1. INTRODUCTION

1.1 Location of the study area

The 2050 Ma (Harmer and Von Grunewaldt, 1991) Bushveld Complex of South Africa is the world's largest layered igneous complex extending over 66 000 km^2. The Complex is host to several economically important ore deposits such as chromium, vanadium and platinum-group elements (Von Grunewaldt and Harmer, 1993). The study area encompasses the whole of the Bushveld Complex and surrounding areas, stretching from longitude 25.6° E in the west to 31°E in the east, and from latitude -26.25°S in the south up to –23°S in the north (Figure 1.1).

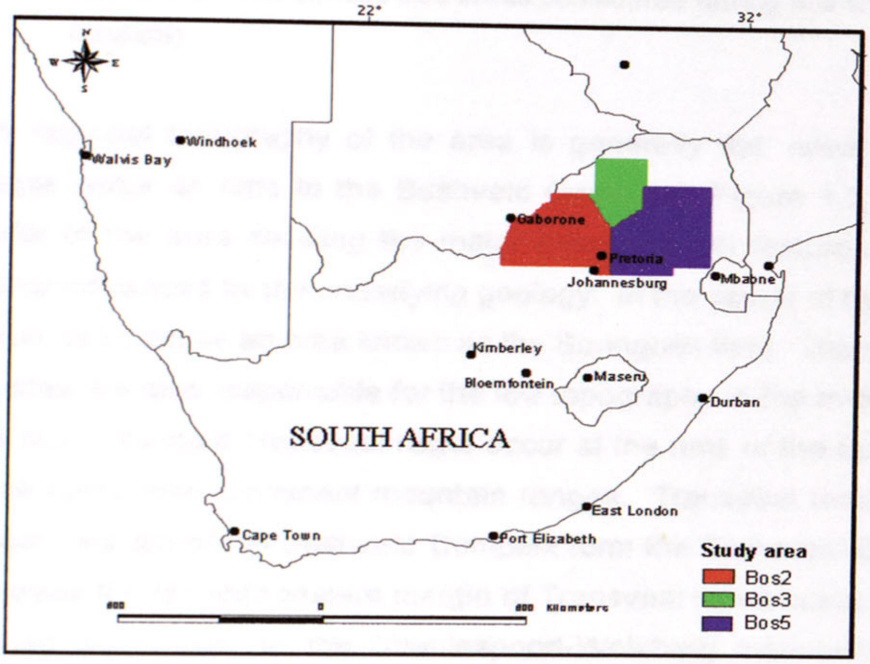

Figure 1.1. Location of the study area.

The study area was divided into three smaller regions based on the outcrop distribution of the Bushveld Complex. These areas include the western (Bos2), northern (Bos3) and eastern (Bos5) Bushveld Complex (Figure 1.2).

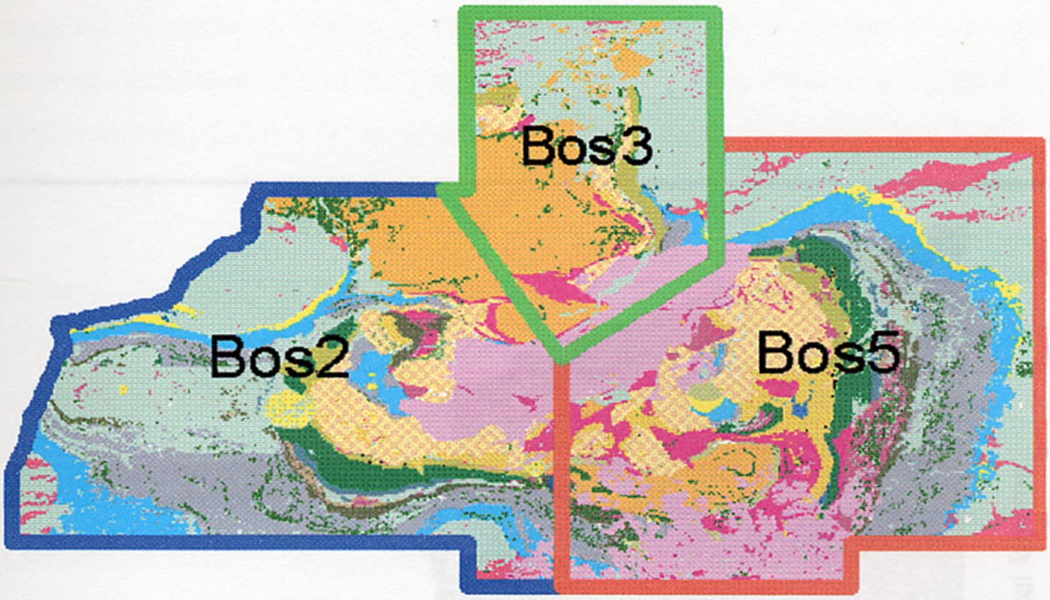

Figure 1.2. The various Bos areas considered during this study. (See Figure 1.1 for location)

The regional topography of the area is generally flat, however various mountain ranges occur as rims to the Bushveld Complex. Figure 1.3 is a digital elevation model of the area showing the major topographical features. The topography is mainly influenced by the underlying geology. In the center of the study area flat-lying Karoo rocks define an area known as the Springbok flats. The surrounding Bushveld granites are also responsible for the low topography in the middle of the study area. The more resistant Transvaal rocks occur at the rims of the Bushveld Complex and these rocks form prominent mountain ranges. Transvaal rocks exposed along the eastern margin of the Bushveld Complex form the Transvaal-Drakensberg plateau. Whereas the far northeastern margin of Transvaal rocks occur in a conspicuous NE striking belt known as the Chuniespoort-Wolkberg mountains. The northwestern exposure of Transvaal rocks form the Dwarsberg mountains, and the far southwestern margin defines the Tshwenyana-Enzelberg mountains. Along the southern margin of the Bushveld Complex, the Magaliesberg mountains form a prominent ridge, stretching from Rustenburg to Pretoria. Various isolated occurrences of Transvaal rocks in the Bushveld Complex depict hilly areas such as the Rooiberg fragment. The northern part of the study area is known as the Waterberg plateau, due to flat-lying Waterberg rocks. The southern margin of the plateau is delineated by the Waterberg mountains. This mountain range strikes ENE from Thabazimbi to Naboomspruit. However, just to the south it is locally known as the Swaershoek mountains.

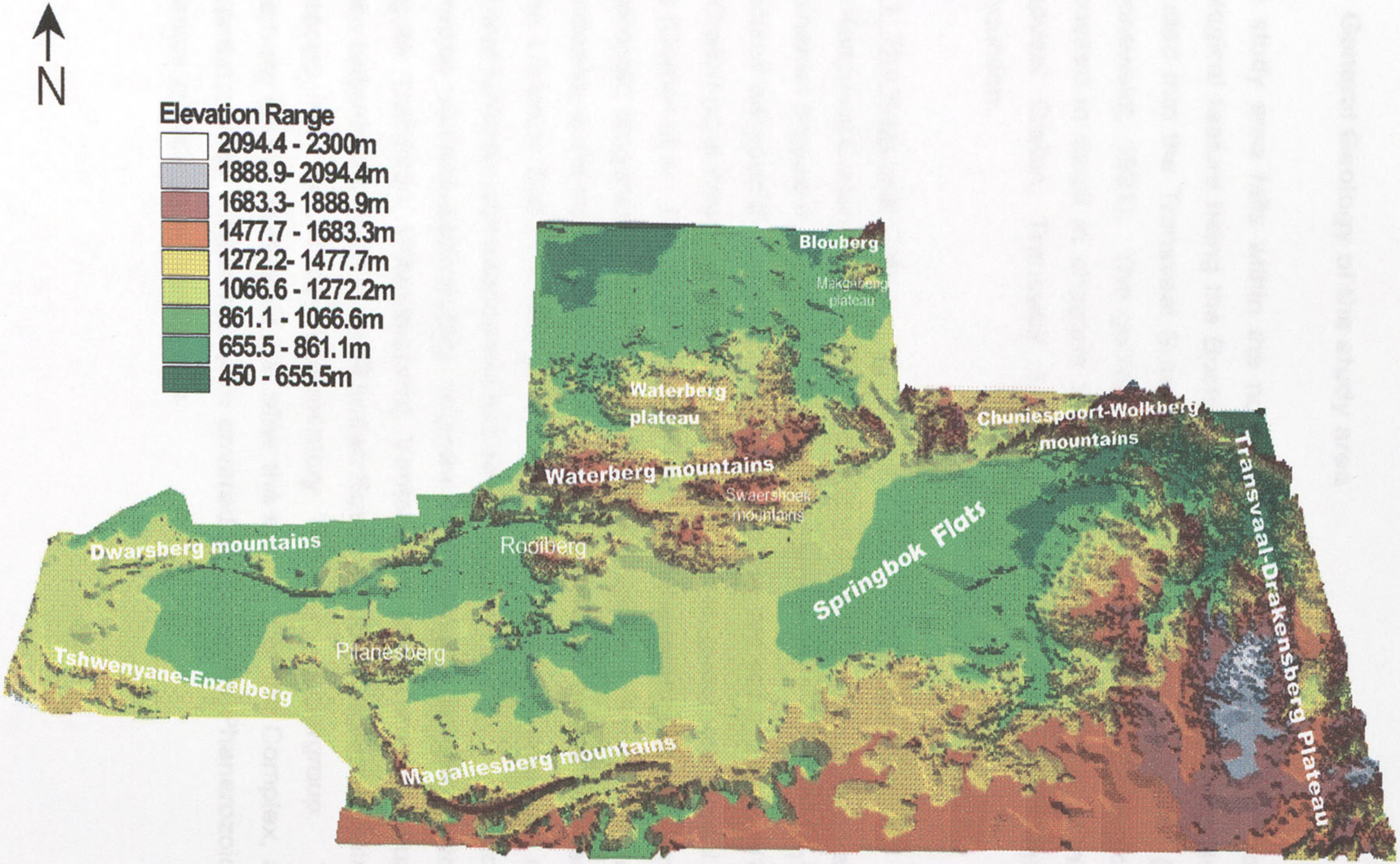

Figure 1.3. Digital elevation map of the study area showing the main topographical features

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Outcrops of Waterberg rocks in the far northern parts of the study area, form the Makgabeng plateau and the Blouberg mountains. The Pilanesberg mountains, related to the Pilanesberg Complex, outline a striking circular topographical high.

1.2 General Geology of the study area

The study area falls within the northern part of the Kaapvaal Craton, with the main geological feature being the Bushveld Complex (Figure 1.4). The Bushveld Complex intruded into the Transvaal Supergroup at approximately 2050 Ma (Harmer and Von Gruenewaldt, 1991). The geology of the area, as well as the regional geology, are discussed in detail in chapters 3 and 4. Only a brief outline of the geology of the Kaapvaal Craton, Transvaal Supergroup and Bushveld Complex will serve as introduction.

1.2.1 The Kaapvaal Craton

The Kaapvaal Craton of South Africa is one of the world's best examples of an Archaean continental fragment. It covers an area of approximately 1.2×10^{6} km^{2} and formed and stabilized between 3.7 and 2.7 Ma years ago (de Wit et al., 1992). The boundaries of the Craton have been well defined using, structural, geochronological and geophysical data (Corner et al., 1990). The Lebombo monocline defines the eastern boundary, Mid-Proterozoic orogenic belts (Namaqua-Natal Mobile Belt) form the western and southern boundaries, while the northern limit is generally taken to be the Southern Marginal Zone of the Limpopo Belt (Thomas et al., 1993). The Craton comprises mainly Archaean granitoid terranes with interleaved remnants of greenstone belts. In addition several late Archaean volcano-sedimentary sequences developed on the Craton, such as the Pongola, Dominion, Witwatersrand, Ventersdorp, and Transvaal Supergroups. The Craton furthermore hosts the well known Bushveld Complex layered intrusion which was emplaced into the volcano-sedimentary Transvaal Supergroup. The Proterozoic Waterberg Group developed just after the intrusion of the Complex, and finally these Precambrian rock sequences were covered in places by Phanerozoic sediments and volcanics of the Karoo Supergroup.

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Geological Map of the Study Area

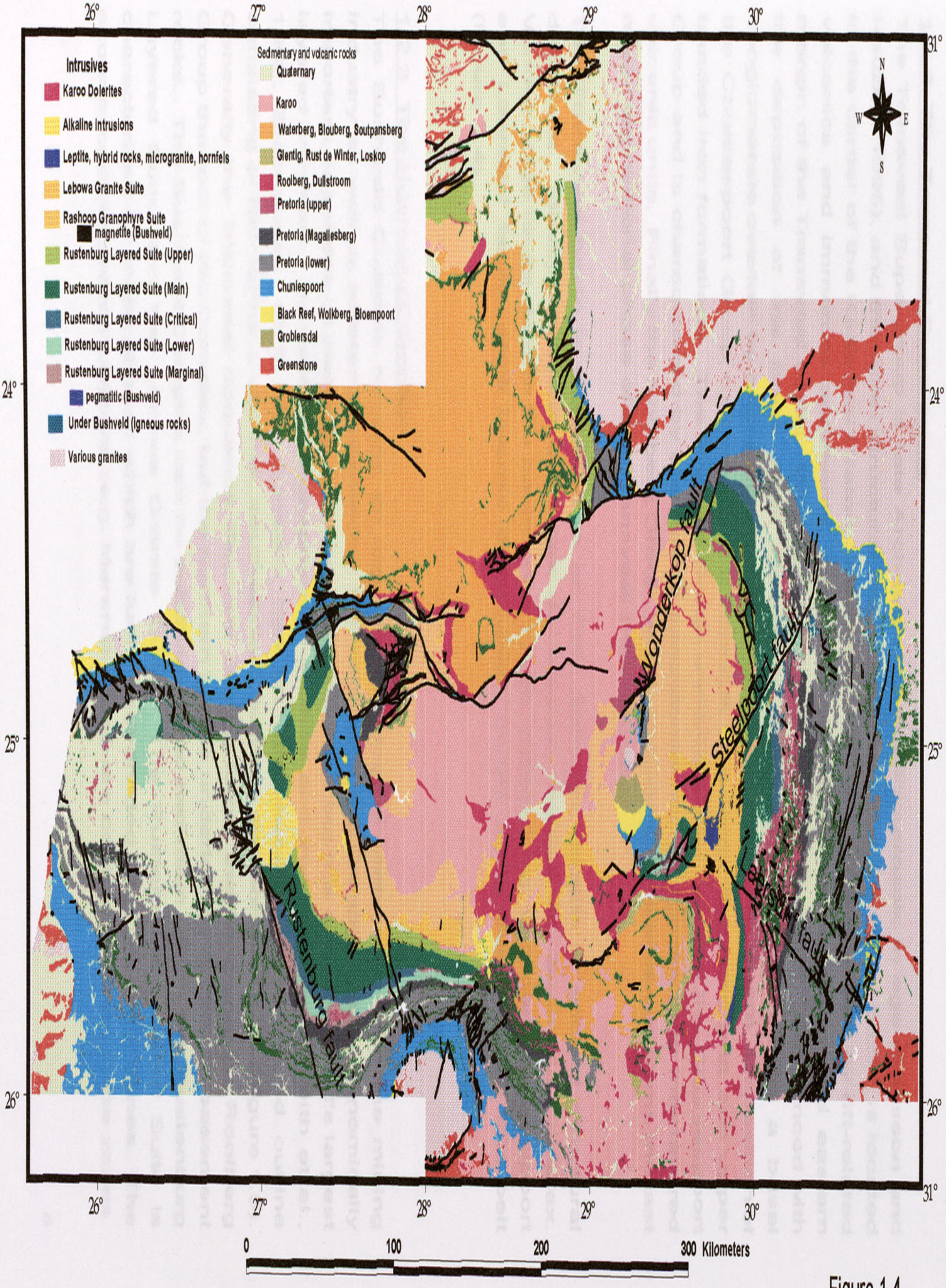


Figure 1.4

1.2.2 The Transvaal Supergroup

The Transvaal Supergroup is late Archaean to early-Proterozoic in age (Eriksson and Reczko, 1995), and the main structural basin, known as the Transvaal basin, is located in the center of the Kaapvaal Craton. Proto-basinal rocks, characterized by rift-related volcanics and immature sediments, are preserved along the northern and eastern margin of the Transvaal basin. Widespread Transvaal sedimentation commenced with the deposition of the Black Reef Formation which is characterized by a basal conglomerate overlain by feldspathic quartzite and shale (S.A.C.S., 1980). Deposition of the Chuniespoort Group followed and it consists of a lower dolomitic unit and upper banded iron formations. The Pretoria Group unconformably overlies the Chuniespoort Group and is characterized by alternating sandstones and mudrocks, with interlayered volcanic units. Finally the Rooiberg Group, which consists of felsitic lavas, forms the last major depositional phase of the Transvaal Supergroup.

The Transvaal basin is elongated in an ENE direction parallel to ancient structural directions. Mostly the Transvaal strata dip inwards, towards the Bushveld Complex. Various large faults deform the basin such as the, Rustenburg, Wonderkop, Steelpoort and Laersdrif faults, while intense deformation occurs along the Mhlapitsi fold belt (Figure 1.4).

1.2.3 The Bushveld Complex

The Bushveld Complex remains an important geological feature for both the mining industry as well as academic research. Not only does the Complex hold economically important quantities of platinum, chrome and vanadium, but it is also the world's largest layered intrusion. According to geophysical studies and investigations (Smith et al., 1962; Biesheuvel, 1970) the Complex has an approximate clover-shaped outline consisting of four lobes: a western, southeastern, eastern and northern lobe (Figure 1.5). Generally the Transvaal Sequence (Pretoria Group) forms the floor and the Rooiberg Group the roof of the Complex, but the northern lobe is underlain by Archaean basement rocks. The Bushveld Complex can be subdivided into two main units: the Rustenburg Layered Suite and the Lebowa Granite Suite. The Rustenburg Layered Suite is characterized by mafic phases which are further subdivided into five major zones. The economically important horizons (e.g. Merensky reef) are contained within these zones.

The Lebowa Granite Suite is slightly younger and marks the acid phase of the layered intrusion.

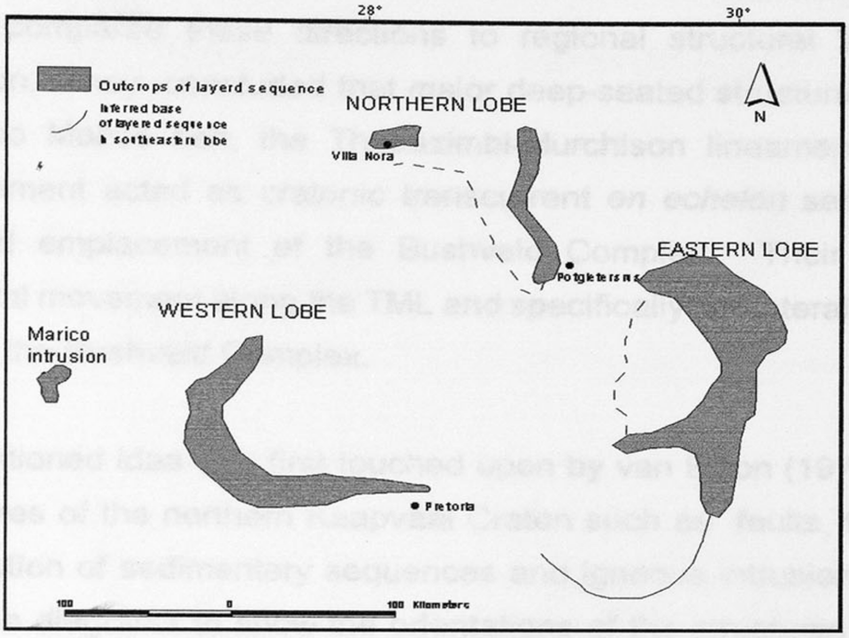


Figure 1.5. The clover shape outline of the Bushveld Complex, (after Tankard et al., 1982.)

Isolated occurrences of deformed Transvaal rocks occur within the Bushveld Complex, they are known as Transvaal Inliers. It is believed (Hartzer, 1995) that earlier tectonic activity caused interference folding in the Transvaal rocks and that Bushveld magmas solidified around these domes. However, some domes are interpreted as diapirs (Sharpe and Chadwick, 1982). Overall the dips of the layered sequences in each lobe are gently (10° to 25°) towards the center except for the northern lobe where dips of up to 60° occur. These dips are generally the same as those in the Transvaal Supergroup and it is proposed by Harmer and Von Gruenewaldt (1991), that this reflects thermal collapse after the emplacement of the Complex.

1.3 Previous research

The Bushveld complex and its tectonic setting has been the subject of much research in the past. Opinions vary greatly from a regional compressional setting (Sharpe and Snyman, 1980; Harmer & von Gruenewaldt, 1991; Uken & Watkeys 1997b) to tensional environments (Van Biljon, 1976). The main theories which consider the orientations of structures are outlined below:

Du Plessis and Walraven (1990) examined the orientations of structures in the Bushveld Complex and compared these directions to regional structural lineaments of the Kaapvaal Craton. They concluded that major deep-seated structural lineaments such as the Limpopo Mobile belt, the Thabazimbi-Murchison lineament (TML), and the Barberton lineament acted as cratonic transcurrent *en echelon* sets, influencing the distribution and emplacement of the Bushveld Complex. Their model promotes continuing lateral movement along the TML and specifically left-lateral movement during the intrusion of the Bushveld Complex.

The above mentioned idea was first touched upon by van Biljon (1976). He examined structural features of the northern Kaapvaal Craton such as faults, folds, lineaments, and the distribution of sedimentary sequences and igneous intrusions. In addition he constructed rose diagrams to show the orientations of the structures in various areas, (Figure 1.6). Van Biljon (1976) attributes the intrusion of the Bushveld Complex to an active spreading center in which major lineaments acted as large transcurrent faults.

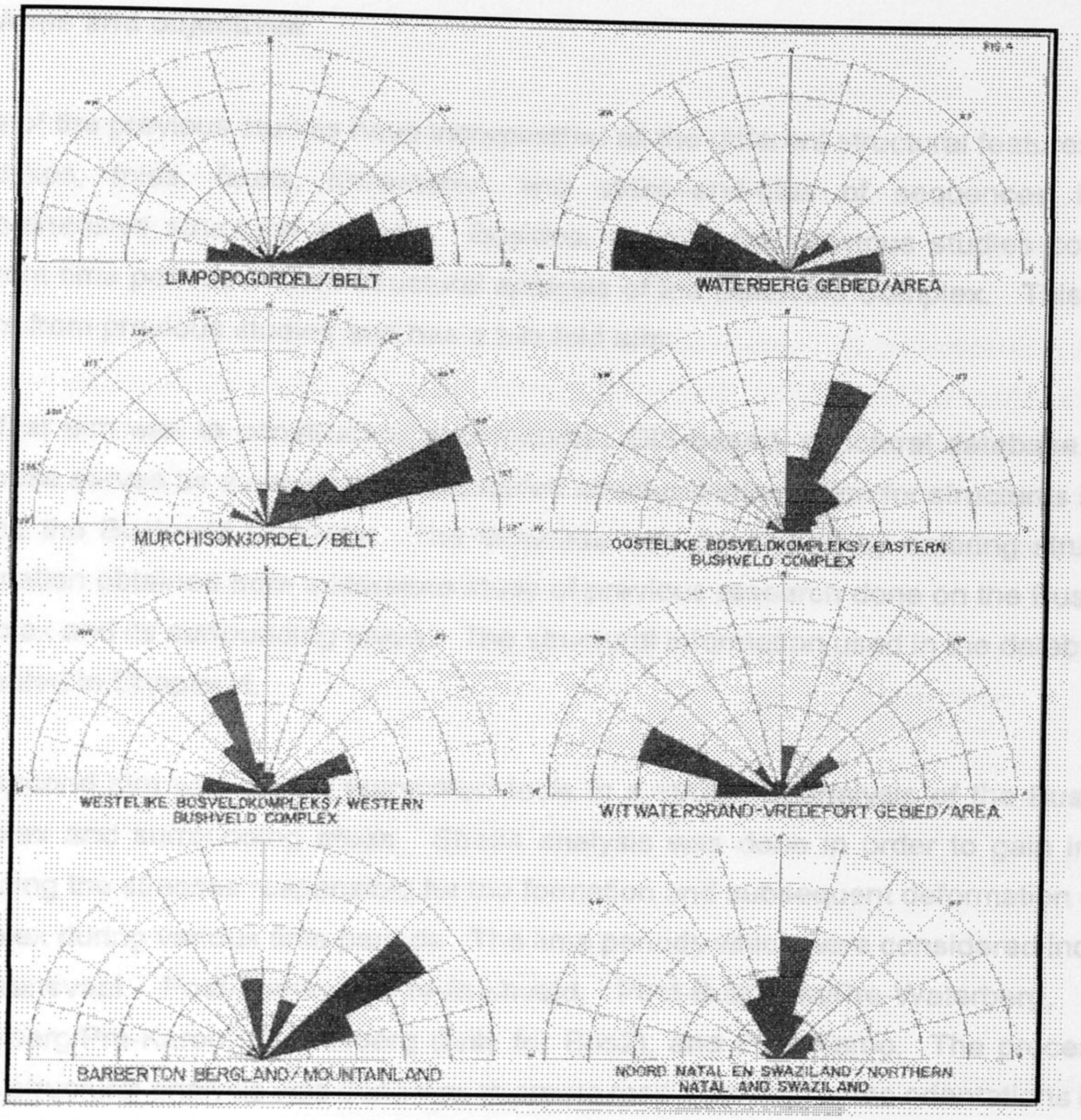


Figure 1.6 Rose diagrams of fault directions (after van Biljon, 1976)

A study done by Lee and Sharpe (1986) on the structural setting of the Bushveld Complex, aided by LANDSAT imagery, are at variance with the above mentioned theories. They concluded that no evidence is present for deep-seated crustal fractures which influenced the location and form of the Bushveld Complex. They based their findings on the fact that no pervasive lineaments are visible with landsat imagery.

1.4 Aims and objectives

None of the previous studies have incorporated all the different structural features such as dykes, folds, faults, lineaments, and strike–and-dips of sequences into a comprehensive structural analysis. Besides, none of the previous studies consider different time periods in their structural analysis of the Bushveld Complex. This study differs from previous studies and has a two fold aim:

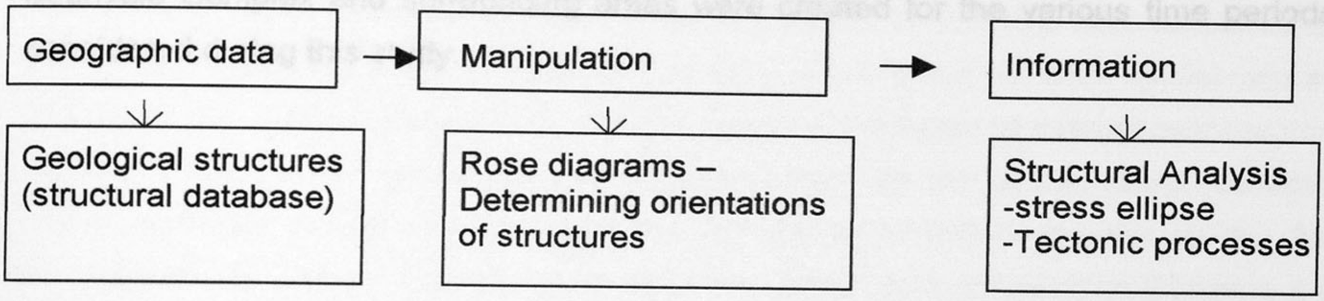
The first aim was to construct a 'user-friendly', GIS-based, structural database. The database serves as a compilation of detailed structural information for structures in and around the Bushveld Complex. The database was developed by entering structural information obtained from a literature study of previous research done on the Bushveld Complex and its surrounding areas. The structural information used in the database is presented in Chapter 4.

The second aim was to use automated tools in a structural analysis of the Bushveld Complex and surrounding areas. Stress analysis was done in order to gain insight regarding the stresses responsible for the formation and subsequent deformation of the Complex during various time periods. The time periods which were considered include; Pre-Transvaal, Post-Transvaal/Pre-Bushveld, Post-Bushveld/Pre-Waterberg, Post-Waterberg/Pre-Karoo, Pilanesberg (only for Bos2), and Post-Karoo. The process by which structural analysis was done was to create rose diagrams of the orientations of the various structures using ArcView 3.2 GIS. Stress directions were interpreted from the rose diagrams, and attempts were made to related these stress directions to tectonic processes affecting the Kaapvaal Craton. In addition, stereographical plots of strike-and-dip data of the Bushveld Complex and surrounding areas were analysed to assist with structural analyses.

By incorporating the structural information gained from the literature study together with structural analyses of rose diagrams and stereographical plots, a clear understanding of the stresses responsible for the formation and subsequent deformation of the Bushveld Complex and surrounding areas should be possible.

1.5 Methodology

GIS (Geographic Information Systems) techniques have been used successfully in a number of fields (wild life studies, agriculture, telecommunications, etc.) This study aims to test the suitability of GIS as a tool in structural analysis, because it allows for the input, storing, manipulation and output of vast amounts of data. By definition GIS makes use of geographic data, which through manipulation and analysis, will provide answers to questions based on the data. Similarly, during this study, structural data were used as input in creating a database, and through manipulation, mostly by creating rose diagrams, a structural analysis of the Bushveld Complex and surrounding areas was done. The GIS process is illustrated by the following diagram:



The basic methods employed during this study were two fold:

Firstly, a detailed literature study was done, to gather structural information relating to the Bushveld Complex and surrounding areas. Detailed research done by Jansen (1982), Du Plessis (1991); Potgieter (1992); Hartzer (1987, 1994); and Bumby (1997, 2000), as well as various review articles and books (Tankard et al., 1982; Thomas et al., 1993; Mc Court 1995; Brandl and de Wit, 1997; Visser 1998) provided much of the information. The structural database was mainly developed for all faults and folds occurring in the Bushveld Complex area. Information for faults include; name of the fault, fault type, displacement style, age, reactivation age as well as any references pertaining to the fault. Folds information include; name for the fold, fold type, axial plane dip, fold axis plunge, age, and references pertaining to the fold. The structural information was coded to allow for easy data retrieval, and can also be easily updated. The coded fields can be linked with appropriate look-up tables which provide the descriptions for the codes.

Secondly, by using GIS techniques, the orientations of structural lines were determined, as well as ages of faults and folds based on cross-cutting relationships. ArcView 3.2 GIS was customized to represent the orientations of these lines with rose diagrams representing different time periods. Structural lines such as dykes and lineaments were grouped into structural domains and rose diagrams were created for the various domains. Stress directions were interpreted from these rose diagrams based on the type of structure using Anderson's theory (1951) of faulting and dyke formation. Strike-and-dip data of the Bushveld Complex and surrounding areas were used to create stereographic plots using Spheristat 2. By using all the structural information gained from the literature study together with information from structural analyses of rose diagrams and stereographic plots, geo-chronological tables of the tectonic history of the Bushveld Complex and surrounding areas were created for the various time periods considered during this study.