CHAPTER 4

METAMORPHISM AND ALTERATION IN EASTERN ZIMBAWE

4.0 Introduction

Rocks of the Umkondo group and the underlying Zimbabwe Archean basement are variably altered and metamorphosed. Archean regional metamorphism in eastern Zimbabwe is a complex subject that deserves a more detailed separate study. In this study, Archean metamorphism in eastern Zimbabwe needs to be defined before Pan African for purposes of continuity. The metamorphic evolution of the Zimbabwe craton has been studied from remnant mafic rocks of the greenstones and mafic dykes that intruded the craton in the mapped area (Fig. 1.10). However, these mafic rock units occur as relatively small units and are probably too small to indicate the regional metamorphism and have been affected by thermal metamorphism during subsequent emplacement of younger granitic intrusions.

The metamorphic evolution of the Umkondo group and the underlying Archean basement rocks in eastern Zimbabwe is outlined and discussed in this chapter. An attempt is made to constrain the metamorphic history of the Zimbabwe craton from mafic rocks in the remnant greenstones, e.g. the Cronley Schist belt that occurs about 5 km north northeast of the mapped area (Fig. 1.3), since the granites are not very sensitive to temperature-pressure changes. An outline of the metamorphism of rocks of the Mozambique facies is partly based on field observations and partly on discussions held with Dirks in 1999 during a field excursion in the area east of Chimanimani town (Fig. 1.3). Metamorphic textures and assemblages in dolerite sills that intrude the Zimbabwe facies and mafic tuffs that are inter-bedded with the Zimbabwe facies metasedimentary rocks are described, based on thin section study, and are used to constrain the metamorphic evolution of the Zimbabwe facies. Hydrothermal alteration in the mapped area was deduced from veins that cut Umkondo sills and cherts of the Zimbabwe facies.

4.1 Pre-Umkondo Regional Metamorphism

The Archean basement granites and gneisses underlying the Zimbabwe facies to the west comprises some gneissic segments and mafic enclaves that bare record of metamorphism prior to deposition of the Umkondo group and emplacement of Umkondo dolerites. The metamorphic history of Archean basement rocks in the study area can be deduced from amphibolite dykes that intruded Archean granites (section 3.1.3) and remnant greenstone rocks of the Cronley Schist belt that occurs about 5 km north northeast of the mapped area (Fig. 1.3). The Cronley Schist belt (Fig. 1.3) records the first regional metamorphic event in Archean basement rocks. The metamorphic event was associated with folding and shearing of the Cronley Schist belt, which predates the emplacement of the Chibi granites at c. 2650 Ma (section 5.11.1). In the mapped area, metamorphism of the Archean basement granites can be constrained from amphibolite dykes and metaironstone horizons.

4.1.1 Metamorphism of Amphibolite Dykes

Schistose amphibolite dykes that intruded Archean basement granites to the south of Chitimani School (Fig. 1.10) appear to record two metamorphic events. The dykes have relict primary clinopyroxene that has been extensively replaced by actinolite and hornblende (Fig. 4.1). Hornblende and actinolite define a schistose fabric. Calcification of plagioclase occurred during metamorphism resulting in the formation of andesine plagioclase with a composition that ranges from An_{42}- An_{48}. The metamorphic event is characterised by the assemblage hornblende-plagioclase-actinolite-quartz. The coexistence of hornblende and actinolite, and the occurrence of andesine plagioclase are indicative of upper greenschist to lower amphibolite facies grades of metamorphism (Spear, 1993). Retrograde metamorphism occurred later and was associated with replacement of andesine plagioclase by epidote, recrystallisation of actinolite and pseudomorphic replacement of actinolite by chlorite along grain boundaries; and the replacement of hornblende by actinolite and minor chlorite. The assemblage chlorite-actinolite-epidote-quartz is indicative of the greenschist facies grade of metamorphism.

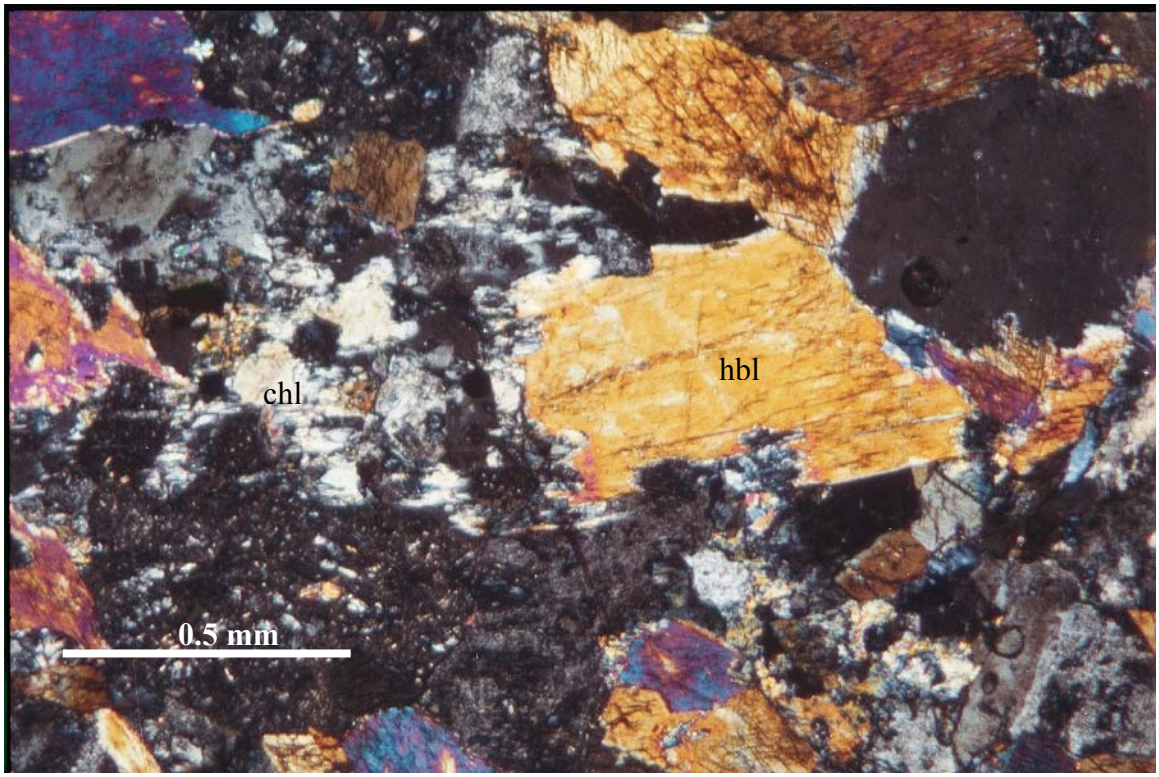
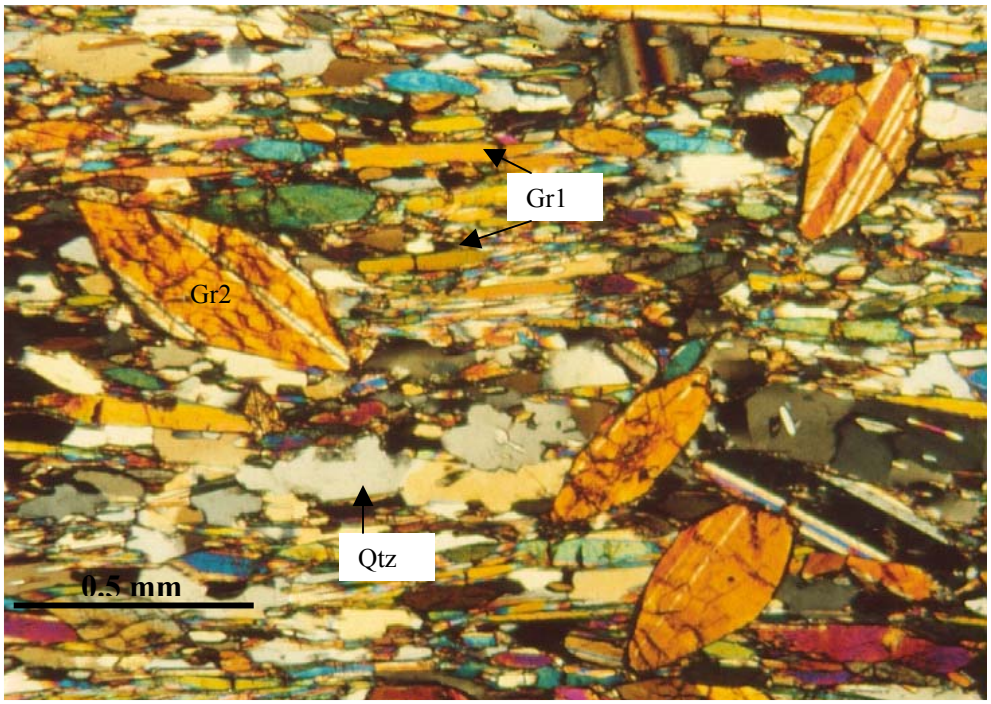


Fig. 4.1. Amphibolite (metamorphosed dolerite) dyke with hornblende (hbl) being replaced by actinolite and chlorite (chl), which indicate retrograde metamorphism. Crossed Polars. Sample JM0217; Grid Ref.: 451463, 7830598.

4.1.2 Metamorphism of Metaironstone

Metaironstone is cut by a northeast trending shear zone and has been sheared into a quartz-grunerite schist. The presence of quartz and grunerite is indicative of an iron-rich sedimentary rock precursor that under went prograde metamorphism to amphibolite facies grade of metamorphism during M_1. The schistosity is defined by alignment of small grains of grunerite that are about 0.1 mm wide and quartz (Fig. 4.2). Quartz ribbons that are parallel to the schistose fabric also occur. Larger grains of grunerite that are up to 0.5 mm wide grow across the schistosity and define a crenulation cleavage that is very clear in hand specimen (Fig. 5.2). Grunerite grains defining the two fabrics possibly developed in a single metamorphic event during progressive deformation and metamorphism. Grunerite is replaced by acicular actinolite and chlorite, which indicates greenschist facies retrogression of the amphibolite facies assemblage in the quartz-grunerite during a second metamorphic event.



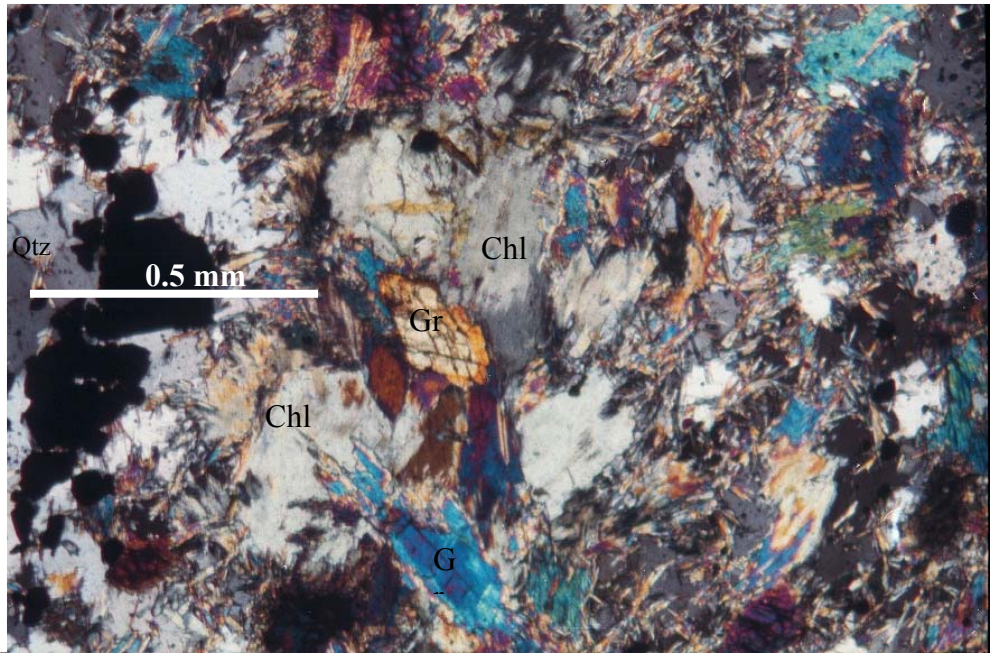


Fig. 4.2. The upper photograph shows schistosity in metaironstone defined by preferential alignment of small crystals of grunerite (Gr1) + chlorite (Chl) and quartz (Qtz). Larger crystals of grunerite (Gr2) that are oblique to the schistosity suggests static new growth across foliation. The presence of grunerite suggests amphibolite facies grade of metamorphism. Crossed polars. Sample JM 0151; Grid Ref.: 451815, 7832550.The lower photograph shows acicular actinolite crystals that are a product of replacement of recrystallisation of actinolite and replacement of grunerite. Crossed polars. Sample JM0149; Grid Ref.: 451850, 7832547.

4.2 Metamorphism of the Mozambique Facies Rocks

Metamorphic grade in the Mozambique facies rocks near the Zimbabwe border is in the amphibolite facies (Tennant, 1995; Werner and Schmidt, 1995; Dirks, Personal Communication, 1999). A pelitic mylonite that occurs at the National Parks Hut (Fig. 1.3, Grid Ref.: 502011, 7812630) is characterised by the assemblage kyanite-chloritoid-chlorite-muscovite-quartz with remnants of sillimanite (Dirks, 1999 personal communication). The metamorphic assemblage is interpreted to indicate amphibolite facies grade of metamorphism at P-T conditions of about 580°C and 5-7 kbar for the Mozambique facies (Dirks, 1999, personal communication). Strongly tectonised and structurally conformable bodies of metadolerites within the Mozambique facies metasedimentary rocks have hornblende-plagioclase assemblages (Munyanyiwa, 1999) that also reflect amphibolite grade of metamorphism for the metadolerites, and hence the Mozambique facies rocks. The metamorphic grade increases to upper amphibolite- and granulite facies farther east in Mozambique (Vail, 1966). The metamorphic grade associated with the Mozambique orogeny in general decreases from east to west.

4.3 Metamorphism of the Zimbabwe Facies

Metamorphism of the Zimbabwe facies is well constrained in volcanic mafic rocks that are interbedded with metasedimentary rocks of the Zimbabwe facies and Umkondo dolerites that intruded the strata. The metamorphic history of the Zimbabwe facies can therefore be indirectly ascertained from these mafic rocks since they are more sensitive to temperature and pressure changes (Spear, 1993) than the arkose and chert units that make up the greater part of the Zimbabwe facies. The Zimbabwe facies shales and slates are also important in determining the grade of metamorphism in the Zimbabwe facies.

4.3.1 Metamorphism of Pelites - the Zimbabwe Facies

Microscope study has shown that slates of the Zimbabwe facies comprise of quartz, chlorite, plagioclase, K-feldspar and epidote. Reaction textures, and hence the P-T paths, are difficult to establish in the slates using thin section study because the slates are very fine grained and have no porphyroblasts. However, the observed mineral assemblage of quartz-plagioclase-chlorite-K-feldspar-epidote is interpreted to indicate the chlorite zone (Yardley, 1989; Spear, 1993). The slaty cleavage is known to form in tectonically deformed rocks that are found in regions of low-grade regional metamorphism, that is greenschist facies or lower (Ramsay and Huber, 1987). These observations show that the slates, and hence the Zimbabwe facies rocks were metamorphosed at low greenschist facies.

4.3.2 Metamorphism of Metabasites - the Zimbabwe Facies

Analcite coexists with quartz in a fine-grained mafic tuff (Grid Ref.: 474277, 8056126) and probably formed from the breakdown of albite during retrograde metamorphism according to the reaction below:

Albite	+	Water	→	Analcite	+	Quartz
($NaAlSi_3O_8$)		(H_2O)		($NaAlSi_2O_6$. H_2O)		(SiO_2)

The coexistence of analcite and quartz suggests zeolite facies grade of metamorphism since these minerals are stable at low temperatures and pressures of not more than 200ºC and 3 kbar respectively (Spear, 1993).

Radiating fibrous aggregates of prehnite occur as amygdales in association with pumpellyite, epidote and anhedral quartz in massive, amygdaloidal, vitrophyric basalt (Fig. 4.3) that is interbedded with- and caps the Zimbabwe facies arkoses. Relict igneous minerals, i.e. clinopyroxene and plagioclase are preserved. Mafic lapilli tuffs that are interebedded with the chert and upper arkose units have radiating pockets of fibrous

aggregates of prehnite that occur in association with metamorphic chlorite, epidote and quartz (Fig. 4.4). In peperite, prehnite occurs in association with pseudomorphs of chlorite and actinolite after clinopyroxene, and epidote. The metamorphic assemblages are indicative of the prehnite-pumpellyite facies low-grade metamorphism and hence suggest low-grade metamorphism.

Clinopyroxene is commonly preserved in dolerite dykes and sills, but some crystals have been entirely- or partially replaced by pseudomorphs of actinolite and/or chlorite along grain boundaries and cleavage planes (Figs. 4.5 and 4.6). Intergrowths of chlorite, biotite and magnetite (Fig. 4.7) have partially replaced actinolite along grain boundaries in dolerite sills and dykes. Intergrowths of chlorite and biotite often occur as pseudomorphs after actinolite in dolerites (Fig. 4.8). Fine grained chlorite replaces actinolite in dolerites (Fig. 4.9). Pseudomorphic replacement of plagioclase by epidote and sericite along cleavage planes and grain boundaries is a common feature in the dolerites.

The replacement textures are indicative of retrograde metamorphism and show metamorphic changes that take place at progressively lower temperatures of metamorphism in mafic rocks. The mafic rocks therefore show characteristic metamorphic mineral assemblages of the greenschist and prehnite-pumpellyite facies that are typical of progressive metamorphism of mafic rocks down temperature to greenschist facies (Winkler, 1979; Spear, 1993).

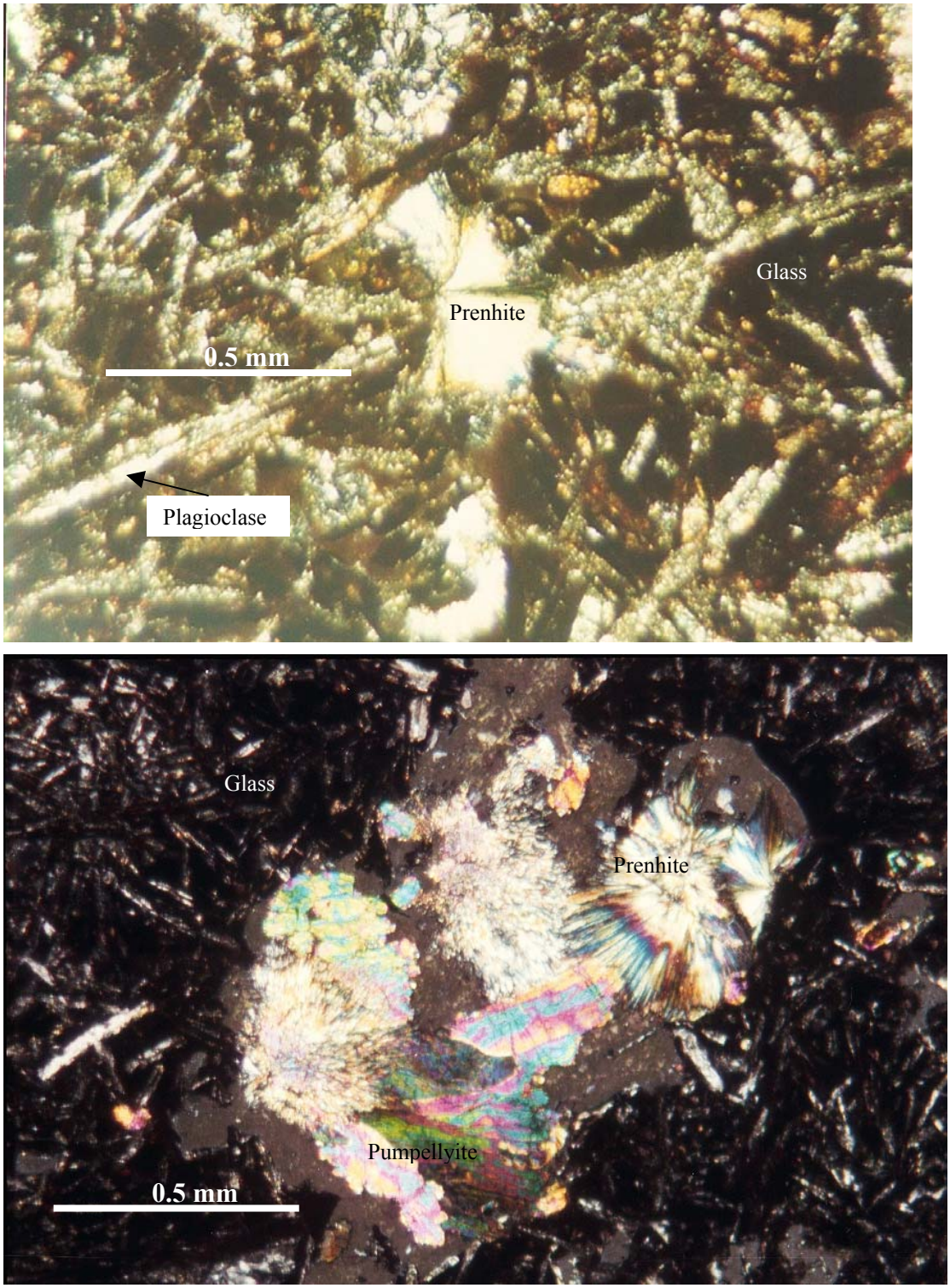


Fig. 4.3. Radiating groups of crystals of prehnite occur as patches (top photograph) or as amygdales (bottom photograph) in an amygdaloidal hypocrystalline basalt. Prehnite occurs in association with pumpellyite, which indicate prehnite-pumpellyite grade of metamorphism for the Umkondo basalts, and hence the Zimbabwe facies. Crossed polars. Sample JM0115; Grid Ref.: 440669, 7819648.

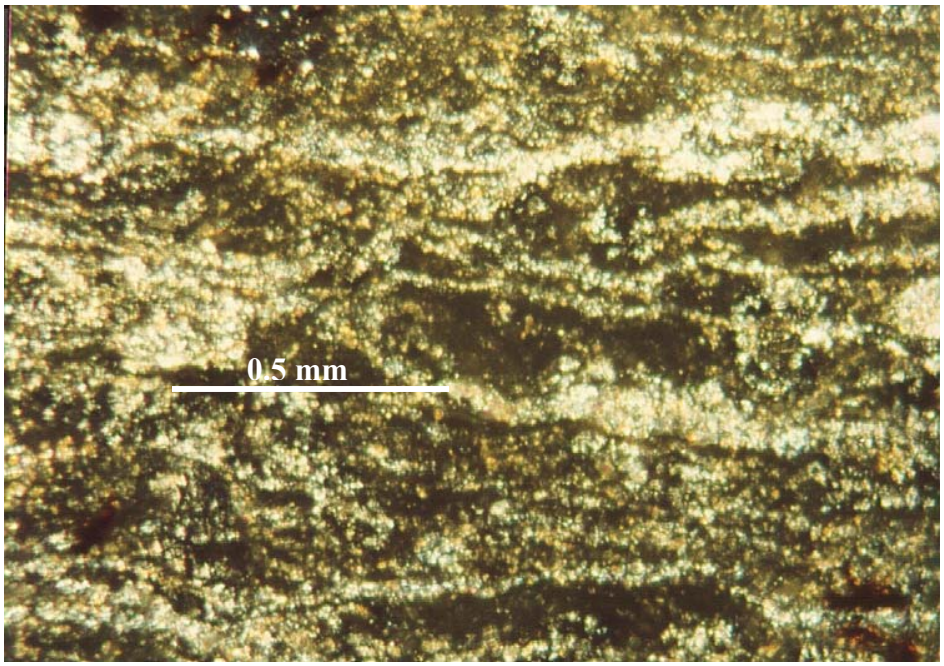


Fig. 4.4. Anastomosing layering in a mafic tuff. The rock consists of metamorphic minerals, i.e. chlorite, epidote, quartz and sericitized plagioclase, and minor analcite and prehnite. The dark material probably represents glass before deformation. Crossed polars. Sample JM0124; Grid Ref. 474277, 8056126.

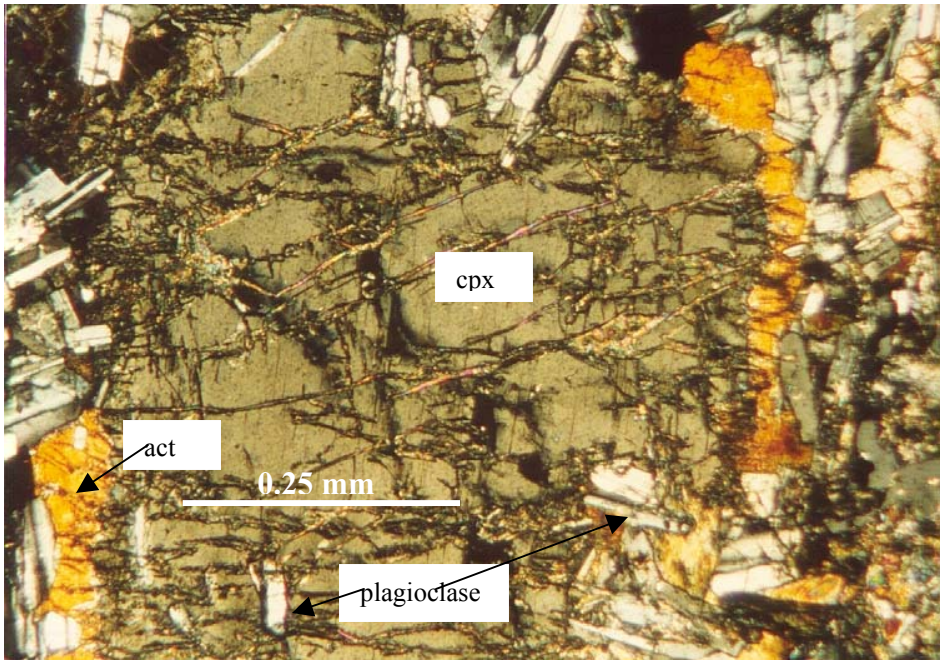


Fig. 4.5. Clinopyroxene rimmed by actinolite (act) suggesting retrograde metamorphism. Relict ophitic texture occurs in clinopyroxene (cpx), i.e. plagioclase crystals are enclosed clinopyroxene. Crossed polars. Sample JM0110; Grid Ref. 436702, 7800301.

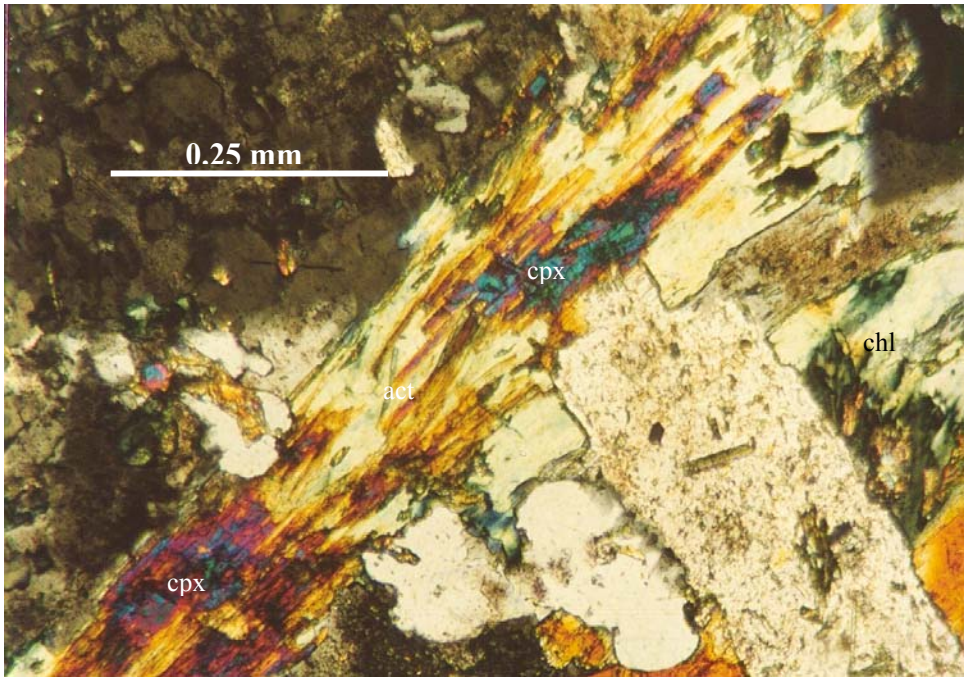


Fig. 4.6. Pseudomorphs of actinolite after clinopyroxene. Relict clinopyroxene (cpx) occurs near the bottom left corner and near the centre of the photograph. Actinolite (act) coexists with chlorite (chl). Crossed polars. Sample JM 0103; Grid Ref.: 464923, 7787195.

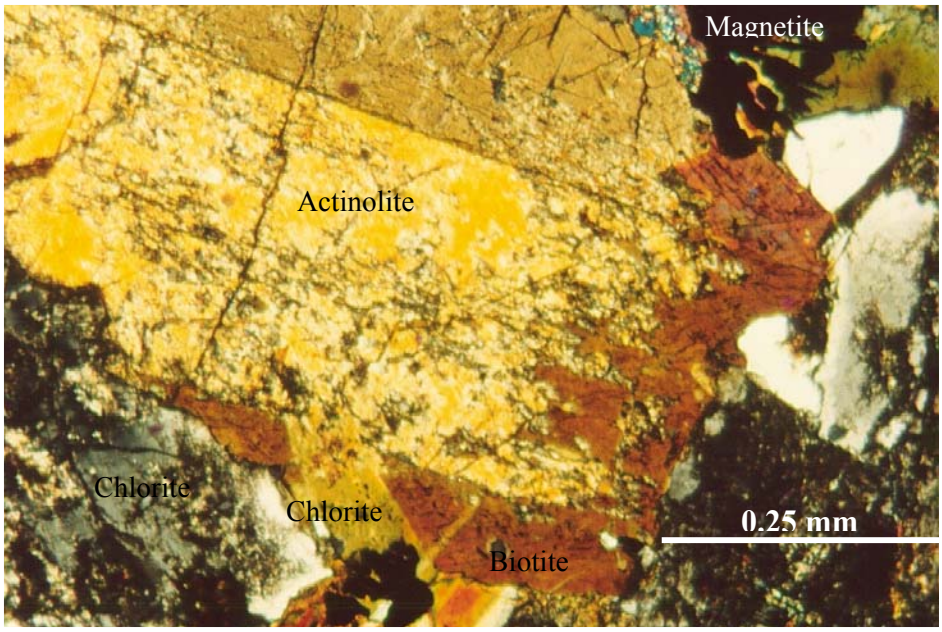


Fig. 4.7. Intergrowths of biotite and chlorite and an opaque mineral (magnetite) replacing actinolite in a gabbro. Crossed polars. Sample JM0137; Grid Ref.: 462471, 7836120.

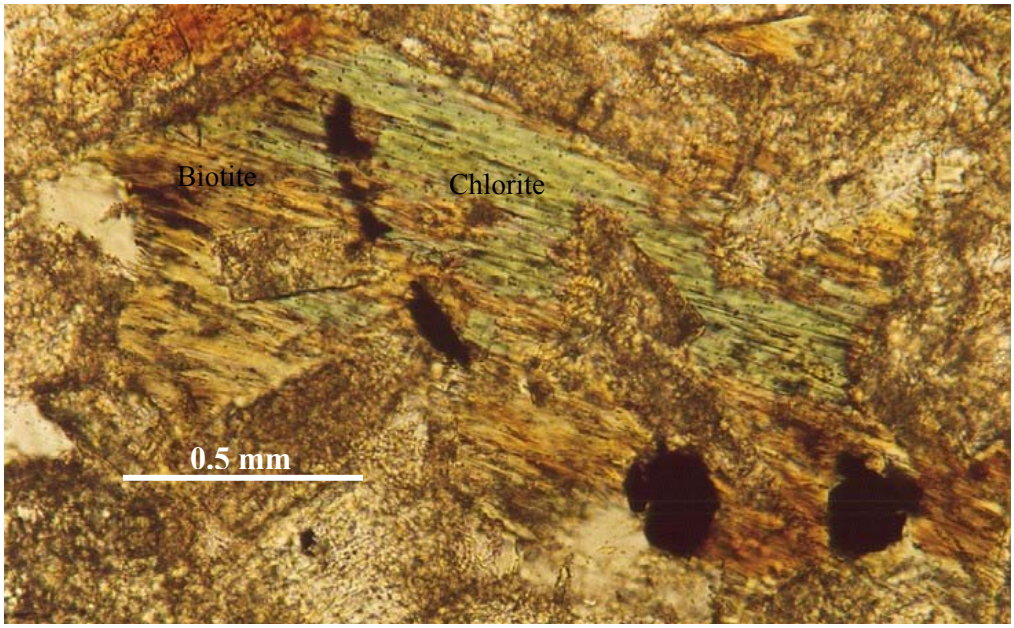


Fig. 4.8. Pseudomorphs of chlorite intergrown with biotite after actinolite. Plain polarised light. Sample JM0137; Grid Ref.: 462471, 7836120

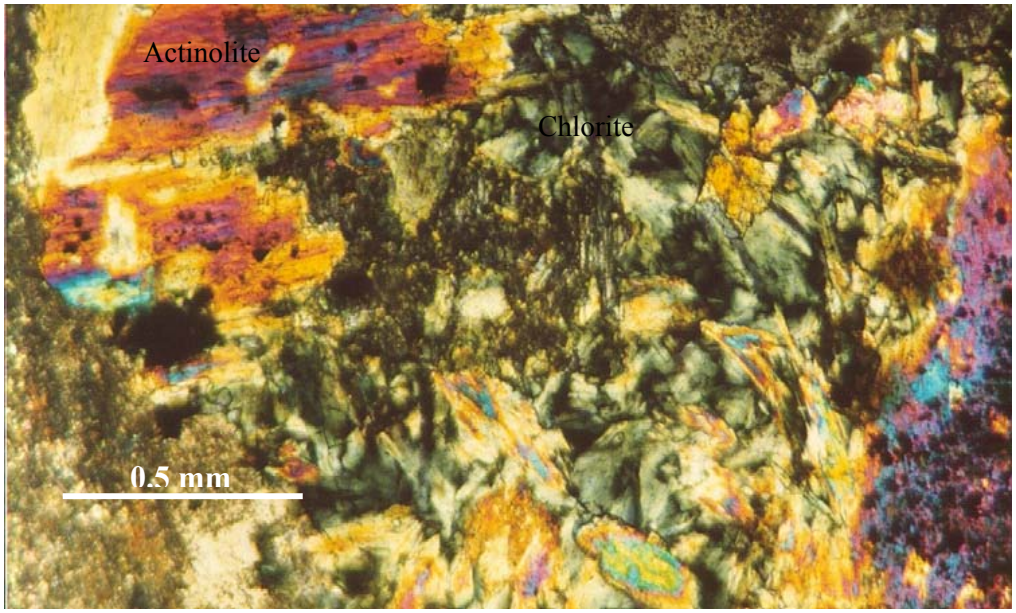


Fig. 4.9. Fine grains of chlorite replacing actinolite in a dolerite, which suggest metamorphism down temperature. Crossed polars. Sample JM0103; Grid Ref.: 464923, 7787195.

4.4 Metasomatism

Hydrothermal alteration in the Chimanimani area postdates the emplacement of Umkondo dolerites. Metasomatism was characterised by circulation of SiO_2-rich hydrothermal fluids that are evidenced by the occurrence of two generations of sphene-bearing epidote-quartz veins in the area around Mutambara Mission. The veins cut a major Umkondo sill exposed in the Umvumvumvu River (Fig. 4.10). The first generation of veins cuts an Umkondo sill, but terminates against two aphyric, post-Umkondo dykes that trend north and north-northeast. Thus the first generation of veins predate the emplacement of the post-Umkondo dykes. The second generation of veins cut the first generation (Fig. 4.10) and the post Umkondo dykes. The second phase of hydrothermal fluid circulation postdates the emplacement of these dykes. Wall rock alteration, marked by a chlorite zone, is associated with some of these veins that cut the sill.

The Zimbabwe facies has also been affected by circulation of hydrothermal fluids as is evidenced by the presence of epidote-rich quartz veins that cut primary layering in cherts (Grid Ref.: 447018, 7818699). Sub-vertical to vertical, east-trending epidote-quartz veins that are up to 5mm wide also occur along joints in porphyritic granite east of Chiramba School (Grid Ref.:459900, 7835875). The veins are red-brown in places and possibly reflect the presence of oxides in the hydrothermal fluids. Reddening of the feldspars has occurred near the red-brown veins.

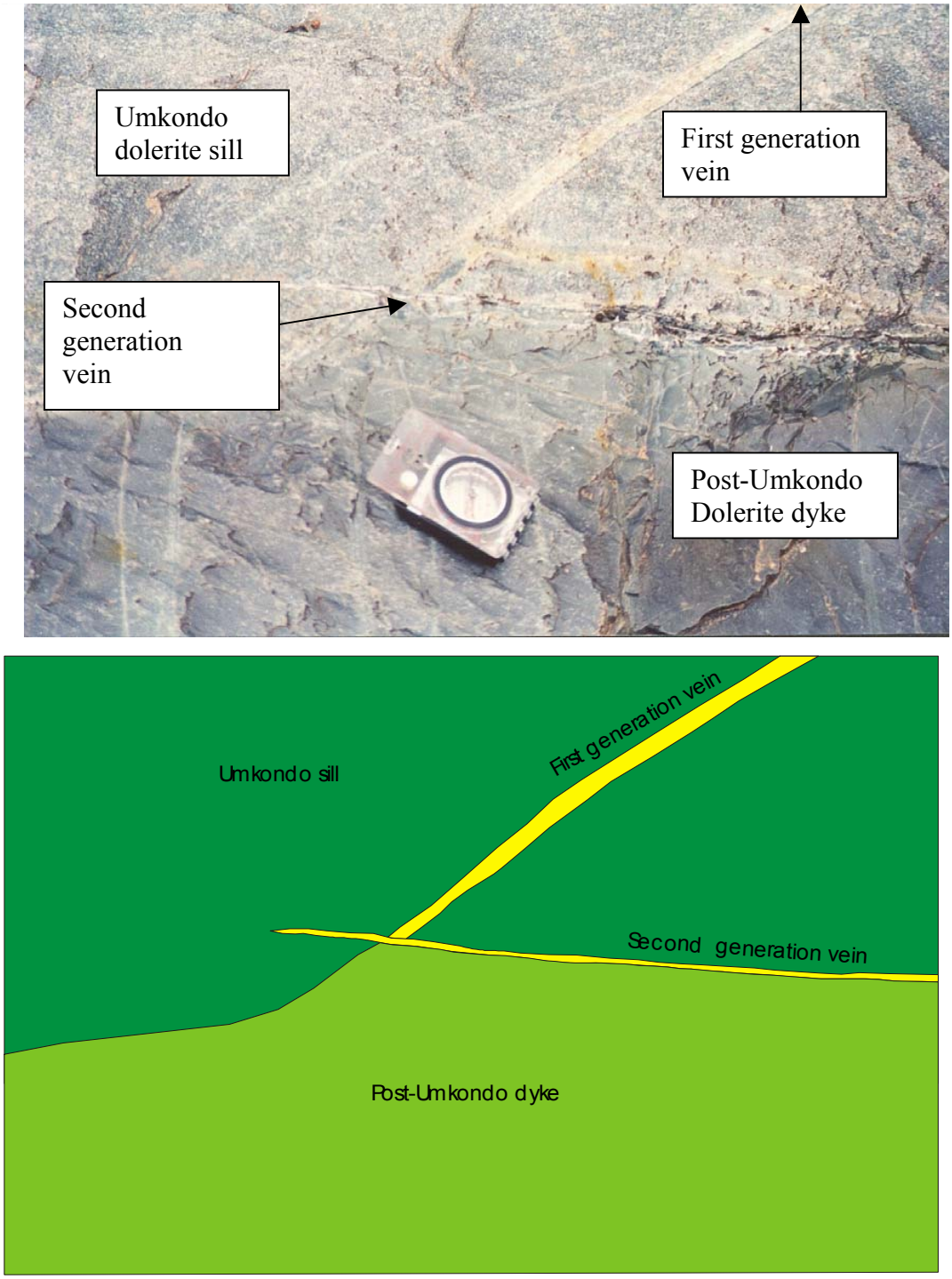


Fig. 4.10. Two generations of epidote-quartz veins cutting an Umkondo sill in the Umvumvumvu River. The first generation of veins terminates against a post-Umkondo dyke. The second generation of veins cut the post-Umkondo dyke and the first generation of veins without any displacement. The two generations of veins represent two generations of hydrothermal alterations that affected the Zimbabwe facies of the Umkondo Group. Grid Ref.: 461700, 7840500.

4.5 Discussion and Conclusions

4.5.1 Metamorphism in the Archean

Quantitative P-T estimates for the Archean basement granites and associated greenstones in Zimbabwe are scarce, largely owing to the difficulty of obtaining precise pressure estimates in low-grade metamorphic rocks (Jelsma, 1993). Saggerson and Turner (1976) classified the granite-greenstone terrains into four metamorphic zones that range from greenschist facies within the central part of the craton to amphibolite facies within the outer parts and granulite facies within the marginal zones. Metamorphic temperatures of 650-720ºC were reported by Tsunogae *et al.* (1992) for the outer part of the craton adjacent to the Limpopo Belt.

In eastern Zimbabwe, at least two major Archean regional metamorphic events have affected the craton. The first metamorphic event (M_1) in eastern Zimbabwe is recorded in the greenstone belts, i.e. Cronley Schist belt (Fig. 1.3) prior to emplacement of the Chibi granites at c. 2650 Ma (section 5.11.1). M_1 was probably associated with folding and shearing in the and the Cronley Schist belt (Fig. 1.3; Watson, 1969). The second regional metamorphism (M_2) was associated with formation of northeast to east trending shear zones in the mapped area. Metamorphic grade reached granulite facies in basement rocks that occur in the Limpopo belt (Fig. 5.21) to the south of Birchenough (Fig. 1.6) and was lower elsewhere (Watson, 1969). In the study area, the metaironstone was sheared into a quartz-grunerite schist (Fig. 1.10) and constrains the highest grade of metamorphism in the Archean basement rocks in eastern Zimbabwe to amphibolite facies, while metamorphosed amphibolite dykes suggest lower amphibolite facies. The absence of high-pressure minerals indicates low pressure metamorphic conditions at temperatures of at least 550ºC since the amphibolite facies begins at this temperature at low pressures (Spear, 1993).

Prograde metamorphism of the amphibolite dykes was possibly driven by heat generated during the diapric ascent and emplacement of the surrounding and underlying younger

granitoid bodies of the Chilimanzi suite, in a manner similar to the "aureole tectonics" described by Jelsma (1993) in the Harare-Shamva greenstone belt in northern Zimbabwe. The timing of metamorphism of the amphibolite dykes is not well-constrained, but apparently pre-dates the Mashonaland tectono-thermal event dated at 1830 ± 230 Ma (Wilson *et al.*, 1987) since the Mashonaland dykes are undeformed and weakly metamorphosed (Munyanyiwa, 1999). Peak metamorphism was reached during the Archean and was associated with emplacement of granitoids of the Chilimanzi suite dated at 2522 ± 36 Ma (Schmidt Mumm *et al.*, 1994) and 2527 ± 632 Ma (Manuel, 1992).

Jelsma (1993) defines "aureole tectonics" as the progressive deformation and metamorphism of mantling rocks, caused by diapric ascent and emplacement of bodies of buoyant material. Thermal aureoles around granitoids were the driving mechanism of metamorphism. Evidence for this has been shown in the Harare-Shamva greenstone belt where metamorphic zones are concentric around batholiths and the metamorphic grades generally increase towards the batholiths (Jelsma, 1993). The pattern is similar around mantled gneiss domes (Allen and Chamberlain, 1989). Metamorphic grades reach amphibolite facies near the granite/greenstone contact and gradually decreases to greenschist facies with distance from the contact in the Mutare greenstone belt (Nyama 1999). These facts may suggest that the amphibolite facies assemblages in schistose mafic dykes and quartz-grunerite schist are a product of contact metamorphism induced by emplacement of granitoids.

Inclusions of amphibolites, calc-silicates and metapelites that occur in granites in the Nyanga area (Stocklmayer, 1978) show medium-grade metamorphic assemblages that are interpreted to have resulted from intrusion of tonalities. Pre-Mashonaland mafic dykes, the Cronley Schist belt (Fig. 1.3) and other inclusions in granites were metamorphosed to varying grades prior to and during intrusion of younger granites in the area. Peak metamorphism was associated with emplacement of granites and reached the hornblende-hornfels (amphibolite) facies, i.e. low pressures and high temperatures of up to 700ºC (Stocklmayer, 1978) possibly during late Archean.

Low-grade greenschist metamorphic assemblages from the metaironstone and the amphibolite dykes, which intruded Archean basement granites, formed during retrograde metamorphism. The retrogression is inferred to have taken place either during the cooling of the younger granitic intrusions or during the Mozambique orogeny. Massive dolerite dykes, of unknown ages, that intrude the Archean basement granites (Fig. 1.6, JM 0108; Fig. 1.5, JM 0110436702, 7800301),) show evidence of retrograde metamorphism. The retrogression assemblages are similar to those in Umkondo dolerites. This raises the possibility that retrogression in Archean basement rocks, i.e. metaironstone and amphibolites in eastern Zimbabwe may reflect Pan-African imprint during the ca. 550 Ma Mozambique tectono-thermal event.

4.5.2 Pan African Metamorphism and Alteration

The metamorphic assemblages characterised by kyanite-chloritoid-chlorite-muscovite-quartz in metapelites and plagioclase-hornblende in metadolerites suggest amphibolite grade of metamorphism in the Mozambique facies of the Umkondo group. Mafic metavolcanics that are interbedded with the Zimbabwe facies metasedimentary strata and Umkondo dolerites that intrude the strata have been metamorphosed at greenschist to prehnite-pumpellyite facies grades of metamorphism. Thus metamorphic grades associated with the Mozambique orogeny decrease from east to west (Vail, 1966; Stocklmayer, 1978). Vail (1966) documented that the metamorphic grade increases to upper amphibolite- and granulite facies in Mozambique. The amphibolite- and greenschist facies grades documented in rocks of the Mozambique facies and the Zimbabwe facies respectively show that a steep thermal gradient exists between the two facies. This evidence supports the idea that rocks of the Mozambique facies were tectonically juxtaposed against the Zimbabwe facies (Payne, 1984; Allsopp *et al.*, 1989; Tennant, 1995).

The timing of the metamorphism in the Chimanimani area is constrained by an $^{40}Ar/^{39}Ar$ muscovite age of c. 550 Ma (Munyanyiwa, 1999). The metamorphism was associated with the formation of the north trending, continent-scale Mozambique belt (Fig. 5.22)

during the Himalayan-type collision of east and west Gondwana (Stern, 1994). Amphibolite facies metamorphism at approximately 510-560 Ma has also been documented in the contiguous Zambezi belt (Vinyu *et al.*, 1997; Goscombe *et al.*, 2000). The thermal perturbation in the Zambezi belt is related to the convergence of the Congo/Tanzania cratonic region with the Kalahari craton (Fig. 5.22; Goscombe *et al.*, 2000). Goscombe *et al.* (2000) obtained a U-Pb zircon age of 526 ± 17 Ma for peak metamorphism in the Chewore Inliers of the Zambezi Belt.

A minimum of two hydrothermal events have affected the Umkondo group and associated dolerites. These are exhibited by the occurrence of two generations of epidote-quartz veins that cut an Umkondo sill (Fig. 4.10). The first generation of veins are cut by a north-trending dyke of probable Pan African age (section 7.11) that intruded an Umkondo sill. The first generation of veins post-dates Umkondo magmatism, but probably predate Pan African mafic magmatism. The second generation of veins cut the probable Pan African dyke. The second generation of veins probably mark circulation of Fe-bearing SiO_2-rich hydrothermal fluids in the Umkondo group and caused reddening of the granites during post-Karoo times. This is because similar alterations have been reported to occur in association with post-Karoo faults in the Middle Sabi area (Swift, 1962; Watson, 1969).