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THE STRUCTURAL EVOLUTION OF THE JOHANNESBURG DOME, KAAPVAAL CRATON, SOUTH AFRICA

MSc UP 1994

The structural evolution of the Johannesburg Dome, Kaapvaal Craton, South Africa.

By

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Submitted in partial fulfilment

of

the requirements for the degree of

Master of Science

Faculty of Natural Sciences

University of Pretoria

January 1994

ABSTRACT

The Johannesburg Dome is a structural unit comprising a basement inlier of Archaean granitoids with greenstone remnants and surrounding radially outwards dipping supracrustals. In this study, the tectonic fabrics and macrostructures of the basement inlier and immediately surrounding supracrustals were documented in order to constrain the structural evolution of the Johannesburg Dome.

Following generation of the basement granitoids in the Mid Archaean (involving at least three tectono-metamorphic events) and development of the Witwatersrand and Ventersdorp Supergroup depositories, a Late Archaean contractional deformation occurred. This event produced a series of northward verging thrusts and has been recognised throughout the study area. Lithostratigraphic constraints place the timing of this thrusting between 2709 and $\approx$2600 Ma allowing correlation with the Limpopo Orogeny.

Deformation features related to the thrusting dominate the rocks of the basement inlier and the West Rand Group rocks along its' southern margin. The Northcliff Promontory (a ridge West Rand Group rocks along the southern margin of the basement inlier) was mapped in detail to serve as a microcosm for the deformation of the West Rand Group in the Johannesburg area. The anomalous strike of the promontory is a result of northward

Cleavage duplexes in phyllite,

Orange Grove Quartzite Formation,

West Rand Group.

Location: Mellville Koppies, Johannesburg.

directed thrusting over the granitoids followed by 2 Km translation along an ENE striking, dextral sense, strike slip shear zone.

A conjugate shear zone set (NNE sinistral strike slip, NNW dextral strike slip) developed in response to north-south orientated regional compression. The shear zones post date the northward verging thrusts but pre-date the deposition of the Black Reef Quartzite Formation.

Following deposition of the Late Archaean\Early Proterozoic Transvaal Sequence, a second northward vergent thrust event occurred. This event was accommodated by bedding parallel slip in the Black Reef Quartzite Formation and is attributed to reactivation of basement thrust structures.

Arching of the crust to form the dome structure was probably due to thermal activity associated with the development and emplacement of the Bushveld Igneous Complex. This arching event caused gentle tilting of the rocks above the BRQF unconformity, but does not appear to have significantly influenced the attitude of the older units.

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1. INTRODUCTION

1.1 General

In structural geology a dome is defined as: *"An uplift or anticlinal structure either circular or elliptical in outline in which the rocks dip gently away in all directions" (Bates and Jackson, 1987).* Such structures develop in response to arching of the crust above a rising diapir or as a result of superimposed folding during orogeny. Implicit in this definition is a conformable relationship between all the units involved in the folding or in the case of igneous domes between the layering in the arched rocks and the outer surface of the intrusion.

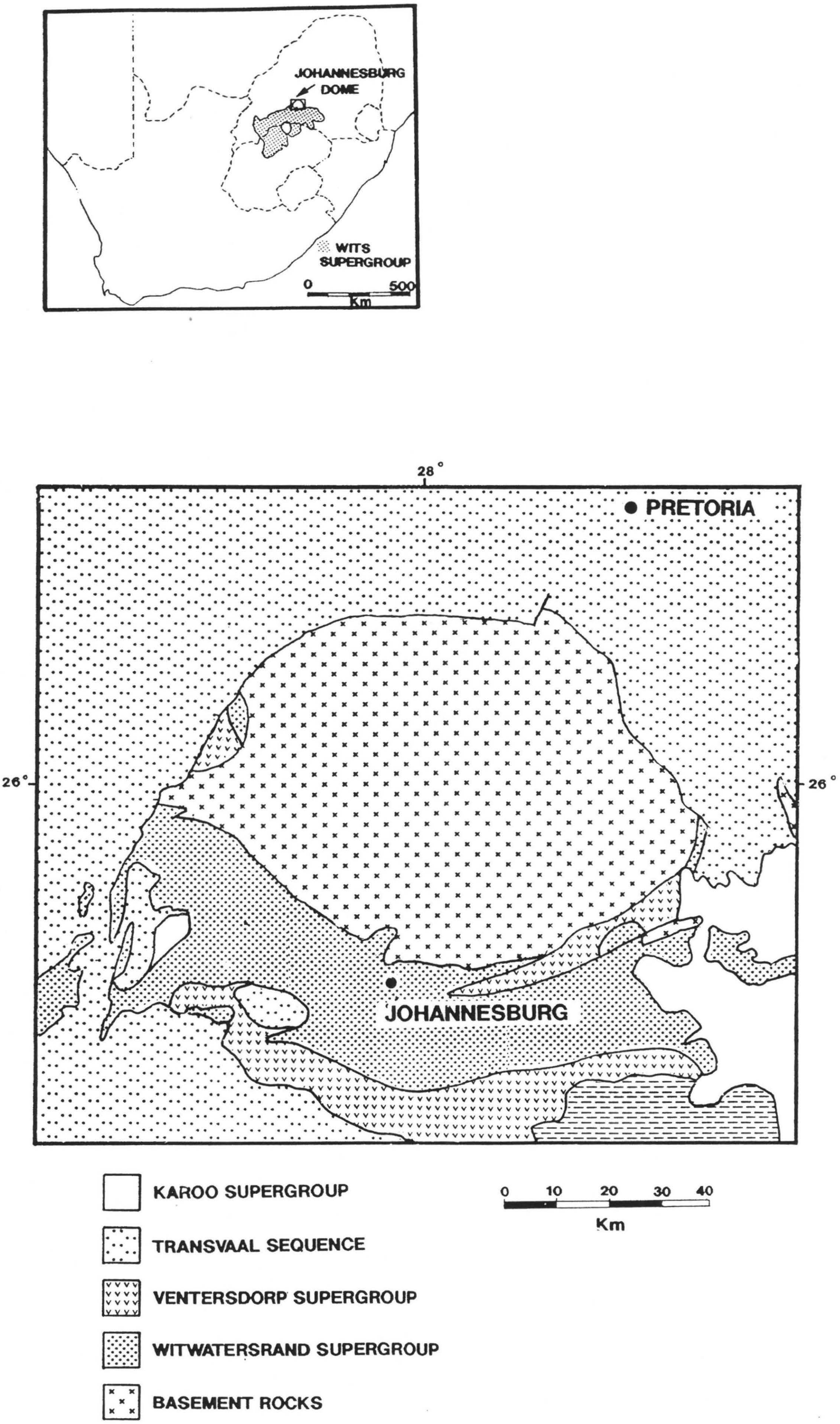
The Johannesburg-Pretoria Dome on the Kaapvaal craton was defined by Anhaeusser (1973) as a " domical window of ancient granite basement ... that had tilted the sediments of the younger cover rocks". Anhaeusser (1973) realised however that the lack of conformity between the foliation in the granitoids and the overlying cover rocks made it unlikely that the granite inlier was a dome *sensu stricto*.

Despite this problem the term Johannesburg Dome has been retained in the literature on the Kaapvaal Craton although it is typically used with reference to the granitoid rocks (e.g De Wit *et al*, 1992). In the account that follows, the term Johannesburg Dome is used to describe a structural unit on the central Kaapvaal Craton exposed in the Johannesburg-Pretoria area (Figure 1.1). The dome is roughly circular in plan, approximately 750 km^2 in area and comprises the following components:

(i) The outcrop of Archaean granitoids and associated "greenstone remnants" (the basement inlier) plus associated rocks of the Witwatersrand and Ventersdorp Supergroups.

(ii) Sedimentary rocks of the Transvaal sequence that fringe this structural window along the north, east and west and dip radially off the granitoid dominated basement inlier.

Figure 1.1: The locality of the Johannesburg Dome.



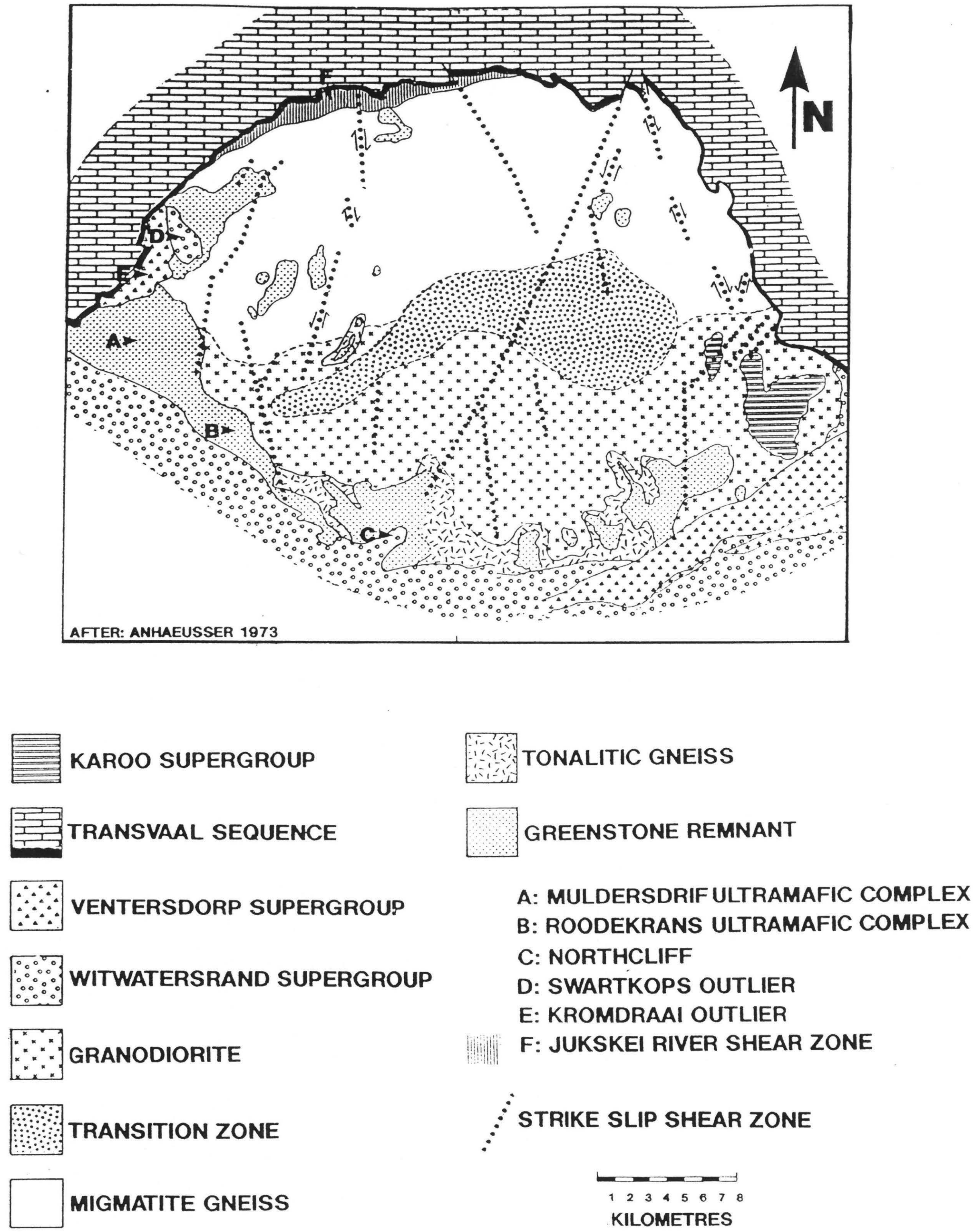
1.2 Aims and Methods

The principal aim of the study was to document the structural evolution of the Johannesburg Dome as indicated by tectonic fabrics and related macro-structures (shear zones, folds and faults) preserved in the basement granitoids and greenstone remnants as well as in the overlying supracrustal rocks. An additional aim was to evaluate the lithostratigraphic position of the various supracrustal rocks exposed on the Dome.

The investigation was field based and comprised regional mapping as well as detailed mapping of key or well exposed areas. After a reconnaissance survey of the area it became clear that the outcrop of the basement rocks as well as much of the surrounding supracrustals was extremely poor. The problem caused by lack of outcrop was compounded by the development associated with the "urban sprawl" between Johannesburg and Pretoria. A sample locality map produced by Anhaeusser (1973) proved invaluable for locating outcrop in extensively developed areas.

Regional mapping was carried out using 1:50 000 air photos as base maps and 1:50 000 topographical sheets for ground control. The final map (Map A) was reduced to a scale of 1:100 000. A detailed study was made of the Orange Grove Quartzite Formation in the Northcliff area (see Figure 1.2) to serve as a microcosm for deformation in the West Rand Group along the

Figure 1.2: *Simplified Geological map of the Johannesburg Dome showing the basic sub-divisions of the granitoid basement as made by Anhaeusser (1973).*



southern margin of the basement inlier, the map produced (Map B - Scale 1:10 000) is located in the back cover along with Map A. The locations of key outcrops in the mapped area are described in Appendix A, these outcrops are referenced in the text using the following format: **ST1, ST2** etc.

The temporal relationship between tectonic fabrics and lithostratigraphy was used to decipher the polyphase history of the area. Of particular importance is the distinction between deformation events that pre-date and post-date the deposition of the Black Reef Quartzite Formation (BRQF), the lowermost Formation of the Transvaal Sequence in the Johannesburg-Pretoria area. For the purpose of this thesis the terms pre-BRQF, post-Ventersdorp Supergroup etc. are used to describe events that occurred pre- or post-deposition/development of the lithostratigraphic unit in question.

Microscopy was used to establish the presence (or absence) of micro-scale structures and to determine where possible the mineralogy of the various rock types. Limited use was made of X-ray diffraction.

1.3 Stratigraphy and Geochronology

Table 1.1 shows the generalized stratigraphy and available geochronological constraints for the granitoids and greenstone remnants of the basement inlier, supracrustal rocks of the Wits Triad (Dominion Group, Witwatersrand Supergroup and Ventersdorp Supergroup) and the lower part of the Transvaal Sequence (SACS, 1980). Although not all units shown in the stratigraphic column are developed in the study area, the presence of structural outliers make their inclusion necessary in order to establish a relative time frame. Units that are represented in the study area are shown in bold type.

The oldest rocks in the study area are the Swazian age (3750-2870 Ma: SACS, 1980) greenstone remnants that occur scattered throughout the basement inlier. These include the Muldersdrif and Roodekrans ultramafic complexes (Anhaeusser, 1977; 1978). The greenstone remnants are intruded by various granitoids grouped by SACS (1980) into one unit, the Halfway House Granitoid. The West Rand Group, the lowermost group of the Witwatersrand Supergroup (SACS, 1980) is exposed along the SE margin of the basement inlier. The stratigraphy of the Group in the Johannesburg area is shown in Table 1.1. West Rand Group rocks also outcrop at Swartkops on the western margin of the basement inlier (see Figure 1.2). The maximum age of the OGQF (2980 Ma) is constrained by the age of the oldest dated detrital zircon found within the formation immediately west of Johannesburg

Table 1.1: *Stratigraphy and Geochronology of the lower part of the Transvaal Sequence, Wits Triad and basement granitoids of the Johannesburg Dome.*

GROUP	SUBGROUP	FORMATION	LITHOLOGY	AGE (Ma)
TRANSVAAL SEQUENCE				
Chuniespoort	Malmani		Dolomite	2557±49[c]
		Black Reef Quartzite	Quartzite and shale	
VENTERSDORP SUPERGROUP				
Pniel Sequence		Allanridge Bothaville	Andesitic lava Sediments	
Platberg		Rietgat Makwassie Goedgenoeg **Kameeldorings**	Lava and sediments Quartz feldspar porphyry Andesitic lava **Sediments**	2709±4[a]
Klipriviersberg		Edenville Loraine Orkney Alberton Venterspost	Amygdaloidal and porphyritic lavas with subordinate tuffs Quartzite and conglomerate	2714±8[a]
WITWATERSRAND SUPERGROUP				
Central Rand	Turfontein Johannesburg	-Various- Krugersdorp -Various-	Quartzite Bird amygdaloid Quartzite and conglomerate	
West Rand	Jeppestown Government **Hospital Hill**	Roodepoort Crown Florida Witpoortjie Coronation Promise **Brixton** **Parktown** **Orange Grove**	Quartzite, shale and conglomerate Amygdaloidal lava Quartzite Shale and quartzite Shale Quartzite and shale **Quartzite and shale** **Shale and quartzite** **Quartzite and shale**	2914±8[a] ≈2980[b]
DOMINION GROUP				
Dominion		Syferfontein Rhenosterhoek Rhenosterspruit	Porphyry, basic lava and tuff Porphyry, lava and tuff Quartzite and conglomerate	3074±6[a] ≈3096[c]

BASEMENT GRANITE AND GNEISS
Tonalite-trondjhemite gneiss: 3170±34 Ma[d]

BASEMENT GREENSTONE REMNANTS
Source of data: [a] Armstrong *et al* (1991) [b] Barton *et al* (1989) [c] Robb *et al* (1991) [d] Anhaeusser and Burger (1982) [e] Jahn *et al* (1990).

(Barton et al, 1989). Debris flow diamictites, argillaceous sediments and quartz porphyry lavas of the Ventersdorp Supergroup outcrop west of Swartkops in the Kromdraai outlier (Hendriks, 1961; Winter 1976). The sediments have been correlated by Winter (1976) with the Kameeldoorns Formation of the Platberg Group. Stanistreet and McCarthy (1986) have suggested that the Kromdraai outlier forms the easternmost extension of the Kromdraai graben (Figure 2.2). The approximate sub-surface extent of the Kromdraai graben (also referred to as the Ireton Graben by Stanistreet and McCarthy, 1990) has been delimited by drilling through the Transvaal cover to the west. Outcropping discontinuously between the Platberg sediments and the West Rand Group rocks of the Swartkops outlier (Figure 1.2) is a thin quartz porphyry lava that has been interpreted by Stanistreet and McCarthy (*1990*) to be part of the Platberg Group.

An important element in the stratigraphy of the Johannesburg Dome is the Black Reef Quartzite Formation (BRQF). This forms the base of the Transvaal Sequence in the area and lies unconformably on the granitoids and greenstones of the basement inlier as well as rocks of the Wits Triad. The overlying dolomites of the Transvaal Sequence are correlated with the Schmidtsdrif Formation in the Griqualand West Basin (Beukes, 1987) which has been dated at 2557 ± 49 Ma (Jahn *et al*, 1990). This implies that the BRQF should be ≈ 2600 Ma.

2 PREVIOUS WORK

2.1 Basement

The earliest geological studies of the Johannesburg Dome were carried out by Hall (1906) and Kynaston (1906,1907,1929) who compiled the first geological map of the area and differentiated between the "Old Granite" and the surrounding supracrustals. Wagner (1907) and Wade (1909) made localised studies of the petrography of the granites. Horwood (1910) analyzed the chemistry of selected granite samples.

Willemse (1933) remapped and described the granitoids making several important observations, among them that: " ...the granite bears a definite intrusive relationship to certain ... basic schists." (The basic schists are now recognised as greenstone remnants). Willemse (*op cit*) also noted that the granitoids had been deformed along NW to NE striking "crush zones" (shear zones) that contain extensive quartz veining.

Anhaeusser (1973) made the first detailed examination of the granitoids and greenstones of the basement inlier and divided the granitoids into the following units (See Fig 1.2) :

(1) Tonalite-Trondjhemite Gneisses

These outcrop in the southern half of the basement inlier except for one small "xenolith" surrounded by younger granitoid in the central part. They have been dated by Anhaeusser and Burger (1982) at 3170 ± 34 Ma (U-Pb zircon) and are interpreted to be the oldest granitoids of the basement inlier (Anhaeusser, 1973; Anhaeusser and Burger, 1982). Typically, the gneissic foliation parallels the margins of the greenstone remnants into which the tonalite-trondjhemites intruded, this phenomenon was considered by Anhaeusser (1973) to be due to deformation associated with intrusion.

(2) Granodiorites

These outcrop in the southern and central parts of the basement inlier and field relations indicate that they are intrusive into the earlier tonalite-trondjhemites. Anhaeusser and Burger (1982) suggested that the granodiorites may have been generated through partial melting of either the tonalite-trondjhemites or an as yet unrecognised source of tonalitic composition. Age data for the granodiorites is equivocal: Allsopp (1961) calculated a Rb-Sr whole rock age of 3132 ± 64 Ma, Burger and Walraven (1979) reported a 207Pb/206Pb zircon age of 2585 ± 65 Ma whereas Anhaeusser and Burger (1982) presented U-Pb zircon data that suggested a minimum age of 2708 Ma. Anhaeusser (1973) further sub-divided the granodiorites into coarse grained, medium grained and porphyritic types.

(3) Migmatite Gneisses

The migmatite gneisses outcropping in the northern half of the basement inlier, are banded gneisses with migmatitic features that were interpreted by Anhaeusser (*op cit*) to represent a product of metamorphism and small amounts of partial melting of the 3170 Ma tonalite-trondjhemites.

(4) Transition Zone

Anhaeusser (1973) recognised a region in the central part of the basement inlier in which the granitoids exhibited features of both the relatively unmetamorphosed and undeformed granodiorites as well as the tonalitic migmatite gneisses to the north. He suggested that this area represents a transitional zone between the two rock types.

Greenstone remnants and xenoliths of talcose schist, serpentinite and amphibolite are found throughout the basement inlier of the Dome. Anhaeusser (1973, 1977, 1978, 1992) has mapped and described the larger remnants and verified the observation of Willemse (1933) that the granitoids are intrusive into the greenstone remnants. Anhaeusser (*op cit*) also noted that considerable contamination of the granitoids has taken place in the contact regions.

Anhaeussers' studies of the granitoids and greenstone remnants of the basement inlier concentrated on petrology, geochemistry and the intrusive history of the rocks but did not deal with the structural geology in any depth. Anhaeusser (1973) described the "shear or crush zones" noted by Willemse (1933), suggesting that they had operated as right lateral strike slip structures in post-Transvaal Sequence times. Anhaeusser (1978) also described folds with doubly plunging, east-west trending axes developed in the layered intrusives of the Muldersdrif ultramafic complex. He interpreted the fold pattern to be as a result of two phases of folding, the first orientated about east-west striking fold axes, the second about north-south striking fold axes. Anhaeusser (1973) documented irregular small scale folding of the gneissic banding in the migmatite gneisses of the northern part of the basement inlier and interpreted them to represent syn-metamorphic flowage folds.

2.2 Supracrustals

Structural studies of the supracrustals immediately surrounding the granitoids and greenstones of the basement inlier have been restricted to the northern margin of the Witwatersrand basin, the Swartkops and Kromdraai outliers on the NW flank of the inlier and a few localities in the BRQF.

Hendriks (1961) investigated the geology around Swartkops and was the first to recognise the folded nature of the West Rand Group rocks forming the Swartkops outlier. Other important observations made by Hendriks (*op cit*) were the identification of numerous thrust faults in the West Rand Group rocks of the outlier and the thrusted nature of the basal contact of the Ventersdorp Supergroup quartz porphyries.

Roering (1984) re-examined the structural geology of the Swartkops outlier and concluded the outlier is an imbricate thrust stack of West Rand Group strata. Roering (*op cit*) identified a dominantly east-west striking, south dipping cleavage with associated south plunging mineral elongation lineations. These features along with S-C fabrics and other kinematic indicators imply a NNE thrust vergence. The fabrics developed in the West Rand Group rocks were traced by Roering (*op cit*) into the Ventersdorp Supergroup rocks of the Kromdraai graben and the adjacent basement rocks. Roering (*op cit*) concluded that the deformation did not affect the BRQF to the west and was thus post mid-Ventersdorp Supergroup, pre-Transvaal Sequence in age. A minimum amount of shortening of 6-7km was calculated by Roering (*op cit*) for the Swartkops outlier.

Roering (1986) described an imbricate thrust stack developed in an east-west striking, south dipping ductile shear zone outcropping along the NW margin of the basement inlier. This shear zone was termed the Jukskei River Shear Zone (JRSZ) by Roering (*op cit*) and its locality is indicated on Map A. Tectonic lenses of quartz mylonite, shale and amygdaloidal lavas are interleaved with highly sheared and mylonitised granitoids. Roering (*op cit*) suggested that the quartz mylonites were originally quartzites and along with the shale represent sedimentary units of the Witwatersrand Supergroup. Roering (pers comm, 1992) has also suggested that the amygdaloidal lavas may represent part of the Ventersdorp Supergroup. Planar fabrics in the thrust pile strike east-west and dip at variable angles to the south, linear fabrics plunge down dip and kinematic indicators are consistent with a south over north thrust sense of movement (Roering, 1986).

The mylonitic fabric of the thrust stack is abruptly truncated by gently folded rocks of the BRQF, indicating that the shear zone deformation pre dates deposition of the Transvaal Sequence (Roering, 1986). The deformation event that produced the JRSZ has been correlated by Roering *et al* (1990), albeit geometrically, with that observed at Swartkops, within an as yet unnamed "klippen" of Witwatersrand Supergroup rocks on the farm Honingklip 178 IQ and along the present northern margin of the Witwatersrand basin. Roering *et al* (1990) envisage a post-mid Ventersdorp Supergroup, pre-Transvaal Sequence northwards directed contractional event with associated footwall collapse to explain this thrust pile (See Figure 2.1).

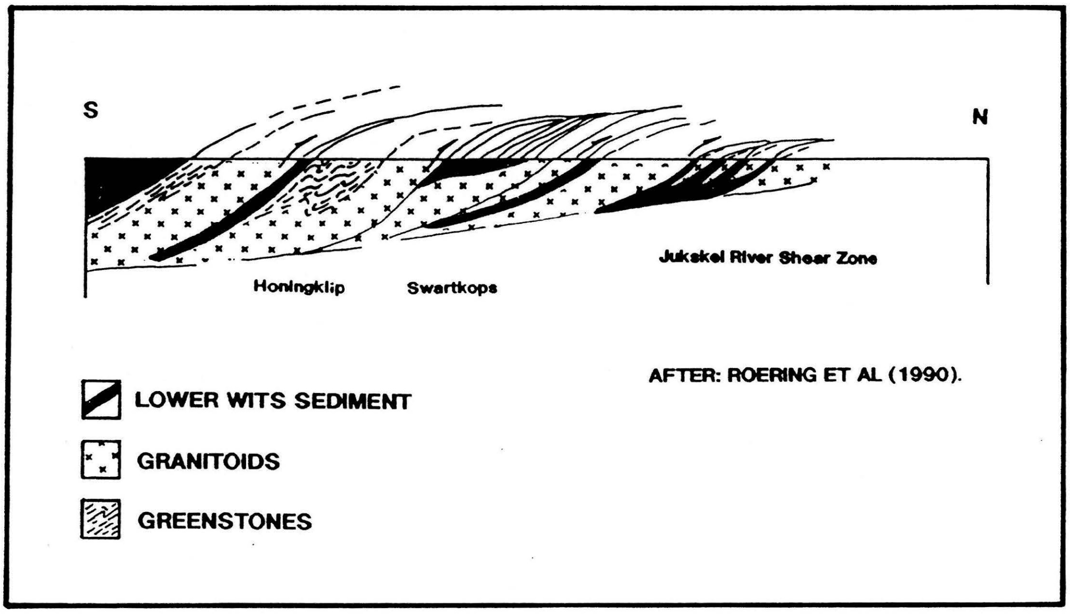


Figure 2.1: *A schematic north-south section across the western side of the basement inlier illustrating the style of thrust deformation envisaged by Roering et al (1990).*

McCarthy *et al* (1986) investigated the BRQF and adjacent Platberg sediments immediately west of the Swartkops outlier on the farms Rietfontein 522 JQ and Tweefontein 523 JQ. Both rock types exhibit an east-west striking, south dipping cleavage and south plunging mineral elongation lineations. Deformation was by simple shear with a south over north thrust sense (McCarthy *et al, op cit*). Strained metamorphic porphyroblasts of similar grade were observed by McCarthy *et al* (*op cit*) in the shales of the BRQF as well as the Platberg Formation diamictites. Fabrics developed in the Platberg sediments and BRQF are similarly orientated to those in the West Rand Group rocks of the Swartkops outlier. McCarthy *et al* (*op cit*) suggested that these fabrics were all produced during the same post BRQF northward directed thrusting event. This is contrary to the ideas of Roering *et al* (1990) who consider that the bulk of the deformation took place pre-BRQF and a post-BRQF deformation of significantly lower intensity (possibly related to reactivation of earlier structures) produced the cleavage in the BRQF.

As part of a structural analysis of the West Rand Syncline (Figure 2.2), Roering (1968) studied the West Rand Group along the SW margin of the basement inlier and identified five phases of deformation:

(1) Development of reverse faults trending 120° with associated folding (fold axes approximately parallel to the fault trend).

(2) Folding associated with the development of the West Rand Syncline.

(3) Development of an east-west striking south dipping cleavage as a result of north-south compression. Roering (*op cit*) concluded that the cleavage development post-dated the folding described in (2) above.

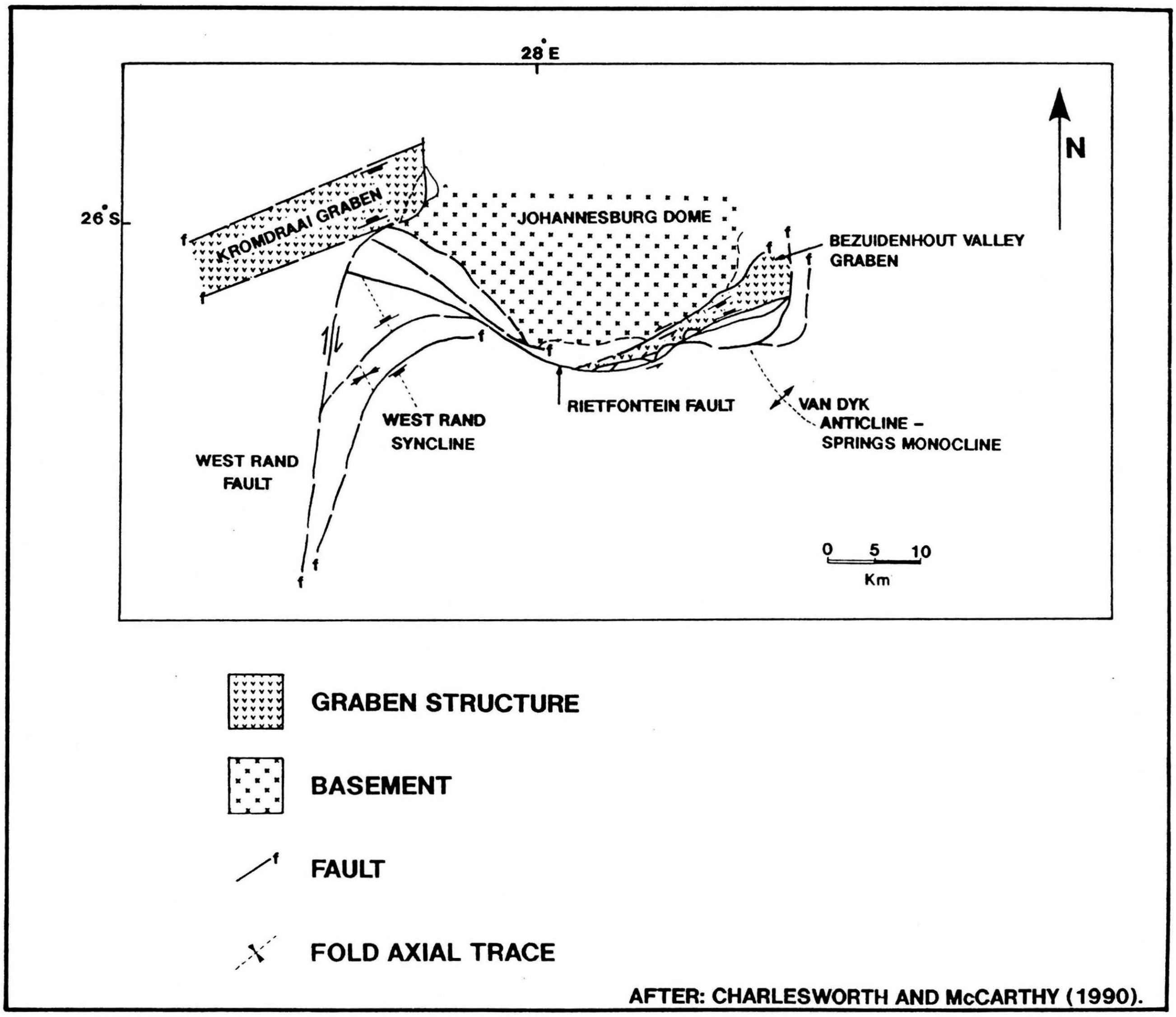
(4) Reactivation of earlier faults as wrench faults with a right lateral sense of movement.

(5) Development of right lateral wrench faults trending 138° as a result of east-west compression.

The majority of papers dealing with the structural geology of the northern margin of the Witwatersrand basin in the vicinity of the Johannesburg Dome deal with the Rietfontein Fault and its associated structures. The Rietfontein fault system, first described by Mellor (1911, 1917), is a curvi-linear fault system situated on the southern margin of the basement inlier (Figure 2.2).

Stanistreet *et al* (1986) interpret the Bezuidenhout Valley Graben (BVG) as a pull-apart basin structure related to left-lateral movement on the Rietfontein fault and a sub-parallel fracture bounding the northern side of the graben (Figure 2.2). Stanistreet *et al* (*op cit*) and Charlesworth and McCarthy (1990) suggest that the Rietfontein and other similarly orientated left-lateral faults were active from Central Rand Group times until mid-Ventersdorp Supergroup times. The faults bounding the BVG are interpreted by Stanistreet *et al* (*op cit*) to be part of a craton scale left lateral fault system which include the inferred bounding faults of the Kromdraai Graben.

Figure 2.2: Major structural features along the southern margin of the basement inlier. Transvaal and Karoo cover has been removed.



Studies by Pitts (1990) in the East Rand Goldfield 10km south of the BVG, document considerable evidence for a "post-Ventersdorp dyke emplacement", pre-BRQF, NE directed, bedding parallel to sub-parallel thrusting event. Pitts (*op cit*) also reported a northwards verging bedding parallel thrusting event of post-BRQF, pre-Karoo Supergroup age. The magnitude of this later event is considerably less than that of the earlier thrust deformation.

The post-BRQF, north directed, simple shear deformation reported by McCarthy *et al* (1986) in the BRQF on the farms Rietfontein 522 JQ and Tweefontein 523 JQ, near Swartkops, and a few localities on the northern margin of the basement inlier was also observed by the same workers in the Rand anticline, the Central Rand and near Heidelberg. The folds and cleavage associated with this deformation are roughly tangential to the Vredefort structure and are interpreted by McCarthy *et al* (*op cit*) to be related to the Vredefort event.

McCarthy *et al* (1986) also showed that the cleavage developed in the BRQF on the farms Tweefontein and Rietfontein has been dispersed and that when corrected for the radial dip away from the basement inlier of the Johannesburg Dome, the cleavage orientations correspond, thus indicating that the deformation event responsible for the development of the cleavage took place prior to the arching of the crust to form the Johannesburg Dome.

2.3 Summary of previous work dealing with the structural history of the Johannesburg Dome.

Very little research has been done on the structural geology of the basement inlier that forms the core of the Johannesburg Dome. NNW to NE striking shear zones were identified by Willemse (1933) and confirmed by Anhaeusser (1973). Anhaeusser (1978) described doubly plunging folds developed in the layered intrusives of the Muldersdrif greenstone complex. The JRSZ documented by Roering (1986), consists of tectonically imbricated basement granitoids and supracrustals. The thrusting in the JRSZ is northward verging and pre-dates the deposition of the Transvaal Sequence.

Structural studies of the supracrustals have been restricted to the rocks of the Witwatersrand Supergroup along the southern margin of the basement inlier and in the area around Swartkops. McCarthy *et al* (1982), Stanistreet *et al* (1986), Charlesworth and McCarthy (1990) and McCarthy *et al* (1986) have studied the Rietfontein fault system and its associated structures. The Rietfontein fault has had a long history of dominantly left lateral movement with different oblique normal or reverse components during various phases of reactivation. All major left lateral movement ceased prior to BRQF deposition.

10 km south of the Rietfontein fault, in the East Rand Basin, Pitts (1990) recognised two phases of northward verging, bedding sub-parallel thrust movement:

(1) A "post-Ventersdorp dyke emplacement", pre-BRQF event.

(2) A post-BRQF, pre-Karoo Supergroup event.

Roering (1968) recognised several phases of faulting in the Krugersdorp-Florida Hills area as well as folding associated with the development of the West Rand syncline. Roering (*op cit*) also described an east-west striking , south dipping cleavage; associated with north-south compression; that developed after the folding event.

The structural history of the Swartkops outlier, the eastern extension of the Kromdraai Graben and adjacent BRQF has been the source of considerable controversy. Roering (1984, 1986) regards the majority of the deformation in the Swartkops area as part of a post-mid Ventersdorp Supergroup, pre-BRQF northwards directed thrusting event and that similarly orientated thrust sense features in the BRQF developed during a later event of much lower intensity. McCarthy *et al* (1986) suggest that all the north directed thrusting and related simple shear features in the area formed during one event, that post-dated the development of the BRQF.

McCarthy *et al* (1986) showed that the cleavage developed in the BRQF in the Swartkops area has been dispersed by the arching of the crust to form the Johannesburg Dome and therefore that the post-BRQF deformation pre-dates the doming event.

3. STRUCTURAL GEOLOGY OF THE GRANITOIDS

3.1 Introduction

The results of a regional mapping program have been summarised on Map A. The subdivision of the granitoids proposed by Anhaeusser (1973) was utilised whenever possible but several changes, particularly with regard to the "transition zone" have been made. Features of the granitoids relevant to this structural study are discussed below, for detailed petrographic and geochemical descriptions of the granitoids, readers are referred to Anhaeusser (1973).

3.1.1 Tonalite-Trondjhemite gneisses.

These outcrop along the southern margin of the basement inlier and are interpreted to be the oldest exposed granitoids of the Johannesburg Dome (Anhaeusser, 1973). They intrude the greenstone remnants and contain xenolithic fragments of greenstone material. A strong gneissic foliation defined by the preferred orientation of biotite and hornblende is developed (Figure 3.1).

The gneissic foliation parallels the contacts with the greenstone remnants. Deformed xenoliths of greenstone material, as noted by Anhaeusser (*op cit*) are aligned parallel to the gneissic foliation. Anhaeusser (*op cit*) related the

Figure 3.1: *Tonalite-trondjhemite gneiss with strong gneissic foliation defined by preferred orientation of mafic minerals. A later pegmatite vein cross-cuts the gneissic foliation.*

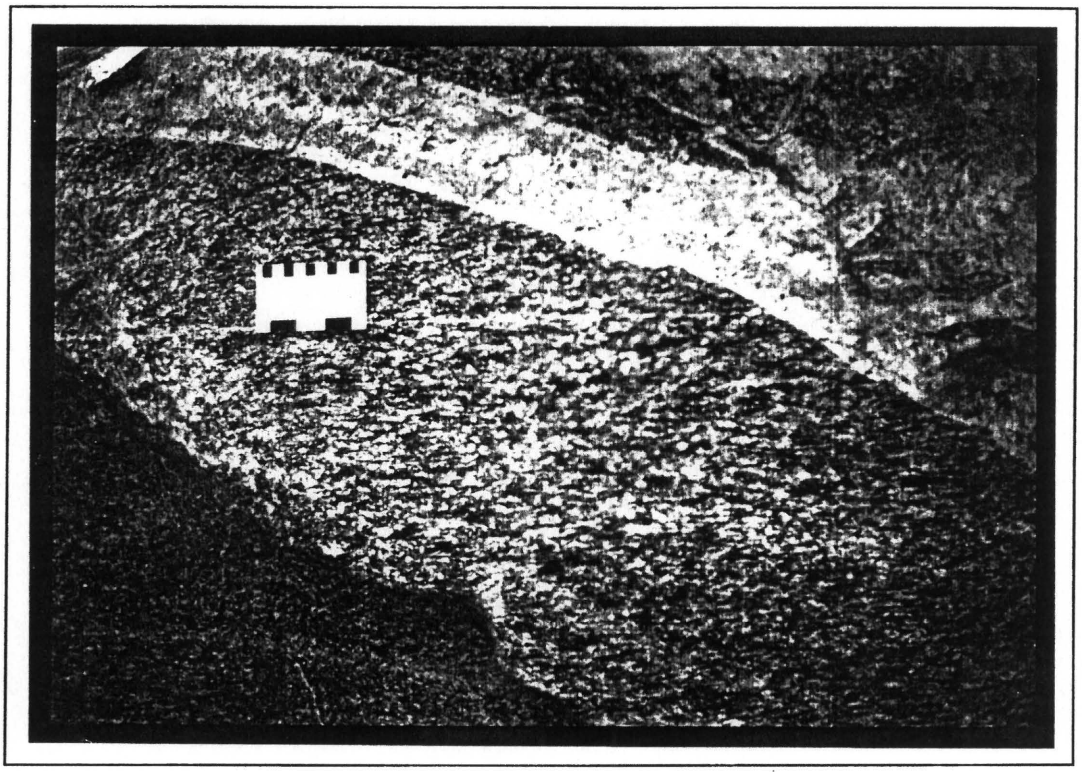


Figure 3.2: *Fresh surface of banded gneiss showing how the banding is defined by alternating layers of melanocratic and leucocratic minerals.*

formation of the gneissic foliation to deformation during the intrusion of the tonalite-trondjhemite magma into the greenstone material.

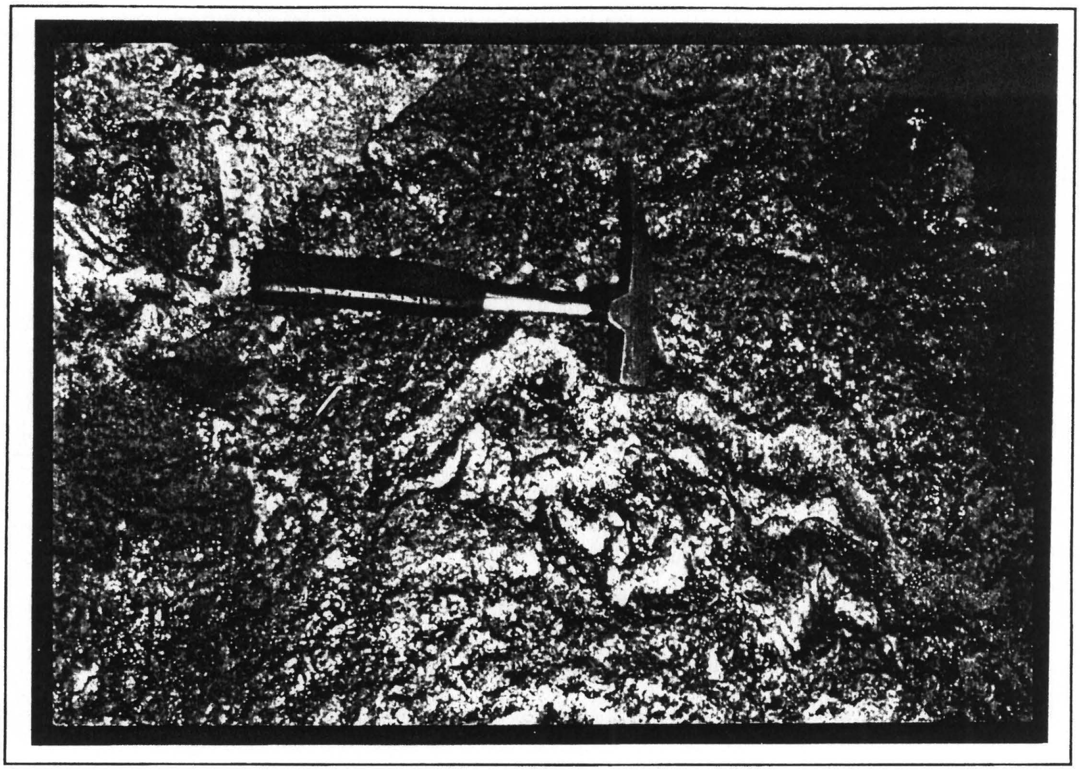
3.1.2 Banded Gneiss

The northern half of the basement inlier consists of gneisses with a strong metamorphic banding defined by alternating quartz-feldspar and biotite rich layers (Figure 3.2). Migmatitic features such as leucocratic "pods" dominated by quartz and K-feldspar indicate that localised partial melting took place. Xenoliths of greenstone material are present in the banded gneiss.

Small scale folding of the gneissic banding is commonplace. These folds have a complex structure (Figure 3.3) implying extremely ductile conditions. They are interpreted to have formed during the high grade tectono-metamorphic event that produced the gneissic banding. Anhaeusser (1973) showed on the basis of rock geochemistry that the precursor rock for the banded gneiss may have been the 3170 Ma tonalites discussed in section 3.1.1.

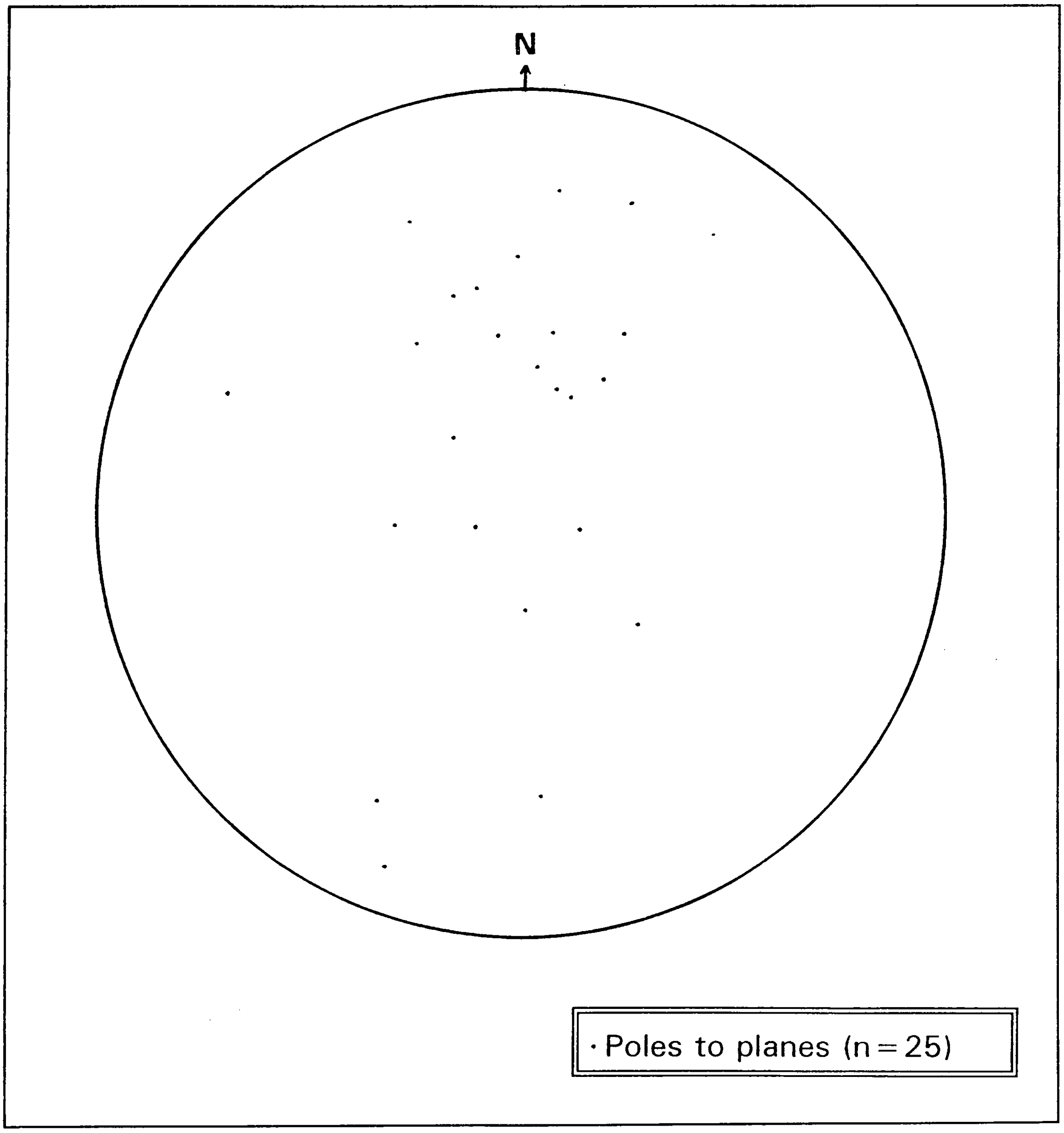
The orientation of the gneissic banding is locally quite variable, but as illustrated by Figure 3.4, has an east-west regional strike. The gneissic banding has been folded about approximately east-west striking axes during a later event, locally dispersing the orientation of the earlier syn-metamorphic

Figure 3.3: *Complex ptygmmatic fold patterns in banded gneiss, evidence for very ductile deformation.*



flowage folds. The appearance of these later folds is that of gentle undulations on a 10-30 metre scale although rare smaller scale structures were observed. Measurement of fold axes plunge direction was not possible on the larger folds , on smaller folds, plunges to both east and west were measured.

Figure 3.4: *Stereonet plot of poles to gneissic banding developed in the gneisses in the northern part of the basement inlier. Although quite dispersed, a regional north-south girdle can be recognised. Planes dip to both north and south due to later folding.*



3.1.3 Foliated granodiorite zone

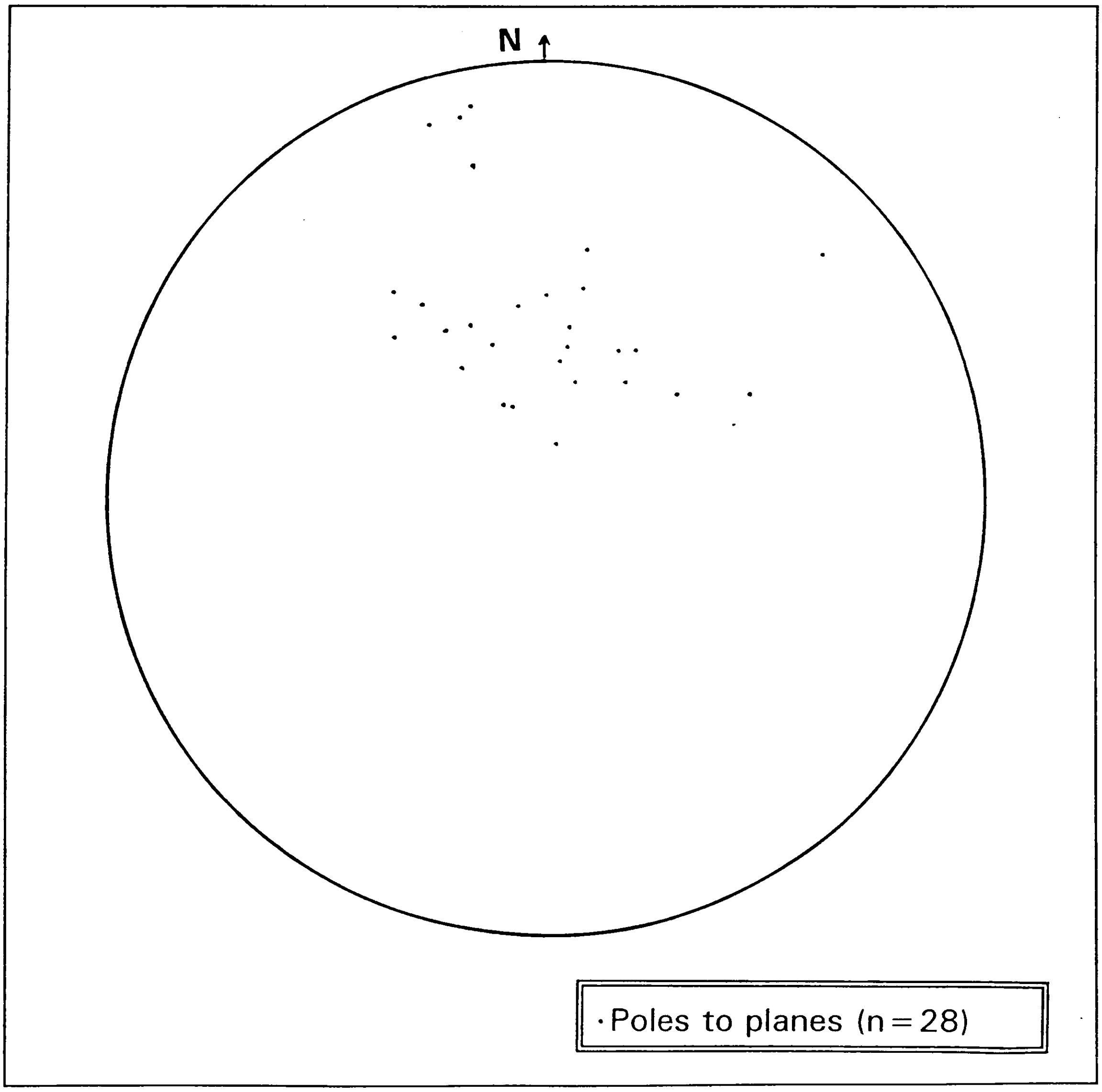
The term Transitional Zone was used by Anhaeusser (1973) to describe an area in the central part of the basement inlier (Figure 1.2) that he considered to be transitional between the banded gneisses in the north and the unfoliated granodiorites in the south. Anhaeusser (*op cit*) suggested that melting of the 3170 Ma tonalites during a tectono-metamorphic event produced the granodiorites in the southern part of the basement inlier, whereas the banded gneisses in the north were produced during the same event by metamorphism and smaller amounts of partial melting of the tonalites. Anhaeusser (*op cit*) arbitrarily delineated the boundaries of the transitional zone by using the area in which granitoids show tor development.

For the purpose of this thesis, the term foliated granodiorite zone will be used instead of transition zone to avoid any genetic implications. Rather than using the development of tors to characterise this central area of the basement inlier, the occurrence of a weak to moderately developed gneissic foliation has been used. Note that the foliated granodiorite zone as determined in this study (Map A) is considerably larger than the transition zone of Anhaeusser (1973) (Figure 1.2).

The following important observations were made in the foliated granodiorite zone:

- The principle rock type is granodiorite (both porphyritic and non-porphyritic) with a weakly developed gneissic foliation striking east-west and dipping south. Foliation data are summarised on Figure 3.5.

Figure 3.5: *Stereonet plot of poles to gneissic foliation developed in the foliated granodiorite zone in the central part of the basement inlier. A regional east-west strike and southerly dip can be recognised.*



- The gneissic foliation is defined by preferred orientation of biotite. Intensity of fabric development is heterogeneous even on outcrop scale. In porphyritic granodiorite where the foliation is strongly developed, euhedral feldspar phenocrysts up to 5cm in length are aligned parallel to the fabric with no apparent recrystallisation or fracture (Figure 3.6).

- Small xenoliths of greenstone material occur within the granitoids of the foliated granodiorite zone. These xenoliths are frequently stretched out in the plane of the fabric. The xenoliths have been partially assimilated by the immediately surrounding granodiorite and in the contaminated area surrounding the xenoliths, the foliation is more visible due to the presence of a higher proportion of mafic minerals.

- The heterogeneity of foliation intensity is strongly suggestive of an origin related to shear zone deformation; the age of this deformation being constrained between the intrusion of the granodiorite and development of the NE/SW - NNW/SSE striking conjugate shear zone set (see section 3.3). The absence of stretching lineations and movement sense indicators prevents any interpretation as regards the kinematics of these shear zones.

- The gneissic foliation has not been folded (c.f the folding in the banded gneisses) suggesting that the tectono-metamorphic event producing the banded gneiss and the event producing the gneissic foliation in the foliated

Figure 3.6: *Foliated porphyritic granodiorite. Euhedral K-feldspar phenocrysts are aligned in the plane of the gneissic foliation.*

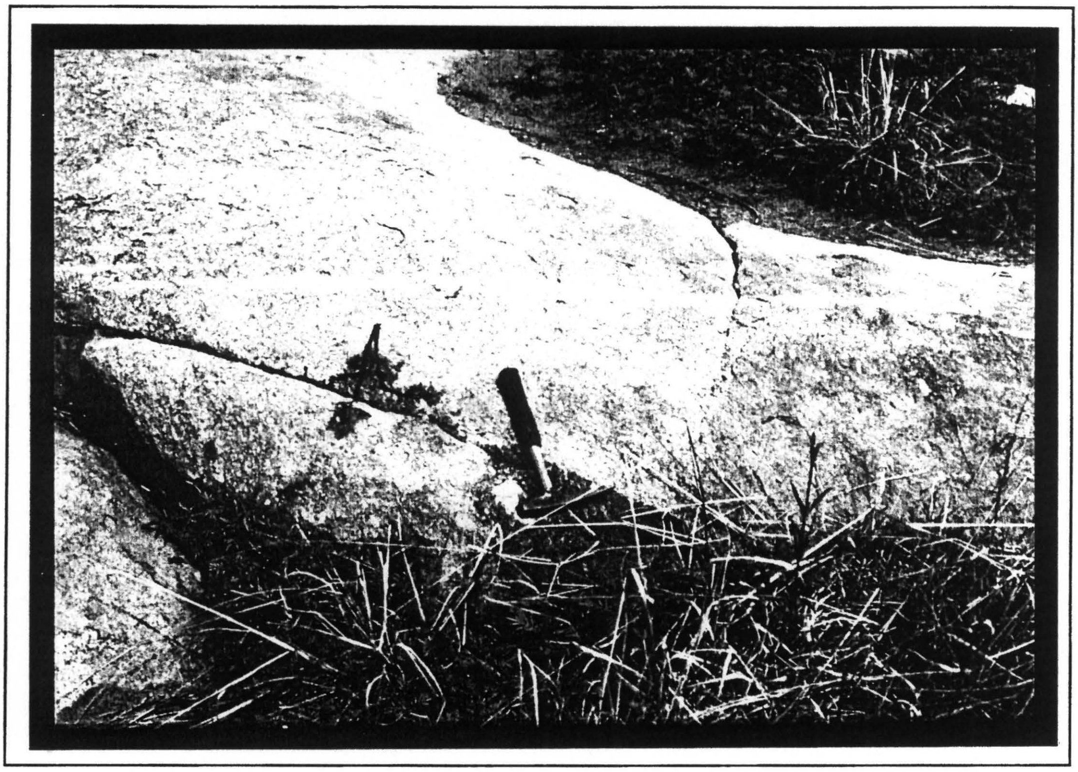
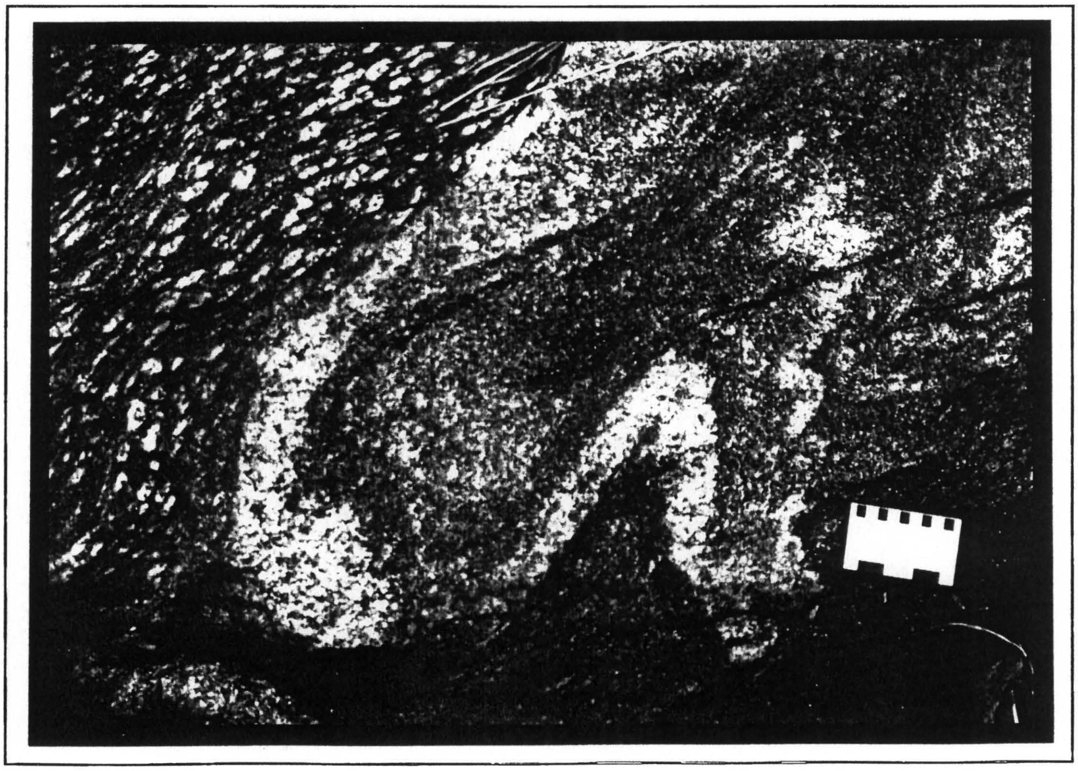


Figure 3.7: *Nebulous banded gneiss in the foliated granodiorite zone.*



granodiorite zone were different events, separated by at least one phase of deformation. The banded gneiss and the granodiorite are thus not co-genetic.

- Small patches of nebulous banded gneiss (See Figure 3.7) occur within the foliated granodiorite zone, mainly along the northern margin near the contact with the banded gneisses. These nebulous banded gneisses are interpreted to be xenoliths of the banded gneiss caught up in the intruding granodiorites.

3.1.4 Granodiorite

The granodiorites in the southern part of the basement inlier are unfoliated but very similar in all other respects to those in the foliated zone immediately to the north. Both porphyritic and non-porphyritic types are present.

3.2 Northwards directed thrust deformation in the granitoids

3.2.1 Jukskei River Shear Zone

Northwards directed thrusting in the Archaean granitoids of the basement inlier has been previously reported from the Jukskei River Shear Zone (JRSZ) by Roering (1986). The JRSZ is an east-west striking, south dipping, ductile shear zone exposed for a maximum width of 1.5 km along the northern margin of the basement inlier (See Map A). Any extension further north is covered by Transvaal Sequence rocks. Contained within the shear zone are tectonically juxtaposed lenses of quartz mylonite (Figure 3.8), shale, mylonitised granitoids and sheared amygdaloidal lava. Planar fabrics in the shear zone dip south, mineral elongation lineations, although uncommon, plunge to the south in the plane of the mylonitic fabric. Figure 3.10 summarises planar and linear fabric data collected along the length of the JRSZ. Kinematic indicators such as composite planar fabrics (S-C) are consistent with a south over north thrust sense of movement. As reported by Roering (1986), the mylonitic fabric of the JRSZ is abruptly truncated by the BRQF, which is itself only gently folded. Nowhere is this relationship more spectacularly exposed than near the confluence of the Crocodile and Jukskei rivers (Figure 3.9) The thrust deformation clearly pre dates the deposition of the BRQF.

Figure 3.8: *Quartz mylonite in the JRSZ. This may represent highly strained Witwatersrand Supergroup quartzite.* (**ST1**).

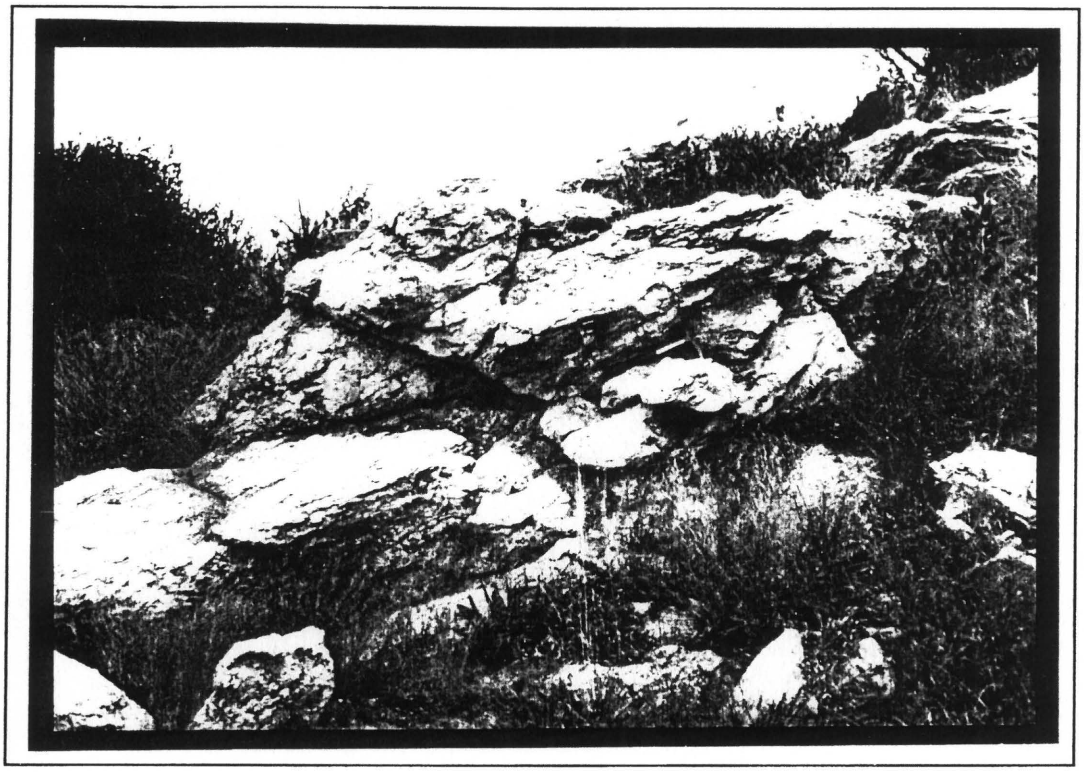


Figure 3.9: *Mylonitised granitoids of the JRSZ (bottom) overlain along an angular unconformity by gently folded BRQF.*

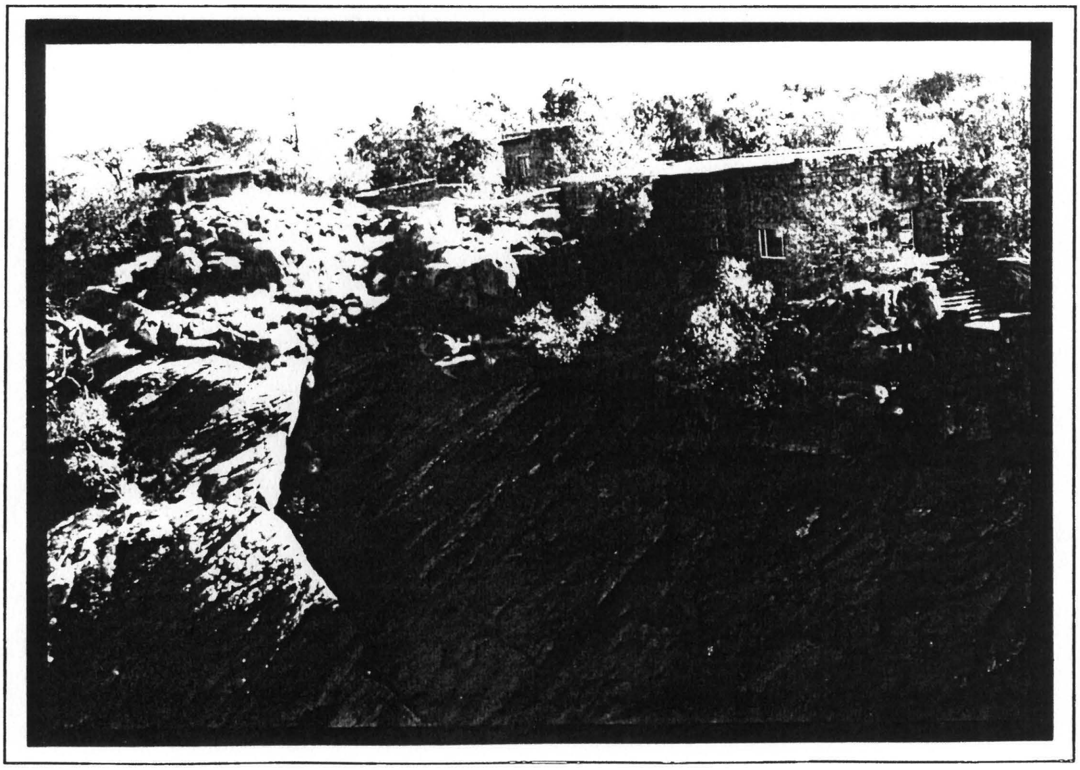
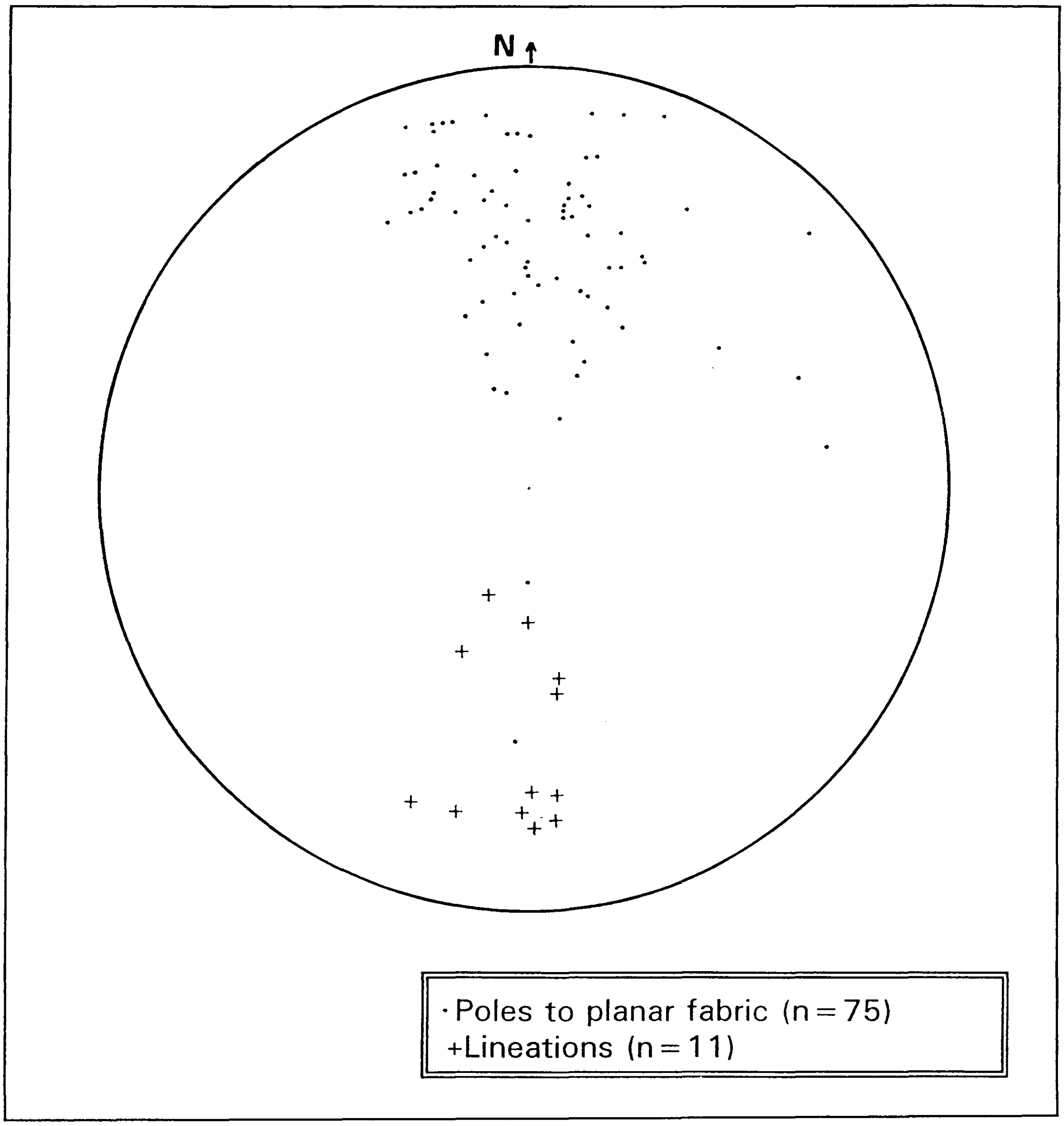


Figure 3.10: *Stereonet projection of planar and linear fabrics measured along the JRSZ. The large variance in dip amount of the planar mylonitic fabric is probably due to ramp and flat thrust geometry within the thrust pile.*



3.2.2 Northwards directed thrusting in the granitoids south of the JRSZ

Evidence for northwards directed thrusting has been observed in all the granitoid types of the basement inlier. Planar and linear fabric data plotted on Map A indicate that this deformation was of regional extent although the intensity of fabric development is clearly heterogeneous.

Figure 3.11 is a stereonet plot showing planar and linear fabrics produced in the granitoids during the thrusting (excluding data from the JRSZ). Planar fabrics strike on average 100° and dip at an average of 25° to the S. Mineral elongation lineations plunge to the SSW. The average azimuth (200°) of the lineations, gives an approximation of the movement direction: 020°.

The nature and intensity of the fabrics developed in the granitoids of the basement inlier suggest an increase in strain towards the north. This trend is best discussed with reference to a series of localities where thrust related features are well developed, starting on the south of the inlier and moving north. The position of each locality is indicated on Figure 3.12.

Figure 3.11: *Stereonet of planar and linear fabrics associated with northwards directed thrusting in the granitoids, excluding data from the JRSZ.*

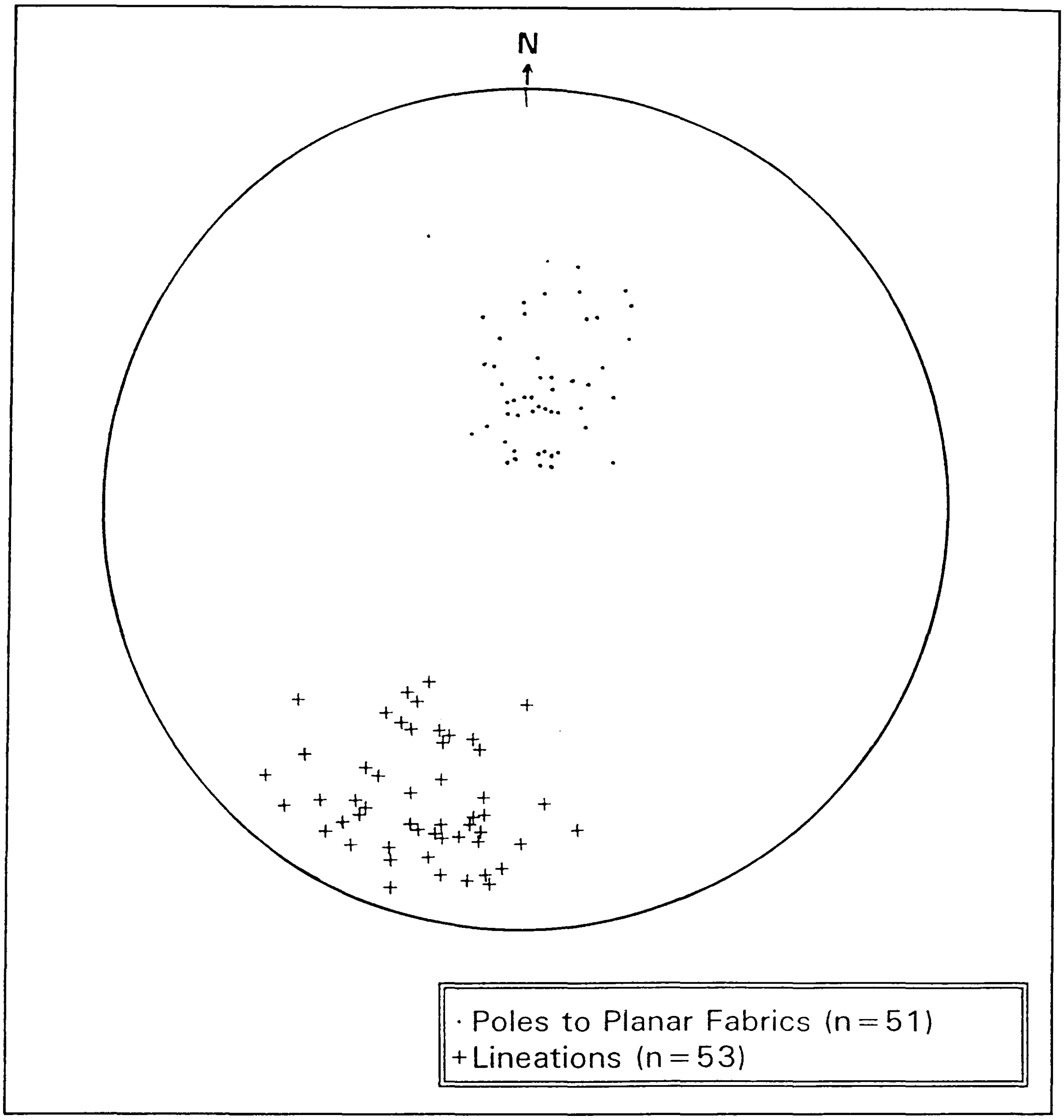
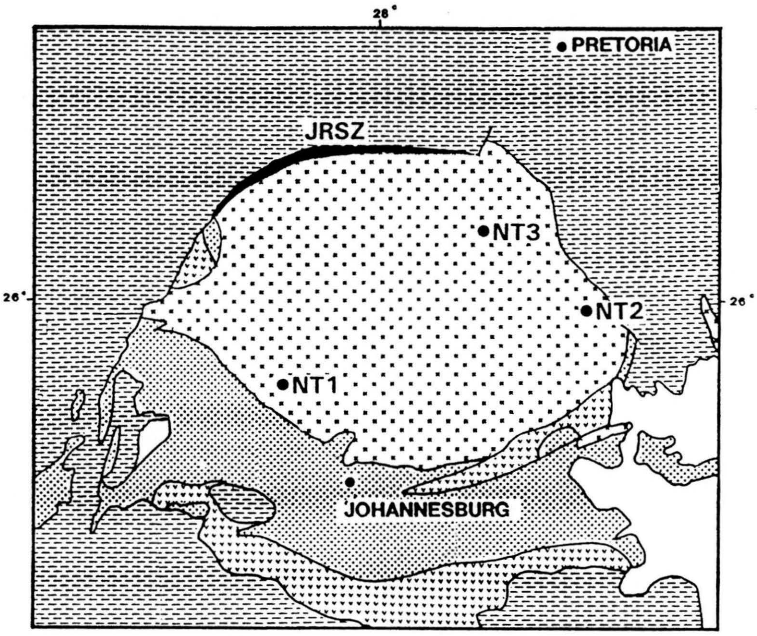


***Figure 3.12:** Simplified geological map of the Johannesburg Dome showing localities NT1-NT3 discussed in the text.*



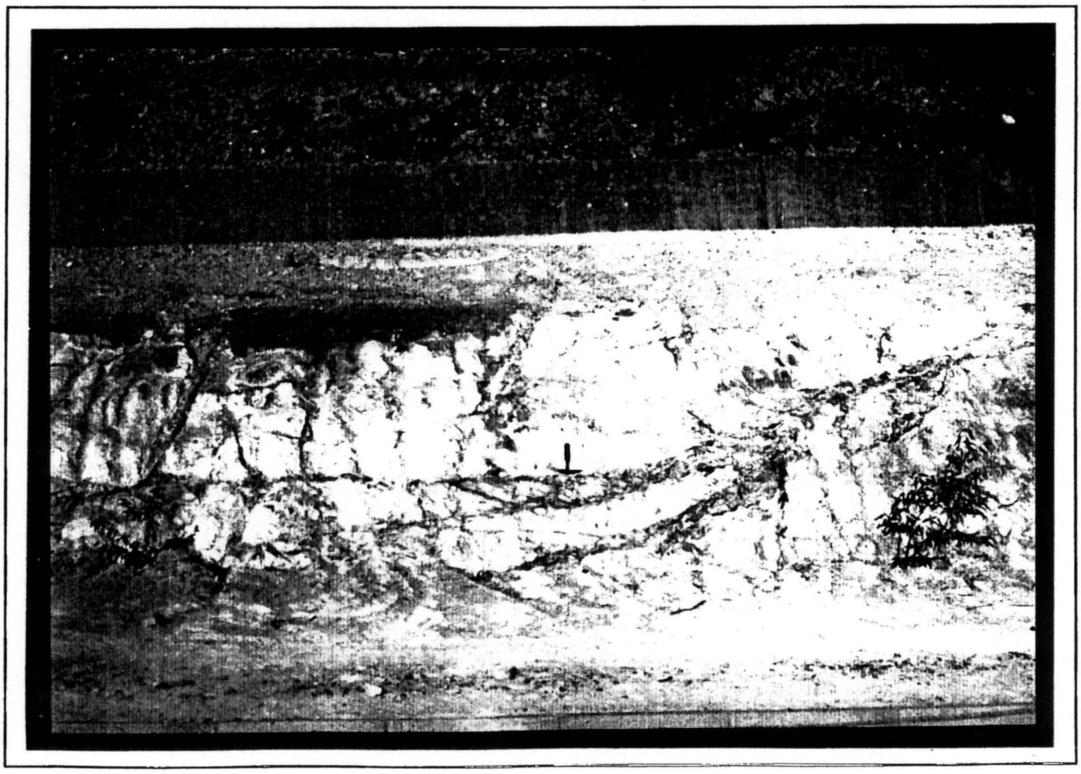
○ Locality NT1 (**ST2**)

Northward verging thrusts are well exposed in weathered granitoid at this locality. Thrust zones are discrete (i.e the bulk of the granitoids are massive). Quartz veining up to 1m thick is developed along thrust planes as illustrated in Figure 3.13.

Zones of fabric development (thrust sense shear zones) in the granitoid itself are narrow, not exceeding 40 cm. Cleavage duplexes are well developed. The thrust planes for the most part dip at shallow angles to the south, but occasionally they roll gently and dip at shallow angles to the north (Figure 3.14).

***Figure 3.13:** Quartz vein developed on a thrust plane in weathered granitoid. South is to the right of the photograph. Locality NT1.*

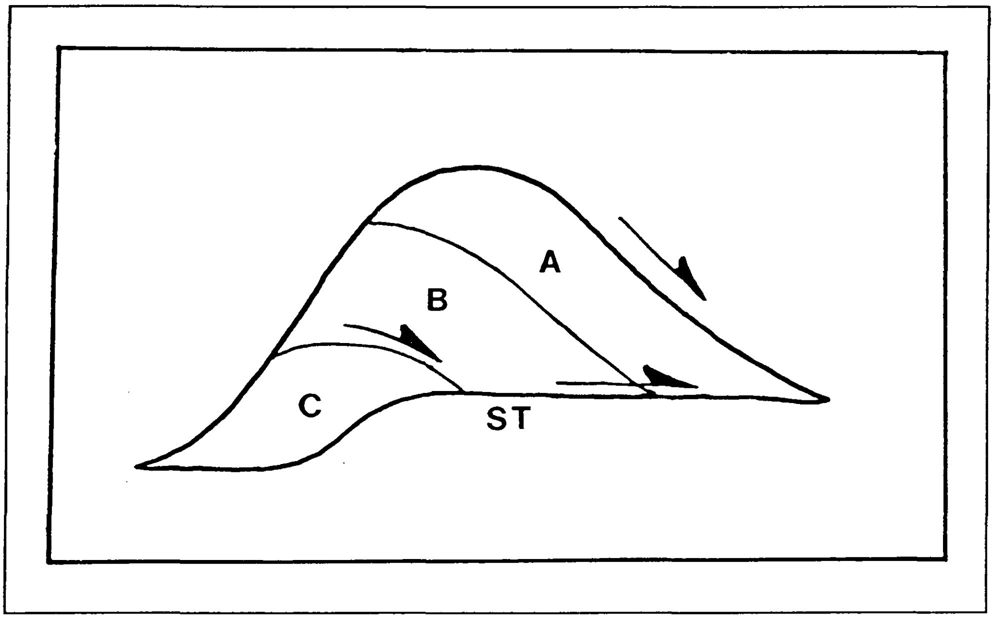
***Figure 3.14:** North dipping thrust planes at locality NT1. Cleavage duplexes indicate northward movement. See text for explanation. North is to the left of the photograph.*



Composite planar fabrics (S-C) and cleavage duplexes consistently indicate a northwards sense of movement. Rotation of thrust planes in the hanging wall of a thrust system propagating by footwall collapse is not uncommon and can result in thrust planes dipping to both the hinterland and the foreland. Typically this process occurs during the development of an antiformal stack (Figure 3.15).

Quartz veining with clearly extensional features (fibres and euhedral crystals growing into cavities) are developed in this outcrop and are interpreted as extensional fractures related to the thrusting.

Figure 3.15: *The geometry of an antiformal stack (after Boyer and Elliott 1982). Hypothetical cross section constructed parallel to movement direction. Thrust horses are labelled A to C in order of their formation. ST is the sole thrust. Arrows indicate movement direction. The individual horses (oldest at the top) are stacked up on each other such that they form an antiform.*



○ Locality NT2 (**ST3**)

At this locality, just NW of Tembisa, thrust horses of unfoliated granodiorite are well exposed in a quarry face (Figure 3.16). As described for Locality NT1, the thrust related planar fabrics are developed in discrete zones rather than pervasively throughout the outcrop. Along boundaries between thrust horses, thin bands of phlogopite (confirmed using XRD) are developed with good down-dip stretching lineations. Small scale S-C type fabric relationships within the bands of phlogopite confirm the movement sense.

○ Locality NT3 (**ST4**)

Banded gneisses at this quarry locality have a fairly pervasive, dominantly southward dipping, planar fabric defined by layers of biotite with preferred orientation. The fabric anastomoses around asymmetric "pods" of less deformed gneiss (Figure 3.17) implying the thrust related foliation has been superimposed on an earlier gneissosity. The asymmetry of these "pods" indicates north directed thrust movement.

In places the biotite is developed in layers up to 2cm thick. Aggregates of biotite occur as pods with duplex geometry along thrust planes. The schistosity within these small scale duplexes defines S-C composite planar fabric relationships indicative of northwards directed thrusting.

At this locality, a zone of north dipping foliation occurs between two zones of south dipping fabric. Kinematic indicators within the zone of north dipping fabric imply south directed thrusting. Cross-cutting relationships between the northwards directed thrusts and the southwards directed thrusts are contradictory suggesting that they are coeval. The southwards directed thrusts are tentatively interpreted as back thrusts in the dominant northwards verging thrust system. Southwards verging thrusts were observed at a few rare exposures in the granitoids of the basement inlier. The plunge directions of these lineations varies between 010° and 030°, consistent with their being developed on back thrusts in a NNE verging thrust system.

Figure 3.16: *Metre scale thrust horses well exposed at locality NT2. Quarry face strikes north-south, south is to the left of the photograph.*

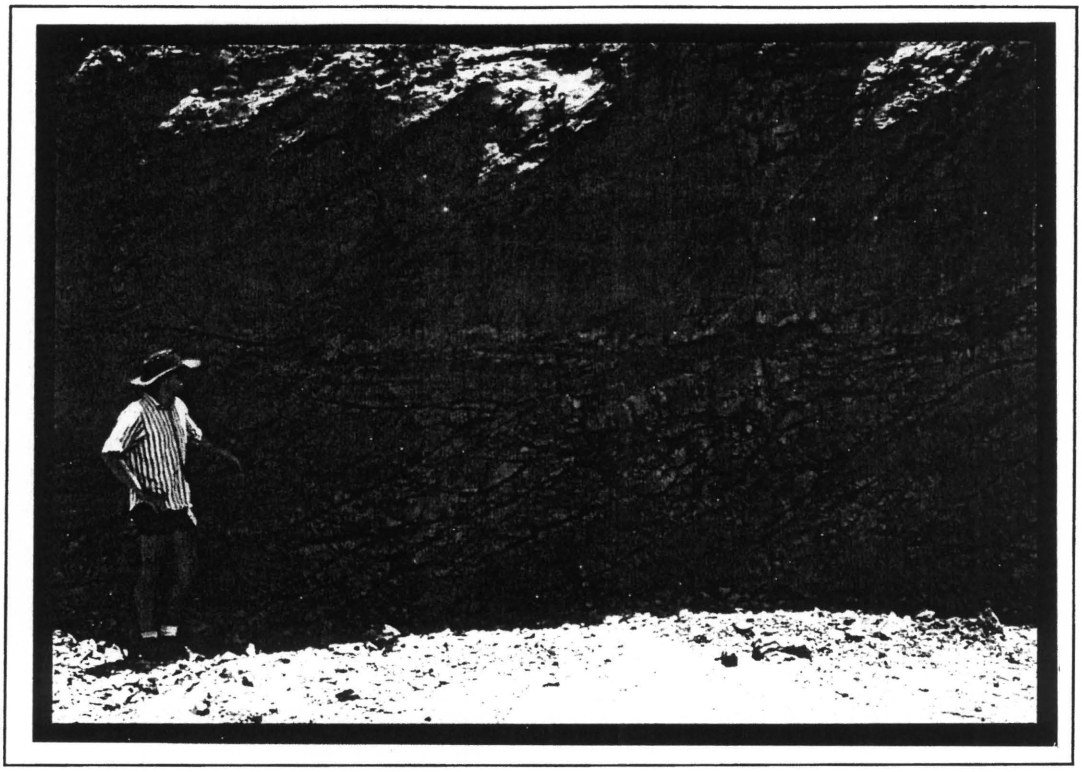
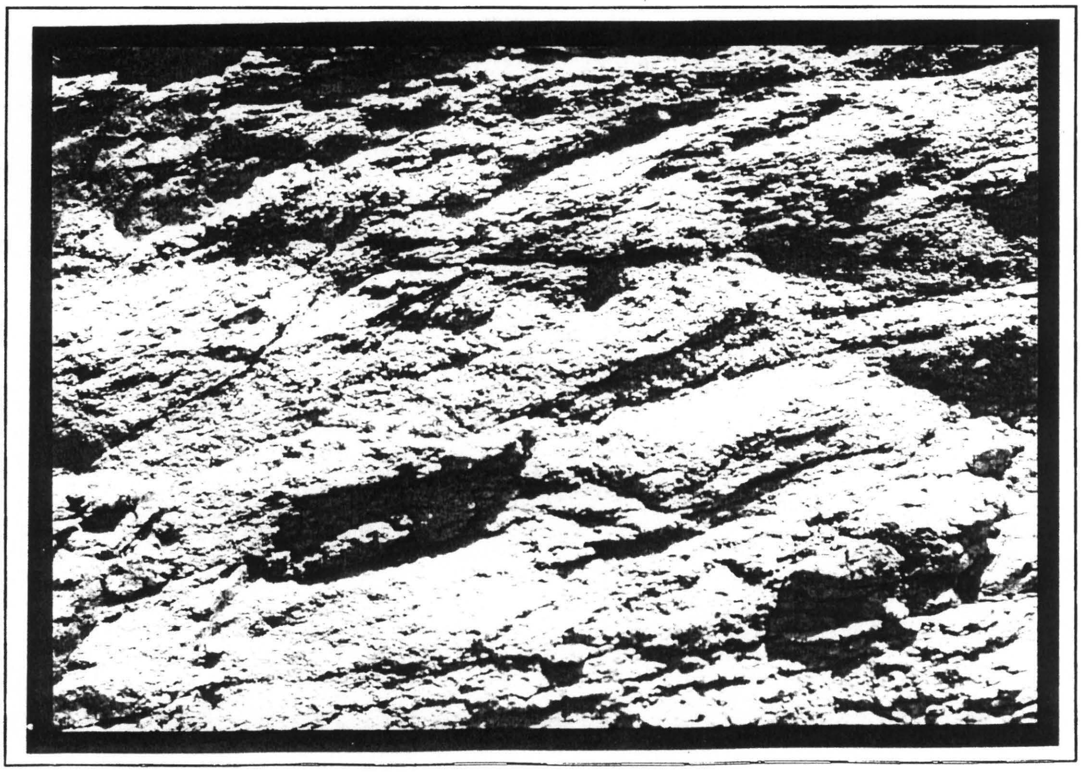


Figure 3.17: *Pervasive foliation developed in banded gneisses at locality NT3. Exposed face strikes N-S, S is to the left of the photograph. Overall geometry of fabric development implies N directed thrusting.*



3.2.3 Summary of northwards directed thrusting in the Granitoids.

Northwards directed thrusting with a movement direction of approximately 010° has previously been reported by Roering (1986) from the JRSZ, a ductile shear zone situated on the northern margin of the basement inlier. The minimum age of the JRSZ is defined by the BRQF unconformity.

South of the JRSZ, northwards directed thrusting and associated features (shear bands, duplexes and back-thrusts) has been documented in all the granitoids exposed in the basement inlier. The approximate movement direction of 020° is geometrically consistent with that of the JRSZ and they are interpreted to be related to the same event.

The northwards increase in strain as evidenced by the sequence:

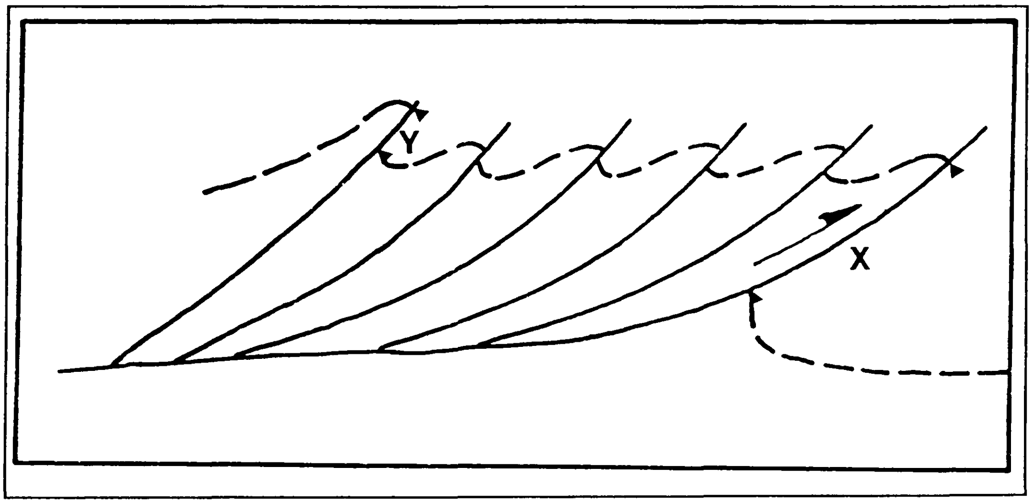
-Zones of discrete fabric development

-Areas of fairly pervasive fabric development

-Zone of mylonite up to 1.5 km wide (the JRSZ)

is interpreted to indicate that : (a) the fabrics are related in time (b) the thrust system has the geometry of a leading imbricate fan related to northwards thrust propagation by footwall collapse (Figure 3.18).

Figure 3.18: *The geometry of a leading imbricate fan (after Boyer and Elliott, (1982). The thrust with the maximum slip is at the front (i.e. X > Y). The maximum strain (intensity of fabric development) would be expected at the leading edge of the fan.*



3.3 Conjugate strike-slip shear zone set.

3.3.1 General

Ductile shear zones with strike-slip geometry are developed within all granitoids of the basement inlier of the Johannesburg Dome. Major shear zones often form prominent linear topographic features. The resistant nature of the shear zones is partly due to the resistant nature of the mylonite developed therein but mainly due to the extensive quartz veining that infiltrated the shear zone during the initial ductile deformation and subsequent brittle reactivation.

The shear zones are characterised by the development of a sub-vertical mylonitic foliation such as that illustrated in Figure 3.19. Deformation is clearly heterogeneous, with zones of intense mylonite being separated by zones of less deformed granitoid. Mylonite development is most intense along the major shear zones (Shown on Map A), but is not restricted to them. Mineral elongation lineations are sub-horizontal (Figure 3.20), indicative of strike-slip movement. Fabric data measured in these shear zones is summarised in Figure 3.21(a) and (b). Two distinct strike orientations of the mylonitic planar fabric are obvious: NE and NNW.

Figure 3.19: *Subvertical, sinistral sense, strike slip shear zone (oblique plan view). Note quartz veining parallel to C- and S-shears.*

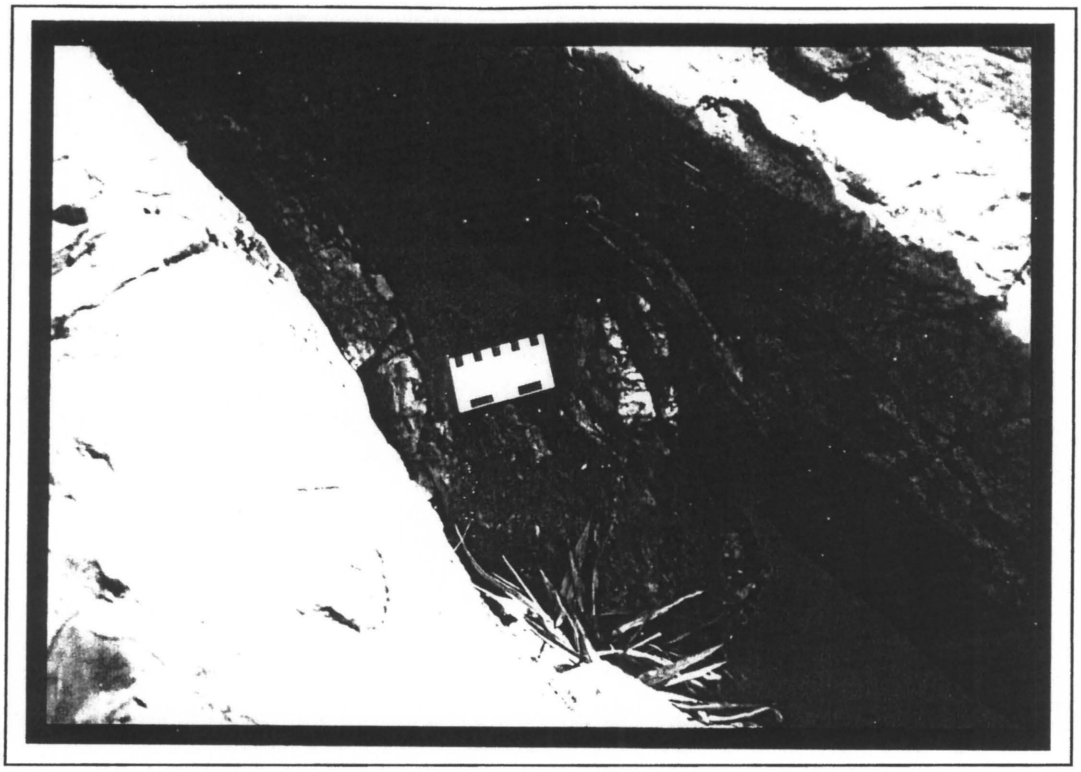


Figure 3.20: *Sub-horizontal mineral elongation lineations (elongate rods of mineral aggregates) in a strike slip shear zone (viewed in section).* (**ST4**)

Figure 3.21a: *Stereonet projection of planar and linear fabrics from NE striking, sinistral shear zones. Mineral elongation lineations are shallow plunging to the NE and SW.*

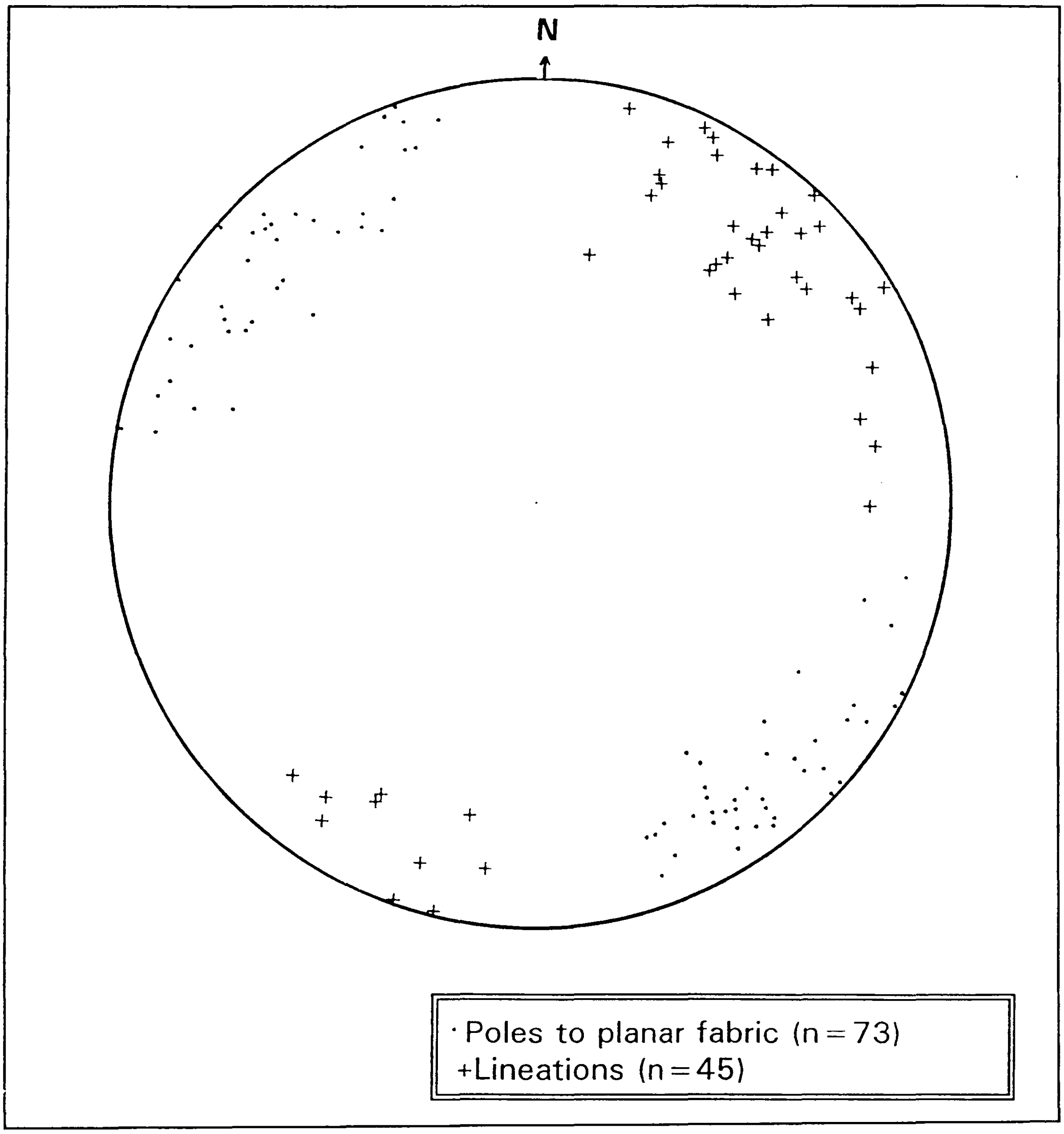
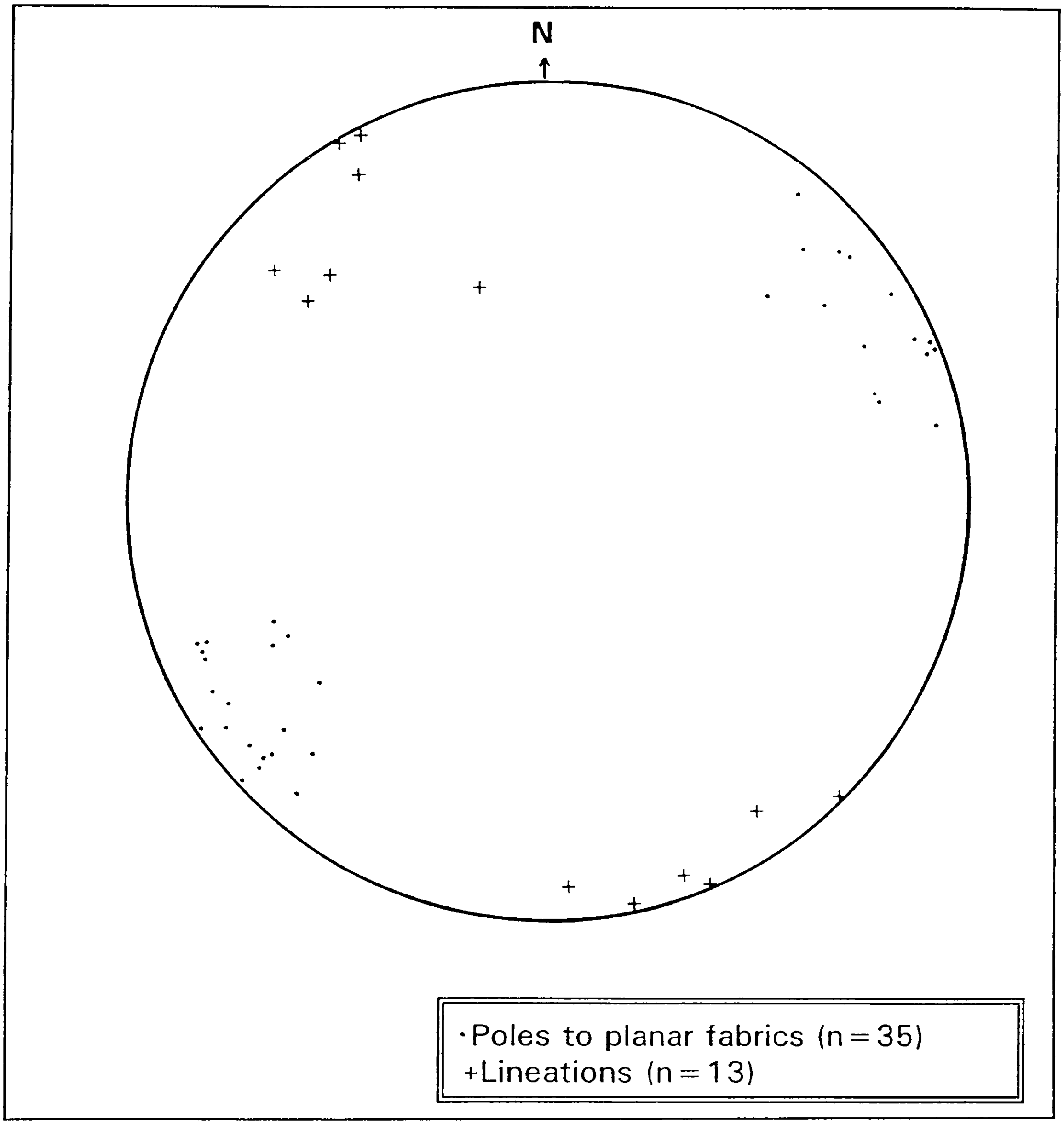
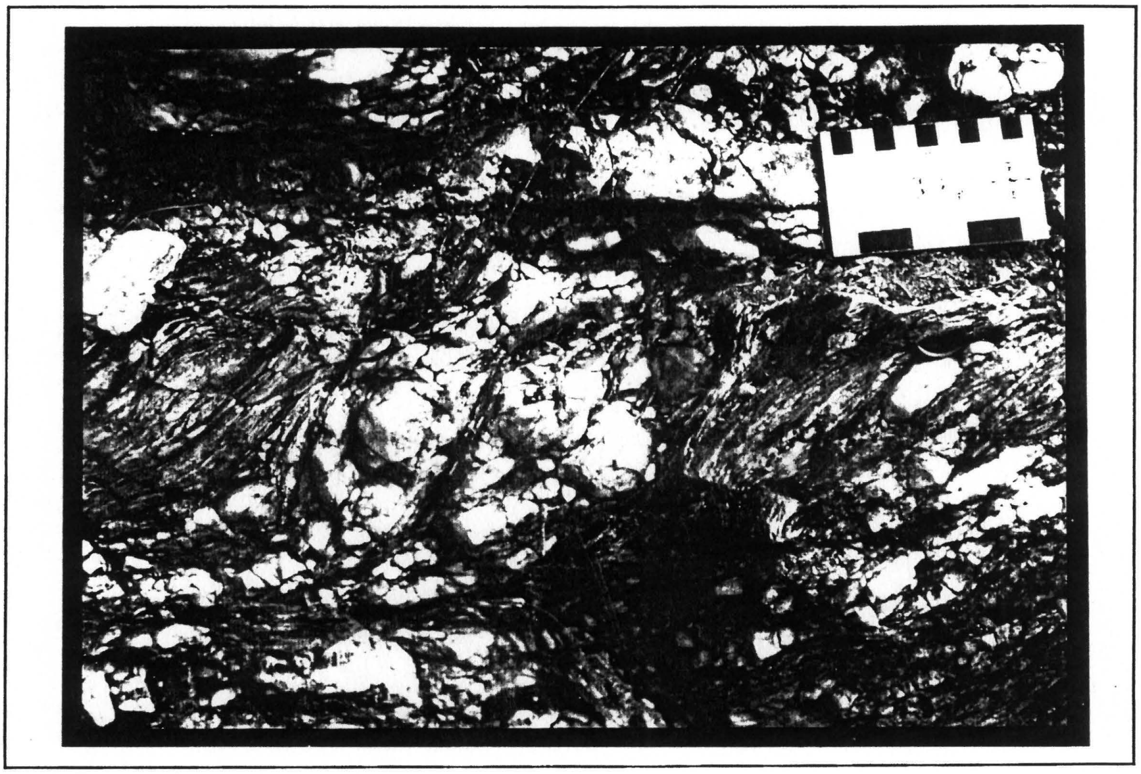


Figure 3.21b: *Stereonet plot of planar and linear fabrics measured along NNW striking, dextral shear zones. Mineral elongation lineations are shallow plunging to the NNW and SSE.*



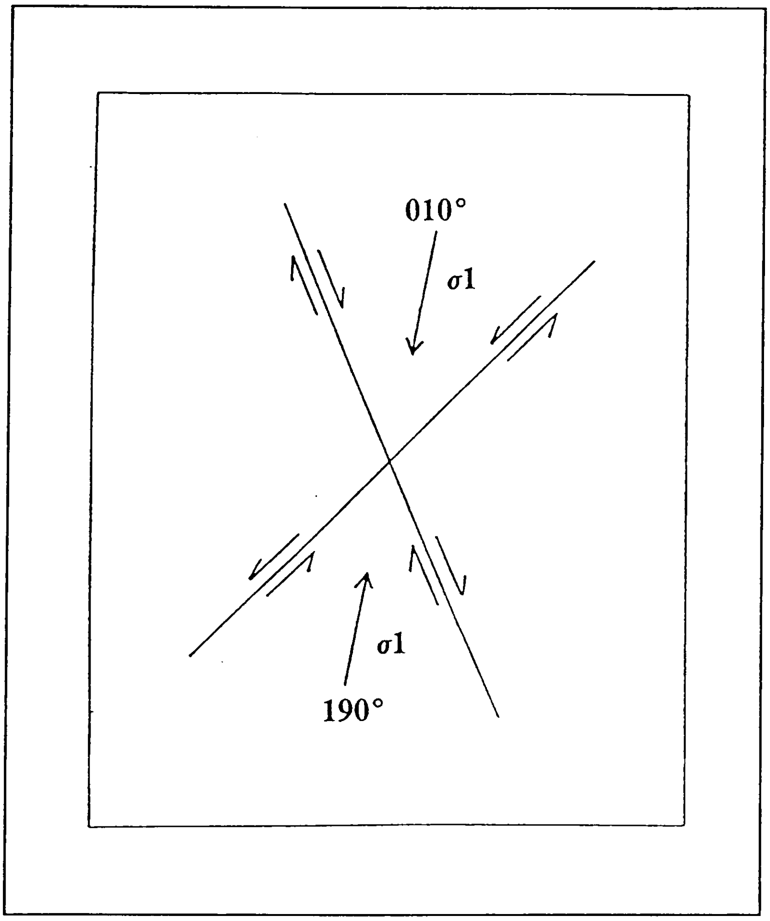
Composite planar fabrics (S-C) were used, where possible, to determine the ductile displacement sense of the shear zones. Figure 3.22 shows a strike-slip duplex, showing dextral displacement sense, developed within a NNW striking mylonite zone. All NNW striking shear zones consistently show a dextral strike slip sense of displacement, whereas all NE striking shear zones have a sinistral sense of displacement.

Figure 3.22: *A strike slip duplex in a dextral sense shear zone observed in plan view. Quartz veining is developed parallel to the S-shears.* **(ST5)**



Cross cutting relationships between the NE striking sinistral and NNW striking dextral shear zones are contradictory. On this basis as well as the overall geometry and similarity of fabrics, the NE and NNW striking shear zones are interpreted to be a conjugate set (Figure 3.23). A conjugate set of this geometry would imply a north-south compressional event with σ_1 (maximum principle compressive stress) orientated at 010°- 190°, σ_2 vertical and σ_3 (bulk extension) orientated approximately east-west.

Figure 3.23: *Geometry of the conjugate shear zone set.*



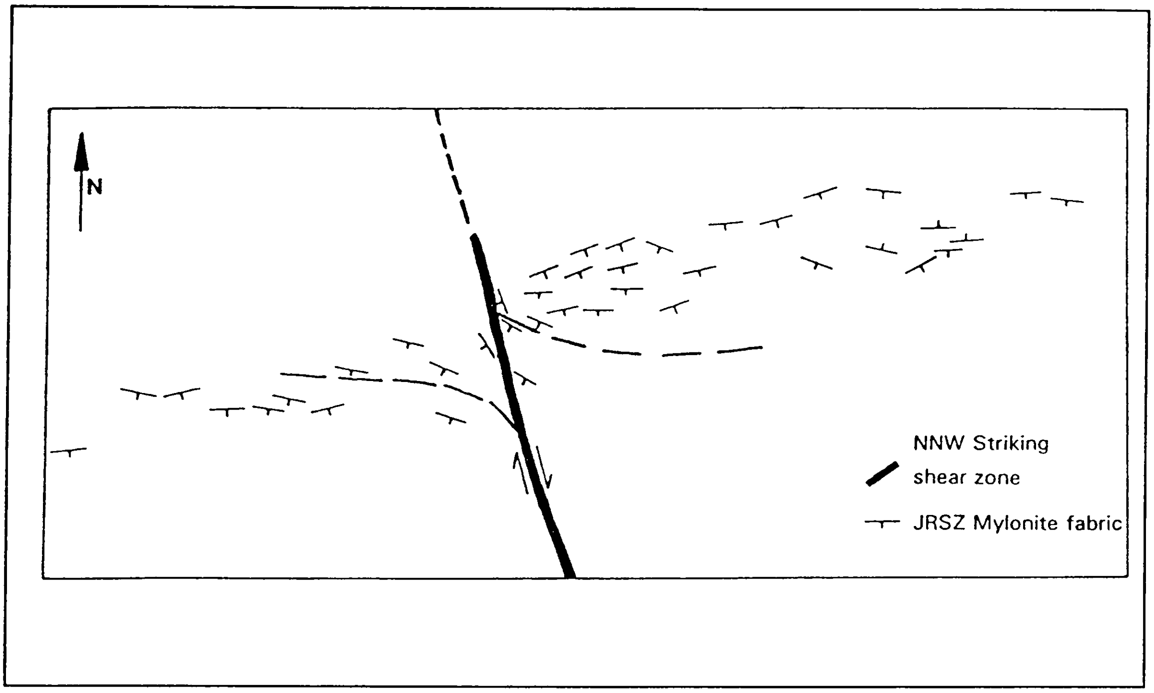
The quite large range in orientations of the mylonite fabric that is evident from Figure 3.21(a) and (b) is due to splaying and "horse-tailing" that is clearly visible on outcrop scale.

Vein quartz is common in the shear zones, developed parallel to both the C-and S-shears (Figures 3.19, 3.22). Quartz veining parallel to the foliation along shear zones in a compressional environment has been documented by Roering and Smit (1987) who suggested that a "filter press type action" on the quartz bearing fluid phase is responsible for the concentration of vein quartz along the shear zone.

Thin sections of the shear zone mylonite, viewed under the microscope, clearly indicate the ductile nature of the deformation. The mylonite consists of quartz and mica. Elongated quartz ribbons with deformation lamellae, typical of plastically deformed quartz grains in mylonite are well developed. S-C fabrics defined by the schistosity of the micas as well as the asymmetric shape of the quartz ribbons ("duplex" shape) confirm the movement sense observed on outcrop scale. Further deformation of the quartz ribbons has caused recrystallisation within the grains, producing elongate aggregates of very small polygonal quartz grains.

Both the gneissic foliation in the foliated granodiorites and the gneissic banding of the banded gneisses is cross-cut and displaced by the strike-slip shear zones of the conjugate set. The shear zones of the conjugate set also cut across the fabrics related tc the pre-BRQF, northwards directed thrusting event discussed in section 3.3. In the JRSZ, the mylonitic fabrics of the thrust pile are rotated into a NNW striking shear zone with a dextral sense, as shown on Figure 3.24.

Figure 3.24: Sketch map illustrating the rotation of the thrust related mylonitic fabric of the JRSZ into a NNW striking dextral shear zone of the conjugate set. (**ST1**)



3.3.2 Deformation history of the shear zones

A NNW striking strike-slip shear zone outcrops in the Rietspruit River (**ST6**) in the NW corner of the basement inlier. Two temporally distinct deformations have been recognised:

(a) An early dextral strike slip ductile movement.

(b) A later sinistral strike slip brittle movement.

The early movement produced mylonites and a well developed westward dipping fabric. No ductile features could be recognised in the Black Reef only a few metres away from the shear zone. The later brittle phase of deformation is evidenced by the spatial distribution of the BRQF and the Chuniespoort dolomites which indicates sinistral movement. Quartz veins, developed in the shear zones, that clearly cross-cut the mylonitic fabric are related to this brittle reactivation.

3.3.3 Summary of the deformation associated with the conjugate strike slip shear zone set.

A conjugate, ductile, strike slip shear zone set is heterogeneously developed in all granitoids of the basement inlier. The geometry of the pair (NE-Sinistral, NNW-Dextral) implies a north-south compression with σ_1 orientated at $\approx$ 10°-190°. The timing of the deformation can be bracketed between the northwards directed thrusting described in the previous section and the deposition of the BRQF. The conjugate shear zone set clearly post-dates the northwards directed thrusting event. Although the σ_1 direction for both events can be correlated, the orientation of σ_2 and σ_3 changed with time. During thrusting σ_2 was orientated approximately east-west and bulk extension (σ_3) was vertical. During the strike slip deformation σ_2 was vertical, bulk shortening was in a north-south direction and extension east-west. The shear zones have been reactivated as brittle faults in post-BRQF times.

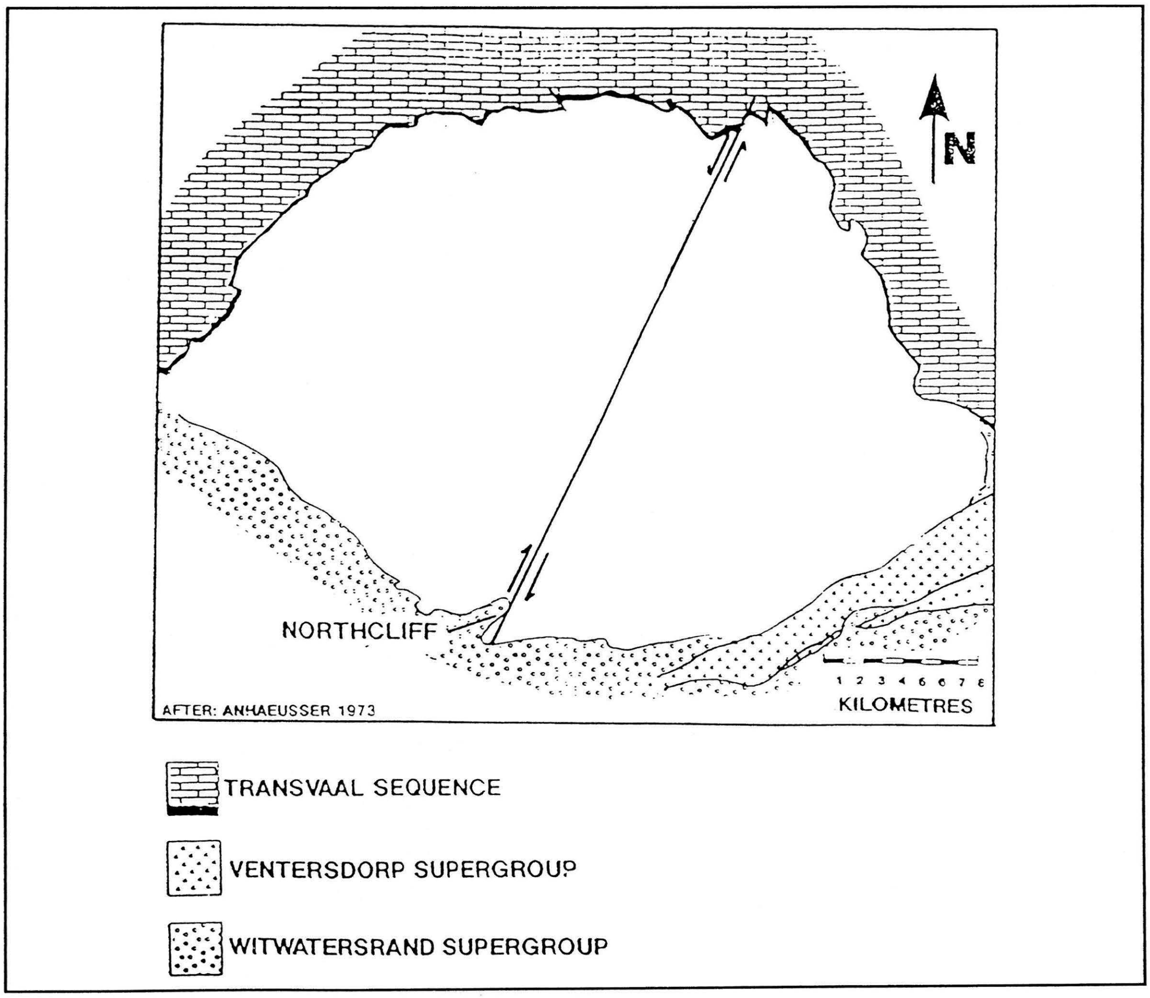
4 THE GEOLOGY OF THE NORTHCLIFF PROMONTORY

4.1 Introduction

The Northcliff promontory is a ridge of West Rand Group rocks situated in the central part of the southern margin of the basement inlier. It's locality is indicated on Figure 1.2 and the inset for Map B. To the east of Northcliff, McCarthy *et al* (1982), McCarthy *et al* (1986), Stanistreet *et al* (1986) and Stanistreet and McCarthy (1990) have recognised dominantly strike slip tectonics associated with the Rietfontein fault system. To the west of Northcliff, Roering (1968) described folding associated with formation of the West Rand syncline. Roering (1986) and Roering and Smit (1987) published evidence for northwards directed thrust tectonics in Witwatersrand Supergroup rocks to the west and south of Northcliff. Northcliff situated between these areas is thus an ideal microcosm in which to study the deformation history of the lower part of the West Rand Group along the southern margin of the basement inlier of the Johannesburg dome.

The Northcliff promontory has an anomalous NE trend when compared with the general east-west strike of the West Rand Group along the southern margin of the basement inlier. All previous maps explained this anomalous trend by the presence of a major NE striking, dextral sense fault or shear zone along the eastern flank of the promontory. This shear zone was believed to cut right across the basement inlier, displacing the BRQF in the north. These features are summarised in Figure 4.1.

Figure 4.1: *Previously published maps of the Northcliff area show a major NE striking shear zone along the east flank of the promontory. This shear zone was thought to extend northwards across the basement inlier and displace the BRQF. Note the discrepancy in displacement sense at the north and south of this shear zone. Also note the lack of displacement, of the contact between the Witwatersrand Supergroup and the basement rocks, by the fault to the east of the Northcliff promontory.*



The Northcliff promontory was mapped on a scale of 1:10 000 using enlarged aerial photographs. Johannesburg City Council contoured street plans were used as a base map.

4.2 Stratigraphy and Lithology

Figure 4.2: The stratigraphy of the West Rand Group in the Johannesburg area.

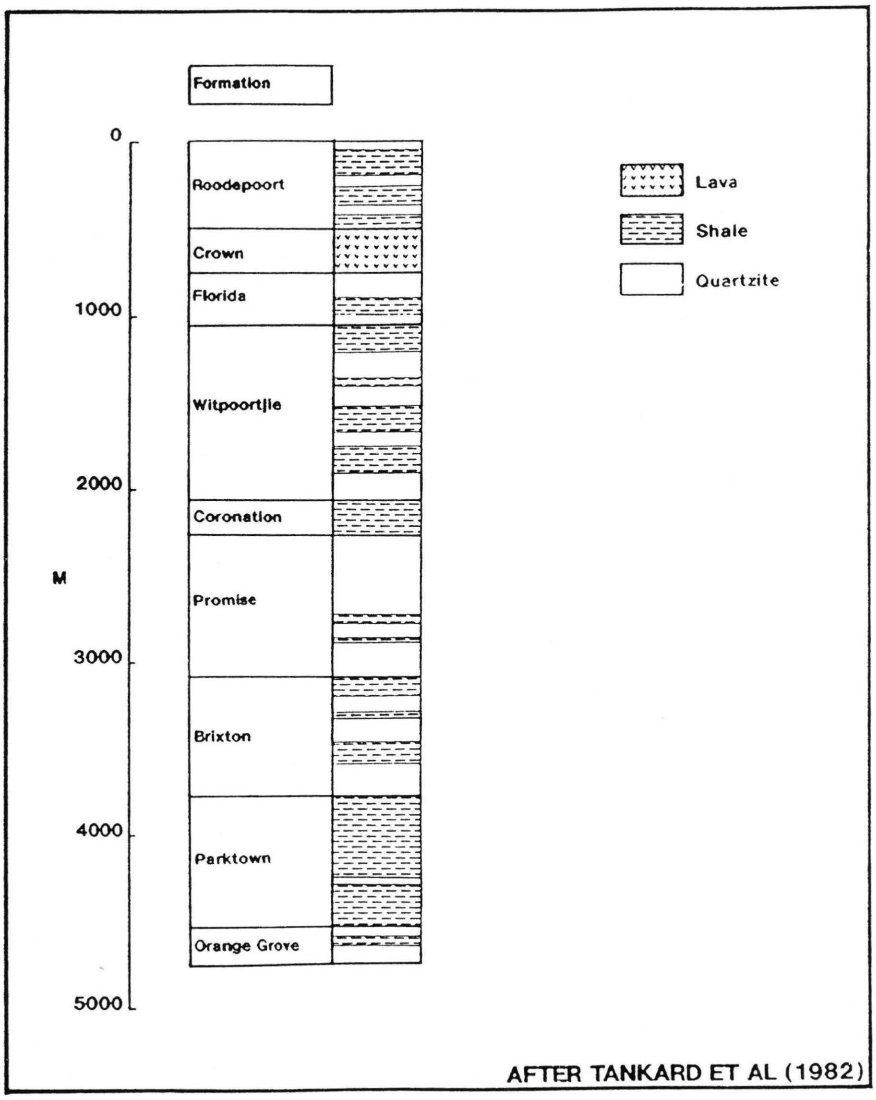


Figure 4.2 shows the stratigraphy of the West Rand Group in the Johannesburg area. The majority of the Northcliff promontory comprises rocks belonging to the Orange Grove Quartzite Formation (OGQF). The OGQF

consists of 3-4 major quartzite bands interbedded with shales. The lowermost shale band includes a distinctive dark-grey band. The remainder of the shales are red-brown in colour and it is difficult to distinguish between them. The quartzites, particularly those near the middle of the sequence are very siliceous. Pebble bands are rare and poorly developed. To the south of the Northcliff promontory, shales and magnetic shales crop out, albeit very poorly. These shales are interpreted to be Parktown Formation.

Housing development on the Northcliff promontory, and particularly its' southern slope, is very extensive, consequently in much of the mapped area individual quartzite or shale bands could not be traced along strike with any degree of certainty. Where possible, dominantly quartzite or dominantly shale bands have been shown on Map B, other areas are shown simply as undifferentiated OGQF.

The OGQF rests with sheared contact on the underlying basement rocks. Foliation developed in the contact zone strikes east-west and dips south at moderate angles. Highly weathered amphibolite greenstone remnants occur along much of the contact (Inset Map B), but in the eastern extremity of the mapped area and south of the Alberts Farm Shear Zone (AFSZ - See Map B) granitoids outcrop.

4.3 Structure

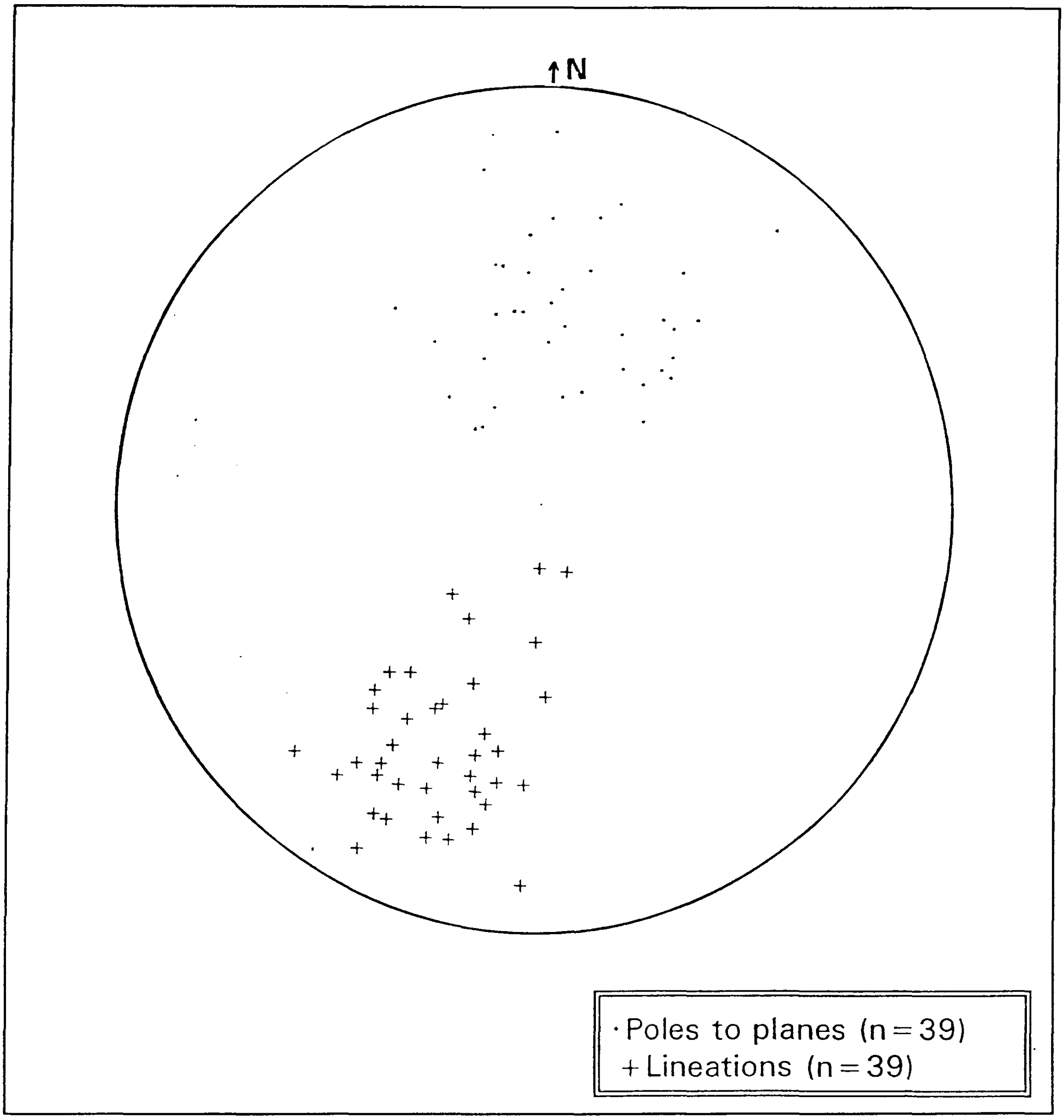
4.3.1 Northwards directed thrusting

A bedding sub-parallel north directed thrusting event has been documented throughout the Northcliff promontory. Similar deformation features can be seen in most north-south orientated road cuts through the West Rand Group along the southern margin of the basement inlier.

A heterogeneously developed, bedding sub-parallel, south dipping foliation was formed during this thrusting event and is well developed in the shale bands as well as in high strain zones within the quartzites of the OGQF. Mineral elongation lineations developed within these bedding sub-parallel shear zones plunge down the plane of the tectonic foliation to the SSW. Orientations of planar and linear fabrics formed during this thrusting event are plotted in Figure 4.3. The average azimuth of the lineations measured in the Northcliff area gives an approximation of the movement direction of the thrusting. Movement direction is 023°/203°.

Figure 4.4 illustrates fabric development in a narrow shale band bounded on either side by quartzite. Cleavage duplexes in the shale band indicate that it has been utilised as a zone of shear strain with movement sense to the north. In zones of higher strain than the example in Figure 4.4, narrow shale bands are often altered to muscovite schists.

Figure 4.3: *Stereonet plot of planar and linear fabrics formed during the northwards directed thrusting event.*



The vast majority of deformation observed is bedding parallel but in places, narrow shear zones ramp through more competent beds at a high angle to bedding.

Figure 4.4: *Cleavage duplexes developed in a shale band. The outcrop strikes north-south, movement sense is to the north (right).* **(ST7)**

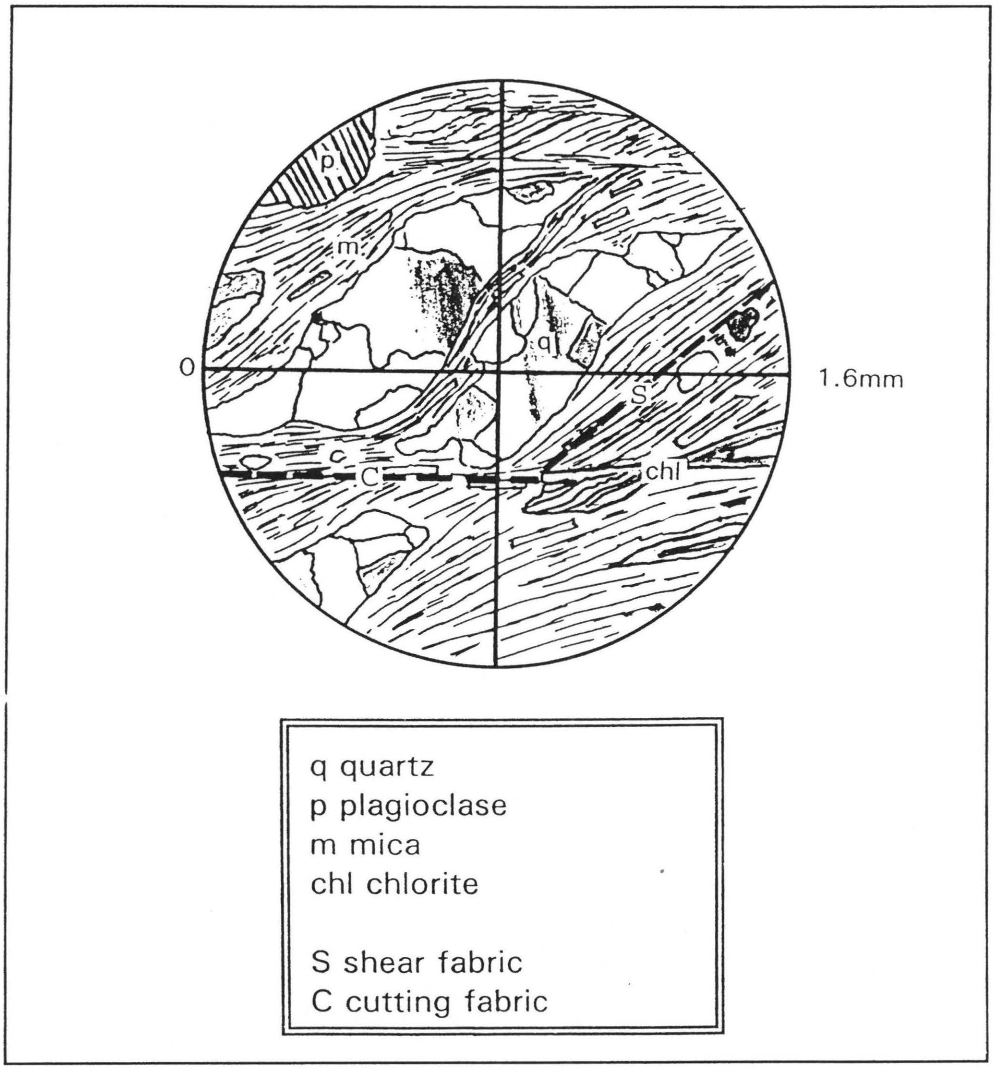
Figure 4.5: *Shear fabric related cleavage in quartzites of the OGQF on Northcliff. Cleavage and bedding dip south. Note similarity to Figure 3.8.* **(ST8)**

Although much of the deformation was concentrated in the shale bands, high strain zones up to 20 m thick are also developed in the quartzites. Figure 4.5 is a photograph of one such high strain zone located near the contact with the overlying Parktown Shale Formation. Given that the OGQF quartzites near the contact with the Parktown Shales are so deformed, it is likely that the contact itself is a major thrust and has been marked as such on Map B.

The development of composite planar fabrics and cleavage duplexes in quartzite indicates that the deformation was fairly ductile in nature. Elongation and recrystallisation of quartz is visible under the microscope. Quartz veining parallel to the foliation, similar to that documented by Roering and Smit (1987) in Central Rand Group rocks, was observed but only rarely.

Near the western edge of the mapped area (**ST9**), tonalite-trondjhemite gneisses are exposed at the contact with the overlying OGQF. The gneisses have an east-west striking, south dipping foliation with mineral elongation lineations plunging down dip to the south. Narrow quartz veins are developed parallel to the foliation. Kinematic indicators visible on the outcrop are equivocal but suggest south over north thrust sense movement. Micro-scale kinematic indicators observed in orientated thin sections were unequivocal (Figure 4.6), implying that the foliation in the granitoids was formed during the northward directed thrusting event. Moving north from the basement-supracrustal contact, the intensity of fabric development in the gneisses rapidly decreases. It is clear that the basement-supracrustal interface played a significant role in the northwards directed thrusting event and has been marked as a major thrust on Map B.

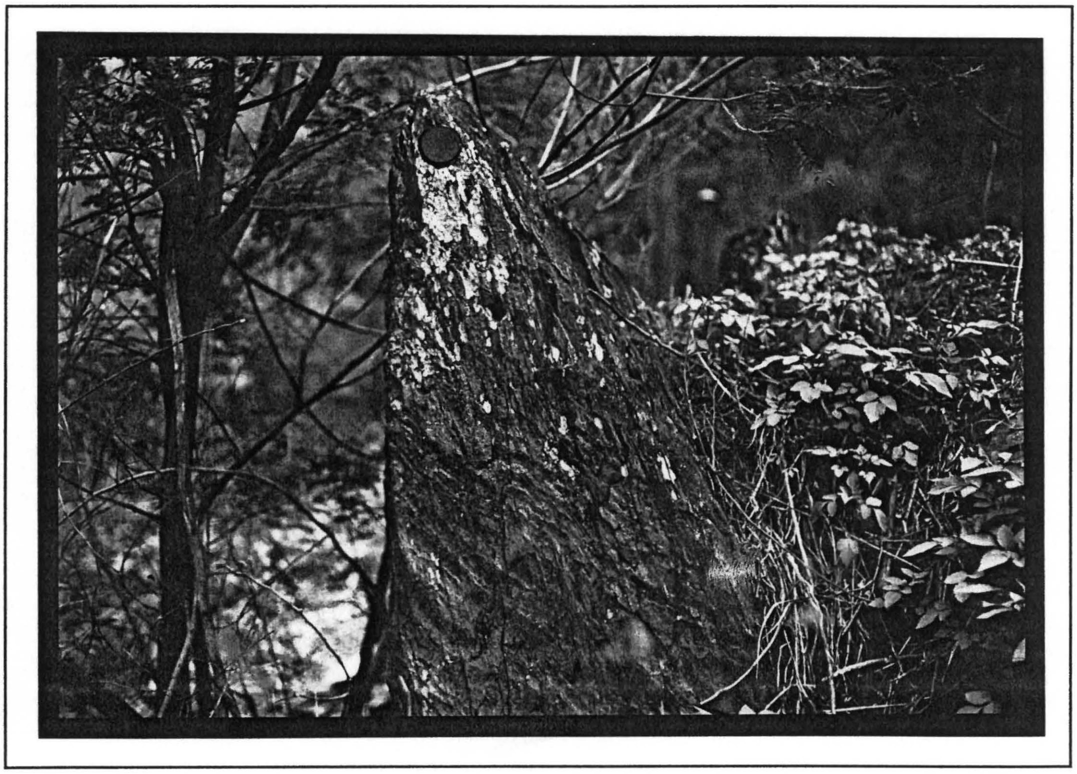
Figure 4.6: *Sketch of microfabrics developed in tonalite-trondjhemite gneisses close to the basement-supracrustal contact. S-C fabrics defined by chlorite and mica as well as elongated quartz grains are unequivocal and indicate northwards directed thrusting.*



4.3.2 ENE Striking, dextral sense, strike slip shear zones.

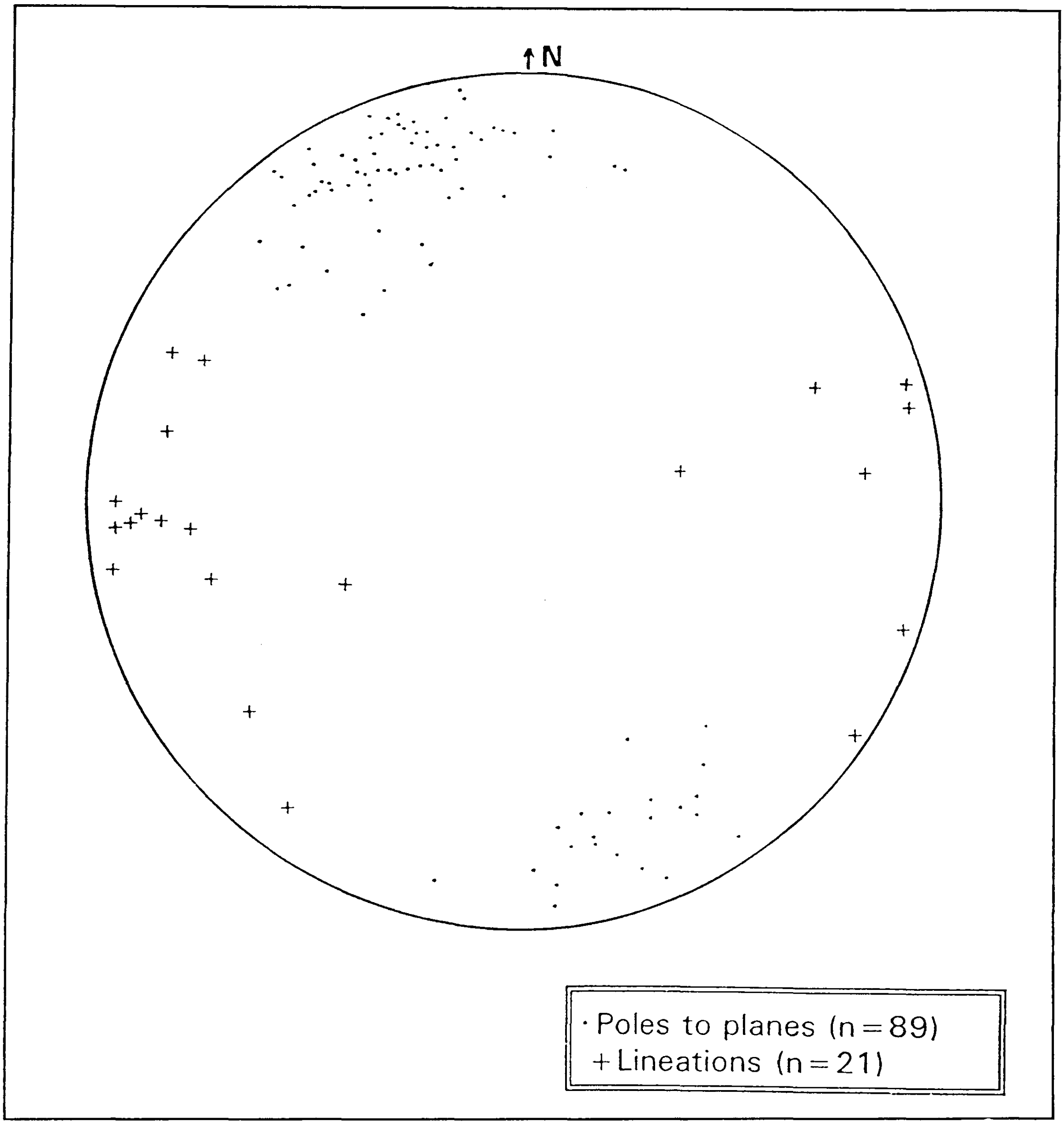
ENE striking, subvertical shear zones are developed in the Northcliff area. Deformation is clearly heterogeneous, zones of intense fabric development being separated by bands of very much less strained rock. In both quartzite and shale bands, the shear zone fabric can be seen to cross-cut bedding at a high angle (Figure 4.7).

Figure 4.7: *Shear zone fabric developed in phyllite. The fabric is steeply dipping and cuts bedding at a high angle. Bedding and cleavage dip north.* **(ST10)**



Orientations of shear zone fabrics (both linear and planar) are plotted on a stereonet in Figure 4.8. The average strike of the shear zones is 075°.

***Figure 4.8:** Stereonet plot of planar and linear fabrics developed in ENE striking, strike slip shear zones.*



The majority of shear zone foliation planes dip at subvertical angles to the SE, some fabric planes however dip to the NW. Lineations, are for the most part sub-horizontal, indicative of strike slip movement. In bends in the shear zones lineations are oblique due to local transpressive or transtensional regimes.

Composite planar fabrics (S-C) such as those illustrated in Figure 4.9 give a consistent dextral strike slip sense of displacement. This is confirmed by the spatial disposition of the stratigraphy on either side of the shear zones (Map A).

Figure 4.9: *S-C fabrics (in plan view) from the Alberts Farm Shear Zone. Movement sense is dextral.* (**ST11**)

The most prominent of these shear zones is developed along base of the dip slope on the southern side of the Northcliff promontory. It is well exposed in a municipal park called Alberts Farm and for the purpose of this report will be referred to as the Alberts Farm Shear Zone (AFSZ). The AFSZ is up to 100m wide and the minimum amount of displacement (based on stratigraphic separation) is 2 km. Tectonic lenses of quartzite and phyllite are present in the AFSZ, with their long axes (in plan) parallel to the shear zone. Planar fabrics related to the bedding parallel northwards directed thrusting event have been rotated into the shear zone indicating the relative timing of the two events.

Thin sections of sheared quartzite and phyllite from the AFSZ were prepared. In the quartzite, the foliation is defined by elongation of the quartz grains. Quartz grains are also characterised by deformation lamellae and strong undulose extinction. Serrated grain boundaries and weakly developed mortar texture indicate that recrystallisation has taken place. In the phyllites, the fabric is defined by strong preferred orientation of micas and small, elongated quartz grains.

The western extension of the AFSZ is truncated by a curviplanar fault striking 120°. The fault was interpreted by Mellor (1917) to be part of the Rietfontein Fault system.

4.3.3 Brittle faulting

The Northcliff promontory and surrounds has been subjected to late stage brittle faulting. Although the faulting was not studied in any great detail. The following observations were made:

- Fault planes of all orientations are subvertical or at least steeply dipping.
- Faulting is characterised by brecciation, quartz veining, fracturing, slickenside striae and quartz slickenfibres.
- Lineations on east-west striking faults are horizontal, indicating strike slip movement.

4.4 Discussion

Three phases of deformation have been reported from the Northcliff area:

(a) NNE directed, bedding sub-parallel thrusting along ductile shear zones.

(b) ENE striking, dextral sense, strike slip shear zones.

(c) Brittle faulting.

No evidence was found for a major NE striking shear zone along the eastern flank of Northcliff promontory as was indicated on previously published maps of the area. The NE striking shear zone that extends much of the way across the dome and was linked to the eastern flank of Northcliff by previous workers forms part of the conjugate set described in the section 3.3.1. It has a sinistral strike slip sense of displacement, not dextral as would be needed to explain the present spatial position of the Northcliff promontory.

The following explanation is proposed to account for the present outcrop pattern at Northcliff:

(1) The OGQF rocks that form Northcliff were thrust northwards over the granitoid/greenstone basement. The majority of the deformation was accommodated at the basement-supracrustal interface and in the shale bands of the overlying sedimentary sequence.

(2) Dextral displacement of at least 2km on the AFSZ and to a lesser extent on subordinate parallel shear zones displaced the promontory to the east to produce the present anomalous outcrop pattern.

The movement direction determined from the Northcliff promontory for the northwards directed thrusting event (NNE/SSW) is consistent with that reported from Swartkops (Roering, 1984) and the East Rand basin (Pitts, 1990) for a post-mid-Ventersdorp Supergroup, pre-Transvaal Sequence thrusting event. Roering and Smit (1987) reported a movement direction towards the NW for Central Rand Group rocks in a road cutting approximately 7km due south of Northcliff.

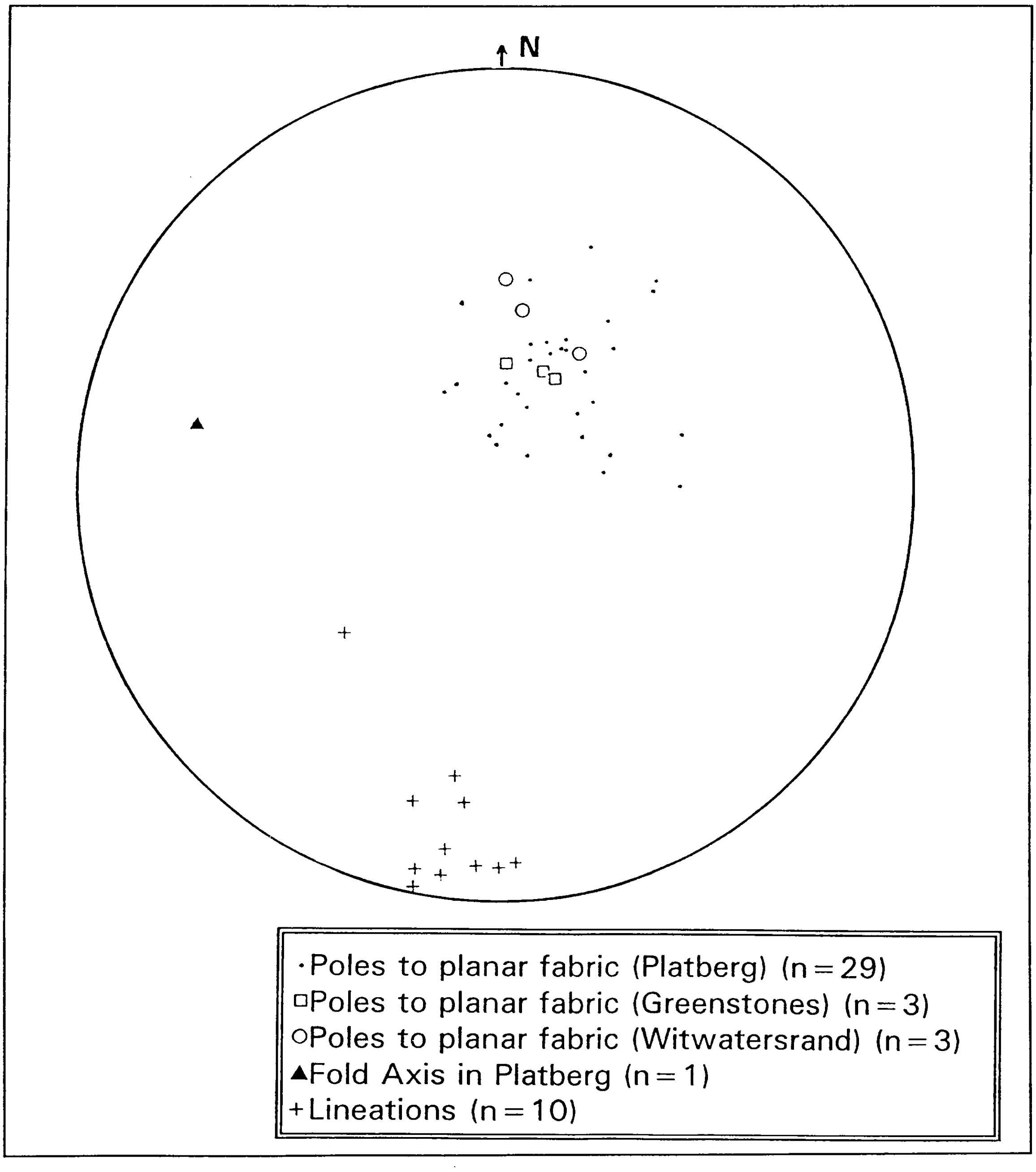
5 STRUCTURAL GEOLOGY OF THE SWARTKOPS - KROMDRAAI AREA

Several workers have published fairly detailed studies of the area around Swartkops (see Figure 1.2). Roering (1984) remapped the West Rand Group rocks of the Swartkops outlier. McCarthy *et al* (1986) studied the Platberg Group sedimentary rocks of the Kromdraai graben as well as the BRQF in contact with it. In this study the Swartkops area was investigated in an attempt to further constrain the timing of the northwards directed thrusting event observed throughout the basement inlier of the Dome as well at Northcliff. The following features are important when considering the Swartkops area:

- The Swartkops outlier is an imbricate thrust stack of West Rand Group rocks that have been thrust northwards over the basement granitoids and greenstones of the dome (Roering, 1984). Movement direction as determined from lineations published by Roering (*op cit*) is NNE.

- Similarly orientated fabrics are developed in the basement granitoids and greenstones around Swartkops as well as in the Platberg Group rocks of the Kromdraai Graben implying a related deformation history. Figure 5.1 shows foliation planes and lineations measured in the Platberg Group rocks (Kameeldorings Formation) of the Kromdraai Graben, the Muldersdrif greenstone complex to the south of the Kromdraai graben as well as the

Figure 5.1: *Stereonet showing the planar and linear fabrics developed in Platberg Group and Witwatersrand Supergroup rocks to the west of Swartkops and the Muldersdrif greenstone complex. Kinematic indicators show the movement sense to be south over north. The movement direction as indicated by the lineations is consistent with that reported from: Swartkops (Roering, 1984), the granitoids of the dome (this study), the JRSZ (Roering, 1986 and this study) and Northcliff (this study).*



contact zone separating the West Rand Group rocks of Swartkops from the adjacent Platberg Group rocks.

The foliation is heterogeneously developed, and in places very intense. Clasts within the Platberg Group rocks are strongly elongated in the plane of the fabric (Roering, 1984; McCarthy *et al*, 1986). Ultramafic rocks of the Muldersdrif ultramafic complex are strongly altered to schists in thrust zones. Kinematic indicators all imply a south over north thrust sense of movement (see Figure 5.2). The azimuth of the lineations show the movement direction to be the same as that for the Swartkops outlier.

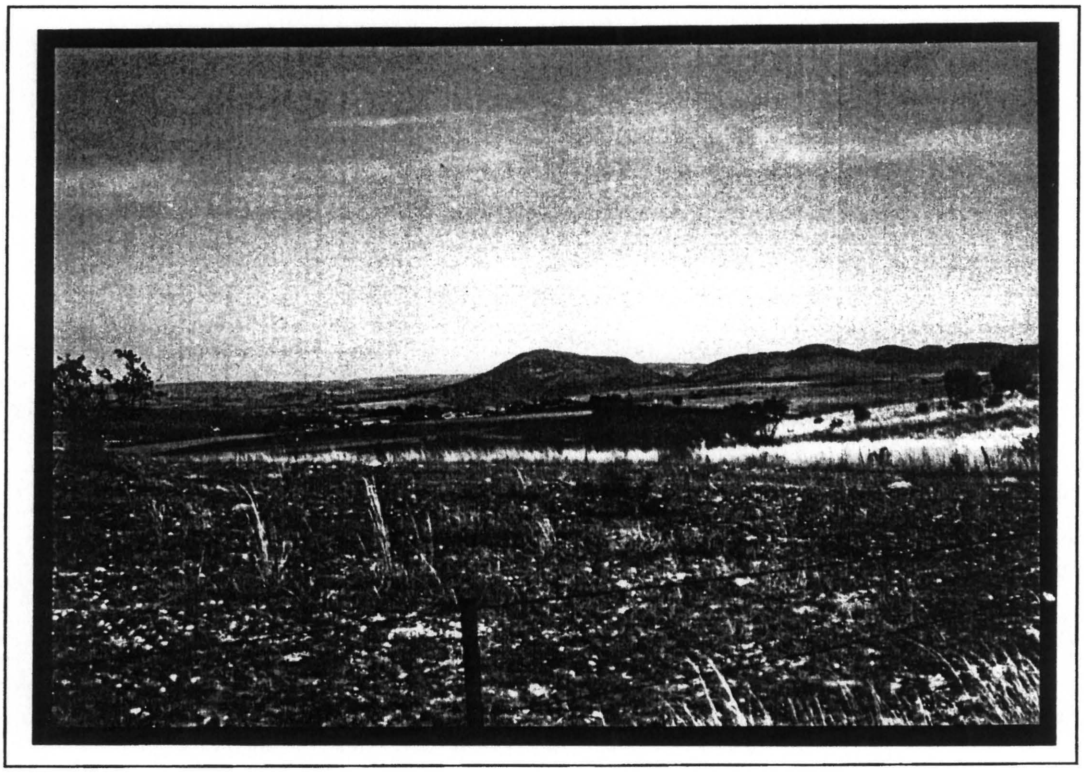
- A zone of intense deformation can be mapped between the Witwatersrand Supergroup rocks of the Swartkops outlier and the Platberg rocks of the Kromdraai graben. It is a zone of ductile deformation up to 100m wide comprising tectonic lenses of Witwatersrand quartzite and Ventersdorp diamictites and lavas. Although the high strain zone is north-south orientated, it has an intense east-west striking, south dipping fabric equated with the north directed thrusting event (Figure 5.3). No steeply dipping, north-south striking foliations were observed in this high strain zone to support the suggestion made by Roering (1984) that it is a lateral ramp structure. Instead it is proposed it simply represents a zone of intense deformation that developed during the thrusting event at the contact between the Ventersdorp and the overlying Witwatersrand Supergroup rocks.

***Figure: 5.2** Highly sheared Platberg diamictite. Cleavage duplexes indicate a south over north thrust sense of movement. North is to the right.* **(ST12)**

***Figure 5.3:** Intense south dipping fabric in Witwatersrand Supergroup rocks at the contact between Swartkops and the Kromdraai Graben.*

• The intensity of deformation observed in the Swartkops outlier (Figure 5.4), in which bedding is often totally obliterated and the Platberg Group contrasts strongly with the much weaker northwards directed, bedding sub-parallel, simple shear deformation in the BRQF to the west of Swartkops (See Chapter 6).

Figure 5.4: *Looking south at the Swartkops outlier. Thrust lenses of West Rand Group sediments are visible on the northern slope. Bedding has clearly been severely disrupted within the thrust pile (after Roering, 1984).*



• Deformed West Rand Group shales can be traced as far as the BRQF unconformity north of Swartkops. Mylonitised Witwatersrand quartzites are unconformably overlain by weakly deformed BRQF to the NNE of Swartkops

(Roering, pers comm). This supports the suggestion that the deformation event responsible for the intense ductile, thrust sense shear zones in the basement, Platberg Group and West Rand Group around Swartkops is post-Platberg, pre-BRQF in age.

6 STRUCTURAL GEOLOGY OF THE BLACK REEF QUARTZITE FORMATION

6.1 Introduction

The BRQF has been studied along the western and northern margin of the basement inlier. Outcrop on the eastern margin is extremely poor. The BRQF covers a regional unconformity, overstepping basement granite and greenstones, Witwatersrand and Ventersdorp Supergroups.

The BRQF has a basal conglomerate which, along the margin of the basement inlier, ranges in thickness between 5 and 40cm. Immediately overlying the conglomerate is a very siliceous quartzite with narrow bands of black shale. The BRQF becomes progressively more argillaceous moving up the Formation, with shale dominating near the top.

The age of the BRQF is constrained between the 2709 ± 4 Ma age obtained from the Makwassie Formation (Armstrong *et al*, 1991) and the 2557 ± 49 Ma age from the dolomites of the Schmidtsdrif Formation (Jahn *et al*, 1990).

6.2 Structure

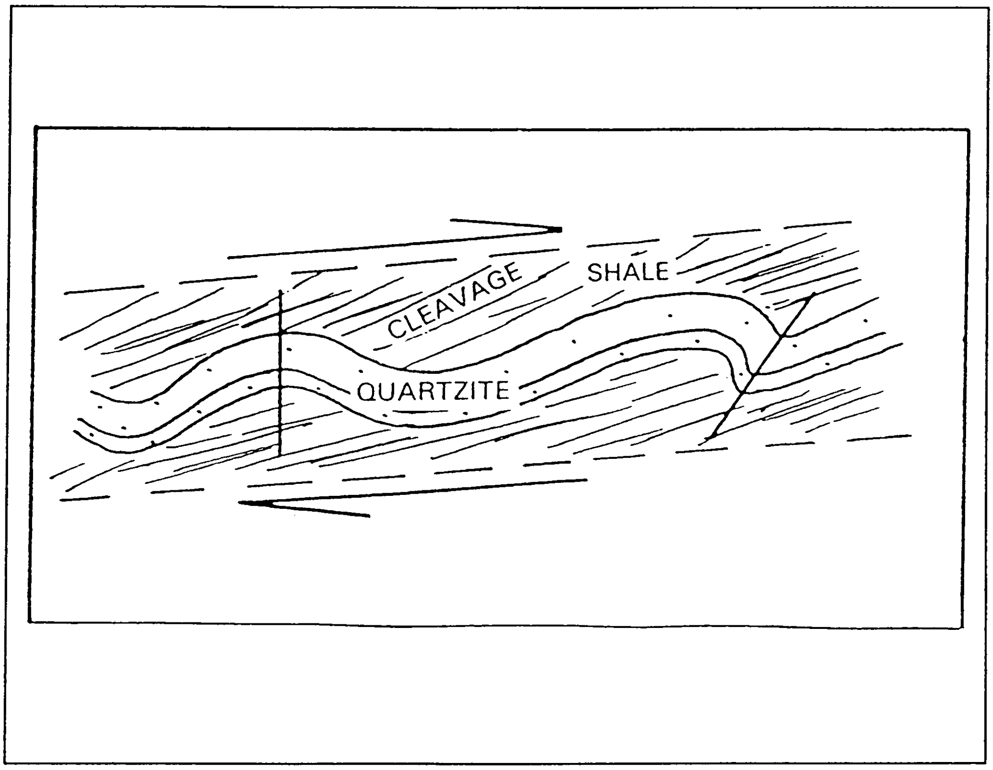
6.2.1 Northwards directed bedding parallel shear

In a study of the BRQF along the present northern margin of the Witwatersrand basin, including the northern margin of the basement inlier of the Johannesburg Dome, McCarthy *et al* (1986) recognised that the BRQF has been deformed by bedding parallel simple shear. Around the northern margin of the basement inlier, they showed that the deformation had a south over north thrust sense of movement. Figure 6.1 illustrates schematically how this deformation has been accommodated in the BRQF. Most of the deformation observed in the BRQF has been accommodated in the shale bands and the quartzite horizons although folded, are not mylonitised or disrupted (c.f. The north directed post-Platberg Group, pre-BRQF thrusting in the Swartkops outlier: Figure 5.4).

Bedding and deformation features produced during this deformation are summarised in Figures 6.2(a) and 6.2(b). 6.2(a) shows data from the BRQF immediately west of Swartkops. This data is consistent with that of McCarthy *et al* (1986). In this area the cleavage is well developed and elongated metamorphic porphyroblasts plunge south, obliquely in the plane of the cleavage. McCarthy *et al* (1986) showed that when cleavage orientations are corrected for the radial dip off the basement inlier of the

Johannesburg Dome, then they show considerably less variation. This indicates that the simple shear deformation pre-dates the doming event.

Figure 6.1: *Schematic diagram, illustrating style of deformation in the BRQF. Simple shear within the shale bands has resulted in upright to slightly overturned folding of the interbedded quartzites. Cleavage in the shale beds always dips to the south at shallower angles than the fold axial planes.*



Fabrics related to the simple shear deformation that were measured in the BRQF along the northern margin of the basement inlier are shown in Figure 6.2(b). At no locality along the northern margin of the dome is the deformation as intense as that observed in the BRQF west of Swartkops. Cleavage development is very subtle, no metamorphic porphyroblasts were observed and overturned folds are extremely rare. Mineral elongation lineations dip to both the north and the south due to rotation during the doming event. Fold axes from the NW and NE plunge to the west and east respectively.

Figure 6.2(a): *Stereonet of bedding, folds, cleavage and lineations developed in the BRQF west of Swartkops.*

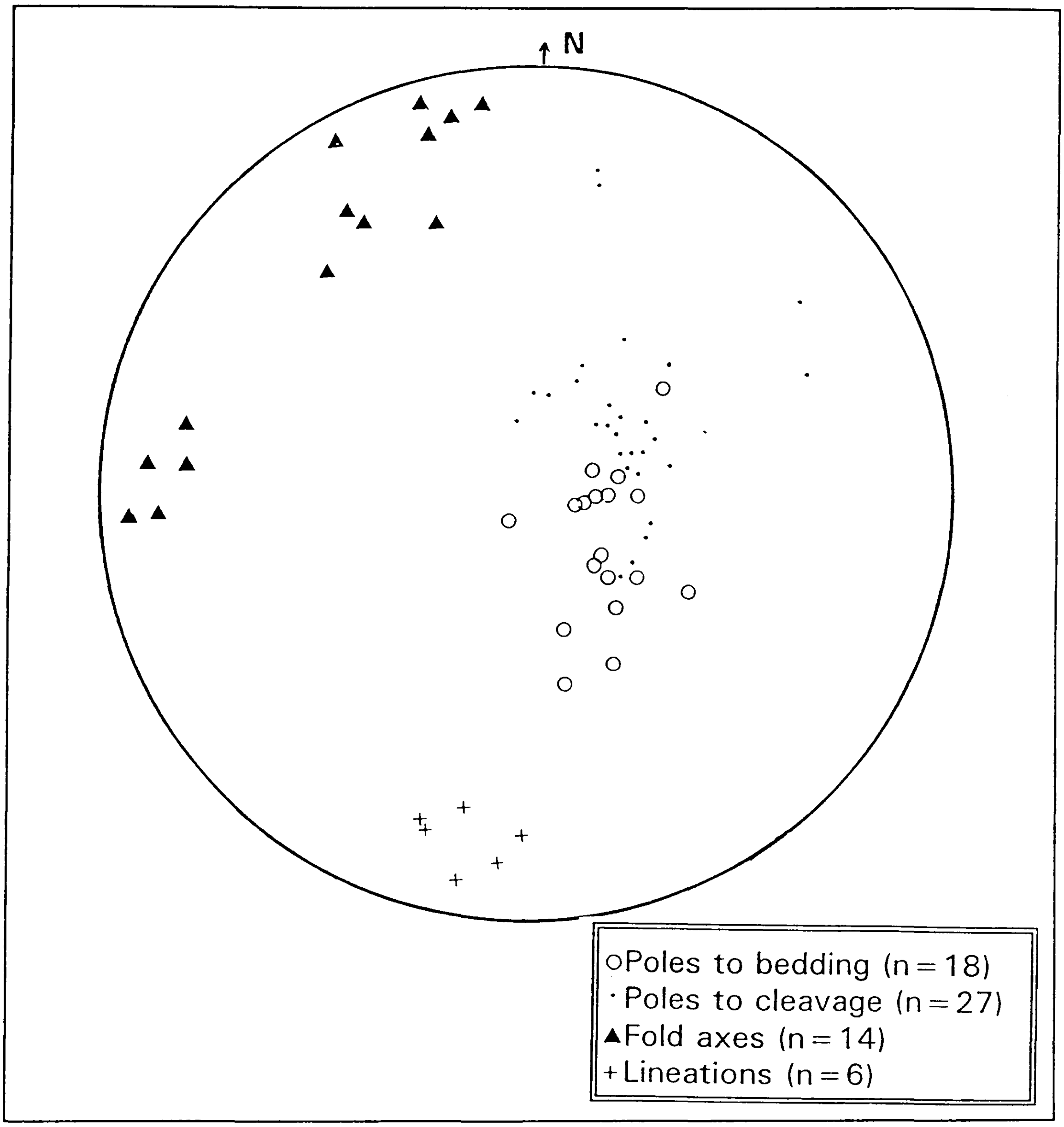
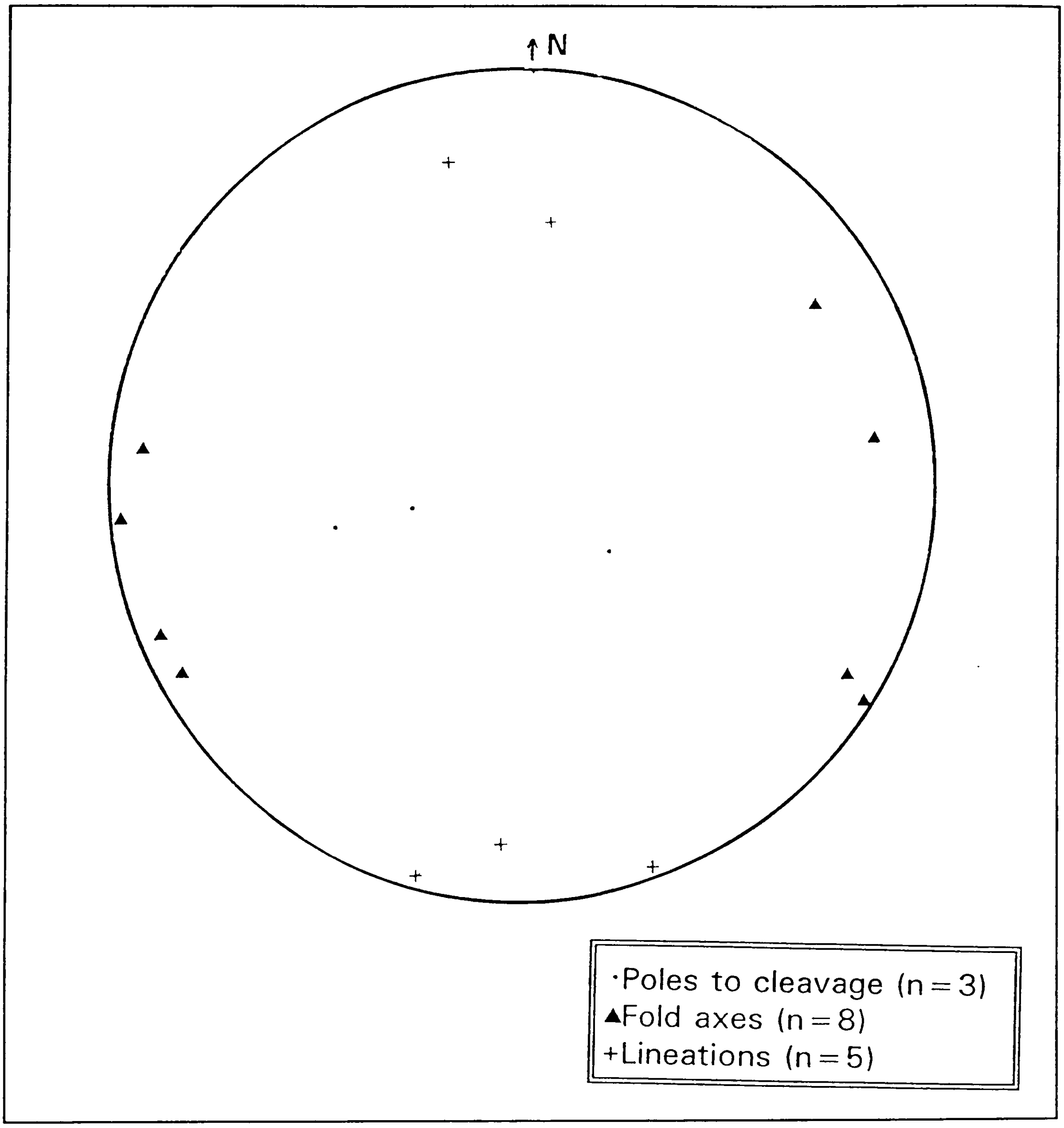


Figure 6.2(b): *Stereonet of folds, cleavage and lineations developed in the BRQF along the northern margin of the basement inlier.*



In a north-south striking road cut along the northern margin of the dome (**ST13**), the BRQF unconformably overlies highly sheared basement of the JRSZ. The mylonitic fabric of the JRSZ dips south and is truncated by the BRQF conglomerate.

The BRQF dips on average 35° to the NE at this locality. Within narrow shale bands a shear foliation (Figure 6.3) is developed that in it's present orientation implies normal movement to the north. One possible interpretation would be to relate this movement to bedding parallel slip during the arching of the crust to form the dome. This interpretation is believed to be erroneous for the following reasons:

Figure 6.3: *Bedding parallel shear zones in the BRQF. Bedding dips north, S-C fabrics imply normal movement in this position.*

- Mineral elongation lineations within the bedding parallel shear zones have an azimuth of 004°. If these features were produced during the arching event it would be reasonable to expect a movement azimuth parallel to the radial dip direction (i.e. NE), this is not the case.

- On the west side of Swartkops, where the north directed thrust sense, simple shear deformation is unequivocal, no evidence for bedding parallel shear zones produced during the arching event were observed in the BRQF. A narrow band of quartz-mica schists (presumably sheared basement) immediately underlying the BRQF has a west dipping foliation parallel to the radial dip off of the basement inlier.

Instead, it is suggested that the shear zones in the BRQF were produced during the post-BRQF northwards directed simple shear event and were subsequently rotated to their present position during the arching event. As the BRQF truncates the southward dipping fabric of the JRSZ at this locality, the northwards directed thrusting in the BRQF cannot be coeval with that preserved in the JRSZ.

The lower age bracket for the thrusting in the BRQF is constrained by the arching of the crust to form the Johannesburg Dome. McCarthy *et al* (1986) showed that shear cleavage related to this deformation is developed in a sill interpreted to be of Bushveld age (≈2050 Ma, Hamilton, 1977) in the

Skeerpoort a few kms NE of Swartkops. If this interpretation is correct, then the deformation must post-date 2050 Ma.

McCarthy *et al* (1986) showed that where deformation features from this event are developed in the BRQF, fold axes are tangential to, and lineations radiate from the Vredefort structure. This would imply that the deformation was as a direct consequence of the enigmatic Vredefort event at approximately 2000 Ma (Nicolaysen *et al* 1963, Hart *et al* 1981).

6.2.2 Brittle faulting

A set of north to NNE striking faults are developed along the northern margin of the basement inlier, displacing the BRQF and Chuniespoort Group dolomites with an apparent sinistral movement in plan (Map A). The faults are defined by zones of vertical fracture, fracture planes are smooth and polished with excellent slickenside lineations. Lineations plunge at very shallow angles to the north. The movement sense is thus sinistral strike slip. Quartz occurs in narrow veins parallel to the fault zones.

The faulting post-dates the northwards directed thrusting event. In places, the faults have reactivated earlier strike slip shear zones (conjugate set, strike slip shear zones, section 3.3).

7 DISCUSSION AND CONCLUSIONS

7.1 Early tectono-metamorphic events affecting the granitoids

The 3170 Ma tonalite-trondjhemites outcropping on the southern margin of the basement inlier of the Johannesburg Dome are interpreted to be the oldest granitoid phase. A gneissic foliation, parallel to the greenstones that they intrude, is developed. Anhaeusser (1973) suggested that the foliation was formed during intrusion. The interpretation favoured in this thesis is that the foliation was due to regional tectonism. The competency contrast between the granitoid and greenstone would have enhanced foliation development parallel to the contacts.

A high grade tectono-metamorphic event produced banded gneisses with some migmatitic features and syn-metamorphic flowage folds in the northern part of the basement inlier. The protolith for these gneisses may have been the 3170 Ma tonalite-trondjhemites (Anhaeusser, 1973). The gneissic banding that developed during this event had a regional east-west strike and was subsequently folded about east-west trending axes.

Anhaeusser (1973) and Anhaeusser and Burger (1982) suggested that the granodiorite from the central and southern part of the basement inlier may have been formed by anatexis of the tonalite-trondjhemite gneiss during the same tectono-metamorphic event that produced the banded gneiss. In the central part of the basement inlier a weakly developed east-west striking, south dipping gneissic foliation is developed. Features such as heterogeneous development of the gneissic foliation and stretched out greenstone xenoliths suggest that the foliation was developed in zones of heterogeneous simple shear. The gneissic foliation is unfolded (c.f. the banding of the gneisses to the north). Consequently the intrusion of the granodiorites must post-date the tectono-metamorphic event that produced the banded gneisses in the north and is separated from it by at least one deformation event.

7.2 Northwards directed thrust sense deformation

A northwards directed thrusting event has been observed in all granitoids of the basement inlier, the West Rand Group at Northcliff, the West Rand Group and Platberg Group sediments in the Swartkops area (Roering, 1984; McCarthy *et al*, 1986 and this study) and the Jukskei River Shear Zone (Roering, 1986 and this study).

At all these localities, planar fabrics dip south to SSW, linear fabrics plunge down dip in the same directions. All kinematic indicators are consistent with northwards directed thrust sense movement. The thrusting in all the rock types listed above is interpreted to be related to the same event.

The intensity of the deformation, as indicated by foliation development, increases from south to north. In the West Rand Group rocks of the Northcliff promontory, thrusting was accommodated along bedding parallel shear zones. Much of the strain was concentrated at the basement-sediment interface and in the shale bands of the overlying sedimentary sequence (although high strain zones also occur in the quartzites).

In the granitoids in the southern part of the basement inlier, thrusting occurred along fairly discrete shear zones, whereas further north, the fabric developed in the granitoids is much more pervasive. The Jukskei River Shear Zone (Roering, 1986) is a zone of mylonite development along the northern margin of the inlier.

This northwards increase in strain is consistent with a leading imbricate fan accommodating northwards thrust propagation by footwall collapse. The model invoking footwall collapse was proposed by Roering *et al* (1990) with evidence from the west side of the Johannesburg Dome and can now be expanded to include the entire Dome.

The movement sense and direction is consistent with that reported from the East Rand basin by Pitts (1990) for zones of bedding parallel shear strain in West and Central Rand Group rocks. The thrusting can also be correlated geometrically with that documented in the outlier of the West Rand Group rocks forming Swartkops (Roering, 1984).

Age of the thrusting:

Roering (1984, 1986) and Roering *et al* (1990) concluded that the deformation was post-Platberg Group, pre-BRQF. Pitts (1990) constrained the movement to between post-Ventersdorp dyke intrusion and the deposition of the BRQF. The youngest lithostratigraphic unit affected by the deformation in the study area is the Kameeldoorns Formation of the Platberg Group. The Black Reef Quartzite Formation post dates the deformation. In terms of the absolute ages available (Table 1.1), the thrusting can be bracketed between 2714±8 Ma and 2557±49 Ma. A major crustal scale event influencing the Kaapvaal craton during this period was the Limpopo orogeny (2700-2650 Ma; Barton and Van Reenen, 1992), caused by the collision of the Kaapvaal Craton, the Zimbabwe Craton and an exotic terrane now represented by the Central Zone to the Limpopo belt (McCourt and Vearncombe, 1992; Thomas *et al*, 1993). It is possible therefore that the thrusting event documented on the Johannesburg Dome is related to the Limpopo orogeny as suggested by De Wit *et al* (1992).

7.3 The conjugate strike-slip, shear zone pair

A conjugate, strike-slip, shear zone pair has been documented from the granitoids of the basement inlier. The strikes of the shear zone sets are NNW and NE, having dextral and sinistral displacement sense respectively. A shear zone pair of this geometry implies a north-south compression.

From field relations, the age of these shear zones can be constrained between the northwards directed thrusting and the deposition of the Black Reef Quartzite Formation.

7.4 ENE Striking, strike-slip shear zones

In the West Rand Group in the Northcliff area, a major ENE-striking shear zone is developed (the Alberts Farm Shear Zone). Subordinate, parallel, shear zones occur throughout the Northcliff promontory. Movement sense was dextral strike-slip. The Alberts Farm Shear Zone has displaced the Northcliff promontory 2km to the east. A combination of this displacement and the earlier northward directed thrusting has resulted in the present anomalous strike of the Northcliff promontory compared to the rest of the West Rand Group along the southern margin of the basement inlier.

Thrust sense shear zone fabrics produced during the northwards directed thrusting event (section 7.2) have been rotated into these ENE striking shear zones. The shear zones must therefore post-date the thrusting event. The relative timing between the ENE striking dextral shear zones at Northcliff and the shear zones of the conjugate pair (section 7.3) is unclear.

7.5 Post Black Reef Quartzite Formation north-directed simple shear

North-directed simple shear in the Black Reef Quartzite Formation as described by McCarthy *et al* (1986) has produced a shear cleavage in the Black Reef shales and upright to slightly overturned (to the north) folds in the quartzites.

The intensity of this deformation is generally very low except in the Swartkops area. Even in the Swartkops area high strain zones are not developed in the quartzite. The writer is in agreement with McCarthy *et al* (1986) that the deformation pre-dates the arching of the crust to form the Johannesburg Dome. McCarthy *et al* (1986) suggest that the deformation is post-Bushveld in age and possibly related to the enigmatic Vredefort event.

7.6 Sinistral, strike-slip, brittle faulting

Approximately north-south striking brittle faults displace the Black Reef Quartzite Formation and the Chuniespoort Formation dolomites along the northern margin of the basement inlier. Movement sense was sinistral. These faults post-date the post Black Reef Quartzite Formation, north directed, simple shear deformation (Section 7.5). Some of these faults have reactivated earlier, ductile, strike slip shear zones of the conjugate pair.

7.7 The Johannesburg Dome

The lithostratigraphy analyzed during the present study exhibits the following interesting structural features:

The rock types exposed below the unconformity at the base of the Black Reef Quartzite Formation share a common deformation history that is dominated by northward vergent contractional faulting (thrusts). In the supracrustal sequences of the Witwatersrand Supergroup and the Ventersdorp Supergroup, much of this deformation has been accommodated along bedding parallel shear zones. The fabric elements related to this deformation strike between east-west and ESE and are always inclined south. There is no indication of any radial pattern of dips in the rocks below the Black Reef unconformity.

The Black Reef Quartzite Formation and younger rocks of the Transvaal Sequence that fringe the basement inlier on the Johannesburg Dome are, for the most part, weakly deformed although high strain zones are locally developed. A consistent feature throughout the outcrop of the Black Reef Quartzite Formation however is the radial dip off the basement inlier. Importantly this attitude can be mapped using both bedding and cleavage in the BRQF.

The questions arise therefore: what caused the doming ? and when did it take place ?

Based on the data collected during the study and presented in this thesis, it is suggested that *geometrically* the doming is only reflected in the rocks of the Transvaal Sequence implying the doming event must post-date the BRQF and the conformably overlying Chuniespoort Group and based on the published geological maps of the West Rand area the Pretoria Group also. The doming cannot be the result of interference folding as suggested by some workers (e.g. Brock and Pretorius 1964) because of the lack of conformity between the rocks above and below the Black Reef unconformity. This implies the doming of the Transvaal Sequence rocks was the result of crustal arching in response to rising magma and it is therefore suggested the doming was a response to thermal activity (plume ?) associated with the development and possibly the emplacement of the Bushveld Igneous Complex at 2050 Ma.

7.8 Conclusion

In conclusion therefore the following deformational events are considered significant in the structural evolution of the study area.

(i) A mid-Archaean tectono-metamorphic event to generate the granitoid inlier now forming the core to the Johannesburg Dome.

(ii) Development of the Witwatersrand basin and the Klipriviersberg Group and Platberg Group depositories between 3074 and 2709 Ma with related deformation not recognised in the study area.

(iii) Late Archaean contractional deformation between 2709 and 2600 Ma that produced a series of northward verging thrusts and caused considerable shortening of the Witwatersrand Supergroup and Ventersdorp Supergroup stratigraphy. It is probable that this deformation was related to the Limpopo Orogeny.

(iv) Uplift and erosion followed by deposition of the Transvaal Sequence

(v) An Early Proterozoic contraction event which reactivated some of the northward verging thrusts below the Black Reef unconformity causing them to cut up through the BRQF and deform it. Exact age and cause unknown

(vi) Arching of the crust in response to thermal activity related to the Bushveld Complex which caused tilting of the rocks above the Black Reef unconformity but does not appear to have influenced the attitude of the older units.

8 ACKNOWLEDGEMENTS

Funding from Anglo American Corporation of South Africa is gratefully acknowledged. Dr's C.P. du Plessis and M.B. Watchorn from Anglo American Prospecting Services (Klerksdorp) went out of their way to promote the project and gave invaluable advice.

Assoc. Prof. S. McCourt supervised the project and deserves a special vote of thanks for all the time spent in discussion and in the field as well as for teaching me the difference between brittle and ductile deformation.

Prof. C.R. Anhaeusser and Prof. C. Roering gave up time from their very busy schedules to show me key exposures on and around the Johannesburg Dome.

Juan Hugo, Ewan Burgers, Nellie Day and Marje Dromaris all opened their doors when I needed accommodation whilst doing fieldwork. Thanks for making me feel so welcome.

Finally, to the staff and students of the Geology Department at the University of Pretoria, many thanks for all the help over the past two years.

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APPENDIX

The following list of key outcrops with directions and brief outcrop descriptions is aimed at allowing the reader to visit spectacular or critical examples of certain features discussed in the text. Stops are referenced in the text (next to photographs or descriptions) using the format **ST1, ST2** etc. All directions are from Pretoria (apologies to those living on the other side of the Jukskei).

ST1:
The Jukskei River Shear Zone

Directions:
N1 south from Pretoria
R28 west (Krugersdorp Highway)
R512 north (Lanseria Road)
Turn right at Living Waters/New Vaalie Farm store sign.
Follow signs to Living Waters
Pass Living waters and Poultry Farm
Approx 800m from Poultry Farm is a dirt track going to the west up a ridge.
Follow track to top of ridge

Description:
The ridge consists of an imbricate thrust pile of: quartz mylonite, mylonitised granitoid and red shale. Mylonitic fabric strikes east-west and dips south. Kinematic indicators imply north directed thrusting. Looking east from the ridge, a prominent linear quartz vein can be seen. This quartz vein marks a NNW striking, dextral strike slip shear zone of the conjugate set. On closer inspection one can see the rotation of the JRSZ mylonite into the shear zone with a dextral sense.

ST2:
Northwards directed thrusting in weathered granitoid.

Directions:
N1 south from Pretoria
R47 west (Tarlton Road - Offramp near Hyperama and Flora Clinic)
Just after the R47 ceases to be a dual carriageway turn right
At the crest of the first hill there is a road cutting

Description:
See locality NT1 in text.

ST3:
Northwards directed thrusting in granodiorite
N.B. Be very cautious in this area

Directions:
N1 south from Pretoria
Olifantsfontein offramp turn East
Consult 1:50 000 Topo. Map 2628 AA. Next to Tembisa.
Dirt road crosses the Kaalspruit close to the boundary of Olifantsfontein 410 JR and Kaalfontein 13 IR.
Approx 1km south of this point on the west side of Kaalspruit is a small quarry.

Description:
See locality NT2 in the text.

ST4:
Northward directed thrusting. Back thrusts. Strike slip shear zones of the conjugate set.

Directions:
N1 south from Pretoria
R28 west (Krugersdorp highway)
Left along Kyalami Road
3km Left at Anglo Alpha Quarry sign
Follow dirt road until small lake on right hand side (model boat club). Park.
Walk west of lake until disused quarry (Partially filled with water)
Best exposures are on the west side of quarry on the lower two benches

Description:
See locality NT2 in text for description of thrusting. Look for the biotite pods with duplex geometry near the pile of "ouklip".
Narrow strike slip shear zones of the conjugate set (Both NNW dextral and NE sinistral) are developed in this quarry, with good S-C fabrics and horizontal lineations (Look for the light-grey mylonite zones along the quarry faces). The shear zones show typical splaying and horsetailing.

ST5:
NNW striking, dextral sense, strike slip shear zone of the conjugate set with extremely well developed mylonite.

Directions:
N1 south from Pretoria
Rivonia offramp
Turn right (Back under N1)
Left at traffic lights (Witkoppen Road)
At first set of traffic lights turn left
Cross back over N1 turn left at first road
First right, road runs along side the Braamfontein Spruit
1km Shear zone exposed in Braamfontein Spruit, near electricity pylons

Description:

A 10 metre wide zone of mylonitised granitoid. Good S-C fabrics indicate dextral movement sense.

ST6:

Rietspruit shear zone. NNW striking, dextral strike slip shear zone of the conjugate set. The Black Reef Quartzite Formation has not been affected by the ductile movement.

Directions:

Old Johannesburg Road south (R101S) from Pretoria
Take Eldoraigne/Wierda Park turn off (right)
Straight for approx 7km, cross over Rietspruit River
Carry on up hill, turn left into Valley View housing estate
Second left, Park as close to Rietspruit river as possible
Exposure in Rietspruit river

Description:

A NNW striking dextral shear zone mylonite is developed in banded gneiss at this locality. Good S-C fabrics and cleavage duplexes. Look out for the small low outcrop of ultra mylonite on the west bank of the river. Just north of this ultramylonite along the strike of the shear zone, Black Reef Quartzite Formation quartzites and shales are exposed. The BRQF is unaffected by the ductile deformation.

ST7:

North directed thrusting in Orange Grove Quartzite Formation quartzites and shales.

Directions:

For the localities on Northcliff only street names will be given. These can easily located in any Johannesburg map book.
Maluti Avenue (Quellerina)
Maluti is a "U" shaped street with a N-S road cutting in the bend of the U.

Description:

A narrow shale band has been utilised as a thrust plane. Mineral elongation lineations plunge south. The foliation in the shale band dips south. Good cleavage duplexes are developed in the shale band. The thrust plane ramps up through the more competent quartzites, truncating the shale band. Just to the north of the road cutting, highly strained quartzites with cleavage duplexes are exposed. Mind the black-jacks.

ST8:

Northward directed thrusting in Orange Grove Quartzite Formation quartzites.

Directions:

Outeniqua cul du sac (Quellerina)
Outeniqua is a small road off of Lange Avenue.
Good outcrops on both sides of the road.

Description:
This is a high strain zone in quartzite. A good east-west striking, south dipping foliation is developed. Look out for cleavage duplexes as well as thrust horses of quartzite several metres in length.

ST9:
Northwards directed thrusting at the basement-supracrustal contact.

Directions:
Soutpans Ave (Quellerina)
The western end of Soutpans becomes Hogsback Road. Where the two meet there is a place to pull off to the right and park.

Description:
Just to the east of the parking spot, tonalites are exposed (in between the trees). They have a weak east-west striking, south dipping foliation. Cross the road and highly strained and altered tonalites are exposed near the contact with the overlying OGQF. The foliation has similar orientation to that next to the parking spot but is much more intense. Kinematic indicators on outcrop scale are equivocal. Micro-fabrics imply north directed thrusting.

ST10:
Alberts Farm Shear Zone. Relationship between this ENE striking strike slip shear zone and the northward directed thrusting event.

Directions:
Mark Avenue (Northcliff)
Vacant lot next to Town house complex

Description:
At the top of the vacant lot, OGQF quartzites with typical thrust foliation are exposed. The strike of the foliation is anomalous i.e not east-west. Moving further down the vacant lot, phyllites with a subvertical foliation are exposed. This is part of the Alberts Farm Shear Zone (AFSZ). The inference here being that movement on the AFSZ rotated the earlier thrust fabrics to their present position.

ST11:
Alberts Farm Shear Zone. Movement sense indicators.

Directions:
De la Rey Road. Northcliff
Park 30 metres before Swazi-De la Rey intersection.

On west side of road is the Alberts Farm Park. Enter the park where the tall fence ends and walk about 30metres NW to a quartzite outcrop.

Description:
Sheared quartzite with steeply south dipping, ENE striking foliation. Foliation is heterogeneously developed. Lineations are sub-horizontal. Composite planar fabrics imply dextral movement sense. Looking WSW along the strike of the shear zone, lenses of phyllite and quartzite can be seen on the far side of the park.

ST12:
North directed thrusting in Platberg Group Diamictites.

Directions:
N1 south from Pretoria
R28 west (Krugersdorp highway)
Swartkops offramp. Turn right (north)
Turn left at Swartkops sign
At T-junction turn left
approx 4 km further turn left at chicken farm sign
Good exposure just north of the chicken batteries

Description:
An excellent east-west striking, south dipping foliation is developed in Platberg Group diamictites. Clasts are strongly elongated in the plane of the fabric defining a south plunging stretching lineation. Duplexes and S-C fabric relationships indicate northward directed thrusting. This exposure may be used as a teaching locality in the future so please keep on good terms with the farm manager.

ST13:
Deformation in the Black Reef Quartzite Formation

Directions:
From Pretoria join the R512 north as for **ST1**
Pass the Living Waters sign and a petrol station on the left side
The road cutting is at the top of the next rise

Description:
See text page 86.