CHAPTER 5

STRUCTURAL EVOLUTION OF THE UMKONDO GROUP AND THE UNDERLYING ARCHEAN BASEMENT

5.0 Introduction

The structural evolution of the Zimbabwe craton remains a subject of controversy and deserves a separate research project. The area mapped in this study (Fig. 1.10) is possibly too small to give a regional view of the structural evolution of the Zimbabwe craton. In this chapter, the structural evolution of the Zimbabwe craton is briefly outlined and discussed for purposes of continuity. The Archean basement granites and gneisses in eastern Zimbabwe suffered at least two regional deformation events prior to the emplacement of the Umkondo dolerites. The Umkondo group was deformed during the Pan African Mozambique orogeny.

This chapter outlines the structural evolution of the Archean basement and the Umkondo group in eastern Zimbabwe. The outline is based on data mainly gathered in the Chimanimani area during a mapping exercise. In the Mozambique facies, data was gathered during a Departmental Honours class field excursion in 1999. In order to make a comprehensive analysis of the structure some data were gathered from maps, reports and bulletins from the Geological Survey of Zimbabwe. The regional implication of the Mozambique orogeny is discussed in the context of Pan African deformation and continental assembly.

5.1 Pre-Umkondo Deformation in Eastern Zimbabwe

A broad northeast trending shear zone cuts the Archean basement granitic rocks and metaironstone near Chitimani School and extends westwards beyond the map (Fig. 1.3). The shear zone predates the emplacement of Umkondo dolerites since probable Umkondo sills truncate foliation in the shear zone. Jelsma (personal communication,

2004) suggests that the zone in fact represents greenstone remnants and gneisses that can be traced to the northeast to the Cronley greenstone belt (Fig. 1.10). The sheared granite has developed a schistose fabric and gneissic banding in places that are defined by alignment of micas, mainly biotite and muscovite, and alternating bands of mafic-rich- and felsic rich layers. The schistose fabric anastomoses and trends between northeast and east northeast, and dip steeply to moderately towards northwest and southeast. A weak stretching lineation that is defined by aggregates of quartz and plagioclase in the shear zones (Fig. 1.10) plunges shallowly towards west or east (Fig. 5.3a). The stretching lineation suggests an east-west transport direction. Sheared quartz veins that cut the granite show that the shearing was associated with a dextral strike-slip sense of displacement (Fig. 5.1). Quartz veins with widths that occur on a scale of a sub-millimetre to a metre cut the granites. Some centimetre wide veins have been boudinaged and later folded into tight and ptyigmatic folds (Fig. 5.1). The fold axes are sub-vertical to vertical, while the fold axial planes are sub-vertical to vertical and trend, approximately east-west (Fig. 5.1). The veins possibly record a single deformation event in which the formation of boudins documents an approximately east-west extension direction. Tight and ptygmatic folds possibly formed during progressive deformation since the geometry of the tight folds (Fig. 5.1) are compatible with dextral strike-slip shears.

A northeast trending shear zone cuts the Archean basement granite and metaironstone south of Chitimani School (Fig. 1.10). The schistose fabric that formed in the granite and metaironstone dips steeply to moderately towards north-northwest and south-southeast. The schistose foliation in the metaironstone has been crenulated (Fig. 5.2). The crenulation cleavage dips moderately to steeply towards northwest and the crenulation lineation plunges moderately towards north-northwest and north (Fig. 5.3a). It is not clear whether the crenulation cleavage represents a separate deformation event or mostly likely developed during progressive deformation. These structures presumably predate emplacement of Umkondo dolerites since the foliation in the Archean basement granites and metaironstone are truncated by a massive dolerite sill that has mineralogical and textural similarities with known Umkondo sills in the area (Fig. 1.10).

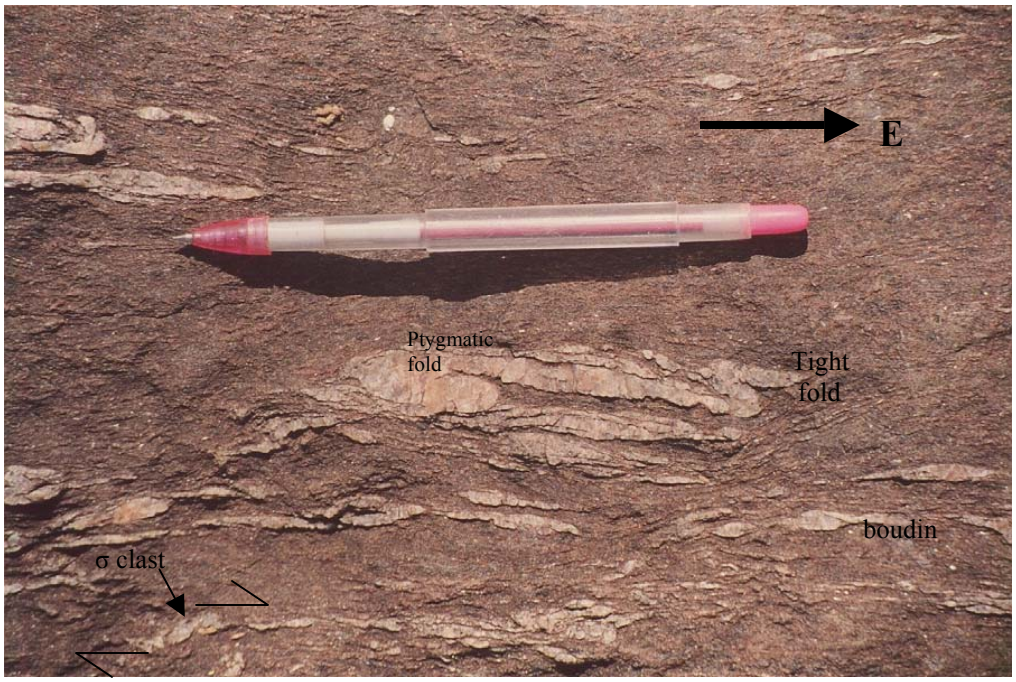


Fig. 5.1. Quartz veins that occur in sheared Archean basement granites are parallel to the schistose fabric. The veins have been boudinaged and then folded into ptygmatic folds during progressive deformation that was associated with dextral strike-slip shears. The boudins document an east-west extension direction during deformation. Grid Ref.: 450085, 7832520.

Fig. 5.2. Crenulation cleavage in meta-ironstone. The crenulation lineation plunges moderately towards north. Grid Ref.: 451669, 7832200.

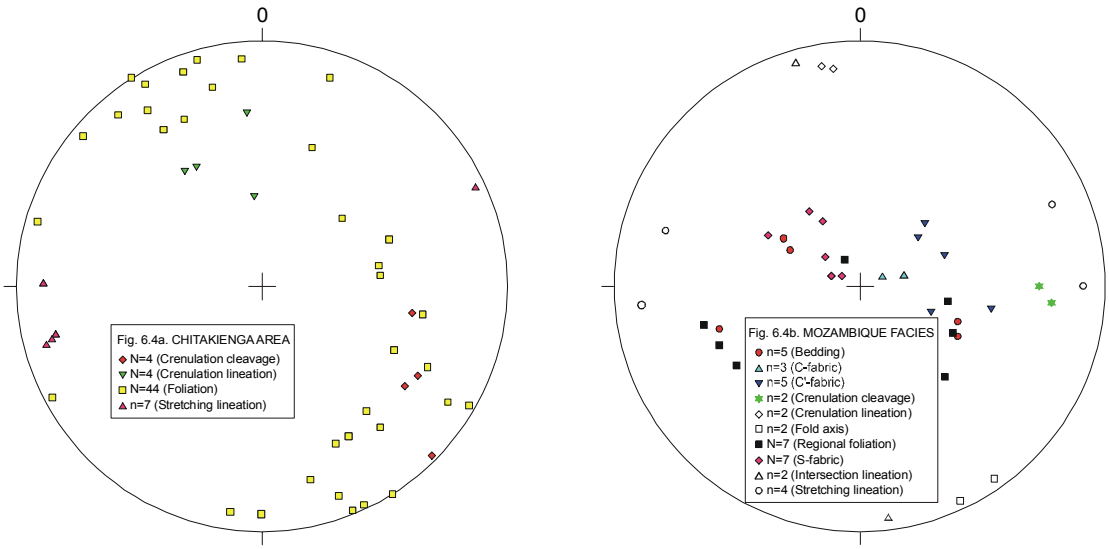


Fig. 5.3. Lower hemisphere, equal area projections of poles to schistosity and crenulation cleavage in: (a) Sheared Archean basement granites and metaironstone in the area south of Chitimani School (Fig.1.10). A crenulation lineation in metaironstone plunges moderately towards north and a stretching lineation in granites plunges shallowly towards west or east and (b) Mozambique facies in the area around the Armour's Gap (Fig. 1.3), a crenulation lineation plunges shallowly towards north and the stretching lineation plunges shallowly towards east or west, which suggests an east-west transport direction.

5.2 Structure in the Mozambique Facies: The Mozambique Orogeny in Eastern Zimbabwe

Rocks of the Mozambique facies have been intensely deformed with penetrative east-dipping structures (Fig.5.4) during the Mozambique orogeny dated at 550 Ma (Munyanyiwa, 1999). Rare primary bedding and cross-bedding are preserved in places in deformed psammites in the area around the Armours Gap (Grid Ref.: 494990, 7825100), where the beds dip moderately to shallowly towards west-northwest or east-southeast (Fig. 5.3b). The penetratively developed schistosity in psammites and mylonites, and a slaty cleavage in slates define the regional foliation. The regional foliation trends north northwest to north northeast and dips moderately towards east or west (Fig. 5.3b). A crenulation cleavage that formed in slates in places (Grid Ref.: 494990, 7821750) trends at a small angle to the slaty cleavage, i.e. north-south and dips moderately to steeply towards west. A weakly developed stretching lineation that is defined by aggregates of

quartz and chlorite occurs in mylonites. The lineation plunges shallowly towards east or west (Fig. 5.3b) suggesting an east-west or west-east transport direction.

Kinematic indicators that include σ-clasts, shear bands, S-C and S-C' fabrics are well developed in psammites and micaceous schists of the Mozambique facies in the area around the Armours Gap. The C and C'-fabric dip shallowly towards west, while the S-fabric dips shallowly to moderately to the east (Fig. 5.3b). The attitudes of the S-C and S-C' fabrics are indicative of low-angle normal faulting, top side down to the west. The S-C intersection lineation plunges shallowly towards north or south and is perpendicular to the stretching lineation, and hence the shear direction. Shear bands and σ-clasts (Fig. 5.5) also indicate that transport direction during deformation was from east to west.

Rocks of the Mozambique facies have been deformed by tight to isoclinal and recumbent folds that occur on a scale of a centimetre to a few hundred metres. The folds have sub-horizontal, north-south trending fold axes (Fig. 5.3b) that suggest shortening in an east-west direction during deformation. Asymmetrical folds that have wavelengths of 5 to 20 cm deform psammites at the Armours Gap (Grid Ref.: 497730, 7824570) and verge to the west. The asymmetrical folds are consistent with a west-directed transport direction. Recumbent folds with sub-horizontal, north-south trending fold axes occur on a scale of 20 to 150 m on a southwest-facing scarp at the Skeleton Pass (Grid Ref.: 500700, 7814050). These structures indicate that the entire Mozambique facies is allochtonous and was thrust to the west. Isoclinal and recumbent folds that occur in the Mozambique facies suggest high strain rates that are consistent with thrusting.

5.3 Mozambique basement Gneiss/Mozambique Facies Contact

The contact between the Mozambique quartzofeldspathic basement gneisses and the Mozambique facies at the Armours Gap dips shallowly to the west (Fig. 5.6). Immediately below the contact, the quartzofeldspathic gneiss has been sheared to a quartz-muscovite schist and the Mozambique facies psammites above the contact have been penetratively deformed by east-dipping structures. The schistosity and an S-C'

fabric that have developed in the gneisses near the contact indicate that the contact was sheared and is therefore a tectonic contact. An S-C' fabric occurs in the quartz-muscovite schist. The C' fabric dips shallowly towards west while the S-fabric dips moderately towards east, which suggest a west-directed movement across the contact. Shear bands that have developed in the schists also indicate a similar transport direction

Above the contact, psammites of the Mozambique facies are intensely and penetratively deformed (Fig. 5.6). Kinematic indicators in the Mozambique facies indicate a west-directed movement direction. The Mozambique basement gneisses/Mozambique facies contact is therefore a sheared contact across which the Mozambique facies was thrust to the west.

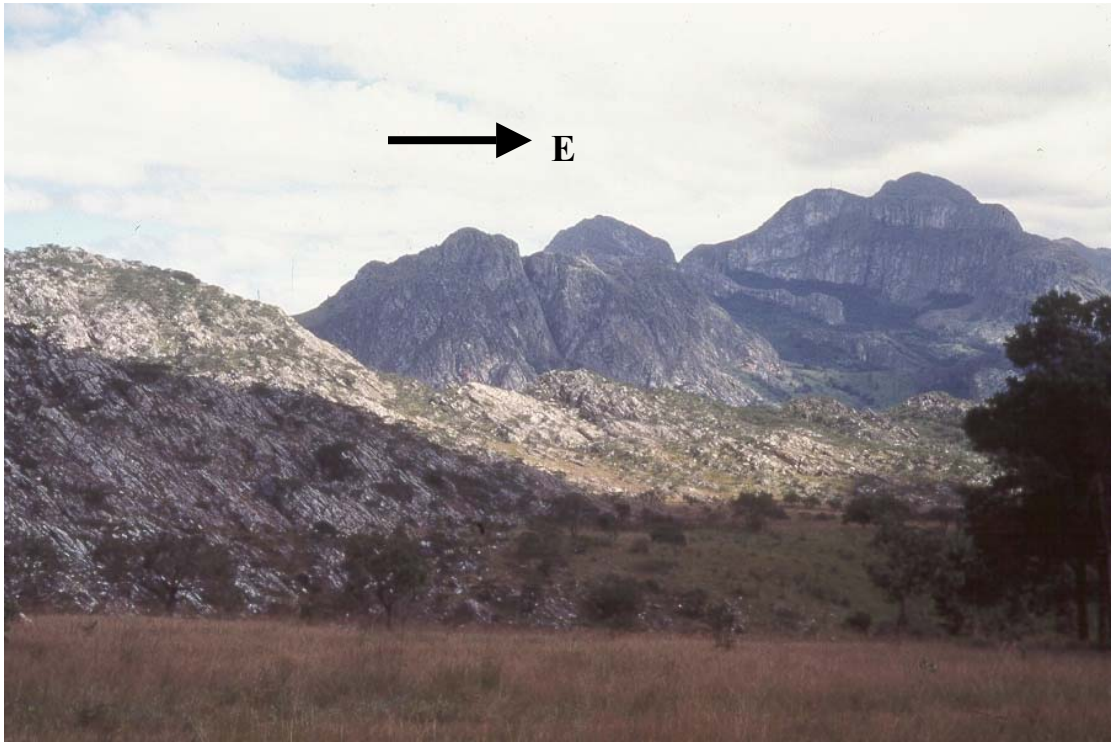


Fig. 5.4. Intensely and penetratively deformed psammites of the Mozambique facies with east-dipping fabrics. Primary bedding is rarely preserved. Nyanga, Exact locality unknown. *Photograph by R. Hanson.*

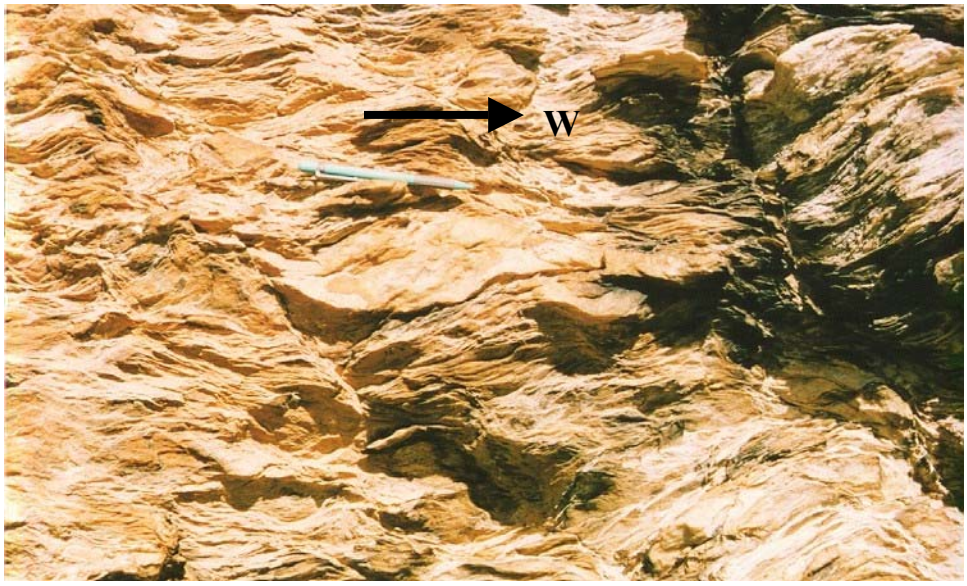


Fig. 5.5. Schistosity in a quartz-mica schist wrapping around a σ-clast near the centre of the photograph. The σ-clast indicates that the top has moved to the west. Grid. Ref.: 497730, 7824570.

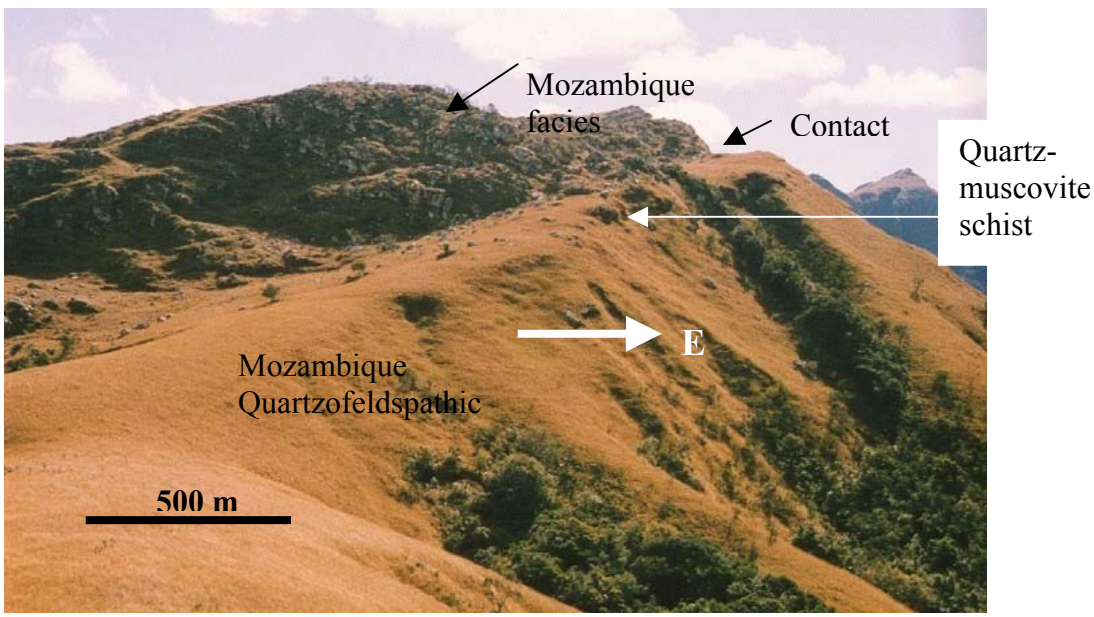


Fig. 5.6. Quartz-mica schists of the Mozambique facies overlying the Mozambique quartzofeldspathic gneiss (masked by brown grass) at the Armours Gap. The gneiss has been sheared into a quartz-muscovite schist and developed an S-C' fabric immediately below the contact. C' dips gently towards west and S dips steeply towards east, which implies a low-angle normal fault tectonic regime. Photograph taken from Grid Ref.: 498640, 7824590.

5.4 Mozambique facies/Zimbabwe facies Contact

The contact between the Mozambique- and the Zimbabwe facies is not exposed. Rocks of the Mozambique facies that are intensely deformed by west-verging structures (section 5.2) clearly dip underneath slates of the Zimbabwe facies (Fig. 5.7). The eastern most portion of the Zimbabwe facies should therefore be underlain by a thrust (Fig100). Slaty cleavage in slates of the Zimbabwe facies dips moderately east. A weak mineral lineation, defined by quartz, occurs in the slates and plunges shallowly towards west. The slaty cleavage is crenulated and the crenulation cleavage dips moderately west. The crenulation lineation plunges shallowly north. These structures are consistent with an east-west transport direction across the contact, and hence the Mozambique facies/Zimbabwe facies contact is a tectonic contact.

5.5 Structure in the Zimbabwe Facies

5.5.1 Bedding

Primary bedding is well preserved in almost the entire Zimbabwe facies. Arkoses exhibit graded bedding and planar cross-bedding in places. Bedding is defined by grain-size variations in which arkoses are inter-layered with horizons of shales. The widths of arkose beds range from 0.2-1 metre, while those of the shale unit range from 0.1 to 0.3 m. In cherts, bedding is defined by colour variations where dark red-brown layers or light green layers alternate with light pinkish-white layers on a scale of a millimetre to 2 m. Primary bedding is generally sub-horizontal throughout the entire Zimbabwe facies, i.e. in Chipinge (Fig. 5.8a), Nyanga (Fig. 5.8b) and Chimanimani (Fig. 5.8c and e).

5.5.2 Foliation and Folding

The Zimbabwe facies of the Umkondo group is locally deformed. In the mapped area, for example, deformed banded cherts that overlie a well-bedded, undeformed pebbly basal arkose unit occur at Mutsago Hill (Fig. 5.11). The arkose unit rests depositionally on Archean basement granites and can be traced around the entire hill. Deformed cherts that

cap the Mutsago Hill have a maximum thickness of not more than 40 m. Cherts show an S_1 foliation that is defined by colour variation banding similar to bedding (chapter 3.3.3), i.e. alternating light green and light pinkish-white layers. Individual layers occur on a sub-millimetre scale to a few centimetres. The thicknesses of individual layers vary along strike and are discontinuous on a scale of a metre, which strongly suggests that the layering is secondary in nature. In one locality (Grid Ref.: 461050, 7835125), S_1 terminates against an S_2 foliation. S_2 is also defined by sub-millimetre to a centimetre wide banding similar to S_1 and occurs at a small angle to S_1. The attitude of S_2 is not known since the foliation was only observed in one locality on a boulder. It is inferred that S_2 developed during progressive deformation in the Mozambique orogeny.

Detailed mapping that was done on a scale of 1:200 on the crest of Mutsago Hill (Figs. 1.11, 1.12 and 1.13) shows that foliation in chert dips moderately towards east or west. The top of the hill is flat and there is limited exposure. The mapping exercise was therefore done on three small isolated areas. The foliation is folded by close, upright antiformal and synformal F_1 folds (Fig. 5.9) that have wavelengths of a few centimetres to a few tens of metres (Fig. 5.11). Sections from the mapped areas (Figs. 1.11, 1.12 and 1.13) show that the amount of shortening accommodated by these folds (Fig. 5.11) ranges from about 10 to 35 m. Asymmetrical parasitic, west-verging folds occur in places on a scale of 10 to 40 cm (Fig. 5.10). The F_1 folds have north-south trending, sub-horizontal fold-axes (Fig. 5.8d). The fold axial planes trend north-south and are near-vertical to vertical (Fig. 5.8d). The pole to the foliation π-pole girdle at Mutsago Hill defines a sub-horizontal fold axis that plunges 01º towards 170º and is consistent with the fold axes measurements from the field (Fig. 5.8d). However, the arkose unit that underlies banded chert is undeformed and is not folded in with the cherts. It is plausible to infer a thrust contact between the chert unit and the underlying arkose although there is no lineation that shows the transport direction. The absence of the lineation in the Zimbabwe facies is attributed to weak deformation of these rocks during the Mozambique orogeny. It appears that the F_1 folds were folded along an east-west axes to form F_2 gentle folds (Fig. 1.11). However, no fold axial cleavage to these probable F_2 folds was observed in the field. A

small-scale fold that has a fold axis that plunges shallowly east was observed at Mutsago hill (Fig. 5.8d; Grid Ref.: 460920, 7836364).

A penetrative slaty cleavage has developed in places south of Cashel in metamorphosed shales (Fig. 1.3). The slates occur as discontinuous thin horizons that are 5-15 cm wide and are interbedded with thickly bedded, pyrite-epidote bearing arkose horizons. The slaty cleavage dips shallowly to moderately northeast (Fig. 5.8e). A gentle asymmetrical fold that has a wavelength of about 20 m and an amplitude of not more than 2 m deforms the upper arkose beds to the south of Cashel (Grid Ref.: 479972, 7835436). The fold has a sub-horizontal, north-plunging fold axis (Fig. 5.8e).

West-verging folds with wavelengths of 10 to 40 cm (Fig. 5.12) deform finely laminated siltstone near the Archean basement granites/Zimbabwe facies contact some 3 km west of Birchenough Bridge along the Mutare-Masvingo road (Grid Ref.: 428670, 7793640). The fold axes and a weakly developed stretching lineation that is defined by aggregates of quartz and chlorite plunge shallowly east. The fold axial planes dip moderately south. The vergence of the folds is interpreted to imply a localised west-directed movement associated with the Mozambique orogeny.

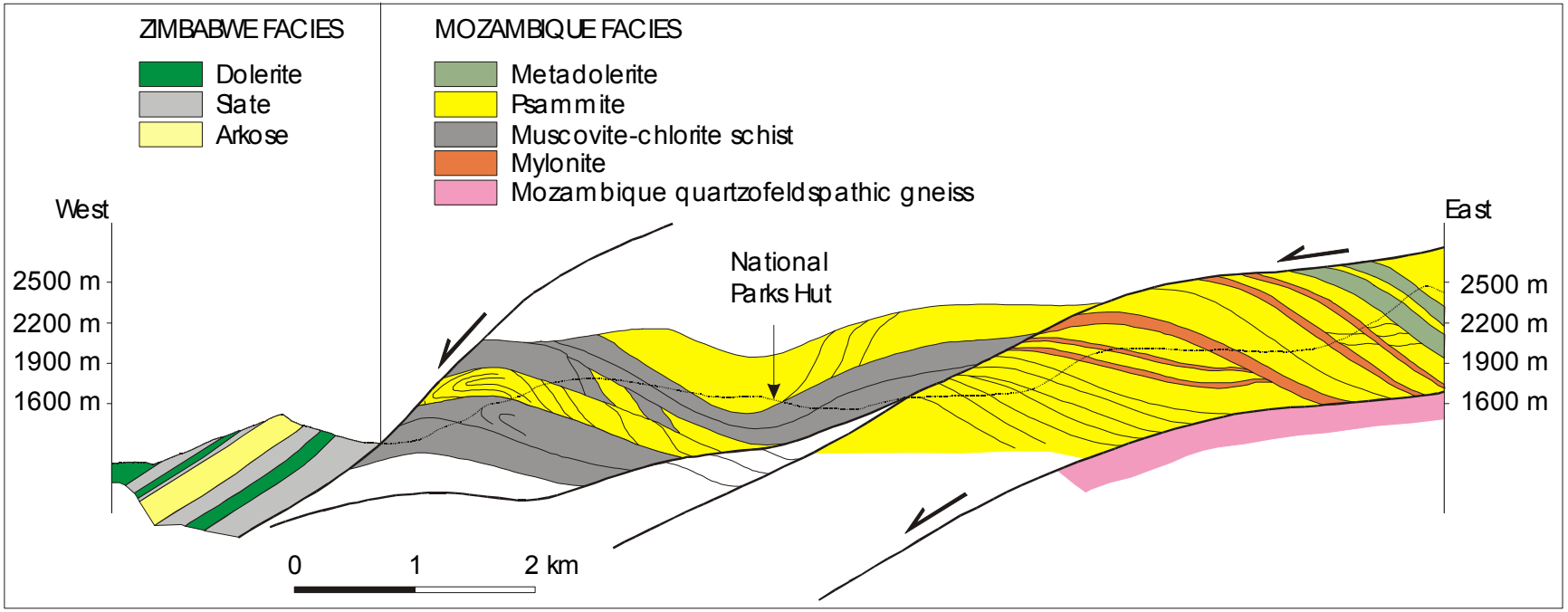


Fig. 5.7. Cross section through the Mozambique facies/Zimbabwe facies contact. Intensely deformed rocks of the Mozambique facies that were thrust to the west dip underneath the Zimbabwe facies, and hence the Zimbabwe facies should be underlain by a thrust and the Mozambique facies/Zimbabwe facies contact is a tectonic contact. The dotted line represents the present erosional surface. The position of the National Parks Hut is shown as a reference point (Fig. 1.3). Modified after Dirks (1999)

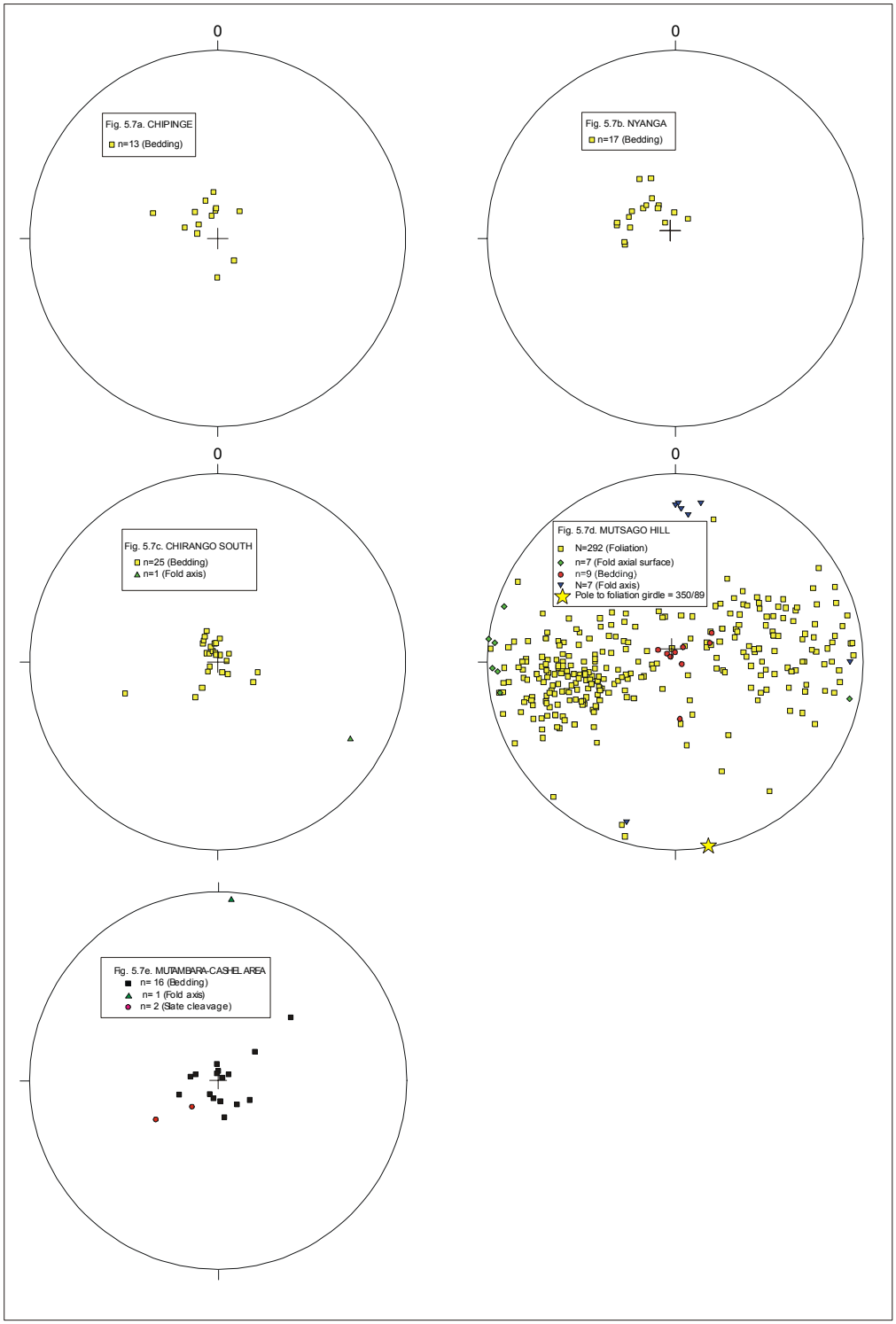


Fig. 5.8. Equal area lower hemisphere projections of poles to bedding and foliation in the Zimbabwe facies in (a) Chipinge, (b) Nyanga and (c to e) Chimanimani areas. Beds are sub-horizontal in a, b, c and e. Foliation in cherts dips steeply to moderately towards east or west (d). Folds in the Zimbabwe facies have sub-horizontal fold axes that plunge towards north or south (d and e).

Fig. 5.9. Upright, open folds in deformed chert on the crest of Mutsago Hill. The chert unit overlies undeformed pebbly basal arkose. The fold has a sub-horizontal, north-south trending fold axis. (Grid Ref.: 460856, 7835245)

Fig. 5.10. An asymmetrical parasitic fold verges towards west below the hammer. The fold axis is sub-horizontal and trends north-south. Grid Ref.: 460843, 7835202.

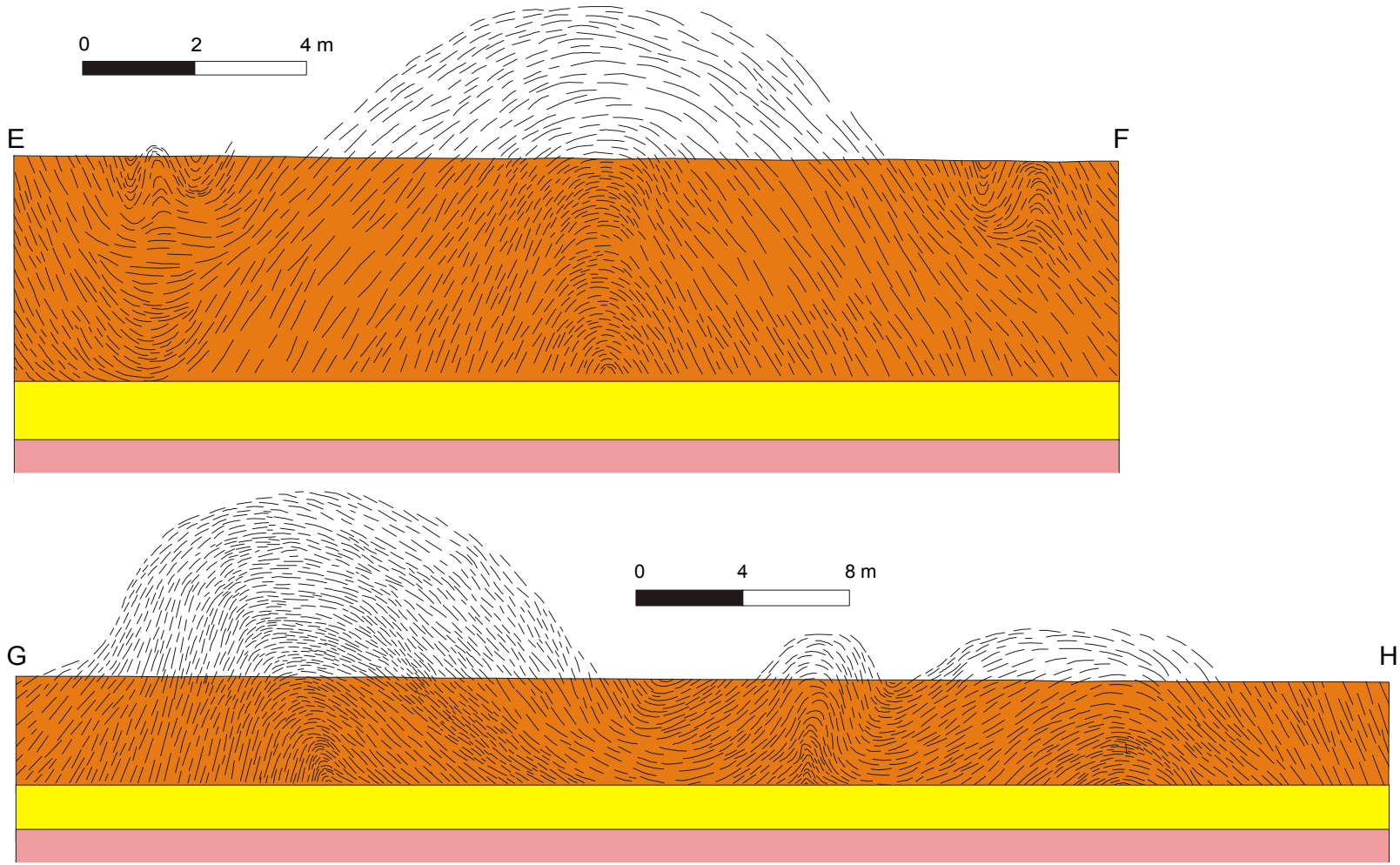


Fig. 5.11. Cross sections showing open, upright folds in the chert unit of the Zimbabwe facies. The folds have wavelengths that range from a few centimetres to about 20 m and sub-horizontal fold axes that plunge north-south. The folds suggest an east-west shortening direction during deformation and accommodated shortening on a scale of ~10-40 m. The chert unit overlies an undeformed, sub-horizontal pebbly basal arkose (yellow) unit.

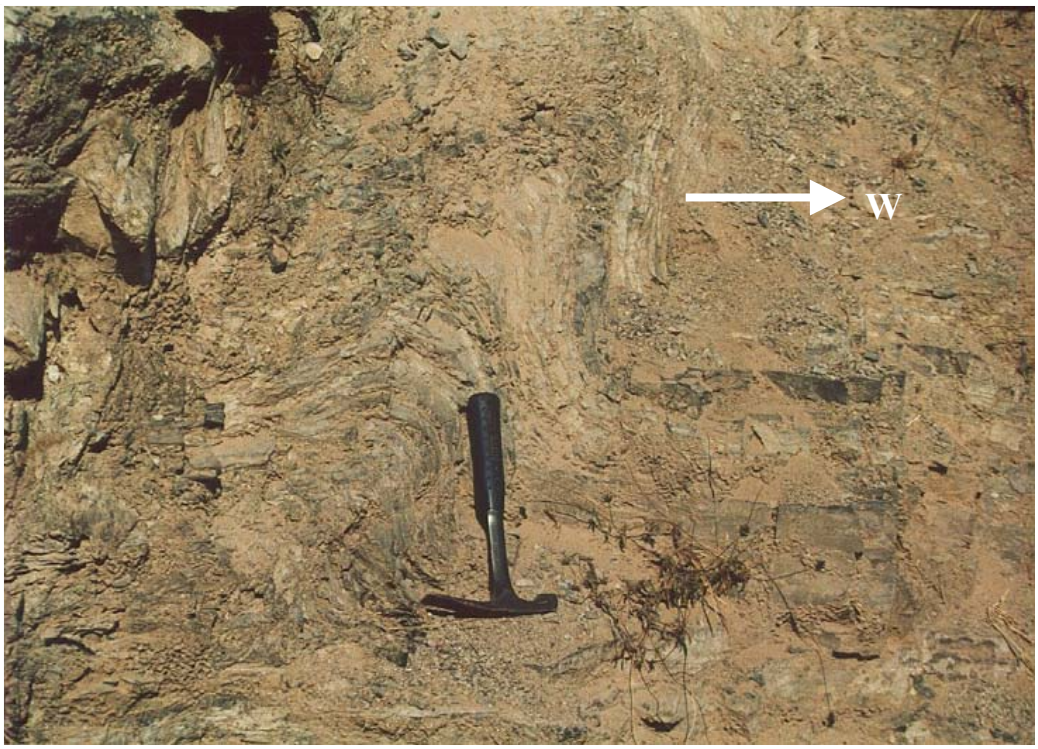


Fig. 5.12. Finely laminated siltstone (Grid Ref: 428670, 7793640) deformed by a west verging fold that has a north, shallowly plunging fold axis. Fold vergence suggests an east to west direction of transport.

5.5.3 Small-scale thrusts

The Zimbabwe facies of the Umkondo Group in places are deformed by small-scale thrusts. Siltstone beds near the Archean basement granites/Zimbabwe facies contact some 3 km west of Birchenough Bridge along the Mutare-Masvingo road (Grid Ref.: 428670, 7793640), have been displaced by an east-dipping thrust that has a dip separation of about 60 cm (Fig. 5.13). On the crest of Mutsago Hill (Grid Ref.: 460794, 7835284), a shallow east-dipping small-scale thrust has displaced secondary layering in banded cherts (Fig. 5.14) and has caused a dip separation of a few centimetres. Layering on the hanging wall curves downwards towards the thrust plane, suggesting a west-directed reverse sense of movement across the thrust. These shallow east- dipping thrusts show a reverse sense of movement and imply an east over west transport.

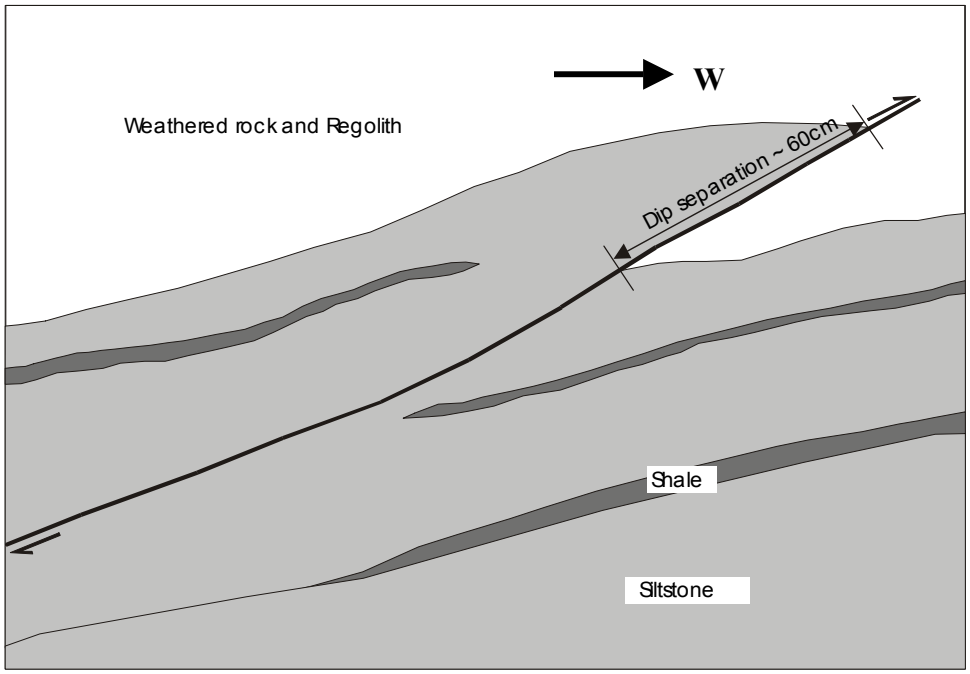


Fig. 5.13. Shallowly east-dipping (104/30) thrust displacing siltstone beds (above the hammer in photograph) near the Zimbabwe facies/Archean basement granite contact with a reverse sense of movement, i.e. top to the west. The dip separation, illustrated in the sketch diagram, is about 60 cm (Grid. Ref.: 428670, 7793640).

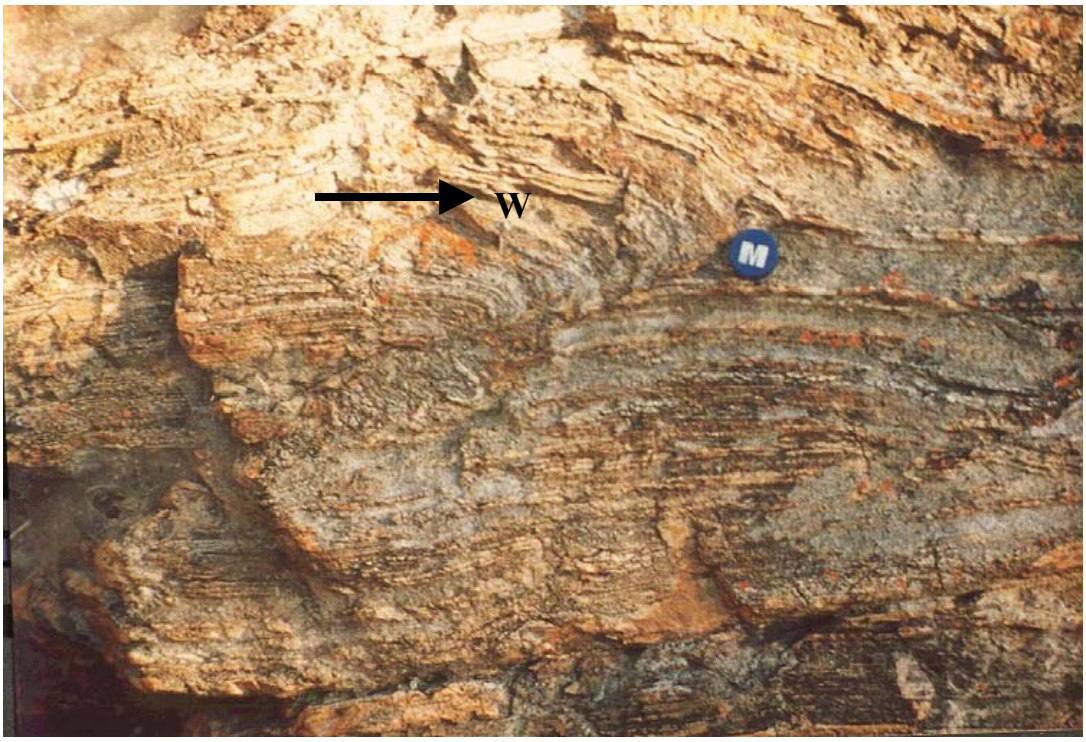


Fig. 5.14. Small-scale thrust cutting through the centre of the microphotograph. The thrust dips shallowly towards east and has displaced layering in banded cherts. Layering in the hanging-wall curves downwards suggesting a reverse sense of movement, that is top to the west (Grid Ref.: 460794, 7835284).

5.6 Small-scale Faults.

Small-scale faults, which cut a dolerite sill flanking Basement Complex granites to the west, were only observed on a south-facing scarp road section on the eastern bank of Umvumvumvu River (Grid Ref.: 461820, 7840655). These fault surfaces were exposed during road construction and have not been observed elsewhere in the mapped area. Thus these faults were the only ones available for this study and were used for fault analysis (Section 5.8.1). The faults are sub-vertical to vertical and have sub-horizontal slickenside striations that plunge mostly towards north or south, and to a lesser extent, towards northeast or northwest (Fig. 5.15). The large proportion of the faults trend between north northwest and north northeast (Fig. 5.17b). The remainder of the faults trend southeast to south southeast (Fig. 5.17b). The sense of displacement, determined from fault grooves and growth direction of quartz crystal fibres, is dextral strike-slip and sinistral strike-slip

for the north northwest to north northeast and southeast to south southeast trending faults (Fig. 5.17a; Table 1). The faults are likely to be contemporaneous since they mutually cross-cut and terminate against each other. The faults are therefore conjugate faults.

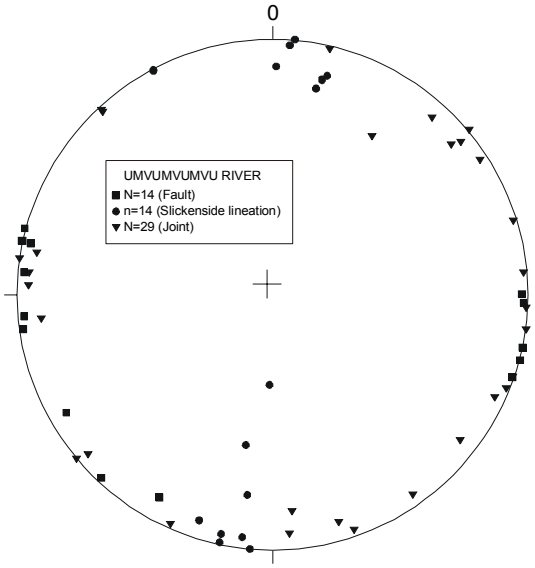


Fig. 5.15. Equal area lower hemisphere projections of poles to faults and joints. Faults and joints are sub-vertical. Slickenside lineations on fault planes plunge shallowly towards north or south. Fault data were obtained from the Umvumvumvu river bridge (Grid Ref.: Grid Ref.: 461820, 7840655).

5.7 Joints

Joints are well developed in a dolerite sill that crops out in the mapped area, i.e. around Nhedziwa Business Centre (Fig. 1.10). However, measurements were not made in a number of places where the sill is magnetic. The strong magnetism in the sill is possibly a result of remagnetisation due to lightning strikes. Joints also occur, to a lesser extent, in Archean Basement Complex granites and are rare in the Zimbabwe facies metasedimentary rocks, possibly owing to their low competence contrast. East of Chiramba School (Grid Ref.: 459900, 7835875), near vertical, east-trending joints in porphyritic granite are filled with quartz-chlorite-epidote veins that are up to 5 mm wide. The joints are vertical to sub-vertical (Fig. 5.15) and have a strike extent ranging from a metre to a few tens of metres.

Systematic joint measurements mostly done on a vertical, south-facing road section on the eastern bank of Umvumvumvu River (Grid Ref.: 461820, 7840655) show that the joints can be subdivided into 3 major sets (Fig. 5.16b). The definition of sets and subsets is as in section 7.1. The trends of joints are northeast to east for set 1, southeast for set 2 and east northeast to north northeast for set 3. Set 1 and 3 joints are parallel to set 1 and 2 faults (chapter 7). Joint-spacing is variable for all sets and ranges from 20–100 m, although some set 1b and c joints are in places very closely spaced on a scale of 1-5 cm.

The joint sets mutually crosscut and terminate against each other in places, suggesting that they are possibly contemporaneous. The faults are younger and are likely to have formed on earlier joints.

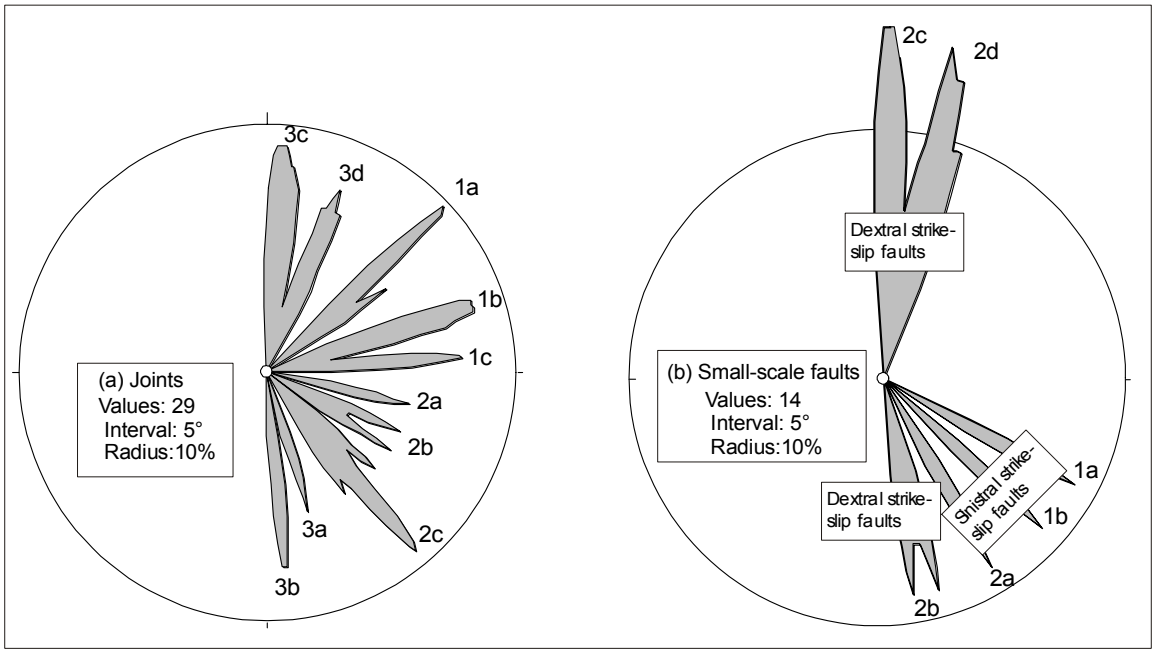


Fig. 5.16. Moving average rose diagrams showing the orientations of joints (a) and small-scale faults (b). The majority of the faults trend between north northwest and north northeast and have accommodated a dextral strike-slip displacement. The faults are parallel to joints suggesting that the faults formed on pre-existing joints.

5.8 Kinematic Analysis

The sample size of small-scale structures and the fault population data available for kinematic/dynamic analysis are small and may be considered to be statistically invalid. However, these data may have regional implications on the structural evolution of rocks in the area, but more measurements need to be done at different localities to substantiate the validity of the data. The possible implications of these structures are described and discussed in the following sections.

Table 5.1. The attitude of small-scale faults that cut an Umkondo dolerite sill and the associated slickenside lineation. Most faults have a dextral sense of displacement.

Fault plane		Slickenside lineation		Sense of shear
Dip direction	Dip	Plunge	Plunge direction	
102	86	01	192	Dextral
085	87	12	355	Dextral
043	88	10	320	Sinistral
095	87	07	175	Dextral
082	88	18	352	Dextral
272	88	04	183	Dextral
029	80	02	119	Sinistral

5.8.1 Fault Analysis

The Fault data from seven small-scale faults that showed the sense of displacement (Table 1) were used for kinematic analysis using the Faultkin Programme (Marrett and Allmendinger, 1990). The faults are described in section 5.6. The population data available for the analysis is too small and the measurements were made over a small area (Section 5.6). Five of the faults show dextral strike-slip displacement and the other 2 faults show sinistral strike-slip displacement (Fig. 5.17a). The programme gives contours for the P- and T axes (Figs. 5.17b and c), which are the shortening and extension principal incremental strain axes respectively. The P- and T axes are equivalent to the eigenvectors of the symmetric part of the displacement gradient tensors of the faults

(Marrett and Allmendinger, 1990). The axes represent the principal axes of the incremental strain tensor for the fault (Marrett and Allmendinger, 1990). The programme gives a best fit of 0° towards 326° and 0° towards 236° for the orientation of the extension (T-axis) and shortening axes (P-axis) respectively (Fig. 5.17d). The results suggest that the P- and T-axes were horizontal and trended west-southwest and north-northwest respectively during propagation of the faults.

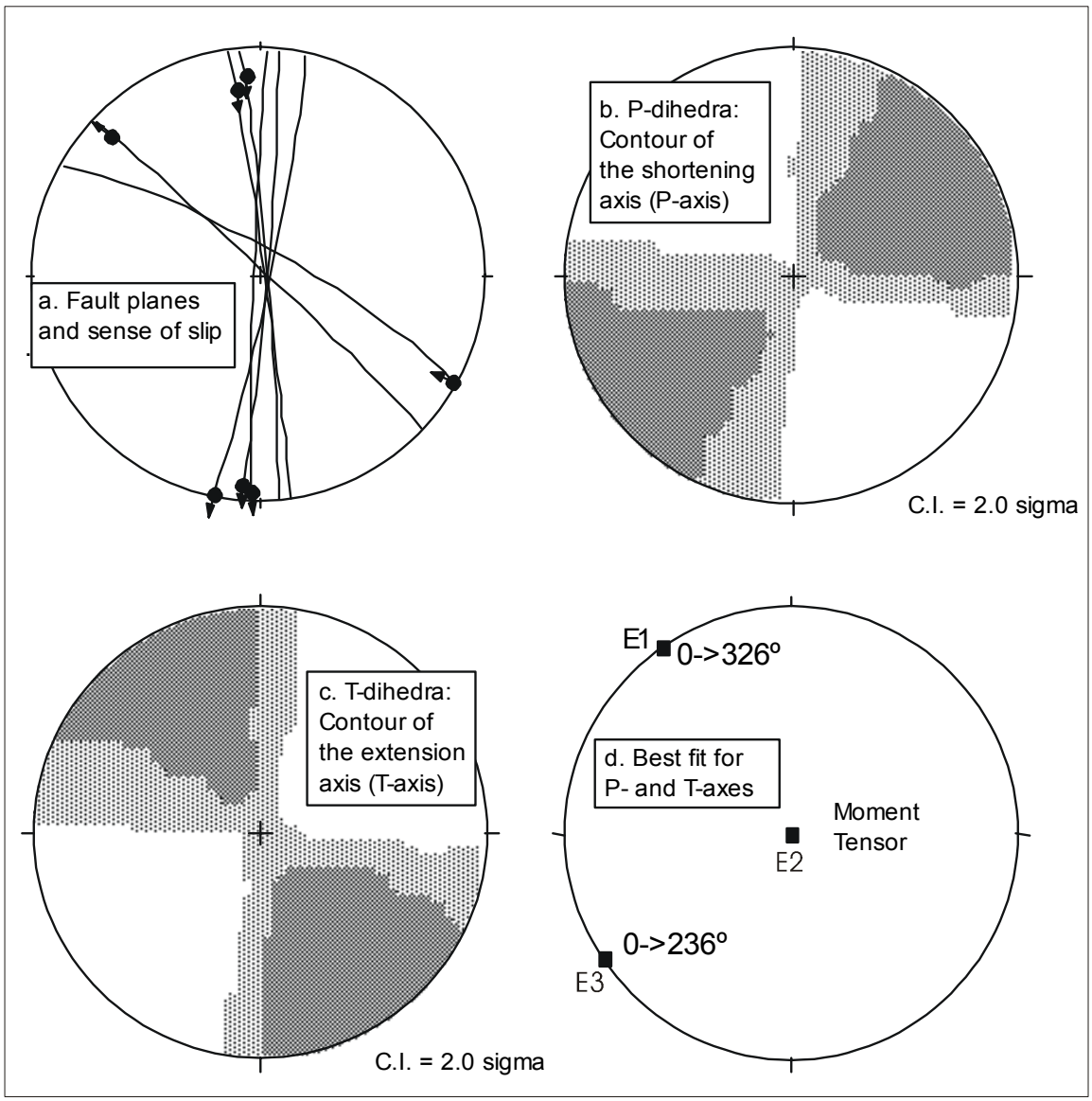


Fig. 5.17. Results of the kinematic analysis. (a) Lower hemisphere stereographic projections of 7 faults with a predominantly dextral strike-slip displacement from the Umvumvumvu River. (b) Contours for the P-axis shortening and (c) Contours for the T-axis representing the direction of extension. (d) Eigenvectors for the P and T axes.

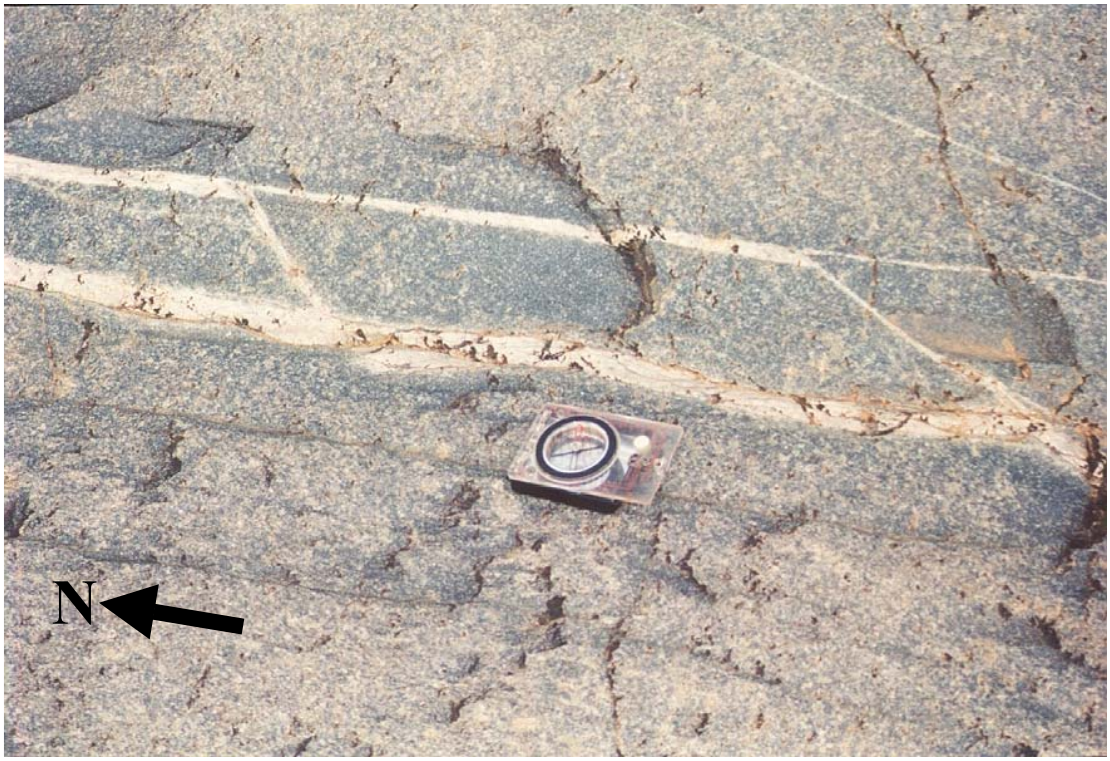
5.8.2 Quartz Veins

North-south trending epidote-quartz veins are continuous with northeast-southwest trending epidote-quartz veins and cut an Umkondo dolerite sill in the Umvumvumvu River (Fig. 5.18). The veins are therefore contemporaneous. A chlorite selvedge along the edges of the veins marks wall-rock alteration. The extension direction during the propagation of the veins is not well constrained from the geometry of the veins. However, simultaneous propagation of these veins possibly required a tectonic regime in which the extension direction ranged from east-west to northwest-southeast in order for the two fracture sets to open up. The geometry of the veins further suggests that their propagation was associated with dextral strike-slip sense of shears. The age of the veins is not well constrained, but they postdate Umkondo magmatism since the veins cut an Umkondo sill.

5.8.3 Dolerite Dyke – Pull Apart Structure

A very thin (5 mm-wide) north-northeast trending, sub-vertical, chilled dolerite dyke intrudes an Umkondo sill and has displaced two epidote-quartz veins that are perpendicular to the dyke in the Umvumvumvu River (Fig. 5.19; 461725, 7840406). The strike-slip separation shown by the veins is about 5 cm. The dyke is undeformed and forms a jog that shows a dextral strike-slip sense of movement. The jog suggests that dyke emplacement occurred in a tectonic regime that was associated with dextral strike-slip and extension. This sense of displacement is consistent with that shown by the displaced veins (Fig. 5.19).

The opening vector, which is the line connecting two points that were originally joined, measured from displaced epidote-quartz veins (Fig. 5.19) trends approximately 339º. The opening vector suggests a north northwest-south southeast extension direction, assuming that the principal strain axes were horizontal and vertical. A sub-horizontal slickenside lineation associated with sub-vertical faults (Fig. 5.15) that are sub-parallel to the dyke in the area suggests that the principal strain axes were nearly horizontal and vertical.



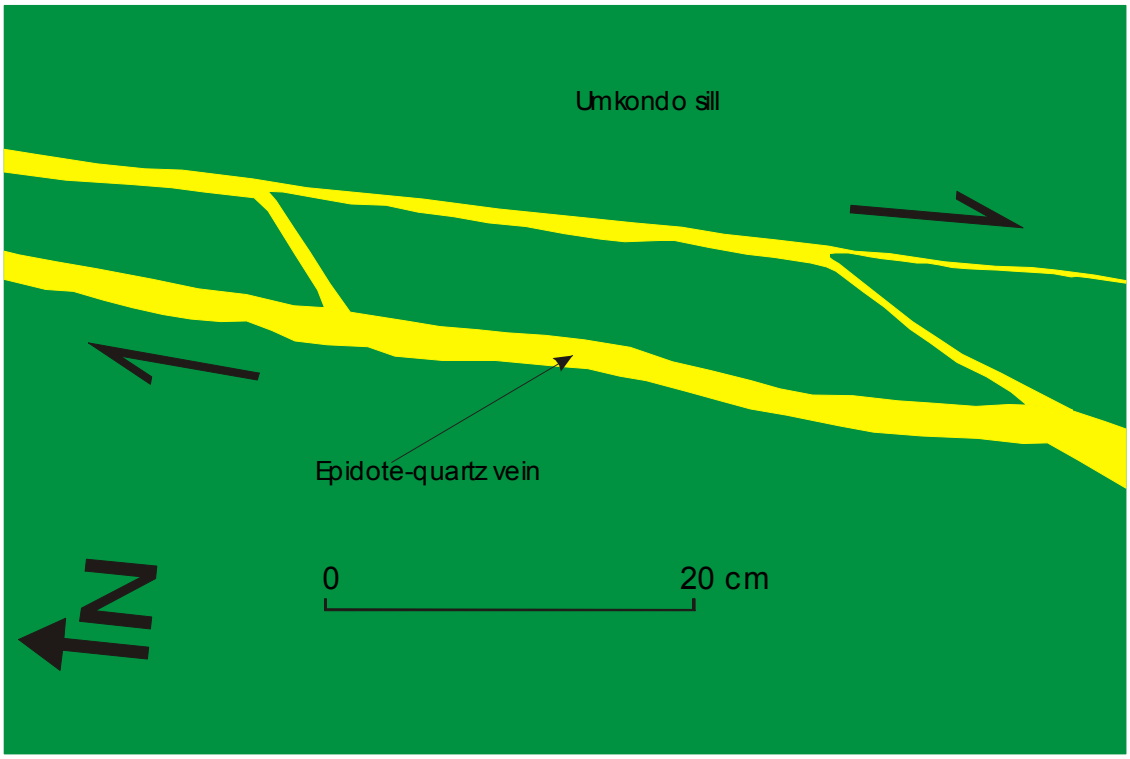


Fig. 5.18. Contemporaneous north- and east trending epidote-quartz veins that cut an Umkondo sill in the Umvumvumvu River (Grid Ref.: 461765, 7840438). The geometry of the veins suggests that the opening direction during vein propagation probably ranged from east-west to northwest-southeast and was associated with dextral strike-slip sense shears.

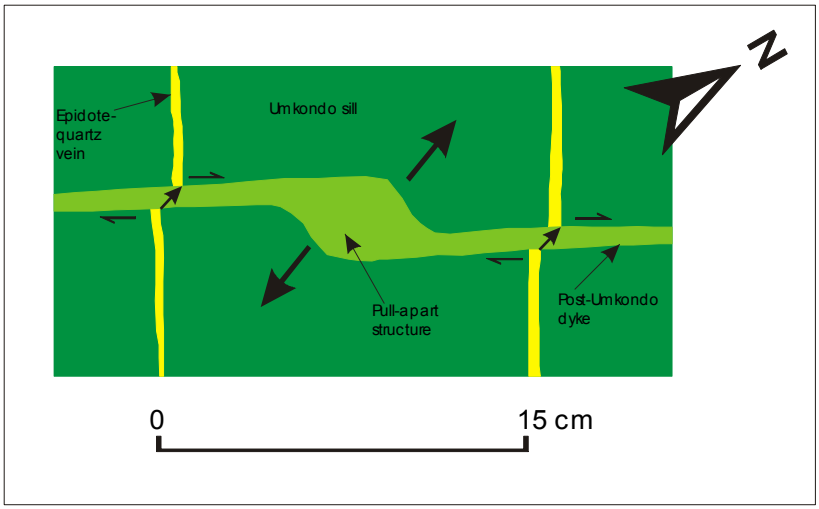


Fig. 5.19. A north northeast trending dyke intruding an Umkondo sill and displacing epidote-quartz veins in the Umvumvumvu River (Grid Ref.: 461725, 7840406). The dyke was emplaced in a pull-apart structure and displaced epidote-quartz veins. The sense of displacement is dextral strike-slip and the opening vector is 339º. The orientation of the least compressive stress (σ_3) was north northwest-south southeast during dyke emplacement and was a dextral strike-slip tectonic regime.

5.9 The Zimbabwe Facies: An Autochtonous Sequence?

The Zimbabwe facies exhibits tectonic relationships with the Mozambique facies in places. Evidence for this includes the occurrence of small-scale thrusts (Figs. 5.13 and 5.14) and west-verging folds (Figs. 5.10 and 5.12), which indicate that localised, west-directed movements have at least occurred in places in the Zimbabwe facies near the contact with the Archean basement granites. Lineations are rare in rocks of the Zimbabwe facies, possibly owing to the low-grade nature of metamorphism. On the crest of Mutsago Hill (Fig. 1.10), intensely deformed, folded banded cherts overlie a thin, persistent horizon of undeformed pebbly basal arkose (Fig. 5.11). The cherts are, in places, deformed by small-scale thrusts (Fig), west-verging folds and open folds with north-south trending sub-horizontal fold axes. These structures show that west-directed movement may have occurred in these cherts. Thus deformed cherts that cap Mutsago hill are allochtonous with respect to the arkose, and hence the Archean basement granites since the chert/arkose contact is tectonic.

Small-scale thrusts that occur in the Zimbabwe facies are analogous to the large-scale thrusts that occur in the Mozambique facies near the Zimbabwe/Mozambique border. Thus the small-scale structures documented in the Zimbabwe facies were associated with an east-west shortening direction and thrusting, and hence are considered to have been generated during the Pan-African Mozambique orogeny. The attitudes of the fold axes and orientation of the stretching lineation suggest that the maximum principal shortening, which is perpendicular or at a high angle to the fold axes, was east-west during deformation.

However, the greater part of the Zimbabwe facies appears to rest depositionally on the Archean basement granites. The sequence of pebbly basal arkoses, stromatolitic limestones, argillaceous rocks and upper cross-bedded arkoses is basically uniform throughout the Zimbabwe facies of the Umkondo group. Lack of discontinuity at the contact and the occurrence of thin, sub-horizontal arkose beds, whose thicknesses do not vary significantly and are parallel to the contact, suggest that the contact is locally a nonconformity (Fig. 1.10). Discontinuous thin horizons of limestone (Fig. 1.10) are primary sedimentary lenses that have no structural implications since they conformably overlie the arkose unit and do not truncate against any structures. Unstrained stromatolites in limestones that occur near the contact with Archean basement granites in places show that there has been no deformation in many parts of the Zimbabwe facies, compatible with the Zimbabwe facies resting nonconformably on the Archean basement granites.

The contacts between Umkondo dolerite sills and the Zimbabwe facies form surfaces of weakness across which the Zimbabwe facies might potentially have been thrust. Some sills are continuous in places between the Archean basement granite and the Zimbabwe facies and transgress the contact without any break (Figs. 3.18 and 5.20). Some sills that were emplaced along the granite/Zimbabwe facies contact have purely intrusive contacts with both the underlying granites and the Zimbabwe facies. North of Nhedziwa Business Centre, a sill that was emplaced partly along the nonconformity has intrusive contacts with the Archean basement granites and cherts and the sill transgresses bedding without

breaks (Figs. 3.18 and 5.20). The Zimbabwe facies is autochtonous with respect to Umkondo sills since the contacts between the sills and the Zimbabwe facies are clearly intrusive and have not been reactivated. The fact that Umkondo sills transgress the non-conformity in places without displacement suggests that the Zimbabwe facies is autochtonous with respect to the Zimbabwe craton and was not affected by large-scale thrusting that affected the Mozambique facies.

The presence of outliers of Umkondo rocks to the west of the Umkondo/Archean basement granite boundary would be indicative of large-scale, west-directed thrusting of the Zimbabwe facies. Although such outliers have not been observed, their absence does not rule out the possibility of large-scale thrusting of the Zimbabwe facies to the west since the outliers might have been eroded. Repetition of units, which is common in thrust terranes, has not been documented in the Zimbabwe facies.

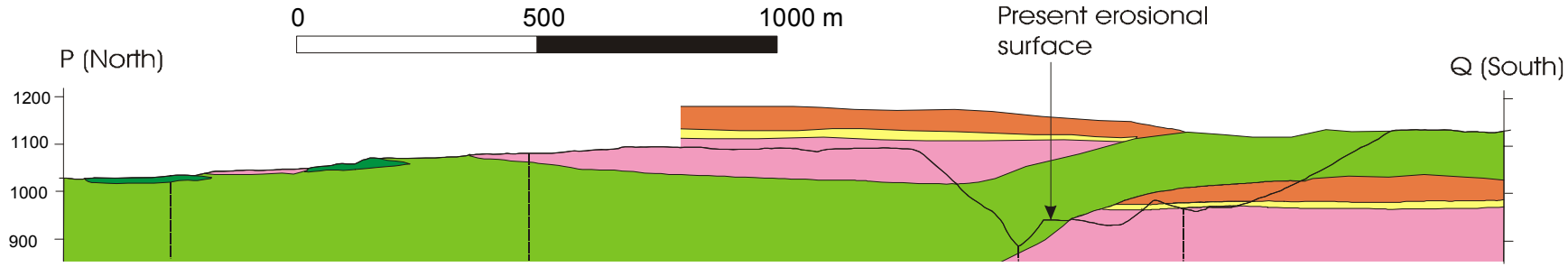


Fig. 5.20. Cross section showing a sill that is continuous from Archean basement granite to the Zimbabwe facies. The sill transgresses the contact without break suggesting that the Zimbabwe facies is autochtonous on a large scale.

5.10 Post-Umkondo Kinematic/Dynamic Analysis

Kinematic analysis on faults in the Umvumvumvu River using the Right Dihedra Method suggests a north-northwest extension direction and is consistent with that shown by displaced epidote-quartz veins and a pull-apart structure. The extension direction is near perpendicular to some east to east-northeast trending dykes of unknown age that occur to the east and north of Mutambara Mission (Fig. 1.3). The relation between these dykes and Umkondo sills cannot be established in the field due to lack of cross cutting relationships. A north-northwest extension direction would ideally facilitate preferential emplacement of dykes along near perpendicular fractures even with low magma pressures. It is plausible to suggest that at least some east to east-northeast dykes were contemporaneous with faults and a pull-apart structure in the Umvumvumvu River and therefore post-date the Umkondo Igneous event. Emplacement of these dykes was possibly associated with dextral strike-slip shears since the pull-apart structure and the majority of faults in the area show a dextral strike-slip sense of movement. Epidote-quartz veins in the Umvumvumvu River give a wide range of possibilities for the extension direction. The geometry of the veins indicates an E-W to NW-SE extension direction associated with a dextral sense of shear.

5.11 Discussion and Conclusions:

5.11.1 Synthesis of the Tectonomagmatic Events in Eastern Zimbabwe

The evolution of the granite-greenstone belts remains a subject of controversy. 'Vertical' or 'diapric' tectonic models and 'horizontal' crustal shortening models have been used to explain the dome-and-keel configuration of the granite-gneiss terrains and enveloping greenstone belts (Jelsma, 1993). Jelsma (1993) have shown that pluton emplacement triggered deformation of the greenstone sequences in the Harare-Chinamora-Shamva granite-greenstone terrain. Flattening fabrics with down-dip stretching lineations that occur in the greenstone belts have been interpreted to show that the north northwest-south southeast crustal shortening associated with the Limpopo orogeny affected the entire

Zimbabwean craton (Treloar and Blenkinsop, 1995). The Limpopo orogeny generated northeast to east trending shear zones that formed in response to shortening in central and eastern Zimbabwe (Treloar and Blenkinsop, 1995, Fig. 5.21). Deformation in the granite-greenstone terrains may be explained by both 'vertical' and 'horizontal' tectonic models.

The earliest deformation (D_1) on the Zimbabwe craton in eastern Zimbabwe was limited to the greenstone belts and syntectonic gneisses and resulted in regional folding of the Cronley Schist belt and possibly the Mutare greenstone belt (Fig. 5.21; Chenjerai, 1995) (Fig. 1.3). The Cronley Schist belt (Fig. 1.3) represents one relict northern limb of a synclinal structure of which the rest of the southern limb has been assimilated into the surrounding Chibi batholith (Watson, 1969). Subsequent to being metamorphosed and folded about east northeast trending axis, the Cronley Schist belt has been intruded by pegmatites from the Chibi batholith dated at 2650 Ma. Folding in the Cronley Schist belt therefore predates emplacement of the surrounding Chibi granites, and hence c. 2650 Ma is the minimum age of the first regional deformation.

The second major deformation event (D_2) involving basement rocks that underlie the Umkondo group are documented in garnetiferous granulites and charnockites of the Northern Marginal Zone of the Limpopo belt that occur to the south of Birchenough (Fig. 1.5). The Northern Marginal Zone (Fig. 5.21) has suffered three deformation events between c. 2.72 Ga and 2.0 Ga (Chiwara, 2003). The main deformation event that was associated with high temperature-low pressure granulite metamorphism in the Limpopo belt occurred from 2.62 to 2.58 Ga (Chiwara, 2003) and peak metamorphism has been dated at 2591 ± 4 Ma (Kamber *et al.*, 1995a) using conventional U-Pb zircon geochronology. The main deformation event was associated with north northwest-south southeast directed maximum shortening that was associated with north-directed thrusting of the Northern Marginal Zone onto the Zimbabwe craton (Coward *et al.*, 1976; Mkweli *et al.*, 1995; Rollinson and Blenkinsop, 1995; Treloar and Blenkinsop, 1995). North-northeast trending faults that are parallel to the Popoteke fault, herein called the Popoteke fault set (Fig. 2.2), cut the Zimbabwe craton and formed in response to this deformation.

The Great Dyke was emplaced at 2575 ± 0.7 Ma (Fig. 5.21, Oberthür *et al.*, 2002) parallel to, and probably contemporaneous with the Popoteke fault set.

Set 1 and 2 faults (chapter 7) that were possibly propagated during the Limpopo orogeny had a structural control on mafic dyke emplacement during subsequent igneous events and consequently mafic dykes of different ages may be parallel to these directions. The emplacement of the Mashonaland dykes and sills across the entire Zimbabwe craton during the early Proterozoic at 1830 ± 230 Ma (Wilson *et al.*, 1987) was related to north-northwest-south southeast maximum compressive stresses acting on the Zimbabwe craton that were related to limited overthrusting of the Central Zone onto the Northern Marginal Zone and south part of the craton (Fig. 5.21; Wilson *et al.*, 1987). The faults possibly acted as conduits for the emplacement of Umkondo dykes that fed Umkondo sills at c. 1100 Ma, which are penecontemporaneous with the Umkondo group; and subsequent Pan African dyke intrusions in eastern Zimbabwe (chapter 7). Kinematic analysis shows that post-Umkondo faults were generated in a tectonic regime that was associated with a north-northwest-south-southeast extension, which possibly facilitated preferential emplacement of some east to east-northeast trending, post-Umkondo dykes that occur to the east and north of Mutambara Mission (Fig. 1.3). Dyke emplacement at this age was associated with dextral strike-slip shears since most of the faults have dextral strike-slip sense of displacement. Displaced epidote-quartz veins and a pull-apart structure show a similar sense of movement and direction of opening.

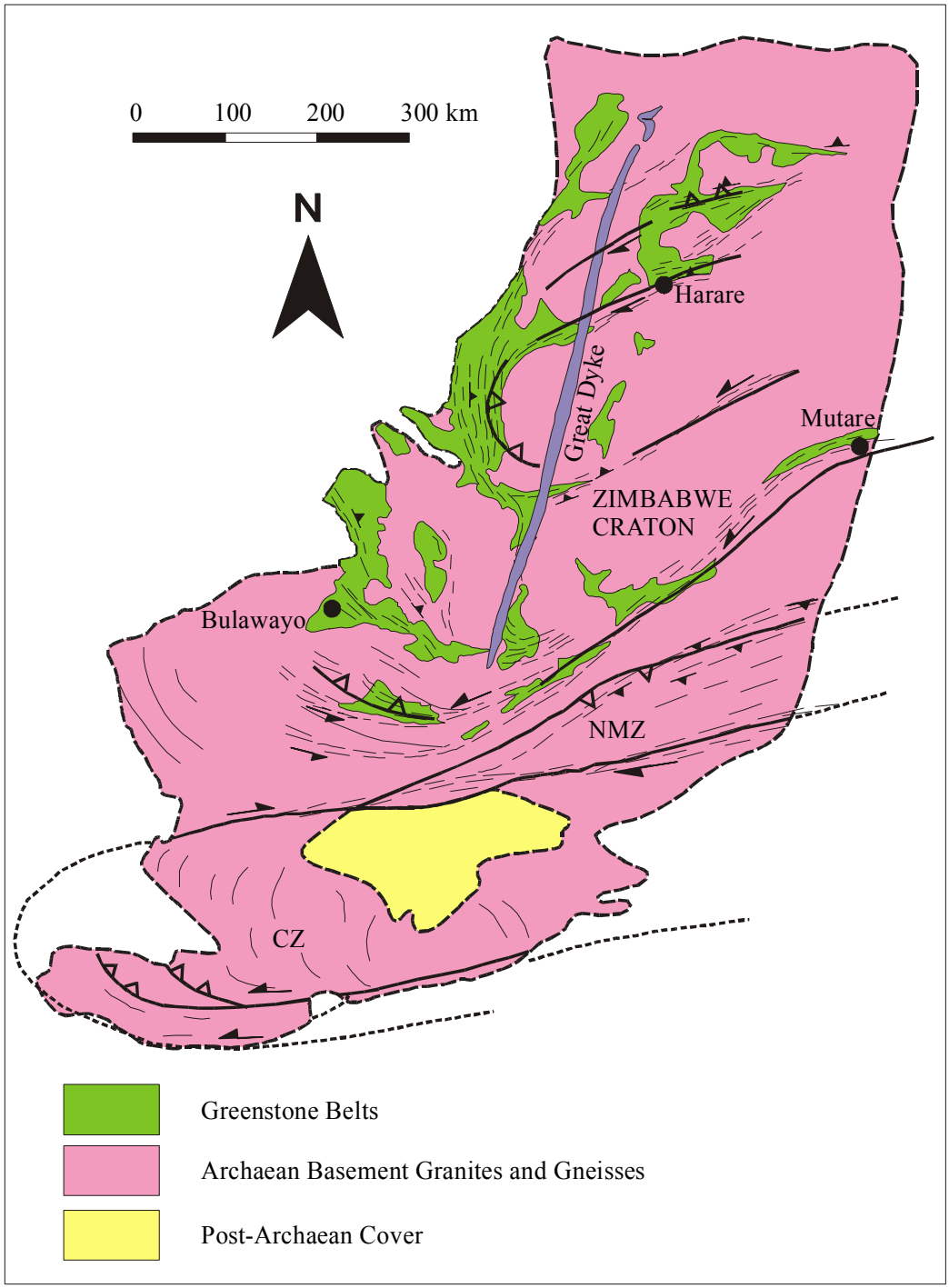


Fig. 5.21. Structural map showing the major fabric trends, zones of thrusting and strike-slip shear zones in the granite-greenstone terrains of the Zimbabwe Archean craton. The east northeast to northeast trending strike-slip shear zones in the Zimbabwe craton were formed during a north northwest-south southeast compression associated with thrusting of the Northern Marginal Zone (NMZ) of the Limpopo belt onto the Zimbabwe craton. CZ: Central Zone of the Limpopo Belt. The structural map is modified after McCourt and Vearncombe (1991) and Treloar *et al.* (1991)

5.11.2 Pan African Deformation

Rocks of the Mozambique facies were intensely deformed during the Pan-African Mozambique orogeny dated at ~550 Ma (Munyanyiwa, 1999). The contact between the Mozambique facies and the underlying Mozambique basement quartzofeldspathic gneisses is a sheared contact. West-verging structures and a sub-horizontal lineation that occur at the contact as well as throughout rocks of the Mozambique facies show that the Mozambique facies was thrust to the west, and, in contrast to the Zimbabwe facies, is clearly allochtonous.

The structural evolution of the Zimbabwe facies has been a subject of controversy. The original idea of a simple non-conformity has been challenged by suggestions that the entire Umkondo group may be allochtonous. The Zimbabwe facies exhibits some tectonic relationships with the Mozambique facies in places. Lineations are rare in deformed rocks of the Zimbabwe facies, possibly because they are generally weakly deformed. West verging small-scale structures, i.e. thrusts and folds, documented in places in rocks of the Zimbabwe facies, are equivalent to the Mozambique facies large-scale structures, which indicate that the Zimbabwe facies was at least locally affected by the Mozambique orogeny. However, these small-scale structures in the Zimbabwe facies, i.e. west-verging folds and thrusts that occur on a scale of a few metres in places have not accommodated movement on the scale of more than hundreds of metres since the Zimbabwe facies clearly rests depositionally on the basement in many places. Thus the Zimbabwe facies of the Umkondo Group is basically an autochtonous sequence on a large scale. East-west directed maximum compression during Pan African may have favoured reactivation of pre-existing faults and propagation of dykes along some northeast to east-northeast trends (chapter 6). The faults were also reactivated during Karoo or post-Karoo times since some faults displace thrusts in the Mozambique facies with a dextral strike separation of about 300 m.

The Mozambique facies is part of the north trending Mozambique belt that extends for thousands of kilometres on the eastern margin of Africa (Fig. 5.22). The 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). West-verging structures documented in the Mozambique facies are consistent with the collision model. However, precise dating of the Mozambique orogeny in eastern Zimbabwe needs to be done. The Mozambique belt converges with the Pan African Zambezi belt in a complexly deformed triple junction in northeast Zimbabwe and west Mozambique (Fig. 5.22; Barton *et al.*, 1985).

The Zambezi belt suffered three tectonothermal events (Dirks *et al.*, 1998; Mariga, 1999). The main deformation and metamorphism (M_1) in the Zambezi belt (Fig. 5.22) is considered to be ~ 820-830 Ma although some felsic igneous rocks that are interpreted to be syntectonic have given isotopic ages that range from ~ 880 Ma (Hanson *et al.*, 1994) and 805 Ma (Vinyu *et al.*, 1997). M_2 and M_3 were closely spaced, occurred from ~ 535 to 500 Ma (Vinyu *et al.*, 1997; Goscombe *et al.*, 1998, Hanson et al, 1998a; Hargrove, 1999; Mariga, 1999) and were possibly contemporaneous with the Mozambique orogeny and the Lufilian orogeny that occurred ~ 550 Ma ago (Fig. 5.22; Porada and Berhorst, 2000). M_2 and M_3 in the Zambezi belt were associated with south-directed thrusting onto the Zimbabwe craton (Barton *et al.*, 1985, 1991; Treloar *et al.*, 1990; Wilson *et al.*, 1993; Mariga, 1999). Thrusting in the Zambezi and Lufilian belts was contemporaneous with east-directed thrusting in the Mozambique belt and was driven by relative motion of the Zimbabwe and Congo cratons during Gondwana assembly (Fig. 5.22). The continental scale dextral shearing along the Mwembeshi Dislocation Zone accommodated the displacement of the Congo craton relative to the Zimbabwe craton (Porada and Berhorst, 2000).

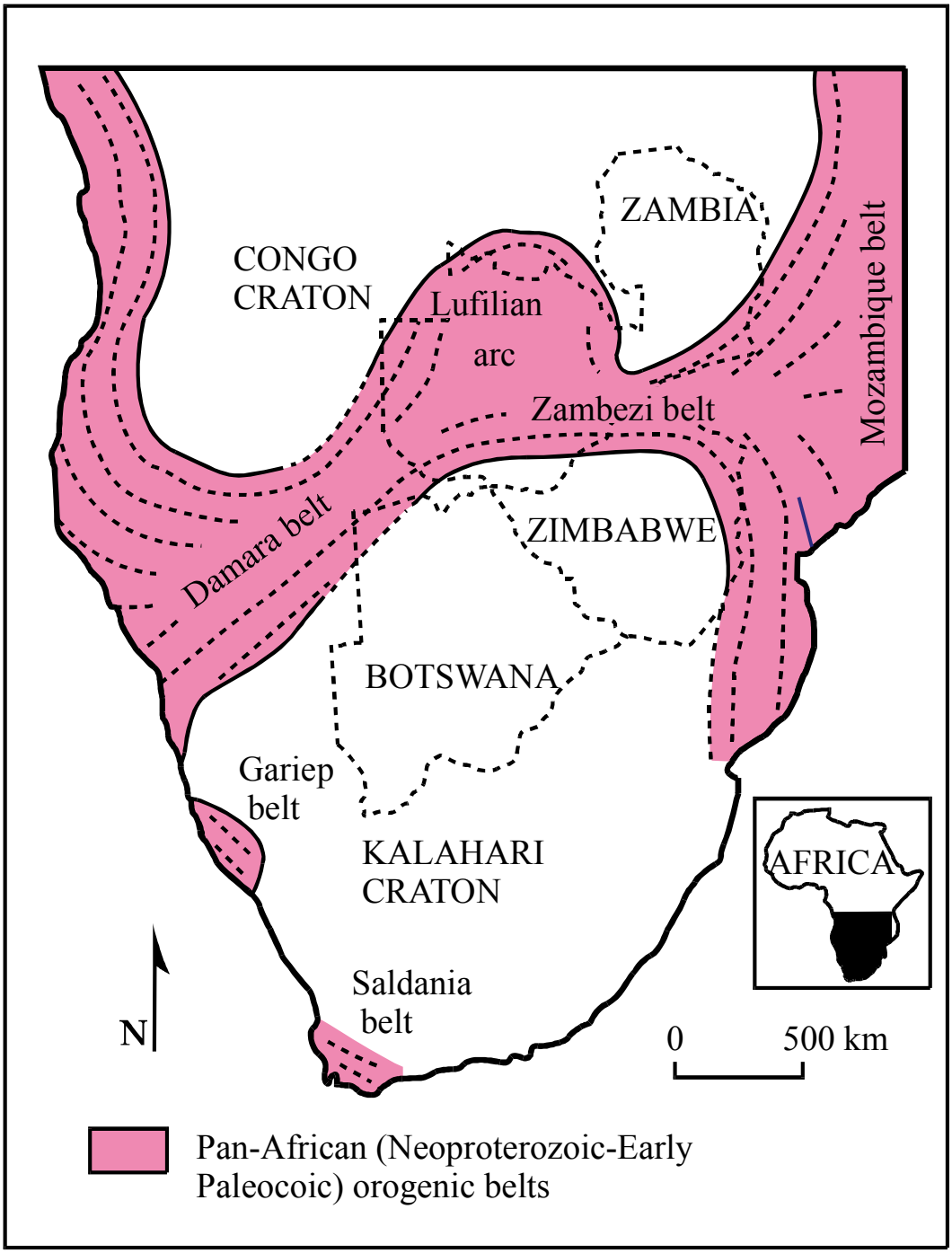


Fig. 5.22. Pan African orogenic belts in Southern Africa: The Mozambique belt is located on the eastern margin of southern Africa resulted from collision of east and west Gondwana. The Damara-Lufilian-Zambezi belt system by collision of the Congo and Kalahari cratons. Deformation in the Zambezi belt was contemporaneous with magmatism in the Congo and Zimbabwe cratons at about 720 Ma. The map is modified after Hanson (Unpublished manuscripts).