5: STRUCTURAL GEOLOGY OF THE BUSHVELD COMPLEX AND THE SURROUNDING AREAS

In this chapter the nature and geometry of all the major structures occurring in the eastern, northern and western Bushveld Complex and surrounding areas, as present in BOSGIS, are described. All the data were obtained from the literature and no additional fieldwork was done. Archaean structures are not discussed in detail and only major features are mentioned. The younger structures are discussed in more detail but due to the paucity of published data many descriptions are therefore incomplete. Structures are firstly organized into the separate areas of the Complex in which they are located, and then discussed according to the ages of the rocks which they deform.

5.1 THE WESTERN BUSHVELD COMPLEX

A geological map, including all the various structures, of the western Bushveld Complex area is shown in Figure 5.1.

5.1.1 ARCHAEAN STRUCTURES

Archaean structures are confined to the Makoppa dome and the Johannesburg dome. Both of these domes form part of the Vryburg Arch.

5.1.1.1 Makoppa dome

According to Beukes (1983) and Hunter (1975, 1976) the Makoppa dome might be the result of two intersecting fold directions which trends NW and NE. Fourie (1984) concluded that the dome formed a palaeo-high during the deposition of the Chuniespoort Group. Minor greenstone fragments are present in the dome but nothing is known about any structures contained within these greenstone fragments. A few minor shear zones orientated more or less EW are observed, (Figure 5.1). In addition, well defined NNE satellite lineaments can be traced, but it is unknown what these lineaments represent. However these lineaments do not cut across into adjacent younger strata.

Geological Map of the western Bushveld Complex and surrounding areas

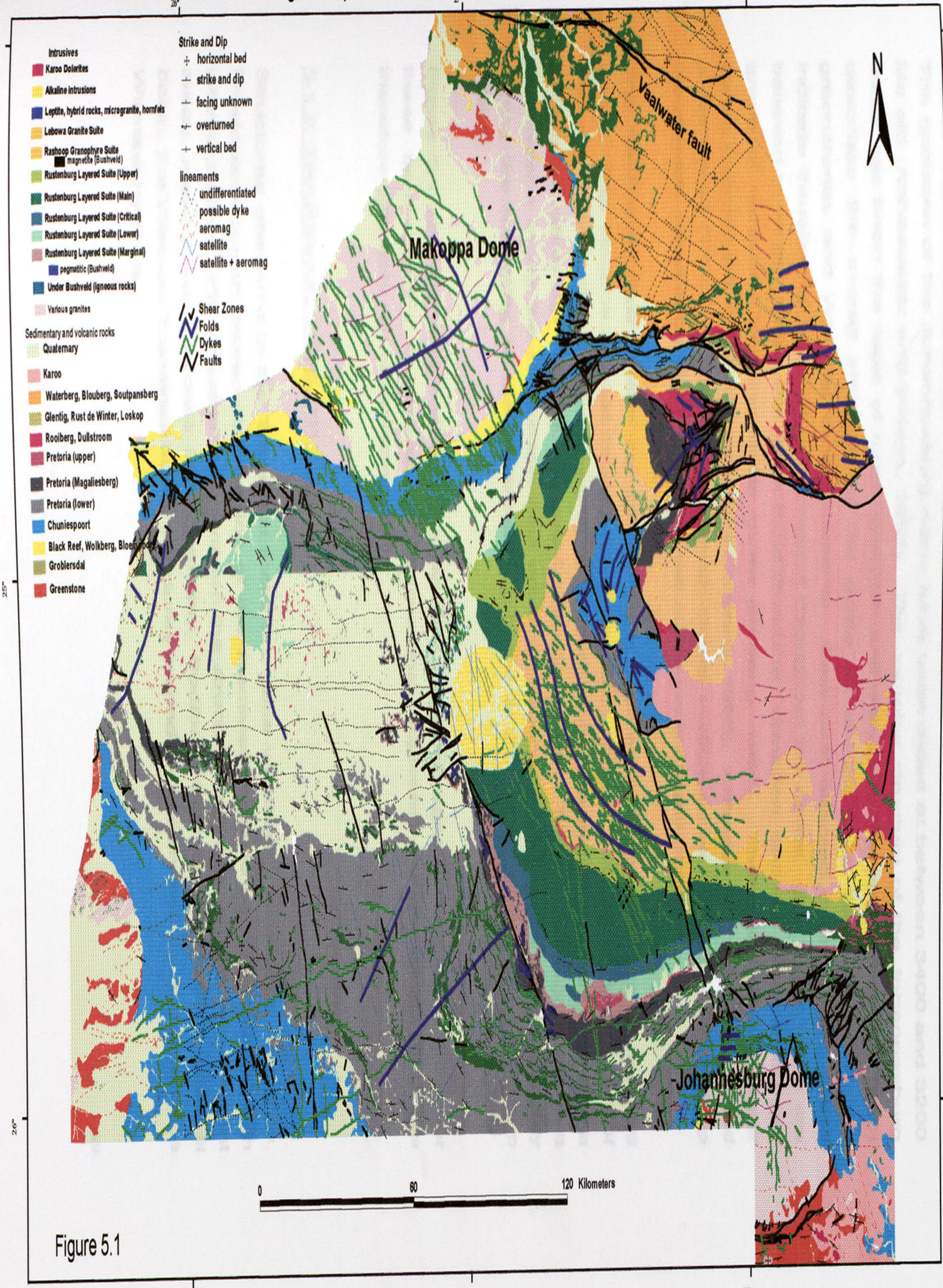


Figure 5.1

5.1.1.2 Johannesburg dome

The gneisses of the Johannesburg dome have been dated at between 3400 and 3200 Ma old (Anhaeusser and Wilson, 1981). The complex structure of the Johannesburg dome has been the topic of much research and debate in the past. Roering (1986) describes the overall structure of the dome as an imbricate stack of granitoids, greenstones and Witwatersrand sediments. East-west oriented shear zones, which indicate thrusting to the north are present throughout the dome. The thrust faults are believed to be older than the Black Reef Quartzite Formation, and are cut by a younger group of northeast trending shear zones (Roering, 1986). These NE striking shear zones indicate left lateral displacement (Roering, 1986). Anhaeusser (1973) also noted a prominent NE striking shear zone which shows vertical as well as dextral strike-slip movement. He proposed a post-Transvaal activation for these structures.

The *Rietfontein fault* system occurs along the southern margin of the Johannesburg dome. This sinuous approximately EW striking fault system, has had a long history of activation. According to Charlesworth et al. (1986) it has been continuously active as a left-lateral strike-slip fault during pre-Transvaal times. They also suggested that reactivation along the Rietfontein fault occurred during post-Transvaal times, possibly during the reheating of the Johannesburg dome at 2.1 Ga as postulated by Allsopp (1961).

Figure 5.1 also indicates EW trending satellite and aeromagnetic lineaments, however these aeromagnetic lineaments cut across into adjacent younger strata and are therefore probably not of Archaean age.

5.1.2 TRANSVAAL STRUCTURES

Structures observed in the Transvaal rocks are quite variable in orientation and style. Previous research proved deformation of the Transvaal rocks to be quite extensive in different areas. For convenient description the structures are grouped into six different areas, namely the Crocodile River fragment, Rooiberg fragment, Western Transvaal basin, Far Western Transvaal basin, structures around the Johannesburg dome, and the Warmbaths area.

5.1.2.1 Crocodile River fragment

The general geometry of the Crocodile River fragment is domal with rocks of the Transvaal Supergroup dipping towards the surrounding Bushveld Complex (Figure 5.2). The Transvaal rocks in the Crocodile River fragment are intensely deformed and a detail description of the deformation is provided by Hartzer (1987).

Faults

Two main NW striking faults can be traced in the fragment. Hartzer (1994) referred to these faults as V1 and V2. V1 is now named the Brits fault and V2 the Crocodile River fault. The faults are defined by a ferruginized breccia which mainly consists of chert, quartzite and dolomite fragments. Both these faults display dip-slip normal movement and dip very steeply towards the outside of the fragment. The central portion of the fragment moved upwards relative to the western portion and the Rooiberg fragment. Hartzer (1994) estimated the vertical displacement of the Brits fault to be in the order of 1 300m and that of the Crocodile River fault to be about 3000m. Crocker (1976) proposed the Crocodile River fault to be a right-lateral strike-slip fault with displacement of 1- 2 km which was superimposed on the downthrow to the NE. These faults are believed to have been active after the Bushveld Complex intrusion as a response to isostatic imbalances (Hartzer, 1994).

Folds

The Crocodile River fragment contains complex folding in which overfolding is common. Hartzer (1987) recognized three phases of folding. The first set of folds (F_1) trend northwest in the southern portion of the fragment and NE in the northern and central portion of the fragment. These F_1 folds were later refolded along an ENE trending axis (F_2), and later NW trending, F_3 folds, formed. F_1 and F_2 are believed to be of pre-Bushveld age, while F_3 are probably post-Bushveld in age.

5.1.2.2 Rooiberg fragment

The Rooiberg fragment occurs to the NE of the Crocodile River fragment but is not as intensely deformed as the Crocodile River fragment. The general shape of the Rooiberg fragment is that of a synform (Figure 5.2). A comprehensive overview of the Rooiberg fragment is provided by Hartzer (1994).

Geological Map of the Crocodile River Fragment (A) and the Rooiberg Fragment (B)

Figure 5.2

Faults

Several faults of various orientations can be observed in the Rooiberg fragment (Figure 5.2). The main faults include the Elandsberg fault, Kwarriehoek and South Parallel/Nieuwpoort Fault. The Elandsberg fault strikes NW, and according to Leube and Strumpfl (1963) it is a thrust fault which passes into a left-lateral strike-slip fault towards the east. The Kwarriehoek fault strikes ENE and is believed to be a strike-slip fault (Stear, 1976). The South Parallel/Nieuwpoort fault has a sinuous course of mainly NE, and the main fault exhibits thrust movement (Hartzer, 1994). However, towards the north, the fault splits into several sub-parallel normal and reverse faults (Stear, 1976).

Folds

The Rooiberg fragment consists of two synclines separated by an ENE trending anticline. Overall two main fold trends can be seen. NE trending folds are defined by the Rooiberg anticline and syncline while NW folds are defined by the Elandsberg syncline. The synclines consist of volcanic rocks of the Rooiberg Group (Hartzer, 1994). Minor interference folds have also been reported by Stear (1976). He proposed that the folds follow the same directions as interference folding in the Crocodile River fragment, but on a smaller scale.

Shear zones

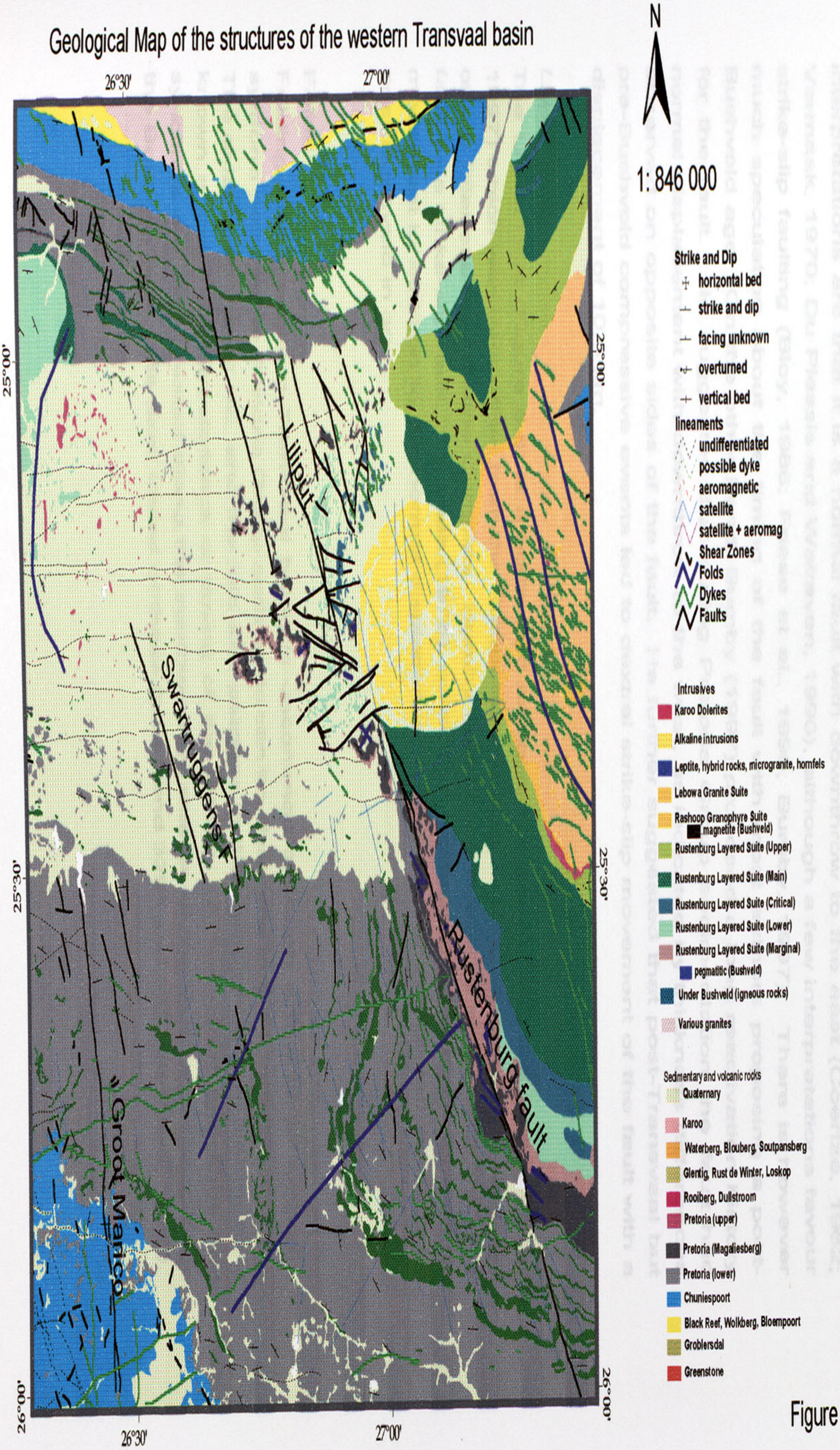
Figure 5.2 indicates NNE trending shear zones in the far NW portion of the fragment. However, nothing is known about the displacement or timing along these shear zones.

5.1.2.3 Western Transvaal basin – Rustenburg area

This area include all the structures from the Rustenburg fault up to just east of the Nietverdiend Complex (Figure 5.3). Rocks of the western Transvaal basin dip at low angles toward the center of the basin.

Faults

The most prominent fault in the area is the large NW striking Rustenburg fault (Figure 5.3). Several other faults strike parallel to this orientation such as the Swartruggens and Groot Marico faults. The geology of these faults are not well known due to poor outcrop,



Geological Map of the structures of the western Transvaal basin
26°30'
27°00'
25°00'
25°30'
26°00'
N
1: 846 000
Lilliput
Swartruggens F
Rustenburg fault
Groot Marico
Strike and Dip
horizontal bed
strike and dip
facing unknown
overturned
vertical bed
lineaments
undifferentiated
possible dyke
aeromagnetic
satellite
satellite + aeromag
Shear Zones
Folds
Dykes
Faults
Intrusives
Karoo Dolerites
Alkaline intrusions
Leptite, hybrid rocks, micrograite, hornfels
Lebowa Granite Suite
Rashoop Granophyre Suite
magnetite (Bushveld)
Rustenburg Layered Suite (Upper)
Rustenburg Layered Suite (Main)
Rustenburg Layered Suite (Critical)
Rustenburg Layered Suite (Lower)
Rustenburg Layered Suite (Marginal)
pegmatitic (Bushveld)
Under Bushveld (igneous rocks)
Various granites
Sedimentary and volcanic rocks
Quaternary
Karoo
Waterberg, Blouberg, Soutpansberg
Glentig, Rust de Winter, Loskop
Rooiberg, Dullstroom
Pretoria (upper)
Pretoria (Magaliesberg)
Pretoria (lower)
Chuniespoort
Black Reef, Wolkberg, Bloempoort
Groblersdal
Greenstone

Figure 5.3

but they have been documented as gravity faults (Visser, 1998). However, much research has been done on the Rustenburg and Liliput faults. The nature of these faults have been the subject of much debate in the past.

Rustenburg fault

The Rustenburg fault (Figure 5.3) has a NNW orientation and can be traced for approximately 200km. Various authors have described the Rustenburg fault and most interpretations are that it is a normal fault with downthrow to the east (Coertze, 1962; Vermaak, 1970; Du Plessis and Walraven, 1990), although a few interpretations favour strike-slip faulting (Bloy, 1986; Friese et al., 1995; Bumby, 1997). There is however much speculation about the timing of the fault with most authors proposing a post-Bushveld age. On the other hand, Bumby (1997) proposed a long reactivation history for the fault. He suggested that during Pretoria Group sedimentation the fault had normal displacement with downthrow to the west, as indicated by thickness differences observed on opposite sides of the fault. He further suggested that post-Transvaal but pre-Bushveld compressive events led to dextral strike-slip movement of the fault with a displacement of 10.6 km.

Liliput fault

The Liliput fault (Figure 5.3) is a northward extension of the Rustenburg fault (Bumby, 1997) which was later offset from the Rustenburg fault by faulting related to the intrusion of the Pilanesberg Alkaline Complex. Bumby (1997) has therefore also interpreted this fault as a strike-slip fault. Vermaak (1976) noted that the fault exhibits slight right-lateral movement in addition to the normal displacement. He however interpreted the fault as post-Bushveld in age.

Folds

Folding in the western Transvaal basin is uncommon although a few large antiform-synform pairs in the Pretoria Group sediments can be observed in the south (Figure 5.3). The axial trace trends NE, and the fold axis plunges in the same direction. Not much is known about the characteristics or timing of the folding. A few minor anticlines and synclines are also present along the southwestern margin of the Bushveld Complex in the Boshoek area. The axial traces of these folds trend 329° and 65° (Vermaak, 1970).

Bumby (1997) described the same interference fold pattern along the Rustenburg fault as were documented by Hartzer (1995) in the Transvaal inliers, namely NW orientated F_1 and NE orientated F_2 folds.

Lineaments

Numerous large undifferentiated lineaments are present in the area with generally poor outcrop. These lineaments exhibit a strong EW trend (Figure 5.3). Just to the south of these lineaments, various smaller NNW orientated aeromagnetic lineaments can clearly be traced in the upper Transvaal sequence.

Dykes and Sills

Only a few large dolerite dykes striking NE cut through the upper and lower Transvaal Supergroup in the southern part of the area (Figure 5.3). However, numerous concordant sills are present in the Pretoria Group. Studies done by Cawthorn et al. (1981) determined pre-, syn- and post-Bushveld ages for the sills based on their different compositions.

5.1.2.4 Far Western Transvaal basin – Nietverdiend-Zeerust area

Interpretation of the geology in this area is complicated due to limited outcrop (Figure 5.4). Previous research in this area was done by Engelbrecht (1986) and Crockett (1969, 1971). They proposed a syn or post-Transvaal, pre-Bushveld deformation event during which gravity-driven slides of upper Transvaal Supergroup rocks moved from east to west. This event is envisioned as a 'catastrophic' lowering of the Transvaal basin floor. Engelbrecht (1986) recorded intense folding and faulting of the overlying upper Transvaal slab, in contrast to the undeformed underling lower Transvaal sequence rocks.

Faults

Mannyelanong fault

This fault is located in the far western portion of the Transvaal basin and extends into Botswana (Figure 5.4). The fault has a NE strike and deforms rocks belonging to the Transvaal Supergroup, although small outcrops of what is believed to be Waterberg sediments have been found on the eastern side of this fault. The fault is proposed to be

Geological Map of the far western Transvaal basin

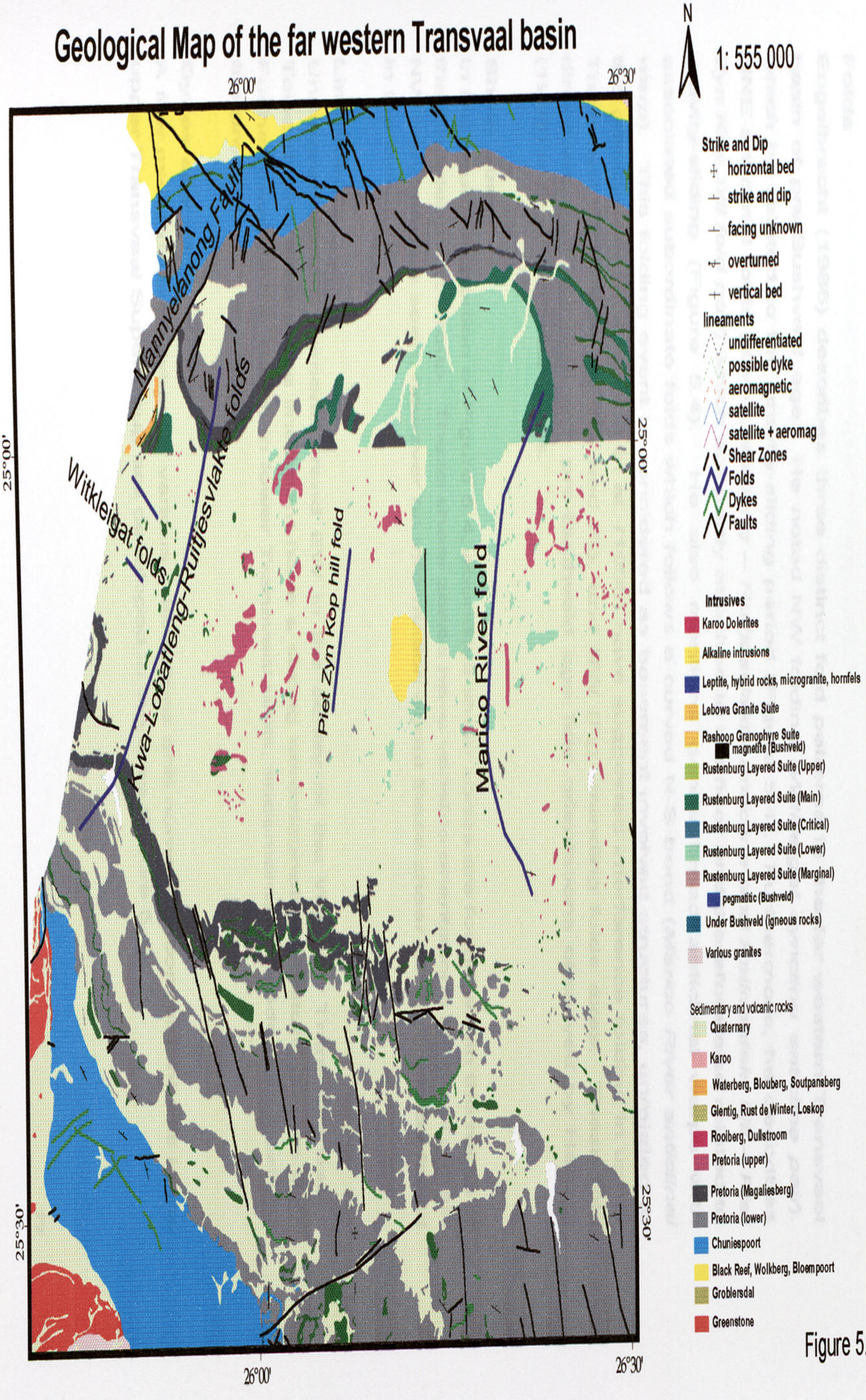


Figure 5.4

a strike-slip fault (Eriksson et al., 1998) and could possibly be as young as post-Waterberg.

Folds

Engelbrecht (1986) describes three distinct fold patterns in the far western Transvaal basin of pre-Bushveld age. He noted NW folding (*Witkleigat syncline anticline pair*). which he related to the gravity-sliding period (Figure 5.4). Furthermore, he describes NNE anticlinal folds *(Kwa-Lobatleng – Ruitjesvlakte anticline and Kalkfontein hill – Piet Zyn Kop hill fold pair*) which are partly attached to the floor and therefore also related to gravity-sliding (Figure 5.4). He also mentions gentle broad anticlinal warps with associated subordinate folds which follows a curved N-S trend (*Marico River anticlinal warp*). This folding event is considered as basement involved structures, unrelated to the gravity-sliding. Eriksson et al. (1998) have suggested interference folding in upper Transvaal rocks with NE (F_1 and F_3), and NW (F_2) trending folds axes. These fold directions also coincide with pre-Bushveld age fold orientations observed by Hartzer (1995) in the Transvaal inliers.

Shear zones

In the southern portion of Figure 5.4, abundant shear zones are found within the rocks of the Chuniespoort Group. These shear zones have variable orientations although a main NW trend can be seen, however no information about these shear zones could be found in the literature.

Lineaments

Undifferentiated lineaments trend EW in the center of the Western Transvaal basin. Towards the west these lineament have a strong aeromagnetic signature (Figure 5.4). Further towards the south, in lower Transvaal units, lineaments of random orientations are present.

Dykes and sills

A few minor dolerite dykes of various orientations and numerous concordant sills in the upper Transvaal Supergroup are developed in the area (Figure 5.4).

5.1.2.5 Transvaal structures around the Johannesburg-Pretoria dome

Deformation of Transvaal strata along the northern margin of the Johannesburg-Pretoria dome is fairly complex. The rocks dip generally to the north, and various types of faults and folding have been recorded (Figure 5.5).

Faults

Towards the northwest of the dome the faults have a NW trend. These faults are subvertical and display strike separations of up to 300m (Gibson et al., 1999). Gibson et al. (1999) noted evidence for both sinistral and dextral strike-slip and dip-slip movement. To the northeast of the dome the faults trend NE to ENE. The dominant sense of movement along these faults is right-lateral although one fault displays a reverse sense of movement (Visser, 1998). The faults along the northeastern rim of the dome are almost at right angles with respect to the strike of the bedding, with local horst and graben structures. Towards the east of the dome there is an approximately NS striking thrust fault. This fault has caused duplication of the Chuniespoort Group and lower parts of the Pretoria Group (Figure 5.5) .

Folds

The Black Reef Formation and Chuniespoort Group have been intensely folded along the northwestern part of the Johannesburg dome. Folds have been described by Gibson et al. (1999) as open to tight asymmetric, inclined to reclined, doubly plunging (periclinal) folds. He recorded wavelengths from a couple of meters to tens of meters with amplitudes of up to 1-2 m. Fold hinges plunge shallowly on an east-west trend, and axial planes dip shallow to moderately steep to the south. Gibson et al. (1999) also noted overturned bedding in some places along the steep northern limbs of anticlines. The age of this folding is not well constrained, however, Gibson et al. (1999) proposed a post-Bushveld pre-Pilanesberg age (related to the Vredefort event) to the folding. These folds trend parallel to Waterberg-age folds observed along the Thabazimbi belt and therefore, it might be possible that these folds formed during post-Waterberg times.

Geological Map of the Johannesburg Dome area

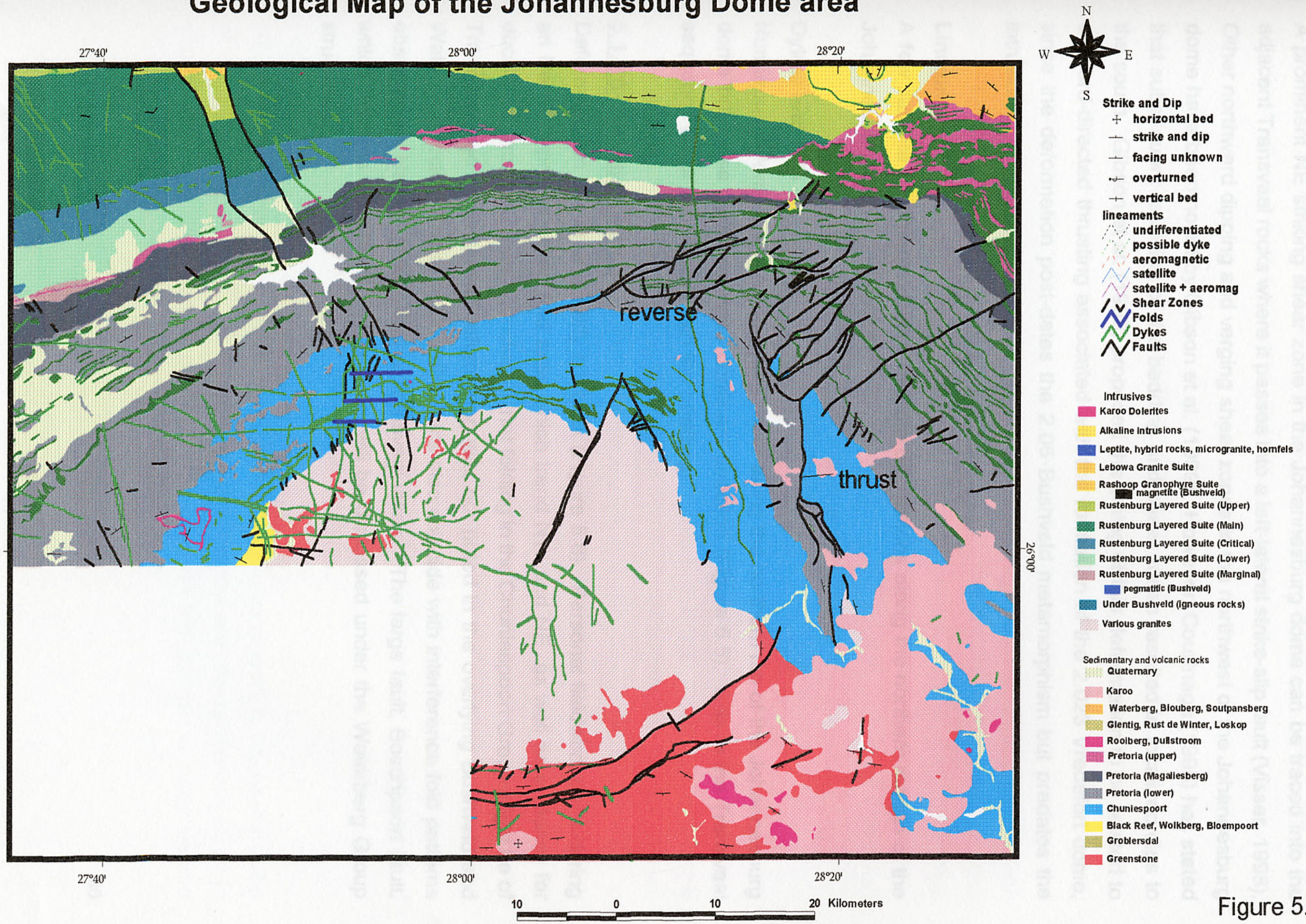


Figure 5.5

Shear zones

A prominent NE striking shear zone in the Johannesburg dome can be traced into the adjacent Transvaal rocks where it passes into a left-lateral strike-slip fault (Visser, 1998). Other northward dipping and verging shear zones to the northwest of the Johannesburg dome have been noted by Gibson et al. (1999). However, Courtnage (1995) has stated that subsequent refolding of the bedding and shear zones resulted in localized dips to the south. Gibson et al. (1999) proposed the timing of this deformation to be related to outward-directed thrusting associated with the formation of the 2.023 Vredefort dome, since the deformation post-dates the 2.06 Bushveld metamorphism but predates the intrusion of Pilanesberg dykes.

Lineaments

A few satellite lineaments display random orientations along the northern margin of the Johannesburg dome (Figure 5.5).

Dykes and sills

Numerous dolerite and syenite dykes occur along the northern rim of the Johannesburg dome but these dykes show no dominant direction (Figure 5.5). Sills in the Transvaal sequence occur concordant with the bedding.

<u>5.1.2.6 Warmbath's area</u>

Deformation in this area is fairly complex (Figure 5.8). Personal fieldwork done during an Honours project noted fold axes which trend NW and NE, as well as evidence for ductile deformation. It was concluded that folding in the Chuniespoort Group might be of Transvaal age since similar deformation was not noted in the overlying Bushveld and Waterberg rocks. These folding directions also coincide with interference fold patterns observed by Hartzer (1995) in the Transvaal inliers. The large fault, Boschpoort fault, which deforms Waterberg Group rocks will be discussed under the Waterberg Group structures.

5.1.2.7 Thabazimbi area

The Transvaal rocks in the Thabazimbi area are intensely deformed and forms part of the TML. However, since this deformation involves Waterberg Group rocks the structures will be describe under the Waterberg structures.

5.1.3 WESTERN BUSHVELD COMPLEX STRUCTURES

The western lobe of the Bushveld Complex consists of two compartments: a far western Nietverdiend compartment and the main western compartment. It is yet uncertain if these two compartments are connected at depth (Visser, 1998). The main western compartment generally dips at low angles towards the center of the Complex, and gravity surveys of the Nietverdiend compartment reveal shallow centripetal dips (Biesheuvel, 1970). The dominant structural direction of the western Bushveld Complex is defined by the NNW trending Brits and Welgevonden Graben as well as antiformal-synformal structures observed in the granites (Figure 5.6).

Faults

The Brits and Welgevonden graben has a NNW strike (Figure 5.6), and appears to be a southward extension of the Crocodile River fault. These faults exhibit normal displacement with fault planes dipping outward at steep angles (Visser, 1998). However, seismic reflection modeling by Du Plessis and Levitt (1987) led them to conclude that these faults might have been active during pre-Bushveld times, controlling the emplacement of the Rustenburg Layered Suite. Another conspicuous set of faults occur along the northwestern margin of the Lobe. These faults are known as the Roodedam Graben and they strike parallel to other extensional faults such as the Brits and Welgevonden graben. Other smaller faults occur throughout the Rustenburg Layered Suite and are almost orientated at right angles with respect to the bedding of the Complex.

Folds

Figure 5.6 shows large anitformal and synformal structures present in the western lobe of the Bushveld Complex. The trend of these structures are mainly NW but curve to approximately follow the shape of the contact between the granites and the layered

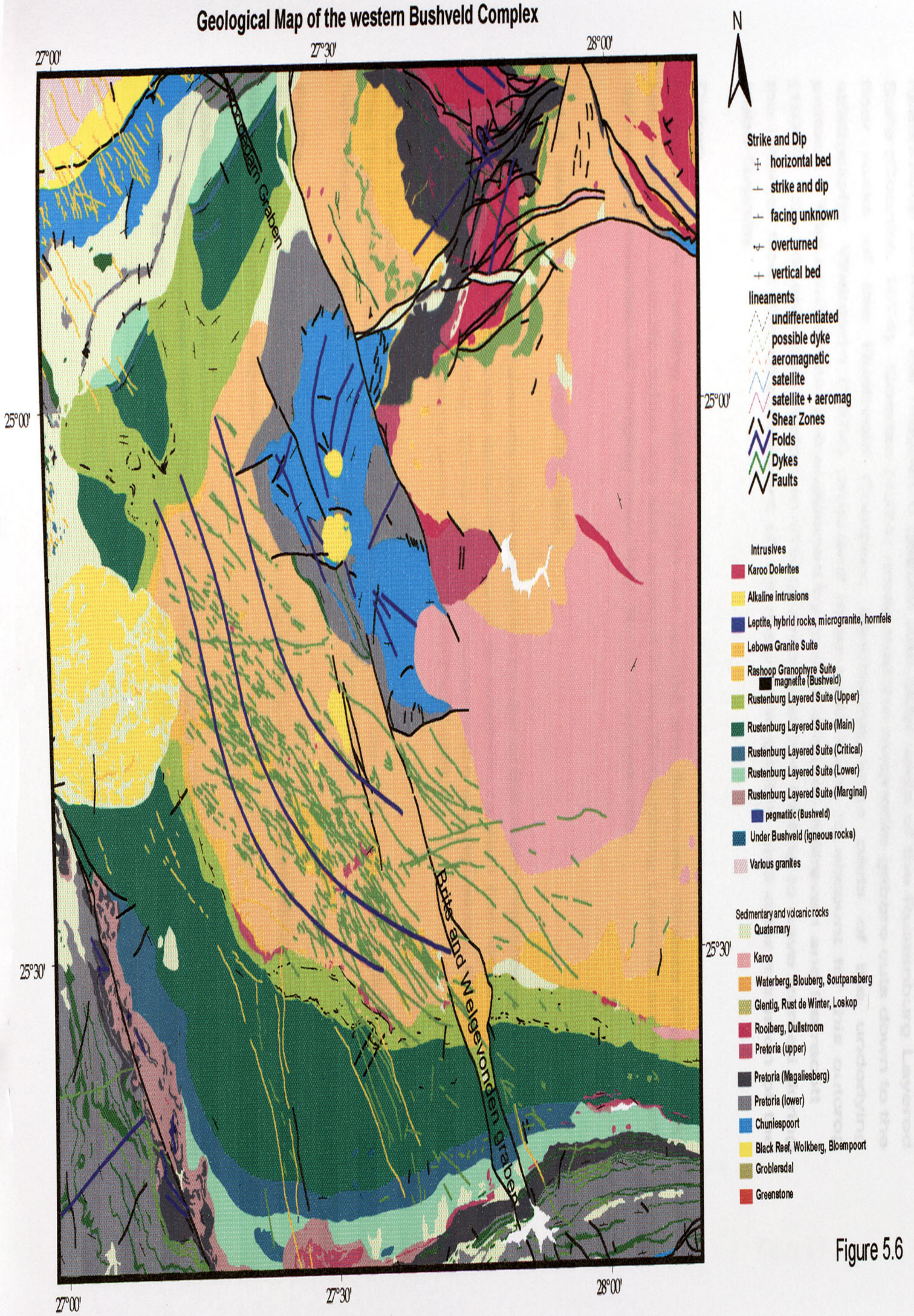

Geological Map of the western Bushveld Complex
27°00'
27°30'
28°00'
25°00'
25°30'
N
Pilanesberg Graben
Brits and Welgevonden graben
Strike and Dip
horizontal bed
strike and dip
facing unknown
overturned
vertical bed
lineaments
undifferentiated
possible dyke
aeromagnetic
satellite
satellite + aeromag
Shear Zones
Folds
Dykes
Faults
Intrusives
Karoo Dolerites
Alkaline intrusions
Leptite, hybrid rocks, microgranite, hornfels
Lebowa Granite Suite
Rashoop Granophyre Suite
magnetite (Bushveld)
Rustenburg Layered Suite (Upper)
Rustenburg Layered Suite (Main)
Rustenburg Layered Suite (Critical)
Rustenburg Layered Suite (Lower)
Rustenburg Layered Suite (Marginal)
pegmatitic (Bushveld)
Under Bushveld (igneous rocks)
Various granites
Sedimentary and volcanic rocks
Quaternary
Karoo
Waterberg, Blouberg, Soutpansberg
Glentig, Rust de Winter, Loskop
Rooiberg, Dullstroom
Pretoria (upper)
Pretoria (Magaliesberg)
Pretoria (lower)
Chuniespoort
Black Reef, Wolkberg, Bloempoort
Groblersdal
Greenstone

Figure 5.6

mafic suite. These folds were recognized on the basis of a discordant intrusive relationship between the magnetite gabbro and older units of the Rustenburg Layered Suite (Coertze, 1974). Coertze (1974) noted that the magnetite gabbro cuts down to the floor rocks of the Bushveld Complex, eliminating large parts of the underlying stratigraphy. Walraven (1974) proposed large open folds to account for this outcrop pattern. This model was also supported by gravity data of Walraven and Darracott (1976). Du Plessis and Walraven (1990) proposed this folding to have formed during the interval from the emplacement of the magnetite gabbro until after intrusion of the Nebo Granite.

Dykes

Numerous NW trending dolerite dykes cut across the Bushveld Granite (Figure 5.6). However, few syenitic dykes are also present in the Rustenburg Layered suite. These dykes have orientations ranging from NW, NNW to almost NS.

5.1.4 WATERBERG STRUCTURES

The Waterberg rocks generally dip towards the center of the main Waterberg basin. The basin has been extensively deformed along its southern margin but towards the north the deformation is minimal. Three structural domains are distinguished, the Thabazimbi area, Nylstroom-Warmbath's area, and the Northern area.

<u>5.1.4.1 Thabazimbi area</u>

The Thabazimbi area makes up an integral part of the TML and the rocks in this area have been subjected to intense deformation (Figure 5.7).

Faults

The dominant orientation of the faults in this area is approximately EW. The main faults will be discussed individually:

Bobbejaanwater fault

The Bobbejaanwater fault (Figure 5.7), also known as the Crocodile Bridge fault (Jansen, 1982) and the Middle Thrust Range (Strauss, 1954), exhibits a complex

Geological Map of the Thabazimbi area

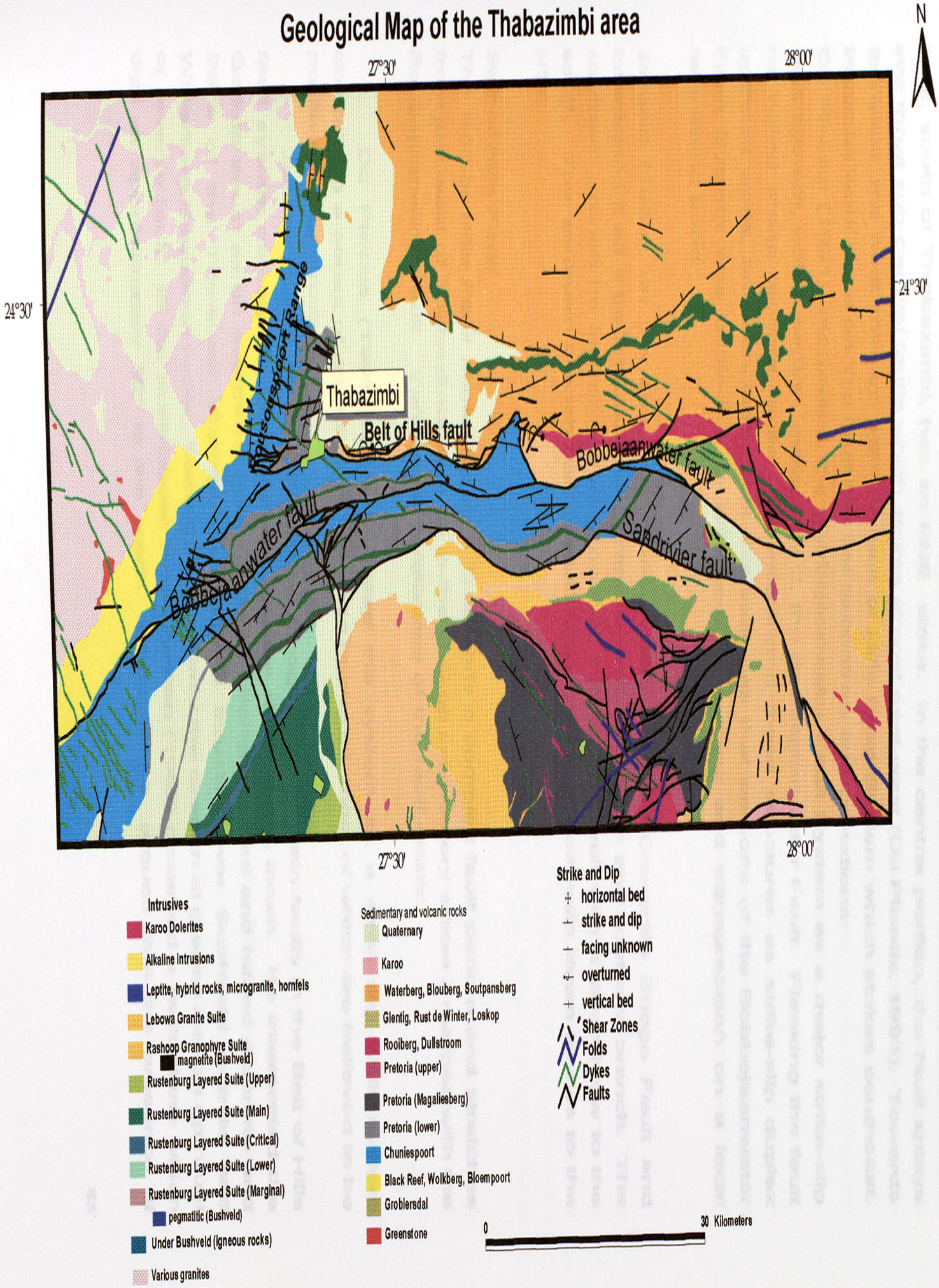


Figure 5.7

structural pattern. The fault has a approximate strike length of 120 km and can be traced from south-east of Thabazimbi until close to Loubad. The eastern portion of the fault, south of Thabazimbi, has an ENE strike. In the central portion, the fault splays into three sub-parallel faults which strikes almost east-west (Du Plessis, 1991). Towards the west, the fault links up with the Belt of Hills Fault System which strikes southeast. Previous work done on this fault has led to contrary interpretations:
Du Plessis (1991) interpreted the Bobbejaanwater Fault System as a major strike-slip fault system, with a central 'master' fault, the Bobbejaanwater Fault. Flanking the fault he noted steep reverse faults. He interpreted these structures as strike-slip duplex upthrust welts, and concluded that this indicates that portions of the Bobbejaanwater Fault System was subjected to left-lateral wrenching and transpression on a local restraining bend.

Jansen (1982), on the other hand named this fault the Crocodile Bridge Fault and interpreted it as a thrust fault which branches into a northern and southern branch. The southern branch he interpreted as a normal, sub-vertical fault with a downthrow to the south. The southern branch has two NE striking splays, both with down throws to the NW.

Belt of Hills Fault
The Belt of Hills Fault zone (Figure 5.7) exhibits a complex fault pattern and stretches from just west of Thabazimbi through to the Gatkop promontory where it merges with the Bobbejaanwater fault. Various interpretations of the fault exists:

Du Plessis (1991) has interpreted the system as a strike-slip fault system comprising a series of en echelon strike-slip duplexes, most of which are believed to be positive flower structures

Jansen (1982), on the other hand, recognized two main faults in the Belt of Hills fault system namely the Gatkop thrust and the Buffelshoek thrust. He interpreted the Gatkop thrust as an overthrust which involves strongly faulted and folded dolomite and BIF's of the Transvaal Supergroup which is thrusted over Bushveld granite and Waterberg Sequence rocks. Towards Thabazimbi the overthrust grades into an upthrust or reverse fault. In the Buffelshoek thrust Jansen (1982) observed a fault plane which dips at approximately 30° to the south. However, he argued that the presence of slickensides not parallel with this dip direction suggests that the fault might be a reactivated tear fault.

Strauss (1954) has interpreted the area as being intensely faulted, the main components being low-angle strike faults (Gatkop thrust and Middle Range thrust) caused by overthrusting from the south. He noted that the fault plane of the Gatkop thrust dips at progressively lower angles in an eastward direction, until the Gatkop promontory, where it is practically horizontal.

Rousouspoort Range

Field work done by Du Plessis (1991) has noted shears orientated in an arrangement similar to a left-lateral strike-slip regime. Therefore he concluded that the east west striking faults must all be left-lateral strike-slip faults.

Folding

Du Plessis (1991) described a large fold in Pretoria Group sedimentary rocks in the area between the Bobbejaanwater fault and the Belt of Hills fault. This fold is however not indicated in the BOSGIS data base. The northern limb of the fold dips to the south, the fold axis plunges towards the ESE. Du Plessis (1991) interpreted the fold as a possible drag fold in response to left-lateral strike-slip faulting along the Bobbejaanwater Fault System.

5.1.4.2 Nylstroom-Warmbath's area

In this area Waterberg, Bushveld and Transvaal rocks occur in a complex arrangement, and numerous faults and folds are responsible for the current structural pattern (Figure 5.8).

Faults

Boschpoort fault

The Boschpoort fault has a northwest strike and is responsible for the contact of overturned Waterberg sediments against Rooiberg Felsites. The fault dips southward at an estimated 65°, and is interpreted as a normal fault (Pringle, 1986). The faults has a speculative age of late-Waterberg.

Geological Map of Nylstroom-Warmbath's area

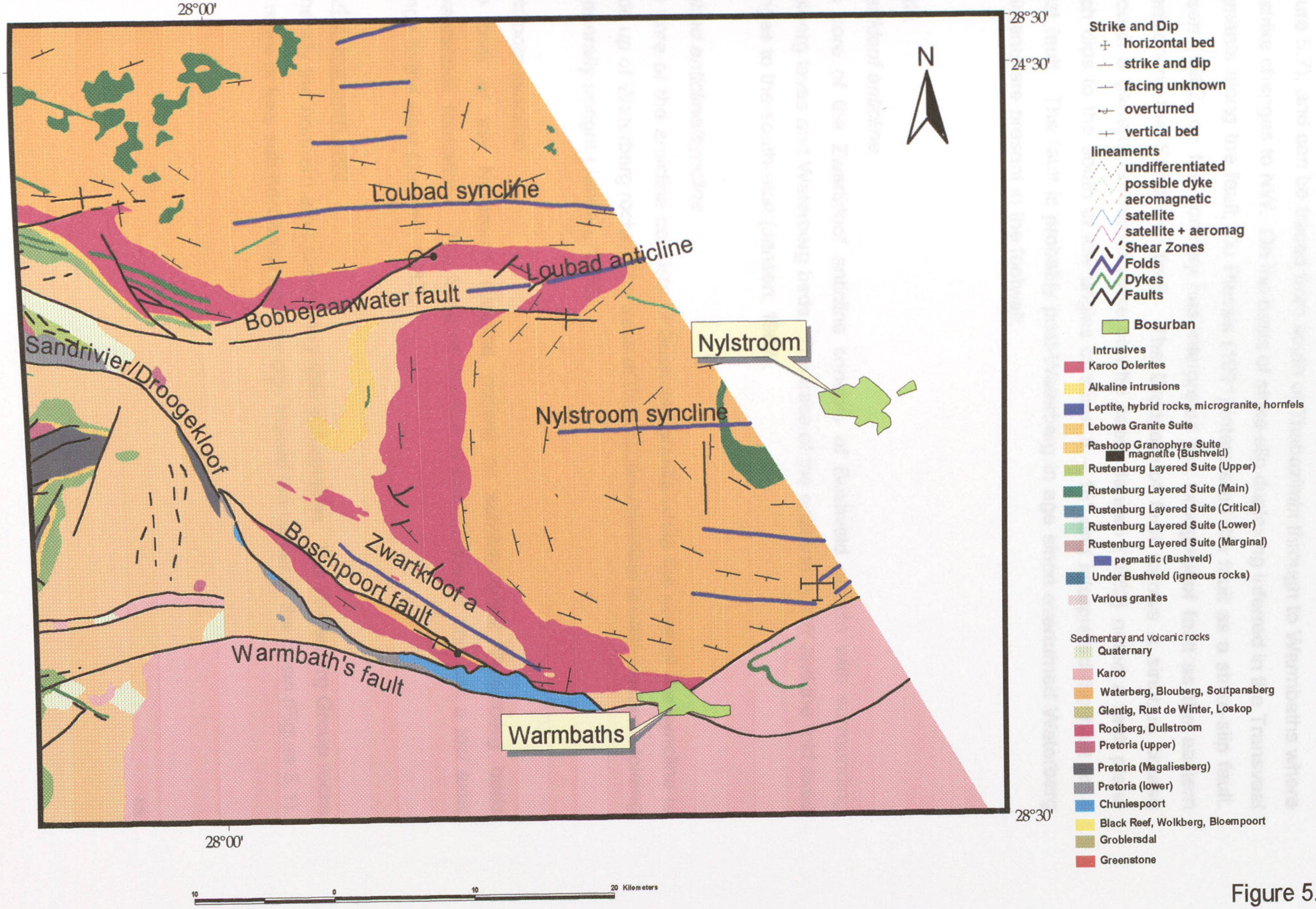


Figure 5.8

Sandrivier fault /Droogekloof thrust

The Sandrivier fault strikes parallel to the Bobbejaanwater and Belt of Hills fault systems (Figure 5.7), and can be traced from south of Thabazimbi through to Warmbaths where the strike changes to NW. On the basis of strike-slip duplexing inferred in the Transvaal fragments along the fault, Du Plessis (1991) interpreted the fault as a strike-slip fault. Jansen (1982) on the contrary has interpreted the Droogekloof fault as the eastern extension of the Sandrivier fault. The Droogekloof fault follows a sinuous course although a general northwest strike can be seen. Jansen (1982) noted a fault plane which dips to the south at low angles of about 5 – 15° and interpreted the fault as a thrust fault. The fault is probably post-Waterberg in age since overturned Waterberg sediments are present in the footwall.

Folds

Zwartkloof anticline

The core of the Zwartkloof anticline consists of Bushveld granite with surrounding Rooiberg lavas and Waterberg beds. The trace of the anticline is NW and the fold axes plunges to the south-east (Jansen, 1982).

Loubad anticline/syncline

The core of the anticline consists of Bushveld granite while the core of the syncline is made up of Waterberg rocks. The trace of the anticline/syncline is east-west and folding is generally upright (Jansen, 1982).

Nylstroom syncline

The core of the Nylstroom syncline consist of sub-horizontal Waterberg beds (Swaershoek formation). The trace of the fold is east-northeast and has a low axial plunge to the west (Jansen, 1982).

<u>5.1.4.3 Northern area</u>

Generally the northern area shows very little deformation. The Waterberg Group rocks are more or less sub-horizontal with low dips toward the center of the basin (Figure 5.1).

Faults

The only fault in this area is the large NW trending Vaalwater fault zone. This fault is probably a normal fault of post-Waterberg age (Jansen, 1982).

Lineaments

Numerous undifferentiated lineaments are present in this area. The lineaments have mainly NW and NNE orientations.

Sills

Extensive sills can be seen in this area which are probably related to tension during post-Waterberg times.

5.1.5 PILANESBERG STRUCTURES

The Pilanesberg Alkaline Complex intruded along the margin of the Rustenburg Layered Suite and the Granitic rocks of the Bushveld Complex (Figure 5.9). The intrusion caused local deformation of the complex in the form of radial normal faults which are prominent towards the west of the complex. The emplacement of the Pilanesberg Complex might have caused reactivation of earlier formed structures (Vermaak, 1976). These structures are represented by the two faulting directions, the ENE Vlakfontein trend, and the NW Gevonden trend (Vermaak, 1976). Van Zyl (pers. comm.) noted dome and basin structures in the Transvaal and lower Bushveld rocks on the western side of the Pilanesberg Complex. He propose this deformation to be post-Bushveld but pre-Pilanesberg in age as a response to the formation of a periclinal type basin. The complex fault pattern around the Complex is therefore due to this basining. The faults were then later reactivated during the intrusion of the Pilanesberg Complex.

Syenite dykes are a characteristic feature associated with the Pilanesberg Complex. NW trending syenite dykes cut across the Bushveld Complex.

Geological Map of Pilanesberg area

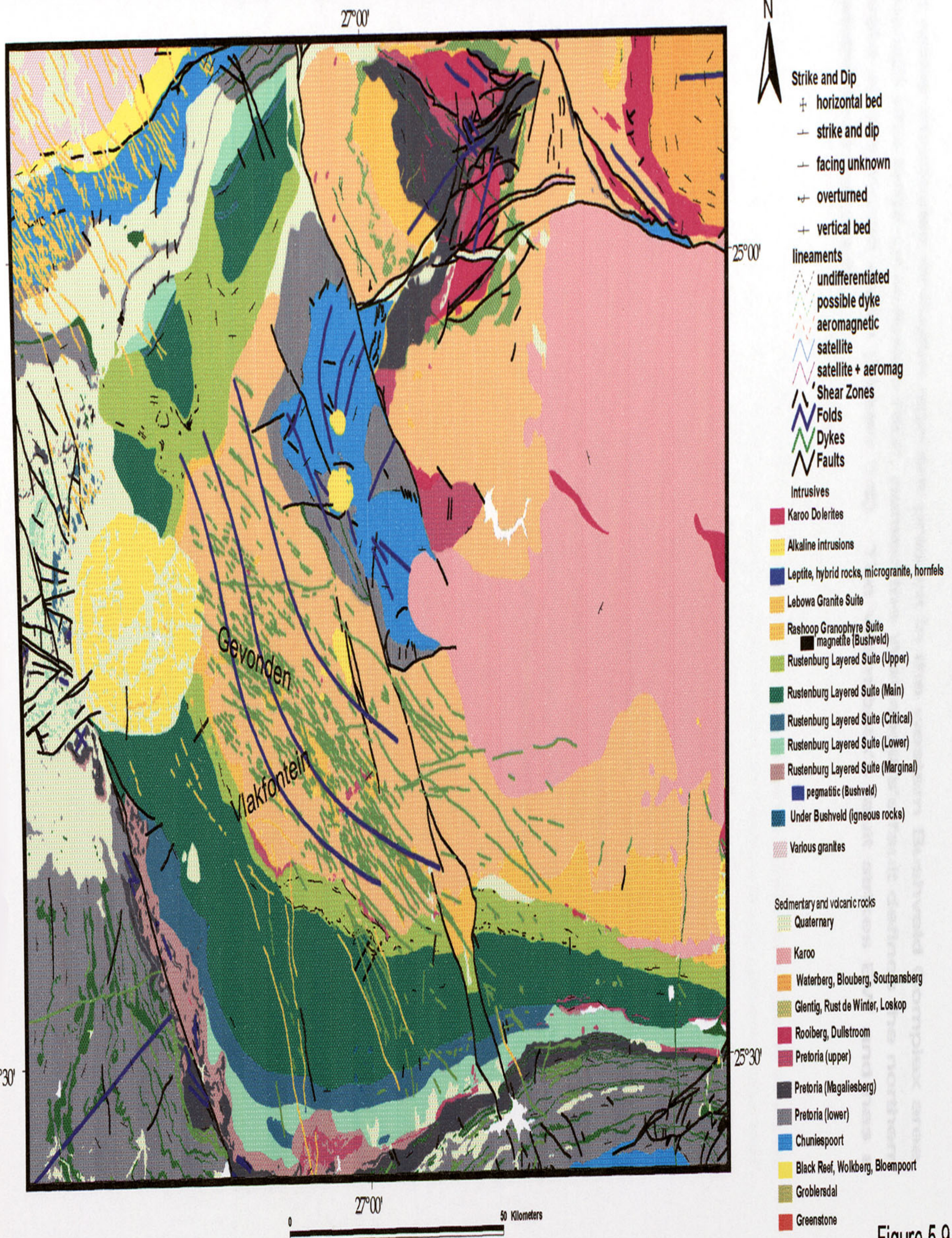


Figure 5.9

5.1.6 KAROO STRUCTURES

Not many structures of Karoo age are present in the western Bushveld Complex area. Although one large post-Karoo fault, named the Warmbaths's fault defines the northern margin of the Karoo basin (Figure 5.8). The Warmbath's fault strikes EW and has a downthrow to the south.

5.2 THE NORTHERN BUSHVELD COMPLEX

A geological map including all the various structures of the northern Bushveld Complex area is shown in Figure 5.10.

5.2.1 ARCHAEAN STRUCTURES

Archaean structures in this area include the Southern Marginal Zone and Central Zone of the Limpopo Belt. Even though just a small portion of the Pietersburg greenstone belt occurs in this area its structures will be discussed as part of the northern Bushveld Complex.

5.2.1.1 Limpopo Belt

Part of the Central and Southern Marginal Zone of the Limpopo Belt is contained within the Northern Bushveld Complex area (Figure 5.11). The Central Zone is characterized by granulite-grade gneiss of the Beitbridge Complex (S.A.C.S., 1980) as well as pelite, quartzite and carbonates (McCourt and Vearncombe, 1992). In contrast, the Southern Zone consists of granite and greenstone material metamorphosed at granulite facies (van Reenen et al., 1992).

Central Zone

Isotopic signatures, lithology and structural characteristics have shown that the Central Zone formed independent of the Limpopo Belt (McCourt and Vearncombe, 1992). The Zone was later thrusted into the heart of the orogen by SW directed thrusting as an allochthonous thrust sheet during peak collision of the two cratons (Van Reenen et al., 1988; McCourt and Vearncombe, 1987: 1992; McCourt and Wilson, 1992; Treloar et al., 1992). The Central Zone has been deformed by several deformational events. Many authors (Barton et al., 1979; Fripp et al., 1980; Fripp, 1981; Watkeys, 1984) have done extensive research on the Central Zone. Tankard et al. (1982) summarizes four main deformational periods, all older than 2.5 Ga:

- An early D_1 deformational event younger than 3.2 Ga (pre-Messina Intrusive) which was responsible for isoclinal recumbent folding and flat-lying ductile shearing.

Geological map of the northern Bushveld Complex

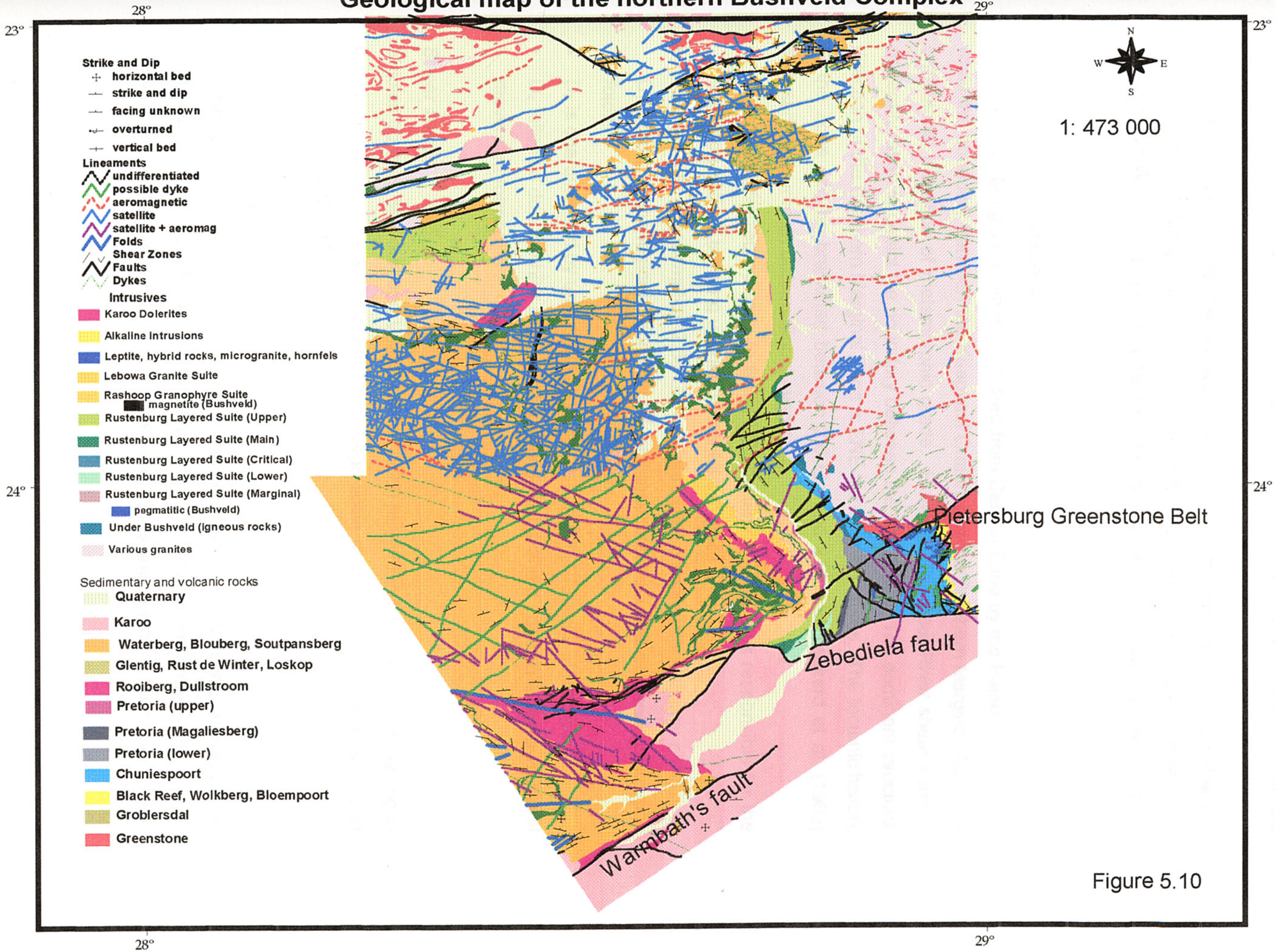


Figure 5.10

- A D_2 period of intense crustal shortening just after 2.7 Ga. This event is characterized by tight, isoclinal upright folds with NE axial trends and intense ductile shearing.
- A final D_3 and D_4 event which was responsible for the present outcrop pattern of interference folding between D_3 and D_4 folds. NE trending F_3 folds were refolded around NW trending F_4 axial surfaces. This resulted in a periclinal interference set of folds.

The Southern Marginal Zone

The Southern Marginal Zone is separated from Central Zone by the Palala shear zone, while the boundary between the Kaapvaal Craton and the Southern Marginal Zone is a gradational transition of metamorphic grade. However, the Hout River shear zone is generally taken to depict the boundary between the two zones. The dominant structural direction of the Southern Marginal Zone is ENE-trending structures. The tectonic history of the Zone can be bracketed between 2.6 Ga and 2.5, and Tankard et al. (1982) summarizes four main deformational events:

- D_1 is characterized by early regional NS shortening. This was responsible for the formation of ENE trending upright horizontal synclines
- During D_2 at approximately 2.58 Ga continuing NS compression (slightly oblique to D_1) produced the regional fabric of upright transecting cleavage and steeply plunging folds.
- D_3 is characterized by upright folding and periclinal interference structures.
- D_4 followed during which large south dipping ductile shear zones marked by sinistral movement formed.

Shear zones

Studies done by McCourt and Vearncombe (1992) have found that crustal shortening in the Limpopo Belt was accommodated by large-scale ductile shear zones which trend approximately ENE-WSW.

Palala Shear Zone

The Palala shear zone represents one of these zones of crustal compression and is proposed to be a crustal scale lateral ramp (McCourt and Vearncombe, 1992). The shear zone is approximately 10-km wide and forms the northern boundary of the

Geological map of the southern portion of the Limpopo Belt

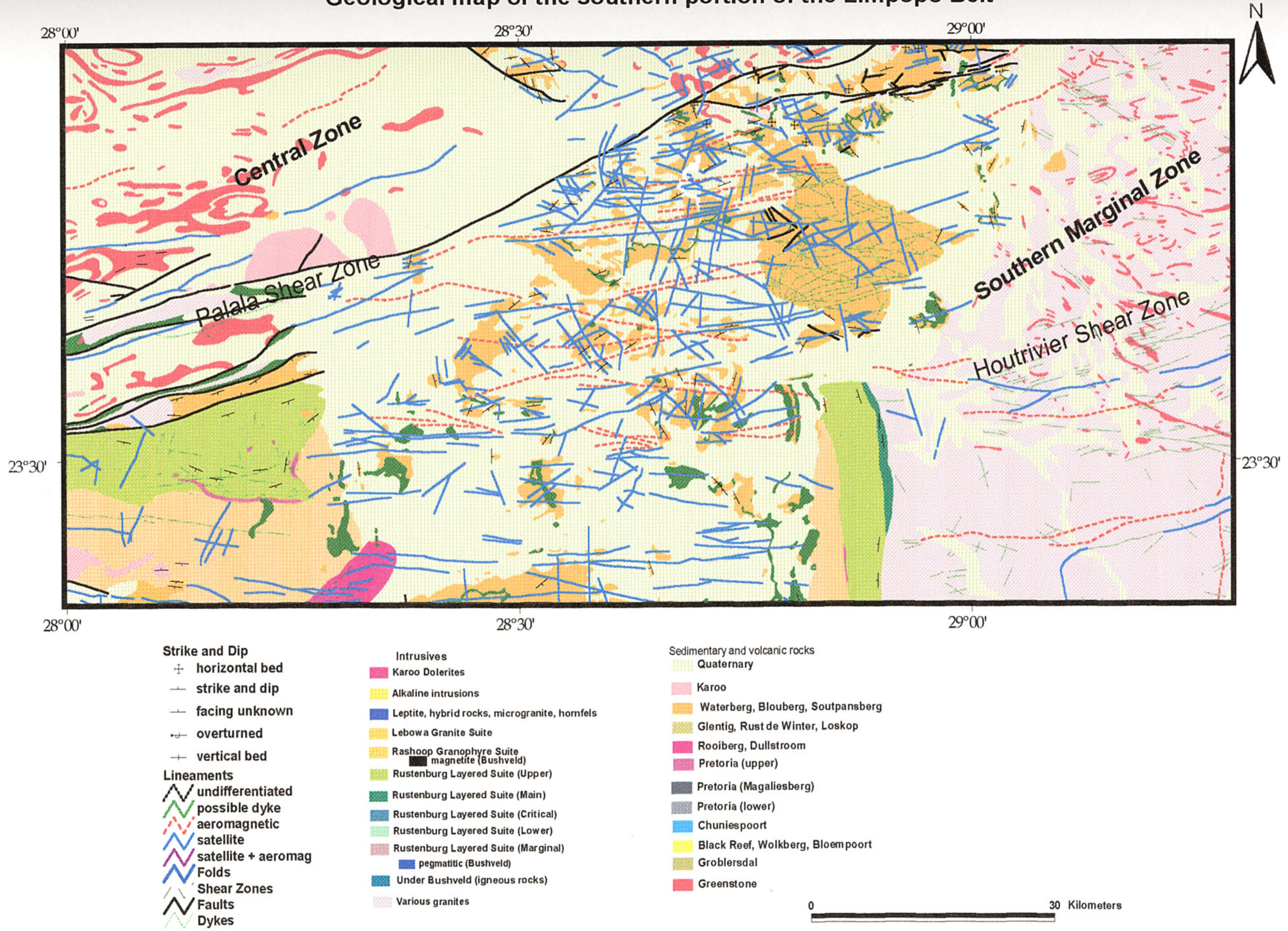


Figure 5.11

Southern Marginal Zone. N-ward dipping mylonitized rocks of Archaean gneiss, Transvaal, and Bushveld Complex rocks depict this zone of intense deformation. The Palala shear zone is believed to have been constantly reactivated, the oldest deformation marking the collision of the Central Zone of the Limpopo belt and the Southern Marginal Zone. This ductile deformation event was responsible for strong left-lateral shearing which pre-dates the intrusion of the Bushveld Complex. In addition, tight, south verging, ENE trending faults are present in this zone. McCourt and Vearncombe (1992) also recorded changes in mineral elongation lineation along the southern margin of the zone which implies an overall thrust geometry. The age of the last ductile deformational event in this zone is believed to have ceased at 2042 Ma (Brandl and Reimold, 1990). Later deformation along the shear zone is observed along the Melinda and Abbotspoort faults. These faults, however will be discussed under Karoo structures.

Hout River shear zone

The Hout River shear zone is generally taken to form the boundary of the Southern Marginal Zone and the Kaapvaal Craton, marking the transition of granulite facies rocks to low-grade granite greenstone rocks (Smit et al., 1992). The shear zone system dips steeply to the north, and C-S kinematic indicators imply SW-directed thrusting at around 2.67 Ga (McCourt and Vearncombe, 1992). McCourt and Vearncombe (1992) further described the shear zone as an anastomising network which defines a series of 10 km scale structural domains characterized by steeply NE-plunging folds, probably sheath-folds. Estimates of the displacement along the shear zone is unknown but McCourt and Vearncombe (1992) suggested a vertical displacement in the order of at least 10 - 15km.

Dykes

Numerous small dykes occur in the granite-gneiss terrain. Although various orientations of dykes are present, a vague NE trend can be seen (Figure 5.11).

Lineaments

Various large aeromagnetic and satellite lineaments transect the granite-gneiss terrain in the northern Bushveld Complex area. These lineaments have various orientations although a ENE trend, resembling the Limpopo Belt trend, can be distinguished. It is interesting to note that these satellite and aeromagnetic lineaments occur at the boundary between the Southern Marginal Zone and the Kaapvaal Craton (Figure 5.11).

5.2.1.2 Pietersburg Greenstone belt

The Pietersburg Greenstone belt has an approximate NE trend and is dominated by northwest verging thrust tectonics (de Wit, 1991) (Figure 5.11). De Wit (1991) ascribes a maximum age of 2.88 Ga to the deformation and relates it to terrane accretion along the northern margin of the Mid-Archaean core of the Kaapvaal Craton. Grobler (1972) recognized three periods of deformation. The first deformation precedes the deposition of the Uitkyk Formation (upper sequence of the Pietersburg Greenstone Belt). The second period is characterized by isoclinal overfolding to the NW during which pronounced slaty cleavage and schistosity developed. The last deformational event was the crenulation of existing foliation. However, Visser (1998) mentions only two main deformational events. A D_1 event during which open EW trending anticlines and synclines formed, and a later D_2 event during which these folds were tightened.

5.2.2 TRANSVAAL STRUCTURES

The Transvaal rocks in the northern Bushveld Complex area strike NS to NW and dip west to southwest, and have been deformed along the TML (Figure 5.13).

Faults

NE, NW and NS orientated faults are prominent in Transvaal rocks and these faults were active at various times (Potgieter, 1992).

NE trending faults – Ysterberg fault

The Ysterberg fault trends NE and cuts obliquely through Bushveld rocks, Transvaal strata, the Pietersburg Greenstone belt and Archaean gneiss (Figure 5.13). The fault displays about an 8 km left-lateral displacement. The earliest movement along this fault is believed to be pre-Transvaal, possibly lateral movement (De Wit and Roering, 1990). Grobler (1972) proposed the fault to be a wrench fault which was genetically associated with the Pietersburg greenstone belt, but reactivated during Bushveld times, or an oblique-slip fault associated with the formation of the Bushveld Complex.

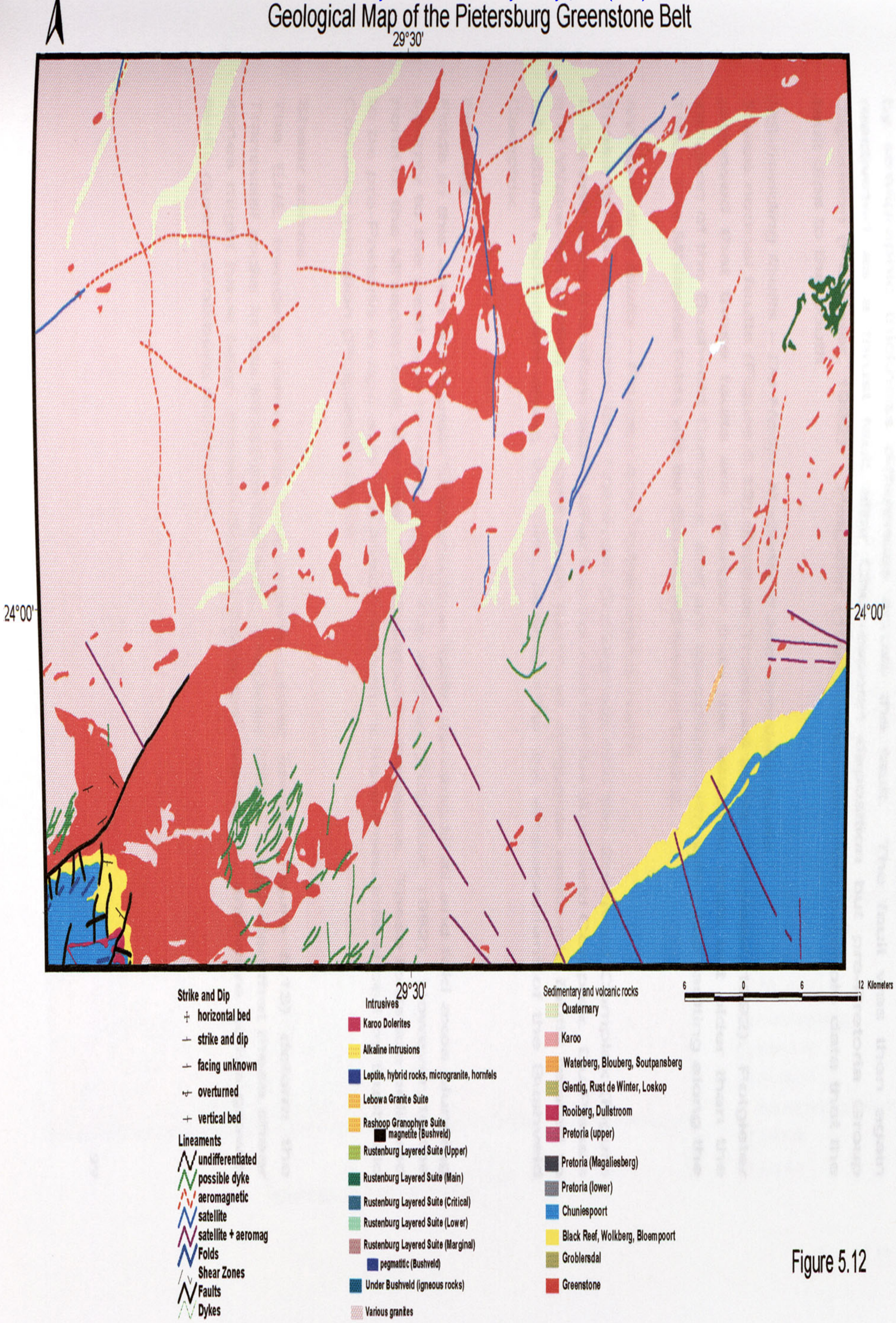

N
Geological Map of the Pietersburg Greenstone Belt
29°30'
24°00'
24°00'
29°30'
6
0
6
12 Kilometers
Strike and Dip
horizontal bed
strike and dip
facing unknown
overturned
vertical bed
Lineaments
undifferentiated
possible dyke
aeromagnetic
satellite
satellite + aeromag
Folds
Shear Zones
Faults
Dykes
Intrusives
Karoo Dolerites
Alkaline intrusions
Leptite, hybrid rocks, microgranite, hornfels
Lebowa Granite Suite
Rashoop Granophyre Suite
magnetite (Bushveld)
Rustenburg Layered Suite (Upper)
Rustenburg Layered Suite (Main)
Rustenburg Layered Suite (Critical)
Rustenburg Layered Suite (Lower)
Rustenburg Layered Suite (Marginal)
pegmatitic (Bushveld)
Under Bushveld (igneous rocks)
Various granites
Sedimentary and volcanic rocks
Quaternary
Karoo
Waterberg, Blouberg, Soutpansberg
Glentig, Rust de Winter, Loskop
Rooiberg, Dullstroom
Pretoria (upper)
Pretoria (Magaliesberg)
Pretoria (lower)
Chuniespoort
Black Reef, Wolkberg, Bloempoort
Groblersdal
Greenstone

Figure 5.12

Potgieter (1992) noted post-Wolkberg Group reactivation as a growth fault, as indicated by stratigraphic thickness differences across the fault. The fault was then again reactivated as a thrust fault after Chuniespoort deposition but pre-Pretoria Group deposition (Potgieter, 1992). Potgieter (1992) concluded from borehole data that the fault dips to the south.

NS-trending faults – De Hoop, Nederland and Grootvlei faults

These normal faults (Figure 5.13) displace Transvaal strata (Potgieter, 1992). Potgieter proposed that these faults are younger than the Mhlapitsi folds but older than the intrusion of the Bushveld Complex, and are associated with strike-slip faulting along the TML. The Mhlapitsi folds will be discussed later in 5.3.2.2.

NW-trending faults – Pruizen and Potgietersrus faults

These faults cut across the Transvaal Supergroup and the Bushveld Complex (Figure 5.13) and were therefore active after the intrusion of the Bushveld Complex. Du Plessis and Walraven (1990) interpreted these faults as conjugate strike-slip faults related to left-lateral movement along the TML, directly after the emplacement of the Bushveld Complex.

Folding

Folds in this area are typical Mhlapitsi-type folds, trending ENE and fold axes plunging steeply to the west and in some places sub-vertical (Potgieter, 1992). However, to the north of the Mhlapitsi belt, the folds have random orientations. These folds are believed to be pre-Pretoria in age and fold axes orientations have been influenced by Bushveld Complex intrusion (Potgieter, 1992).

Shear zones

The ENE trending Eersteling and Spanje shear zones (Figure 5.13) deform the Transvaal rocks in the Mhlapitsi fold belt. Potgieter (1992) suggested that these shear zones might have been present before Transvaal deposition, and were active growth faults during Wolkberg deposition.

Geological Map of Transvaal rocks in the northern Bushveld Complex area

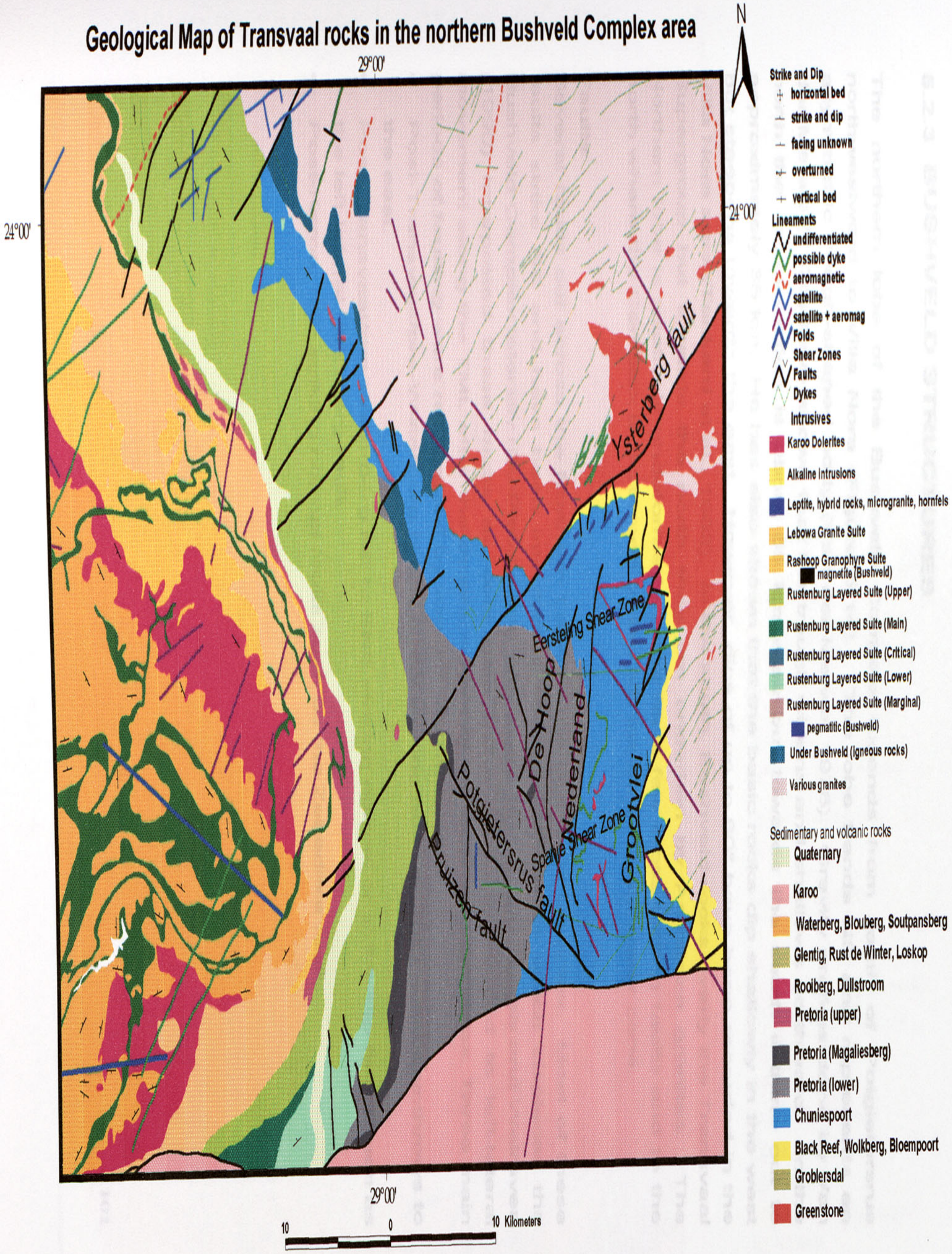


Figure 5.13

5.2.3 BUSHVELD STRUCTURES

The northern lobe of the Bushveld Complex extends from south of Potgietersrus northwestward to Villa Nora (Figure 5.14). The lobe trends NS and represents an asymmetric trough-shaped body (Van der Merwe, 1976). Gravity profiles done by Van der Merwe (1976) have shown that the trough widens and shallows northward. In the north the cross-section is about 85 km wide but towards the south it thins out to approximately 35 km. He has also shown that the basic rocks dip shallowly in the west but steepens towards the east. However, dips of up to 60° have been recorded in the Villa Nora area (Tankard et al., 1982). In the south, Bushveld rocks overly the Transvaal Supergroup but towards the north they are underlain by Archaean granites. The Northern lobe is relatively undeformed except for a few cross-cutting faults and to the north where the Complex is deformed by the NE trending Palala shear zone.

Faults

Several faults cut across the Northern Lobe of the Bushveld Complex. Most of these faults strike NE and have been interpreted as strike-slip faults which displaces the Bushveld Complex laterally (Du Plessis and Walraven, 1990). Du Plessis and Walraven (1990) interpreted these faults as conjugate strike-slip faults related to left-lateral movement along the TML after the emplacement of the Bushveld Complex. Three main periods of faulting were recognized by van der Merwe (1976).

- Post-Transvaal/pre-Waterberg N and NNW striking normal faults with downthrows to the east.
- Post-Transvaal/pre-Waterberg NE to ENE striking normal or strike-slip faults such as the left-lateral Ysterberg fault.
- Post-Karoo, NW striking normal faults such as the Zebediela fault.

Geological map of the northern lobe of the Bushveld Complex

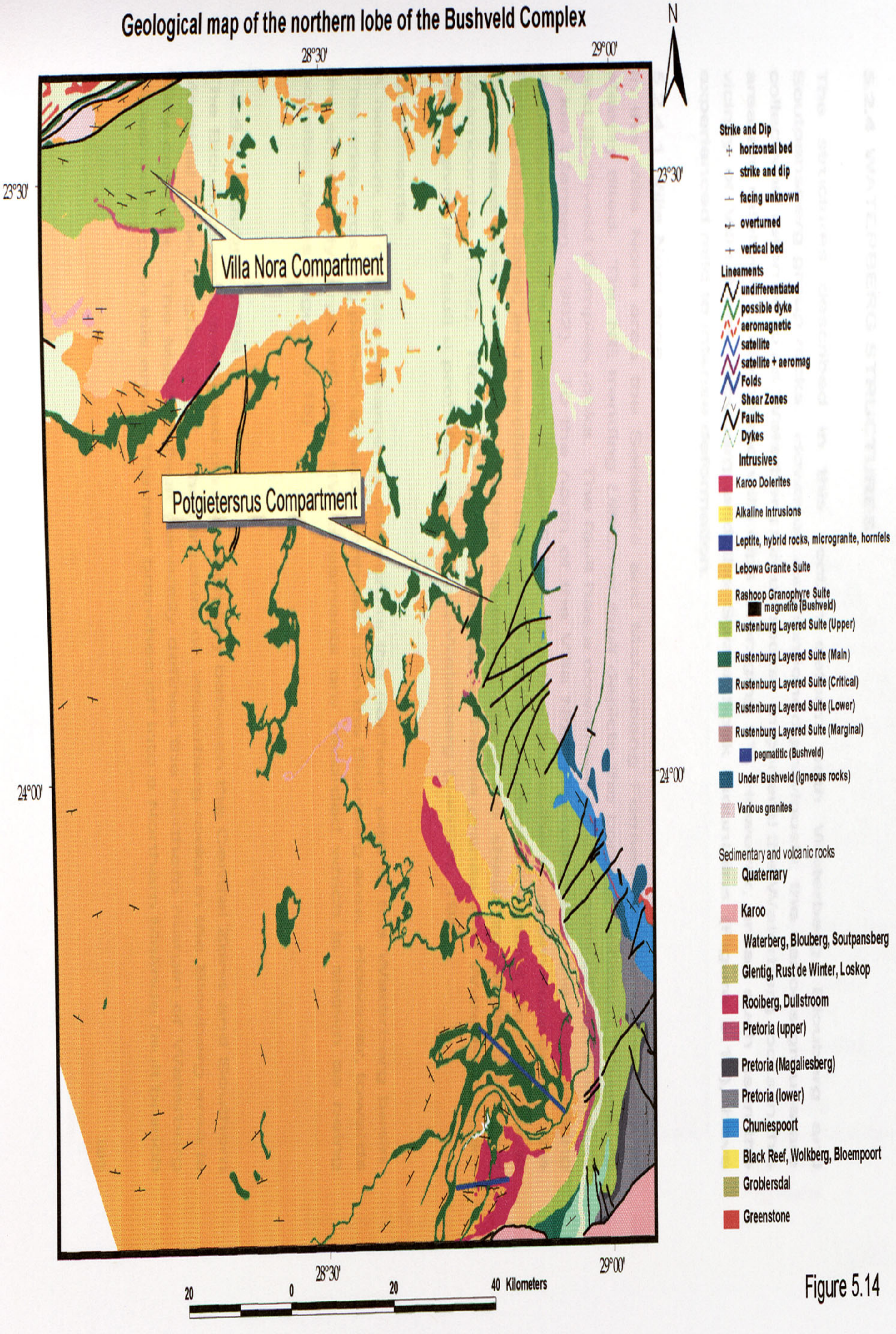


Figure 5.14

5.2.4 WATERBERG STRUCTURES

The structures described in this section deform both Waterberg, Blouberg and Soutpansberg group rocks. However, as mentioned previously, the various groups are collectively referred to as Waterberg Group rocks. In general the Waterberg rocks in this area are relatively undeformed with dips averaging 5°. However, areas such as in the vicinity of Villa Nora, Blouberg and the Swaershoek mountains (Figure 5.15), have experienced mild to intense deformation.

5.2.4.1 Villa Nora area

In the Villa Nora area the Setalaole and Makgabeng Formations are moderately to steeply tilted. The NE trending *Uitkomst fault* depicts the contact between Waterberg and Bushveld Complex rocks. The fault has a downthrow to the south of approximately 1 km (Jansen, 1982). To the north of the Villa Nora Compartment, the ENE striking *Abbotspoort fault* is present, (Figure 5.15). This fault forms the southern boundary of the Palala shear zone, and therefore it is possible that the earliest movement along this fault could have been related to sinistral movement along the shear zone (McCourt and Vearncombe, 1992). However, the fault displaces Palala granite and Waterberg rocks which gives the fault a probable age of post-Waterberg (Jansen, 1982).

Lineaments

A network of satellite lineaments criss-cross the northern part of the Waterberg basin. This criss-crossing pattern extends northward into the Blouberg area. However, towards the south only large NE and NW lineaments are recorded which is shown as being possible dykes (Figure 5.15).

5.2.4.2 Blouberg area

The Blouberg area is situated on the boundary between the Central Zone and Southern Marginal Zone, (Figure 5.15). The structure of Waterberg rocks in the Blouberg area is fairly complex. The Melinda fault generally defines the northern margin of Waterberg Group outcrops in this area. The fault branches off into a Northern Melinda fault branch

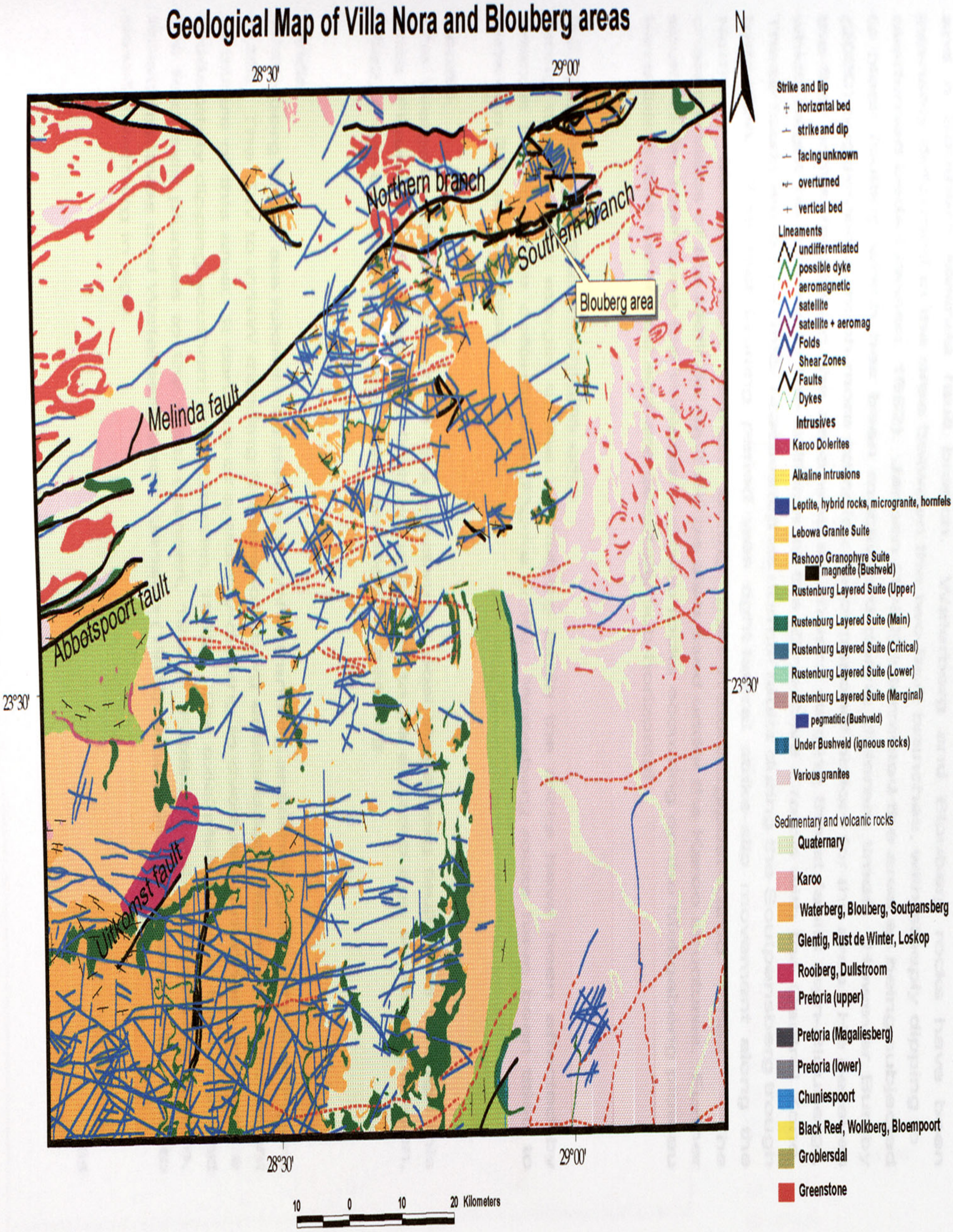

Geological Map of Villa Nora and Blouberg areas
28°30'
29°00'
N
23°30'
Northern branch
Southern branch
Blouberg area
Melinda fault
Abbetspoort fault
Uitkomst fault
10 0 10 20 Kilometers
Strike and dip
horizontal bed
strike and dip
facing unknown
overturned
vertical bed
Lineaments
undifferentiated
possible dyke
aeromagnetic
satellite
satellite + aeromag
Folds
Shear Zones
Faults
Dykes
Intrusives
Karoo Dolerites
Alkaline intrusions
Leptite, hybrid rocks, microgranite, hornfels
Lebowa Granite Suite
Rashoop Granophyre Suite
magnetite (Bushveld)
Rustenburg Layered Suite (Upper)
Rustenburg Layered Suite (Main)
Rustenburg Layered Suite (Critical)
Rustenburg Layered Suite (Lower)
Rustenburg Layered Suite (Marginal)
pegmatitic (Bushveld)
Under Bushveld (igneous rocks)
Various granites
Sedimentary and volcanic rocks
Quaternary
Karoo
Waterberg, Blouberg, Soutpansberg
Glentig, Rust de Winter, Loskop
Rooiberg, Dullstroom
Pretoria (upper)
Pretoria (Magaliesberg)
Pretoria (lower)
Chuniespoort
Black Reef, Wolkberg, Bloempoort
Groblersdal
Greenstone

Figure 5.15

and a Southern Melinda fault branch. Waterberg and Blouberg rocks have been intensely deformed in the area between the two fault branches, with steeply dipping to overturned beds (Jansen, 1982). Jansen (1982) interpreted the area as being subjected to block faulting which has been reactivated during different times. However Bumby (2000) suggested a much more complex deformational history for the area. He believes the first active faulting in the area was southward verging thrust faults (syn-Blouberg), which might be related to the collision of the Zimbabwe Craton with the Central Zone. These faults were then later reactivated as normal faults during the Soutpansberg trough formation. The last faulting period was right-lateral strike-slip movement along the Northern Melinda fault branch during post-Waterberg/post-Karoo times. The characteristics of the Melinda fault will be discussed under the Karoo structures. Further south of the fault zone the Waterberg Group rocks occurring on the Makgabeng plateau have been little deformed and are generally sub-horizontal.

5.2.4.3 Swaershoek mountains area

Along the eastern margin of the Waterberg basin the rocks have been affected by intense to moderate deformation (Figure 5.16). Waterberg rocks have been titled to between 30° and vertical.

Faults

The Welgevonden fault, which is a reactivated post-Waterberg fault, cuts through this area (Figure 5.16). Since the fault is suggested to be a Karoo age structure (Jansen, 1982) it will be discussed under the appropriate heading.

Folds

Waterberg strata are folded into NW and WNW trending anticlinal-synclinal pairs (Figure 5.16). The EW to WNW trending Swaershoekberg anticlinorium makes up a prominent structure of this area. It consists of a steeply-dipping to overturned northern limb and a moderately dipping southern limb (Jansen, 1982). The axial plane dips to the south and the fold axis plunges to the west (Jansen, 1982). Folding involves Bushveld granite, Rooiberg lavas and Waterberg beds. Jansen (1982) suggested the folding to be early to post-Waterberg in age.

Geological map of the Swaershoek area

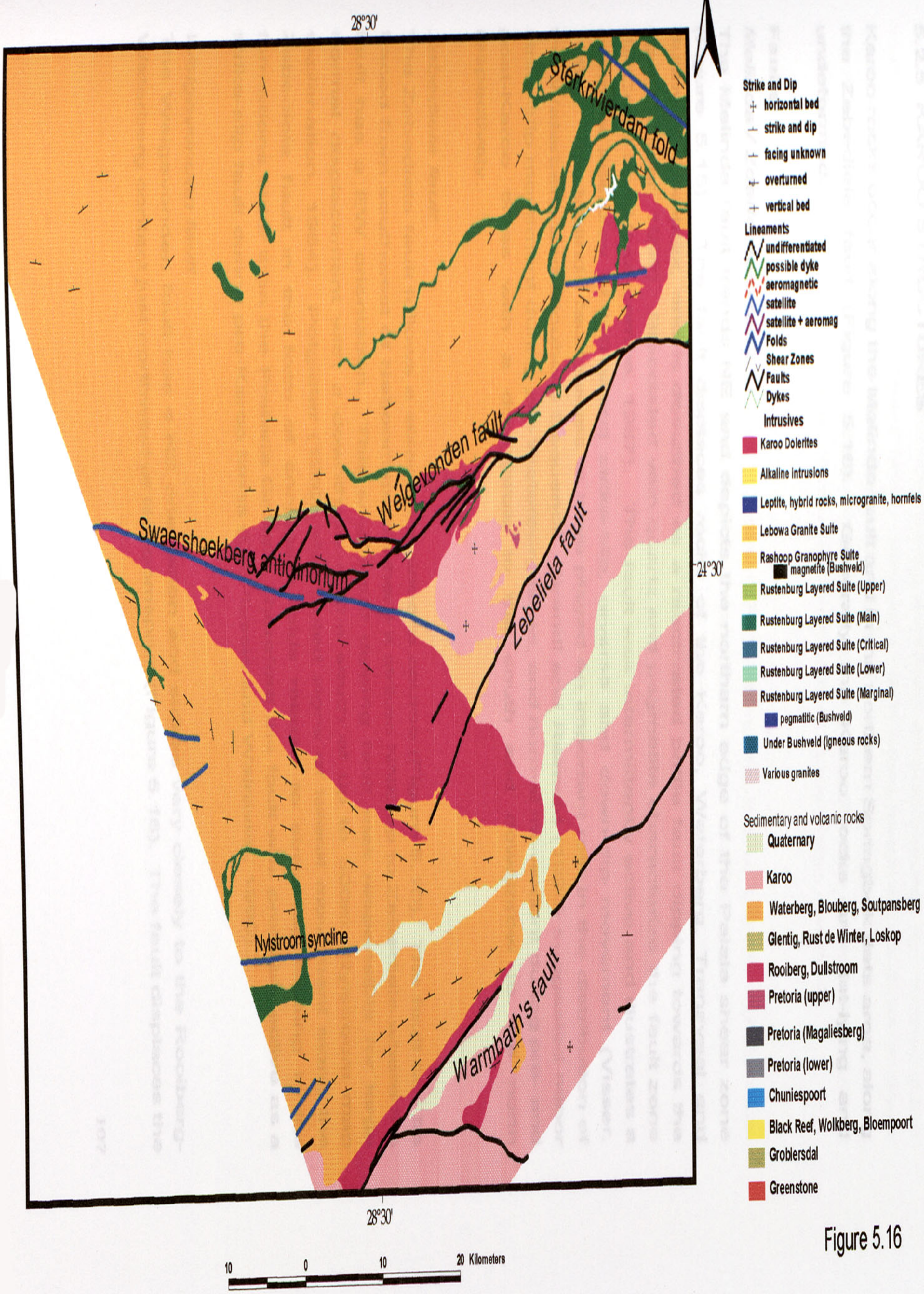


Figure 5.16

5.2.5 KAROO STRUCTURES

Karoo rocks occur along the Melinda fault and in the northern Springbok flats area, along the Zebediela fault (Figure 5.16). Generally the Karoo rocks are flat-lying and undeformed.

Faults

Melinda / Zoetfontein fault

The Melinda fault trends NE and depicts the northern edge of the Palala shear zone (Figure 5.15). The fault displaces rocks of the Karoo, Waterberg, Transvaal and Bushveld Complex, and is described as a reactivated brittle fault dipping towards the north (Visser, 1998). Brecciated vein quartz and pegmatite characterize the fault zone (McCourt and Vearncombe, 1987). The fault was intermittently active and illustrates a complex interplay of left-lateral strike-slip, reverse and down-dip movement (Visser, 1998). The Melinda fault seems to have played an important role in the distribution of the Waterberg and Blouberg Sequence. Brandl and Reimold (1990) suggested minor strike-slip movement during pre-Waterberg times, and normal movement during pre- and post-Karoo times with a downthrow to the south and downthrow to the north respectively.

Zebediela fault

The Zebediela fault follows a somewhat sinuous course (Figure 5.10). The fault can be traced from southwest of Naboomspruit where it strikes NNE up to Zebediela where the fault has a EW orientation. This southward dipping fault was responsible for large normal displacement with a downthrow to the south of up to 300m (Nylstroom map explanation, 1984). Potgieter (1992) also noted signs of lateral movement along the Zebediela fault in the form of conjugate folds related to strike-slip faulting in the formations older than the Pretoria Group. Therefore the fault was probably active as a strike-slip fault during pre-Karoo times (Du Plessis and Walraven, 1990).

Welgevonden fault

The Welgevonden fault has a NE orientation and strikes very closely to the Rooiberg-Waterberg contact just northwest of Naboomspruit (Figure 5.16). The fault displaces the

Bushveld Complex, Waterberg Sequence and Karoo rocks. To the west the fault extends into the core of the Swaershoekberg anticlinorium and towards the northeast the fault merges with the Zebediela fault. Jansen (1982) interpreted the fault as a steep reverse fault which dips north. However, towards the north he noted a breccia zone dipping at 80° S. He explains this abnormal behaviour of the fault as being a reactivated post-Waterberg thrust fault, with movement on the fault plane being reversed.

Warmbaths fault

The Warmbaths fault is a large generally EW striking fault and can be traced from Warmbaths, through the Springbok flats, up to the Stavoren fragment. The fault probably has a downthrow to the south and is responsible for the contact of Transvaal rocks with Karoo rocks (Figure 5.10).

5.3 THE EASTERN BUSHVELD COMPLEX

A geological map including all the various structures of the eastern Bushveld Complex area is shown in (Figure 5.17).

5.3.1 ARCHAEAN STRUCTURES

Archaean structures are generally confined to the Barberton, Murchison and Pietersburg Greenstone belts. However, the structure of the Pietersburg belt has already been discussed as part of the northern Bushveld Complex area.

5.3.1.1 Murchison Greenstone belt

The Murchison Greenstone belt trends east-northeast and makes up the eastern most component of the TML (Figure 5.18). Visser (1998) summarizes three deformational events in the belt:

- D1 is characterized by upright, tight to isoclinal folds with steep ENE-plunging axes.
- During a later D2 event these folds were refolded about E-trending axes.
- Finally during D3 local kink bands and crenulation cleavages developed.

Shear zones

The *Letaba shear zone* strikes NE and separates the northern and southern part of the belt. The shear zone has been interpreted by Fripp et al. (1980) to exhibit dextral movement, but Vearncombe (1988, 1991) suggests sinistral movement. Late vertical movement along the shear zone has also been mentioned by Visser (1990).

The *Constantia shear zone*, just to the north, trends parallel to the Letaba shear zone and exhibits dextral sense of movement (Brandl, 1987).

The economically important *Antimony line* is also considered to be a ductile shear zone with a north-over-south sense of movement related to D1 (Visser, 1990). Vearncombe (1988) noted nappe-like structures in the hangingwall, and attributed it to SW-directed oblique (reverse-sinistral) shear movement.

5.3.1.2 The Barberton Greenstone belt

Only a portion of the Barberton Greenstone belt is exposed in the eastern Bushveld Complex area. However the Barberton belt forms an integral part of the tectonic

Geological map of the eastern Bushveld Complex area

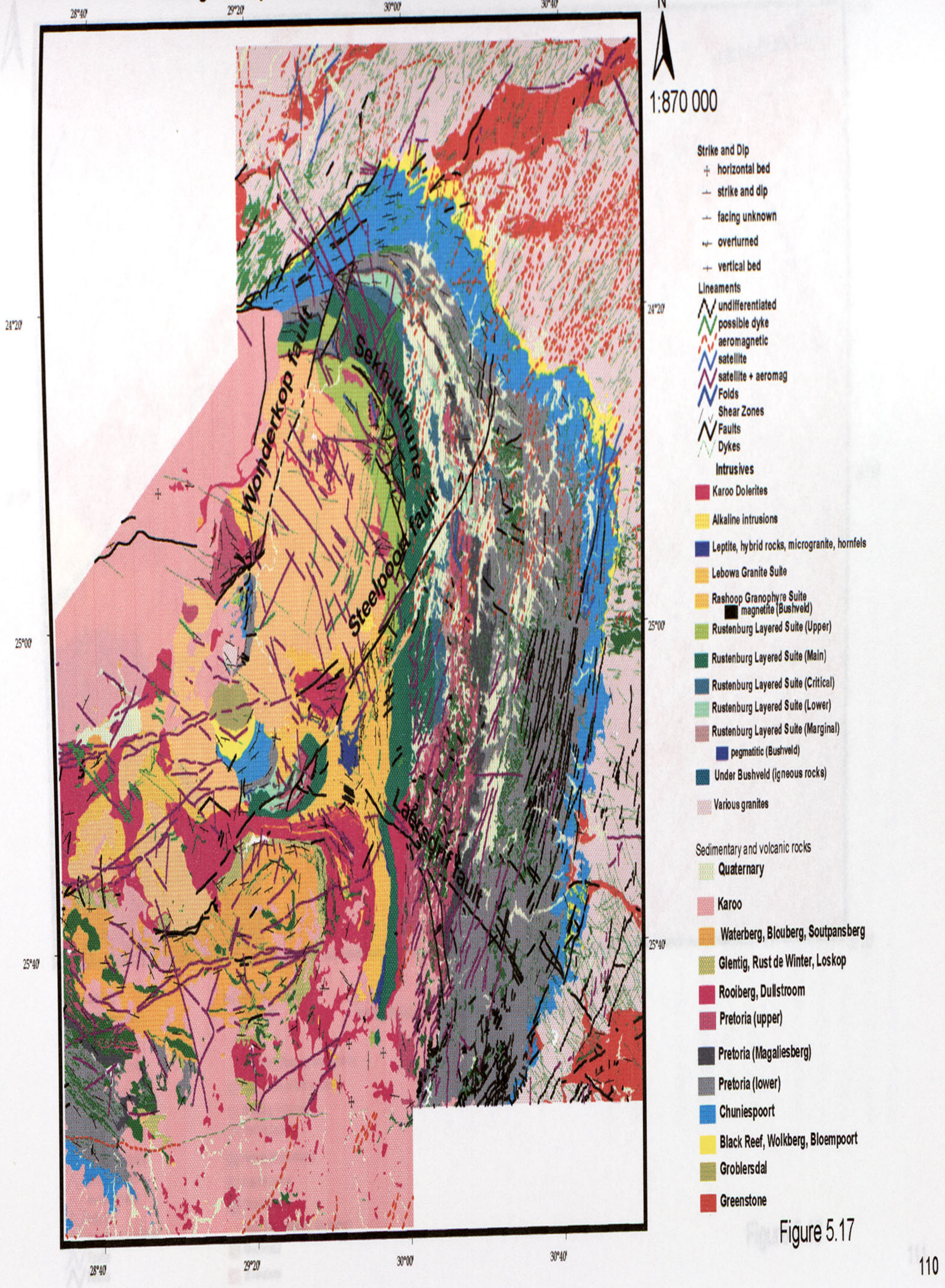


Figure 5.17

Geology of the Murchison Greenstone belt area

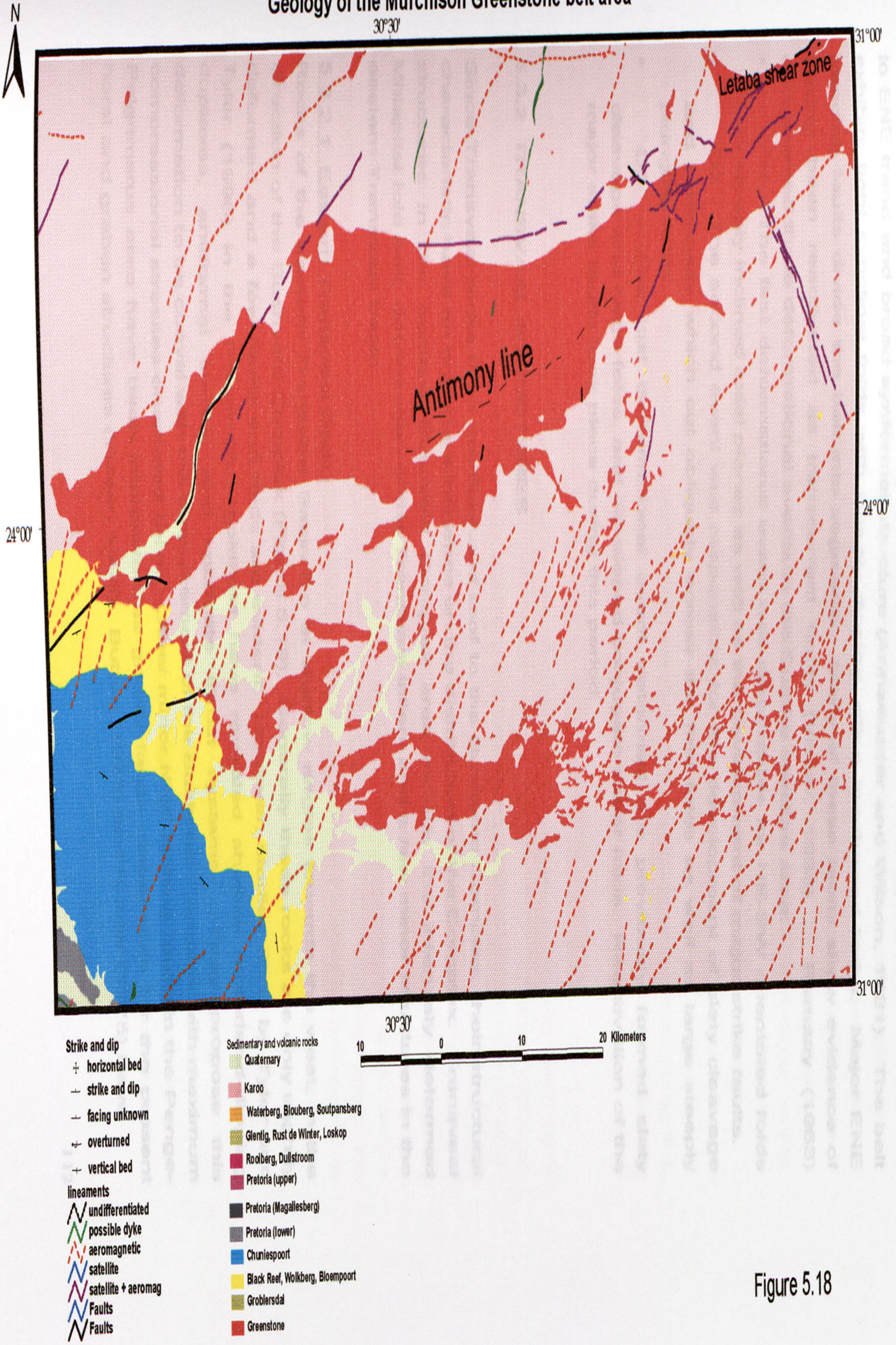


Figure 5.18

evolution of the Kaapvaal Craton and is therefore worth mentioning. The belt has a NNE to ENE trend and broad synformal structure (Anhaeusser and Wilson, 1981). The belt exhibits tight synclinal folds with steeply dipping, often overturned limbs. Major ENE trending faults divide the belt into segments. Many of these faults show evidence of having been reactivated as transcurrent faults (Visser, 1998). Ramsay (1963) documented three deformational events in the Eureka syncline area:

- D1 - The first deformational event was responsible for NE-SW orientated folds with steeply inclined axial planes as well as the development of major strike faults.
- D2 - The second event was responsible for the development of slaty cleavage and schistosity which cut obliquely across the first folds as well as large steeply plunging folds.
- D3 - The last deformational event deformed the previously formed slaty cleavage and large folds, and developed conjugate shear folds. Reactivation of the major strike faults took place during this period.

5.3.2 TRANSVAAL STRUCTURES

Since Transvaal rocks form the floor and roof to the Bushveld Complex, their structural characteristic have an important influence on the distribution of the Complex. Transvaal structures in the eastern Bushveld Complex area include the intensely deformed Mhlapitsi fold belt, deformation of the Transvaal inliers and a few minor structures in the eastern Transvaal basin.

5.3.2.1 Eastern Transvaal Basin

Rocks of the eastern Transvaal Basin dip at shallow angles towards the west, in the direction of the Bushveld Complex (Figure 5.19). Generally these rocks are only slightly deformed and a few faults and folds are evident. However, studies done by Tyler and Tyler (1996) in the Pelgrimsrus goldfield have revealed shallow hinterland-dipping duplexes, antiformal stacks, and imbricate thrust systems. They propose this deformation to be coeval with the emplacement of the Bushveld Complex with maximum compressional stresses orientated E-NE. Other minor NNE striking faults in the Penge-Pelgrimsrus area have been interpreted as gravity faults responsible for the present horst and graben structures (Visser, 1998). Button (1973) and Hunter (1975) have proposed large scale anticlinal and synclinal warps based on the outcrop pattern of the Transvaal rocks along the NE margin of the basin. They suggested that the intrusion of the Bushveld Complex was controlled by these pre-existing folds in the Transvaal rocks. In addition various prominent NNE trending lineaments are present in the eastern Transvaal rocks. Figure 5.18 shows some of these lineaments as undifferentiated, aeromagnetic and satellite lineaments. These lineaments exhibit a definite curve towards the NE as it enters the adjacent Archaean rocks.

5.3.2.2 The Mhlapitsi fold belt

The Mhlapitsi fold belt trends NE and Transvaal rocks are intensely deformed along the belt (Figure 5.20). The belt dips towards the Bushveld Complex (south) at steep angles. Faulting, folding and shearing are characteristical structural features of the belt.

Faults

Faults trend mainly ENE and include, the *Welkommyn, Serala, Wolkberg* and *Acre Faults* respectively (Figure 5.20). These faults are interpreted by Potgieter (1992) as dip-slip faults which were active during and after Wolkberg deposition, and then later reactivated as thrust faults, before Pretoria Group, but after Chuniespoort Group deposition (Potgieter, 1992). However, a very prominent fault, the *Strydpoort fault*, forms the northern boundary of the fold belt. The fault strikes ENE and can be followed for approximately 70 km along the contact between Transvaal and Archaean rocks (Potgieter, 1992). This fault dips to the south and was a strike-slip fault before deposition of the Transvaal Supergroup. During deposition of the Wolkberg Group the fault was reactivated as a normal fault and then later again reactivated as a thrust fault after the deposition of the Chuniespoort Group but before Pretoria Group deposition (Potgieter, 1992).

Folds

Fold axes are mainly orientated ENE and folding involves the Black Reef Formation and Chuniespoort Group. Potgieter (1992) named the folds the *Acre, Wolkberg, Serala, The Downs, Moltke, and Welkommyn folds* respectively (Figure 5.20). According to Potgieter these folds are closely related to thrust movement along faults after Chuniespoort, but

Geological Map of the eastern Transvaal basin

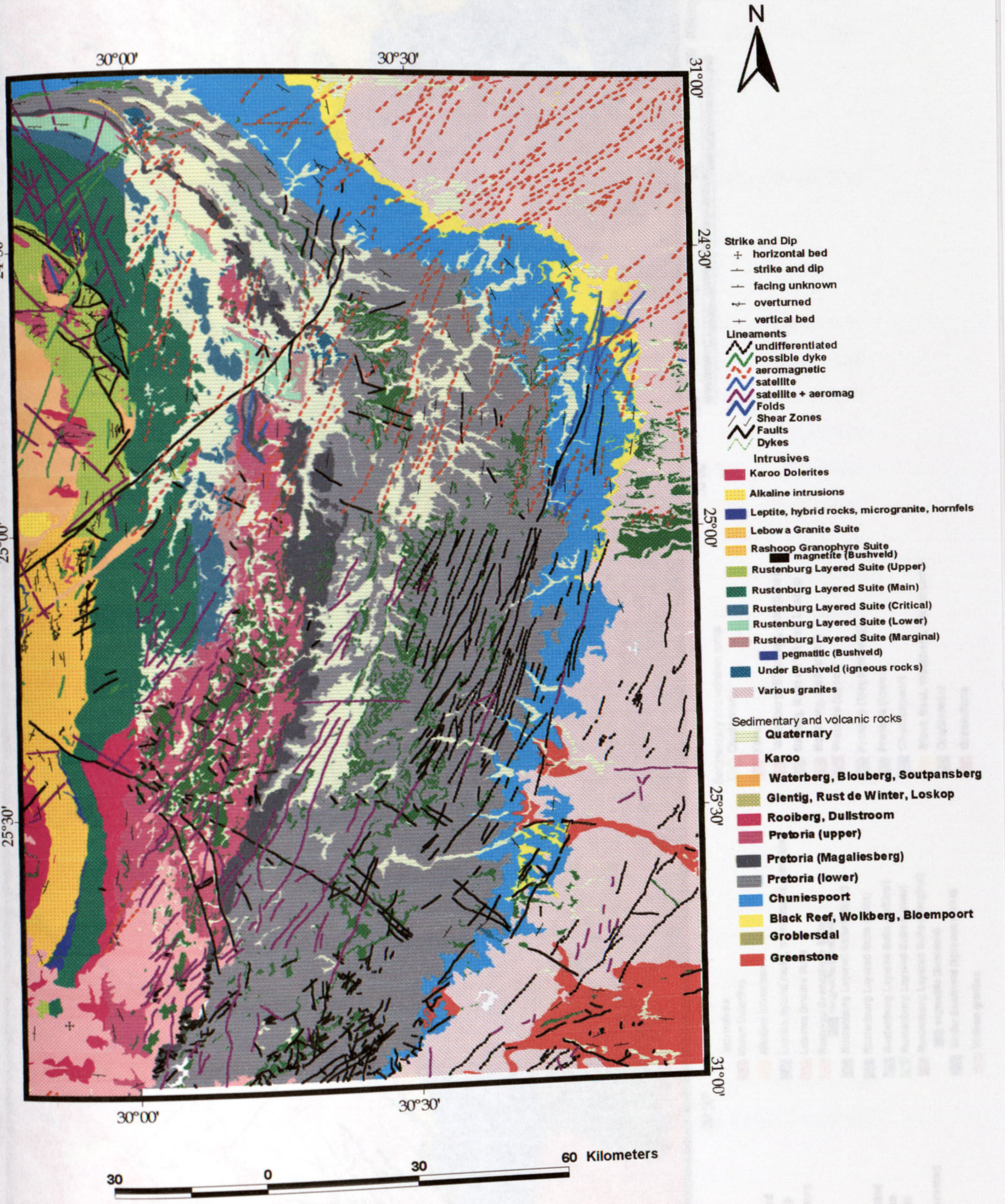
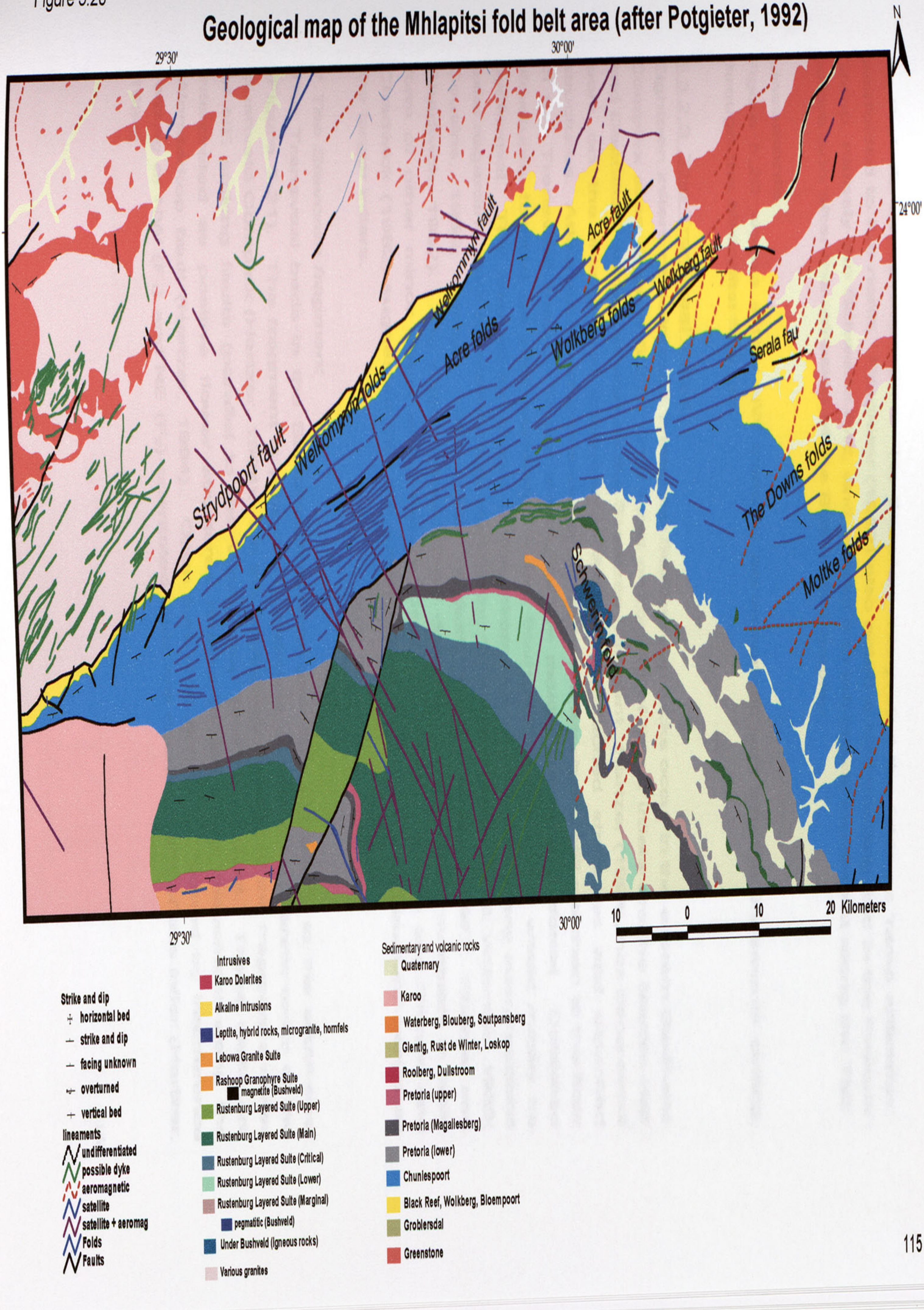


Figure 5.19

Figure 5.20

Geological map of the Mhlapitsi fold belt area (after Potgieter, 1992)



pre-Pretoria Group deposition. He therefore interpreted the folds as 'ramp anticlines' overfolded to the north. Potgieter (1992) also noted a NW trending fold in the Pretoria Group, namely the Schwerin fold, and related it to left-lateral movement along the TML before and after the intrusion of the Bushveld Complex.

Lineaments

Figure 5.20 shows a few NW trending aeromagnetic and satellite lineaments cutting through the Mhlapitsi fold bet.

5.3.2.3 The Transvaal inliers

Eighteen inliers of deformed Transvaal Supergroup rocks occur in the eastern Bushveld Complex area (Figure 5.21). The most prominent of these inliers are the Marble Hall and Dennilton domes as well as the Stavoren fragment. Hartzer (1994), has done detail work on the inliers and categorized them into attached structures and detached structures. Attached structures include all the inliers which are still attached to the floor of the Transvaal basin. These structures are mostly anticlinal or domal. Detached structures formed as roof pendants to the Bushveld Complex and would mainly be synformal. The internal structures of the inliers are variable and many interpretations exist regarding their formation (e.g. Humphrey, 1906, 1908; Daly, 1928; Willemse, 1959; Cousins, 1959; Hartzer, 1987, 1994; Button, 1986; Hamilton, 1977; Sharpe and Chadwick, 1982). The major inliers will be discussed briefly and a summary in table form of other minor inliers are given in Table 5.1. Hartzer (1994) and Sharpe and Chadwick (1982) suggested that the smaller inliers have the same structural trends as the larger inliers.

1. The Stavoren fragment

The Transvaal beds in the Stavoren fragment generally dip gently to the south-east (Figure 5.21). The fragment is probably completely underlain by granitic rocks of the Bushveld Complex (Hartzer, 1994). On the southeastern edge of the fragment a series of NE striking faults (parallel to the Wonderkop fault) is present. These faults are interpreted as positive flower structures related to left-lateral movement along the Wonderkop fault (Hartzer, 1994). Open syn- and anticlines, formed by interference folding of NW (F_1) and NE (F_2) orientated folds are characteristic of this inlier (Hartzer, 1994).

Tabel 5.1. Summary of Transvaal Inliers in the eastern Bushveld Complex area. (After Hartzer (1994) and Sharpe and Chadwick (1982).

Inlier Name	General form	Geological setting	Fault trends	Fold trends	linear trends	Deformation age	Class
Malope	Dome (3 antiforms)	Surrounded by Bushveld Complex granite and gabbro		interference NE, NW (elongated along 015° axial plane)	shear zones with northerly trend	pre-, syn- and post-Bushveld	Dome (fault bounded, not updomed floor, (Sharpe Chadwick)/Diapir [upfolding of basement rocks pre-Bush, (Meyer and De Beer, 1987)]
Adriaanskop	Sheet	Within Bushveld Complex granite	along the Wonderkop fault	ENE		syn-Bushveld	Xenolith (Sharpe and Chadwick)
Fortdraai/ M'Phatlele	Anticline	Surrounded by Bushveld Complex gabbro, partially fault-bounded	Wonderkop fault forms western margin. Secondary fault, linked to Wonderkop fault, cuts through central part	NW, small scale tight folds plunging to the SE	shear zones	pre- to mid Main Zone	Dome/ Diapir
Katkloof	Anticline	At contact between Bushveld Complex gabbro and the Transvaal Supergroup, partially fault-bounded	Wonderkop fault forms northwestern margin	Plunging anticline, fold axis NNW		pre-Bushveld to top of Critical zone	Dome/Diapir
Schwerin	Anticline	At contact between the Bushveld complex gabbro and the Transvaal Supergroup		interference folds NW, ENE		pre- to lower Main Zone	Dome
Paradys	domal structure	Surrounded by Bushveld Complex gabbro		F1: (anticlinal axis) N-S TO NNW F2; ENE - intensly folded	shear zones	pre and syn Bushveld	Dome/Diapir
Potosenyane	Fragment - structure dips towards NE	At contact between the Bushveld Complex gabbro and granite	block faults	ENE fold axis, NW trending syncline and ?, small scale folds (rotated)		pre-and syn-Bushveld	Xenolith
Lezwete	Fragment/synform - dipping towards the N and E	In Bushveld Complex gabbros		gently folded around NW, ENE		pre- and syn-Bushveld	Xenolith
Parys	Fragment - random dips	In Bushveld Complex gabbros		(situated on an anticline)		pre- and syn-Bushveld	Xenolith
Signal Hill-Boschpoort	Fragment	At contact between the Bushveld Complex gabbro and granite		E-ENE, gently folded		pre- and syn-Bushveld	Xenolith

Dwars River	Anticline (double plunging anticline and syncline)	In the Bushveld Complex gabbro, near contact with the Transvaal Supergroup. Partially fault-bounded		axial traces NNW - small scale folds also plunge NNW, curved axial plane = refolding around ENE	shear zones	syn-Bushveld	Dome
Steelpoort	Anticline	At contact between the Bushveld complex gabbro and the Transvaal Supergroup		NW-NNE, D2 ENE - small scale folds		pre-Bushveld	Dome
Derde Gelid	Anticline (pericline)	At contact between the Bushveld complex gabbro and the Transvaal Supergroup		NNW-NE, sligthly refolded along E-ENE (parallel to Steelpoort F)		pre- and syn-Bushveld	Dome
De Berg	Syncline	At contact between the Bushveld complex gabbro and the Transvaal Supergroup, but surrounded by the Critical Zone of the Rustenburg Suite		NW, ENE		syn-Bushveld	Dome
Stoffberg	Sheet	At contact between the Main and Upeer Zones of the Rustenburg Suite					Xenolith

Hartzer (1994) proposed the following deformational history for the Stavoren fragment:

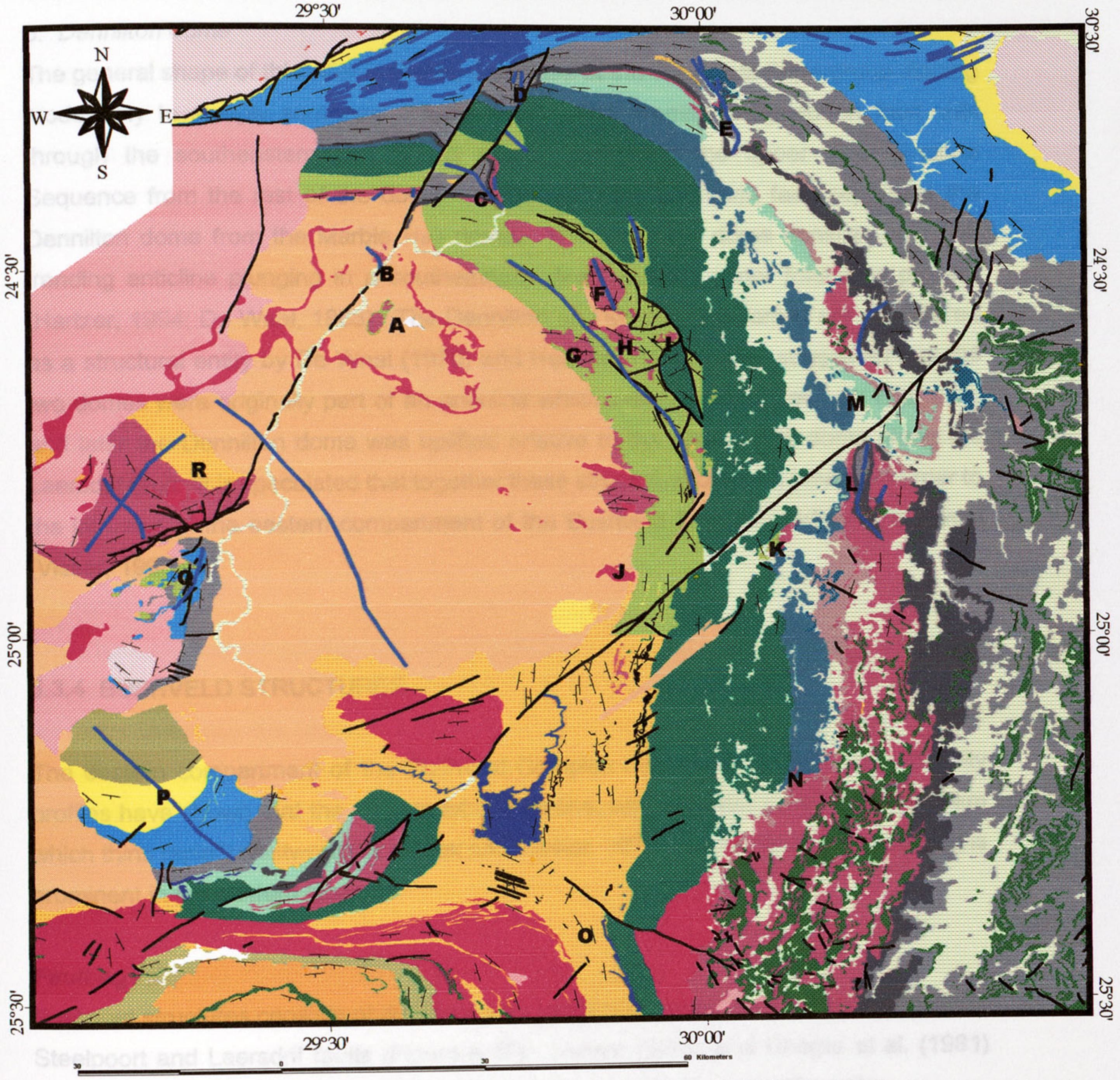
1. During phase 1 (post-Pretoria but pre-Bushveld), folds with axial planes in a NW-SE direction formed due to compression from the NE and SW.
2. During phase 2 (post-Pretoria but pre-Bushveld), folds with axial planes in a NE-SW direction developed due to compression from the NW and SE.
3. The Wonderkop fault zone caused lateral and vertical displacement of the Stavoren succession along a wide zone. Displacement took place along a pre-existing line of weakness and in close association with the intrusion of the Bushveld Complex. Internal right-lateral displacement took place within the fault zone.
4. Secondary faults developed in the Wonderkop fault zone which were partially filled with pegmatitic vein material.
5. The intrusion of Bushveld granite lifted the fragment relative to adjacent Marble Hall dome. Isostatic adjustment after emplacement of the Bushveld caused normal faulting along the Wonderkop fault zone.

2. *Marble Hall dome*

The Marble Hall dome is separated from the Stavoren fragment by the left-lateral Wonderkop fault zone (Figure 5.21). The general shape of the inlier is domal with rocks of the Transvaal Supergroup dipping outward, (Hartzer, 1994). Several NNE striking faults are present, and the fold pattern of the dome is fairly complex. A general NNE trending anticline, the Swartkop-Marble Hall anticline, exist in the center of the dome. Hartzer (1994) noted that parasitic folding caused severe thickening in the center of the anticline, and that parallel folding and faulting are responsible for the very complex outcrop pattern. Hartzer (1994) noted several NW (F_1) fold axes that have been refolded about a NE (F_2) axes. Snyman (1956) suggested the folding was linked to the intrusion of the Nebo Granite. However, Clubley-Armstrong and Sharpe (1979) proposed structural irregularities in the Transvaal floor which was reactivated during Bushveld intrusion. Hartzer (1994), on the other hand, suggested that most of the folding took place before the emplacement of the Bushveld Complex.

Figure 5.21

Geolgical map of the distribution of the Transvaal Inliers, (after Hartzer, 1994)



Intrusives
- Karoo Dolerites
- Alkaline intrusions
- Leptite, hybrid rocks, microgranite, hornfels
- Lebowa Granite Suite
- Rashoop Granophyre Suite
  - magnetite (Bushveld)
- Rustenburg Layered Suite (Upper)
- Rustenburg Layered Suite (Main)
- Rustenburg Layered Suite (Critical)
- Rustenburg Layered Suite (Lower)
- Rustenburg Layered Suite (Marginal)
  - pegmatitic (Bushveld)
- Under Bushveld (igneous rocks)
- Various granites

Sedimentary and volcanic rocks
- Quaternary
- Karoo
- Waterberg, Blouberg, Soutpansberg
- Glentig, Rust de Winter, Loskop
- Rooiberg, Dullstroom
- Pretoria (upper)
- Pretoria (Magalesberg)
- Pretoria (lower)
- Chuniespoort
- Black Reef, Wolkberg, Bloempoort
- Groblersdal
- Greenstone

Strike and dip
- horizontal bed
- strike and dip
- facing unknown
- overturned
- vertical bed
- Folds
- Faults

A. Malope structure
B. Adriaanskop structure
C. M'Phatele/Fortdraai structure
D. Katkloof structure
E. Schwerin structure
F. Paradys structure
G. Potosenyane structure
H. Lezwete structure
I. Parys structure
J. Signal Hill - Boschpoort structure
K. Derde Gelid structure
L. Steelpoort structure
M. Dwars River structure
N. De Berg structure
O. Stoffberg structure
P. Dennilton structure
Q. Marble Hall dome
R. Stavoren fragment

3. *Dennilton dome*

The general shape of this inlier is domal, with rocks of the Transvaal Supergroup dipping moderately to steeply southeast (Figure 5.21). The prominent Steelpoort fault cuts through the southeastern part of the dome, separating the upper most Pretoria Sequence from the rest of the dome. In the north the Laersdrift fault separates the Dennilton dome from the Marble Hall dome. The Dennilton dome consists of a NW trending anticline plunging in a southeasterly direction, and minor folding is present (Hartzer, 1994; De Waal, 1963). The Dennilton and Marble Hall domes are considered as a structural entity by De Waal (1970) and Hartzer (1994). They suggested that the two domes were originally part of an anticline which were refolded along an ENE axis, and later the Dennilton dome was uplifted relative to the Marble Hall dome along the Laersdrif fault. It is speculated that together these structures formed a physical barrier to the intrusion of the eastern compartment of the Bushveld Complex further to the west (Visser, 1998).

5.3.4 BUSHVELD STRUCTURES

The eastern compartment of the Bushveld Complex dips mainly to the west. Gravity profiles have shown that the eastern lobe is sill-like, with a maximum thickness of 5 km which thins rapidly westward (Molyneux and Klinker, 1978). Large faulting and folding is prominent in the eastern lobe.

Faulting

Bushveld structures consists of the three very prominent faults, namely the Wonderkop, Steelpoort and Laersdrif faults (Figure 5.17). Hunter (1976) and Sharpe et al. (1981) considered these faults as presumed feeder fissures to the Bushveld Complex.

Wonderkop fault

The Wonderkop fault strikes over a distance of more than 120 km and has a general NNE strike. Some authors suggests that the fault extends beyond the Chuniespoort Group towards the northeast (Schwellnus et al., 1962). The fault is not very well exposed but based on outcrops in the Stavoren fragment and along the northern rim of the Bushveld Complex, Hartzer (1994) interpreted the fault to be a left-lateral strike-slip fault with some internal right-lateral movements. The Wonderkop fault has been active over a long period, stretching from pre-Bushveld times to post-Bushveld times. Du Plessis and Walraven (1990) mentions post-Bushveld normal faulting, and Visser (1998) ascribes the normal displacement to thermal collapse after the intrusion of the Complex.

Steelpoort fault

The Steelpoort fault strikes NE and can be followed for approximately 95km. Even though the fault is a very prominent structure cutting through the Bushveld Complex very little research has been done on the fault. Shearing in places along the fault zone indicates right-lateral movement (Visser, 1998). In contrast, Sharpe and Chadwick (1982) suggested that the Dwars River fragment is a horst block related to vertical movement along the fault. The fault is believed to be post-Bushveld in age, however pre-Bushveld movement might have been possible (Visser, 1998).

Laersdrif fault

The Laersdrif fault strikes NW and cuts trough the upper Transvaal Supergroup and the Lower Bushveld Complex. The northwestern continuation of the fault is uncertain although some authors consider it to be responsible for the separation of the Dennilton and Marble Hall domes (De Waal, 1970). Up to date no detail study of the Laersdrif fault has been done. The timing of the fault can be constrained to post-Bushveld due to cross-cutting relationships. However, pre-Bushveld activation should not be discarded.

Sekhukhune fault

The Sekhukhune Fault (Figure 5.17) displaces the upper and lower zones of the Rustenburg Layered Sequence. The fault has a very sinuous nature but mainly follows the outcrop pattern of the Rustenburg Sequence. Molyneux (1970) noted vertical displacement along the fault zone. The type of faulting however is uncertain.

Folding

A few NW trending anticlines and synclines are present in the eastern Bushveld Complex area. Molyneux (1970) noted the existence of an anticline in the Rustenburg Layered Sequence close to Magnet Heights. Walraven (1986) proved through trace-element distribution indexes, which indicates stratigraphic height, that a large NW orientated open synclinal structure is present in the Nebo Granites of the eastern compartment of the Complex (Figure 5.21). Other workers such as Lenthall (1975) and MacCaskie (1983) reported the same structure.

Lineaments

Numerous lineaments can be traced through the eastern compartment of the Bushveld Complex (Figure 5.17). BOSGIS show these lineaments as satellite and aeromagnetic lineaments and some possible dykes. During an Honours project undertaken by Hoffmann (1997) on the Nebo granites of the eastern Bushveld Complex, five different orientations of fractures were recorded. They include the following orientations from oldest to youngest (Hofmann, 1997):

- 170°-180°
- 40°-50° and 140°-150° (Same orientation as Wonderkop and Sekhukhune fault)
- 80°-90°
- 120°-130° (possibly post-Karoo age)

Although many different orientations of fractures exist, Hofmann noticed that most of the displacement along shear fractures indicate right-lateral shearing.

5.3.5 WATERBERG STRUCTURES

Waterberg rocks in the Cullinan-Waterberg basin are relatively undeformed and dip towards the center of the basin (Figure 5.22). However, prominent faulting and small scale folding have been observed along the northern margin of the basin (Van der Neut, 2000). The most prominent structure is the large E to ENE trending Wilgerivier fault, extending for approximately 75 km. The fault displays a very complex geology with Waterberg rocks dipping steeply towards the north, south, vertical, and overturned. Van der Neut (pers. Comm.) describes ramp flat geometry for the fault zone with fault planes dipping south. Small-scale NE trending folds and thrusts are developed in shale layers, whereas approximately E-W orientated mullion structures are present in local quartzite layers. Van der Neut (pers. Comm.) attribute the structures of the fault zone to thrust movement towards the north during post-Waterberg but pre-Karoo times.

5.3.6 KAROO STRUCTURES

Karoo rocks occur to the south of the Bushveld Complex as well as in the center of the Complex, known as the Springbok flats. The Karoo rocks in this area is relatively undeformed and no major Karoo structures are present in the eastern Bushveld Complex area. A few satellite and aeromagnetic lineaments have been recorded in the Karoo rocks occurring to the south of the Complex (Figure 5.17). These lineaments show various orientations and cut through adjacent Waterberg rocks.

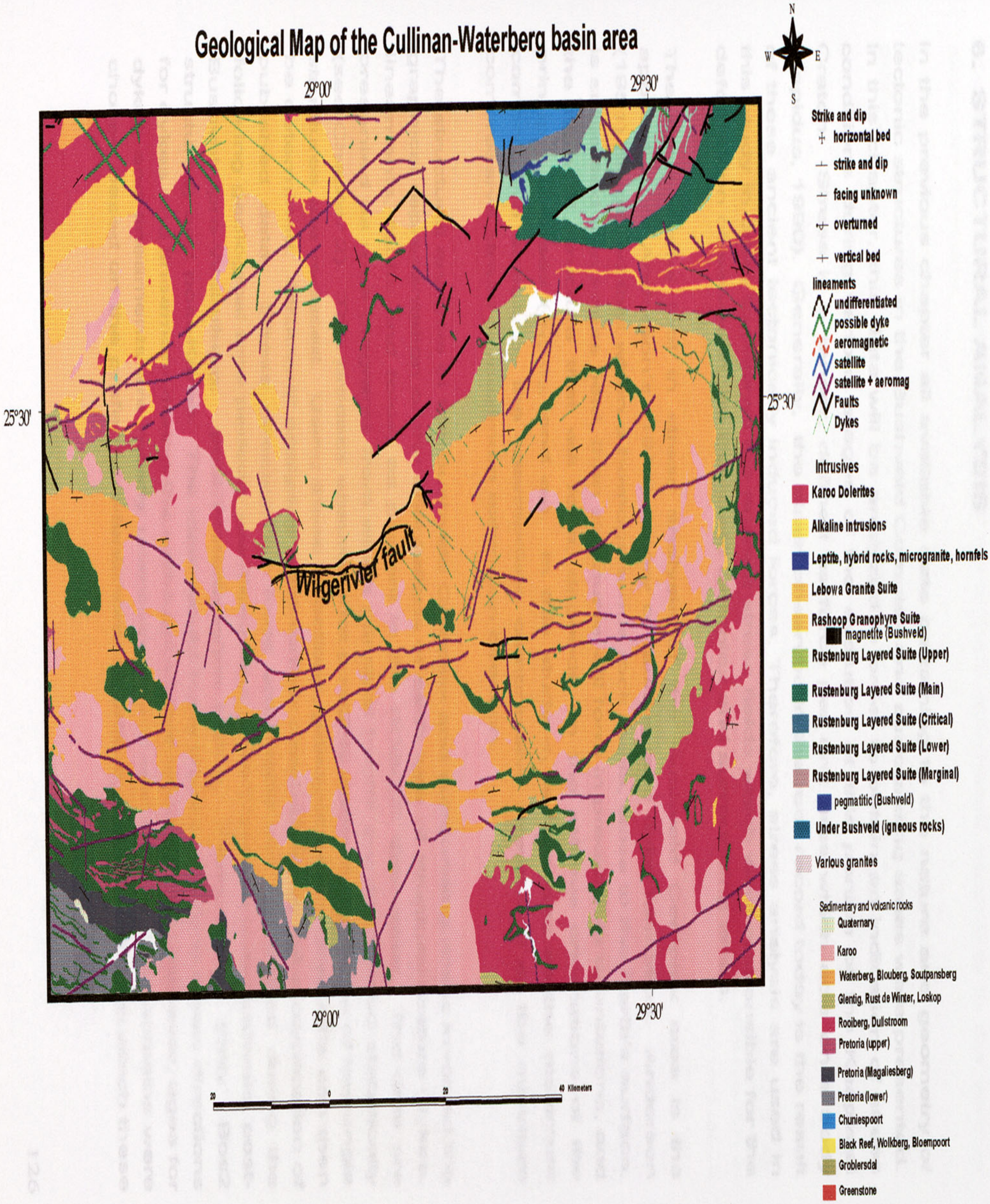

Geological Map of the Cullinan-Waterberg basin area
N
W
E
S
29°00'
29°30'
25°30'
Wilgerivier fault
Strike and dip
horizontal bed
strike and dip
facing unknown
overturned
vertical bed
lineaments
undifferentiated
possible dyke
aeromagnetic
satellite
satellite + aeromag
Faults
Dykes
Intrusives
Karoo Dolerites
Alkaline intrusions
Leptite, hybrid rocks, microgranite, hornfels
Lebowa Granite Suite
Rashoop Granophyre Suite
magnetite (Bushveld)
Rustenburg Layered Suite (Upper)
Rustenburg Layered Suite (Main)
Rustenburg Layered Suite (Critical)
Rustenburg Layered Suite (Lower)
Rustenburg Layered Suite (Marginal)
pegmatitic (Bushveld)
Under Bushveld (igneous rocks)
Various granites
Sedimentary and volcanic rocks
Quaternary
Karoo
Waterberg, Blouberg, Soutpansberg
Glentig, Rust de Winter, Loskop
Rooiberg, Dullstroom
Pretoria (upper)
Pretoria (Magaliesberg)
Pretoria (lower)
Chuniespoort
Black Reef, Wolkberg, Bloempoort
Groblersdal
Greenstone
20
0
20
40 Kilometers

Figure 5.22