Mutare dykes. The Mashonaland dolerites have been documented over much of northeastern and eastern Zimbabwe (McElhinny and Opdyke, 1964). Thus, the classification of dyke swarms on the basis of trends without precise age data for individual dykes is an oversimplification. The dyke swarms of Wilson *et al. (1987)* are strictly not swarms since a dyke swarm should comprise dykes that are contiguous, contemporaneous and consanguineous (Ward *et al.*, 1999, 2000). These dykes were therefore emplaced at different tectonomagmatic regimes that were related to Rodinia assembly and breakup, and subsequent assembly of Gondwana.

8.5. The 1.1 Ga Umkondo Igneous Event in Zimbabwe

Available precise U-Pb zircon/baddeleyite dates constrain the emplacement age of Umkondo sills that intrude the lower, middle and upper stratigraphy of the Zimbabwe facies of the Umkondo group in eastern Zimbabwe to between 1105 Ma and 1109 Ma.

The occurrence of peperite along one well-exposed sill margin suggests that the Umkondo sills were penecontemporaneous with or immediately followed sedimentation in the Umkondo basin. This idea is further substantiated by the occurrence of basalts that are conformably interbedded with Umkondo metasedimentary rocks and are geochemically similar to the Umkondo dolerites (Munyanyiwa, 1999). Mafic tuffs that are interbedded with the Zimbabwe facies strata record input of pyroclastic material into the Umkondo basin and possibly reflect explosive volcanic activity related to the Umkondo igneous event. These facts suggest the presence of a flat, peneplained Umkondo basin located right on the eastern edge of the Kalahari Craton at c. 1100 Ma (Mukwakwami *et al.*, 2001).

Understanding the palaeogeography of the Umkondo group may therefore provide a useful constraint on Rodinia reconstructions. If this edge of Kalahari Craton originally was adjacent to another craton within Rodinia, then a model of Rodinia at c.1100 Ma should show the Umkondo sedimentary basin on the Kalahari Craton matching with a coeval basin on the other craton.

Disparate subgroups occur in the Mutare, Guruve and Kamativi dykes. The occurrence of a subgroup in each of the Mutare and Guruve dykes, which have geochemical signatures similar to Umkondo dolerites (Ward, 2002) raises the possibility that at least some of the dykes belong to the Umkondo igneous event. However, the spatial extent of igneous rocks associated with the Umkondo igneous event in Zimbabwe remains a subject of speculation since the majority of the dykes did not yield any baddeleyite/zircon grains for radiometric dating.

8.6. Implications of the Age of Umkondo Sills

Available precise U-Pb zircon/baddeleyite ages and palaeomagnetic data in the Umkondo Province constrain the main magmatism to have occurred at c. 1111-1105 Ma across the Kalahari Craton (Hanson *et al.*, 2003). The Kalahari Craton is bordered by the c. 13-1.0 Ga Namaqua-Natal-Maud belt (Thomas *et al.*, 1994; Groenewald *et al.*, 1995; Powell *et*

al., 2001). U-Pb zircon ages of 1083 ± 6 Ma (Johnston *et al.*, 2000) and 1057 ± 8 to 1029 ± 10 (Clifford *et al.*, 1995; Robb *et al.*, 1999) have been documented for mafic suites that intruded the Namaqua-Natal belt. The mafic rocks in the Namaqua-Natal Belt were emplaced in close association with peak metamorphism and widespread crustal anatexis and may be indicators of advective heat transport to the crust via mantle-derived magmas (Thomas *et al.*, 1992; Gibson *et al.*, 1996). Although the relationship of these rocks to the Umkondo Province is not known, Hanson *et al.* (2004) assert that there is a possibility that the thermal and magmatic evolution of coeval parts of the Namaqua-Natal-Maud belt were influenced by large-scale mantle processes recorded by the Umkondo province.

Protolith crystallization ages that fall within the range of Umkondo igneous activity have been documented in the Pan-African Zambezi and Mozambique Belts (Hanson *et al.*, 2004). The Mpande orthogneiss, which intrudes the Zambezi supracrustal sequence in the Zambezi Belt in Zambia has a U-Pb zircon age of c. 1106 ± 19 Ma (Hanson *et al.* 1988). Goscombe *et al.* (2000) obtained a SHRIMP U-Pb zircon age of c.1087 ± 9 for the Chewore Inliers in northwestern Zimbabwe further east in the Zambezi Belt. Granite and granodiorite orthogneiss in the Mozambique Belt gave SHRIMP U-Pb zircon ages of 1112 ± 18 and 1108 ± 12 Ma (Manhica *et al.*, 2001). These age data are within the margin of errors for the age of igneous rocks in the Umkondo Province and permit a plausible suggestion that the Mesoproterozoic magmatism recorded in the Zambezi and Mozambique belts may be related to the Umkondo Province or vice-versa. Rb-Sr whole-rock data yielded an age of 1119 ± 27 for extensive mafic sheets intruding the Chela Group and older basement the Congo Craton (Carvahlo *et al.*, 1987; Carvahlo and Alves, 1993). Hanson *et al.* (2004) consequently speculate that the mafic sheets may be contemporaneous with the Umkondo Province. This would suggest that the Umkondo Province extends to the Damara Belt and into the Congo Craton (Hanson *et al.*, 2004) and support the supposition that the Damara Belt, the Lufilian and the Zambezi Belt were formed by closure of a series of intracontinental rifts or narrow ocean basins (Kröner, 1993; Miller, 1983; Kampunzu *et al.*, 1991, 2000b; Hanson *et al.*, 1994; Hanson, 2003).

Magmatism in the Umkondo Province is inferred to have occurred during culminating phases of assembly of the Rodinia supercontinent, in contrast to many other large igneous provinces that formed during supercontinent break-up (White and McKenzie, 1989, 1995; Hill, 1991; Storey, 1995; Courtillot *et al.* 1999; Ernst and Buchan, 2001). Emplacement of large volumes of tholeiitic magma in the Umkondo province over a short time interval has been interpreted by Hanson *et al.* (1998b, 2004) to reflect decompressional partial melting of anomalously hot mantle (Richards *et al.*, 1989; White and McKenzie, 1989, 1995; Coffin and Eldholm, 1994; Hawkesworth *et al.*, 1999; Ernst and Buchan, 2001). Faulting driven by stresses transmitted cratonwide during collisional orogenesis along the margin is likely to have controlled the emplacement of magma in parts of the province (Dalziel *et al.*, 2000). The presence of a mantle plume beneath the Kalahari Craton is not supported by available geochemical data since plume signatures are lacking in most of the Umkondo rocks, although the Guruve and Mutare dykes that are distinctively enriched in trace elements may reflect a plume contribution (Hanson *et al.*, 2004). However, the ages of these dykes are not well constrained and can therefore not be wholly relied upon since they may indicate different magmatic events.

Although the Umkondo Province in the Kalahari Craton shows striking similarities in age and tectonic setting to the Keeweenawan Province in the Laurentia Craton, the genetic relationship between the two provinces remains unclear. The similarities in geochronological and palaeomagnetic data probably indicate that the two provinces either represent coeval, but spatially unrelated large igneous provinces emplaced on two cratons or they represent a single large igneous province that formed during Rodinia assembly (Hanson *et al.*, 1998b, 2004a). The position of the Kalahari craton in Rodinia configuration remains uncertain.

8.7. Pan African Magmatism

An age of 724 ± 2.1 Ma for a north-northwest trending dyke that intrudes the Zimbabwe facies raises a possibility that some of the set 2 dykes, i.e. Mutare dykes of Wilson et al (1987) were contemporaneous with this dyke. The maximum principal stress (σ_1) during

the emplacement of the dyke was north northwest-south southeast, assuming a minimum magma pressure needed to dilate north northwest trending fractures. The orientation of σ_1 at the time of dyke emplacement is consistent with contractional deformation in the Zambezi belt resulting from the collision between the Congo and the Kalahari cratons during Gondwana assembly. Perturbations on the K-Ar system (table 2.1; Snelling *et al.*, 1964; Vail and Dodson, 1969) of some Umkondo sills and the U-Pb system (Wingate, 2000) of the Great Dyke around this time show that the tectonomagmatic event may have been widespread across the Zimbabwe craton. It is further inferred that some northeast to east trending dykes (set 1 dykes) were emplaced in response to an east-west maximum principal stress generated during the latest stages of the Mozambique orogeny. Alternatively, the possibility that some set 1 and set 2 dykes were contemporaneous cannot be ruled out. Contemporaneous emplacement of the two dyke sets could occur when σ_1 was oriented in a north northeast south southwest direction and such stresses may have been generated during collision of the Congo and the Kalahari craton during the Zambezi orogeny. These speculations remain to be proven after further precise geochronological work on the dykes.

8.8 Conclusions and Recommendations

The Umkondo Group in eastern Zimbabwe was deposited nonconformably on the east side of the Kalahari Craton and the Zimbabwe facies of the group and is autochtonous at a large scale. The sedimentary strata of the Umkondo Group were deposited in fluvial to shallow marine environments and record the presence of a major epicontinental basin in this part of southern Africa. The widespread 1100 Ma Umkondo Province mafic magmatism was penecontemporaneous with or immediately followed sedimentation in the Umkondo basin of east Zimbabwe. The Umkondo igneous event is coeval with widespread magmatism on the Laurentia craton. The two igneous provinces may either imply the existence of two coeval, but spatially unrelated large igneous provinces in the two cratons or may represent a single large igneous province that was associated with Rodinia assembly.

Umkondo sills that are intrusive into rocks of the Zimbabwe facies of the Umkondo group are autochtonous since they intrude an autochtonous sedimentary strata. These sills can provide additional primary palaeopoles that can be used to constrain the position of the Kalahari craton in Rodinia t at c. 1100 Ma. A Pan African age of 724 ± 2.1 Ma for one mafic dyke in eastern Zimbabwe raises the possibility of the existence of another mafic igneous event that has not been documented across the Zimbabwe craton. The igneous event was possibly associated with the breakup of Rodinia and subsequent assembly of Gondwana at ~ c. 550 Ma. Additional geochronological work on mafic dykes in Zimbabwe is necessary to establish the extent of the Umkondo and the probable Pan African igneous events across the Zimbabwe craton.