2. EXPERIMENTAL METHODS – GEOGRAPHIC INFORMATION SYSTEMS

2.1 Geographic Information Systems

Geographic Information Systems (GIS) are automated tools which are used in the input, storing, manipulation, analysis, and reporting of spatial data. The ideas originated in the 1960's but at first the applications were limited. Today GIS is applied to a wide variety of business and organizations and the applications are almost endless. However, the use of GIS applications within geological discipline, are primarily used as map creation software, and the true value of a Geographic Information System is under-utilized. GIS can be especially useful in geology because, instead of working with conventional printed geological maps, the user can now analyze, explore and visualize spatial data as separate coverages. GIS also allows for the storing of attributes of a map coverage and therefore, queries and calculations can be performed on the spatial data. DeMers' (1997) definition of GIS describes well the application of GIS during this study. He defines GIS as follows; "In the broadest terms, Geographic Information Systems are tools that allow for the processing of spatial data into information, generally information tied explicitly to, and used to make decisions about, some portion of the earth". The GIS *'tools'* (software) that were used during this study is ArcView 3.2. The *'spatial data'* are BOSGIS (see 2.2), and the *'decisions'* that were made, involve the interpretation of the structural history of the Bushveld Complex (see Chapter 6).

2.1.1 The Software – ArcView 3.2 GIS

Many different GIS software packages are available on the market. ArcView 3.2 GIS, created by Environmental Systems Research Institute (ESRI), was the main GIS software program used during this study. The foundation of ArcView is it's ability to manage spatial data. Spatial data is geographic data that stores the geometric location of particular features, along with attribute information describing what these features represent. ArcView organizes its spatial data into projects, and each project consists of various documents:

- **Views** – A view consists of a logical group of related point, line or polygon features known as layers or themes which cover more or less the same geographical area. These themes are stored as shape files (*.shp), which is a simple non-topological format for storing the geometric location and attribute information of geographic features.
- **Tables** – An ArcView table references the tabular data source it represents, but doesn't contain the tabular data itself. Tabular data can be stored in dBASE, INFO (an ArcInfo data file format), and ASCII delimited text files.
- **Charts** – Charts are also fully integrated into ArcView's geographic environment, and allows for the graphical display of tabular and chart representations of the attributes of geographic data.
- **Layouts** – Layouts assemble all the components of a project to produce high quality printable maps. A direct live link exist between the layout and the data it represents.
- **Scripts** – Avenue, the object-orientated programming language of ArcView allows for the customization of ArcView by changing the graphical user interface, by directing ArcView to perform a specific task or manipulating tabular data. ArcView scripts (*.ave files) are macros written in Avenue. Various scripts are included with ArcView and additional scripts can be obtained from the ESRI homepage (www.esri.com).

ArcView has many analytical capabilities a few of which are mentioned here.

1. Adjacency analysis – 'Theme on theme' selections can be performed between any feature themes displayed in a view. For example: all the points that completely fall within a selected region of a polygon theme can be selected or, all the lines that intersect a specific point theme can be chosen.
2. Proximity analysis - 'In distance of' operations can also be performed between any feature themes displayed in a view. For example all the points that lie within a distance of 3 km from a selected point theme can be chosen.
3. Queries – When themes need to meet specific requirements queries can be performed on the theme. For example: all the lines with a length greater than 100 m need to be selected. Arc View's query builder allows complex queries to be executed using logical operators such as 'and', 'or', '≤', '=' and the like statements.

4. Calculations – Mathematical calculations can be performed on number fields in the attribute table of a theme. ArcView allows for a range of mathematical operations such as square root, trigonometric functions, logs, etc.

ArcView contains many extensions which have the potential to be very useful to geological problems. These extensions include, Spatial Analyst, 3D Analyst and various other image processing tools. None of these extensions were employed during this study.

2.1.2. Other non-GIS software

Other non-GIS software, used in conjunction with ArcView, include Spheristat 2. Spheristat allows for the entering of structural field measurements (either axial/non-directed or polar/vector) in tabular form and plotting them in a variety of ways: on a stereonet (Schmidt equal area or Wulff equal angle), on a map, or rose diagram. Each plotting method offers one or more analytical tools to extract more information from the data (Stesky, 1998).

2.2 BOSGIS

BOSGIS is a computerized geological database of the Bushveld Complex. The database was created by the Department of Earth Sciences, University of Pretoria in collaboration with the Council for Geoscience. The basis for BOSGIS is a generalized digital geological database, comprising the Pietersburg (2328), Tzaneen (2330), Thabazimbi (2426), Nylstroom (2428), Pelgrimsrus (2430), Mafikeng (2524), Rustenburg (2526), Pretoria (2528), Barberton (2530), and East Rand (2628), 1:250 000 map sheets. Other data include cadastral, contour, topographical and geochemical data of the Bushveld Complex and surrounding areas. A manual for the use of BOSGIS was compiled by Brynard (1996) as an internal report to the Department of Earth Sciences, University of Pretoria. Since the database serves as foundation for this study, a brief description of the nature of the various components of BOSGIS follows:

2.2.1 Geological data

Geological data are subdivided into polygon (gst), point (gsp), and line (gsr & gdb) data.

- *Polygon* – This includes the geological boundaries of the Bushveld Complex and surrounding areas. The geological map of the Bushveld Complex and surrounding areas was divided into six subdivisions, namely Bos1 to Bos6 (Figure 2.1). These maps include the stratigraphical subdivisions of the Bushveld Complex as present on the 1:250 000 geological maps as well as a simplified version of the formations younger and older than the Bushveld Complex (Figure 1.4). Only three of these map areas contain rocks of the Bushveld Complex. They are Bos2 (western Bushveld Complex), Bos3 (northern Bushveld Complex), and Bos5 (eastern Bushveld Complex). The lithostratigraphic units of these maps are identified by a unique numeric key (code) defined by the 'newclass' field in the theme's attribute tables. This descriptive data or attributes allow logical selections to be made at Formation, Group or Supergroup level for sedimentary units, and Suite or Complex level for igneous rocks.

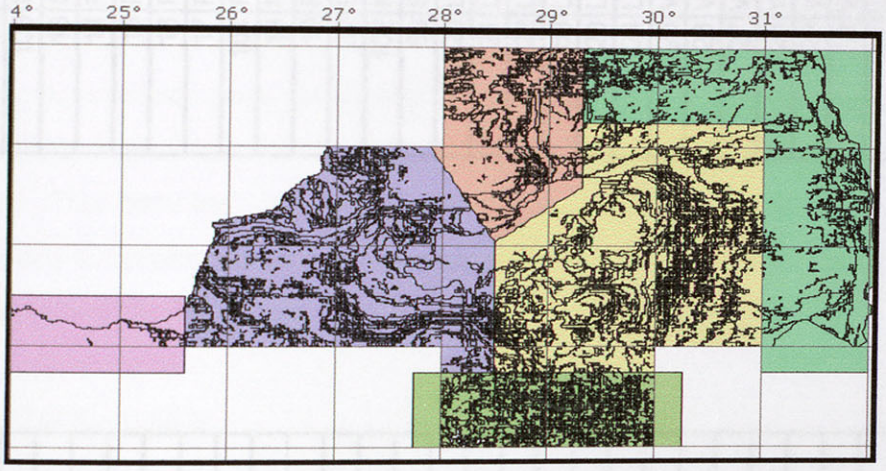


Figure 2.1: The various component maps of the BOSGIS database

- *Point* data (gsp) contain all the point features found on the 1:250 000 geological maps comprising the Bushveld Complex area. This includes most importantly strike and dip values recorded in dip-dip direction format. Other points include mines, trigonometric points, diatremes, mineral deposits etc. (Table 2.1). The 'lin' field in the theme's attribute table reflects the key to the various point features.

Table 2.1. Point features in BOSGIS.

LIN	Description
10	Horizontal bed
69	Strike of vertical bedding
12	Strike and dip of bed (facing unknown)
21	Strike of anticlinal axis
197	Strike of antiformal axis
24	Strike of overturned anticline
27	Strike of inverted anticlinal axial plane
22	Strike of synclinal axis
198	Strike of synformal axis
25	Strike of overturned syncline
26	Strike of inverted synclinal axial plane
23	Strike of monoclinal axis
29	Strike of vertical axial plane
11	Strike and dip of bed
13	Strike and dip of overturned bed
9	Volcanic pipe, basic
8	Volcanic pipe, alkaline
6	Kimberlite pipe
5	Kimberlite pipe (suboutcrop)
113	Diatreme
4	Magnetite pipe
184	Mine in production
185	Mine in disuse
55	alluvial workings
56	Alluvial workings in disuse
114	Mineral occurrence/deposit
53	Gravity base station
54	Gravity observation point

Table 2.2. Line features in BOSGIS

LIN	Description
10	Fault, observed
11	Fault, observed, normal
12	Fault, observed reverse
100	Fault, observed, high angle reverse
13	Fault, observed thrust
14	Fault, observed, slip
15	Fault, inferred/concealed
16	Fault, inferred, normal
17	Fault, inferred, reverse
101	Fault, inferred, high angle reverse
18	Fault, inferred, thrust
19	Fault, inferred, slip
82	Breccia fault
102	Mylonitization
69	Shear zone
20	Linear feature, undifferentiated
21	Linear feature, possible dyke
22	Linear feature, aeromagnetic
68	Linear feature, magnetic anomaly, surface survey
23	Linear feature, satellite imagery
24	Linear feature, aeromag. & sat. imagery
25	Vein, undifferentiated
26	Vein, quartz
27	Vein, iron-rich
28	Vein, aplite
29	Vein pegmatite
30	Vein, granophyre
31	Vein, breccia
32	Joint
33	Fold axis, undifferentiated
34	Anticlinal axis
35	Synclinal axis
36	Antiformal axis
37	Synformal axis
103	Structural form line

- *Line* data (gdb = dykes and beds), and (gsr = structural lines) contain various structural lines found on the 1:250 000 geological maps. Each gdb folder contains a unique 'dat' file which provides a key for the type of dyke represented on the map. The 'key' field of the 'dat' file can be joined with the 'key' field of the attribute table of the theme to enable logical selection of the dykes. For example distinction can be made between dolerite, diabase, and syenite dykes. Structural lines (gsr), include data such as faults, folds and linear features (Table 2.2). The 'lin' field in the theme's attribute tables provide a key for the type of line represented on the map.

2.2.2 Cadastral data.

The cadastral data were provided by the Department of Land Affairs. The data include the provincial-, magistrate-, and farm boundaries of portions of Mphumalanga (etvl), Gauteng (gaut), the Northern Province (ntvl), and the Northwestern Province (nwes) which encompasses the Bushveld Complex area. It is recommended that the data should not be used at a scale larger than 1:500 000 (Brynard, 1996).

2.2.3 Topographical data

The topographical data were originally obtained from the Department of Land Affairs and converted from the National Exchange format (NES) by Brynard (1996) into Arc/Info format. The data include all general topographical and man-made features found in the Bushveld Complex area, for example, tunnels, railways, dams, channels, buildings, mines, power lines, urban areas, etc.

2.2.4 Contour data

The data include a line theme of 100 m contour intervals, and at some places, 50 m intervals for the Bushveld Complex and surrounding areas, as shown in Figure 2.2.

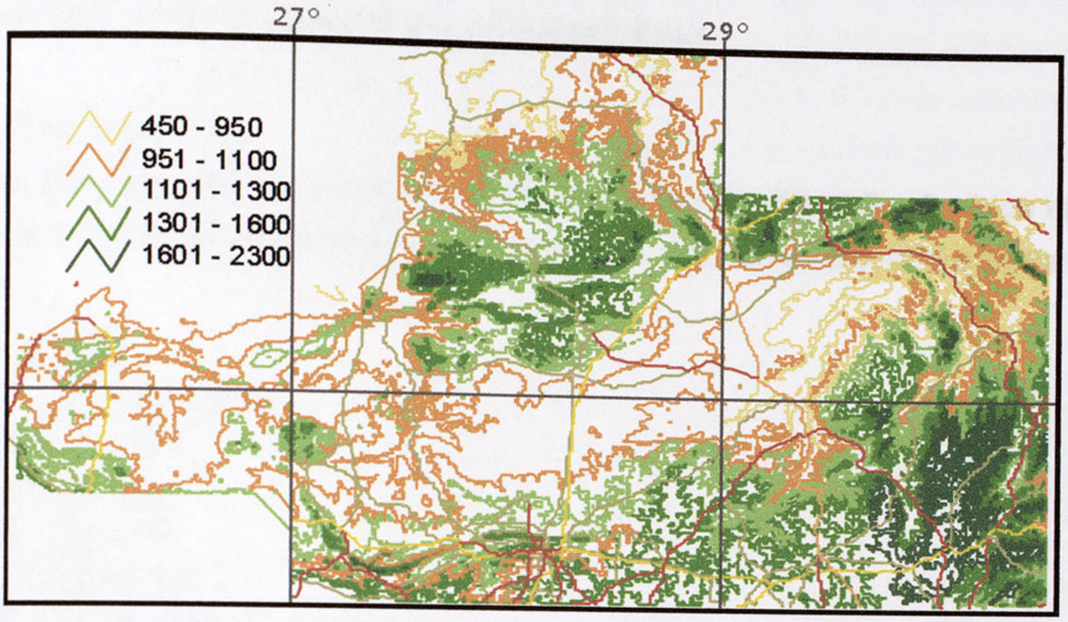


Figure 2.2 100 m topographic contour intervals of BOSGIS

2.2.5 Geochemical data

Geochemical data include a geochemical database created by Brynard (1996). Chemical analyses from theses, publications, and other sources were digitized and compiled into a database. The database currently contains 1 700 georeferenced chemical analyses of mostly main and trace elements of rocks comprising the Bushveld Complex.

2.3 GIS Methods and Techniques

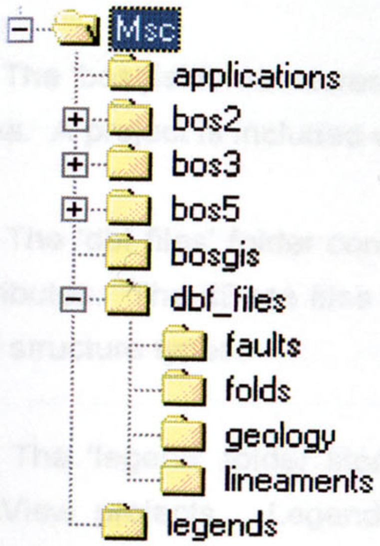
During this study GIS methods and techniques were applied on a revised version of BOSGIS. The new database was modified from the existing BOSGIS. A few modifications had to be made in order for the database to function correctly during execution of the various GIS techniques. In addition the revised BOSGIS was organized in such a way to serve as a proper structural database. Firstly the file structure, project structure and modifications to the revised BOSGIS are discussed. Secondly the structural database creation process is outlined and then finally the GIS methods and techniques are explained.

2.3.1 Revised BOSGIS

An explanation of the creation of this database follows.

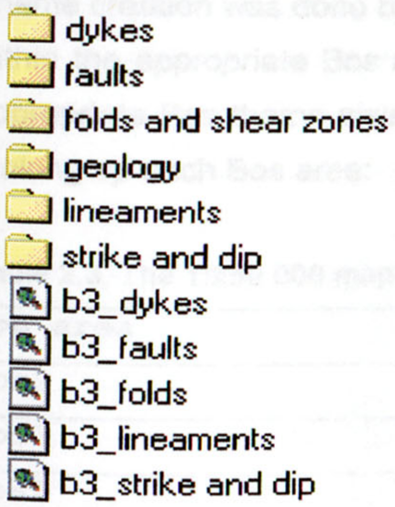
2.3.1.1 File structure

The files are organized into three main folders, Bos2, Bos3 and Bos5 which reflect the components of BOSGIS as explained previously. The hierarchy of the folders are as follows:



1. The 'Applications' folder contains all the avenue scripts and other programs used to customize the ArcView projects. All scripts are included in Appendix 1.

2. Bos2, Bos3, and Bos5 folders store all the projects and structural data which were created for the structural analyses. Each of these folders contains the following sub-folders, as well as five ArcView project files:



The project files organize and compile the different types of structural data which were considered in the structural analyses, and will be described in more detail later. The sub-folders store the data which are used by each project. The Dykes, Faults, Folds and Shear zones, and Lineaments sub-folders each contain 'gen file' folders which store the generate and output files used to create rose diagrams, which will be explained later. The Geology folder has a sub-folder named, 'age layers' storing the various age layers. The strike and dip folder has a sub-folder named 'spheristat files' which stores the spheristat data.

3. The 'bosgis' folder stores data which encompass the whole of the Bushveld Complex area. A project is included which compiles and presents the various BOSGIS data.

4. The 'dbf files' folder contains all the dBase files used for explanation of a theme's attributes. The dBase files are organized under the appropriate sub-folders reflecting the structure types.

5. The 'legend' folder stores all the legends which were applied to themes of the ArcView projects. Legends were created based on specific attribute information contained in a theme.

2.3.1.2 Theme creation

The Bos2, Bos3 and Bos5 geology themes already existed but new dykes, faults, folds, and lineament themes for these areas had to be created from the existing BOSGIS data. Theme creation was done by merging the respective gsp, gsr and gdb themes which lie within the appropriate Bos area. These themes were clipped to the exact size of the appropriate Bos theme size. The following table shows the gsp, gsr and gdb themes making up each Bos area:

Table 2.3. The 1:250 000 map sheet numbers used in creation of the respective Bos areas.

Bos area	**gsp, gsr and gdb themes**
Bos2	2426 2428 2524 2526 2528 2628
Bos3	2428 2328
Bos5	2328 2330 2428 2430 2528 2530 2628

The strike and dip themes were generated by selecting the points from the gsp theme with Lin field values of 10, 11, 12, 13, and 69 (Table 2.1). The faults, folds and lineament themes were created by selecting Lin field values (Table 2.2) from the gsr themes as shown in the following table:

Table 2.4 The lin field values selected from BOSGIS for the creation of the respective themes.

Theme	**Lin field values**
Faults	10, 11,12,13,14,15,16,17,18,19,82,100
Folds and shear zones	33,34,35,36,37,69
Lineaments	20,21,22,23,24,68

The dyke themes were more cumbersome to create since no uniform field existed which described the different types of dykes. Each gdb file contains its own attribute file which were joined with the gdb theme. These joins were performed before merging the gdb files and then only the diabase, dolerite and syenite dykes were selected and converted into the respective dyke themes.

2.3.1.3 Project Structures

All the projects of the various Bos areas consist of the same structure. A detailed description of the organization of the projects follows:

- **Fault projects** – Each fault project consists of four *Views* namely, Fault Map, Age Map, Rose diagram Map1 and Rose diagram Map2. The Fault Map view is the geological map of the area with the Fault theme displaying the various types of faults present in the area. The Age Map view displays the fault related themes according to the ages of the faults. The Rose diagram Map view displays an outline of the geology of the area as well as the various age fault themes used in the creation of the rose diagrams. The *Table* documents include all the fault related dBase files which can be joined with the feature attribute table to provide descriptive data. Three map *layouts* were created for each fault project. The layouts include a general geological map made from the Fault Map view, as well as layouts of the two Rose diagram maps. Four Avenue *scripts* are included in the Fault projects which were used for rose diagram production.

- **Dyke projects** – These projects consist of two *Views*, a Dyke Map view and a Rose diagram Map view. *Table* documents included a domain dBase table which explains the domains used in the rose diagrams. Two *layouts* were made of the general dyke map and rose diagram map.
- **Lineament projects** - The structure of the lineament projects is the same as the dyke projects.
- **Folds projects** – These projects consist of three *views*, a general geological map, Age Map view and a Rose diagram view. *Tables* include all the dBase files explaining the codes for the folds attribute table. Two *layouts* were made of the general geological map and the rose diagram map view.
- **Strike and dip projects** – These projects consist of two *Views*, a Strike and Dip Map and a Spheristat Map. *Table* documents include a dBase file for explaining the domains in the attribute field. The number of *layouts* varied according to the amount of stereonet plots.

2.3.1.4 Changes to the existing BOSGIS database

Stratigraphy

- A new lithostratigraphic attribute file was created which accurately portrays the stratigraphy of the Bushveld Complex and surrounding areas. Table 2.5 and Table 2.6 show the difference between the two stratigraphic tables. The MEMBER field was discarded since it is redundant, as only generalized distinction is being made between the various formations. Furthermore, changes were made, such as the division of the Pretoria Group into an Upper, Magaliesberg, and Lower formations. Also newclass 13 was changed to Wolkberg/Black Reef formations and Newclass 24, labeled Soutpansberg was useless, see Chapter 3.

Table 2.5. Lithostratigraphic attributes of BOSGIS

USER_ID	SUPERGROUP	GROUP	FORMATION	MEMBER	NEW CLASS
1	Bushveld Complex	Rashoop Granophyre Suite			1
2	Bushveld Complex	Lebowa Granite Suite			2
3	Bushveld Complex	Rustenburg Layered Suite	Upper Zone		3
4	Bushveld Complex	Rustenburg Layered Suite	Main Zone		4
5	Bushveld Complex	Rustenburg Layered Suite	Critical Zone		5
6	Bushveld Complex	Rustenburg Layered Suite	Lower Zone		6
7	Bushveld Complex	Rustenburg Layered Suite	Marginal Zone		7
8		Glentig, Rust de Winter, Loskop			8
9		Rooiberg, Dullstroom			9
10	Transvaal	Pretoria	Rayton	Houtenbek	10
10	Transvaal	Pretoria		Steenkampsberg	10
10	Transvaal	Pretoria		Nederhorst	10
10	Transvaal	Pretoria		Lakenvlei	10
10	Transvaal	Pretoria		Vermont	10
10	Transvaal	Pretoria		Makekaan	10
10	Transvaal	Pretoria		Smelterskop	10
10	Transvaal	Pretoria		Leeuwpoort	10
10	Transvaal	Pretoria		Rayton	10
11	Transvaal	Pretoria		Dwaalheuwel	11
11	Transvaal	Pretoria		Boshoek	11
11	Transvaal	Pretoria		Rooihoogte	11
11	Transvaal	Pretoria		Silverton	11
11	Transvaal	Pretoria		Daspoort	11
11	Transvaal	Pretoria		Strubenkop	11
11	Transvaal	Pretoria		Hekpoort	11
12		Chuniespoort	Duitschland, Penge, Malmani	Frisco	12
12		Chuniespoort	Duitschland, Penge, Malmani	Eccles	12
12		Chuniespoort	Lyttleton, Oaktree, Black Reef	Monte Christo	12
13		Groblersdal	Dennilton		13
14		Groblersdal	Dennilton		14
15	Transvaal	Pretoria		Magaliesberg	15
16	Karoo	Karoo Dolerites			16
20		Archaean Rocks			20
21	Karoo	Karoo			21
22		Waterberg			22
23		Quaternary			23
24		Soutpansberg			24
25		Intrusions			25
26		Pilanesberg, Spitskop etc.			26
27		Various Granites			27
28		Hybrid rocks			28
29		Dunites			29
30	Bushveld Complex	Under Bushveld			30
31	Bushveld Complex	Magnetite			31

Table 2.6 Revised lithostratigraphic attributes for the BOSGIS database

SUPERGROUP	GROUP	NEWCLASS
Bushveld Complex	Rashoop Granophyre Suite	1
Bushveld Complex	Lebowa Granite Suite	2
Bushveld Complex	Rustenburg Layered Suite (Upper)	3
Bushveld Complex	Rustenburg Layered Suite (Main)	4
Bushveld Complex	Rustenburg Layered Suite (Critical)	5
Bushveld Complex	Rustenburg Layered Suite (Lower)	6
Bushveld Complex	Rustenburg Layered Suite (Marginal)	7
Transvaal	Glentig, Rust de Winter, Loskop	8
Transvaal	Rooiberg, Dullstroom	9
Transvaal	Pretoria (upper)	10
Transvaal	Pretoria (lower)	11
Transvaal	Chuniespoort	12
Transvaal	Wolkberg	13
Transvaal	Groblersdal	14
Transvaal	Pretoria (Magaliesberg)	15
Karoo	Karoo Dolerites	16
Archaean Rocks	Archaean Rocks	20
Karoo	Karoo	21
Waterberg	Waterberg, Blouberg	22
Quaternary	Quaternary	23
Soutpansberg	Soutpansberg	24
Intrusions	Intrusions (diabase)	25
Pilanesberg	Alkaline Intrusions	26
Precambrian granites	Various Granites	27
Post-Transvaal	Leptite, Hybrid rocks	28
Bushveld Complex	Pegmatitic	29
Bushveld Complex	Under Bushveld igneous rocks	30
Bushveld Complex	Magnetite	31
Bushveld Complex	Rashoop	32
Dam		100

Legends:

- The original BOSGIS geology legend was appropriately changed to a revised legend which reflects the changes of the revised lithostratigraphic attribute table. Other legends which were created include a lineament, fault-type, folds, and a strike-and-dip legend. These legends were based on attribute values obtained from the BOSGIS database, and provided symbols to discern between the various objects. However, the strike-and-dip themes needed an additional field, which was used to rotate the dip symbol. ArcView uses a cartesian orientation system and not a geographic one where north is at 0°. The Azimuth field was therefore not appropriate to use as rotation field for dip symbols. A new field was created, Dip_Rot, and these values were obtained from a simple calculation expression: [360 – [Azimuth]].

Addition of new data

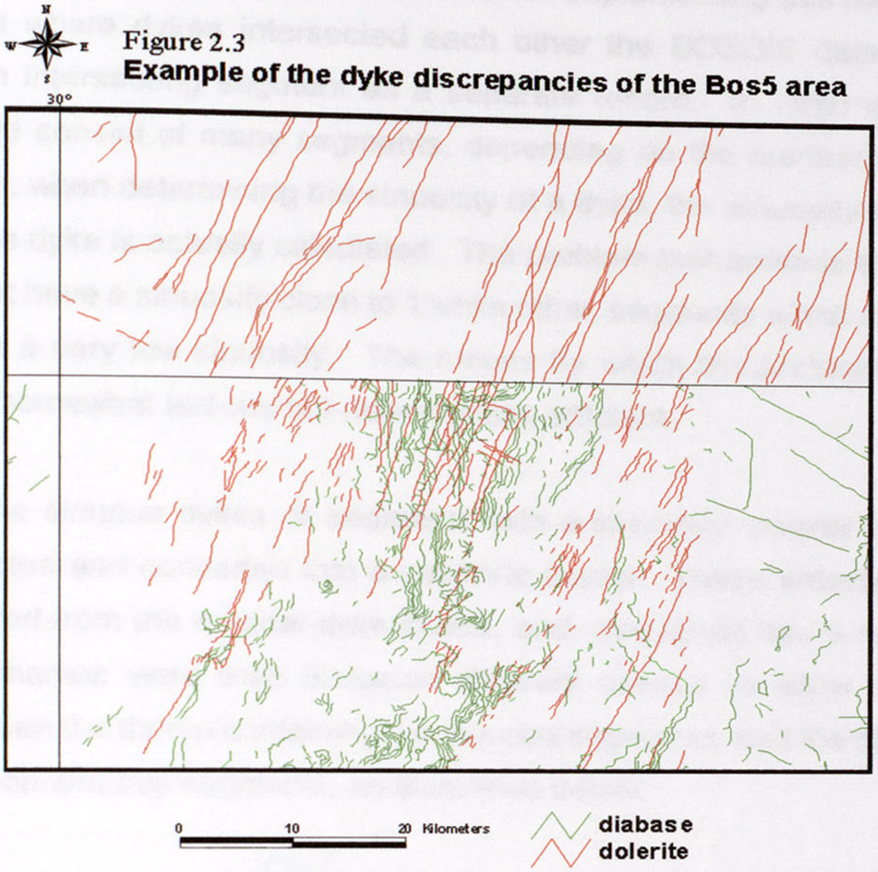
- Fold themes were expanded by digitizing folds documented in the literature. Digitized structures include: folds of the Mhlapitsi fold belt as mapped by Potgieter (1992), Hartzer's (1992) folds in the Transvaal Inliers, a few folds around the Pilanesberg Complex, and minor folding in the far Western Transvaal basin as mapped by Vermaak (1970). In addition, folds along the southern margin of the Waterberg basin (Jansen, 1982), and estimated folds around the Johannesburg dome recorded by Gibson et al. (1999) were included.

Dykes

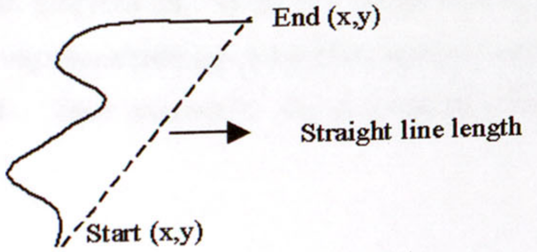
- The original dyke theme from the BOSGIS database contained a few discrepancies. These discrepancies, however, were carried over from the original data capturing during the production of the 1:250 000 geological maps. Firstly, since the geological maps were compiled by different people, inconsistencies exist between the dykes and their compositions as recorded from one map to another (Figure 2.3). However, no automated solution could be employed to resolve this problem, and the different compositions were simply ignored.

  Secondly, many of the dykes present in the Bos5 area have a very sinuous nature, as illustrated by Figure 2.3. Dykes are known to be more or less vertical planar features, and therefore it's surface intersection should be fairly straight. It is therefore unlikely that these 'sinuous dykes' are representative of real dykes, but is thought to rather be a reflection of sills intersecting the surface. It was therefore decided to exclude these 'sinuous dykes' from the Bos5 project.

Figure 2.3
Example of the dyke discrepancies of the Bos5 area

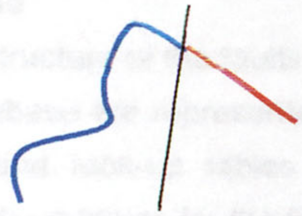


The method by which this was done is based on calculating the sinuosity of all the dykes. Sinuosity is the straight line length divided by the total length of the dyke, thus perfectly straight dykes would have a sinuosity of one. In this study all the dykes with a sinuosity smaller than 0.824 were deleted. The total length of the dykes were determined by a simple ArcView calculation command, [Shape].returnLength. However, calculating the straight line length was somewhat more involved. Firstly an ArcView system script was executed which calculated the beginning and end X/Y coordinates of every dyke record. Pythagoras's theorem was then used to calculate the straight line length, as illustrated below:



However, a few problems occurred when implementing this method. For each case where dykes intersected each other the BOSGIS database registered each intersecting segment as a separate record. In other words, one dyke would consist of many segments, depending on the number of intersections. Thus, when determining the sinuosity of a dyke, the sinuosity of each segment of the dyke is actually calculated. The problem that arose is that one segment might have a sinuosity close to 1 while other segments of the same dyke would have a very low sinuosity. The means by which the problem was overcome was somewhat tedious but nevertheless efficient.

All the sinuous dykes or segments with a sinuosity smaller than 0.824 were selected and converted into a separate theme. These selected records were deleted from the original dyke theme, and converted into a new theme. The two themes were then allocated different colours to allow easy distinction between the theme containing the sinuous segments, and the theme containing the non-sinuous segments, as illustrated below.



The non-sinuous dyke theme was then manually checked for every case where a sinuous dyke was broken up into segments of which one dyke consists of straight and sinuous segments. These straight segments were then deleted from the non-sinuous theme. This non-sinuous dyke theme was lastly converted to a new theme.

Faults

- At every intersection of one fault line with another, the fault line was split into various segments, as in the case of the dykes. Therefore, instead of one fault being represented by a single record, each segment of the fault was an individual record. This posed to be a problem for later queries performed on the fault themes. Therefore, all the segments pertaining to a single fault were selected and unioned so that each fault was represented by a single record.

2.3.2 Database design

After changes were made to the original BOSGIS, the structural database was developed. The database was created for all the fault and fold themes of each of the Bos areas considered during this study. Structural data were obtained from a literature study which is described in detail in Chapter 4. However, creating the database from this information was not straightforward, since different opinions and theories regarding the age, type, displacement style etc. of the same structures exist. These differences are not all reflected in the database since attribute fields contain single entries. However, a complete reference list of all the references pertaining to a particular structure form part of the database which covers all the previous research done on a structure.

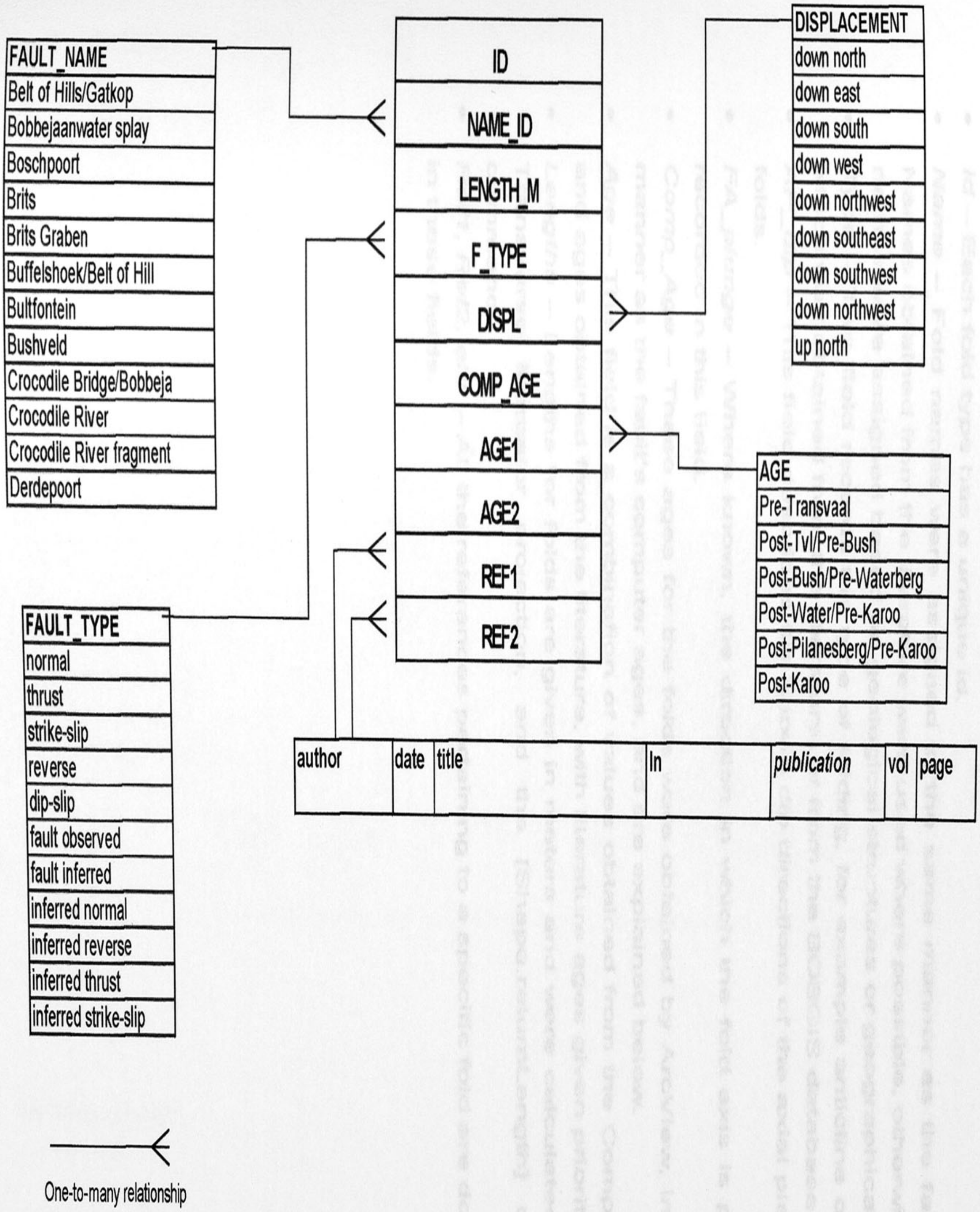
2.3.2.1 Faults database

Figure 2.4 shows the structure of the faults database with its associated look-up tables. All the data in the database are represented by codes. The codes allow for easy data retrieval or queries, and look-up tables can easily be joined with the database. Examples of all the look-up tables for the faults database of Bos2, 3 and 5 are included in Appendix 1. The following fields make up the fault database:

- *Id* – Each fault was allocated a unique ID.
- *Name* – Fault names were entered where possible. If no names were found in the literature a name would be assigned either, reflecting the geological structure, for example the Pilanesberg Complex, or the geographic area, such as the Dwarsberg Mountains.
- *Type1* – This field reflects the first type of faulting proposed for the fault, for example normal, thrust etc. If the type is unknown the original code from the BOSGIS database was used, such as 'fault observed' or 'fault inferred'.
- *Type2* – If a fault was reactivated at some stage, the reactivation type is recorded in this field. If no reactivation is known for the fault, the code would stay the same as in the Type1 field.

- *Displ1* – This field records the displacement style of Fault type1, for example normal, thrust etc.
- *Displ2* – This field records the displacement style of Fault type2.
- *Comp_Age* – The ages of the faults selected by ArcView are recorded in this field. The method by which this was done is explained below.
- *Age1* – The values of this field are a combination of the Comp_Age values and ages of the faults obtained from the literature, with literature ages given priority.
- *Age2* – This field reflects the known reactivation ages of the faults. If no reactivation is known, the value would be the same as Age1.
- *Length* – The lengths of the faults are given in meters and were calculated in a projected view, using Transverse Mercator projection, and a simple calculation formula: [Shape].returnLength.
- *Ref1, Ref2, etc.* – All the known references found during the literature study pertaining to a structure are reflected by these fields. To allow for easy querying and sorting each field contain only one entry. Therefore, the number of 'Ref' fields reflect the number of references.

Figure 2.4 Entities relationship diagram for the faults database.

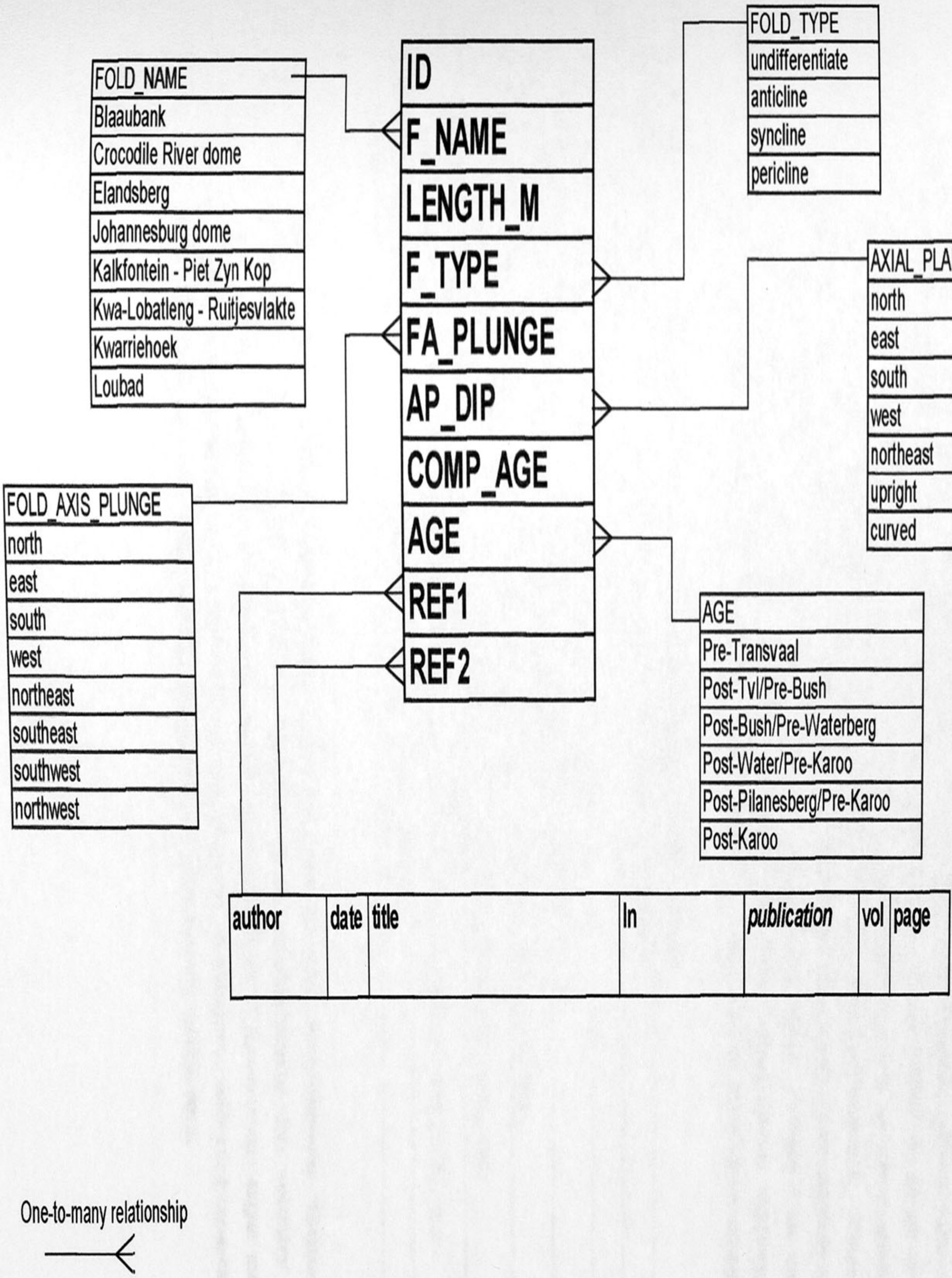


2.3.2.2 Folds database

The folds database follows the same general structure as the faults database (Figure 2.5). Codes are used to describe the various attributes and look-up tables were created which store the explanations of these codes (see Appendix 2). The folds database consists of the following fields:

- *Id* – Each fold type has a unique id.
- *Name* – Fold names were assigned in the same manner as the fault names. Names obtained from the literature were used where possible, otherwise general names were assigned based on geological structures or geographical area.
- *Type* – This field records the type of folding, for example anticline or syncline, which was obtained from the literature, or from the BOSGIS database.
- *AP_dip* – This field describes the known dip directions of the axial planes of the folds.
- *FA_plunge* – Where known, the direction in which the fold axis is plunging is recorded in this field.
- *Comp_Age* – These ages for the folds were obtained by ArcView, in the same manner as the fault's computer ages, and are explained below.
- *Age* – This field is a combination of values obtained from the Comp_Age field and ages obtained from the literature, with literature ages given priority.
- *Lengths* – Lengths for folds are given in meters and were calculated by using Transverse Mercator projection, and the [Shape.returnLength] calculation command.
- *Ref1, Ref2, etc.* – All the references pertaining to a specific fold are documented in these fields.

Figure 2.5 Entities relationship diagram for the folds database.



Method of determining 'Comp_Age' for faults and folds

This method involves an automated technique which assigns a maximum age for a fault based on cross-cutting relationships. These are the steps which were followed:

Firstly 'age layers' were created. Age layers are polygon themes representing the various rocks which were present during the five different geological time periods, namely; Pre-Transvaal (500), Post-Transvaal/Pre-Bushveld (400), Post-Bushveld/Pre-Waterberg (300), Post-Waterberg/Pre-Karoo (200) and Post-Karoo (100). Age layers for the Bos2 area differ in that an age of Post-Pilanesberg/Pre-Karoo (150) was added. Age layers were created by building queries based on the newclass field of the geology themes. The query selects all the lithostratigraphic units which fall within the above mentioned time period. The selected polygons were converted into a new shape file and age codes were used as names. Table 2.7 shows the Newclass values which were considered when creating each of the age layers for the Bos maps.

Table 2.7 Newclass values used for creation of age layers.

Age layer	**Newclass field values**	**Age code**
Pre-Transvaal	20, 27	500
Post-Transvaal/ Pre-Bushveld	'Age layer 500' + 8,9,10,11,12,13,14,15	400
Post-Bushveld/ Pre-Waterberg	'Age layer 400' + 1,2,3,4,5,6,7,30,31,28,29,25	300
Post-Waterberg/ Pre-Karoo	'Age layer 300' + 1,2,3,4,5,6,7,30,31,28,29,25,22	200
Pilanesberg	'Age layer 200' + 1,2,3,4,5,6,7,30,31,28,29,26,25,22	150
Post-Karoo	Select all records	100

To determine the computer ages of the faults, ArcView's 'Select by Theme' function was used. All the faults 'that completely lie within' each of the respective age layer themes, were selected and given an age code similar to the age layer theme. The 'select by theme' function, will not operate correctly if all the polygons of each age layer had not been unioned.

2.3.2.3 Attribute tables of the other themes

No new structural data were entered for the dykes, lineaments and strike and dip themes. However, the attribute tables of the other themes were cleared of redundant fields to only contain the following attributes:

ID	LENGTH	LIN	L_DOM
1	0.040075	24	1
2	0.025833	24	1
3	0.099680	24	1
4	0.040064	24	1
5	0.028411	24	1
6	0.078712	24	1
7	0.047851	24	1
8	0.046829	24	1

Each structure received a unique key as reflected by the ID field. Secondly, line lengths were calculated for all the dykes and lineaments, whereas the LIN field was carried over from BOSGIS. Lastly, the domain field (L_DOM) represents structural domains which were determined for each theme. Domains were chosen based on preferred orientations of the structures and no specific method was used in determining the extent of a structural domain. Therefore, domains vary between themes. Legends were created to represent each of the various domains of the respective Bos areas.

2.3.3 Rose diagram production

The creation of rose diagrams is not one of ArcView's primary functions and therefore the software had to be customized to achieve this aim. The steps followed in rose diagram production are explained below:

1. Three Avenue scripts (Appendix 2) are necessary for the execution of the rose diagram process. The first script (*newshape2gen.ave)* exports a shape file to a generate format file. The generate file is a comma delimited text file, and contains an ID number, and x and y coordinates of the beginning and ending of each segment of a line as captured in Arc/Info. This script was modified from the original ArcView system script. The modification to this script changed the exporting format of the gen file, so that, instead of giving one ID for each record which was exported, every segment of a record received an ID.

The function of the second script (calclino.ave) is to activate an external application program (Brynard, pers. comm. 2000). This C++ program (linears.exe) determines the orientation and calculates the length of each segment of a record from the 'gen file' (Brynard, pers. comm. 2000). This new data are exported as a text file with an '*.out ' extension.

The final script (rose.ave) creates rose diagrams from the data stored in a '*.out file'. This script was obtained from the ESRI home page. Rose diagrams can be drawn based on the number of segments or according to the cumulate length of the segments i.e. weighted histograms. All the rose diagrams in this study are based on the cumulative lengths of the segments since it is a statistically more accurate representation of the orientation of the data.

2. The second step was to customize the interface of ArcView by creating buttons and tools to execute each of the scripts. The figure below shows the three customized buttons and tools. The creation of rose diagrams are done by simply clicking consecutively on the three rose diagram icons.

The diamond icon executes the 'newshape2gen' script, the run icon will execute the 'calclino' script and the rose diagram icon executes the 'rose' script. Rose diagrams are drawn as graphics in a view.

3. Rose diagrams were created for all the Fault, Dyke, Folds and Lineament projects. The Rose diagrams for the fault projects were created based on the geological time periods which were considered during this study. However, since some faults experienced reactivation, two sets of rose diagrams, Age1 and Age2 rose diagram sets were made. Rose diagrams of the Fold themes were also based on their ages. Rose diagrams for Dyke and Lineament themes were based on structural domains which were described earlier.

4. Lastly, layouts were made of the Rose Diagram Views on which stress directions were interpreted (Chapter 6).

2.3.4 Production of Stereonet plots

Strike and Dip projects were developed of the different Bushveld Complex areas in order to create stereographic plots of the BOSGIS data. Stereonet plots were produced using the program Spheristat 2, and these plots were included as graphics in the projects layouts. The following steps outline the stereonet production:

- A Spheristat map view was created for each strike and dip project. These views contain an outline theme of the geology, as well as strike and dip locations indicated as points or with other symbols.
- Structural domains were chosen based on the outcrop distribution of these points. For example: ArcView's 'select by theme' function was utilized to select all the strike-and-dip points contained within the Transvaal rocks, or Waterberg rocks. The strike-and dip symbols of the Transvaal rocks were further grouped into domains according to different areas. Domains were represented by displaying the points as different colours and symbols on the maps.
- Each structural domain was converted to a separate theme. These themes' attribute tables (dBase files) were converted to formatted text (.txt) files using Excel, to be imported into Spheristat.
- Stereonet plots were created of the poles to bedding. Similar symbols and colours where assigned to the stereonet plots as were used in the Spheristat map views. Plots were saved as windows meta files (.wmf).
- The '.wmf' files were imported as graphics into the ArcView project's layout.
- In addition, Spheristat's analytical capabilities such as contouring and principal direction analyses, were utilized to evaluate individual stereonet plots.